

New Zealand Freshwater Fisheries Report No. 114

Quinnat salmon spawning in the Waimakariri catchment



MAFFish

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in the
Waimakariri catchment

by
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SUMMARY

Pioneer work on the natural reproduction of quinnat salmon in New Zealand was first done in the 1930s, in the Waimakariri catchment. One of the sites where this research was carried out was Winding Creek, an important spawning site for salmon, particularly in its upper reaches.

Between 1976 and 1984, Winding Creek was trapped regularly to supply eggs for MAF's hatchery at Silverstream. In 1979, a permanent trap was installed and thereafter, until 1984, the annual run of salmon into the stream was monitored between the beginning of April and the middle to end of June each year.

Annual numbers of migrant salmon varied between 169 and 3045. By comparison, the range recorded in Glenