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The Fate and Fisheries Biology of Sub-adult Australian Salmon in South Australian Waters

Michael C Cappo
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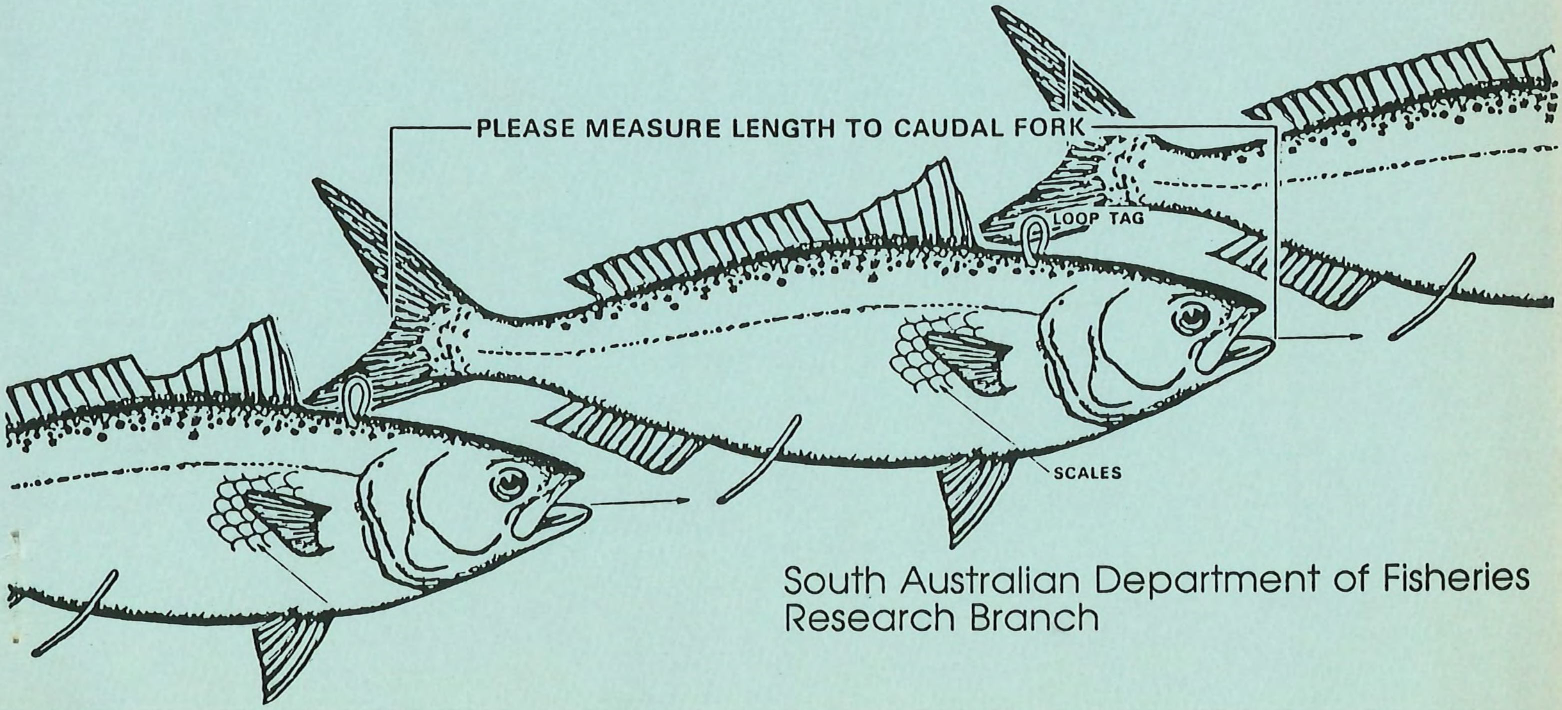

South Australian Department of Fisheries
Research Branch

THE FATE AND FISHERIES BIOLOGY OF SUB-ADULT AUSTRALIAN SALMON

IN SOUTH AUSTRALIAN WATERS

by

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F.I.R.T.A. 84/75

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SUMMARY

A three-year research programme has been completed, on the fate of adult Australian Salmon in South Australian waters. The major findings of the study are detailed below.

1. The commercial fishery in South Australia has recently operated at a lower level; average purse-seine catches during the periods 1984-87 and 1975-78 were 421 tonnes and 762 tonnes, respectively. This decline can be attributed to adverse fishing conditions, and a decline in effort; rather than a decline in salmon abundance. Concurrently, there has been a rise in tag returns by anglers; from 16% in 1975-78, to 30% in 1984-87. It is concluded that amateur catch has increased to a significant level; estimated to be in the order of hundreds of tonnes annually. The average length of salmon caught by anglers was significantly lower than the average length of salmon caught by professional fishers.

2. The purse-seine fishery was unstable during the study, and patterns of catch did not represent patterns of abundance. However, broad changes were discernible; in catch composition, in comparison to the period 1975-78. The catch of 1+ fish has declined in importance, but the numbers of older salmon caught were broadly similar. Despite the lowered catch, there were no shifts in capture locality back to the areas fished in the pre-purse-seine era. That is, the most important fishing areas were the West Coast, near Streaky Bay; the southern portions of Yorke and Eyre Peninsulas; the South-Central coast; and Kangaroo Island. The areas of greatest exploitation by anglers were the West Coast and southern Yorke Peninsula.

3. Levels of F and M were estimated at levels similar to those of previous years, if tag loss is allowed for; despite the lowering of commercial catch in South Australia (F = 0.2, M = 0.5). Preliminary yield-per-recruit analyses suggested that the South Australian population was being underfished in the study period, although the size classes exploited were near the optimum range at which biomass was maximised (31.0 - 35.0cm LCF).

The overall rate of exploitation of South Australian salmon may have increased; as tag recovery rates in 1975-78 and 1984-87 were 21% and 32%, respectively.

4. Migration into the Western Australian fishery occurred at ages of 3+ to 8+; mainly 4+ and 5+. Salmon "dropped out" of migrating schools and postponed movement to Western Australia by one year. These fish were significantly smaller-at-age than other school members, which recruited during the season of tagging. Salmon which postponed movement were not subsequently recruited into the South Australian fishery; this may have reflected a lack of fishing effort. Catch curves showed that fish of 5+ were only partially recruited into the South Australian fishery. Migration to Western Australia was rapid (as little as 47 days duration), and occurred until late January within the season of recapture in that State.

   Rates of tag recovery in Western Australia, of 4+ salmon tagged in South Australia, have increased; from 1.7% (1950's), 9.7% (1960's) and 10.8% (1970's); to above 20% during this study period.

5. The level of recruitment into the Western Australian fishery was the highest yet recorded; daily entry of tagged salmon from South Australia was strongly correlated with south-coast daily catches, during the whole season, with a catch of 1877 tonnes in 1987. This represented rates of migration of 20% to 60% of tagged adults; mainly of 4+ and 5+ fish. Previously, South Australia was suggested to be the source of a base level of catch of 1,000-1,300 tonnes, annually; and daily entry of tagged salmon was correlated highly with catches made only after March 13. The recovery of tags by anglers, in Western Australia, was at an inexplicably low level of 9%, in comparison to professional recaptures there.

6. Aerial surveys of salmon schools, in the area fished by purse-seiners, indicated that the population was relatively small; in the order of 3600-6200 tonnes. The most, and largest, schools were sighted on the West Coast, along the south coast of Kangaroo Island, and in the South-East of the State. Sightings of schools along the southern coast of Yorke Peninsula were very low; in comparison to the high rates of exploitation there in angling and purse-seine operations.

Estimates of population size from aerial surveys were biased by differential visibility of small and large schools.

7. For the first time, females in an advanced state of ovarian development were recorded from South Australia. However, all available evidence indicated that no significant spawning activity occurs in this State.

8. Clupeid fish, mainly pilchards, predominated in salmon stomach contents. The chance ingestion of King George whiting, by salmon in sheltered bays, was not considered of relevance to management of fisheries for either species.

1.1 JUSTIFICATION

A scientific workshop on Australian salmon was held by the Western Fisheries Research Committee at Waterman, Western Australia, in 1981. It was proposed that the workshop "....should summarise the present understanding of the fishery and the biology of the species, and point out the consequences of different options for management". As a result, it was concluded the "the Western Australian salmon fishery appears to be in a fine balance at a low level of production, with at least a suggestion of stock-related lower recruitment. Any increase in fishing effort in Western Australia, as well as in eastern States, might prejudice spawning stock/recruitment success". Furthermore, it was recommended at the workshop the need for collection of data on;

(a) catch and fishing effort in South Australia and other States,

(b) length and age compositions of catches made by all States fishing the stock; and

(c) the relative importance of professional and amateur catches.

1.2 OBJECTIVES

Subsequently, the Research Branch of the South Australian Department of Fisheries was granted funds, from the Fishing Industry Research Trust Account (FIRTA 84/75), to study the fate of adult Australian salmon occurring in South Australian waters. Research was undertaken to:

(a) determine the movement patterns of different age groups of salmon;

(b) determine the relative proportions of salmon taken in the commercial and recreational fisheries in South Australia;

(c) determine the size and age compositions of catches made in both these fisheries; and to

(d) survey the relative abundances of the South Australian salmon population.

2.1 INTRODUCTION

The Australian "salmon" is a sea perch, of the family Arripidae, and is in no way related to the true salmons, of the family Salmonidae, in the Northern Hemisphere. The family Arripidae contains a single genus, *Arripis*, comprising two species only - the Australian salmon *Arripis trutta* (Bloch and Schneider) and the Australian herring or Tommy Ruff, *Arripis georgianus* Cuvier and Valenciennes.

Two sub-species of Australian salmon are present in Australian coastal waters: the eastern sub-species, *Arripis trutta marginata*, (Cuvier and Valenciennes) and the western sub-species, *Arripis trutta esper* (Whitley). The two sub-species are morphologically identical in external appearance; but can be separated on the basis of counts of gill rakers on the first gill arch, which have been proposed to be related to differences in feeding habits; and counts of dorsal fin rays (Fairbridge, 1951, Malcolm, 1959). Fish of the western sub-species have fewer gill rakers (from 25 to 31) and prey predominantly on pilchards, anchovies and other small fish; in comparison to the eastern sub-species which forage on small euphausiids ("krill") mainly, and have from 33 to 40 gill rakers (Malcolm, 1959). The spawning areas of the two sub-species are separated in space and time; the western sub-species spawning in late summer in the south-west of Western Australia only; and the eastern sub-species spawning in the area of southern New South Wales and eastern Victoria only, in early summer (Malcolm, 1966a, Stanley, 1978, 1980a).

Stocks of *Arripis trutta* sp. occur also in New Zealand, where they are referred to as Kahawai, and around Lord Howe, Norfolk and the Kermadec group, islands. The distribution of Australian salmon is shown in Malcolm (1960). The current research programme concerns the western sub-species, *Arripis trutta esper*; hereafter referred to as western salmon or salmon.

2.2 DISTRIBUTION

Western salmon occur predominantly south of latitude 30°S, from Perth in Western Australia, throughout South Australia and Victoria, to Tasmania. Specimens have been recorded as far north as Geraldton in Western Australia, and in the east at Eden. The range of western salmon overlaps with that of the eastern sub-species in eastern Victoria and around Tasmania, and the two sub-species intermix in schools in these areas. This spatial and temporal coincidence of the two sub-species is restricted to juvenile and sub-adult stages of the life history and is shown in Malcolm (1960).

2.3 BIOLOGY

Essential to a review of the fisheries for western salmon is a knowledge of the life history of this sub-species.

Western salmon are an inshore schooling species which make both inshore-offshore foraging movements, and migrations connected with spawning behaviour. They are most commonly sighted schooling in shallow water behind the surf zone, adjacent to beaches, headlands and reefs; but are known to forage in, and migrate through, deep, open expanses of water, such as Bass Strait (Malcolm, 1959, Stanley, 1978). Schools of salmon in excess of 120 tonnes have been captured, and sightings have been recorded of schools estimated to contain in excess of 1,000 tonnes of salmon, in South Australian and Western Australian waters (WFRC 13 p.37, R. Hendry, pers.comm)

The large body of evidence from tagging (Malcolm, 1960, Nicholls, 1973, Stanley, 1978, 1979) and morphological (Malcolm, 1966a) investigations; and studies of reproductive biology (Malcolm, 1960, Stanley, in prep.) and population genetics (MacDonald, WFRC 9), strongly support the conclusion that western salmon are a single interbreeding stock with a spawning area in southern Western Australia.

The time and place of spawning of western salmon are not precisely known, and may vary to some extent between years. Malcolm (1960) examined seasonal distribution and ovarian and testicular cycles in both South Australia and Western Australia and recognised spawning and post-spawning phases associated with a migration of adults. He concluded that the area of intensive spawning was centred on the south-western coast around the Cape Leeuwin to Busselton area (See Figure 1.2) in late April, and May, at the apparent end point of a spawning migration.

However, Stanley (in prep.) found that western salmon can spawn on both the south and south-western coasts, and throughout the migration, from mid-March to the end of April. He examined ovary weights, condition factors and the occurrence of ova in plankton samples, and proposed that spawning does not immediately precede the post-spawning phase (Malcolm, 1960); but is spread out in time and area, and ends in a post-spawning group of fish in the Busselton area in late April to May. Stanley (in prep.) suggested also that areas east of Albany, on the south coast, are of importance only in mid-March as spawning areas; although in years of high stock abundance, more spawning appears to take place on this coast.

Spawning in the western salmon is fractional and very few female fish have ever been sampled in an immediate spawning condition; as the last stages leading up to spawning are rapidly accomplished (Malcolm, 1960, Stanley, in prep.). This observation led Malcolm (1960) to suggest that spawning may take place offshore away from the coast. However, Stanley (in prep.) recorded the highest numbers of ova from inshore sampling stations, and proposed that spawning may take place in localised concentrations; perhaps in the vicinity of rocky headlands, inaccessible to beach seining operations.

The lack of "running-ripe" females in catches frustrated attempts to describe embryonic and larval development, by the procedure of stripping eggs from females and fertilising them artificially (Munro, 1963). Egg and early larval stages of eastern salmon have been described by Munro (cited in Malcolm, 1966a) and hatching of the egg occurs within 40 hours of fertilisation in this sub-species (Stanley and Malcolm, 1977).

2.4 DISPERSAL OF JUVENILE STAGES

Transport of juvenile stages to nursery areas east of the spawning area occurs via complex southward and eastward flowing currents. At least three sets of currents move up, or down, the southern half of Western Australia's coast at various times of the year (Anon., 1981) Meanders and eddies of the northward flowing west-Australian current flow southward from latitude 30°S; and wind-driven southward and northward flowing currents occur in summer and winter, respectively, under the influence of prevailing winds. Superimposed on these flows is the Leeuwin current; a body of water from the tropics that, during autumn and early winter, flows around the south-west corner at Cape Leeuwin and into the Great Australian Bight. Studies by the CSIRO Division of Fisheries and Oceanography, of drifting buoys and hydrology, showed that the Leeuwin current consists of warm (2°C above local seas), low salinity water of tropical origin. The Leeuwin current forms, between April and July, a water mass some 20 kilometres wide that may flow at nearly 4 kilometres per hour (2 knots), (Anon., 1981).

Juveniles (0+ age group) are carried southward and eastward, to the western Bight, South Australia, Victoria and Tasmania, by the Leeuwin current. The mechanisms by which juveniles maintain position in preferred bodies of water, and move into inshore areas, are unknown (Malcolm, 1960).

The timing of arrival of juveniles in nursery areas varies from year to year. Malcolm (1966a) recorded western salmon of 5 cm TL (total length) in Tasmania during August or September. In Westernport Bay, Victoria, Robertson (1982) captured western salmon of 6.1 and 5.7cm LCF (length to caudal fork) in late October, 1974, and late August, 1975, respectively. During regular small-mesh netting surveys of the Port Adelaide River estuary, Jones (pers.comm.) has first recorded young-of-the-year juvenile salmon during the months of July, August and September.

Juveniles may be transported to the Esperance area or northward from the spawning area also, to estuaries south of Perth. The latter movement is considered to be of small significance to later recruitment to the fishery for adults (Walker, 1982a). The occurrence of many juveniles (0+ group) in the Esperance area was recorded in 1949 by Malcolm (1960) and was considered by him to be atypical. Stanley (WFRC 1) suggested that settlement in the Esperance area is of major importance later to the fishery for adults, and this proposal is discussed further in section (9.3.1).

Juveniles of the 0+ group may leave inshore nursery habitats in late summer, and this movement may be associated with a change in diet (Stanley, 1979, Robertson, 1982, Jones pers.comm.). These habitats are typically shallow sand flats with marine seagrass beds (Zostera sp., Heterozostera sp., Posidonia sp.) and the fish feed along the edges of channels. Epibenthic crustacea, demersal gobies and clinids, and atherinids from the water column, have been recorded from the stomach contents of western salmon foraging over these seagrass beds (Robertson, 1982). The diet later changes, to include predominantly pilchards and other clupeid fish, and is reviewed in section (12.1).

2.5 AGE AND GROWTH

Western salmon attain a maximum age, length and weight, on average, of about 9 years, 80cm LCF and 10.5kg, respectively (Malcolm, 1966a, Stanley, 1980a). Growth rates decline from west to east within the sub-species' range (Nicholls, 1973, Stanley, 1980b), and vary between bays within South Australia (Stanley, 1977). Using a series of Von Bertalanffy growth curves, Nicholls (1973) described and compared growth in different parts of the range of western salmon. He considered that growth data could be pooled to produce a single curve for South Australian fish (t_o = -0.2360 years, K = 0.2751, L_∞ (LCF) = 68.91cm, t = 5.832, d.f. = 5).

The most significant result of the slower growth rate at the eastern end of the distribution is that fish there do not attain the mean length acquired by 4-year old fish in Western Australia, until they are 5 years of age. Western salmon tend to school by size rather than by age; and a school may have a narrow range in size composition, yet comprise up to four age groups. Nicholls (1973) suggested, also, that sexual maturity is related to size, rather than age.

Lee's phenomenon occurs when back calculation from scale measurements, of fish lengths at early ages, gives progressively smaller lengths the older the fish is at the time of scale collection (Ricker, 1969). Stanley (1980b) found that the phenomenon is evident in scale readings of western salmon: in the adult fishery, caused by the selective arrival of salmon with progressively slower growth rates; and, in the juvenile habitats, caused by selective departure of faster-growing salmon.

Checks in growth of circuli on scales have been determined to be laid down on an annual basis, during late October; by comparing the age at release and recapture of tagged fish (Malcolm, 1960, Stanley, 1980b); and by back-calculation of length at age, from diameters of checks, by Nicholls (1973).

Bow (cited in Nicholls, 1973) and Nicholls (1973) recognised the presence of six-month checks on scales of western salmon from South Australia and Victoria. They proposed that fish spawned early in the year formed a check in growth in the October following the spawning season; that is, a six-month check. Salmon spawned later in the season did not form a check in scale growth until the October some eighteen months after spawning. Bow recognised a six-month check on 65% of scales examined from fish caught at Ceduna, and Nicholls (1973) found the check in 5-12% of scales examined. In contrast, Stanley (1980b) found a six-month check on less than 4% of scales from fish caught throughout South Australia; and ignored their presence for the purposes of his analyses. It is possible that the spawning season in Western Australia is too protracted, in time and space, to allow for the widespread occurrence, later, of variation in age at first formation of growth checks. The key to the occurrence of six-month checks lies in a knowledge of the path and duration of the "oceanic" phase of the juvenile life history; which is lacking.

2.6 MIGRATION

Information on the spawning migration in Western Australia, of maturing juveniles and adults has been collected by tagging studies (Malcolm, 1960, Nicholls, 1973, Stanley, WFRC 1, Walker,WFRC 6), observations of seasonal fluctuations in commercial catches (Malcolm, 1960, Walker 1982b), and by use of aerial survey data (Stanley, WFRC 4).

In the non-spawning phase (Malcolm, 1960) the adults are concentrated chiefly in the area between Bremer Bay and Esperance. A westerly movement, by fish in spawning phase, commences in February (the "front run") and apparently has been completed by all fish in mid-April. After spawning, the fish move back south and eastwards (the "back-run") in a movement which begins in mid-May, usually, and is over by July (Malcolm, 1960). The front-run ends usually in the Busselton area; but schools move northward to the Perth area in some seasons. The eastward extent of the back-run is unknown; but may extend into the western Bight. No salmon tagged in Western Australia have ever been recaptured in South Australia (Anon. WFRC 12, p.49) and it is concluded that the back-run does not extend into the commercial fishery of this State.

The "cues" that send maturing juveniles on migration from eastern nursery areas into Western Australia, and the "clues" that these salmon follow (Harden-Jones, 1984 p.3) when on migration; are unknown. The migration path is unknown also. It is known that recruits from Tasmania traverse Bass Strait, so open-water travel is possible; but it is considered more likely that salmon migrate through inshore waters (Malcolm, 1960, Stanley, pers.comm.).

There is a lack of information also on the timing of departure from nursery areas and arrival in Western Australia. Nicholls (1973) tagged salmon at 4+ years of age, and older, in Lacepede Bay (Kingston, South-eastern South Australia) which were recaptured on, or after, March 13 in Western Australia; at least 90 days after release.

It has been suggested that South Australian participants in the migration must be tagged before November of the year preceding the spawning season; if they are to be recaptured during that season (Anon., 1969). The area south of Kangaroo Island was suggested to be an assembly area for these older South Australian salmon, prior to their migration to Western Australia (Anon., 1969).

Stanley (WFRC 1) found that migration by South Australian fish is spread over four age groups, and is connected with growth rates: the fastest growing fish migrating at an age of 3+ years and the slowest growing fish at 6+ years.

3.1 FISHERIES FOR WESTERN SALMON

Western salmon form the basis of substantial commercial fisheries in Western Australia (800 to 4,000 tonnes per annum), South Australia (450 to 1,900 tonnes p.a.) and Victoria (an average of 180 tonnes p.a.). Annual production figures are given for South Australia and Western Australia, for the period 1963/64 to 1985/86, as Table (1.1) and Figure (1.1) A fishery situation report has been prepared by Stanley (1980a).

Throughout their distribution, western salmon are valued highly as a premier sportfish, for boat and shore-based anglers (Walker, 1982b, Jones, 1983a); but accurate statistics on landings are lacking.

3.2 WESTERN AUSTRALIA

3.2.1 Fishing Method

A beach-seine fishery for western salmon has existed in Western Australia since 1945, at the beaches shown in Figure (1.2). The nature of this beach-seine fishery has been described by Malcolm (1960), Nicholls (1973) and Walker (1982b). There are 40 teams of fishermen who seasonally occupy beaches, upon which they are endorsed to fish. There is observation for fish throughout the year, which becomes continuous in daylight hours during the spawning migration; assisted often by use of aircraft. When a school moves in to a position suitable for capture, a beach-seine net is shot around it; using rowing

Table (1.1) Annual production figures (kilograms live-weight) for the western salmon fisheries in South and Western Australia.

* = Estimate of catch; as of 30/5/87.

YEAR	SOUTH AUSTRALIA	WESTERN AUSTRALIA	TOTAL
1964	564723	2097727	2662450
1965	523890	1545909	2069799
1966	637298	2958182	3595480
1967	1075015	3659857	4734872
1968	1080464	4222504	5302968
1969	796898	2292894	3089792
1970	1404164	2318186	3722350
1971	1038877	1495267	2534144
1972	1880759	1792365	3673124
1973	798881	1164214	1963095
1974	1897000	1255990	3152990
1975	864640	1282719	2147359
1976	684701	1086115	1770816
1977	1111520	1517830	2629350
1978	1169070	754548	1923618
1979	449727	1191177	1640904
1980	702390	1260086	1962476
1981	683353	1373284	2056637
1982	608000	1546962	2154962
1983	1028000	2517708	3545708
1984	447931	3543000	3990931
1985	621018	2321471	2942489
*1986	648616	2489135	3137751
*1987	507000	1876828	

* = ESTIMATE OF CATCH

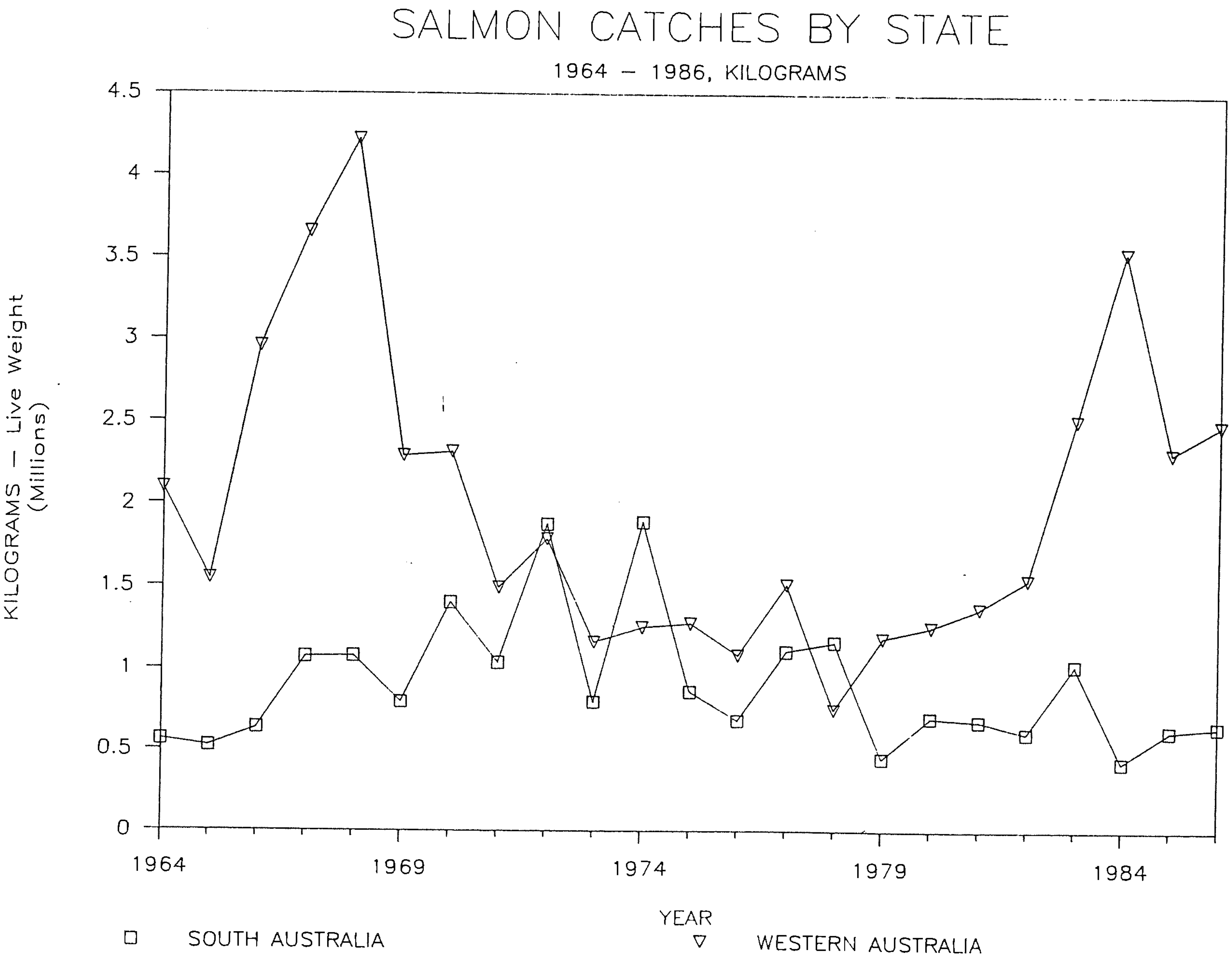


Figure (1.1) Fluctuations in levels of catch in the western salmon fisheries of South and Western Australia.

WESTERN AUSTRALIAN FISHING BEACHES

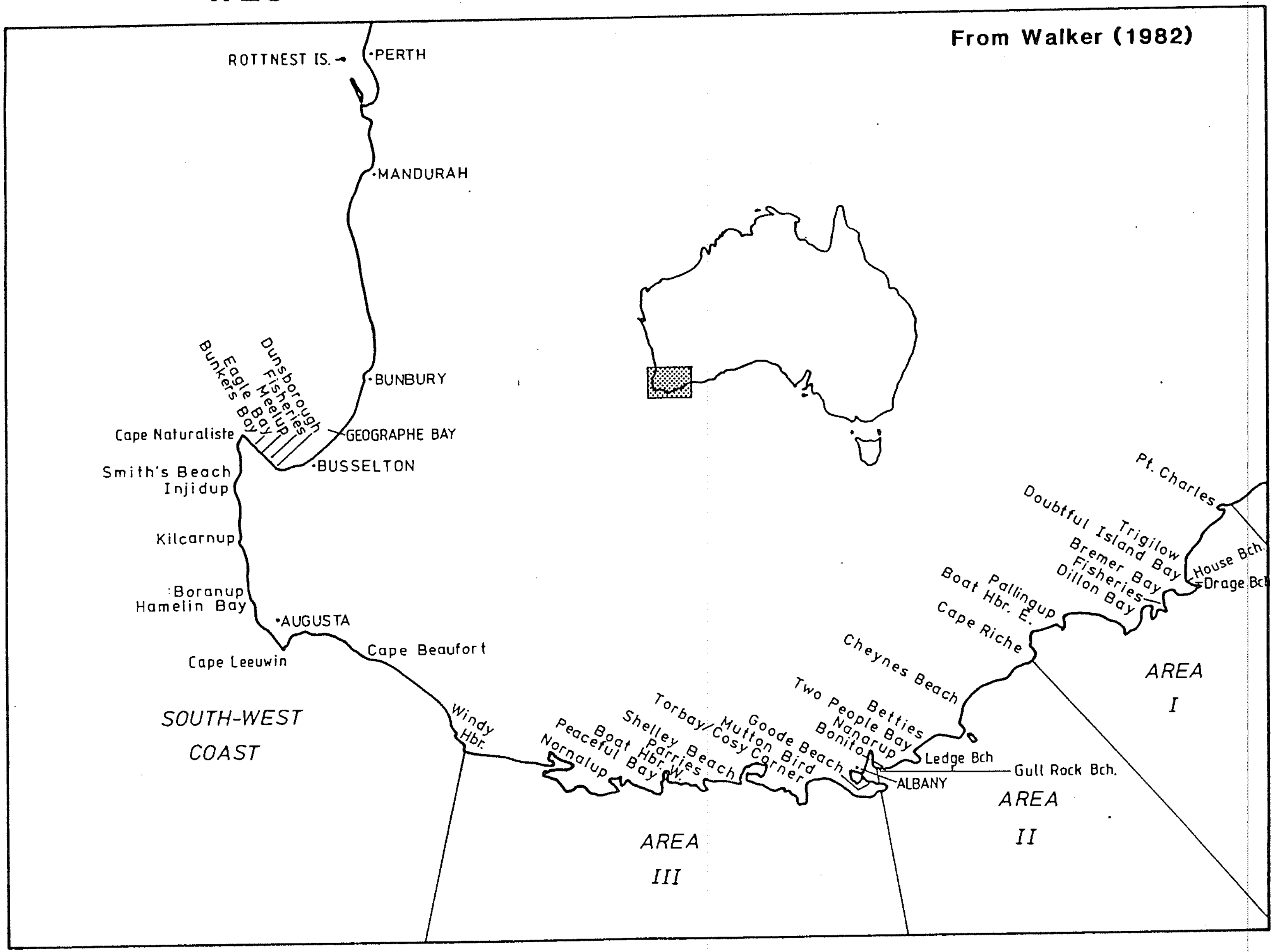


Figure (1.2). Salmon fishing beaches in Western Australia in designated fishing areas.

boats or boats powered by jet motors. Once the school is encircled, the net is drawn ashore with the aid of motor vehicles and the catch is transported by road to processors. Schools of less than 1 tonne, to upwards of 100 tonnes have been caught. The net is never shot blindly and the fishery is dependent wholly upon the chance visits of schools to accessible positions; none of the normal units of effort is applicable to this fishery.

3.2.2 Management

The fishery is managed by limited entry. Various fishing beaches are proclaimed as fishing zones from February 15 to April 30 each year, where only fishermen holding concessions to take salmon can operate. On the south coast, each team is restricted to a particular beach; whilst in the south-west the teams may occupy a number of beaches. A minimum length at first capture has been set at 30cm, and anglers are restricted to a bag-limit of five salmon per day.

3.2.3 History

Prior to 1952, the fishery was centred mainly at Hopetoun, east of Esperance, where fishermen caught salmon from stationary schools in the non-spawning phase. That fishery failed, and ceased in 1952. Since that year, beach-seine teams have concentrated on the front-run and back-run associated with the spawning migration, during a short season. In the seasons since 1967, the back-run catch has declined in importance; in 1981 the ratio of front-run to back-run catch was 1142 : 38 tonnes (Walker, 1982b). Malcolm (1960) suggested that the failure of the Hopetoun fishery was due to a shift in distribution, westward to inaccessible areas, of salmon in the non-spawning phase. However, Walker (1982b) considered that the intensity of exploitation on the front-run, and the high natural mortality of the adults, has caused the decline in back-run landings and extinguished the Hopetoun fishery. For either reason, the Western Australian beach seine fishery effectively operates now on salmon participating in a spawning migration.

The commercial salmon catch declined over a four-year period from record levels of 1966/67 and 1967/68 (3,660 and 4223 tonnes). For the period 1972/73 to 1980/81, the fishery operated at a low level of between 754 and 1518 tonnes (average catch 1209 tonnes). Associated with this drop in landings, was: a change in the distribution on the south coast catch, with Area I (Trigalow-Cape Riche) having taken over in importance from Area II (Cheynes Beach - Albany East); a westward decline in catch, and; a decline in back-run catches.

Catch represents abundance in this intensive fishery (Stanley, WFRC 1, Walker, 1982b) and effort, in terms of number of fishing teams and beaches fished, had remained remarkably constant in the period 1962-1981 (Walker, 1982b). During that time, efficiency had increased by about 10%; due to improved equipment and keener fishing practise. Over the same period, sightings of schools, catch per day of observation, and the average school size, had decreased. This information was collected from analysis of research log-books, kept by fishermen.

Since the 1983/84 season, the Western Australian catch had recovered to levels not recorded for 16 years (1984 catch = 3,543 tonnes). Catches had been more evenly distributed, and the West Coast catch increased at a slightly higher rate than that of the south coast. This was attributed partly to the prohibition of use of trap nets for Australian herring (Arripis georgianus - Tommy Ruff), between February 10 and March 25, on the lower south-west coast. These nets act as blocking devices and their action is presumed to alter the behaviour of migrating salmon schools; to the detriment of the salmon fishery to the west of the nets (Walker, 1985).

Australian herring make a spawning migration of similar route, but later timing, to Australian salmon, (Anon., WFRC 12). Some salmon teams can make fishing profitable only by combining salmon and herring fishing activities.

3.2.4. Utilisation of Catch

The fate of the salmon catch in Western Australia has varied since the inception of the fishery. The majority of product has been canned for human consumption, but there has been an increasing trend for sale of fish for the purposes of pet food manufacture, and for use as rock lobster bait. Traditionally, salmon heads, and some bodies, have been sold as rock lobster bait, but in 1977 the sub-species was declared a food fish in Western Australia; preventing the use of salmon bodies as bait. In 1986, a year of high catch, this regulation was relaxed partially; to allow salmon fishermen to sell 7 tonnes of their catch for rock lobster bait. The price paid to salmon fishermen, for fish intended for canning purposes, has declined markedly in recent years of high catch and is lower than returns from sales for bait (Walker, 1982b, 1985). This decline was attributed by processors to increased competition from lower-priced imports of Kahawai canned in New Zealand (Walker, 1985). However, a survey of the effect of New Zealand imports on the Australian salmon fishery (Anon, 1986) found no evidence of "dumping" of product on Australian markets; and no marked difference in price between local and imported cans of salmon.

3.3 SOUTH AUSTRALIA - AN OVERVIEW

The South Australian fishery for western salmon is the subject of detailed discussion in further sections of this report (Sections 5.1-6.1), but an overview is given here.

3.3.1 Fishing Method

In order of magnitude of catch, western salmon are taken in South Australia by the use of "purse-seines", hauling nets and beach seines, mesh nets and by trolling. Most age classes present in South Australia are exploited by the use of "purse-seines"; but younger fish predominate in catches made by all other methods. The different methods are utilised in different habitats within South Australia. Purse-seines, beach-seines and mesh nets are employed along exposed and sheltered coasts; while hauling nets are restricted to shallow, sheltered waters, of five metres depth, or less. South Australian fishing areas are shown in Figure (1.3), and salmon fishing areas are outlined in Figure (1.4).

Salmon are actively sought in operations utilising purse-seine, beach-seine and trolling gear; but are taken as by-catch, or by design, with hauling nets and mesh nets. Fishing areas are observed from high vantage points, from boats, or from aircraft, in the search for salmon schools.

The use of different methods is described in Section (5.2-5.4).

3.3.2 Management

The commercial fishery is regulated by an annual quota of 1,000 tonnes; to be taken by four purse-seine operators sharing a special salmon quota (800 tonnes), and by operators in the marine scale and rock lobster fisheries (general quota; 200 tonnes). The latter group comprises 500 licensees eligible to take salmon by use of nets; but individual catches are not permitted to exceed 20 tonnes on an annual basis. There is no restriction on the annual catch of fishers employing hand-lines and troll-lines. The special quota is transferable, and present legislation allows for annual review of the general quota; and for closure of the net fishery, upon attainment of the aggregate quota (Kirkegaard, 1984).

Netting activities of all forms are restricted by the proclamation of areas closed to netting within all fishing zones of the State; especially those comprising sheltered embayments. Beaches on the south-central coast (Waitpinga and Parson's beaches) and southern Yorke Peninsula (Brown's Beach, Troubridge Point) have been closed specifically to exclude salmon netting (see Appendix 1.1). A general limit of minimum size for the taking of salmon has been set at 21cm (total length). There are no limits on the extent of the catches made by recreational fishers.

The dimensions, and conditions of use, of nets are regulated also (under the Fisheries Act, 1982).

3.3.3 History

Three components can be recognised in the history of the South Australian fishery; the pre-purse-seine era, the purse-seine era and the present era (Stanley, WFRC 1, pers.obs.). In the years preceding 1966, the fishery mainly comprised operators of hauling nets and beach seines, and the catch averaged 500 tonnes (Malcolm, 1960, Stanley, WFRC 1). As early as 1955 (47 tons caught at Wedge Island by F.V. "Tacoma"), modified purse-seines were employed to encircle large salmon schools in inshore waters. After 1966/67, the annual catch doubled from a consistent figure of about 500 tonnes to 1,000 tonnes; due to the entry into the fishery of more large boats employing this method.

3.3.4 Utilisation of Catch in South Australia

Salmon caught in the marine scale fishery supply a low volume fresh fish market of the order of 60 - 150 tonnes annually. Some of the beach-seine caught salmon on the south-central and Kangaroo Island coasts are sold for use as bait in the rock lobster industry. Similarly, all fish caught by rock lobster fishermen, by trolling, mesh-net, or beach-seine, are utilised as bait.

Following the closure of salmon canning lines at Port Lincoln, purse seine operators sought markets in interstate canneries, and in the rock lobster industry. The rock lobster bait market in South Australia exceeds 3,000 tonnes per annum; and recently

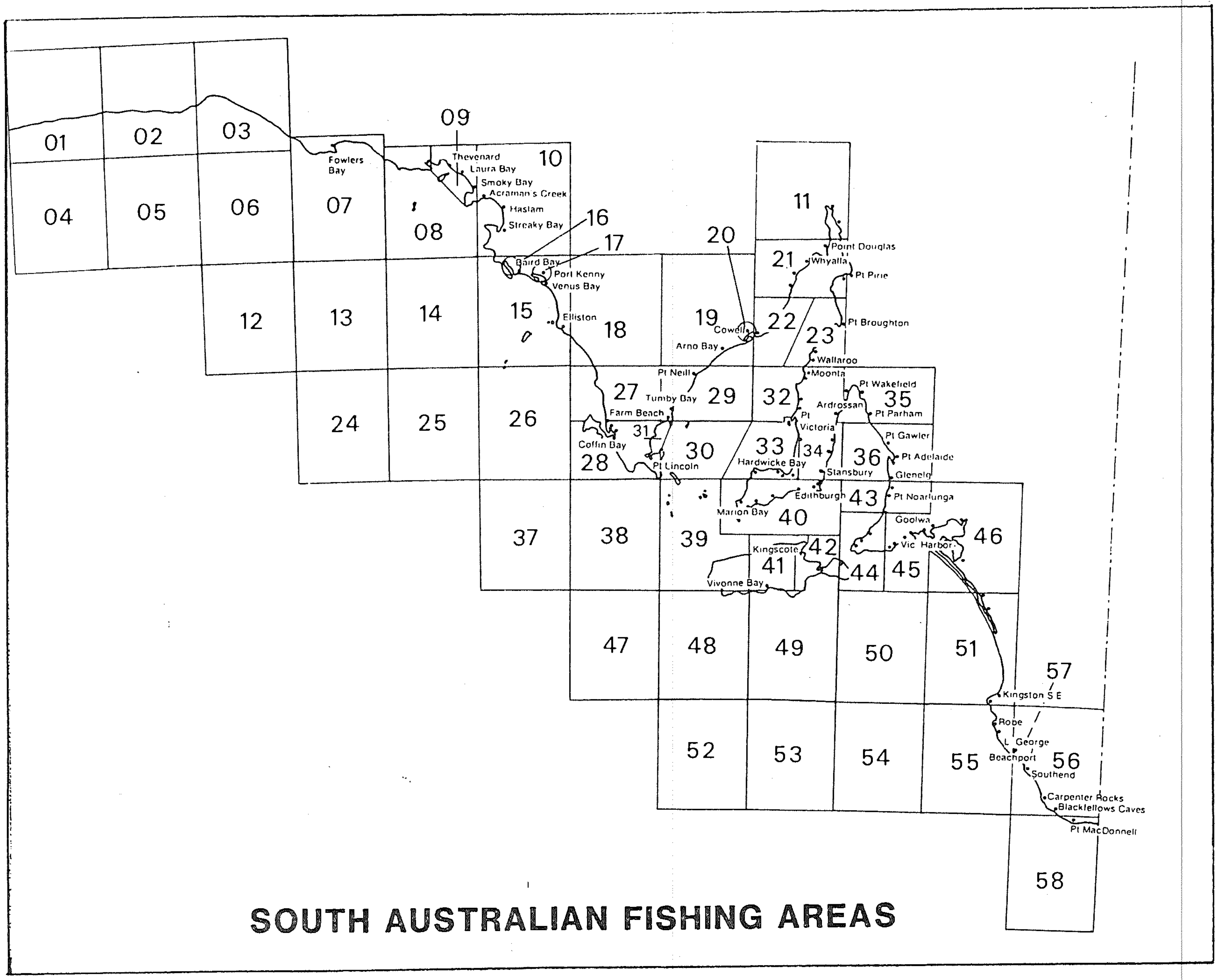
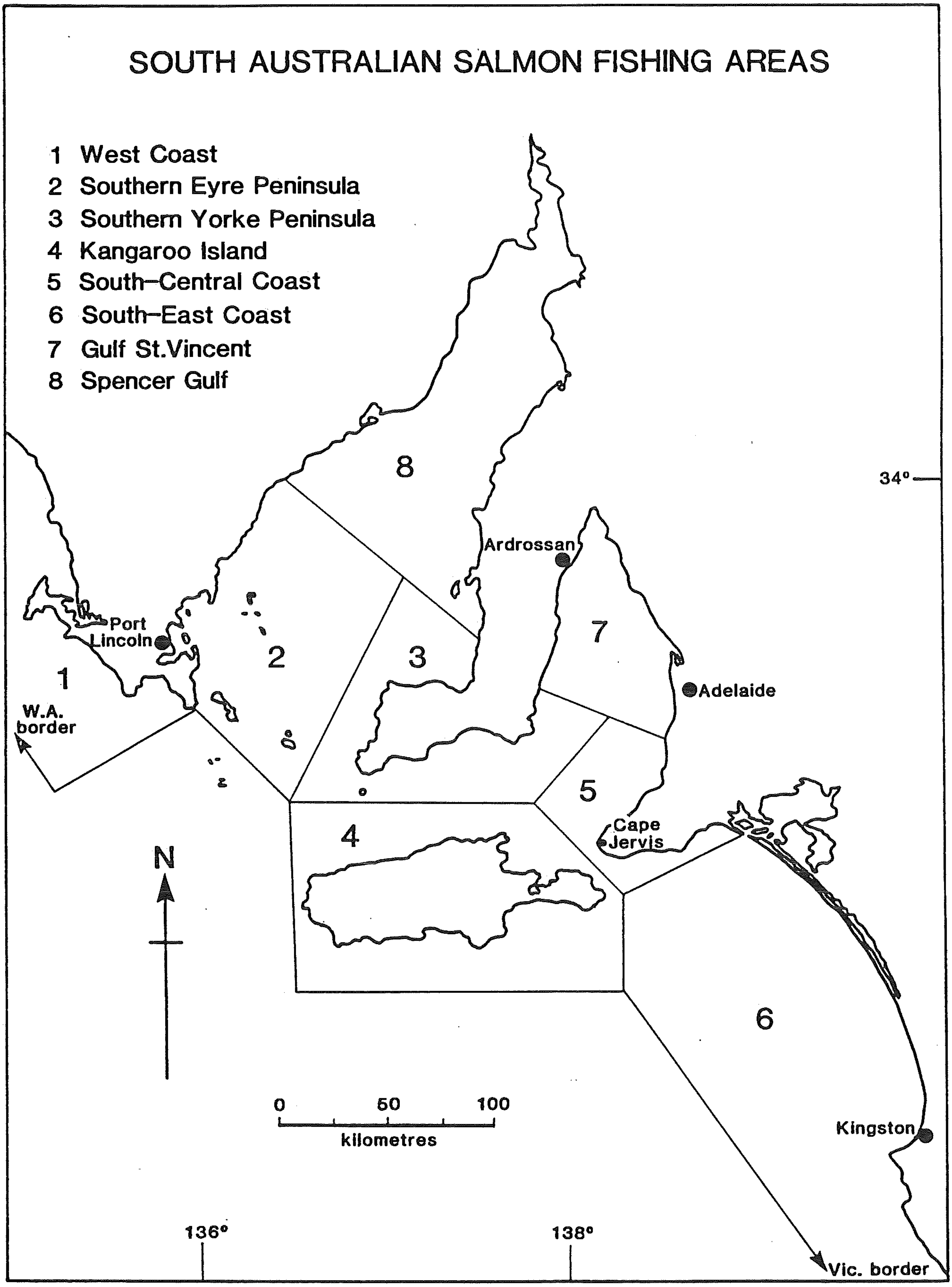


Figure (1.3) South Australian Fishing Areas.

Figure (1.4). South Australian Salmon fishing areas recognised during the study.



this market has increased in value. During the study period, the entire purse-seine catch was sold for rock lobster bait; and the prices obtained were higher than those offered by canners of product for human consumption, in both Western and eastern Australia. Smaller salmon, of 30-40cm LCF, * are most favoured as bait (pers.comm. E. Hendry).

The demand for salmon for use as bait, or pet-food, is increasing, whereas the demand for human consumption is static.

4.2 METHODS AND MATERIALS

4.2.1 Catch and Effort Statistics

Statistics on catch and effort in the commercial fishery for Australian salmon are entered on the GARFIS catch and effort system. The system is maintained by the South Australian Department of Fisheries and is based on monthly records kept by fishermen, as a condition of issue of licence. A blank form is included as Appendix (1.2).

4.2.2. Catch Sampling - Purse Seine Catches

Catches made by purse-seine vessels were sampled at ports of landing (Streaky Bay, Port Lincoln, Port Turton); at packing facilities (Port Lincoln, Warooka); and aboard vessels at sea, between sets of the net. (see Appendix 1.1).

For each catch, attempts were made to; measure the length (LCF* - length to caudal fork), to the nearest millimetre, of 50 fish; to dissect 20 fish; and to collect a sample of scales from the area behind the pectoral fin of each of these 20 fish. Scales were packed in envelopes, and dried, for later use in ageing analyses.

The location and date of capture, and weight in kilograms, of each catch were recorded and compared with fishermen's monthly returns on GARFIS.

When two or more catches were stored in the holds of vessels, the estimated weight of each catch was obtained from the vessel master. Representative samples of each catch were obtained despite this limited mixing of some catches before unloading. The majority of catches made during the study period were intercepted for sampling purposes; as detailed in Table (4.1).

4.2.3 Landings in the Marine Scale Fishery

Funds from the project, from the Commonwealth Employment Programme (CEP), and from the SADF Research Branch were used to employ several fish measuring personnel at the SAFCOL fish market in Adelaide, and at fish processors in Port Lincoln. On each market day these staff measured lengths (usually two boxes, each of 15kg net weight) of salmon landed in the marine scale fishery. The sample weight, total catch weight, date of landing, name of captor and method of capture were recorded and compared with statistics entered in the GARFIS data base. Sampling commenced in November 1984 and ceased in February 1986.

4.2.4 Catch Sampling - Recreational Fishery

Catches of salmon made in the recreational fishery were sampled by research staff at weigh-ins of major angling conventions, and by issue of survey forms for use by angling clubs (Australian Anglers Association) at the weigh-ins of club outings. A survey form is enclosed as Appendix (4.1).

The survey form was used to collect data on; the location and duration of angling; the number of anglers landing salmon; the total number of salmon landed; and the maximum number of salmon landed by an individual angler. Measuring kits were issued to enable weigh-masters to record the lengths of salmon landed.

Table (4.1) Interception of catches made in the purse-seine fishery, and in the marine scale fishery, during the study period (kilograms live-weight).

FISHERY		YEAR 1984/85	1985/86	1986/87
MARINE SCALE FISHERY				
AREAS POOLED	CATCH	163453	139004	
	SAMPLED	17350	77043	
	%	10.6	55.4	
PURSE SEINE FISHERY				
WEST COAST	CATCH	140968	247624	64375
	SAMPLED	134065	224624	64375
	%	95.1	90.7	100.0
STHN EYRE PENINSULA	CATCH	34881	43175	117300
	SAMPLED	34881	29400	76500
	%	100.0	68.1	65.2
STHN YORK PENINSULA	CATCH	64741	35933	18075
	SAMPLED	64741	8308	0
	%	100.0	23.1	0.0
KANGAROO ISL + STH-CENTRAL CST	CATCH	243279	182880	98525
	SAMPLED	214074	151362	48250
	%	88.0	82.8	49.0

4.3 SALMON DISSECTIONS

For each fish dissected, the following information was recorded:

- length (LCF) to the nearest millimetre,
- weight to the nearest 0.25 kilograms,
- gill raker count (first gill arch, left side),
- sex,
- presence or absence of cestode parasites on mesenteries,
- stomach contents (identified to species level, incidence recorded only).

Gonads were dissected out of the body cavity and preserved in 10 percent sea-water formalin.

4.4 TAGGING

Plastic (Astralon Ace) internal tags, of oblong shape, with attached streamers, were used to tag 4,102 western salmon throughout the area of operation of the commercial purse-seine fishery. Two sizes of internal tags were applied, depending upon fish size. Large tags (50mm x 23mm x 0.5mm) were applied to fish ranging from 35cm LCF to 70cm LCF; whilst small tags (25mm x 11mm x 0.8mm) were used to tag fish of less than 45cm LCF only. Both tags had rounded corners.

Streamer colour, length and material, on large tags, were varied during the study. During the 1984/85 summer, the streamers used were of 8cm length; of yellow colour; and were made of Poly Vinyl Chloride tubing (PVC). During the 1985/86 summer, the streamers used were of 10-13cm length; of orange colour; and were constructed of polyethylene rod. All streamers were of, approximately, 1.3mm in outside diameter.

It was apparent that the short, yellow streamers were less visible to captors; being easily confused with the yellow pectoral fins of the fish. Dye from PVC streamers migrated from the material; the streamers became blackened at points of contact with fish tissue; and a breakdown, in strength and integrity, was evident for PVC streamers attached to salmon at liberty for periods of a year or so. Large tags and streamer material were manufactured by HALLPRINT PTY.LTD. (S.A.) and small tags were supplied by STOCKBRANDS PTY.LTD. (W.A.)

Salmon were obtained for tagging purposes from purse-seining and beach-seining operations; or were captured by hand-lining with pilchard bait, or trolled lure with single hook.

Fish were tagged directly from the bunts of fishing nets, or were transferred to holding caufs before tagging commenced. The caufs were 1.8m x 1.5m x 1.5m in dimensions and were walled with 2.0cm Rachelle, knotless, fishing mesh. The knotless mesh minimised scaling and bruising of the salmon, and prevented hook-ups between the mesh and the hinges of the salmon's jaws; as experienced with larger meshes. The caufs were buoyed by fishing floats set on a rigid, tubular PVC frame, and accommodated up to 50 salmon of 4kg in weight. In some cases, the fish were held in the circulating seawater holds of purse-seine vessels.

A restraining cradle was used to measure and hold salmon during the application of tags. The cradle was described by Walker (1977) and incorporates 3 or more belts, fastened by Velcro material, which strap the fish securely into position atop a measuring rule; and allow easy access to the tagging site, on the left side of the fish. Tags were inserted at a point anterior to, and slightly off centre from, the anus. The position of insertion anterior to the anus ranged from 3cm; for 35 cm LCF salmon, to 10cm; for fish of 60cm LCF.

Fish were measured to the nearest millimetre, and scales were taken, with forceps, from the tagging site for later age determination. A small incision was made with a scalpel through the body wall and the tag was slipped through into the abdominal cavity. The streamer was left protruding from the body wall, and was tugged lightly to anchor the internal tag. Tagged fish were released from a recovery cauf, as a single school, or were released individually. Tagging wounds healed within several weeks, although reddish scars were still apparent around the streamer exit on large salmon at liberty for over one year. There was little growth of algae on tag streamers.

The dates and locations of tagging operations are summarised in Table (4.2); with information of the tag type employed, the capture method and the number tagged.

The external streamers made tagged fish readily identifiable; and tags were returned from commercial fishermen, anglers, processors and fish packers. A choice of reward of $5.00, or a specially printed "Tagged Salmon T-shirt", was offered as an incentive for the return of tags, scales, and associated information.

The effects of tagging on salmon, shedding of internal tags, and the application of internal tags, were reviewed by Walker (1981), Stanley (1983) and Kirkwood and Walker (1984).

No double-tagging was undertaken in the programme, due to the costs and time associated with the procedure.

4.5 AERIAL SURVEY

Aerial survey forms (enclosed as Appendix 4.2) were issued to salmon spotters for use on a regular basis, and research staff accompanied spotters on an opportunistic basis. Data were collected on the position and size of schools, their behaviour, and the estimated size of individuals within them. Spotting was carried out from single-engine, or twin-engine, aircraft, flying at approximately 300 metres above sea level and at a speed of 110 knots.

Surveys were carried out along stretches of coastline comprising traditional fishing areas, or during the surveillance of a target school. There was no sampling design employed, and survey effort was spatially and temporally dependent upon commercial fishing activities.

Unlike the Western Australian fishery (Stanley, WFRC 4), no written records are kept by spotters as part of normal fishing activities. Some historical data are available from several survey flights made in South Australia, during 1950-1963, by Mr Hunt of the Hunt's Fish Canning company at Albany.

Table (4.2) Details of tagging operations conducted during the study period. Tagging locations are shown in Appendix (1.1).

OPNUM	TAGGING LOCATION	AREA CODE	DATE	NUMBER TAGGED	GEAR TYPE	TAG TYPE
49	CAPE BAUER	3	2/11/85	340	Purse-sei e	L L O
1	SCOTT'S BAY	7	6/10/84	7	Line - pilchard	L S Y
21	POINT DILLON	9	1/2/85	64	Trolling	L S Y
22	POINT DILLON	9	2/2/85	2	Trolling	L S Y
48	HIGH CLIFF	10	27/10/85	115	Purse-seine	L L O
15	SCEALES BAY	10	7/12/84	3	Trolling	L S Y
14	BACK BEACH	10	6/12/84	1	Lure casting	L S Y
13	EBA ISLAND	10	6/12/84	11	Trolling	S S Y
50	BACK BEACH	10	22/11/85	64	Purse-seine	L L O
58	ANXIOUS BAY	15	27/1/86	168	Purse-seine	L L O
10	MAD MILE POINT	15	20/11/84	6	Lure casting	L S Y
12	SILICON BEACH	15	21/11/84	1	Lure casting	L S Y
6	SILICON BEACH	15	15/11/84	1	Lure casting	L S Y
18	ANXIOUS BAY	15	19/1/85	235	Purse-seine	L S Y
11	SALMON BEND	16	20/11/84	5	Line - pilchard	L S Y
7	SALMON BEND	16	16/11/84	11	Line - pilchard	L S Y
8	SALMON BEND	16	18/11/84	15	Line - pilchard	L S Y
9	SALMON BEND	16	19/11/84	12	Line - pilchard	L S Y
5	BAIRD'S BAY	16	15/11/84	2	Trolling	L S Y
19	VENUS BAY	17	20/1/85	36	Trolling	S S Y
42	ALMONTA BEACH	28	1/8/85	37	Line - pilchard	L L Y
44	ALMONTA BEACH	28	3/8/85	19	Line - pilchard	L L Y
43	ALMONTA BEACH	28	2/8/85	23	Line - pilchard	L L Y
40	BOSTON ISLAND	31	18/4/85	6	Trolling	S S Y
39	BOSTON POINT	31	18/4/85	3	Trolling	S S Y
4	FANNY POINT	31	26/10/84	21	Trolling	L S Y
37	BICKER'S ISLAND	31	10/4/85	3	Trolling	L S Y
38	BICKER'S ISLAND	31	11/4/85	156	Purse-seine	L S Y
47	BICKER'S ISLAND	31	2/10/85	61	Purse-seine	L L O
36	BICKER'S ISLAND	31	9/4/85	1	Trolling	L S Y
46	BOSTON POINT	31	28/9/85	53	Purse-seine	L L O

Table (4.2) Continued

23 CORNY POINT	33	10/2/85	15 Trolling	L S Y
35 BERRY BAY	33	21/3/85	89 Purse-seine	L S Y
34 POINT TURTON	33	19/3/85	104 Purse-seine	L S Y
27 POINT TURTON	33	21/2/85	103 Purse-seine	L S Y
28 WATTLE BAY	40	27/2/85	56 Purse-seine	L S Y
32 CAPE D'ESTAING	41	13/3/85	1 Trolling	L S Y
24 CAPE D'ESTAING	41	16/2/85	3 Trolling	L S Y
45 WHITTLE BAY	41	11/9/85	51 Purse-seine	L L Y
26 STOKES BAY	41	17/2/85	88 Purse-seine	L S Y
52 SMITH'S BAY	41	7/1/86	133 Purse-seine	L L O
31 CAPE D'ESTAING	41	11/3/85	4 Trolling	L S Y
33 CAPE D'ESTAING	41	14/3/85	26 Trolling	L S Y
25 STOKES BAY	41	17/2/85	79 Purse-seine	L S Y
51 HOG BAY	42	22/11/85	83 Beach-seine	L L O
55 BALLAST HEAD	42	10/1/86	30 Purse-seine	S L O
29 MARSDEN POINT	42	5/3/85	40 Purse-seine	S S Y
56 HOG BAY	42	23/1/86	136 Beach-seine	L L O
17 HOG BAY	42	4/1/85	102 Beach-seine	L S Y
57 HOG BAY	42	24/1/86	201 Beach-seine	L L O
61 HOG BAY	42	21/2/86	175 Beach-seine	L L O
16 HOG BAY	42	3/1/85	186 Beach-seine	L S Y
30 MARSDEN POINT	42	6/3/85	129 Purse-seine	L S Y
62 BALLAST HEAD	42	20/2/86	96 Purse-seine	S L O
54 HOG BAY	42	9/1/86	145 Beach-seine	L L O
53 BALLAST HEAD	42	9/1/86	1 Trolling	S L O
59 HOG BAY	42	20/2/86	105 Beach-seine	L L O
60 HOG BAY	42	21/2/86	103 Beach-seine	L L O
41 CAPE COUTTS	44	1/5/85	142 Purse-seine	S S Y
3 D'ESTREE BAY	49	23/10/84	29 Purse-seine	L S Y
2 D'ESTREE BAY	49	23/10/84	56 Purse-seine	L S Y
63 RAPID HEAD	44	23/2/86	105 Purse-seine	S L O
20 SEAL ROCKS	45	26/1/85	7 Line - pilchard	L S Y

L L O = TAG SIZE STREAMER LENGTH STREAMER COLOUR
L = LARGE L = LONG (12 cm) Y = YELLOW PVC
S = SMALL S = SHORT (8 cm) O = ORANGE POLYETHYLENE

4.6 DATA ANALYSES

All data were entered on electronic data bases using IBM personal computers. A tagging data base was built using RBASE software provided by the Microrim Corporation. All other data were stored on spread sheets using LOTUS 1-2-3. Graphs were prepared using GRAFTALK software (REDDING GROUP INC.) and Hewlett-Packard plotters. Statistical analyses were performed using SPSS and programs written by staff of the SADF Research Branch.

4.7 VALIDATION OF AGEING ANALYSES

Salmon were aged by reading checks in circuli, laid down on scales. It has been proposed that these growth checks are laid down on an annual basis (Nicholls, 1973, Stanley, 1980b). To validate the scale reading, tagged fish were aged at release and upon recapture. Under the assumption that determination of age at release was correct, the observed age at recapture was compared with the expected age in Table (4.3).

Table (4.3). Confidence interval for the probability, p, of observed age at recapture equalling expected age.

Number of fish aged at release and recapture	N = 77
Observed age at recapture equals expected age	n = 58
Observed age not equal to expected age	n = 19
95% Confidence Interval for p = (0.65 - 0.84).	

The probability that checks were laid down annually, and read accordingly, was reasonable for the present ageing analyses. However, scales from all salmon caught on the West Coast were extremely difficult to read, and checks on scales of fish older than 5+ from more easterly areas were also difficult to interpret.

5.1 THE PRESENT STATE OF THE SOUTH AUSTRALIAN COMMERCIAL FISHERY FOR AUSTRALIAN SALMON

With the introduction of a purse-seine component into the South Australian fishery, Stanley (WFRC 1) recorded some changes in the localities fished and size-classes exploited, during the period 1975-78. Between fishing areas (see Figure 1.4) the West Coast had assumed more importance; and the Spencer Gulf-southern Eyre Peninsula area, less importance. Within fishing areas, shifts in capture localities were recorded; on the West Coast, to the western portion; in both Gulfs, to the southern portions; around Kangaroo Island, from the east to the south and west coasts; and on the South-Central coast, from the east to the west of Cape Jervis.

The increase in purse-seine catch involved an increase in the catch of younger 1+ fish, and an increase in the catch of older 3+ to 6+ fish. Associated with the rise in exploitation of 1+ fish, was an increase in the overall percentage recovery rate of tags; from 6 - 9% (1952-64) to 21% (1974-76). Despite the increase in exploitation of 1+ fish, there was no evidence of a decline in numbers of older salmon in South Australia, or of the catch of adults in Western Australia. Although the South Australian catch reached its highest level (1897 tonnes) in the period 1972-74, when the Western Australian catch was at a low level; Stanley (WFRC 1) found no correlation between catches in South Australia and Western Australia, over a 15 year range.

The South Australian catch of salmon; by area, month and gear type, is shown for the period 1983-86 in Tables (5.1), (5.2) and (5.3). The aggregate quota of 1,000 tonnes has not been attained since 1982/83; because of adverse weather conditions and a reduction in effort, not a decline in salmon abundance.

During the study period, three special quotas were brought under the control of one company. This had the effect of reducing effective effort to the full-time activities of one purse-seine vessel, and the part-time activities of another. The latter vessel was seasonally engaged in the pole-and-live-bait fishery for tuna, and fished for salmon only during October and November of 1984 and 1985; and not at all during 1986. The lack of interest during 1986 reflected economic considerations, not a lack of salmon schools.

Adverse, unseasonal weather conditions during all three summers, from 1984-1987, prevented the major quota holder from obtaining its quota.

Thus, the purse-seine fishery has not been stable enough recently to enable detailed comparisons to be made with patterns observed by Stanley (WFRC 1) for the 1970's. In the present fishery, catch does not directly represent abundance in the fished area, especially on the West Coast. Seasonal and spatial variations in abundance were evident for specific areas, and gear types; although the variability in purse-seine catches obscures these data in Tables (5.1) and (5.2). For example, the monthly catch for area 45, on the South-Central coast, is shown in Table (5.4). The main method used there was mesh-netting, and predominantly large salmon were caught during the summer. The importance of this movement is discussed in Section (9.2.3).

Although purse-seine vessels were often forced to concentrate on schools along lee-shores, the shifts in capture location, reported by Stanley (WFRC 1), have been maintained. Salmon were caught mainly on the West Coast, around Kangaroo Island, on the South-Central coast and on the southern ends of Yorke and Eyre Peninsulas.

Despite the lowered level of catch, there was no shift of big schools back to the areas where salmon were often caught in the pre-purse-seine era; Wedge Island, the Althorpes and Spencer Gulf waters. The abundance of salmon along the South-Central coast was reported to be the greatest since the last decade, and effort was concentrated there by a purse-seiner during 1985-87.

Salmon are caught mainly in summer months, by all methods. During this time; (1) beach-seine teams intensify effort along the south-central coast, and on the north-east coast of Kangaroo Island; (2) rock lobster fishermen troll and mesh-net salmon, for use as bait, in the south-east; and (3) salmon are caught, incidentally or intentionally, by the use of hauling nets in the upper regions of both gulfs, and in enclosed bays. Mesh-nets are used to capture small juvenile salmon in the waters of the Coorong lagoon; annual catches there are given in Table (5.7).

Table (5.1) Salmon catch by area (live-weight; kilograms) for the period 1983-86. All methods pooled; Coorong landings shown in Table (5.7).

FISHING AREA	CODE	1983/84	1984/85	1985/86	1986/87
West Coast	1	95,380	153,058	254,982	95,683
Southern Eyre Peninsula	2	68,196	37,893	51,082	197,852
Spencer Gulf	8	14,730	10,034	18,894	23,573
Southern Yorke Peninsula	3	120,255	70,953	39,872	21,415
Kangaroo Island	4	57,630	213,673	63,696	90,196
Gulf St Vincent	7	9,217	11,153	17,417	10,330
South-Central Coast	5	31,665	105,259	186,303	54,130
South-East Coast	6	19,698	18,995	14,689	13,572
Other		31,160	964	1,627	-
TOTAL		447,931	621,018	648,616	506,751*

* until 30/3/87

Table (5.2) Salmon catch by month (Live-weight; Kilograms) for the period 1983-86. Coòrong landings not included.

MONTH	1983/84	1984/85	1985/86
July	5607	11198	9917
August	3699	26584	1898
September	10750	4365	7634
October	150947	60712	78423
November	88707	116486	181320
December	55278	11077	29097
January	18800	60953	108617
February	44473	95672	88734
March	40314	84374	84351
April	17431	9488	21692
May	4736	133455	30126
June	7189	7615	6807

Table (5.3). Salmon catch by gear type (live-weight; kilograms) for the period 1983-86. Coorong landings not included.

GEAR TYPE	1983/84	1984/85	1985/86
Purse-Seine	331,410	491,121	509,612
Hauling-Net	87,800	88,538	108,553
Mesh-Net	11,419	11,108	19.139
Handline/Trolling	16,490	30,958	10,505
Other	812	257	717
	447,931	621,982	648616

Table (5.4) Catch by month for area 45 on the South-Central coast; kilograms live-weight.

	YEAR		
MONTH	1983/84	1984/85	1985/86
July	0	0	12
August	0	0	15
September	6	0	0
October	1586	522	520
November	1732	1392	1698
December	1074	1005	1235
January	1023	1062	2210
February	167	862	1653
March	679	261	672
April	15	0	6
May	0	0	0
June	0	0	0

Beach-seine operators on the South-Central coast and on the northern coast of Kangaroo Island supply the bulk of the limited fresh fish market. Some of these operators have formed teams of two licensees; each holding a netting endorsement, and having an upper limit on catch of 20 tonnes. As a unit this has allowed them to take 40 tonnes of salmon annually.

5.2 THE USE OF PURSE-SEINES FOR THE CAPTURE OF SALMON

The term "purse-seine" is a mis-nomer when applied to the fishing operations undertaken by the holders of special quota. A review of the operation is given here to allow better understanding of this fishery for salmon.

Salmon schools are spotted from aircraft, which direct the carrier vessel to target schools; usually only those of at least 15 tonnes in size. The salmon are netted in, or behind, the surf zone close to shore.

Four factors are essential for a successful operation to be mounted; (1) sea conditions of negligible ground swell, or wave-action; (2) a smooth sea-bed free of unbroken rock; (3) little current or tidal movement; (4) shallow water depth; and, a stationary, or slowly moving, school of salmon which are not "flighty" in nature. These four factors describe the "position" of the school.

Once spotted, the target school is continuously monitored until its "position" is favorable. During the study, one vessel waited for several months for conditions to become suitable on the West Coast for a school to be fished.

When conditions become favorable, a large (7m) net skiff of shallow draught is launched from the carrier vessel, with two tender dinghies. A 600 metre net is loaded aboard the skiff, which sets off to encircle the school. The net has a bunt section, and varies in depth along its length; up to 13 metres. Purse rings are attached by slings to the lead-line for all except a single wing panel of the net.

With the aid of a rowing dinghy containing a portion of the wing, the net skiff carefully shoots the net around the school to form a circle. Once the net is joined, two divers from a hookah tender are immediately employed to haul the lead-line along the sea-bed and across obstacles; and to ensure the free passage of the purse-line through the rings. Meanwhile, the rowing dinghy is used to position numerous grapples and anchors; to hold the net skiff in place and prevent the net collapsing upon itself in prevailing wind or tide. The lead-line remains on the sea-bed at all times. The net is hauled into the skiff by hand, with the strain taken up on the purse-line by careful use of a hydraulically-driven winch. Divers assist with hauling underwater, throughout the set. The school is gradually driven into the bunt section. When pursing-up is complete, the skiff, bunt full of fish and dinghies, are winched out into deeper water. Anchor lines are paid out from the skiff as it is moving outward to the carrier vessel.

The salmon are brailed out of the bunt into holds containing refrigerated sea-water, and the temperature of the catch is reduced rapidly to the range 0^{o}-2^{o}C. The catch is prevented, by pound boards, from moving during transit. The product is usually of excellent quality; retaining colour, rigor and freshness for several days.

The entire operation is complex, often of many hours duration, and involves a high element of risk of loss of vessels and equipment. Weather conditions often become favorable for a set just before a change in wind direction; heightening the risk.

5.3 LENGTH AND AGE COMPOSITIONS OF CATCHES IN THE COMMERCIAL FISHERY

The catch composition, by length, for the commercial fishery is shown in Figure (5.1) for the years 1984/85 and 1985/86. Results were obtained by raising sample measurements to catch weights, and finally to total catch. There are three main features of these data; (1) the large numbers of small and large size classes taken in both years; (2) the absence in 1984/85 of salmon of 38-49cm LCF; and (3) the prevalence of fish of this length in catches made during 1985/86.

The catch is partitioned, by method for both years, in Figure (5.2).

In terms of length at first capture, salmon became fully recruited into the marine scale fishery at lengths to caudal fork between 20cm and 30cm; and into the purse-seine fishery, between 30cm and 40cm. Large salmon, from 55-65cm LCF were landed in the marine scale fishery, by beach-seine and mesh-net; but to a far lesser extent than in the purse-seine fishery. The significance of those catches is outlined further in Section (9.2.3). Salmon of less than 55cm LCF predominated in both sectors; and during both years the length composition of catches did not overlap significantly between sectors.

Superficially, it appears that there has been a failure in recruitment, and/or a very good recruitment, in 1984/85 of the size classes between 38-49cm and 30-40cm, respectively. However, catch did not represent abundance during those years, for the reasons given in Section (5.1), and the data are insufficient for further comment. As salmon move into exposed areas of adult habitat they leave the marine scale fishery and become fully recruited into the purse-seine fishery. The numbers of fish caught in the marine scale fishery (MSF) and the purse-seine fishery (PS), were broadly similar in magnitude (MSF : PS 1984/85 = 201,000 : 267,000 ; 1985/86 = 164,000 : 289,000) despite the great differences in catch weight.

The age and length compositions of purse-seine catches are summarised as catch curves for the past three seasons in Figure (5.3); by plotting Log_e of the numbers present, in catches, of each age group. Full recruitment into the fishery occurred during 1984/85, 1985/86 and 1986/87 at ages of 1+, 2+ and 2+, respectively. From an age of 5+ onwards, salmon disappear from catches; presumably migrating away from South Australia to spawn in Western Australia. Incomplete data were obtained for 1986/87, but the previous years show consistent catch curves.

The purse-seine catch is further dissected by fishing area; in Figure (5.4) by length composition; and, in Figure (5.5) by age composition.

It is considered that the purse-seine catch did represent abundance, of fully recruited age groups; during 1984/85, around Kangaroo Island; during 1985/86 on the far West Coast; and during 1986/87, along Southern Eyre Peninsula. Fishing was relatively intensive at those times and places.

At other times, fishing was carried out according to the spatial and temporal constraints imposed by the adverse, unseasonal weather conditions.

The largest, oldest salmon were most prevalent on the West Coast, and on the south coast of Kangaroo Island. Salmon of age 6+ were found in purse-seine catches only at Anxious Bay and Back Beach (Corvisart Bay) on the West Coast.

From these catch curves it is suggested that salmon leave the purse-seine fishery at ages of 5+ onwards; although fish appear to begin movement from the Southern Eyre Peninsula (Boston Bay) area at an age of 3+ to 4+.

These data are summarised in Tables (5.5) and (5.6) for comparison with two previous decades of catches in the purse-seine fishery. The fishery has recently operated at a much lower level than these previous periods. Average catches during the periods 1975-78 and 1984-87 were, respectively; 762 tonnes and 421 tonnes. Associated with the reduction in catch, there has been no marked change discernible in the relative numbers of older fish caught. However, since the period 1975-78, the relative number of small (<40cm LCF), young (1+) salmon has decreased in the purse-seine catch. In 1984/85, this age group predominated in the catch; but declined in importance, relative to 2+ fish, in 1985/86 and 1986/87.

It is possible that reduced competition between boats, and reduced effort, has shifted exploitation away from 1+ salmon. In some fisheries, over-fishing is marked by disappearance of older year classes from catches; at progressively younger ages. There is no recent evidence of such a shift, although catch does not directly represent abundance.

Despite the lowering of catch in South Australia, there has been an overall increase in the recovery of tags; from 21% in 1975-78, to 32% in 1984-87.

5.4 CATCH COMPOSITION - OTHER GEAR TYPES

The length compositions of catches made by use of different gear types, in the marine scale fishery, are shown in Figure (5.6) for the year 1985/86. Information on the proportion of catches sampled in the marine scale fishery was given in Table (4.1).

The use of beach seines is not distinguished from the use of hauling nets in the GARFIS data base. However the data presented in Figure (5.6) were constructed directly from market measuring and do give an accurate estimate of the catch composition.

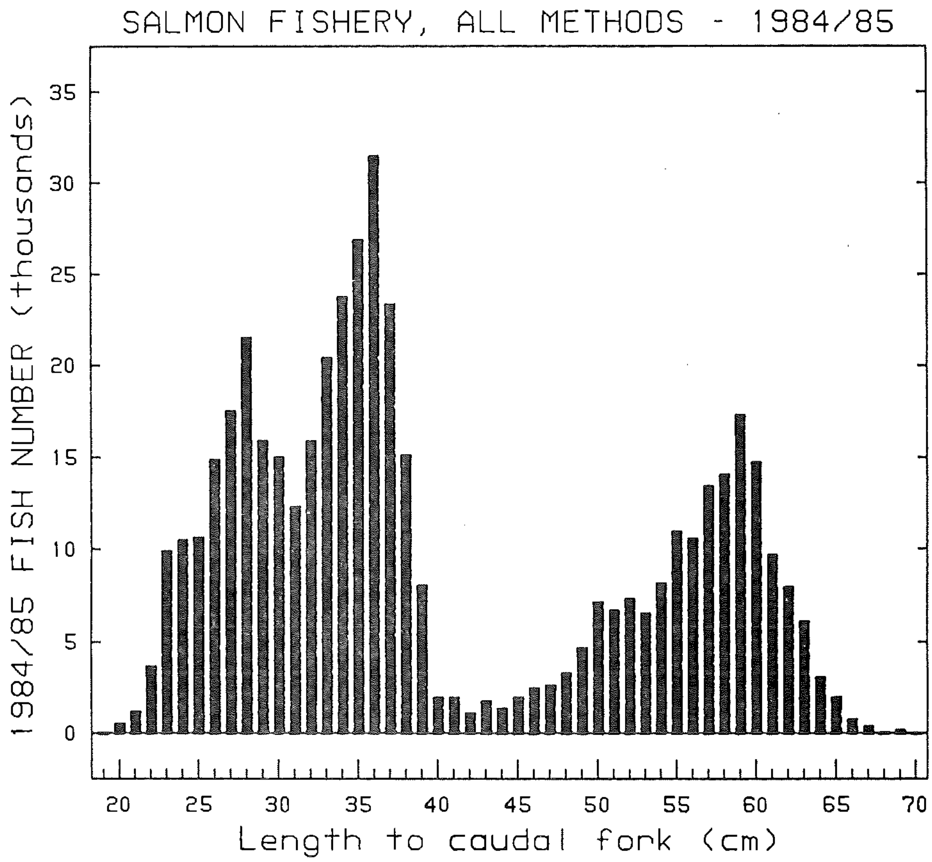
Trolling, hand-lining, and the use of haul nets in ring-shots, power-hauling and drain-off shots, all resulted in catches of salmon of less than 50cm LCF. Salmon were fully recruited into the hauling net fishery immediately upon attainment of the minimum legal length. Individuals larger than 30cm LCF were caught by trolling and hand-line, although only a small percentage of the catch was sampled.

Salmon from 50-66cm LCF were landed in the marine scale fishery only by the use of beach-seines and mesh-nets. These large fish were caught on the north-east coast of Kangaroo Island, on the South-Central coast; and by rock lobster fishermen at Sceales Bay, on the West Coast. Beach-seines were employed in summer months to take large salmon for bait, in the Sceales Bay - Streaky Bay area.

Mesh-nets were set overnight in shallow water from rocky shores, to catch salmon, mulloway and shark moving along the coast. No measuring was undertaken of the catch by this method in the South-East, where the catch is used as bait for rock lobster.

Catches in the Coorong lagoon have not been included in the present analysis; but are significant, in terms of the numbers of small salmon captured. Yearly catches are listed in Table (5.7). The catch is comprised almost solely of 0+ fish less than 30cm LCF (pers.comm. D. Hall), caught by mesh-netting.

Figure (5.1). Catch composition by length, by year; all methods pooled.



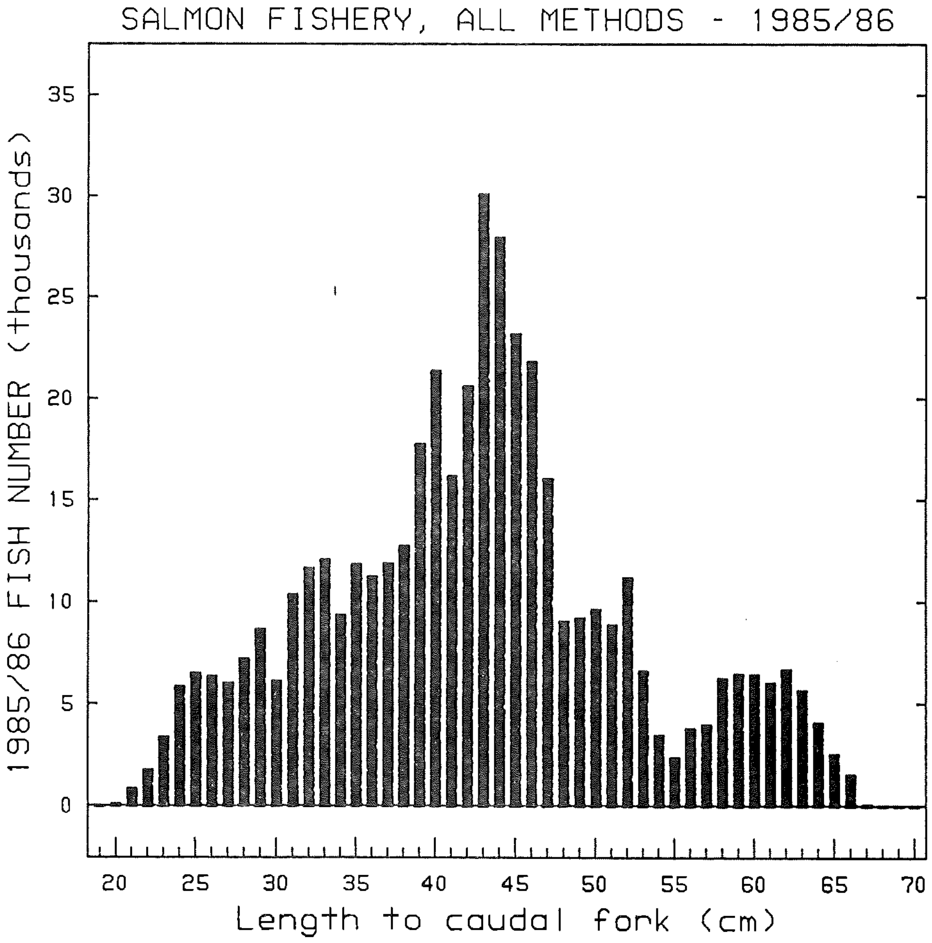


Figure (5.2). Catch composition by length, by year, by fishery; for 1984-86. Coorong catches not included.

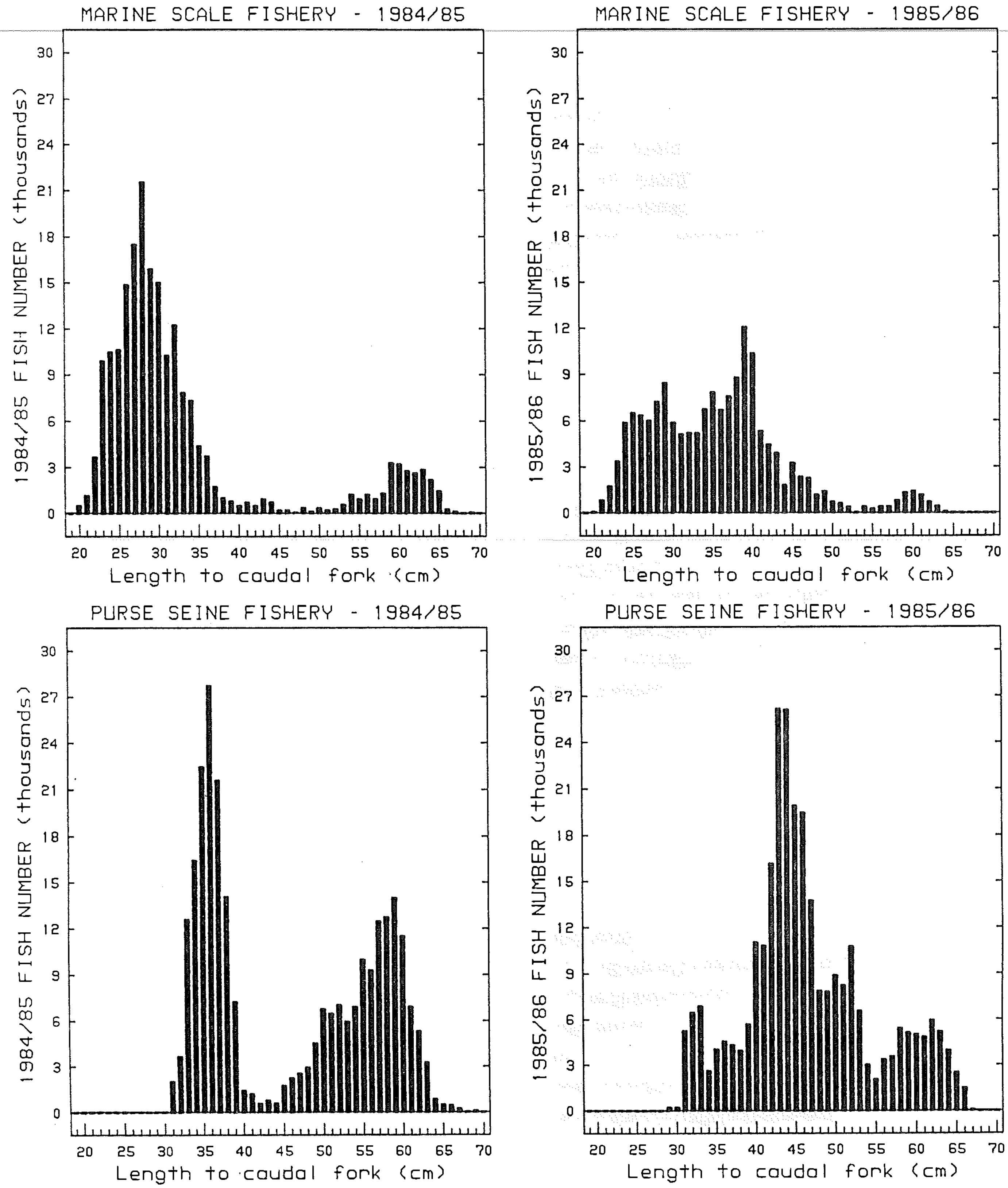
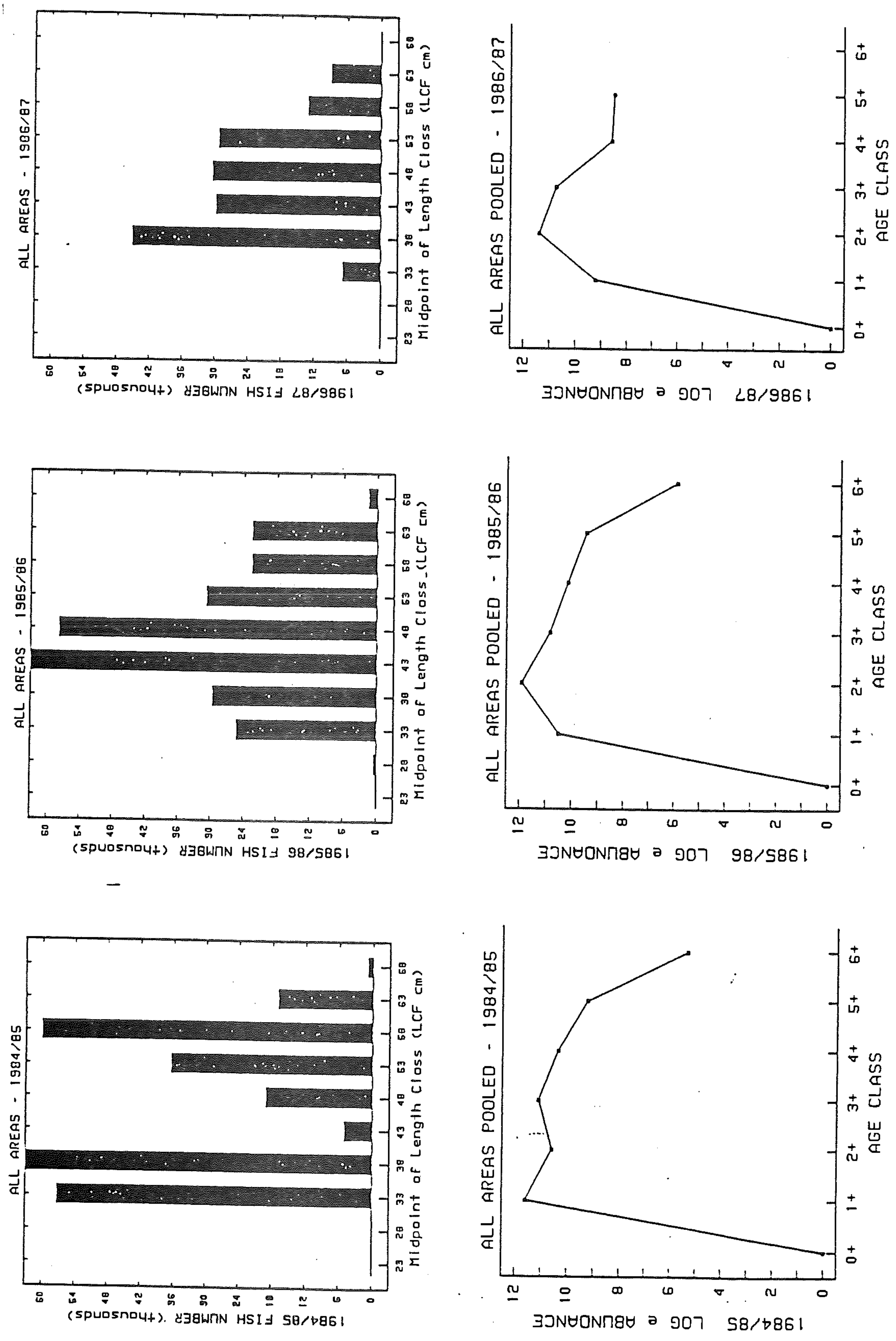


Figure (5.3). Age and length compositions of purse-seine catches summarised for years 1984-1987; areas pooled. Increments of five centimetres in length to caudal fork, and one year in age.



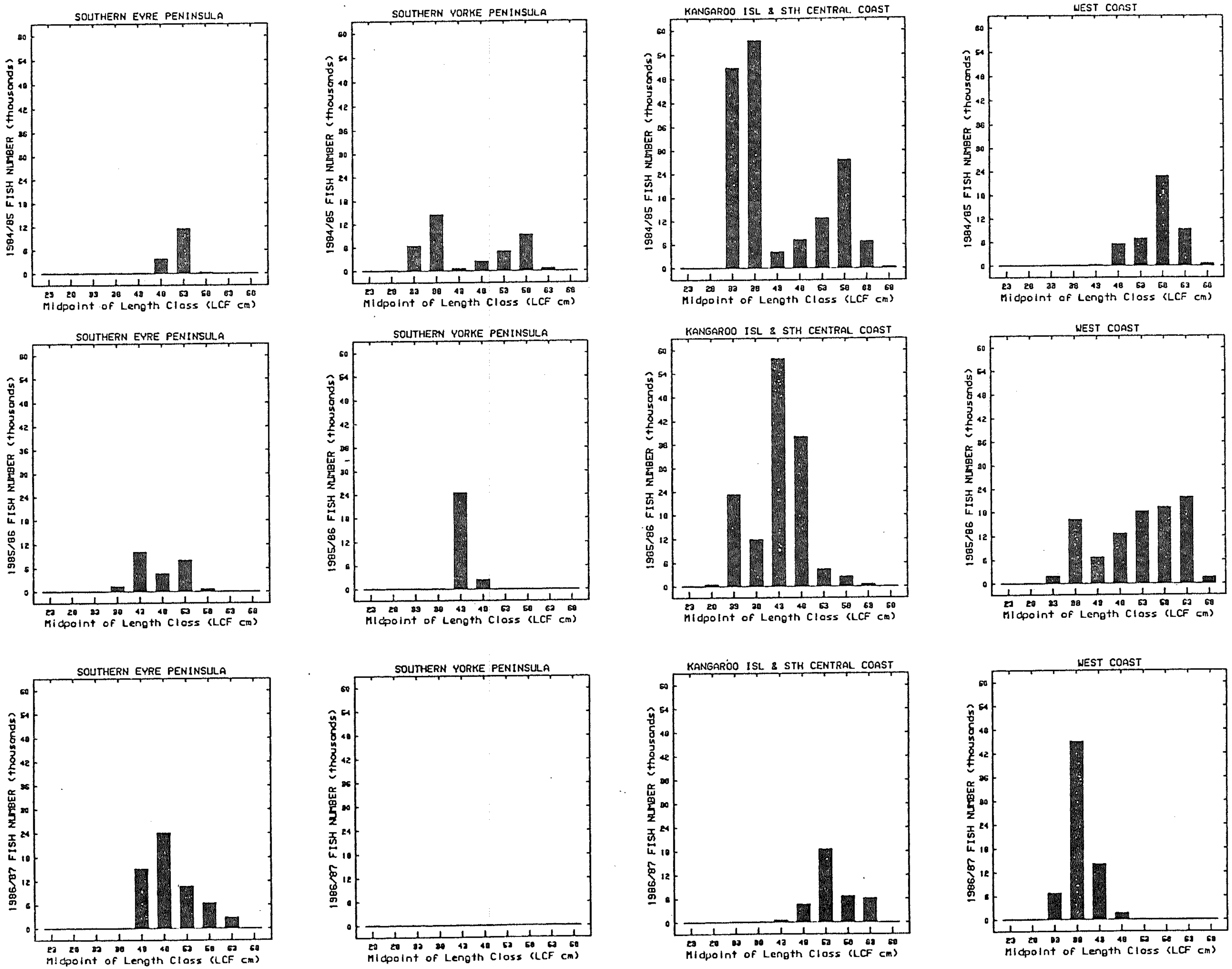


Figure (5.4) Purse-seine catch by area by year; length composition of catches 1984-87. Increments of five centimetres in length to caudal fork.

Figure (5.5) Purse-seine catch by area by year; catch curves for the period 1984-87. Increments of one year in age.

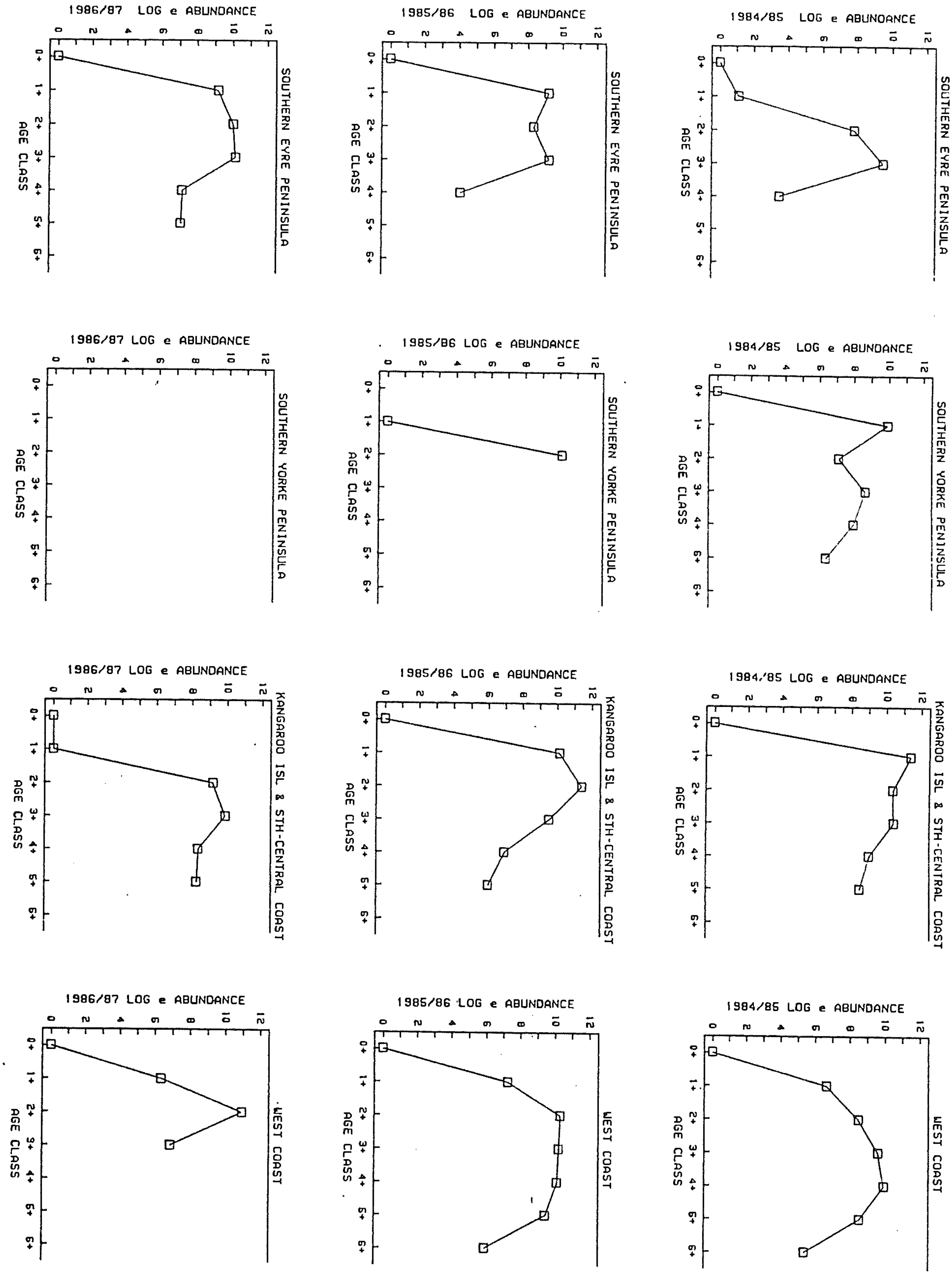


Table (5.5) Estimated numbers (thousands) of salmon in 5cm length (LCF) classes, caught in the purse-seine fishery in all areas during three decades. Data from previous studies summarised from Stanley (WFRC 1).

YEAR	-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	TOTAL CATCH (NUMBERS)	TOTAL CATCH (TONNES)	% OF CATCH SAMPLED
1964	11	156	97	11	11	2	11	6	305	392	34
1965	23	96	42	55	31	3	1		251	301	26
1966	25	55	16	53	214	31	1		395	835	27
1967	32	96	61	82	51	84	61	3	470	988	86
1968	6	64	38	68	69	78	41	2	366	820	93
1975	137	110	59	86	36	80	46	5	559	985	91
1976	9	65	62	144	62	21	19	2	384	690	98
1977	179	162	73	65	28	46	25	1	579	795	86
1978	73	51	49	86	40	34	9	1	343	581	80
1984	57	72	5	19	36	60	17	1	267	458	98
1985	26	29	99	58	31	22	22	2	289	509	81
*1986	7	45	30	30	29	13	9	1	163	298	63
AVERAGES											
1964-5	17	126	70	33	21	3	6	3	279	346	
1966-8	21	72	38	68	111	64	34	2	410	881	
1975-8	100	97	61	95	42	45	25	2	467	762	
1984-7	30	49	45	36	32	32	16	1	241	421	

* Until 28/02/87

Table (5.6). Age composition (thousands) of the purse-seine catch for all areas, during two decades. Data from previous studies summarised from Stanley (WFRC 1).

	AGE						TOTAL	CATCH WEIGHT
YEAR	1+	2+	3+	4+	5+	6+	NUMBERS	(TONNES)
1975	218	154	80	69	44	5	570	985
1976	66	147	122	43	9		387	690
1977	277	208	61	21	12	4	583	795
1978	106	146	66	22	4		344	581
1984/85	108	40	66	31	10	0.2	255	458
1985/86	36	148	50	25	12	0.4	271	509
*1986/87	10	87	45	5	5		152	298*

AFTER STANLEY (1981)

95% confidence limits of length range	32	35	43	52	56	58	lower
LCF (cm)	40	53	61	65	67	69	upper

* until 28/02/87

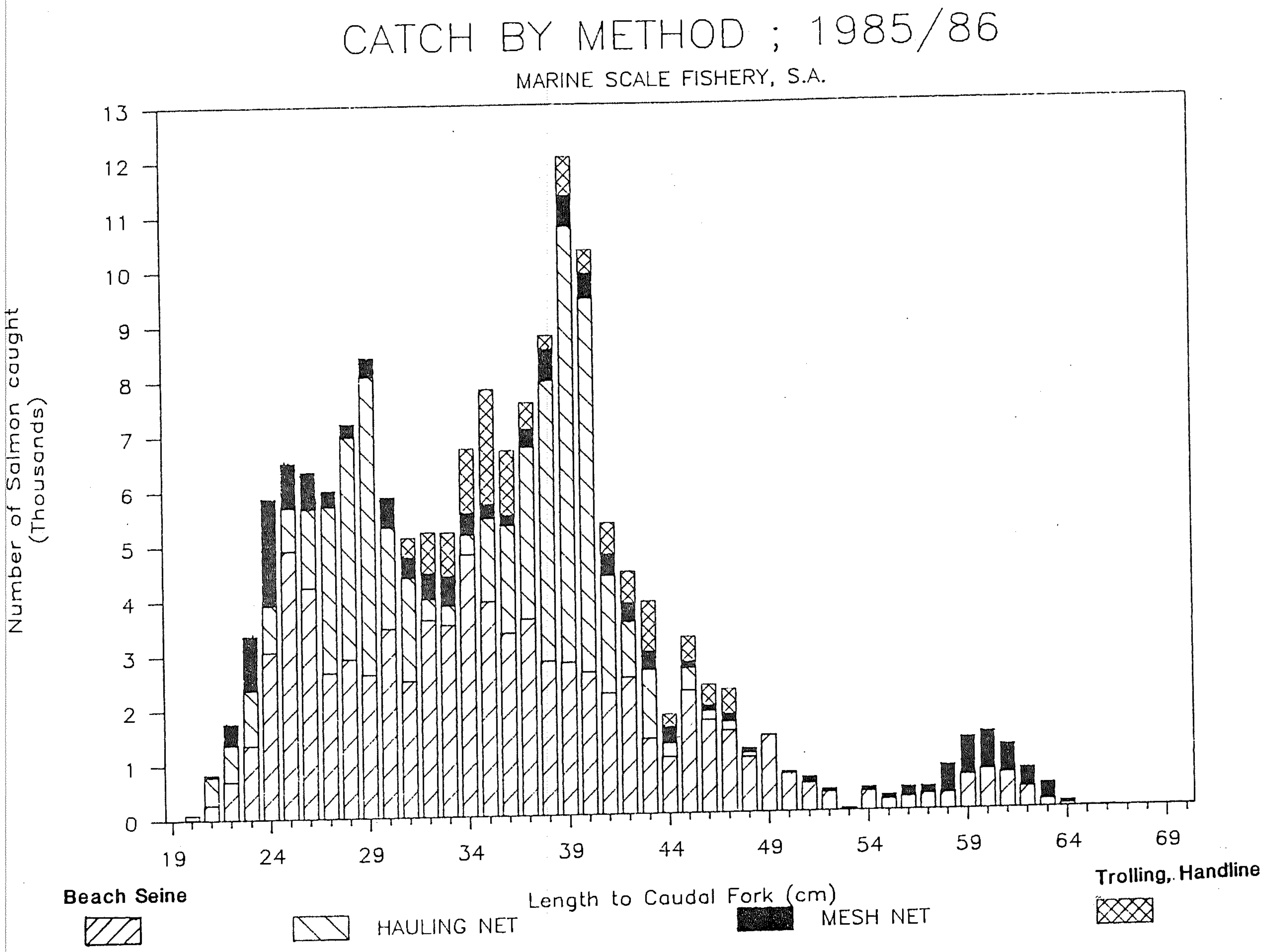


Figure (5.6). Catch compositions by length, by method, for the marine scale fishery; 1985/86.

Table (5.7). Catches of juvenile salmon in the Coorong lagoon (kilograms live-weight).

YEAR	CATCH
1976/77	12574
1977/78	2895
1978/79	8795
1979/80	21072
1980/81	15862
1981/82	12000
1982/83	15000
1983/84	2900
1984/85	1000

Catch in the Coorong does not directly reflect abundance, because of environmental variability. The outflow of the Murray River causes great changes in the salinity of the fished area.

5.5 THE USE OF CATCH-PER-UNIT OF EFFORT IN THE SALMON FISHERY

In biological management of commercial fisheries it is usually assumed that catch-per-unit of effort (C/E) is proportional to stock abundance (P), with a fixed constant of proportionality (catchability coefficient), q. The relationship C=qEP is combined with an appropriate model of population dynamics to produce a dynamic fishery model, which can be used as a basis for management policy (Clark and Mangel, 1979). The major assumptions underlying this relationship pertain to the fishing process; particularly that a) an appropriate unit of effort (E) is available; b) that fishing consists of a random search for fish; and c) that all fish in the stock are equally vulnerable to capture.

All three assumptions are violated in the fishery for western salmon.

No unit of effort has been found suitable for application to the beach-seine and purse-seine fisheries. The capture of salmon schools by purse-seine involves a large component of "waiting" time. The size of catch from a school depends upon size of the school, with an upper limit imposed by holding capacity of the fishing vessel. The success of a fishing trip is independent of its duration; but, rather, depends upon weather, sea-bed terrain and behaviour of fish schools. Searching for schools and fishing is carried out in traditional fishing areas; not on a random basis. Salmon school by size and not all schools are vulnerable to capture.

6.1 THE PRESENT STATE OF THE RECREATIONAL FISHERY FOR AUSTRALIAN SALMON IN SOUTH AUSTRALIAN WATERS

Recreational fishers in South Australia are not required to purchase a licence for access to the salmon resource, nor do they return catch and effort statistics on their activities. Thus, the extent of their activities are largely unknown. Several Australian studies have estimated the economic value of angling (Kirkegaard, 1985) but few have estimated recreational catch (Pollock and Williams, 1983, Henry 1984).

It is a well known paradox that, while average catch rates by anglers are low, the recreational catch can form a substantial proportion of the total catch in a fishery; due to the large numbers of fishers participating. In many well-documented cases in America, the catch by anglers far exceeds that of the professional sector (Cunningham et al., 1985) and the fisheries are managed accordingly.

Walker (WFRC 6) estimated the salmon catch by Western Australian anglers from tag returns. He found that amateur fishing effort had increased markedly in the period 1950-81, because of better access to fishing locations and the provision of more time for leisure activities. During the period 1975-81 anglers recovered 22.3-46.7 percent of all tags returned. The average catch, including tagged fish, on the occasion an angler recaptured a tagged salmon was 4.4 fish in 1975; 4.6 in 1976; and 8.6 in 1977.

Successful anglers generally were local people of the south-west, rather than visitors from the Perth metropolitan area. They operated year-round and often in locations inaccessible to the professional beach-seine fishery. At times, when salmon schools remained within casting range, catches by groups of anglers were observed to be very large, despite the limit on catch of five salmon per day; at Canal Rocks, the amateur catch was up to 2 tonnes (500 fish) an evening in February, 1983 (Walker, 1983).

The information presented here is derived from surveys of amateur catches through; (1) interviews of anglers recovering tags; and, (2) monitoring of the club "weigh-ins" at Australian Anglers Association (A.A.A.) outings. The interview forms used in both surveys are included as Appendices (6.1) and (4.1), respectively.

6.2 METHODS OF OPERATION

Since 1970, there have been changes in the South Australian fishery for Australian salmon. Most importantly, vehicular access to recognised salmon beaches has been vastly up-graded. The locations of these beaches have been widely publicised by country councils, and the angling media; often through fishing conventions at which salmon are the species sought. There has been a great increase in the ownership of four-wheel-drive-vehicles during this period, and little of the coast now remains inaccessible. Angling tackle, in the form of nylon lines, hollow fibreglass rods and quality geared reels, has become more efficient and cheaper in relative price. It is presumed that angling effort has become more intensive and more effective as a result of these changes.

Associated with these discernible changes has been a doubling in the recovery of tags by anglers, as a proportion of the total number of tags returned from South Australia; from 16% in 1975, to 30% in 1984-87.

The target species, gear types employed and fishing platform are given in Table (6.1) for tags recovered by anglers. The majority of tagged salmon were caught by shore anglers using pilchards for bait, on linked hooks, with the intention of catching salmon.

The few tags recovered by boat anglers fishing for whiting shows the relative unimportance of larger salmon, as by-catch, in this major sector of the recreational fishery. Tags recovered from this sector of the recreational fishery, and from the recreational use of mesh-nets, were from the smallest (25-35cm LCF) size classes tagged. These smaller salmon are sought, and caught, by amateur netters, especially in the Coorong lagoon and Boston Bay (D. Hall, pers.comm., Jones, 1986).

Most anglers (71.5%) reported that they were not fishing in the vicinity of visible salmon schools when tagged salmon were caught. The most common method involved casting weighted pilchards into holes and gutters of surf beaches, and passively waiting for strikes. Boat anglers mainly fished visible schools, by actively trolling, or casting, lures into the vicinity of the school.

The home areas of anglers catching tagged salmon were (by number of tags recovered); Adelaide metropolitan area (28.3%); towns north and west of Adelaide (32.7%); towns south and east of Adelaide (36.4%); and, Victoria (2.6%). The distances travelled, from home address to fishing location, by anglers who caught tagged salmon are summarised in Figure (6.1). There are three main peaks in the data, which can be

Table (6.1) Target species, gear type employed and fishing platform when a tagged salmon was recovered by an angler.

TARGET SPECIES	N TAGS	%	GEAR USED	N TAGS	%	PLATFORM	N TAGS	%
Salmon	212	78.8	Pilchard Bait	198	64.7	Beach	181	59.7
Mulloway	13	4.9	Other Bait	64	20.9	Rocks	52	17.1
Whiting	8	3.0	Lure Casting	20	6.5	Boat	48	15.8
Mullet	2	0.7	Trolling	19	6.20	Wharf	22	7.2
Snook	1	0.4	Mesh Net	2	0.65			
Tommy Ruff	2	0.7	Spearfishing	2	0.65	N records	303	
Any Species	6	4.8						
			N records	305				
Salmon and Mulloway	14	5.2						
Salmon and Mullet	1	0.4						
Salmon and Snook	1	0.4						
Salmon and Tommy ruff	2	0.7						
Salmon and any species	7	2.6						
N records	269							

Figure (6.1). Distances travelled to fishing locations by anglers who caught tagged salmon.

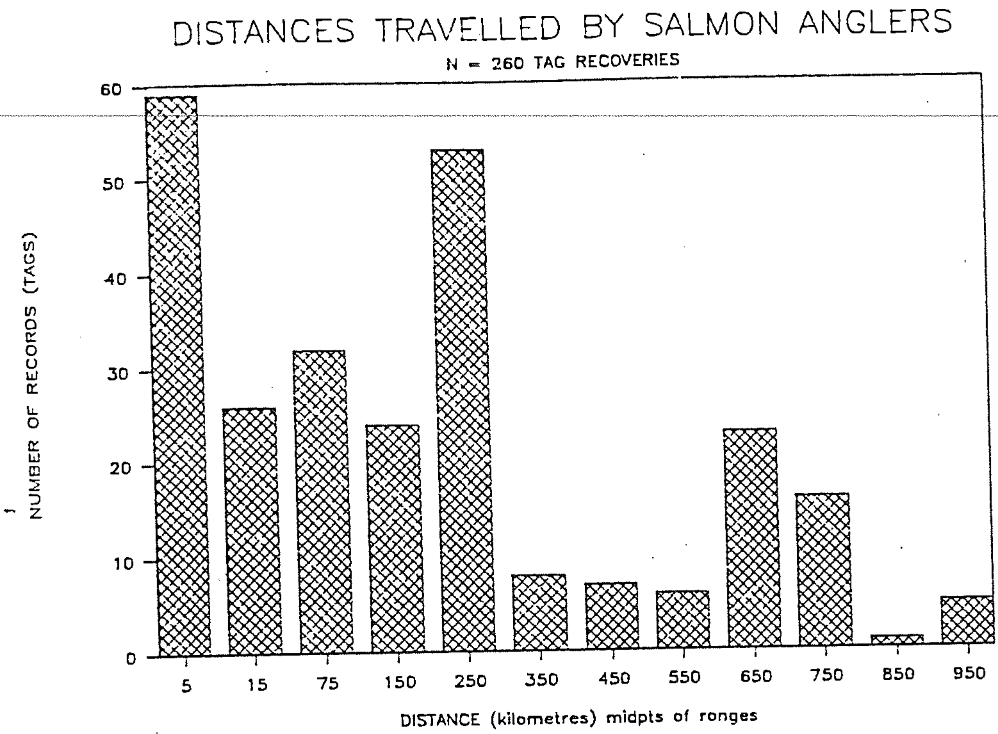
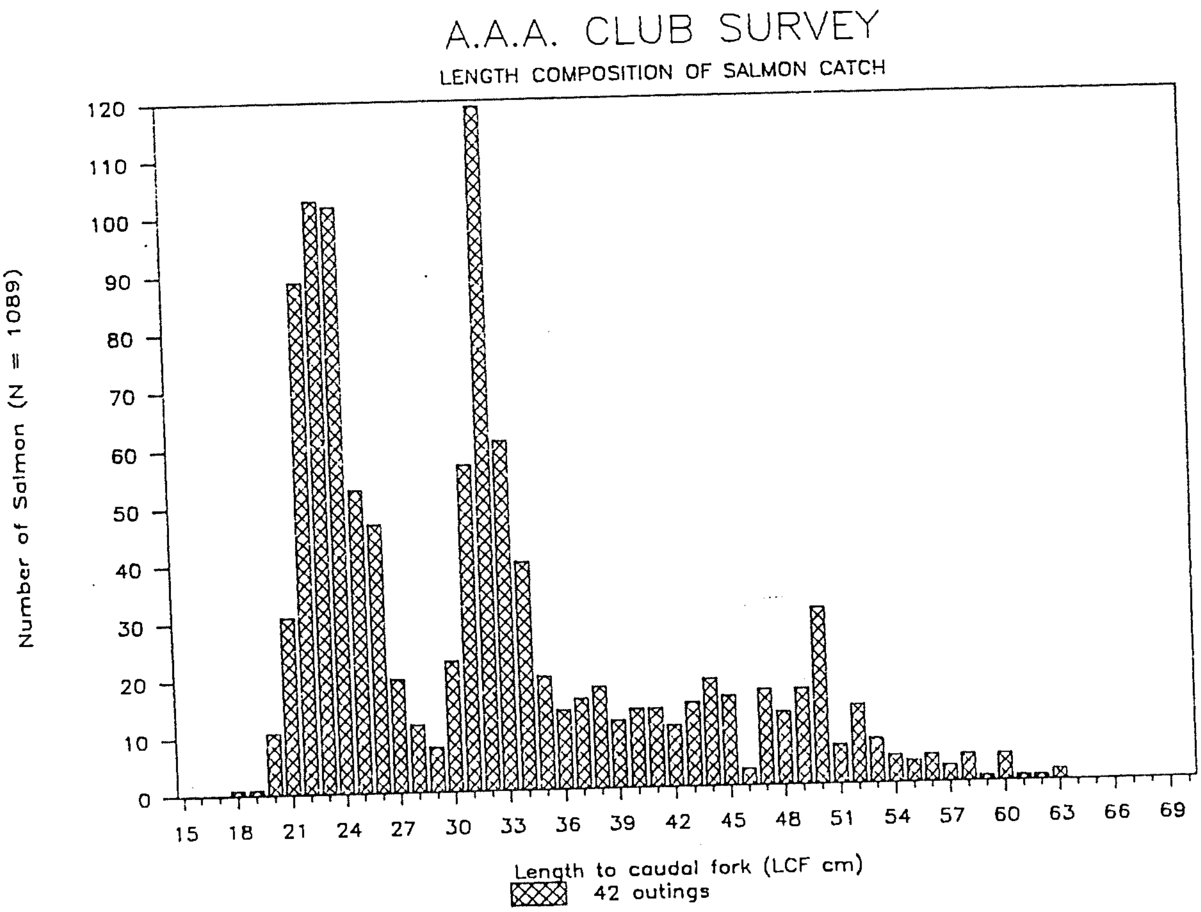


Figure (6.2). Length composition of catches made by A.A.A. clubs during outings; sample dates and locations pooled.



attributed partially to; (1) Port Lincoln-based anglers fishing Boston Bay; (2) Adelaide - based anglers fishing at Yorke Peninsula, and Port Augusta - based anglers fishing the West Coast; and, (3) Adelaide-based anglers travelling long distances to fish the West Coast.

The salmon population throughout the State provides recreation to anglers from local centres and the Adelaide metropolitan area.

6.3 LENGTH COMPOSITION OF THE RECREATIONAL CATCH

The lengths of salmon captured during 62 outings by angling clubs are given in Figure (6.2). No distinctions are made between areas fished or seasons. The major portion of the sample comprised 20cm LCF (just above the legal limit on minimum length) to 40cm LCF salmon in the 0+ - 2+ age groups. Errors in salmon measurement by anglers probably caused the peak of 32cm fish. Jones (1983a) reported similar findings for a West Coast angling competition covering bay, beach and rock fishing.

Surveys of club outings were biased by; (1) the lack of salmon landed on most trips (see Section 6.4); (2) the use of techniques aimed at catching species other than large salmon; and, (3) the restricted number of surveys completed.

The use of tag returns, in estimating length composition, is biased by the large proportion of large salmon in the tagged sample. In terms of mean length at recapture (in both South Australia and Western Australia), salmon caught by anglers were 51.94 ± 11.38cm LCF; and those caught by professionals, 53.76 ± 11.39cm LCF.

6.4 CATCH RATES

The average catch rate, for anglers returning tags, was 3.10 ± 4.10 salmon per angler hour. The average catch, including the tagged individual, was 12.20 ± 18.77, upon each occasion a tag was recovered by an angler. From Figures (6.3) and (6.4) it can be seen that most anglers caught only 1-5 salmon, at a rate of 0.01-1.0 salmon per angler hour; each time a tag was recovered. These results cannot be compared directly with those of Walker (WFRC 6), as he provides average values only, and no indication of variance from those averages.

Figure (6.3). Size of catch of salmon, including tagged individuals made by anglers who caught tagged salmon; all data pooled.

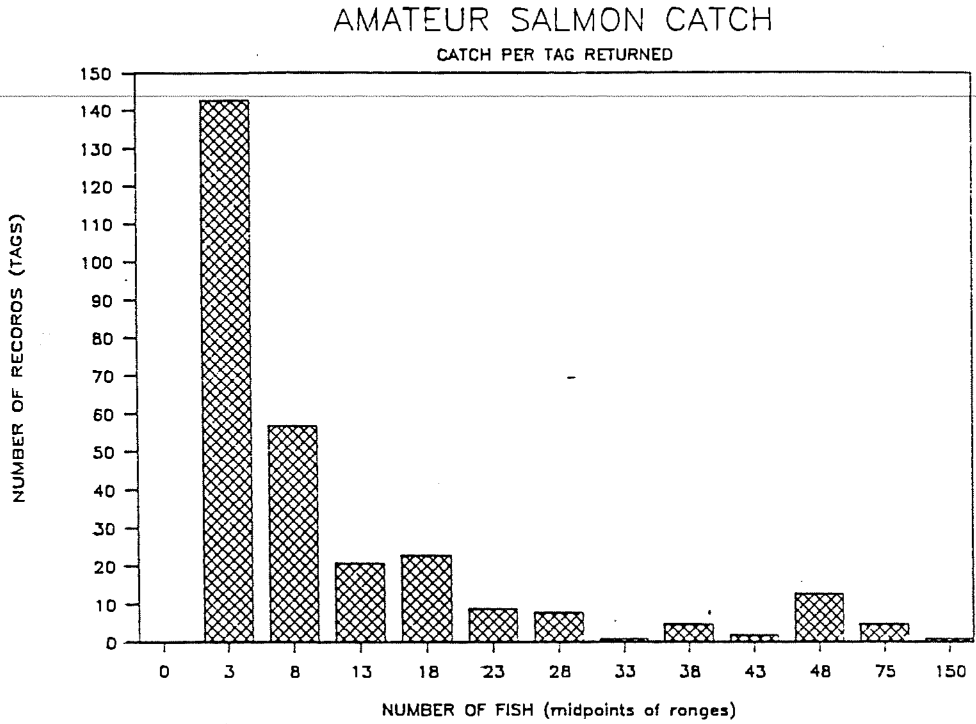
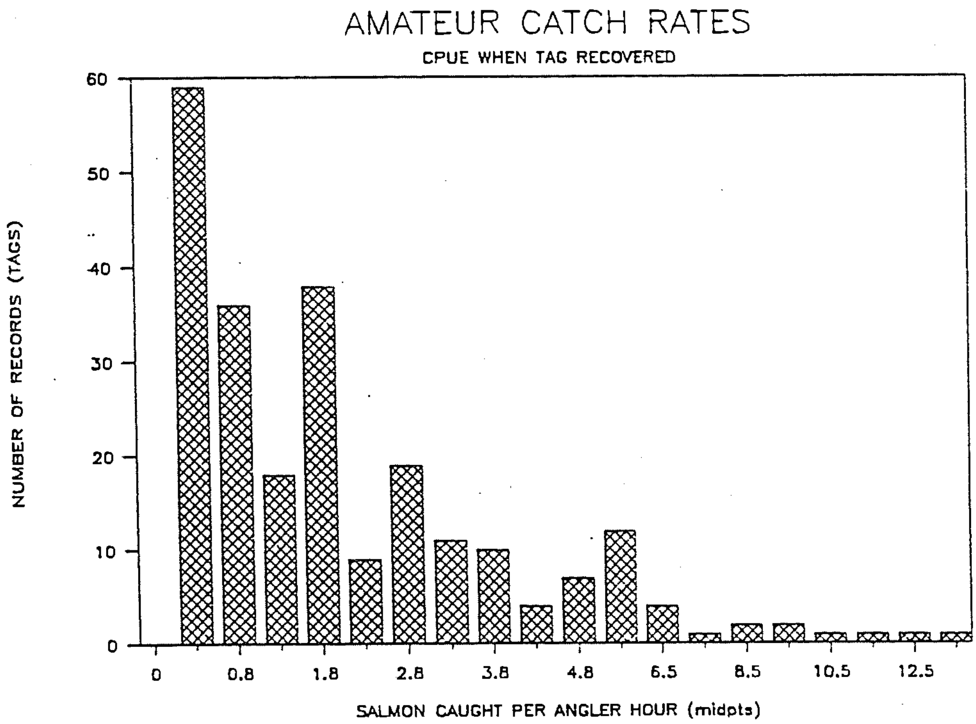


Figure (6.4). Catch rates by anglers who recaptured tagged salmon; all data pooled.



The tails of high values in Figures (6.3) and (6.4) were due to large catches of salmon made by anglers from boats. Catch rates on different fishing platforms are given in Table (6.2).

These estimates were biased by the fact that anglers usually fish from boats in groups; but, when completing interview forms, they often assigned the entire catch to their personal hours spent fishing. It is concluded, therefore, that the tails of high values represent group fishing efforts. This bias is added to, further, by the fact that unsuccessful trips were not included in interviews; anglers returning tags were always successful, having landed at least one salmon.

The survey of A.A.A. clubs did include trips during which no salmon were caught; and there were many such outings for the majority of club anglers. The total numbers of salmon landed during 60 outings is given in Figure (6.5). No salmon were caught during 24% of the surveyed events, and the entire salmon catch comprised less than 10 fish for 47% of the successful outings. However, there was a particularly successful club, based on Eyre Peninsula, which regularly recorded the larger catches figured. It must be stressed here that the surveyed outings did not all involve angling specifically for salmon.

When these catches are related to angler effort, in Figure (6.6), it is evident that catch rates were generally low. The average catch rate was 0.27 ± 0.52 salmon per angler hour, with a long tail of higher values up to 2.3 salmon per angler hour.

The skewed distribution of all data presented in Figures (6.3) - (6.6) reflects the schooling behaviour of the sub-species and the ranges in angler skill, weather conditions and productivity of different locations. For the angler, low average catch rates are offset by the relatively high unit weight of the catch, and the knowledge that, should a school visit the fishing location, large catches can be made. At such times, over one tonne of salmon have been landed during club outings. However, the catch is limited by the ability of the angler to transport its bulk, by foot. Boat anglers do not have such limitations and, in Western Australia, anglers often exceed the bag limit when trolling from power-boats (Walker, 1982b).

Figure (6.5). Number of salmon landed during 60 outings of A.A.A. clubs.

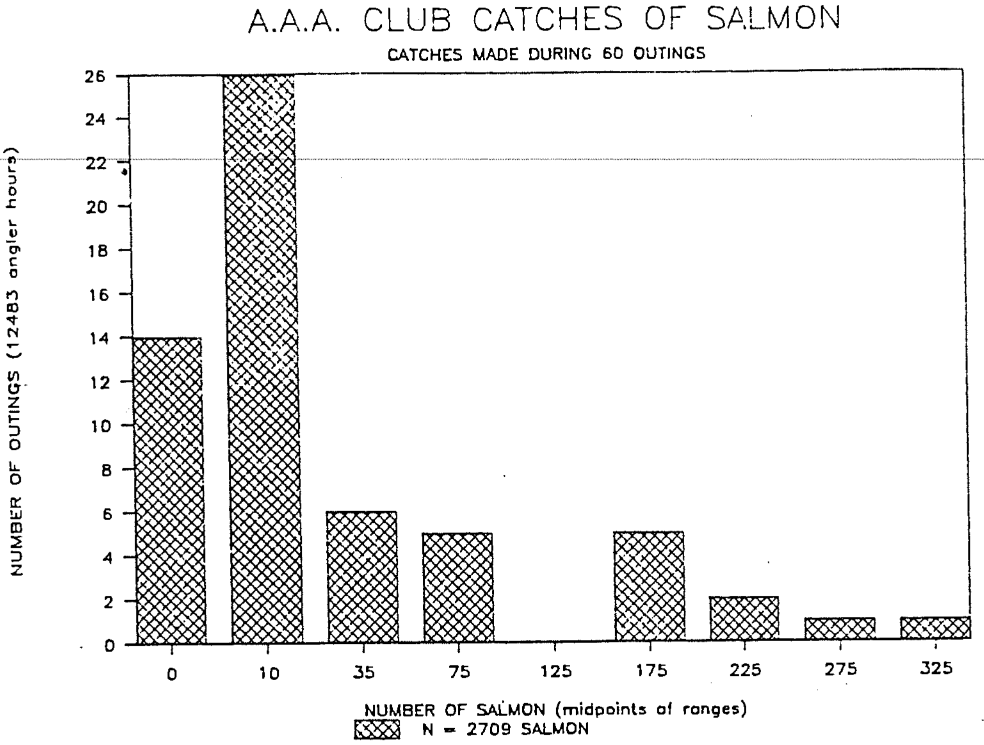


Figure (6.6). Catch rates by A.A.A. club members during outings.

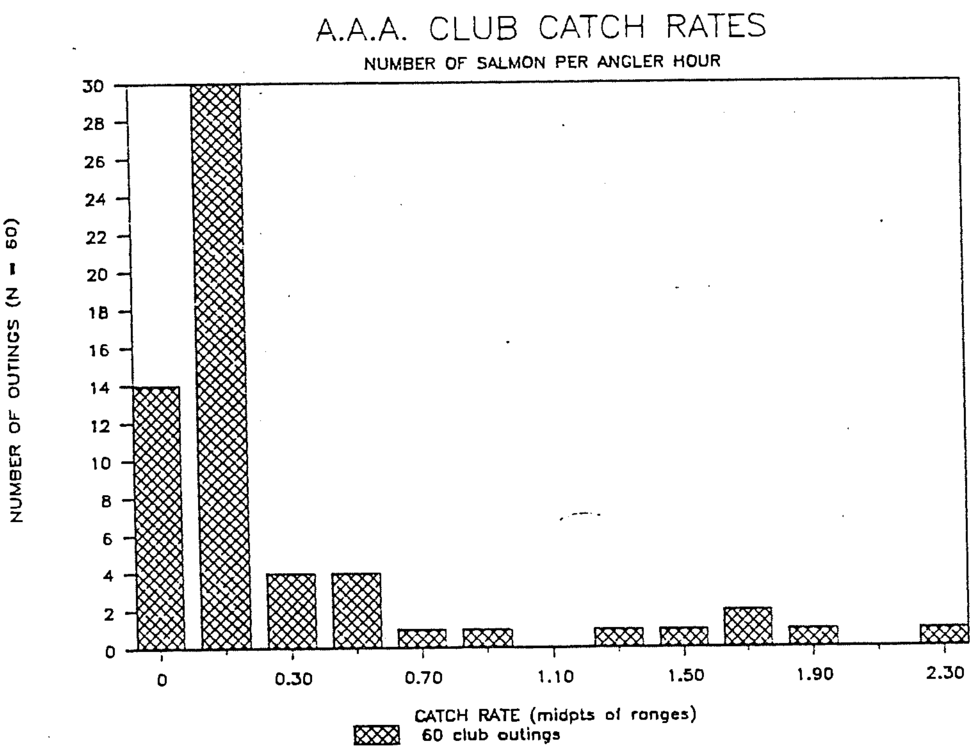


Table (6.2) Catch rates recorded by anglers catching tagged salmon from major fishing platforms; expressed as salmon caught per angler hour.

FISHING PLATFORM	MEAN CATCH RATE	Std. Dev.	N tags (Records)
Boat	4.38	5.81	38
Wharf	3.79	6.28	18
Beach	2.69	3.03	148
Rocks	1.57	2.62	37
Average	2.87	3.92	241

6.5 SPATIAL VARIATION IN CATCH RATE

Catch rates varied widely between fishing locations in South Australia. In Table (6.3), the catch rates recorded by anglers catching tagged salmon are ranked by State fishing areas. In Table (6.4), the catch rates of A.A.A. club anglers are ranked by coastal zones.

For anglers returning tags, catch rates varied between areas within fishing regions, and were highest on the north coast of Kangaroo Island and along the West Coast. Most of the tags returned from the north coast of Kangaroo Island were recovered by local anglers trolling from power boats around visible schools. In area 31 (Boston Bay) of southern Eyre Peninsula, high catch rates were recorded by local anglers using pilchard baits around tuna boats moored at

Table (6.3). Catch rates by fishing areas (from Figure 1.3) for anglers who caught tagged salmon; expressed as salmon caught per angler hour.

FISHING REGION	GARFIS AREA	MEAN CATCH RATE	Std Dev.	N TAGS (Records)
NTH KANGAROO ISL.	41	9.844	8.022	7
STHN EYRE PEN.	31	4.396	6.772	15
NTH KANGAROO ISL.	42	4.232	7.601	11
WEST COAST	8	4.804	4.851	5
WEST COAST	28	4.003	4.797	18
ST VINCENT GULF	35	3.749	3.829	8
SOUTH EAST	46	3.430	2.979	6
WEST COAST	7	3.300	0.000	1
WEST COAST	10	3.124	2.991	58
WEST COAST	9	3.000	3.677	2
STH-CENTRAL COAST	45	2.574	2.304	10
WEST COAST	27	2.400	0.000	1
STHN YORK PEN.	40	2.326	3.981	13
STH-CENTRAL COAST	43	2.000	0.000	1
STHN YORK PEN.	33	1.888	1.445	26
STH-CENTRAL COAST	44	1.800	2.269	20
STHN EYRE PEN.	30	1.750	0.000	1
WEST COAST	18	1.725	0.877	4
ST VINCENT GULF	36	1.707	1.462	3
WEST COAST	15	1.190	1.209	4
SPENCER GULF	23	0.770	0.325	2
SOUTH EAST	51	0.701	1.125	3
WEST COAST	17	0.280	0.000	1
AVERAGE CATCH RATE		2.955	3.982	245

Table (6.4). Catch rates by A.A.A. club members in different coastal zones; expressed as salmon caught per angler hour.

ANGLING ZONE	COASTAL ZONE FROM	TO	MEAN CATCH RATE	St.Dev.	N OUTINGS
11	Cape Donnington	Point Whidbey	1.75	0	1
13	Point Drummond	Point Brown	1.42	0.76	4
12	Point Whidbey	Point Drummond	1.12	0.94	3
14	Point Brown	Twin Rocks	0.43	0	1
3	Murray Mouth	Cape Jervis	0.18	0.16	5
7	Giles Point	Corny Point	0.16	0.27	14
5	Port Adelaide	Port Wakefield	0.12	0.19	7
10	Port Neill	Cape Donington	0.12	0.17	3
2	Robe	Murray Mouth	0.09	0.	5
4	Cape Jervis	Port Adelaide	0.03	0.06	10
8	Corny Point	Port Augusta	0.01	0.02	5
6	Port Wakefield	Giles Point	0.01	0.01	2
		AVERAGE	0.27	0.52	60

Brennan's Wharf. Along the West Coast, large catches were made by local, and visiting, anglers at Almonta Beach (Area 28) and Back Beach (Area 10).

6.6 AN ESTIMATE OF THE AMATEUR SALMON CATCH

Philipson et al (1986) surveyed angling effort in South Australia, and provided estimates of person-days expended in angling activity during 1982-83. Summaries of these data are used here to construct estimates of the amateur catch of salmon made during the study period.

A three-hour angler day was adopted in Table (6.5) to produce an estimate of amateur catch, based on average catch rates recorded by A.A.A. club anglers. The length composition data presented in Figure (6.2) was combined with the estimates of fish numbers, to give estimates of catch weight; through the formula, Log (weight) = 3.0485 (Log LCF) - 1.8772 (Malcolm, 1966a).

The estimate of annual amateur catch of 795,000 salmon (544 tonnes) is considered to be an overestimate of catch; because Philipson's et al (1986) figures on angler effort do not distinguish between target species, or fishing method, in fishing areas. However, it is considered that amateur catch is in the order of hundreds of tonnes annually; rather than tens of tonnes. For example, during the tagging programme, 221 anglers caught 3327 salmon, of 51cm LCF in average length, in catches containing tagged salmon. This sample was estimated to weigh at least seven tonnes. The A.A.A. club catches surveyed were estimated to total nearly one tonne, using length/weight keys.

In the absence of more data on catch and effort, it is concluded that the amateur catch was less than the commercial catch during the study period; but was highly significant, probably in the order of hundreds of tonnes annually.

Raw tag recovery data showed that, of all tags recovered, anglers in South Australia returned 20.6% of tags; compared with S.A.

Table (6.5). Estimates of catch by anglers in South Australia fishing regions, based on average catch rates by A.A.A. club anglers. A three-hour angler-day has been adopted to relate catch rates (salmon per angler hour) to angler days. * From Philipson et al. (1986), Table 7.

FISHING ZONE	POOLED ANGLER DAYS *	ZONAL CATCH RATE	NUMBER OF SALMON CAUGHT	WEIGHT OF SALMON CAUGHT (KG)
West Coast	81199	1.75	426293	292074
Spencer Gulf	280125	0.12	100845	69093
Sthn Yorke Peninsula	65528	0.16	31453	21550
Gulf St Vincent	565068	0.12	203424	139376
Kangaroo Island	30688	-	-	-
Sth-Central and South East	120880	0.09	32638	22361
Other	74705	-	-	
TOTAL	1218191		794653	544456

NOTE: Data given in Philipson et al (1986), Table 7, has been adjusted to produce effort statistics used here, by; (1) considering only marine waters; (2) considering shore-based angling only, by removing boating effort (a factor of 30.78%), calculated from Table 9; and, (3) reducing recalculated figures, to consider use of line and hook only, by removing effort with other gears (a factor of 35.8%).

professionals, 47.3%, W.A. professionals, 29.1%; and W.A. anglers, 2.6%.

Associated with a rise in angler effort and efficiency, has been an increase in the recovery rate of tags by anglers in South Australia; from 16% in 1975-78, to 30% in 1984-87. It is concluded that the annual catch by anglers has increased in this State during the past decade. The recovery rate of tags in Western Australia, by anglers, was inexplicably low; 9% of the total recovered from that State.

6.7 OVERLAP IN THE ACTIVITIES OF AMATEUR AND COMMERCIAL SECTORS OF THE FISHERY

Within South Australia, anglers returned over 30 percent of the tags recovered from this State. The spatial overlap in activities of the two user groups can be examined by comparing tag recoveries with commercial catches, by area, in Table (6.6).

Although the professional catch along Southern Yorke Peninsula was relatively low, over 25 percent of tags were recovered there; and anglers returned over one quarter of these tags. Exploitation of salmon schools was at a high level, during the study period, in this fishing area.

The largest component of the professional catch came from West Coast waters; yet anglers fishing there returned the greatest proportion (58%) of tags. This illustrates the magniutde of the catch by recreational fishers in that area.

Of particular importance was the relative lack of tag recoveries by anglers fishing on Kangaroo Island. A large proportion of the professional catch was taken there; yet anglers did not recover a single tag on the south coast, where salmon were visibly abundant (see Section 10.1); and tag returns from this group came mainly from local anglers trolling from boats in the Bay of Shoals area, on the north coast of the island.

Table (6.6). Tag returns by status of captors, by fishing area; and professional catches (kg live-weight) for the period 1984-86.

FISHING AREA	PROFESSIONAL CATCH (1984-86)	ANGLERS (%)	PROFESSIONALS (%)	N TAGS
West Coast	408,040 (32.1)	107 (58.1)	77 (41.8)	184 (20.3)
Southern Eyre Peninsula	88,975 (7.0)	24 (22.8)	81 (77.1)	105 (11.5)
Spencer Gulf	28,928 (2.3)	2 (66.6)	1 (33.3)	3 (0.3)
Southern Yorke Peninsula	110,825 (8.7)	58 (25.4)	170 (74.6)	228 (25.1)
Kangaroo Island	277,369 (21.9)	27 (15.2)	150 (84.7)	177 (19.5)
Gulf St Vincent	28,624 (2.2)	11 (84.6)	2 (15.4)	13 (1.4)
South-Central Coast	291,562 (23.0)	35 (18.9)	150 (81.0)	185 (20.4)
South East Coast	33,684 (2.6)	11 (100)	0 (0)	11 (1.2)
TOTAL	1,268,007	275 (30.3)	631 (69.7)	906

Unfortunately, the "type C" errors outlined in Section (7.3.1) resulted in under-estimation of amateur activities of Yorke Peninsula, and along the South-Central coast. There, the professional catch of tagged fish was comprised of very large groups (>65) of tagged salmon recaptured in schools soon after release.

It is concluded here that the areas of greatest overlap occur along the West Coast, and in the waters of Yorke Peninsula. The highest amateur catch rates were recorded for the West Coast. There is cause for concern over the fact that levels of exploitation were relatively very high around southern Yorke Peninsula, yet this area supported a low level of professional catch. There was negligible overlap between anglers and professional fishers around Kangaroo Island. The abundance of salmon schools in these fishing areas is quantified in Section (10.1).

6.8 CONFLICT BETWEEN USERS OF THE RESOURCE

Along the South-Central coast, between Rapid Head and Blow-hole Creek, purse-seine operations were frustrated by the disturbance of target schools by amateur boat traffic. On several occasions, schools were scared deliberately by anglers and professional boats (pers.obs.). In the past, it has been reported that competition between purse-seine vessels was high for single schools (Departmental Correspondence File, "Salmon"; Archives). Under these conditions, sets of the nets were mis-timed often, and schools were disturbed and rendered un-catchable.

The levels of conflict observed were low, and not considered significant, during the study period. Anglers operated mainly on individual salmon, or small groups of fish, moving along surf beaches. Purse-seine operations were relatively few, and were separated spatially from most centres of angling activity.

In the past, conflict and competition between user groups was alleged to be high by anglers; and areas such as Waitpinga Beach and Brown's Beach were subsequently closed to netting, to reserve salmon schools there for angling purposes.

7.1 MORTALITY

Estimation of rates of fishing and natural mortality of salmon are frustrated, in South Australia, by the nature of the fishery and the biology of the species. Different age groups of salmon are exploited in multi-method fisheries; for which catch statistics are kept for the commercial sector only. No unit of fishing effort has been found suitable for application to the purse-seine and beach-seine sectors of the fishery. Each year a portion of the South Australian population leaves the fished area and migrates into Western Australia.

Two independent methods of mortality estimation are presented here, with qualification, to provide estimates of rates of fishing mortality (F), natural mortality (M) and total mortality (Z = F + M).

7.2 ESTIMATION OF MORTALITY FROM CATCH CURVES

If it is assumed that the initial number of fish of two broods (now of age t and t + 1) was the same; and if they have been subject to similar mortality rates at corresponding ages; then an estimate of survival rate from age t to age t + 1 can be obtained from the ratio : $Z = N_{t+1}/N_t$. Here, N represents the number found, of each age, in a representative sample. The instantaneous rate of mortality Z = - ln (N_{t+1} - 1 ln N_t) (Ricker, 1975). In essence, the catch curve is considered to be a "fossil history" of mortality in the fished population; if the age composition of the catch represents the age composition of the population.

Applying this formula to the catch curves constructed in Section (5.3), and summarised as Table (7.1), gives estimates of Z from the purse-seine fishery. These estimates are listed in Table (7.2). Values estimated for the period 1975-78 by Stanley (WFRC 1) are listed in Table (7.3).

Stanley (WFRC 1) considered that, during the period 1975-78, the age composition of the purse-seine catch represented the natural abundance of fully-recruited age groups in the fished area. As many as nine

Table (7.1). Estimated number of individuals in each age group captured in the purse-seine fishery (fishing areas pooled by year).

	AGE						
YEAR	1+	2+	3+	4+	5+	6+	TOTAL
1984/85	108321	39581	66368	31207	10216	206	55900
1985/86	35592	147833	49768	25117	12516	358	271243
1986/87	10071	87038	45437	5307	4834	0	152688

Table (7.2) Estimates of instantaneous rates of mortality (Z) of salmon from data listed in Table (7.1).

	AGE				
YEAR	1+/2+	2+/3+	3+/4+	4+/5+	5+/6+
1984/85	1.00	-	0.75	1.11	3.90
1985/86	-	1.08	0.68	0.69	3.99
1986/87	-	0.65	2.14	0.09	-

Table (7.3) Estimates of Z constructed from catch curves by Stanley (WFRC 1), for the period 1975-78.

		AGE			
YEAR	1+/2+	2+/3+	3+/4+	4+/5+	5+/6+
1975	-	0.65	0.15	0.45	2.17
1976	-	0.19	1.04	1.56	-
1977	-	1.23	1.07	0.56	1.10
1978	-	0.79	1.10	1.70	-
Average	-	0.72	0.84	1.07	-

boats took salmon by purse-seine during this era, although two boats only took the major portion (86%) of the catch during this time (Stanley, Department File 13/36, 1982).

During the current study, the number of fishing units declined to two boats in the purse-seine fishery; one full-time, and one part-time. Although schools were visibly abundant in traditional fishing areas, unseasonal prevalence of strong winds caused concentration of effort along lee-shores and away from exposed coasts.

For these reasons, it is considered that the age composition of the catch does not closely represent the abundance of all age groups in the whole population.

Estimates constructed for 1986/87 were made from the incomplete sampling of the few catches made by one vessel, and are of limited use. Similarly, the high values of Z (average of 3.94) estimated for 5+/6+ age groups must be partly due to the lack of fishing along exposed coasts, and migration. From the ages of 3+ onward; mainly 4+; faster growing salmon leave the fishery to participate in a westward migration to Western Australia. Hence, estimates of Z for these age groups will comprise a component of loss through migration.

For age groups 2+ to 4+, the estimates given here for Z (average 0.9 to 1.08) are in the range of those values estimated by Stanley (WFRC 1) from the period 1975-78 (average 0.72 to 1.07).

7.3 ESTIMATION OF RATES OF MORTALITY FROM TAGGING OPERATIONS

If rates of mortality from fishing are constant during an interval of time t, then the plot of the line of the natural logarithm of number of tag recaptures with time intervals will have a slope equating to -Zt; and a y-intercept (b) equating to the rate of fishing mortality, F; by :

$$b = \ln (F\ No) - \ln (Z) + \ln (1 - e^{-zt})$$

Where No = number of tagged salmon released.

Once the conditional rate of fishing mortality (F) is found, the conditional rate of natural mortality (M) can be derived from the relationship Z = F+M (from Gulland 1983, p.110).

To estimate rates of mortality in the South Australian population of younger salmon, Stanley (WFRC 1) utilised the number of tags recovered in time intervals of 50 days duration. By dividing up the tag recovery data into length (at release) classes of 5cm width, Stanley examined variation in mortality rate with fish size. These data are summarised, for the period 1975-78, in Table (7.4).

In Western Australia the fishery for adult salmon is markedly seasonal, so Walker (WFRC 6) utilised tag recoveries in time intervals of t = 1 year to overcome temporal variation in fishing effort; and thus estimate mortality rates. However, tagged adults do not survive for long in the Western Australian population, because of the intensity of fishing and high levels of natural mortality; so the number of data points are few when using intervals of one year.

The tagging operations undertaken in the current study were aimed at older, larger salmon occurring in South Australia. These fish are subject to exploitation in both S.A. and W.A.; and fishing effort varied widely during the year in South Australia during the study period. Plots of $\log_e$ (number of tags recovered) with time intervals of 50 days, and 100 days, were not linear; and a time interval of one year was utilised to obtain estimates of mortality rates.

The number of tags recovered in intervals of one year are listed in Appendix (5.1). A feature of these data is the large number of operations for which the number of tag recoveries <u>increased</u> with time interval. This phenomenon can be attributed to the fact that older fish departed from South Australia and were captured during the second year in the Western Australian fishery. At release, not all tagged salmon were fully recruited into either the S.A. or W.A. fisheries.

Estimates of mortality rates for those operations where reasonable numbers of salmon were recaptured, and recaptures declined with time, are given in Table (7.5).

A second set of estimates of rates of mortality was obtained by using Ricker's method (Ricker, 1975, Chapter 5). Using this method, fish were tagged at the start of the fishing season in two consecutive years. If natural mortality was the same for all ages tagged, then the survival rate in the first year (S_1) equates to;

$$S_1 = \frac{R_{12} M_2}{M_1 R_{22}} \text{, where;}$$

M_1 = number of fish tagged at the start of the first year,
M_2 = number of fish tagged at the start of the second year,
R_{11} = recaptures of first-year tags in the first year,
R_{12} = recaptures of first-year tags in the second year,
R_{22} = recaptures of second-year tags in the second year.

The large-sample variance of the estimate of S_1 can be found by;

$$V(S_1) = S_2 \left(\frac{1}{R_{12}} + \frac{1}{R_{22}} - \frac{1}{M_1} - \frac{1}{M_2} \right)$$

From Ricker (1975) p. 138, F_1 can be found from the relationship;

$$\frac{R_{11}}{M_1} = \frac{F_1 (1 - S_1)}{Z_1}$$

To approximate the assumption of constancy of natural mortality at all ages, this method was applied to data from large salmon of similar length tagged at Hog Bay, Kangaroo Island, in January, 1985 and January, 1986.

Table (7.4). Estimates of instantaneous rates of fishing (F) and natural mortality (M) from tagging in South Australia, 1975 - 78. From Stanley (WFRC 1).
* Values adjusted for tag loss estimated by Kirkwood and Walker (1984)

Length at release (cm)	F	M	M*
- 15	0.10	0.82	0.53
16 - 20	0.10	0.99	0.70
21 - 25	0.17	0.98	0.69
26 - 30	0.39	1.06	0.77
31 - 35	0.20	0.96	0.67
36 - 40	0.23	0.96	0.67
41 - 45	0.26	0.56	0.27
46 - 50	0.21	1.11	0.82
Average	0.20	0.93	0.64

Table (7.5) Estimates of Z, F and M from tagging in South Australia, 1984-86.
* M Values adjusted for tag loss after double-tagging experiment by Kirkwood and Walker (1984).

OPNUM	Length at release (Rel lcf cm)	Average Rel lcf	F	M	Z	M*
38	39.2 - 56.4	48.6	2.10	2.2	1.81	1.81
26	42.6 - 65.8	51.6	0.56	1.26	0.41	0.41
49	45.5 - 62.4	52.6	0.07	1.35	1.42	1.06
25	41.8 - 68.5	52.8	0.54	0.88	1.42	0.59
28	42.9 - 58.9	53.0	0.29	0.68	0.97	0.39
45	44.1 - 62.7	55.3	0.22	1.24	1.47	0.95
35	45.4 - 62.7	57.0	0.80	0.66	1.46	0.37
57	53.8 - 66.3	59.2	0.15	0.29	0.44	-
56	54.9 - 64.9	60.7	0.14	0.30	0.45	-
16	55.9 - 68.3	60.9	0.25	0.94	1.19	0.69
51	57.8 - 64.4	61.4	0.20	0.90	1.10	0.61
54	55.6 - 66.2	61.6	0.15	0.31	0.46	-
50	58.2 - 69.3	62.0	0.17	1.13	1.30	0.84
58	56.8 - 67.3	62.8	0.18	0.64	0.83	0.35
Average			0.27	0.86		0.73

The estimates obtained are listed, with details of capture and release, in Table (7.6).

7.3.1 Estimates of Mortality from Tagging - Sources of Error

Ricker (1975) outlines sources of error which may act to bias estimates of mortality from tagging operations. These are classified as "Type A", "Type B" and "Type C" errors, and their occurrence in the current study is outlined here.

Type A Errors

These errors act to affect the estimate of fishing mortality (F), but not the estimates of total mortality (Z) and natural mortality (M). Initial loss of tags, mortality induced by the tagging operation, and incomplete reporting of recovered tags, are included in this category.

Table (7.6) Estimates of Z, F and M, using Ricker's method, for salmon released at Hog Bay, Kangaroo Island.

YEAR	OPNUM	N RELEASED	LENGTH AT RELEASE (cm) MEAN	St.Dev.	R_{11}	R_{12}	R_{22}
01/85	16	186	60.9	2.36	22	13	
01/86	54,56,57	482	60.7	2.90		91	

S_1	$V(S_1)$	Z_1	F_1	M_1
0.3702	0.0111	0.993	0.186	0.807

In the current study, tags were recovered from salmon handled individually by fishermen, anglers and fish processors. An attractive incentive to return tags was offered, in the form of a printed T-Shirt or $5.00.

It would seem unlikely that tags would be overlooked, or not returned. However, from one catch in S.A., 4% of tags recovered were found by rock lobster fishermen baiting pots with salmon previously handled individually by packers.

Stanley (1983) reviewed the effects of handling techniques on returns of tagged Australian salmon and found that length of time held before release, injury, and scale removal did not cause significant mortality. Salmon are a robust species and the use of internal tags with attached streamers produced greatest rates of recovery, and the most long-term returns. Kirkwood and Walker (1984) estimated rates of shedding of these tags from salmon, under the restrictive assumptions that there was no initial tag loss; and the rate of long-term tag loss was constant over time.

Without more detailed study of tag shedding, and tagging mortality, it is unknown to what degree Type A Errors have influenced estimates of mortality rates.

Type B Errors

This second group of errors include those which act to affect estimates of total mortality (Z); but not estimates of fishing mortality (F). These include; (1) shedding of tags at a constant, or variable, instantaneous rate throughout the study; (2) differential mortality of tagged fish; and (3) emigration of tagged fish away from the fishing area.

Kirkwood and Walker (1984) constructed an estimate of shedding of tags from salmon using data from a double-tagging experiment. They estimated the instantaneous rate of tag shedding to be 0.29 per year; corresponding to annual tag retention of 74.5%. However, the data set used was small (95% C.I. = 0.11 - 0.65) and it was unknown whether the loss of a tag from a double-tagged fish occurred at the same rate as that from a single-tagged fish. In the absence of further data, the current estimates of natural and total instantaneous mortality rates have been adjusted in Tables (7.4) and (7.5), according to Kirkwood and Walker's (1984) estimate.

Internal tags with attached streamers were encapsulated in layers of tissue within the abdominal cavity; and the insertion wound healed quickly to form a scar of varying severity. Although some streamers were lost, there is no evidence from this, or preceding, studies that the rate of tag shedding accelerates with time; as does occur with other designs (Stanley, 1983).

However, there is clear evidence that a Type B error is active in the results of the current tagging study; in the form of emigration away from the fished area, and through differential vulnerability of tagged salmon to exploitation.

The lack of movement of tagged salmon within and between S.A. fishing areas is outlined in Section (9.1.2). Emigration of 1+ to 3+ age groups is not evident in the current study; yet Stanley (WFRC 1) attributed a rise in estimates of M from an age of 2+ onwards to movement of fish away from the fished areas, starting at this age.

Tagged fish of age 4+, and older, migrated to Western Australia, although other fish tagged from the same schools remained in the immediate vicinity of the tagging site; often for long periods (see Section 9.1.1). Consequently, salmon of these age groups were not fully recruited into either the South Australian or the Western Australian fisheries. With time, slower growing fish do move to Western Australia (Stanley, WFRC 1) and become fully recruited into the fisheries of that State. This is evident from the rise in recaptures, with time, for some tagging operations (Appendix 5.1). Movement of older South Australian fish to more exposed coasts, and migration of adults to Western Australia, introduced type B error into the results of the tagging operations undertaken in this study.

This would cause an elevation of the estimates of Z and M; yet the present estimates do not appear excessive. This may be due to the fact that only those operations for which recoveries decline with time were included in analysis; that is, only those operations from which salmon were at least partially recruited into fisheries in S.A. and W.A.

Type C Errors

The operations referred to above, which were omitted from analyses, are included in the third group of systematic errors. These errors render the tag recoveries of the first year unusable in estimating either F or Z; but do not prejudice the estimation of either of these parameters from data of latter years.

Type C errors include; (1) abnormal behaviour of tagged fish; (2) non-random distribution of tagged fish in the general population during the year of tagging; and (3) non-random fishing effort during the year of release of tagged fish.

These three forms of Type C error all were inherent in the tagging study.

Stanley (1983) showed that declining rates of return of tags; initially ascribed to tagging mortality, are the result of a change in behaviour of tagged fish. Fish tagged under adverse conditions, or those bearing wounds, delayed their departure from S.A. to the spawning area in W.A. However, there was no evidence of delayed mortality, or decline in physical condition, of tagged salmon; the fish recover from the adverse effects of tagging.

Postponement of movement to Western Australia of tagged salmon may be caused by natural variation in growth rate and migratory urge; and by abnormal behaviour induced by tagging. These factors are discussed further in Section (9.2.1). Both causes result in Type C errors.

There is also evidence that tagged salmon move into "hospital" areas, such as gutters of surf beaches, to recuperate (Malcolm, 1960, Walker, pers.comm.). In these areas they are vulnerable to capture, particularly by anglers. In fact, some anglers in Western Australia concentrate effort on hospital schools (Walker, pers.comm). This form of abnormal behaviour would result in Type C error also.

Finally, tagged fish were not distributed randomly throughout the S.A. population; and fishing effort was concentrated often in areas inhabited by tagged salmon.

Salmon are a schooling species, and tagged fish joined neighboring schools or the parent school from which they were taken. This fact, the localised movements of S.A. salmon, and the concentration of purse-seine effort along lee-shores of traditional fishing areas, all acted to make the tagged salmon particularly vulnerable to capture within the year of tagging. This generalisation did not apply to the tagging operations conducted at Hog Bay, for reasons outlined in Section (9.2.3), and those operations undertaken outside of the area fished by purse-seine vessels.

The two obvious effects of Type C errors on the tag recoveries presented in Appendix (5.1) are; (1) the increase in tag recoveries with time for operations 17, 18, 46, and 59; and, (2) the very high percentages of tags recovered within the year of tagging for operations 27, 30, 34, 38, 49, 62 and 63.

These operations were not included in the analyses of mortality rates; but subtle effects of Type C errors are undoubtedly present in the estimates of Z, F and M given here. Their action probably has caused an underestimation of Z, F and M.

7.4 ESTIMATES OF MORTALITY - DISCUSSION

In this study, catch curves do not provide a useful independent estimate of Z for comparison with those estimates obtained from the tagging operations. The tagging is not yet complete, as tagged salmon will appear in both the S.A. and W.A. fisheries for at least the 1988 and 1989 seasons. Consequently, data points are few when using tag recoveries in time intervals of one year in length.

The estimates that have been obtained are affected by type A, B and C errors. The least detectable are the Type C errors acting on the results of tagging operations on large fish. Within each of these operations some tagged fish postpone movement (and hence recruitment) into the W.A. fishery because of adverse effects of tagging; whilst others do so because of their growth rate, and size/age characteristics, at the time of tagging (Malcolm, 1959, Stanley, WFRC 1).

To detect these effects, tag recoveries in intervals of one year can be examined; (1) by age of fish at release; and (2) by length (in one centimetre intervals) at release. This proposal is developed further in Section (9.2.1).

Without adjustment for tag shedding, the estimates of mortality constructed here are far lower than those estimates made for the adults found in Western Australia.

Walker (WFRC 6) summarised estimates of Z, F and M from tagging undertaken in W.A. during the period 1951-1978 on the south coast. Since 1975, estimates of these parameters were extremely high ($Z = 3.3 - 2.2$, $F = 1.95 - 0.68$, $M = 1.38 - 1.52$); and higher than those from previous years. This suggests that salmon surviving from one fishing season contribute only minimally to subsequent fisheries. Irrespective of age, natural mortality after spawning is high; perhaps due to the physiological stresses involved in sequestration of energy into production of gonads and migration. Exploitation by both anglers and professional beach-seine teams was very high in Western Australia.

The estimates given here must be considered preliminary only, and used with caution. Tag recoveries from further years must be analysed to give more meaningful estimates. Hearn, Sandland and Hampton (1987) have proposed a method for the robust estimation of the natural mortality rate, in a completed tagging experiment with variable fishing intensity. Their model was applied to data for the southern bluefin tuna fishery; a fishery not unlike the salmon purse-seine fishery in many respects. However, it will be some years before tag recoveries are complete for the present study.

8.1 AN EXAMINATION OF YIELD-PER-RECRUIT IN THE SOUTH AUSTRALIAN FISHERY FOR AUSTRALIAN SALMON

In the stock of Australian salmon there is evidence that recruitment is variable, and these variations may be independent of adult stock size; being determined by environmental factors (Malcolm, 1960, Stanley, WFRC 1).

Estimation of yield-per-recruit for such a stock will not yield accurate predictions concerning catch in years beyond the life-span of fully recruited year classes. However, the estimates are useful in discussing observed patterns of mortality and the effects of implementing some measures of fishery management.

Sluczanowski (1985) has developed a program for performing Beverton and Holt (1957) yield-per-recruit analyses using the microcomputer package; LOTUS 1-2-3. The Beverton and Holt (1957) equation essentially calculates the equilibrium relationship between biomass added to the stock, through growth; and biomass lost from the stock, through mortality. To overcome the fundamental problem of variable recruitment, the model expresses yield as a biomass-per-recruit. Sluczanowski's (1985) program plots variation in the percentage of B max (maximum biomass-per-recruit) attained at age, or length, under different regimes of fishing mortality, natural mortality, and length, or age, at first capture.

The levels at which yield-per-recruit is maximised in the present analyses take no account of;

(1) the minimum size/age of first spawning,
(2) the existence of spawner/recruit relationships,
(3) the biovalue of different sizes,
(4) seasonal or long-term variation in rates of natural mortality between size/age groups, and sexes; and
(5) short-term effects of variation in fishing mortality.

A detailed treatise incorporating all these factors is beyond the scope of the present study; but should be undertaken to fully predict the effects of revisions in management strategy.

8.1.1 Simulations at Three Levels of Natural Mortality

The yield-per-recruit analysis is sensitive to changes in M; the instantaneous rate of natural mortality. Salmon are relatively short-lived; and a moderate to high value of M would be expected from estimation of mortality. The difficulties in estimating M have been outlined in Section (7.3.1) An overestimate of M leads to a scenario where fishing effort may be erroneously increased to maximise yield-per-recruit.

Three levels of natural mortality are used here; a low level of M = 0.2; a moderate level of M = 0.5, estimated from tagging data in Section (7.3); and two high levels of M = 0.8 and M = 1.0, estimated by Stanley (WFRC 1) for S.A. salmon. Parameters and their sources are listed in Table (8.1).

The maximum biomass-per-recruit, and the age at which this is attained; and the optimum average length at first capture, are shown in Table (8.2), for three levels of fishing effort.

The yield-per-recruit is plotted with fishing mortality, at five average lengths at first capture, for four values of M in Figures (8.1)-(8.4). The estimated numbers of salmon present at each age, under a fishing mortality of F=1.0, are plotted for four values of M in Figures (8.5)-(8.8).

Table (8.1). Parameters used in the yield-per-recruit analyses, and their sources.

Parameter	Value	Source
W_∞	5.33	Nicholls (1973)
L_∞	68.91	Nicholls (1973)
K	0.2751	Nicholls (1973)
to	-0.2360	Nicholls (1973)
Age max	9	Malcolm (1966a)
M		Stanley (WFRC 1), present study
F		Stanley (WFRC 1), present study
Lc	31.0-62.0	Present study

Table (8.2) Maximum biomass-per-recruit (Bmax), the age at which this occurs; and the optimum average length (Lc) at first capture; for three levels of fishing mortality, F, at four levels of natural mortality, M.

			Optimal Lc (cm)*		
M	B max	Age	F=0.25	F=0.75	F=1.25
0.2	0.888	5.71	38.7	46.5	54.2
0.5	0.246	3.31	31.0	38.7	38.7
0.8	0.107	2.34	23.2	23.2	31.0
1.0	0.069	1.95	15.5	23.2	23.2

* It should be noted that western salmon from South Australia did not spawn in Western Australia at lengths of less than 58cm LCF, at ages of 3+ to 6+.

8.1.2 Variation in Yield-Per-Recruit with Estimates of the Instantaneous Rate of Natural Mortality, M

As M is increased, from low to high levels, the optimal average length at first capture decreases, and the value of F at which yield-per-recruit is maximised also increases. Theoretically, fishing strategy should be related to the ratio of M to K, the growth parameter. If M/K is small (as in the case of low M) it would be optimal to fish lightly, and at older ages; as the fish will have a higher chance of attaining large size. In contrast, if M/K is large, many fish will die before realising their potential for growth; and it would be best to fish relatively hard at lower sizes at first capture.

It can be seen from Figures (8.5)-(8.8) that the number of older fish present in the unfished stock decreases rapidly at higher values of M.

The practical effect of over-estimating M would be to implement a high level of fishing mortality; with the consequences of drastically reducing the number of older fish present in the population (see Figure 8.9). Such an effect has profound implications for the salmon fishery, which will be discussed in Section (13.1).

8.2 THE PRESENT STATUS OF THE SOUTH AUSTRALIAN FISHERY

Figure (8.2) represents the present state of the S.A. fishery; with levels of M and F estimated from the current study. The present level of F has been estimated at 0.2 to 0.4. At this level, yield-per-recruit is optimised at an average length of first capture of Lc = 31.0cm.

Coincidentally, this is the average size of salmon caught in the commercial fishery as a whole (see Section 5.3). Theoretically then, there would be no gain in increasing the length at first capture of salmon in the present fishery. However, western salmon first spawn at a length of approximately twice that at which biomass is maximised, Figure (8.1). Yield-per-recruit versus fishing mortality, at five levels of Lc, where M=0.2.

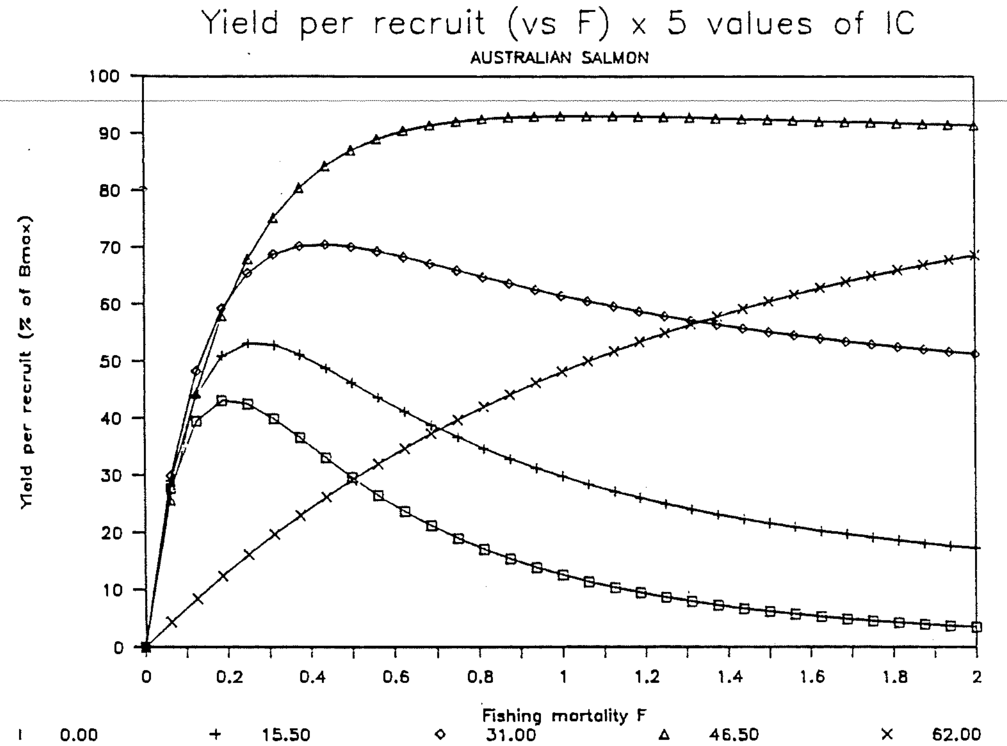


Figure (8.2). Yield-per-recruit versus fishing mortality, at five levels of Lc, where M=0.5.

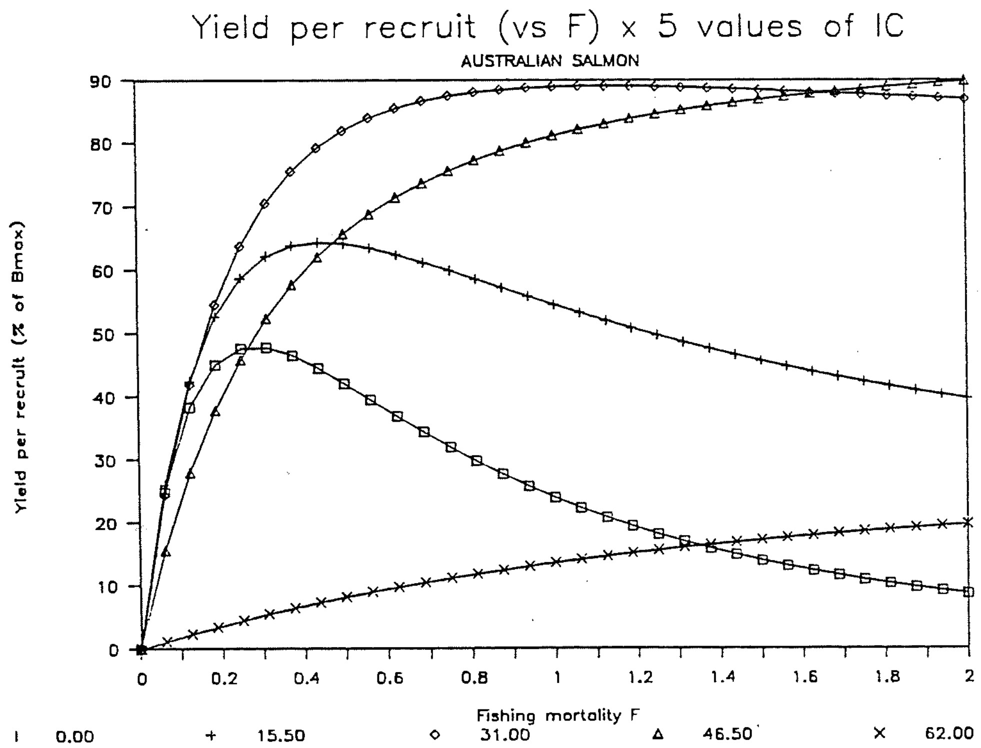


Figure (8.3). Yield-per-recruit versus fishing mortality, at five levels of Lc, where M=0.8.

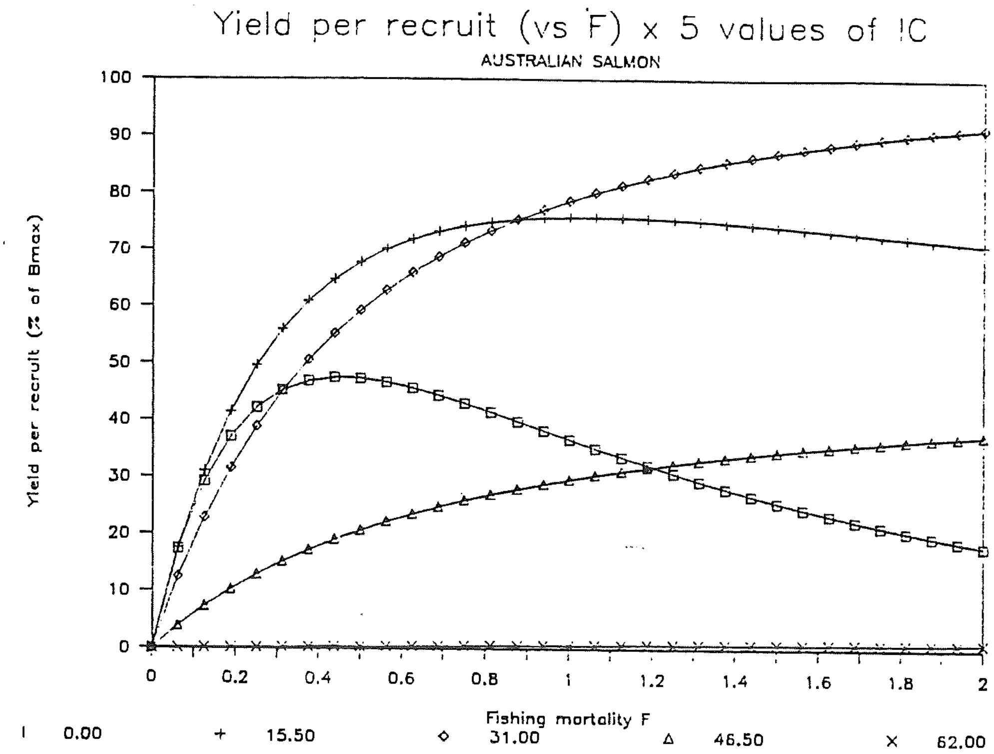


Figure (8.4). Yield-per recruit versus fishing mortality, at five levels of Lc, where M=1.0.

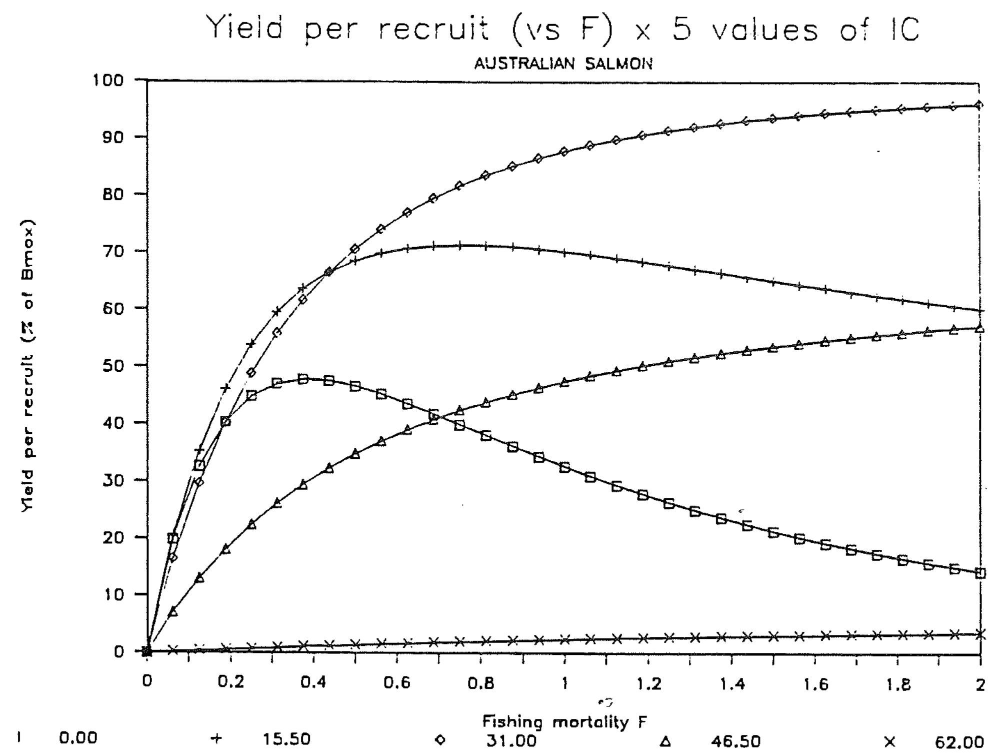


Figure (8.5). Estimated number of salmon at each age for unfished and fished (F=1.0) situations, where M=0.2.

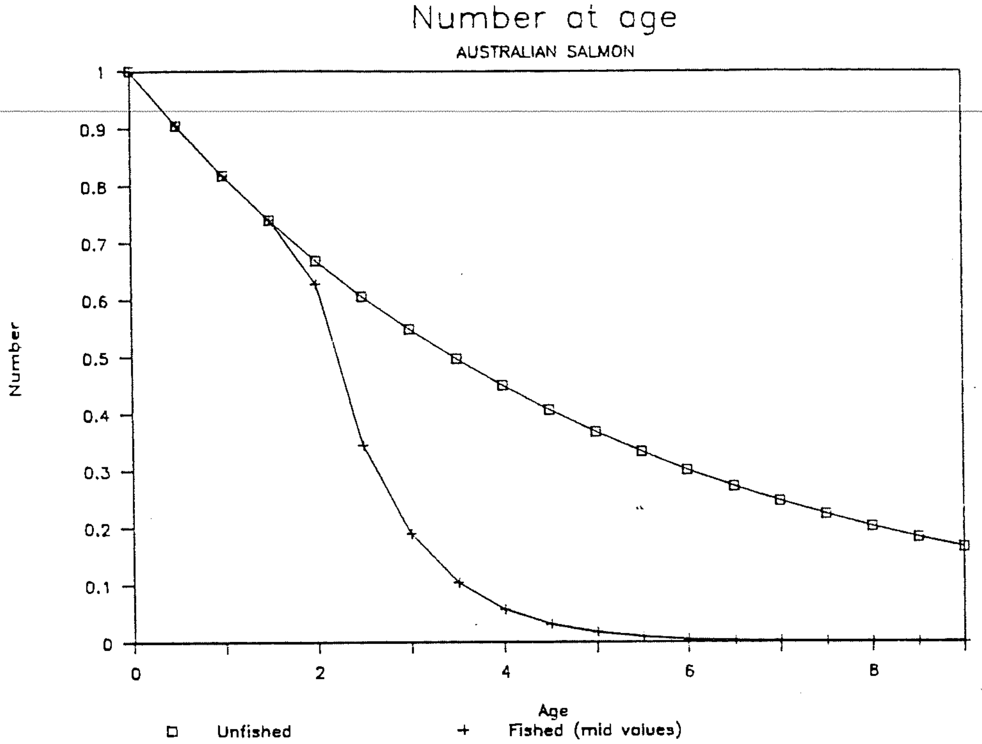


Figure (8.6). Estimated number of salmon at each age for unfished and fished (F=1.0) situations, where M=0.5.

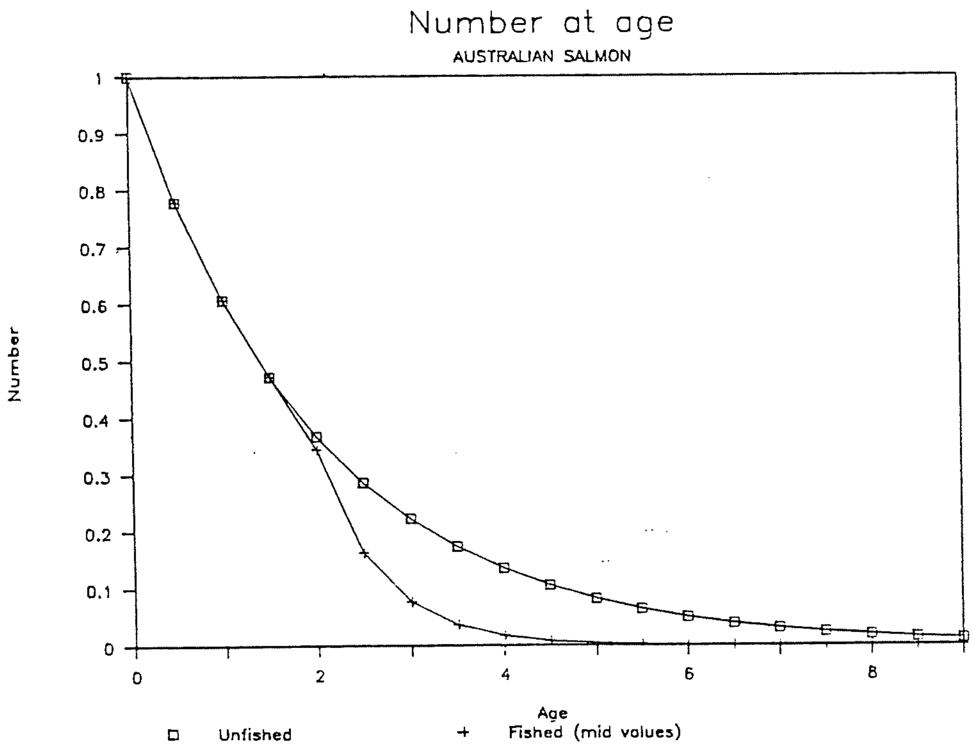


Figure (8.7). Estimated number of salmon at each age for unfished and fished (F=1.0) situations, where M=0.8.

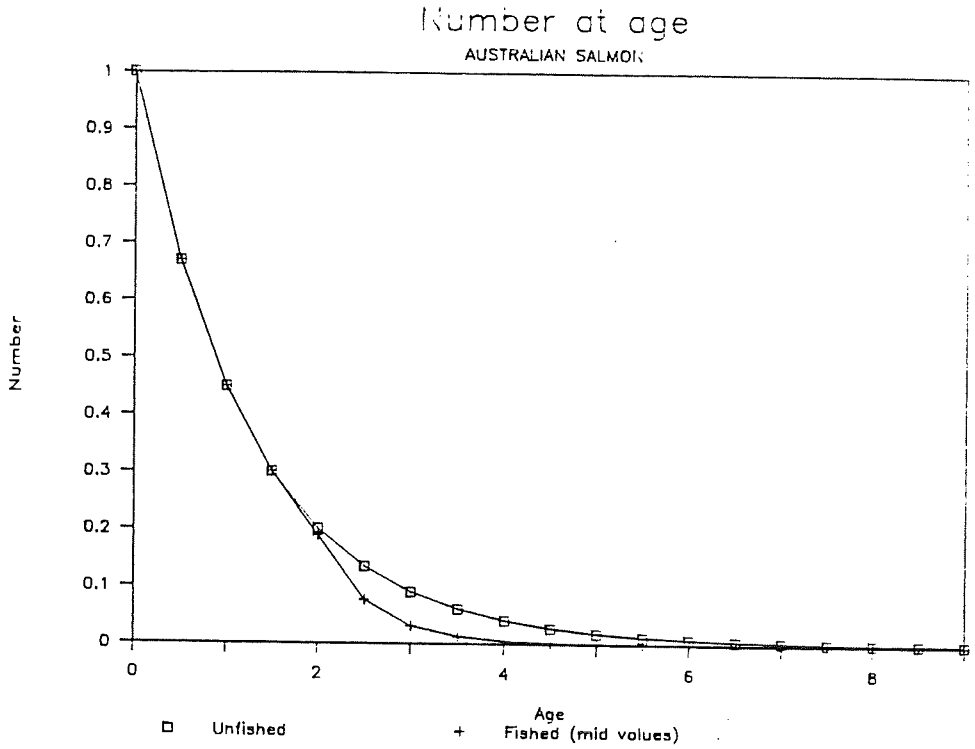


Figure (8.8). Estimated number of salmon at each age for unfished and fished (F=1.0) situations, where M=1.0.

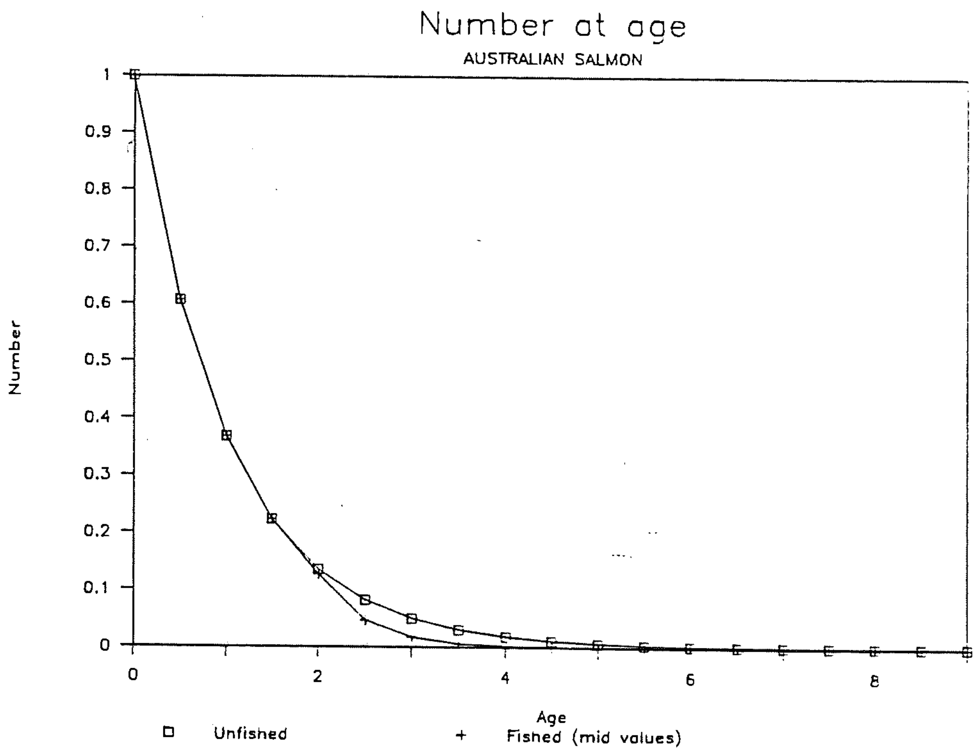
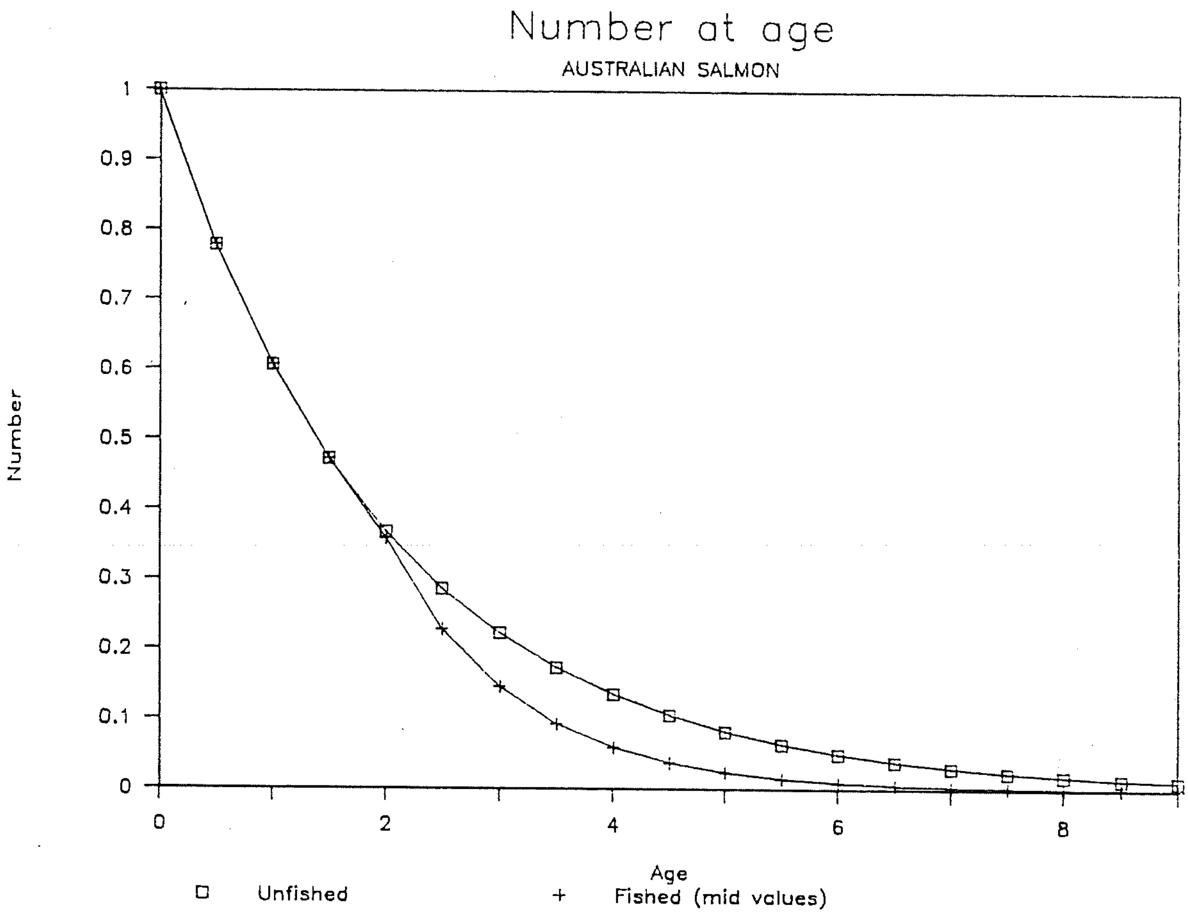


Figure (8.9). Numbers of salmon present at each age for unfished and fished (F=0.2) situations, where M=0.5. This diagram estimates number-at-age in the present S.A. fishery.



and attention must be given to this factor in holistic modelling of yield-per-recruit.

From Figure (8.2) it could be proposed that yield-per-recruit is not being maximised in the present fishery. A rise in effort, calculated to produce a doubling of F=0.2 to F=0.4, would produce an increase in yield-per-recruit of 25 percent. However, a further rise in effort, to raise F=0.4 to F=1.0, would result only in an increase of 10 percent.

At F=1.0, the numbers of salmon older than three years of age (represented by age 4 on the Figure (8.6) would be reduced by a factor of more than 85 per cent, in comparison to unfished stock. At the present rate of F=0.2, the number of older fish is reduced by a factor of less than 50 percent (see Figure 8.9). The model overestimates age at length; therefore, the precise ages at which the reduction is greatest are unknown.

If it is assumed that all adult salmon from S.A. migrate to W.A.; and the W.A. catch depends solely on S.A. recruits; then a rise in effort in South Australia, to increase F to 1.0, would reduce recruitment to W.A. by more than 50 percent. These recruits are on a spawning migration, and such a reduction in numbers would have a profound effect on both the W.A. fishery and the spawning potential of the sub-species. This hypothetical case illustrates the importance of considering spawning stock reduction in yield-per-recruit analyses.

8.3 IMPLICATIONS FOR MANAGEMENT

It can be stated that, for a range of levels of M or F, the average length at first capture is near an optimum value in the present S.A. commercial fishery, with respect to biomass.

The simulations presented here give an indication of the necessity for obtaining precise values of M and F in the salmon fishery. Small changes in these parameters may have marked effects on yield and population structure. Yet, there is presently no equation relating levels of F to levels of effort. No useful unit of effort has been devised. Thus, effort cannot be regulated to bring about the small changes in F required to optimise yield-per-recruit.

With respect to providing sufficient escapement of spawners, it is unknown whether such a low length at first capture is optimal.

8.3.1 Regulating Effort by Imposition of Catch Quotas

In the absence of a mechanism for measuring and regulating effort, catch quotas may be introduced; in an attempt to raise F, and fish a stock at its maximum sustainable yield (MSY).

Beddington and Cooke (1983) examined the validity of a common approximation to MSY from a previously unexploited fish stock. This approximation relates MSY to biomass present before exploitation starts (Bo), through the equation; MSY = 1/2 M Bo, where M = the instantaneous rate of natural mortality.

They simulated the effects of variation in recruitment, and the stock/recruitment relationship, on this approximation. It was found that fishing at MSY may reduce the spawning stock biomass to some threshold below which a stock/recruitment relationship arises; if it had not been in existence before. For a species like Australian salmon, with high values of M; an old age at first spawning (3+ - 6+); and a young age at recruitment; the spawning stock biomass may be reduced to less than 4 percent of its unfished level, when fishing is undertaken at MSY (Beddington and Cooke, 1983, Appendix 2, Table 3). This result was obtained using a deterministic model where recruitment was kept constant.

When stochastic variations in recruitment levels are introduced, the level of MSY (or catch quota) must be downgraded even further; to ensure that the probability of the spawning stock biomass falling below a certain level is constrained to some low value. The application of a fishing quota will require initially a small rise in F (in "fishing-up" of accumulated stock); which will necessarily be increased as an equilibrium level is reached.

Beddington and Cooke (1983) provided a regimen for estimating a reasonable range of values of MSY from a survey of an unfished stock. Their criteria and checks are relevant to estimation of a suitable quota for application to the salmon fishery. Given information on the biomass present, mortality and growth; a range of estimates of the MSY can be obtained for a chosen age of recruitment. A check must be made to see if the catch will reduce the spawning stock biomass below a target level. Given a level, or range, of recruitment variation, the modification that must be made in catch can be calculated; to ensure a low probability of spawning stock biomass falling below the target level.

For the salmon fishery in South Australia, the target level of spawning stock biomass is unknown; as is the range of variation in recruitment. However, data on fecundity has been gathered in Western Australia, where the sub-species spawns. The approach of Beddington and Cooke (1983) is used to simulate values of MSY for the S.A. salmon fishery in Table (8.3). At higher values of M the MSY must be down-graded greatly to take account of variability in recruitment.

If the biomass of the unfished salmon stock was 10,000 tonnes in South Australia, then Beddington and Cooke (1983) predict that only 900 tonnes should be taken, as MSY, at low levels of recruitment variation; when M = 0.5. This approximation does not predict the escapement of spawners.

8.3.2 Recommendations

Robust estimation of a quota for the South Australian salmon fishery would best be undertaken through development of a stochastic model of the entire fishery; incorporating and revising the large amount of biological data already available. Preliminary estimation of yield-per-recruit, using a deterministic model under restrictive assumptions, suggests that the S.A. population could withstand higher levels of fishing mortality. However, the effects of increased effort may influence recruitment to the W.A. fishery; and the spawning stock biomass may be reduced markedly. Such effects are particularly pronounced for salmon; which have high ages at first spawning, but are fished mainly at early ages in South Australia.

Table (8.3) Estimation of MSY (after Beddington and Cooke, 1983) for a range of levels of natural mortality, M and recruitment variation rv. Indices of variation in recruitment were calculated by Beddington and Cooke (1983) from the standard deviations from the means of recruitment measured in long-term data series for a variety of marine teleosts fished commercially.

M	0.2	0.5	0.8
MSY (as % Bo)	60	12.0	0.8
SSB (as % So)	20.1	10.2	3.3
MSY at rv = 0.4	5.0	9.0	12.0
MSY at rv = 1.0	5.0	7.5	8.0

Bo = Biomass of unfished stock
So = Biomass of unfished spawning stock
Age at recruitment = 1.0
Age at first spawning = 4.0
K (growth constant) = 0.3

Deterministic production models are sensitive to variations in estimates of the rate of natural mortality, M. The estimates of M obtained to date for Australian salmon are not precise; and it is clear that M varies greatly with age for this sub-species, violating basic assumptions of these models. Stochastic models must be developed to account for variation in M with age, and current estimates should be revised.

9.1 MOVEMENT PATTERNS OF TAGGED AUSTRALIAN SALMON IN SOUTH AUSTRALIA

Of 4,102 western salmon tagged during the programme, there have been 1376 recoveries[1], of which 1298 were accompanied by sufficient information to study movement. The majority of these recaptures have been made in South Australia. This reflects exploitation of the large proportion of smaller size classes included in the tagged sample; rather than a lack of migratory movement to Western Australia.

Tagging was undertaken to determine the local movement patterns of salmon in South Australia; and to determine the sources, and age/size characteristics, of migrants from S.A. into the Western Australian Fishery.

9.1.1 Movement Patterns of Different Size Classes

Movements of tagged salmon are summarised by lengths at release in Table (9.1). There are three main features of this data; (1) the movement to Western Australia, represented by distances travelled of more than 1,000 kilometres; (2) the paucity of movements of 200 - 1,000 kilometres; and (3) the great majority of localised movements by fish of all length classes. The "tail" of smaller length classes that have moved to Western Australia represents the growth and departure of these salmon after long periods at liberty. When results of the tagging programme are complete, the tail will encompass more, and smaller, length classes.

The largest movements within South Australia were generally made by larger size classes of 56 - 60cm LCF, and above.

9.1.2 Movement Between Fishing Areas

Tagged salmon were caught within fishing areas mainly; but individuals of all length classes did move between fishing areas. The locations of release and recapture of salmon which

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1 Recoveries of tags up to June 1, 1987.

Table (9.1). Frequency distribution of distances travelled by recaptured tagged salmon summarised by lengths at release.

	KILOMETRES TRAVELLED BY TAGGED SALMON									
length class (cm)	0-5	6-20	21-50	51-100	101-200	201-500	501-1000	1001-2000	2001-2500	2501-3000	TOTAL
21-25	10	0	0	1	0	0	0	0	0	0	11
26-30	4	1	1	0	0	0	0	0	0	0	6
31-35	58	46	20	3	1	0	0	0	0	0	128
36-40	114	17	10	18	4	1	0	0	0	0	164
41-45	41	26	15	12	3	0	0	1	1	0	99
46-50	92	45	16	6	4	1	0	4	3	0	171
51-55	50	34	3	8	2	1	1	18	13	1	131
56-60	62	38	30	14	6	4	0	52	84	1	291
61-65	31	13	25	3	2	5	0	79	108	10	276
66-70	2	0	0	0	0	0	0	14	4	1	21
71-75	0	0	0	0	0	0	0	0	0	0	0
TOTALS	464	220	120	65	22	12	1	168	213	13	1298

Table (9.2) Movement (more than 20 kilometres) of tagged salmon between fishing areas.

FISHING AREA AT RELEASE	RELEASE LOCATION	RECAPTURE LOCATION	N tags
Sthn Eyre Pen.	Boston Island	Anxious Bay	1
	Bicker's Island	Almonta Beach	2
	Boston Point	Almonta Beach	1
Yorke Peninsula	Wattle Bay	Cape D'Estaing	3
	Wattle Bay	Stokes Bay	1
	Point Turton	Wallaroo	1
	Point Turton	Smith's Bay	1
	Berry Bay	Anxious Bay	1
Kangaroo Island	Hog Bay	Waitpinga Beach	5
	Hog Bay	Salt Creek Beach	6
	Hog Bay	Port Elliot	1
	Hog Bay	Glenelg	1
	Hog Bay	Rapid Head	36
	Hog Bay	Troubridge Point	2
	Hog Bay	Hillock Point	1
	Hog Bay	Anxious Bay	3
	Stoke's Bay	Anxious Bay	1
	Point Marsden	Murray Mouth	1
	Emu Bay	Salt Creek Beach	1
	Cape Coutts	Murray Mouth	1
	Cape Coutts	Port Elliot	1
	Cape Coutts	Waitpinga Beach	2
	Cape Coutts	Parson's Beach	1
	Cape Coutts	Rapid Head	2
	Smith's Bay	Back Beach	1
	Smith's Bay	Thistle Island	1
	Smith's Bay	Louth Bay	1
	Ballast Head	Boston Island	1
	Ballast Head	Brown's Beach	1
	Ballast Head	Outer Harbour Breakwater	1
	Ballast Head	Rapid Head	1
	Ballast Head	Port Willunga	1
South-Central Coast	Rapid Head	Antechamber Bay	1
TOTAL			86

moved between fishing areas are summarised in Table (9.2). No tagged salmon moved from the West Coast and Southern Eyre Peninsula tagging locations to fishing areas in the east. The greatest interchange of tagged fish occurred between Yorke Peninsula and Kangaroo Island; and Kangaroo Island and the South-Central Coast.

Movements between fishing areas represent less than 10 per cent of all movements in South Australia. Movement may become more widespread as tagged fish grow older; but, whilst the tagging programme is still not complete, it is suggested that fished populations in different fishing areas are largely independent. Stanley (1979) found that salmon began to move out of nursery areas; in the gulfs, at ages of 1+ to 2+; and, in West Coast embayments, at ages of 2+ and 3+. However, at all ages, up to 6+, some tagged salmon remained in the vicinity of the tagging location. Stanley (1979) suggested that movement of the population was only partial. In that tagging programme, no tagged fish moved eastward into other fishing areas from the West Coast. At younger ages salmon moved between eastern fishing areas to a limited extent; as in the present tagging programme.

The movements of tagged fish from all fishing areas to the West Coast are considered to be representative of participation in migration to Western Australia. The timing of recapture, and lengths of the fish involved, are given in Table (9.3). It is possible that salmon do gradually move westward as they grow; however, the weight of evidence suggests that these recaptures were fast-moving migrants travelling along the West Coast. The salmon were large; and other fish, tagged from the host schools on the West Coast, subsequently were caught in Western Australia. The dates of recapture coincide mainly with times of departure of migrants, which are discussed in Section (9.2.2).

Apart from the movements associated with migration of adults, there was little evidence of seasonal movements of younger salmon within this State. It was not possible to weight the tag returns, in time and space, by variations in fishing

Table (9.3). Details of release and recapture of salmon tagged in fishing areas to the east of the West Coast, and subsequently captured on the West Coast.

OPNUM	LOCATION OF RELEASE	LOCATION OF RECAPTURE	DATE OF RECAPTURE	SALMON LENGTH (CM)	TIME AT LIBERTY	DISTANCE MOVE (KM)
16	Hog Bay	Anxious Bay	27/1/86	64.7	389	445
17	Hog Bay	Anxious Bay	27/1/86	61.4	389	445
17	Hog Bay	Anxious Bay	27/1/86	62.8	389	445
26	Stokes Bay	Anxious Bay	27/1/86	-	344	388
35	Berry Bay	Anxious Bay	27/1/86	63.8	312	350
4	Boston Island	Anxious Bay	27/1/86	59.0	459	300
47	Bickers Island	Lock's Well	9/5/86	58.7	220	200
58*	Anxious Bay	Point Sinclair	3/3/86	63.2	35	280
52	Smiths Bay	Back Beach	12/2/87	-	401	510

* Tagged on the West Coast

effort; so only the most pronounced patterns of movement would appear in the results of the tagging programme. Malcolm (1960) suggested that there was a northerly movement of tagged fish in Spencer Gulf, during the winter months of April - October. He noted that most recaptures of tagged fish in South Australia were localised.

The movement patterns of tagged fish are shown for tagging operations carried out; on the West Coast, and in Boston Bay, in Figure (9.1); along Yorke Peninsula, in Figure (9.2); and around Kangaroo Island, in Figure (9.3). The results of tagging at Hog Bay were numerous, and are shown separately in Figure (9.4). A summary of movements between fishing areas is given as Figure (9.5).

Of particular importance are; (1) the eastward movements of salmon along the northern coastline of Kangaroo Island; (2) the eastward movements of these salmon to the Victor Harbour and Kingston areas; and (3) the southerly movement, to exposed beaches, of salmon tagged in Boston Bay and Hardwicke Bay.

9.1.3 The Significance of an Easterly Movement

Stanley (WFRC 1) found that, after 200 days at liberty, tag recoveries from 0+ fish declined markedly. There was an extremely low rate of recovery of tags in Western Australia from 0+ fish tagged in South Australia; even after natural mortality had been allowed for. He concluded that the most reasonable explanation was that the 0+ fish had left the area of operations of the fishery. There was evidence of an easterly movement of 0+, 2+, and older, fish toward the south-east of the State. In this area, large tonnages of salmon were sighted during the summer months (Stanley WFRC 1, pers.comm. R. Hendry), but the prevailing weather conditions and limestone sea bed prevented purse-seining operations. There is consequently a lack of data on the population occurring there, and the movement of tagged fish to the area. Stanley (WFRC 1) suggested that a portion of the South Australian population may

Figure (9.1). Patterns of movement within South Australia (greater than 20km) of salmon tagged on the West Coast, and in Boston Bay. Unless specified by a printed number, the arrowheads represent movement by a single fish.

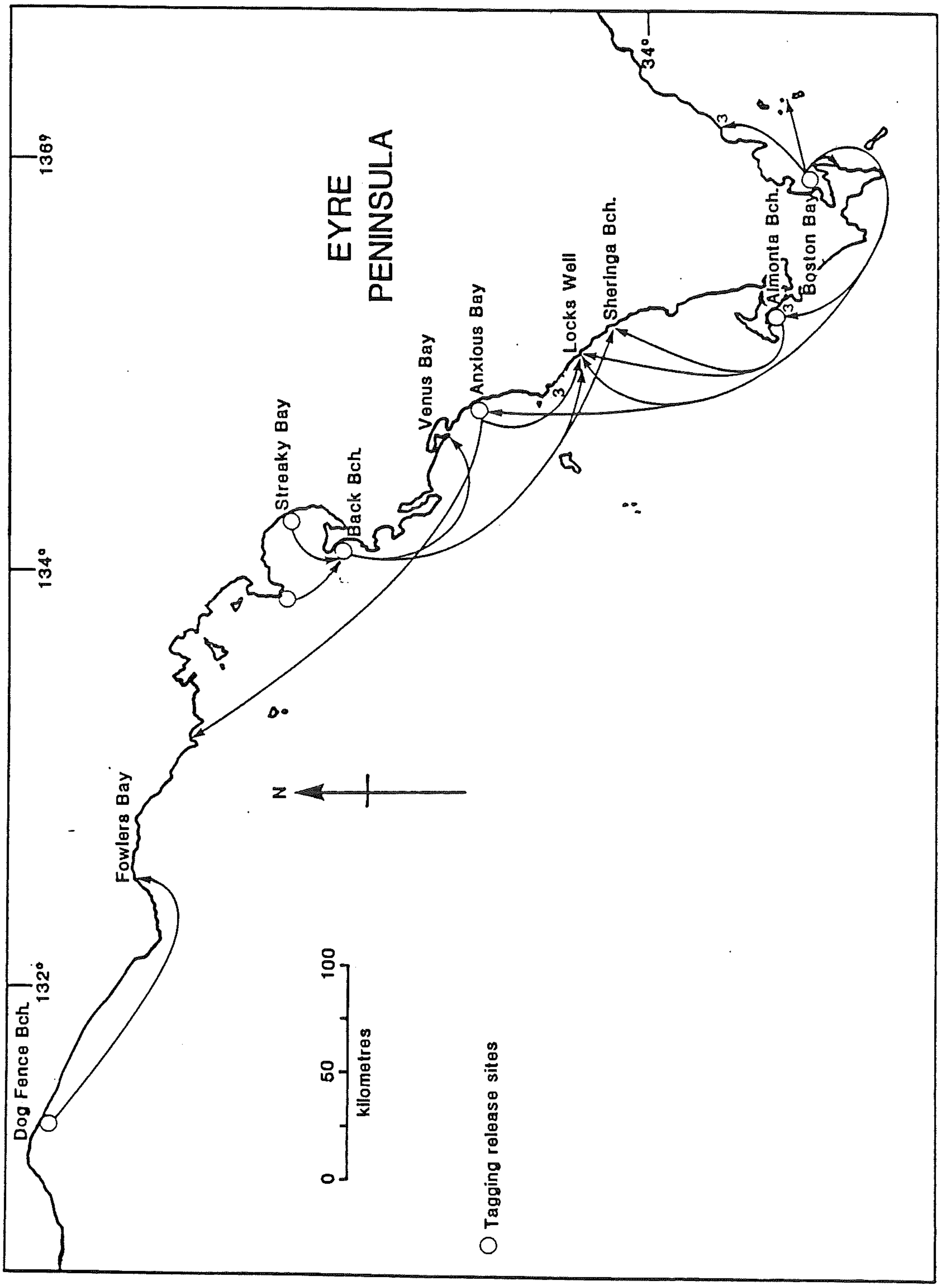


Figure (9.2). Patterns of movement within South Australia (greater than 20km) of salmon tagged along Yorke Peninsula. Unless specified otherwise, the arrowheads represent movement by a single fish.

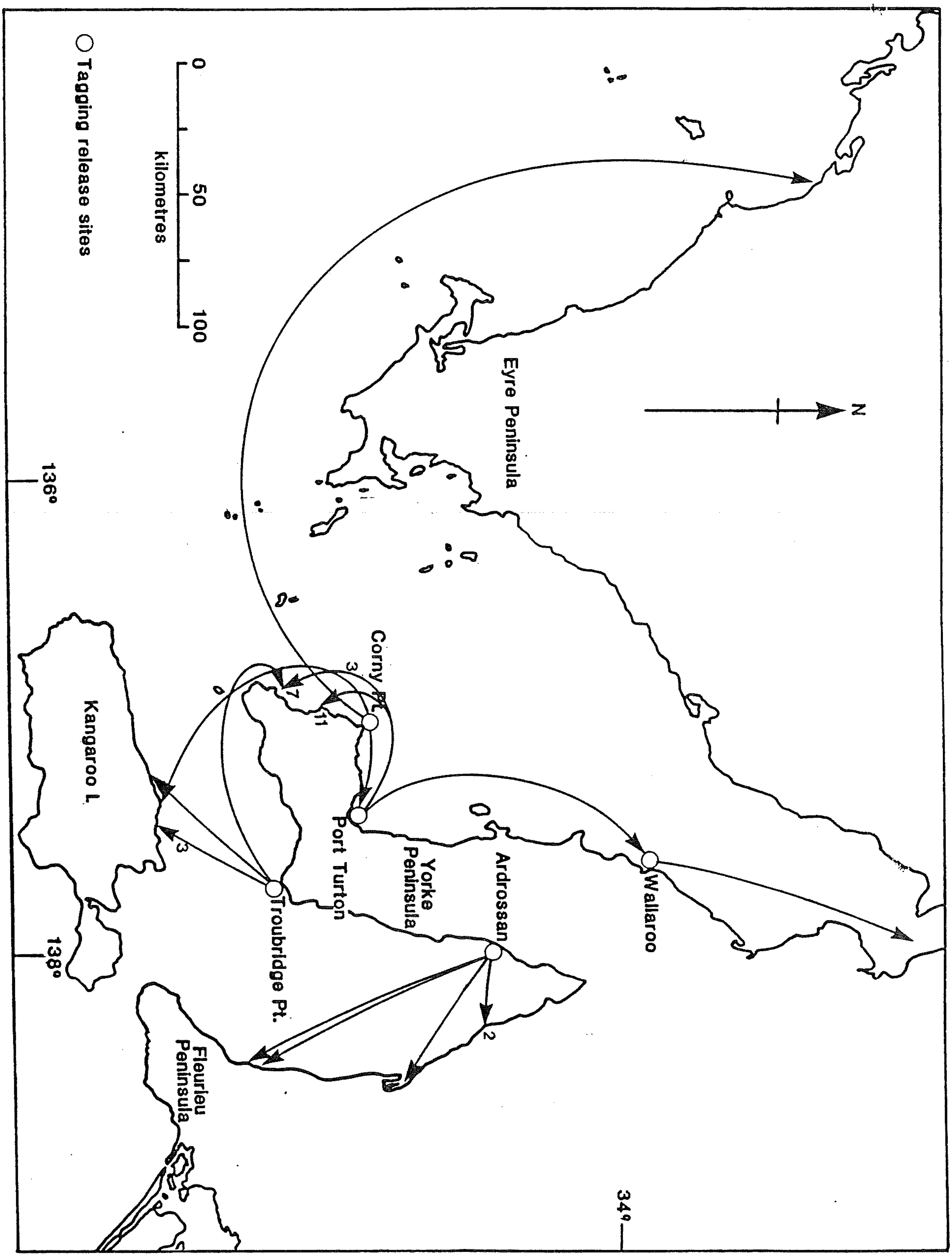


Figure (9.3). Patterns of movement within South Australia (greater than 20km) of salmon tagged around Kangaroo Island. Unless specified otherwise, the arrowheads represent movement by a single fish.

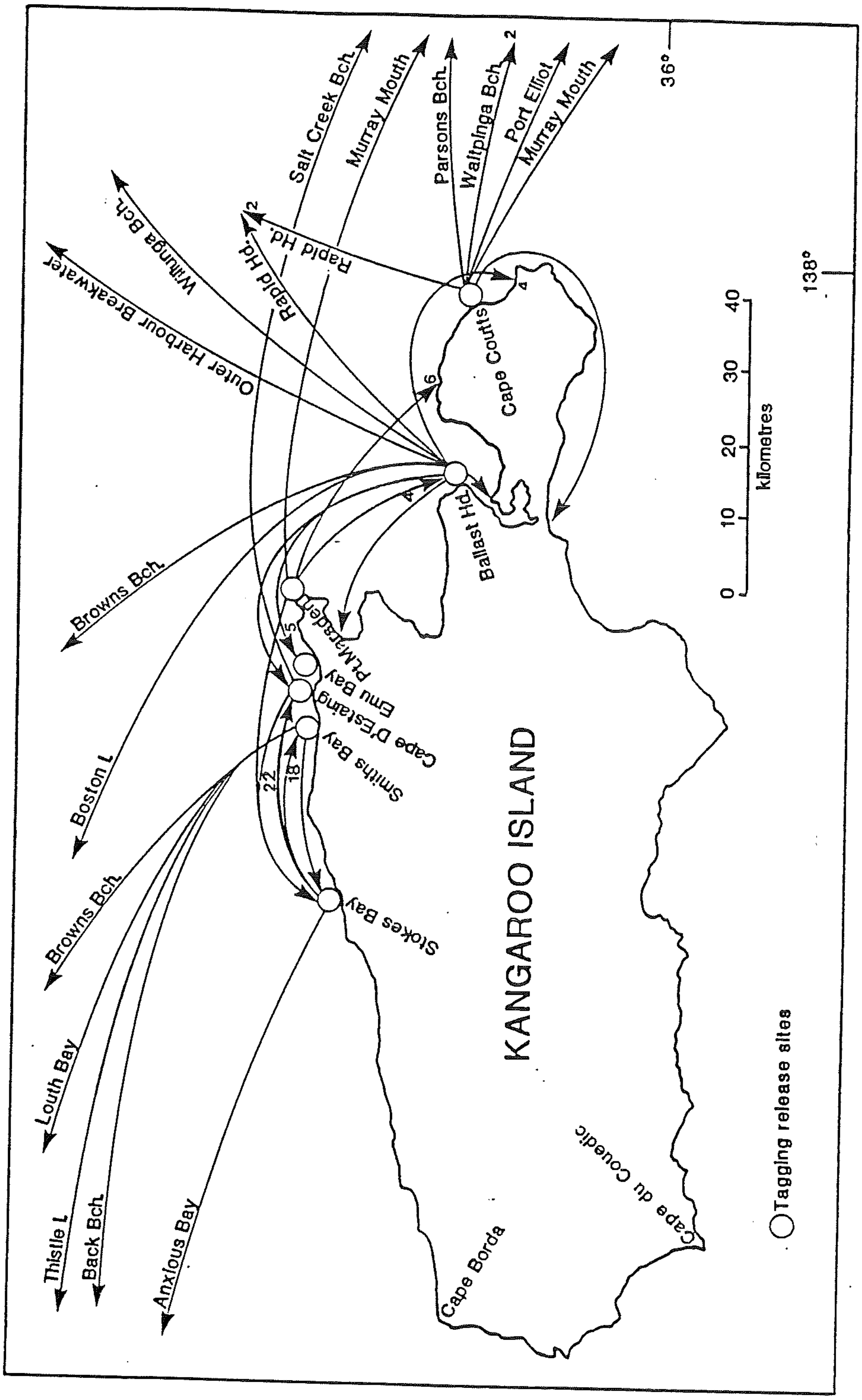


Figure (9.4). Patterns of movement within South Australia (greater than 20km) of salmon tagged at Hog Bay, Kangaroo Island. Unless specified otherwise, the arrowheads represent movement by a single fish.

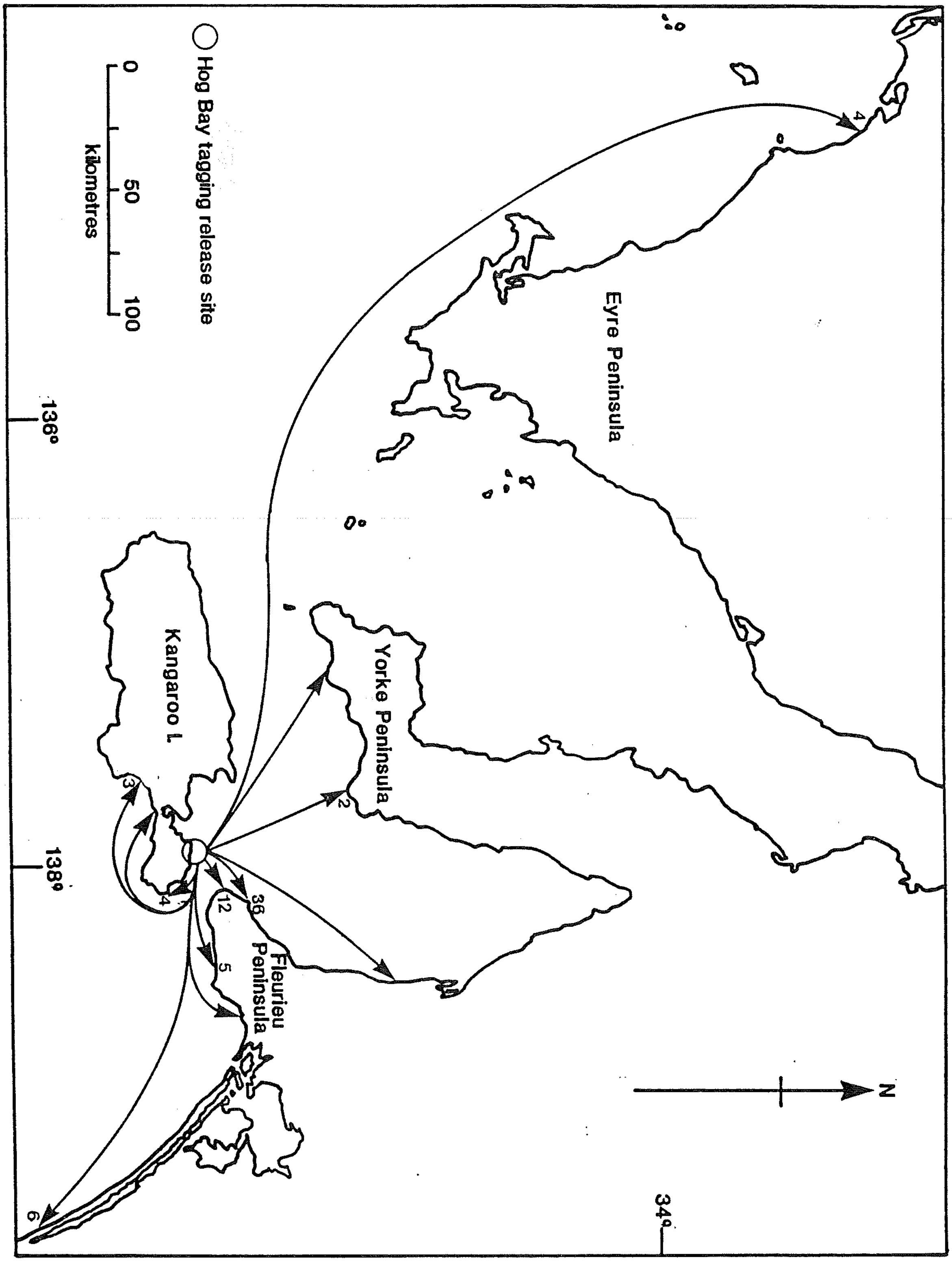
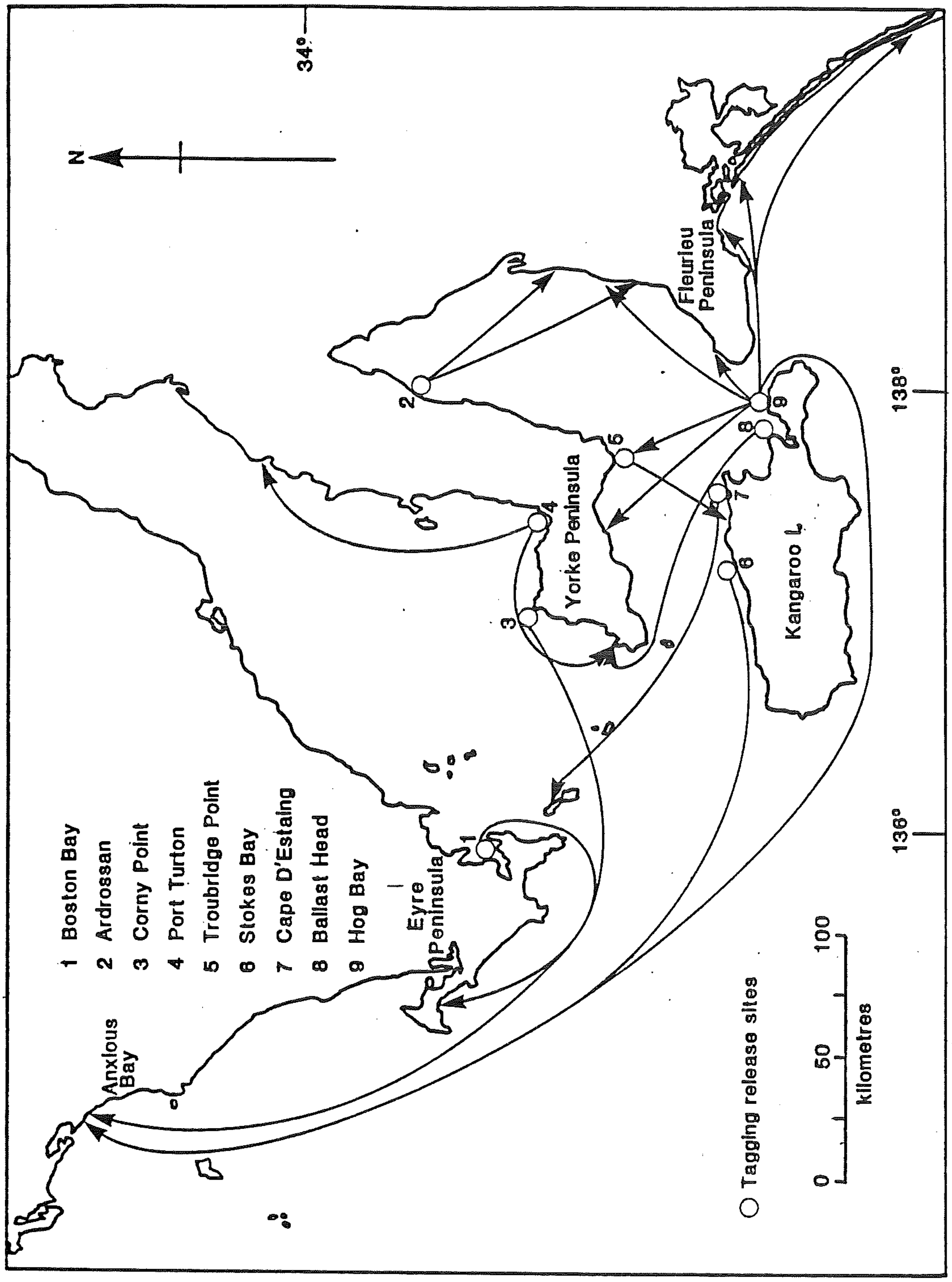


Figure (9.5) A summary of movement (by tagged salmon) between fishing areas. Arrowheads represent movement of one, or more, fish. Numbers are outlined in Table (9.2).



move to the South-East coast, prior to departure to Western Australia at older ages than the rest of the population.

In the current study, fish aged from 1+, and above, moved eastward from Kangaroo Island to Waitpinga Beach, the Murray Mouth and Salt Creek Beach near Kingston. Without further data on the South-East schools, it is not possible to add significantly to Stanley's hypothesis.

It is possible to discuss patterns of recruitment to beaches fished commercially and/or by anglers. Beaches on the south and east coasts of Kangaroo Island were colonised by some salmon from nursery areas in Shoal Bay, on the sheltered northern side of the island. Schools on the south-western coast of Yorke Peninsula were contributed to by recruits tagged in Hardwicke Bay. Similarly, some fish moved from Boston Bay around to the exposed Almonta Beach.

It is suggested that the major sources of recruitment for the fisheries along exposed coasts come from adjacent nursery areas; in sheltered bays, in the gulfs or in the Coorong lagoon. There was no evidence of a gradual westward movement of growing salmon, nor was there evidence of long, random movements along the South Australian coastline. Salmon continue to recruit into, and to be caught in, the same localised areas of the South Australian coastline.

9.2 MIGRATION TO WESTERN AUSTRALIA

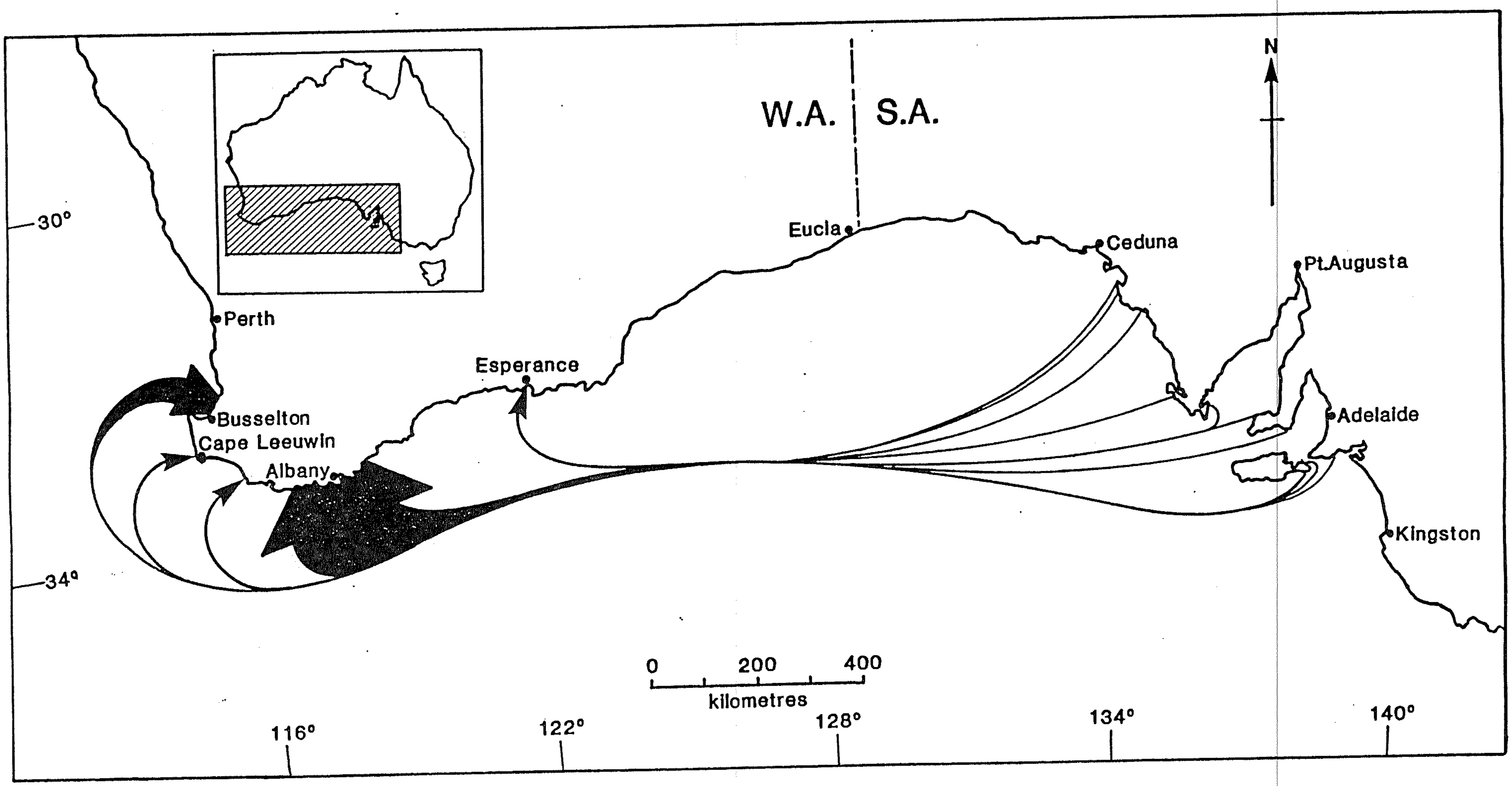
The numbers of tagged salmon recaptured during the 1985, 1986 and 1987 seasons are shown, by tagging operation, in Table (9.4). Tag recoveries in the table are expressed both as a percentage of the total numbers released; and as a percentage of the survivors available to migrate, after S.A. recaptures have been allowed for.

The locations of release and recapture of migrating salmon are summarised in Figure (9.6). Tag recaptures, at Western Australian fishing beaches, are given in Appendix (9.1).

Table (9.4). Recaptures in Western Australia of salmon tagged in South Australia, by season of recapture and by tagging operations.

OPNUM	OPDATE	LOCATION	N tagged	SEASON OF RECAPTURE 1985	1986	1987	TOTAL	as % of Ntagged	as % of survivors
42	01/08/85	ALMONTA BEACH	37		2	4	6	16.2	16.7
44	03/08/85	ALMONTA BEACH	19		0	2	2	10.5	14.3
43	02/08/85	ALMONTA BEACH	23		2	3	5	21.7	21.7
58	27/01/86	ANXIOUS BAY	168		44	21	65	38.7	38.9
50	22/11/85	BACK BEACH	64		15	6	21	32.8	36.8
21	01/02/85	POINT DILLON	64	0	1	0	1	1.6	1.8
49	02/11/85	CAPE BAUER	340		2	12	14	4.1	4.9
10	20/11/84	MAD MILE POINT	6	0	1	0	1	16.7	16.7
48	27/10/85	HIGH CLIFF	115		0	2	2	1.7	2.0
9	19/11/84	BAIRD'S BAY	12	0	0	1	1	8.3	9.1
18	19/01/85	ANXIOUS BAY	235	4	48	0	52	22.1	28.4
4	26/10/84	FANNY POINT	21	0	4	1	5	23.8	31.3
47	02/10/85	BICKERS ISLAND	61		3	6	9	14.8	17.0
28	27/02/85	WATTLE BAY	56	0	1	3	4	7.1	11.4
35	21/03/85	BERRY BAY	89	1	8	2	11	12.4	21.2
16	03/01/85	HOG BAY	186	13	12	2	27	14.5	15.3
51	28/11/85	HOG BAY	83		27	10	37	44.6	46.3
17	04/01/85	HOG BAY	102	5	14	1	20	19.6	20.6
54	09/01/86	HOG BAY	145		14	16	30	20.7	22.4
26	17/02/85	STOKES BAY	88	0	10	2	12	13.6	19.0
56	23/01/86	HOG BAY	136		4	16	20	14.7	17.4
57	24/01/86	HOG BAY	201		2	25	27	13.4	16.5
45	11/09/85	CAPE D'ESTAING	51		4	5	9	17.6	32.1
2	23/10/84	D'ESTREE BAY	56	3	8	1	12	21.4	22.6
25	17/02/85	STOKES BAY	79	0	9	1	10	12.7	16.4
3	23/10/84	D'ESTREE BAY	29	2	2	0	4	13.8	13.8
59	20/02/86	HOG BAY	105		0	14	14	13.3	13.9
20	26/01/85	SEAL ROCK	7	0	3	0	3	42.9	42.9
TOTALS			2571	28	237	156	421	16.4	19.2

Figure (9.6). Locations of release and recapture of tagged salmon which migrated from South Australia. Lines do not imply knowledge of the path of migration.



Rates of recovery in Western Australia were the highest yet recorded; at an average of 20 percent for the operations listed. These operations comprised salmon older than 3+; mainly 4+. Stanley (WFRC 1) summarised tag recoveries of earlier programmes where fewer large salmon were tagged. For 4+ fish, recoveries in Western Australia were 1.7%, 9.7% and 10.8%, respectively, for tagging undertaken in the 1950's, 1960's and 1970's.

The number of recaptures in Western Australia will increase to a higher level, once younger fish have developed sufficiently to migrate. In comparison to previous programmes, this higher level is partially due to the large number of large fish tagged; over 60 percent of the salmon tagged were greater than 50cm LCF. However, the tag recoveries reflect also the magnitude of the annual participation of South Australian adults in a migration to spawn in Western Australia.

There was no evidence of a decrease in recruitment to Western Australia with release location, from west to east. Recoveries of up to 38% and 46%, respectively, were recorded for Anxious Bay (West Coast) and Hog Bay (Kangaroo Island). However, the Hog Bay operations were based on migrating salmon (see Section 9.2.3) and other "resident" fish tagged in the same area are not yet of sufficient age to migrate.

Stanley (WFRC 1) found that there was little movement to Western Australia, at older ages, of the 0+ and 1+ salmon tagged at Tickera, Cape Jervis, Kangaroo Island and Port Elliot. He suggested that the coastline west of Coffin Bay was the greatest source of migrants to Western Australia.

9.2.1 Size and Age Characteristics of Migrants

The number of tagged salmon recaptured in Western Australia, by length at release, is given in Table (9.5). Recoveries have been adjusted by allowing for recaptures in South Australia. Recaptures in W.A. increase, with length at release, up to 36% for the largest length class from which fish were tagged. With

Table (9.5) Recaptures in Western Australia, by length class of salmon at release; expressed on a survivor basis (after allowance has been made for local recaptures).

LENGTH CLASS (CM)	NUMBER TAGGED	S.A. RECAPTURES	W.A. RECAPTURES	EXPRESSED AS % OF SURVIVORS
26-30	40	6	0	0.0
31-35	313	128	0	0.0
36-40	361	164	0	0.0
41-45	251	96	2	1.3
46-50	531	164	8	2.2
51-55	527	99	38	8.9
56-60	962	154	159	19.7
61-65	1057	79	198	20.2
66-70	59	2	21	36.8
TOTAL	4101	892	426	13.3

time, recaptures in W.A. of smaller size classes will increase also.

A more accurate representation of the extent of migration can be estimated by allowing for loss of potential migrants through both exploitation in South Australia, and natural mortality. In Tables (9.6), and (9.7), the formula $Nt= No / e^{Zt}$ (Gulland, 1983) has been used to estimate the number of tagged salmon remaining after each year of residence in South Australia. A value of 0.5 has been assigned to M, the instantaneous rate of natural mortality, and F has been allowed for by subtracting yearly recaptures from the survivors.

There are three features of the data presented in Tables (9.5), (9.6) and (9.7): (1) there is no evidence of a senile, non-spawning population in the fished area of South Australia; recaptures in W.A. increase with length at release; (2) the proportion of larger fish recaptured in W.A. is high; and (3) recaptures of these tagged fish in W.A. decline rapidly in the third year at liberty.

Migration from tagged schools of fish larger than about 60cm LCF is spread over two years, mainly; the season immediately after tagging, and the season in the summer of the following year.

Exploitation of the spawning stock in Western Australia has been estimated to vary about a level of 30 percent (Walker, pers.comm.). It could be argued that a tag recovery rate of 20 percent, in Western Australia, represents a recruitment rate of 60 percent into that stock, of adults from South Australia.

In Section (7.3), reference was made to the spread over time of recaptures in Western Australia; with an increase in rate of recovery, with time, for some operations detailed in Appendix (5.1) and Table (9.4). Rates of exploitation and natural mortality are very high in Western Australia; and it is

Table (9.6) Results from tagging in summer, 1984/85: Western Australian recaptures expressed as a percentage of those surviving fishing and natural mortality after the first (Year 1) and second (Year 2) full years after release.

		1986 SEASON - W.A.		1987 SEASON - W.A.	
LENGTH GROUP (CM)	NUMBER TAGGED	W.A. RECAPTURES	AS % OF SURVIVORS FROM YEAR 1.	W.A. RECAPTURES	AS % OF SURVIVORS FROM YEAR 2.
26-30	39	0	0	0	0
31-35	226	0	0	0	0
36-40	332	0	0	0	0
41-45	91	0	0	2	6.8
46-50	255	2	2.6	2	2.4
51-55	172	20	29.3	4	9.5
56-60	437	74	36.8	6	10.0
61-65	288	24	16.8	0	0
66-70	18	3	33.6	0	0
TOTAL	1858	123	18.8	14	2.9

Table (9.7) Results from tagging in summer 1985/86; Western Australian recaptures expressed as a percentage of those surviving fishing and natural mortality after the first full year (Year 1) after release.

LENGTH GROUP (CM)	NUMBER TAGGED	W.A. RECAPTURES	AS % OF SURVIVORS FROM YEAR 1
26-30	1	0	0
31-35	87	0	0
36-40	29	0	0
41-45	160	0	0
46-50	276	4	4.3
51-55	355	13	8.3
56-60	525	52	22.3
61-65	796	70	20.7
66-70	41	3	25.3
TOTAL	2243	119	15.8

unlikely that migrants from South Australia could persist and become resident in large numbers, in that State. Tag recoveries by anglers were not significant between seasons in Western Australia.

Therefore, it is proposed that the spread of recaptures represents a postponement of migration by tagged salmon. Stanley (1980b, 1983) demonstrated that migration to Western Australia is dependent upon growth rates; with faster-growing fish migrating at younger ages. He found also that the effects of tagging may result in the postponement of migration, through behavioural changes (Stanley, 1983).

In line with these hypotheses, the lengths at release, and ages at recapture, were examined; of salmon recaptured in the seasons immediately following (Season 1) and one year after, (Season 2) release. To overcome differences in rates of growth, data from operations at Anxious Bay (West Coast) and Hog Bay (Kangaroo Island) were treated separately.

Two questions are examined in Tables (9.8) and (9.9); (1) are the lengths at release of tagged school members lower for those fish migrating in Season 2?; and, (2) are the ages at release of tagged school members lower for those fish migrating in Season 2?

There are significant differences in the lengths at release of tagged salmon which migrated to Western Australia in two different seasons; for both Hog Bay and Anxious Bay operations. The larger fish in the tagged schools migrated first, and the smaller fish postponed movement to Season 2. The differences in length were quite subtle for Hog Bay fish exhibiting these different movement patterns.

However, the results of analyses of age at recapture differed. The age at recapture of Anxious Bay fish was independent of the season of recapture. That is, fish recaptured in season 2 were younger when tagged than those individuals recaptured in season

Table (9.8) Tests of the null hypothesis (Ho) that mean length at release is equivalent for salmon captured in season 1 and season 2, after release.

SPSS Student's t-test, reject Ho if $P < 0.05$

HOG BAY, All Operations Pooled

	N	Mean	St.D	S.E.
Season 1	62	61.97	1.628	0.207
Season 2	112	60.49	2.415	0.228

Separate Variance Estimate

t-value	d.f	2-Tail Probability (P)
4.80	65.31	P = 0.000

ANXIOUS BAY, all operations pooled

	N	Mean	St.D	S.E.
Season 1	48	63.35	2.204	0.318
Season 2	69	60.45	2.292	0.276

Separate Variance Estimate

t-value	d.f	2-Tail Probability (P)
6.89	103.74	P = 0.000

Table (9.9) Tests of the null hypothesis (Ho) that age at recapture is equivalent for salmon recaptured in season 1 and season 2, after release.

Row by Column test of independence, G-statistic (Sokal and Rohlf, 1973); Retain Ho if G/q $< \chi^2$ (a-1) (b-1) where a = number of rows, b = number of colums.

	AGE AT RECAPTURE IN WESTERN AUSTRALIA						
HOG BAY	3+	4+	5+	6+	7+	8+	TOTAL
Season 1		25	34	2			61
Season 2		16	65	23	1	1	106
TOTAL		41	99	25	1	1	167

G/q = 20.31 $> \chi^2_4$ = 18.46, Reject Ho
chi

	AGE AT RECAPTURE IN WESTERN AUSTRALIA						
ANXIOUS BAY	3+	4+	5+	6+	7+	8+	TOTAL
Season 1	1	24	20	1			46
Season 2	2	27	26	10			64
TOTAL	2	51	46	11			110

G/q = 5.91 $< \chi^2_3$ = 16.266, Retain Ho
chi

1; producing a similar age composition in both seasons, mainly 4+ and 5+. However, scales from Anxious Bay salmon were extremely difficult to read, and these results may be an artifact of the ageing analyses. That is, determinations of age at recapture may have been independent of true age.

Hog Bay salmon recaptured in season 2 were significantly older, by approximately one year, than those recaptured in season 1. That is, fish recaptured in season 2 were of equivalent age at release to fish recaptured in season 1. Fish were recaptured mainly at ages of 4+ and 5+ in season 1; and 5+ and 6+ in season 2.

This directly supports Stanley's (WFRC 1) hypothesis that migration depends on growth rate; smaller-at-age salmon from Hog Bay postponed migration until season 2.

However, the salmon tagged at Hog Bay were not resident fish; but, rather, migrants from unknown sources (see Section 9.2.3) moving rapidly through the bay. Thus, the postponement of movement to Western Australia represents a "dropping-out" of members of the migrating schools from Hog Bay. The timing and location of cessation of migration are unknown, as are the causative mechanisms of this phenomenon.

These salmon were not recruited into the South Australian, or Western Australian fisheries during the year in which migration was postponed.

9.2.2 Timing of Migration

There is evidence that migration is rapid, and can occur relatively close to the start of the spawning season. Fish released as late as the third week of January, at Hog Bay and Anxious Bay, were recaptured in the W.A. fishery immediately following. Times at liberty for these fish ranged from 47 days for Anxious Bay releases, to 86 days for salmon tagged at Hog Bay. No salmon tagged on 20/2/86, at Hog Bay, were caught in the 1986 salmon season in Western Australia.

If it is assumed that the salmon migrate along the coast, the lack of recaptures between the locations of release and recapture may reflect the speed of the movement.

The timing of the onset of migration is unknown. In the "assembly area" (Malcolm, 1960) around Esperance, tagged salmon were captured by anglers in the period September 1986-March 1987. Observations by fishermen, outlined in Section 9.2.3, suggest that salmon pass the Victor Harbor-Hog Bay area in November to March.

9.2.3 The Significance of Hog Bay Schools

Schools of large salmon move through Hog Bay in the summer months, mainly from November to February (pers.comm. S. Noack). Detailed spotting logs kept by this fisherman showed that, during the study period, the schools usually comprised less than 10 tonnes of fish of individual weights estimated at 3.5 kg, and over. The salmon moved rapidly, mainly from east to west.

To the east, at Victor Harbor in area 45, salmon were caught in mesh nets during the period November to March and local fishermen reported that the movement was from east to west, of small groups of fish (pers.comm. R.J. Tugwell). Measurements of these salmon were presented in Section (5.4).

The source of salmon migrating through Hog Bay may be to the east, in the South-East and/or eastern States, or along the south coast of Kangaroo Island. Apart from local recoveries, which represented less than 0.5 percent, no tagged fish were recaptured in these schools.

The habits, and habitat, of tagged fish are largely unknown in the interval between release at Hog Bay and recapture in the W.A. fishery. Several were recaptured at Anxious Bay, presumably enroute to Western Australia, and other recaptures were dispersed around Kangaroo Island, Yorke Peninsula, Fleurieu Peninsula and the South-East (see Figure 9.4). The recaptures made along the Ninety-Mile Beach at Salt Creek are significant. Although there is no commercial fishery for salmon in that area, anglers caught six tagged salmon there. These fish were caught as a by-catch of mulloway fishing activities.

It is suggested here that Investigator Strait may be a corridor through which salmon migrate. Individuals which cease, and postpone, migration may move eastwards, or southwards, to exposed coasts. Without further tag recoveries, it is possible only to speculate on the activities of these tagged adults during their disappearance from the fishery.

9.3 THE RELATIONSHIP BETWEEN CATCH IN WESTERN AUSTRALIA, AND RECRUITMENT FROM SOUTH AUSTRALIA

The central management issue concerning previous studies has been the level of catch in Western Australia contributed to by South Australian recruits.

Stanley (WFRC 1), building on the work of Nicholls (1960's) and Malcolm (1950's), has proposed an elegant hypothesis to explain the fluctuation in Western Australian catch. These studies showed that the sequence of events during the Western Australian season was one of consistent and predictable changes each year. There was a regular progression in the length and age structure at recruitment of salmon which were present in the fishery for only one year.

There was a decrease in mean length of fish in each school during the season; in the order of two to three centimetres. This decline was gradual towards mid-March, but sharp from then on to the end of the season. The date of intersection between two regression lines of mean length of fish, with time, was March 13 $\pm$ 2 days. The decrease in school mean length was caused by progressive entry into the fishery of smaller salmon within each age class.

Studies of the age structure within each period of differing catch composition have shown that; (1) there was a much greater increase in the numbers of 3+ and 4+ fish caught in period 1, as the total catch increased, than for 5+ and 6+ age groups; and (2) the amount of fish caught in period 1 was lower than that landed in period 2 for seasons of lower total catch and, as the total catch increased, the period 1 catch increased at a rate faster than that for period 2.

In summary, Stanley (WFRC 1) proposed that it was the magnitude of the catch made in period 1, of 3+ and 4+ salmon, which determined the overall success of the Western Australian season. From the results of tagging operations, Stanley (WFRC 1) concluded that higher catches were associated with entry of 3+ and 4+ salmon from the Esperance area. Having higher growth rates, these fish were larger-at-age than 4+ salmon from South Australia.

In the south-coast fishery, during 1975-80, catches below 1000 tonnes per season were significantly related to the daily entry of South Australian tagged fish; and above 1,300 tonnes, to the daily entry of Esperance tagged fish. A much larger percentage of Esperance tagged fish (46%) was recaptured in period 1, in comparison to South Australian tagged salmon (25%). Most tagged salmon from South Australia were recaptured after March 13 (75%) in Western Australia.

In Figures (9.7), (9.8) and (9.9) the daily recaptures of South Australian tagged fish (by professionals) are plotted with daily catches on the W.A. south-coast, for the seasons 1985, 1986 and 1987. These data were analysed to test for significance of correlation between daily entry of tagged fish and daily catch magnitude. The results for 1985 were not included in the analyses, because of the low number of salmon tagged prior to commencement of the season. Tag recaptures were not distributed normally, so tests for correlation were carried out using Spearman Rank Correlation coefficients. Catches must be made for tags to be returned, so days on which no catches were made were excluded from analyses. Results are presented in Table (9.10).

Catch has declined since 1984 (3543 tonnes), but the 1986 catch was the second highest catch taken since 1960. In 1986, there was a low correlation between south coast catch and daily entry of tagged salmon from South Australia. Most tags (86%) were recovered during period 2,

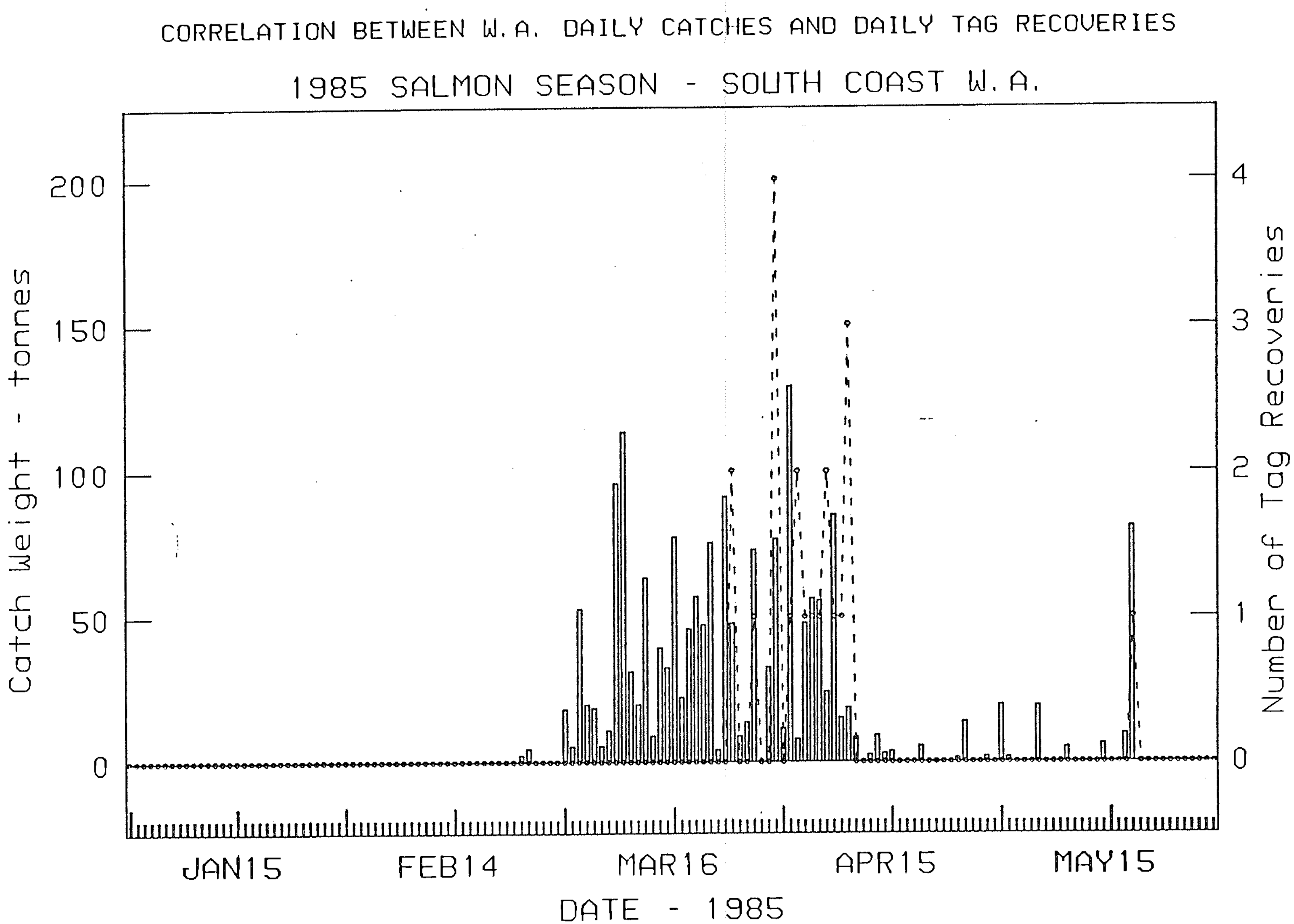


Figure (9.7). Relationship between daily recaptures of tagged salmon, and daily catches on the W.A. south coast in 1985.

0----0 = tags recovered

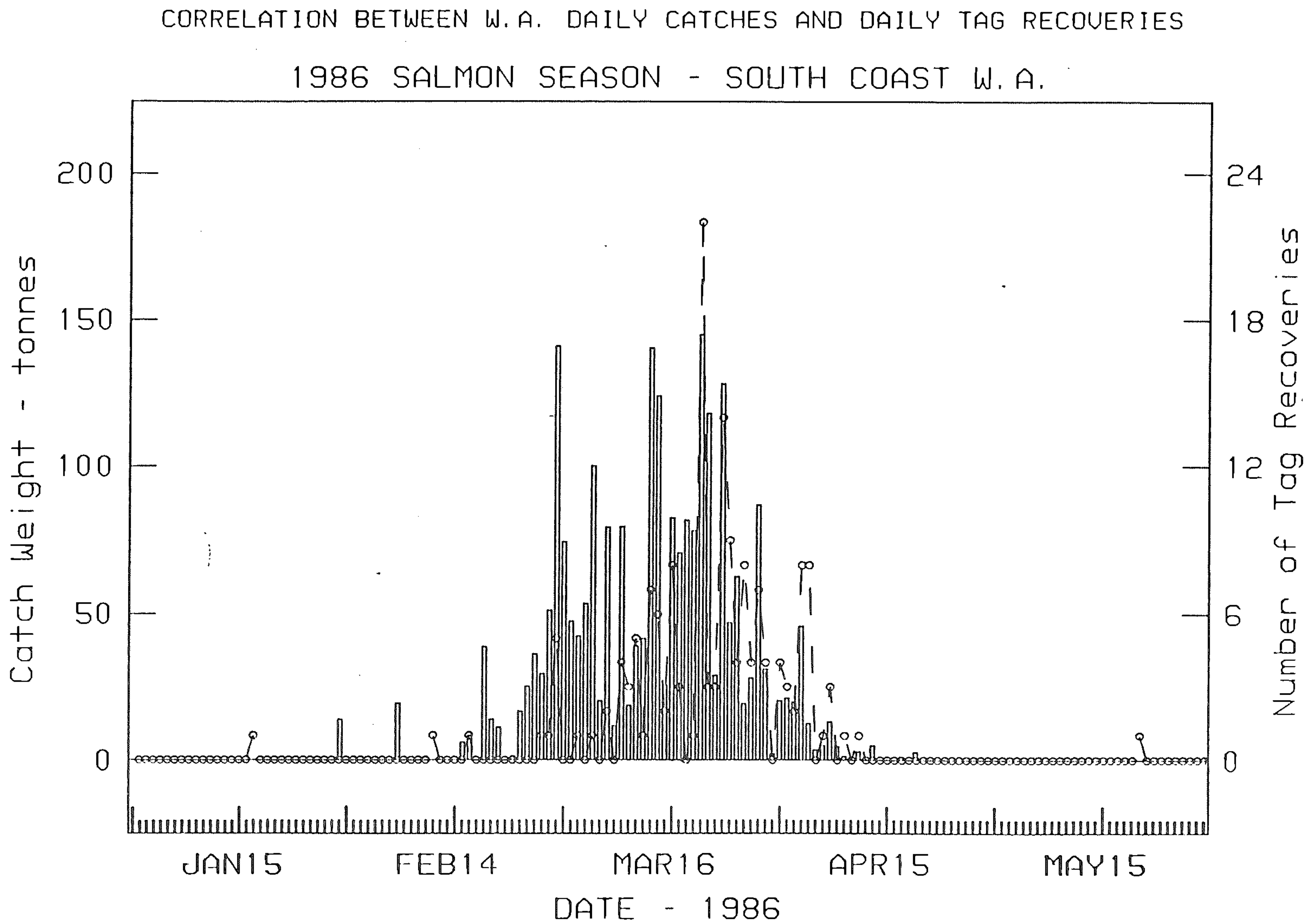


Figure (9.8). Relationship between daily recaptures of tagged salmon, and daily catches on the W.A. south coast in 1986.
0---0 = tags recovered

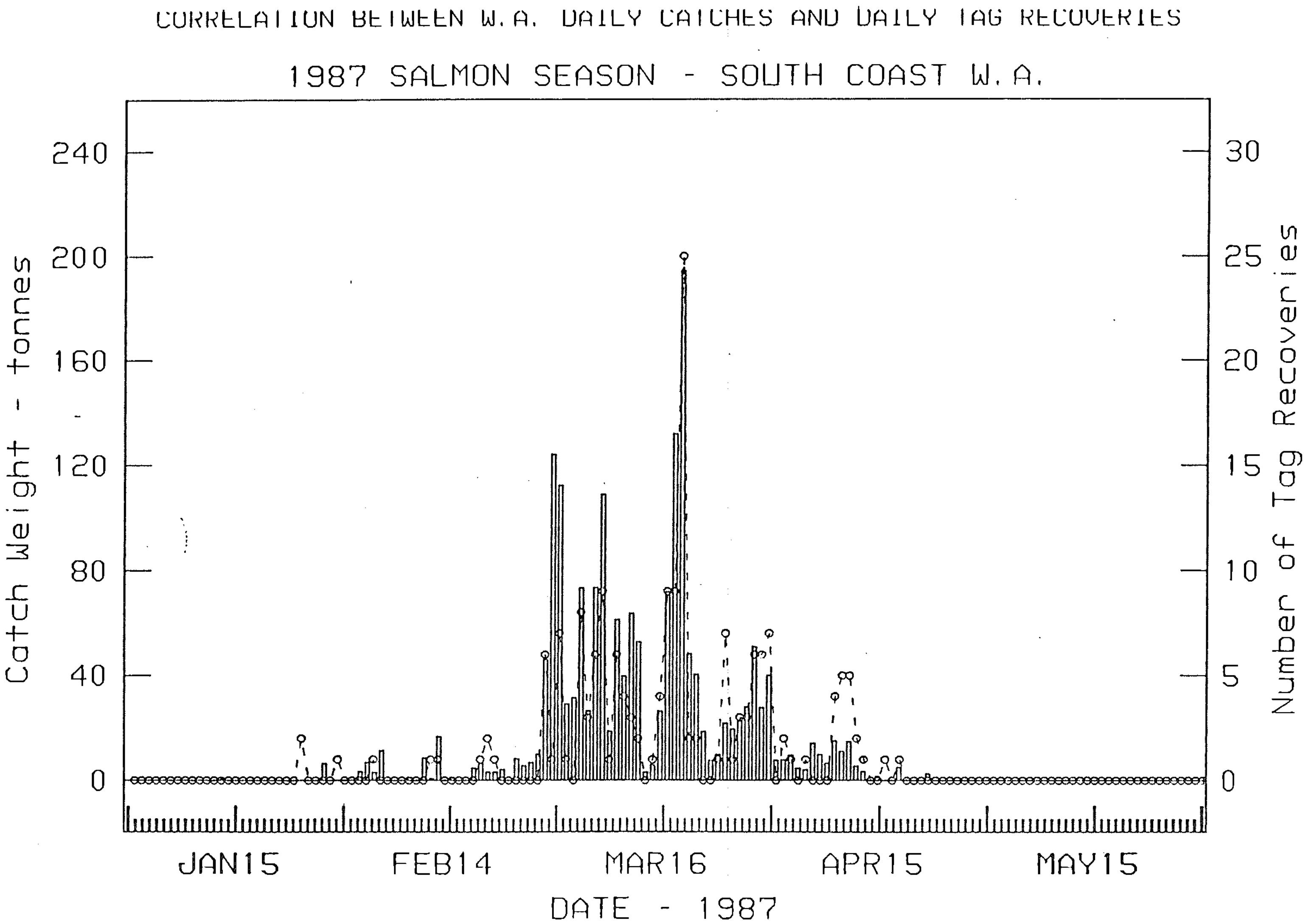


Figure (9.9). Relationship between daily recaptures of tagged salmon, and daily catches on the W.A. south coast in 1987.

O----O = tags recovered

Table (9.10) Spearman Rank correlation coefficients (rs) for daily recaptures of tagged salmon and daily catches by professionals on the W.A. South-Coast.

1985	N tags	Catch (kg)	N days	rs
Period 1**	0	463731	-	-
Period 2	21	1403445	-	-
Whole Season	21	1867176	-	-

1986	N tags	Catch (kg)	N days	rs
Period 1	20	1024259	26	0.59
Period 2	123	1464876	32	0.69
Whole Season	143	2489135	58	0.55

1987	N tags*	Catch (kg)	N days	rs
Period 1	68	978503	35	0.72
Period 2	118	898325	34	0.75
Whole Season	186	1876828	69	0.74

* provisional only

** periods recognised from previous studies on catch structure in W.A. (Stanley, WFRC 1).

and there was a higher correlation between the two factors during this time. Unfortunately, the 1986 catch on the south coast was not sampled, and nothing is known of the age/size characteristics of salmon caught with the tagged individuals.

In 1987, the south coast catch was lower (1,877 tonnes) and was significantly, highly correlated with the entry of tagged salmon from South Australia. Tag recoveries for period 1 were relatively high (36%), and daily entry of tagged salmon was highly correlated with daily catches in both periods. The number of tagged fish present before March 13 seems too large to represent a "carry-over" of survivors from the previous season. Information on the length/age structure of the 1987 catch is not yet available.

In line with Stanley's (WFRC 1) hypothesis, the 1987 catch should not have been highly correlated with daily entry of tagged salmon from South Australia. However, there are insufficient data here to test the hypothesis. Significantly, Walker (1985) reported that the proportion of 3+ fish was particularly high for the good seasons of 1983 and 1984; during the end of the salmon run (period 2 in April), and for the eastern part of the fishery. Stanley (WFRC 1) predicted that, in years of high catch, greater numbers of 3+ and 4+ salmon would be caught; but these fish should recruit into the fishery from the Esperance area, before March 13 in period 1.

In order to understand the relationship between annual catch and recruitment in Western Australia, it is essential that all age and length data are analysed for recent seasons of higher levels of catch. Without this synthesis of catch data, it is not currently possible to discuss the full implications of the results of tagging presented here. Levels of recruitment from South Australia may be higher than previously predicted.

9.3.1 The Mechanism Governing Recruitment

Stanley (WFRC 181) considered that South Australia provided a "background" level of recruitment of up to 1,000 tonnes during the era of low catch in that State. High catch levels were considered to be the result of high levels of recruitment from the western Bight - Esperance area. As there was no fishery in there, Stanley (WFRC 1) suggested that environmental conditions in the spawning area caused variable recruitment of juveniles into the Esperance area. The lack of juveniles in the Esperance area, reported by Walker (pers.comm.), was suggested to be the result of sampling bias toward years of low W.A. catch, and low recruitment in that area (Stanley, pers.comm.).

Stanley (WFRC 1, pers.comm.) found that there was a correlation between salinity levels in the time and area of spawning, and catch four years later in Western Australia. The envelope of predicted values included the recent seasons of high catch. Timing of the seasonal interchange from higher salinity (>35.8%) subtropical water in summer, to lower salinity (<35.0%) tropical water in winter may be critical to the survival, and dispersal, of juvenile stages (Stanley, WFRC 1).

In response to environmentally-induced recruitment variation and intensive, constant effort, management strategies must be aimed at conserving spawning stock at sufficient levels in Western Australia each year.

10.1 THE ABUNDANCE OF SALMON IN SOUTH AUSTRALIA

Salmon spotters fly over traditional fishing areas in the search for salmon schools. Once a congregation of target schools is located, the aerial search becomes aerial surveillance of localised areas. For the purposes of estimation of population abundance, the aerial spotting of salmon schools is biased in this State.

During the period October 1984 - June 1986, a total of 64 aerial surveys were completed by spotters and research staff. No sampling design was employed in the surveys, and estimates of school tonnage and individual fish size were not "ground-truthed" with catches. with the exception of two flights to the South-East, surveys were undertaken in the area of operations of the purse-seine fleet.

During survey flights, spotters flew along the coast, slightly to one side of the surf-zone at a height of about 300 metres. estimates of school size and fish size were made by the spotters, from many years experience in the industry, and recorded by research staff or other passengers.

The coast within fishing areas was partitioned into 40 zones, according to the scheme in Table (10.1). An example of the aerial survey form is included as Appendix (4.2).

The results of surveys are summarised in Table (10.1) and (10.2). The two main summarising statistics used here are; the average tonnage sighted per zone, during flights in that zone when salmon were sighted; and the maximum tonnage sighted per zone, on any single flight when salmon were sighted there.

For the purposes of population estimation, the following assumptions are made here; (1) the pooled survey results represent a single point sample of the population; (2) there was no movement of salmon between zones; (3) there was no mortality or recruitment within zones; (4) the entire population inhabits the coast, but forages offshore; and (5) all size classes school, and all school sizes are equally visible from the air.

Under these assumptions, a lower and upper limit of population size within fishing areas was calculated by summing, respectively, the average and maximum tonnages sighted per zone. The population size in the sampled area was estimated at 3602-6193 tonnes.

It is considered that this range significantly underestimates population size. The mean size of schools varied greatly as salmon left them to forage offshore, or joined them from nearby schools. Spotters overlooked small schools, particularly those below 10 tonnes, because they were insufficient as purse-seine targets. The smallest school recorded was one tonne. School visibility was not equal, but depended upon school size and spotting conditions.

The tonnage range of schools sighted during the survey, and during Western Australian surveys, are shown in Table (10.3). Western Australian sightings were skewed in distribution; from a peak at less than six tonnes, along a "tail" to 400-500 tonnes. There are two main features of the South Australian data. More larger schools were sighted, and the most commonly recorded schools were of 11-50 tonnes

Table (10.1). Summary of results of aerial survey undertaken in the period 1984-86.

FLIGHT PATH from zone	to	N FLIGHTS	SALMON SIGHTED ON FLIGHT	NO SALMON SIGHTED ON FLIGHT	SIGHTED N SCHOOLS	SIGHTED T TONNES	AVERAGE TONNAGE SIGHTED	MEAN SCHOOL WEIGHT	Std Dev.	MAXIMUM TONNAGE SIGHTED
40 KINGSTON	MURRAY MOUTH	2	1	1	5	1100	1100	183.3	400.2	1100
1 MURRAY MOUTH	CAPE JERVIS	1	1	0	5	90	90	18	10.95	90
2 CAPE JERVIS	PT NOARLUNGA REEF	5	4	1	9	301	75	33.4	33.7	119
3 CP WILLOUGHBY	HOG BAY	6	3	3	6	136	45	22.6	31.6	80
4 HOG BAY	MARSDEN POINT	7	5	2	10	190	38	19	21.51	70
5 MARSDEN PT	STOKES BAY	6	4	2	7	136	34	19.4	18.7	65
6 STOKES BAY	CAPE BORDA	6	3	3	4	260	87	65	47.4	200
7 CP BORDA	CAPE DU COUDEIC	6	5	1	12	276	55	23	27.8	127
8 CP DU COUDEIC	CAPE GANTHEAUME	3	3	0	9	368	123	40.8	62.3	260
9 CP GANTHEAUME	CAPE WILLOUGHBY	10	10	0	35	3110	311	88.8	140.4	230
10 EDITHBURGH	PORT MOOROWIE	5	5	0	5	72	14	14.4	10	30
11 PT MOOROWIE	STENHOUSE BAY	3	2	1	2	20	10	10	7	15
12 STENHOUSE BAY	WEST CAPE	2	0	2	0	0	0	0	0	0
13 WEST CAPE	DALY HEAD	13	10	3	18	246	25	13.6	11.3	60
14 DALY HEAD	CORNY POINT	13	5	8	5	72	14	14.4	8.7	30
15 CORNY POINT	POINT TURTON	8	5	3	7	76	15	10.8	9.2	25
16 SIR JOSEPH BANK GROUP		5	4	1	4	92	23	23	18.2	50
17 THISTLE ISLAND		6	1	5	1	1	1	1	0	1
18 PORT NEILL	POINT BOLINGBROKE	2	0	2	0	0	0	0	0	0
19 PT BOLINGBROKE	BOSTON POINT	1	1	0	1	25	25	25	0	25
20 BOSTON PT	CAPE DONINGTON	11	7	4	10	156	22	15.6	8.8	40
21 CP DONINGTON	CAPE TOURNEFORT	3	0	3	0	0	0	0	0	0
22 CP TOURNEFORT	CAPE CARNOT	10	10	0	15	1052	105	70.1	94.8	400
23 CP CARNOT	POINT AVOID	20	16	4	24	765	48	31.8	22.9	80
24 PT AVOID	POINT WHIDBEY	19	15	4	28	1406	94	50.2	41.7	280
25 PT WHIDBEY	MOUNT GREENLY	13	3	10	3	34	11	11.3	8	20
26 MT GREENLY	POINT DRUMMOND	14	14	0	62	1806	129	29.1	41.2	307
27 PT DRUMMOND	ELLISTON	10	8	2	19	1126	141	59.2	51.2	405
28 ELLISTON	POINT WEYLAND	11	10	1	20	1204	120	60.2	60	276
29 PT WEYLAND	POINT LABATT	10	6	4	11	835	139	75.9	64.3	500
30 PT LABATT	CAPE BLANCHE	10	6	4	7	395	66	56.4	37	125
31 CP BLANCHE	POINT WESTALL	23	11	12	16	499	45	31.1	53	180
32 PT WESTALL	CAPE BAUER	25	24	1	59	2262	94	38.3	31.6	230
33 CP BAUER	POINT BROWN	14	7	7	16	648	93	40.5	48.3	270
34 PT BROWN	CAPE O'ESTREES	11	10	1	16	1160	116	72.5	53.6	200
35 CP O'ESTREES	ROCKY POINT	2	2	0	4	99	50	24.7	26.4	60
36 ROCKY PT	POINT SINCLAIR	1	1	0	2	20	20	10	0	20
37 PT SINCLAIR	POINT FOWLER	1	1	0	3	20	20	6.6	4.7	20
38 PT FOWLER	CAPE ADIEU	1	1	0	2	203	203	101.5	139.3	203

Table (10.2). A range of estimates for population size in coastal areas, constructed from summarising statistics.

FISHING AREA		SUM AVERAGE TONNAGE PER ZONE	SUM MAXIMJM TONNAGE PER ZONE
South-East		1100	1100
South-Central Coast		165	209
Kangaroo Island North Coast		204	415
Kangaroo Island South Coast		489	617
Southern Yorke Peninsula		79	160
Spencer Gulf	24	51	
Southern Eyre Peninsula	152	456	
West Coast	1389	3176	
TOTAL	3602	6139	

in weight. The lack of smaller schools is considered to be the result of spotter bias.

The smaller size of schools in Western Australia probably reflects the different behaviour of adult salmon in that State. There, salmon are participating in a spawning migration, and move rapidly along the coast.

School activity is detailed, by fish size, in Table (10.4). Smaller salmon, of less than 3 pounds in weight, were not recorded as frequently as larger fish; but predominated in purse-seine catches made during the aerial survey period.

This concentration reflects the difficulty in estimating individual fish sizes from the air. The sightings of feeding schools were insignificant; salmon feed offshore on small clupeids and return to lie-up in the surf zone. No large schools were sighted moving west-ward during the time that tagged fish migrated through the survey area. It is concluded that fish migrate from South Australia in small groups, between stationary schools; not en masse.

Zones are ranked by the average tonnage sighted within them, in Table (10.5). Sightings were highest in the Kingston area, although flights in consecutive weeks in December 1985 yielded records of 1,100 tonnes and 25 tonnes, respectively. Fishermen report that sightings are highest in that area during December - April; after which schools disappear (pers.comm. R. Hendry). In fished areas, the south-east coast of Kangaroo Island, and the West Coast, supported the highest average sightings.

Sightings were consistently low around southern Yorke Peninsula, the Spencer Gulf island groups and southern Eyre Peninsula. However, significant catches were made along southern Eyre Peninsula during the study period. The lack of data for many zones, and the violation of working assumptions, restricts the value of comparisons between zones.

Table (10.3). Tonnage range of schools sighted in S.A. and W.A. *(After Stanley WFRC 4). Data from W.A. represent 5876 schools.

TONNAGE RANGE	N SCHOOLS (S.A.)	PERCENTAGE OF SIGHTINGS S.A. 1984-86	PERCENTAGE OF SIGHTINGS W.A. 1952-77*
<1-5	65	14.0	65.9
6-10	64	13.8	13.5
11-50	232	50.1	16.2
51-100	72	15.6	3.0
101-200	23	5.0	1.2
201-300	2	0.4	0.2
301-400	3	0.6	0.1
401-500	0	0.0	0.03
501-600	0	0.0	-
601-700	1	0.2	-
701-1000	1	0.2	-
N SCHOOLS	463		

Table (10.4). The activity of schools sighted in South Australia, by estimated size of school members.

ESTIMATED FISH SIZE (Pounds)	SCHOOL ACTIVITY FEEDING	SCHOOL ACTIVITY STATIONARY TIGHT	SCHOOL ACTIVITY STATIONARY DISPERSED	MOVING	TOTAL
<3	0	32	0	16	48
4 - 7	3	123	1	26	153
>7	0	150	2	32	184
Unknown	0	56	5	17	78
	3	361	8	91	463

In terms of fish size, schools in the Cape Willoughby - Cape Jervis area were comprised mainly of small (<3 pounds) to medium 3-7 pounds) salmon; whilst those along the exposed south coast of Kangaroo Island, and exposed beaches of the West Coast, were predominantly large (>7 pounds) salmon. Zones are ranked by estimated fish size, by fishing area, in Table (10.6). Sheltered areas were inhabited by schools of small salmon and large salmon, particularly on the West Coast.

11.1 REPRODUCTIVE DEVELOPMENT

Malcolm (1960) and Stanley (in prep.) found no evidence of seasonal maturation of female gonads in large South Australian salmon. Malcolm (1960) found that males in this State did complete the spermatogenic cycle; but the testes showed little enlargement, milt was not extruded from the genital opening under stripping pressure and there was no evidence that spermatozoa were shed by S.A. males. Spermatogenesis may take place in non-migratory males. Stanley (in prep.) found that gonad indices, K (K = gonad weight * 10^4/salmon LCF (cm) raised to the power 3.05), of older 4+ and 5+ fish, never rose above 1.0 during the year. During the spawning season in Western Australia, indices ranged from 1.0 to 15.0.

Testicular and ovarian development of salmon above 49.0 cm LCF is shown in Figures (11.1) and (11.2), where K is plotted by month. It can be seen that, during March, both males and females were found to have high gonad indices of 1.2 to 6.9. These individuals were large fish, from 57.0 to 59.0 cm LCF, from a single school of 22 tonnes caught at Berry Bay, southern Yorke Peninsula, on 21/3/85. Of 89 fish tagged from this school, no fish were recaptured in the W.A. salmon season of 1985. Indeed, all recaptures for the first year of release were localised to the Berry Bay area (see Section 9.1.2). These fish were reported by captors to be in a lean condition, and may have spawned or resorbed the gonads. Alternatively, local recaptures may have been comprised of salmon with low gonad indices at release; as there was considerable variation between the indices of individual fish in the sample examined. In the second and third seasons following tagging, salmon released at Berry Bay were recaptured in the W.A. fishery.

Table (10.5). Flight zones ranked by average tonnage sighted.

FLIGHT PATH FROM	TO	FLIGHTS SALMON SIGHTED	AVERAGE TONNAGE SIGHTED	N SCHOOLS
40 KINGSTON	MURRAY MOUTH	1	1100	5
9 CP GANTHEAUME	CAPE WILLOUGHBY	10	311	35
38 PT FOWLER	CAPE ADIEU	1	203	2
27 PT DRUMMOND	ELLISTON	8	141	19
29 PT WEYLAND	POINT LABATT	6	139	11
26 MT GREENLY	POINT DRUMMOND	14	129	62
8 CP DU COUDEIC	CAPE GANTHEAUME	3	123	9
28 ELLISTON	POINT WEYLAND	10	120	20
34 PT BROWN	CAPE D'ESTREES	10	116	16
22 CP TOURNEFORT	CAPE CARNOT	10	105	15
32 PT WESTALL	CAPE BAUER	24	94	59
24 PT AVOID	POINT WHIDBEY	15	94	28
33 CP BAUER	POINT BROWN	7	93	16
1 MURRAY MOUTH	CAPE JERVIS	1	90	5
6 STOKES BAY	CAPE BORDA	3	87	4
2 CAPE JERVIS	PT NOARLUNGA REEF	4	75	9
30 PT LABATT	CAPE BLANCHE	6	66	7
7 CP BORDA	CAPE DU COUDEIC	5	55	12
35 CP D'ESTREES	ROCKY POINT	2	50	4
23 CP CARNOT	POINT AVOID	16	48	24
31 CP BLANCHE	POINT WESTALL	11	45	16
3 CP WILLOUGHBY	HOG BAY	3	45	6
4 HOG BAY	MARSDEN POINT	5	38	10
5 MARSDEN PT	STOKES BAY	4	34	7
19 PT BOLINGBROKE	BOSTON POINT	1	25	1
13 WEST CAPE	DALY HEAD	10	25	18
16 SIR JOSEPH BANK	GROUP	4	23	4
20 BOSTON PT	CAPE DONINGTON	7	22	10
36 ROCKY PT	POINT SINCLAIR	1	20	2
37 PT SINCLAIR	POINT FOWLER	1	20	3
15 CORNY POINT	POINT TURTON	5	15	7
14 DALY HEAD	CORNY POINT	5	14	5
10 EDITHBURGH	PORT MOOROWIE	5	14	5
25 PT WHIDBEY	MOUNT GREENLY	3	11	3
11 PT MOOROWIE	STENHOUSE BAY	2	10	2
17 THISTLE ISLAND		1	1	1
21 CP DONINGTON	CAPE TOURNEFORT	0	0	0
18 PORT NEILL	POINT BOLINGBROKE	0	0	0
12 STENHOUSE BAY	WEST CAPE	0	0	0

Table (10.6). Flight zones ranked by average size of individuals in schools sighted.

FLIGHT PATH FROM	TO	FISH SIZE - POUNDS LT 3	3 - 7	GT 7	UNKNOWN
37 PT SINCLAIR	POINT FOWLER	0	0	3	0
36 ROCKY PT	POINT SINCLAIR	0	0	2	0
22 CP TOURNEFORT	CAPE CARNOT	0	3	10	2
9 CP GANTHEAUME	CAPE WILLOUGHBY	1	5	23	6
32 PT WESTALL	CAPE BAUER	0	14	33	13
34 PT BROWN	CAPE D'ESTREES	1	1	13	2
7 CP BORDA	CAPE DU COUDEIC	0	2	10	1
28 ELLISTON	POINT WEYLAND	1	3	13	4
38 PT FOWLER	CAPE ADIEU	0	1	1	0
26 MT GREENLY	POINT DRUMMOND	8	22	21	11
23 CP CARNOT	POINT AVOID	0	9	12	7
27 PT DRUMMOND	ELLISTON	0	11	6	4
10 EDITHBURGH	PORT MOOROWIE	0	4	0	1
1 MURRAY MOUTH	CAPE JERVIS	0	5	0	0
16 SIR JOSEPH BANK	GROUP	0	2	2	1
24 PT AVOID	POINT WHIDBEY	2	15	9	6
8 CP DU COUDEIC	CAPE GANTHEAUME	1	4	0	4
13 WEST CAPE	DALY HEAD	3	7	4	7
5 MARSDEN PT	STOKES BAY	1	4	2	2
11 PT MOOROWIE	STENHOUSE BAY	0	1	1	1
29 PT WEYLAND	POINT LABATT	0	2	4	9
20 BOSTON PT	CAPE DONINGTON	0	9	0	5
33 CP BAUER	POINT BROWN	5	5	5	8
35 CP D'ESTREES	ROCKY POINT	2	1	0	1
30 PT LABATT	CAPE BLANCHE	0	2	2	7
2 CAPE JERVIS	PT NOARLUNGA REEF	7	1	1	1
4 HOG BAY	MARSDEN POINT	6	2	1	3
31 CP BLANCHE	POINT WESTALL	1	4	6	17
6 STOKES BAY	CAPE BORDA	0	4	0	3
15 CORNY POINT	POINT TURTON	5	2	0	3
14 DALY HEAD	CORNY POINT	0	5	0	8
3 CP WILLOUGHBY	HOG BAY	3	1	0	5
17 THISTLE ISLAND		0	1	0	5
25 PT WHIDBEY	MOUNT GREENLY	1	1	0	11
21 CP DONINGTON	CAPE TOURNEFORT	0	0	0	3
40 KINGSTON	MURRAY MOUTH	0	0	0	6
18 PORT NEILL	POINT BOLINGBROKE	0	0	0	2
19 PT BOLINGBROKE	BOSTON POINT	0	0	0	0
12 STENHOUSE BAY	WEST CAPE	0	0	0	2

It is possible that salmon from the Berry Bay school spawned in South Australia. However, there is no evidence that such spawning is successful in this State. MacDonald (WFRC 9) failed to detect genetic evidence of more than one breeding population; and Jones (pers.comm.) has recorded a single peak only of juvenile recruitment at the Port Adelaide estuary.

Without more supporting data, the finding of females in an advanced state of reproductive maturity at Berry Bay is not considered significant to the dynamics of the population as a whole.

12.1 DIET

Allegations have been made by several fishermen that the presence of salmon schools in sheltered areas produces a local decline in the abundance of King George whiting (Sillaginodes punctata). The results of stomach content analyses, carried out on salmon caught throughout their range in South Australia, are shown in Figure (12.1). Most stomachs were empty, as schools were netted in a "resting-up" state between feeding bouts offshore. Clupeid fish predominated, by incidence, in stomach contents; particularly the pilchard, Sardinops neopilchardus. Of secondary occurrence were tommy ruff (Arripis georgianus), chow (Trachurus sp.), garfish (Hyporhamphus melanochir) and squid (Sepioteuthis australis). Walker (WFRC 7) found that pilchards predominated in stomach contents of migrating adults in Western Australia; and it is considered that schooling clupeids are the major prey of the western sub-species of Australian salmon. Personal observations have shown that salmon rapidly pursue such prey, and engulf them whole. No King George Whiting were found in stomach contents; although small salmon from Coffin Bay have been netted with juvenile whiting protruding from their mouths. Jones (pers.comm.) recorded juvenile sand whiting (Sillago bassensis) in the stomachs of some 1+ salmon caught around the Sir Joseph Banks group of islands.

It is concluded that salmon do prey on several species of whiting in some areas; however, the major prey item of the adult and sub-adult salmon is the pilchard. Pilchards may be found from just offshore from habitual salmon schooling areas; to many kilometres offshore from them.

Figure (11.1) Gonad indices, K, of male Australian salmon in S.A., plotted by month.

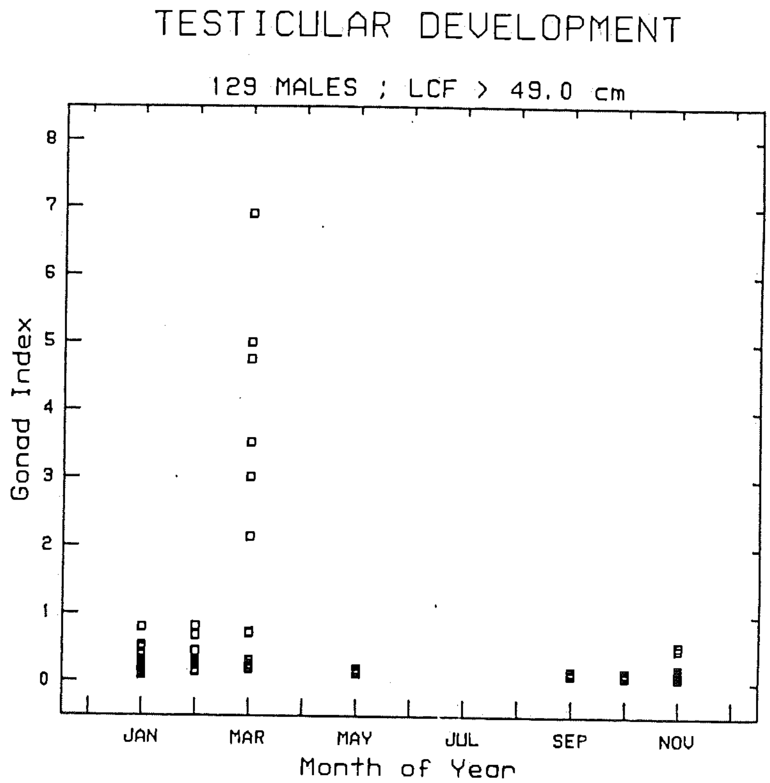
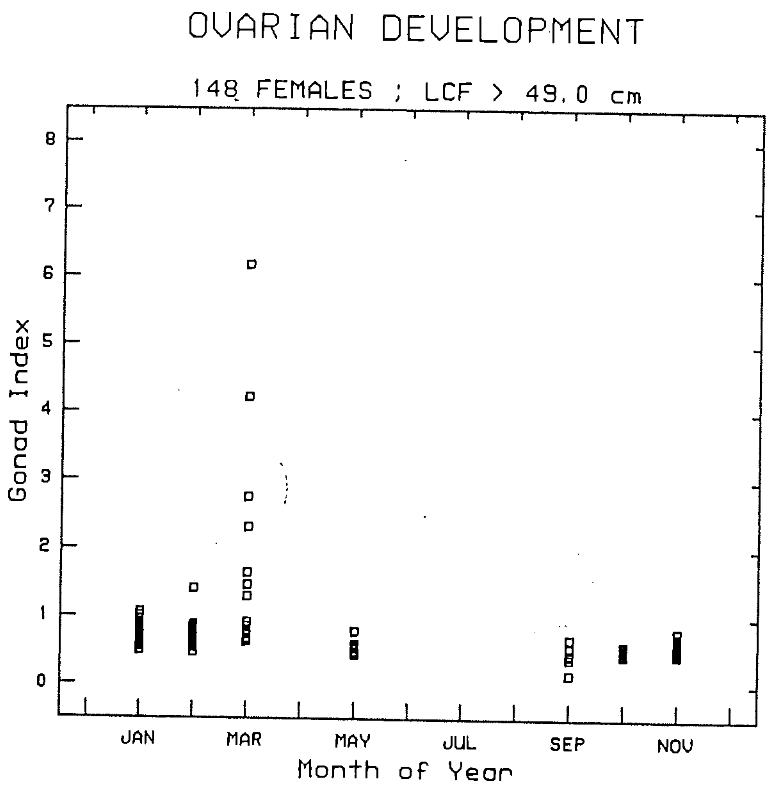


Figure (11.2). Gonad indices, K, of female Australian salmon in S.A., plotted by month.



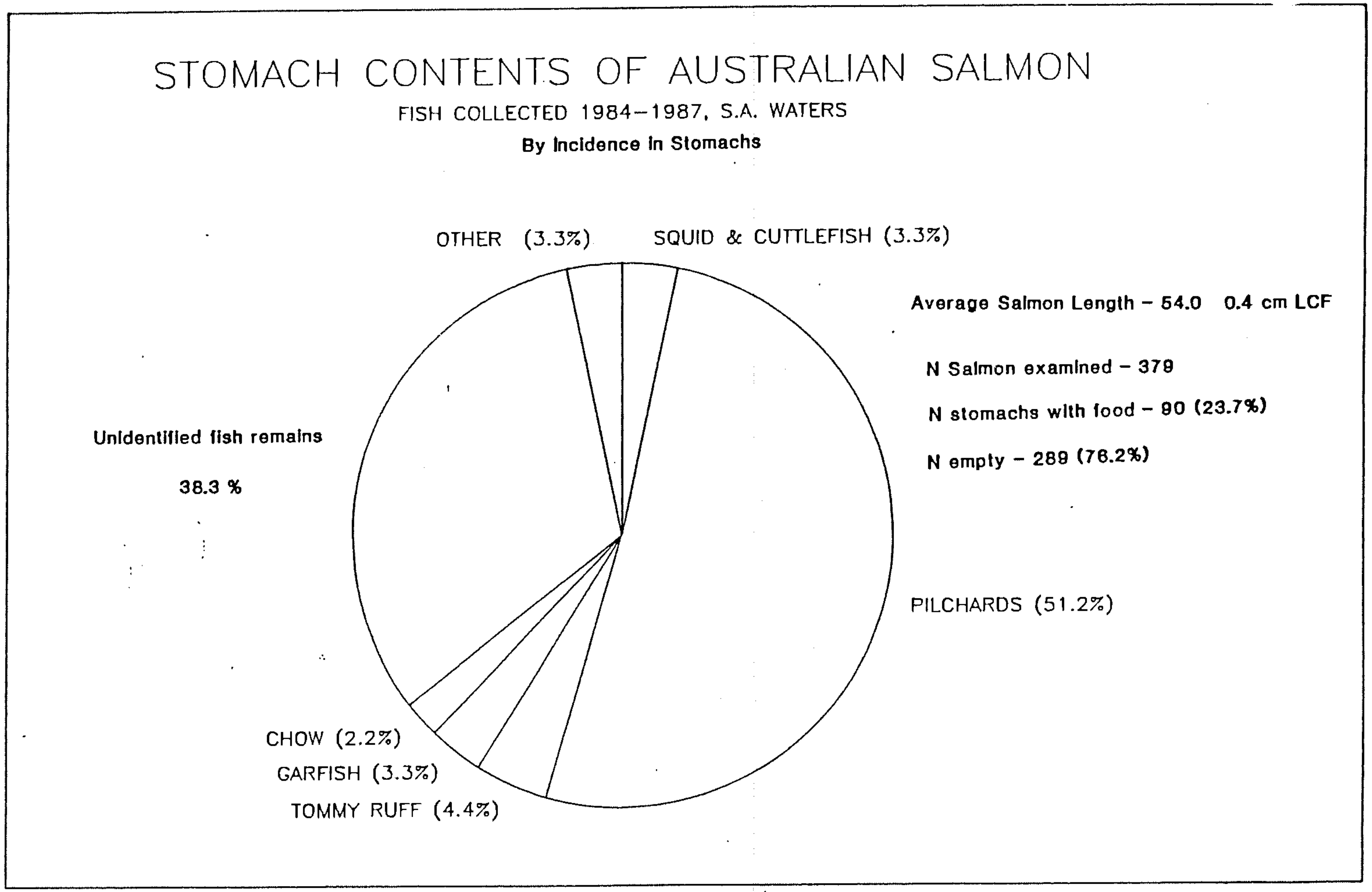


Figure (12.1). Incidence of prey categories in 90 salmon stomachs containing food; areas and times of collection pooled.

13.1 DISCUSSION

This study has addressed four major objectives in an attempt to determine the fate of older age groups of salmon in South Australian waters; with a view to providing additional biological information for management of the resource on an Australia-wide basis.

The data obtained were limited by time and funds available, and the lack of fishing activity in the South-East, and far west, of the State. Within these limits, and the qualifications applied in this report, certain theories can be proposed from the results. These are applied here in the context of management of the entire fishery for salmon.

There was no evidence to support the existence of a large proportion of senile, non-spawning salmon in the fished area of this State. Tagged adults recruited into the Western Australian fishery in the highest numbers yet recorded. This movement of tagged fish was estimated to represent rates of migration of 20-60 percent of adults, after rates of natural and fishing mortality were allowed for. This high level may be, partially, an artifact of the tagging programme; large fish were tagged from schools already on migration. Migration is connected with rates of growth; faster-growing fish migrate at a younger age than slower-growing salmon (Stanley, WFRC 1). In the current study, salmon rarely migrated at an age of 3+; most commonly at 4+, 5+ and 6+ years of age. As a corollary of Stanley's (WFRC 1) findings, it could be proposed that West Coast (of S.A.) salmon migrate at an earlier age, and in greater numbers, than those in eastern nursery areas. Tag recoveries were not complete, and this hypothesis cannot be examined until younger fish reach full representation in the Western Australian fishery.

Large numbers of large salmon occur in South Australia during the spawning season. These are not senile stock, but, salmon which have postponed migration. This postponement may be due to slow rates of growth; or in the case of tagged fish, behavioral changes resulting from disturbance (Stanley, 1980b, 1983). The current study has shown, also, that some salmon "drop out" of the migration to Western Australia. These fish were "smaller-at-age" than other school members which did migrate in the season of release. For some time after release, these salmon were not recruited into either the South Australian or Western Australian fisheries. They may have; (1) remained in the vicinity of the tagging location; (2) reached the Esperance assembly area, but postponed further migration; or (3) moved eastwards and out of the South Australian fishery. Tag returns provided support for each hypothesis.

The lack of South Australian recaptures, between tagging location and Western Australia recapture sites, may reflect the rapidity of migration or lack of fishing effort. The lack of movement between fishing areas reflects the site-specificity of older age groups, until migration occurs.

For management purposes, the different fishing areas can be considered to be largely independent units when examining the purse-seine fishery. There was limited movement of tagged fish between Kangaroo Island, and the southern tips of Eyre, Yorke and Fleurieu Peninsulas; but no movement eastward of fish tagged on the West Coast. There was no evidence of a gradual shift west-ward as salmon aged; fish of all tagged age groups showed remarkable site-specificity, for periods of up to one year, and recaptures of tagged fish were generally localised within fishing areas.

There was no evidence of seasonal differences in local movement within and between fishing areas; however, only the most pronounced patterns would have been apparent from tagging results, as they could not be weighted for differences in fishing effort.

Stanley (1979) summarised the movements of different age groups in South Australia, and suggested that a portion of the population may move to the South-East; and migrate from there at older ages, or not at all. He recorded few recoveries in Western Australia of the large numbers of 1+ fish tagged at Tickera, Kangaroo Island and Cape Jervis. Movement eastwards occurred during the current study from Kangaroo Island; only as far east as Kingston. The significance of such movement is unknown.

Older age groups were exploited mainly in the purse-seine and recreational fisheries in South Australia; but also by the use of beach-seines and mesh-nets at some locations. The catch of salmon by anglers during the study period was considered to be highly significant; probably in the order of hundreds of tonnes. Over 30 percent of tags recovered in South Australia were returned by anglers. The purse-seine catch was reduced, in comparison to earlier periods, by adverse weather and the monopolising of catch quota. Notably, the proportion of 1+ salmon in the catch had declined. The study was not of sufficient duration, and the catch was not stable enough, to determine the relevance to recruitment patterns of "missing" length groups in 1984/85.

Despite the lower level of South Australian catch, tag recoveries have increased from 21%, in 1975-78, to 32%, in 1984-87. Increased exploitation of salmon schools by South Australian anglers may have caused this rise; as tag recoveries by anglers doubled from 16% to 30% during the same period, in South Australia.

The Western Australian fishery for salmon has been characterised by fluctuating levels of recruitment and, hence, catch. Similar fluctuations in catch have occurred in South Australia since the introduction of purse-seiners but these were caused partially by variations in effort and weather; catch did not directly represent abundance in this State. For this reason, and the lack of stability in the purse-seine fishery, there is no information on variability in recruitment to South Australia.

All studies undertaken in this State indicate that western salmon have a relatively high level of natural mortality, an old age at first spawning and a young age at first capture. These combined factors make this sub-species particularly vulnerable to over-exploitation.

This vulnerability is heightened by the schooling nature of the sub-species. Clark and Mangel (1979) hypothesised that surface schooling species are more susceptible to fishing effort than non-schooling species, and indicators of abundance, such as catch and catch-per-unit-effort, are not reliable when the "intrinsic schooling rate is greater than the intrinsic (population) growth rate". Simply, salmon will continue to form schools despite drastic declines in total population size. These schools can still be fished at an economic gain until, theoretically, the last school is caught. Thus, severe depletion could occur in the salmon fishery before indications of such a situation were evident from catch and CPUE data. This "dynamic aggregation process" may be further aggravated when purse-seine vessels are assisted by spotter aircraft, which greatly reduce searching time (Nelson and Ahrenholz, 1986).

It is clear that, at any one point in time, the South Australian salmon population occurs in inshore schools, and as groups or individuals, either offshore or inshore. Successful purse-seine operations usually take entire schools; yet schools of similar length composition form quickly at the fishing location. Presumably these fish were feeding offshore, or travelling between schools, at the time of the operation. Thus, the purse-seine fishery can repeatedly take fish from the same location, within a season; as well as during subsequent seasons. This behaviour caused "type C" errors in estimation of mortality rates from the tagging programme, and represents the action of a dynamic aggregation process.

Estimates of rates of mortality were not precise; but were found to be similar to those of earlier studies in this State when tag loss was allowed for ($F = 0.2 - 0.3$, $M = 0.5 - 0.6$). This supports the suggestion of a rise in exploitation of South Australian salmon schools, indicated by the increased recovery of tags.

Yield-per-recruit analyses suggested that, at the prevailing levels of catch, the South Australian population was not being fished at its capacity during the study period. However, the model used was a deterministic one, and did not take account of; (1) the high age at first spawning; (2) the Western Australian fishery for adults; (3) the potential for variability in recruitment; and (4) the dynamic aggregation process. These factors compound the problem of estimating total allowable catch in the salmon fishery of South Australia.

The imposition of a catch quota is most suitable for management of the South Australian fishery; effort cannot be measured easily and cost-effectively, and, therefore, cannot be regulated. Preliminary yield-per-recruit analyses, under restrictive assumptions, suggested that rates of fishing mortality could be raised to about twice those estimated during the current; that is, from F = 0.2 to F = 0.4. In real terms, this represents a sensitive adjustment in F; and there was insufficient data to estimate the level by which catch should be raised to bring about this adjustment. The relationship between catch and rates of fishing mortality may not be linear.

The relationship of South Australian recruits to the Western Australian fishery may be more important than previously proposed. During 1987, a catch level of 1,877 tonnes on the south coast of Western Australia was strongly, positively correlated with the daily recruitment of tagged fish from South Australia; both before and after the threshold of differing catch structure. Previously, Stanley (WFRC 1) had concluded that catches below 1,000 tonnes were significantly correlated with the daily entry of South Australian tagged fish after March 13; but those above 1,300 tonnes were correlated with the arrival of Esperance tagged fish, before March 13. Based on these findings, it was estimated that South Australia provides a "background" level of recruitment of 1,000 tonnes each year to the Western Australian fishery. Recruitment was much higher in 1987 than this level; but its magnitude could not be estimated in the absence of data on the entry of Esperance salmon.

Significant spawning occurs only in Western Australia, and South Australia provides the bulk of spawners, in years of low recruitment from the western Bight area. Examination of historical data shows that recruitment in Western Australia has fluctuated; and the high levels of catch recorded in 1968 and 1984 may have been abnormal. Consequently, South Australia must be considered as the most important source of spawning stock. It would be naive to assume that there is no variability in levels of recruitment to South Australia and migration from South Australia. Juveniles are transported long distances by a current system, which is known to vary in timing and extent. There is a paucity of data on these processes of recruitment and migration.

Therefore, the South Australian fishery cannot be managed in isolation to that of Western Australia, and the spawning stock as a whole. The effects on the spawning stock of raising South Australian catch were not predicted in the current study; but may be estimated by stochastic modelling. A fishery, of some form, should be maintained in Western Australia to harvest fish which would otherwise die after spawning, due to the high levels of natural mortality of adults. At the same time, a sufficient level of spawning biomass must be maintained. From the history of catch in Western Australia, Stanley (WFRC 1) suggested that, if the seasonal catch there drops below 700-800 tonnes, spawning potential may be impaired.

If the South Australian catch was raised, in the long-term, to allow for escapement of only sufficient spawners, the Western Australian fishery would have to be converted to a post-spawning, back-run fishery in years of low recruitment from the western Bight; and catch would fluctuate more widely, around a lowered mean level. It is doubtful whether such a level could support the present processing infrastructure, and there is clear evidence that back-run fish are less-catchable than front-run fish. In addition, continuous research would be necessary, to predict recruitment levels from the area east of Esperance, and from South Australia.

In the absence of information on the relationships between spawners and recruitment, and yield and recruitment, the fishery must be managed conservatively, and by examining historical data. The fishery, as a whole, has withstood a level of catch of 1900 tonnes in South Australia; however, there is no reason not to believe that recruitment, and abundance, in South Australia was abnormally high at that time.

As an interim measure, the quota for commercial catch should not be raised above the present level of 1,000 tonnes. The population size along the exposed coast was estimated at 3,600 - 6,200 tonnes; a low figure in relation to the catch quota.

If the management aim is to attain the annual quota, but not exceed it, then there must be close monitoring of the catches and activity within each sector of the commercial fishery; the purse-seine fishery; the beach-seine fishery; the general marine scale fishery; the rock-lobster fishery; and the recreational fishery. Although the legislation regarding quotas was introduced in 1981, there is no active monitoring programme to accompany it. Thus, individual quotas, and the aggregate quota, could be exceeded; and management would not be aware of the situation until catches are tallied at the end of the financial year. To avoid this scenario, and prevent mis-reporting of catches, a catch-and-disposal recording system (CDR) could be introduced. Such a system allows for immediate determination of the origin and fate of catches in transit from captor to processor; and has been used successfully in the fisheries for bluefin tuna, and for abalone in the western zone. In the salmon fishery, a catch-and-disposal recording system could be easily applied to all commercial fishers who catch more than 10 tonnes of salmon per year, regardless of method. This group of fishers is small in number and could be readily identified from historical data.

Historically, some problems have occurred in the sharing of the resource between commercial operators. This is not a biological problem; but is addressed here, as small changes in access regulations may improve the probability that the quota is properly utilised.

Firstly, full-time specialisation in the purse-seine fishery is to be encouraged. Such fishing units have the time, expertise and incentive to use their quota. Part-time operators restricted their activities to a few months before the tuna season, and did not fish at all during one year of the study. If the management aim is to attain the quota, then arrangements must be made for transfer of the unused quota; especially in years when part-time quota holders do not intend to fish for salmon. Allowance could be made for these quota holders to lease their quota, on an annual basis. If there is a continued lack of interest, then access to the special quota should be reviewed. Appropriate legislation has been introduced to prevent the quota being exceeded; yet no consideration has been given to under-fishing of the quota. Irrespective of salmon abundance, the purse-seine catch will fluctuate because of adversity of prevailing weather conditions; the probability of under-fishing approaches that of overfishing. Alternatively, the management aim may be only to prevent catch exceeding the quota.

There was no evidence from the study that access to the resource should be increased for licensees in the marine scale fishery, the rock lobster fishery, the beach-seine fishery and anglers.

Beach-seine operators on the South-Central coast and on the northern coast of Kangaroo Island supply the bulk of the limited fresh fish market. Some of these operators have formed teams of two licensees; each holding a netting endorsement, and, thus, having an upper limit on catch of 20 tonnes. As a unit, this has allowed them to take 40 tonnes of salmon annually. During the study the potential for annual catch was 120 tonnes by these units. Unused special quota could be transferred to this sector of the fishery during a season.

During the study period, the special purse-seine quota was assigned to four vessels, but was fished by two vessels; one part-time and one full-time. The boats were based at Port Lincoln and Yorke Peninsula, but fished from Kangaroo Island in the east to Streaky Bay in the west. If a third, or fourth, vessel is employed to fish the special quota, restrictions should be applied to its area of operations. Aerial survey, and examination of catch curves, showed that the West Coast, south-coast of Kangaroo Island, and South-East of the State were the only areas inhabited by large tonnages of salmon which were not heavily exploited, in comparison to other areas. Conversely, Yorke Peninsula was inhabited by few schools, but levels of commercial and, especially, amateur exploitation were relatively high. The West Coast and Yorke Peninsula were considered to be the most significant areas of angling activity within the commercially fished area.

Consequently, it is recommended that additional vessels should be restricted to fish in areas west of West Point, (35°0.3'S 135°56.5'E) on the West Coast, and east of the Murray Mouth, in the South-East. This would prevent significant competition between vessels. However, Stanley (Department File 13/36) suggested that the western coastline of South Australia, from Coffin Bay westward, is the most important source of fish which move to Western Australia. He predicted that catches above 100 tonnes from this area should have an affect on recruitment to the Western Australian fishery. Since 1982/83, when the catch there was 607 tonnes (Jones, 1983b), the West Coast has produced high catches, with no obvious effects on the Western Australian catch.

There is a need for review of the minimum legal length at first capture (LML) of salmon under the Fisheries Act. Yield-per-recruit analyses undertaken in this study were not of sufficient precision to predict a length-at-first-capture in South Australia that would act to; (a) maximise biomass-per-recruit; and, (b) maximise escapement of spawners to Western Australia. Without any consideration of length-at-first-spawning, preliminary analyses suggested that an average length-at-first-capture of 31cm LCF maximised biomass-per-recruit. During the study period, the entire purse-seine catch comprised salmon greater than this length, and the marine scale fishery comprised significant numbers of fish below this length.

Raising LML to 31cm LCF would, therfore, have its greatest effect upon the recreational fishery and the marine scale fishery; particularly beach-seine operators on the South-Central coast.

13.2 SUMMARY OF RECOMMENDED MANAGEMENT MEASURES APPLICABLE TO THE SOUTH AUSTRALIAN FISHERY

1. The quota for commercial catch should not be raised above its present level of 1,000 tonnes; which makes allowance for access to the resource by purse-seine operators (800 tonnes) and licensees in the marine scale, and rock lobster, fisheries (200 tonnes).

2. A catch-and-disposal recording system (CDR) should be applied to the few commercial fishers who catch more than 10 tonnes of salmon annually; and their catches should be monitored closely.

3. Re-distribution of the special (purse-seine) quota should be accompanied by restriction, on vessels, of area of operation to locations west of West Point and east of the Murray Mouth.

4. High levels of exploitation, by anglers and purse-seine operators, around southern Yorke Peninsula are cause for concern, in view of the low levels of abundance there and the popularity of the area for angling purposes. There should be no increased access to the area by purse-seine vessels, apart from the single vessel based there. Areas closed to netting there already protect the most significant angling locations.

5. There is a need for revision of length-at-first capture in the purse-seine fishery; yield-per-recruit analyses suggest that

the exploitation of smaller salmon approximates the theoretical level at which biomass is maximised, but there was no consideration of the level at which escapement of spawners is maximised.

6. The amateur catch was highly significant, in the order of hundreds of tonnes annually, and has increased in the past decade. Bag limits on amateur catch should be considered if the commercial catch quota is raised; and if exploitation by anglers continues to increase. However, catch rates were generally low, and accurate figures on amateur catch are lacking.

7. Revision of quota awaits development of predictive production models; in the interim, management must be conservative.

13.3 RECOMMENDATIONS FOR FUTURE RESEARCH

1. The tagging programme is incomplete. Future tag returns must be analysed to investigate the extent of migration to Western Australia of the 1+, 2+ and 3+ age groups tagged in different fishing areas of South Australia.

2. Complete results of past and present tagging operations must be re-analysed, using the technique of Hearn, Sandland and Hampton (1987), to obtain revised estimates of M and F.

3. Western salmon have been the subject of investigation since 1950's. A large data base has been accumulated on the biology, exploitation and recruitment of the sub-species during periods of high and low abundance. A stochastic production model of the entire fishery, synthesising all available data, could be developed. This would aim to elucidate the relationships between spawners and recruitment and yield and recruitment. Such a model would best be built and manipulated by suitably qualified personnel at a series of workshops, similar to the approach taken by, say, the Southern Shark Task Force.

4. A priority of such workshops should be to ascertain critical levels of spawning biomass, and methods of protecting them. As

a result, a meaningful quota for South Australian catch could be estimated; as a range of values applicable to various levels of recruitment and abundance. By this method also, the legal minimum length at first capture should be reviewed.

5. The amateur fishery was highly significant during the study period, but accurate figures on catch and effort are lacking. High priority should be given to the determination of annual landings in this sector of the fishery.

6. Local recommendations for research in Western Australia were outlined in the Workshop on Australian Salmon, held at Waterman in 1981. It is recommended here that the collection of hydrological data is continued, for testing of the predictive correlation between salinity in the spawning area and Western Australian catch four years later. The results of monitoring of length and age compositions of catches made in Western Australia must be written-up, especially for the period 1984-87, to enable full analysis of present tagging results.

7. In addition, recruitment of 0+ fish should be quantified on an annual basis in nursery areas in South Australia, and in the western Bight - Esperance area. The scale at which recruitment should be measured could be assessed by analysing the correlation between recruitment levels at different sites, within years. Jones (pers.comm.) has obtained data on recruitment for five years at the Port Adelaide River estuary, by the use of small-mesh beach seines, although the salmon were caught as by-catch only.

8. Little information is presently obtained on purse-seine activities from the GARFIS data base. It is strongly recommended that; (1) catch and effort returns are completed on a daily, rather than monthly, basis; and, (2) salmon spotters supply S.A.D.F. with aerial survey logbooks detailing the position, and tonnage, of schools sighted during all flights. A recommended spotting log is enclosed as Appendix (4.2).

Aerial survey data will provide monthly indices of abundance in the fished area. Logbooks should be designed jointly by spotters and research staff. Maintenance of the records may have to be imposed as a licence condition, similar to GARFIS requirements.

9. A monitoring scheme and CDR system should be developed to actively monitor the statistics on salmon catches by licensees fishing the special and general quotas; especially the beach-seine operators on the South-Central coast, and those in the rock-lobster fishery.

10. The size and age compositions of commercial catches made in the South-East of the State should be monitored.

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Appendix (1.1). Location of all South Australian place names used in the report. See Map

LOCATION NAMES DETAILED ON MAP

WEST COAST

1. Scott's Bay
2. Point Sinclair
3. Point Dillon
4. Eba Island
5. Cape Bauer
6. Back Beach
7. High Cliff
8. Sceales Bay
9. Salmon Bend
10. Baird's Bay
11. Silicon Beach
12. Mad Mile Point
13. Venus Bay
14. Anxious Bay
15. Lock's Well
16. Sheringa Beach
17. Mount Greenly
18. Coffin Bay
19. Almonta Beach

EYRE PENINSULA

20. Bicker's Island
21. Fanny Point
22. Boston Island
23. Boston Point
24. Louth Bay
25. Thistle Island
26. Sir Joseph Banks Islands

YORKE PENINSULA

27. Wallaroo
28. Point Turton
29. Corny Point
30. Berry Bay
31. Brown's Beach
32. Hillock Point
33. Troubridge Point
34. Wattle Bay
35. Warooka
36. Ardrossan

KANGAROO ISLAND

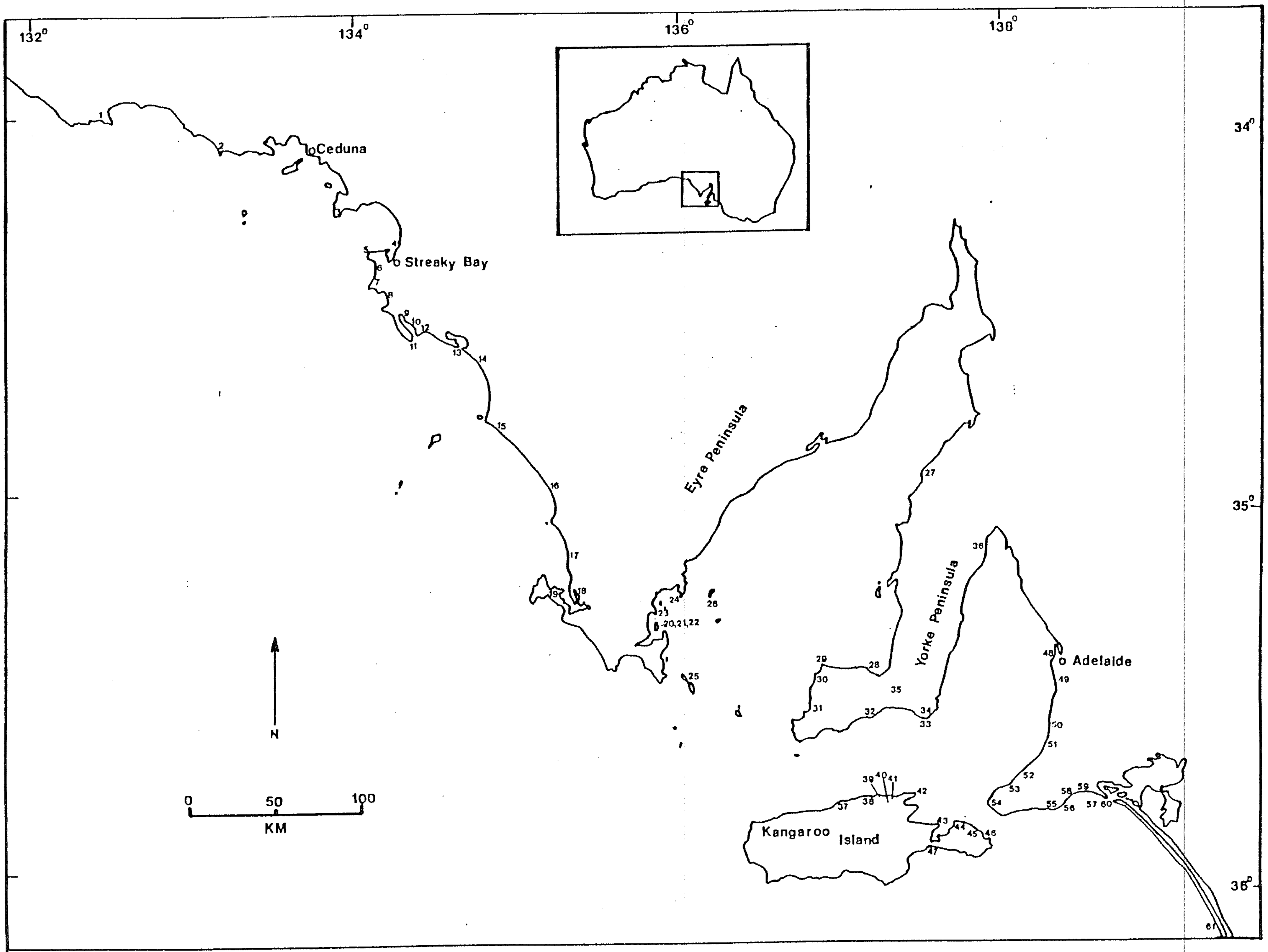
37. Stokes Bay
38. Smith's Bay
39. Cape D'Estaing
40. Whittle Bay
41. Emu Bay
42. Point Marsden
43. Ballast Head
44. Hog Bay
45. Cape Coutts
46. Antechamber Bay
47. D'Estree Bay

SOUTH-CENTRAL COAST

48. Outer Harbour
49. Glenelg
50. Port Noarlunga
51. Port Wilunga
52. Rapid Bay
53. Rapid Head
54. Blowhole Creek
55. Parson's Beach
56. Waitpinga Beach
57. Seal Rocks
58. Victor Harbour
59. Port Elliot

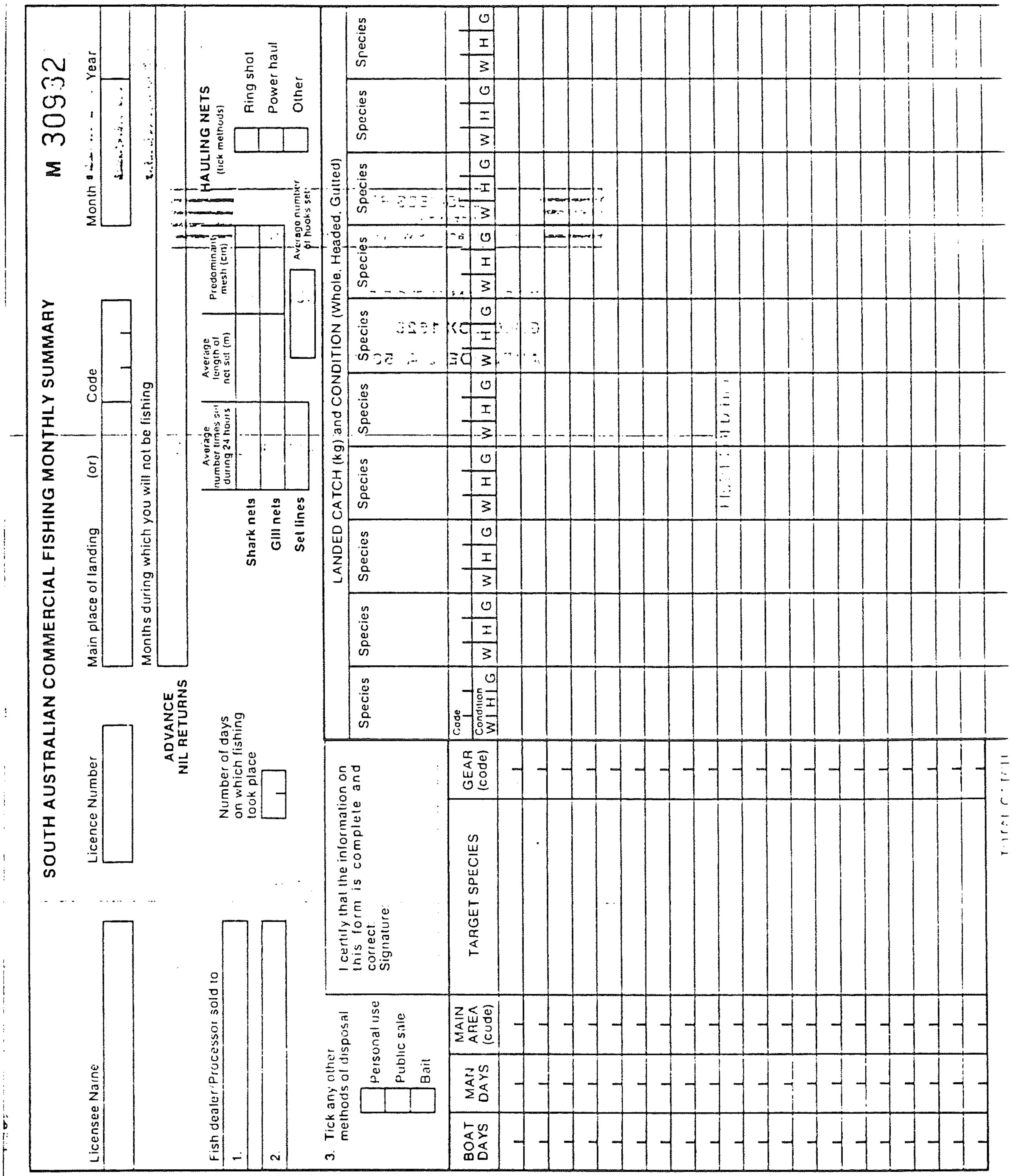
SOUTH-EAST COAST

60. Murray Mouth
61. Salt Creek Beach



Appendix (1.1). Continued

Appendix (1.2). An example of the GARFIS catch and effort form



SOUTH AUSTRALIAN COMMERCIAL FISHING MONTHLY SUMMARY

M 30932

Licensee Name

Licence Number

Main place of landing (or) Code

Month Year

Months during which you will not be fishing

ADVANCE NIL RETURNS

Fish dealer/Processor sold to

1.

2.

Number of days on which fishing took place

	Average number times set during 24 hours	Average length of net set (m)	Predominant mesh (cm)
Shark nets			
Gill nets			
Set lines		Average number of hooks set	

HAULING NETS (tick methods)

Ring shot

Power haul

Other

3. Tick any other methods of disposal

Personal use

Public sale

Bait

I certify that the information on this form is complete and correct.

Signature:

LANDED CATCH (kg) and CONDITION (Whole, Headed, Gutted)

BOAT DAYS	MAN DAYS	MAIN AREA (code)	TARGET SPECIES	GEAR (code)	Species	Species	Species	Species	Species	Species	Species	Species	Species	Species
					Code / Condition W H G	W H G	W H G	W H G	W H G	W H G	W H G	W H G	W H G	W H G

TOTAL CATCH

Appendix (4.1) A.A.A. club survey sheet

SOUTH AUSTRALIAN DEPARTMENT OF FISHERIES
G.P.O. Box 1625, Adelaide, South Australia 5001
135 Pirie Street, Adelaide 5000. Telex SAFISH AA89405

Contact: Michael Cappo, Research Officer, Australian Salmon
Phone : (08) 227 1748

PTO

AUSTRALIAN ANGLERS' ASSOCIATION (SA DIVISION) CATCH AND EFFORT LOG SHEETS TO BE COMPLETED FOR ALL SALTWATER EVENTS

CLUB NAME						
DATE AND TIME OF EVENT	START			FINISH		
VENUE						
STRETCH OF COASTLINE COVERED	FROM			TO		
TYPE OF FISHING	✓	PIER	ROCK	BEACH	ESTUARY	BOAT
DATE OF WEIGH-IN	TIME OF WEIGH-IN					
NUMBER OF ANGLERS ATTENDING VENUE						
AVERAGE NUMBER OF HOURS FISHED BY EACH ANGLER						
NUMBER OF ANGLERS WEIGHING IN CATCHES						
LARGEST NUMBER OF SALMON WEIGHED IN BY A SINGLE ANGLER						
SALMON BAG LIMIT IMPOSED BY CLUB RULES						

	NUMBER OF BAGS CONTAINING THIS SPECIES	TOTAL NUMBER OF THIS SPECIES	TOTAL WEIGHT OF THIS SPECIES
AUSTRALIAN SALMON (including "Salmon Trout")			

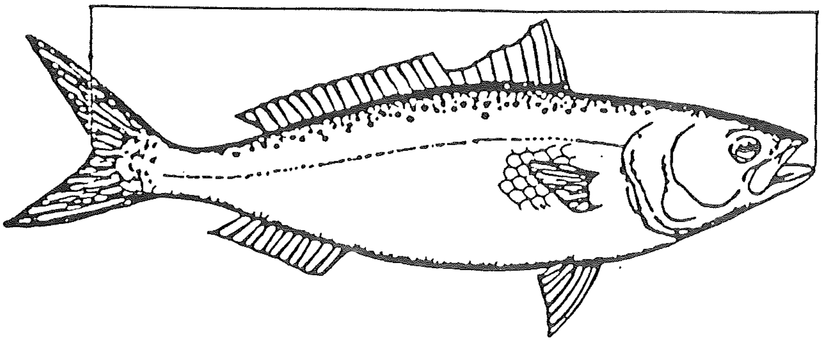
NAME OF WEIGHMASTER		SIGNATURE	

PLEASE RECORD SALMON MEASUREMENTS OVERLEAF

/Please Turn Over

CLUB NAME	
DATE	
VENUE	
MEASURER'S NAME	SIGNATURE
MINIMUM SIZE LIMIT IMPOSED BY CLUB RULES	

PLEASE MEASURE LENGTH TO CAUDAL FORK TO NEAREST CENTIMETRE



* Please Indicate

Fish Condition (✓)

☐ Whole

☐ "Neck Broken"

10		50	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	
9		9	
20		60	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	
9		9	
30		70	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	
9		9	
40		80	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	
9		9	

Appendix (4.2) Aerial survey form used during the study

DEPARTMENT OF FISHERIES

AUSTRALIAN SALMON AERIAL SURVEYS - SOUTH AUSTRALIA

FLIGHT LOG - To be completed for all spotting flights **PTO**

PILOT'S NAME	
CREW NAMES	

DATE	

TIME AT TAKE-OFF		TIME AT LANDING	

LOCATION OF TAKE-OFF		LOCATION OF LANDING	

TOTAL DURATION OF FLIGHT (Excluding stops for refuelling)	Hours	Minutes
TOTAL DURATION OF SEARCH	Hours	Minutes

AVERAGE GROUND SPEED DURING SEARCH	

AREAS OF COASTLINE SEARCHED

FLIGHT LEG	FROM	TO

SIGNATURE OF SPOTTER	

AUSTRALIAN SALMON AERIAL SURVEYS - SOUTH AUSTRALIA

SCHOOL SIGHTINGS -

To be completed for each school sighted.

SCHOOL ACTIVITY KEY	USE
Feeding School.............	F
Tight School...............	T
Moving School..............	M
Dispersed School...........	D

* INDICATE whether
- School Size in Tons or Tonnes
- Fish Size in Pounds or Kilograms

APPROXIMATE LOCATION OF SCHOOL						ESTIMATED TONNAGE (*)	ESTIMATED FISH SIZE (*)	SCHOOL ACTIVITY (USE KEY)

Appendix (5.1) Number of tags recovered in time intervals of one year, by tagging operation and release location.

OPNUM	TAGGING LOCATION	NUMBER TAGGED	YEARS AT LIBERTY 1	2	3	TOTAL RECAPS
49	CAPE BAUER	340	54	13		67
1	SCOTT'S BAY	7				0
21	POINT DILLON	64	5	3		8
22	POINT DILLON	2	1			1
48	HIGH CLIFF	115	14	5		19
15	SCEALES BAY	3				0
14	BACK BEACH	1				0
13	EBA ISLAND	11	1			1
50	BACK BEACH	64	22	6		28
58	ANXIOUS BAY	168	48	21		69
10	MAD MILE POINT	6		1		1
12	SILICON BEACH	1				0
6	SILICON BEACH	1				0
18	ANXIOUS BAY	235	7	102		109
11	SALMON BEND	5	1			1
7	SALMON BEND	11	1			1
8	SALMON BEND	15	4			4
9	SALMON BEND	12	1		1	2
5	BAIRD'S BAY	2				0
19	VENUS BAY	36	5	2		7
42	ALMONTA BEACH	37	3	4		7
44	ALMONTA BEACH	19	5	2		7
43	ALMONTA BEACH	23	2	3		5
40	BOSTON ISLAND	6	4			4
39	BOSTON POINT	3		1		1
4	FANNY POINT	21	4	3		7
37	BICKER'S ISLAND	3	1			1
38	BICKER'S ISLAND	156	54	6		60
47	BICKER'S ISLAND	61	6	11		17
36	BICKER'S ISLAND	1				0
46	BOSTON POINT	53	13	15		28
23	CORNY POINT	15	4	2		6
35	BERRY BAY	89	37	9	2	48
34	POINT TURTON	104	77	3		80
27	POINT TURTON	103	87			87
28	WATTLE BAY	56	21	1	3	25
32	CAPE D'ESTAING	1	1			1
24	CAPE D'ESTAING	3				0

Appendix (5.1). Continued

45 WHITTLE BAY	51	26	6		32
26 STOKES BAY	88	25	10	2	37
52 SMITH'S BAY	133	4	2		6
31 CAPE D'ESTAING	4	4			4
33 CAPE D'ESTAING	26	19			19
25 STOKES BAY	79	17	10	1	28
51 HOG BAY	83	30	10		40
55 BALLAST HEAD	30	3	3		6
29 MARSDEN POINT	40	9			9
56 HOG BAY	136	25	16		41
17 HOG BAY	102	8	18	1	27
57 HOG BAY	201	39	25		64
61 HOG BAY	175				0
16 HOG BAY	186	22	13	2	37
30 MARSDEN POINT	129	39	1		40
62 BALLAST HEAD	96	38			38
54 HOG BAY	145	27	17		44
53 BALLAST HEAD	1				0
59 HOG BAY	105	4	14		18
60 HOG BAY	103				0
41 CAPE COUTTS	142	9	2		11
3 D'ESTREE BAY	29	1	3	1	5
2 D'ESTREE BAY	56	6	8	1	15
63 RAPID HEAD	105	76			76
20 SEAL ROCKS	7		1		1

Appendix (6.1) Interview sheet issued to persons returning tags

AUSTRALIAN SALMON TAGGING PROGRAMME - INTERVIEW SHEET

PTO

Please tick relevant boxes and complete all blanks.

NAME: ____________ PHONE: ____________
ADDRESS: ____________ POSTCODE: ____________

STATUS: FISHERMAN ☐ ANGLER ☐
TAG NUMBERS: ____________
SALMON LENGTH(S): ____________

HOW WAS FISH MEASURED? FORK LENGTH ☐ TOTAL LENGTH ☐

CAPTURE DETAILS:

DATE: ____________ TIME: ____________
LOCATION (please give landmarks or detailed description of capture site):

____

METHOD OF CAPTURE:

NET FISHING: HAULING NET ☐ MESH NET ☐ PURSE SEINE ☐ BEACH SEINE ☐

LINE FISHING: BEACH ☐ ROCK ☐ BOAT ☐ JETTY ☐

METHOD: LURE CASTING ☐ TROLLING ☐ PILCHARD BAIT ☐ OTHER BAIT ☐

HOW MANY SALMON WERE CAUGHT BY YOU PERSONALLY? (including the tagged individual) NUMBER ☐ OR WEIGHT ☐

NUMBER OF HOURS FISHED BY YOU PERSONALLY? ☐

WAS A SCHOOL OF SALMON SIGHTED DURING FISHING? YES ☐ NO ☐

WHAT WERE YOU FISHING FOR WHEN THE TAGGED FISH WAS CAUGHT? ____________

AVERAGE SIZES OF SALMON IN CATCH CONTAINING TAGGED INDIVIDUAL: ____________

TAG WOUNDS:

WHEN WAS THE TAG FIRST NOTICED?

UPON CAPTURE ☐ DURING CLEANING OR FILLETING ☐ DURING PACKING ☐

HOW FAR DID THE COLOURED STREAMER PROTRUDE FROM THE BODY WALL?

NOT AT ALL ☐ LESS THAN HALF ITS LENGTH ☐ FULLY ☐

WAS THE TAGGING WOUND HEALED? GAPING ☐ CLEAR SCAR ☐ REDDISH SCAR ☐

FISH CONDITION: LEAN AND THIN ☐ INJURED ☐ ROUND AND HEALTHY ☐

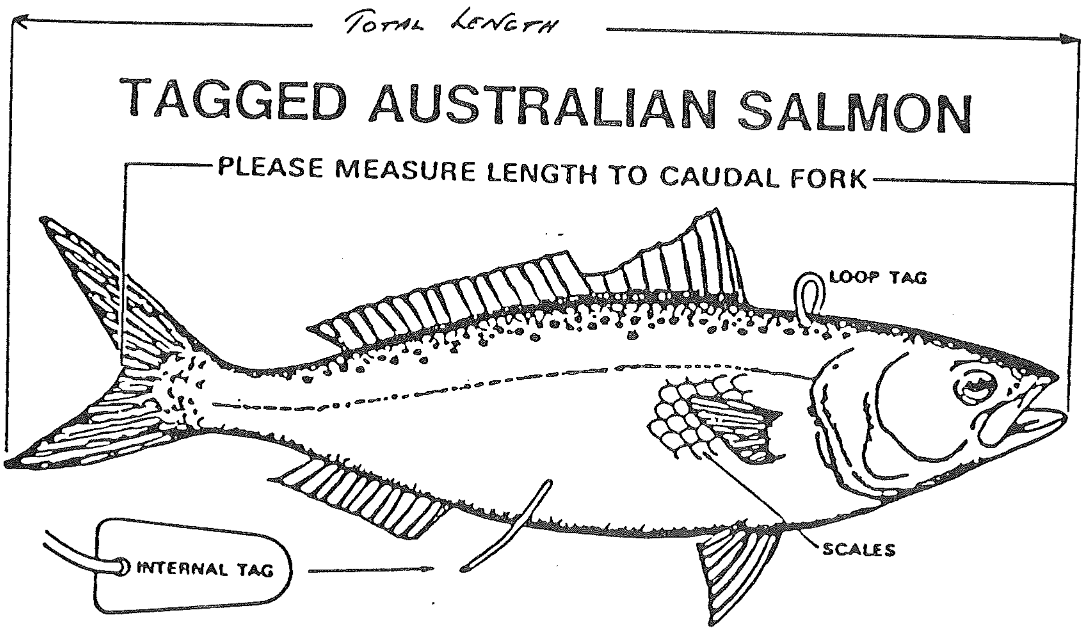
REWARD DETAILS:

HOW DID YOU HEAR ABOUT THE TAGGING PROGRAMME?

SAW POSTER ☐ WORD OF MOUTH ☐ NEWS ARTICLE ☐ UNAWARE ☐ PREVIOUS RECAPTURE ☐

CHOICE OF REWARD? T-SHIRT ☐ T-SHIRT SIZE ☐ $5.00 CHEQUE ☐

THANK YOU



The length to caudal (tail) fork is the preferred measurement of salmon length.

Scales should be taken from the area shown just behind the pectoral (side) fin.

Tags are of either the "internal" or "loop" type shown.

A yellow plastic streamer protrudes from the belly wall of a salmon bearing an internal tag.

Please record the tag numbers and return the whole tag.

Thank you for your help and interest.

M C Cappo.

(Michael Cappo)
RESEARCH OFFICER
(AUSTRALIAN SALMON)

Appendix (9.1) Tag recaptures at Western Australian fishing beaches.

GRID CODE	W.A. BEACH NAME	TAGS RECOVERED
2	TRIGALOW BEACH	27
3	DOUBTFUL ISLAND BAY	14
4	HOUSE BEACH	6
6	BREMER BAY	32
7	PEPPERMINT BEACH	2
8	FISHERIES BEACH (EAST)	5
9	DILLON BAY	2
10	PALLINGUP	18
11	BOAT HARBOUR EAST	11
12	CAPE RICHE	42
13	CHEYNES BEACH	96
14	BETTIES BEACH	37
15	TWO PEOPLE BAY	2
16	NANARUP	9
17	BONITO BEACH	2
20	ALBANY	2
21	GOODE BEACH	1
22	MUTTON BIRD BEACH	8
23	TORBAY / COSY CORNER	3
24	SHELLEY BEACH	7
25	PARRIES BEACH	7
26	BOAT HARBOUR WEST	1
27	PEACEFUL BAY	7
28	NORNALUP	12
29	WINDY HARBOUR	5
31	CAPE LEEUWIN	1
32	HAMELIN BAY	1
36	SMITH'S BEACH	7
37	CAPE NATURALISTE	1
38	BUNKER'S BAY	4
39	EAGLE BAY	2
40	MEELUP	1
44	MANDURAH	1
0	OTHER and BEACH UNKNOWN	50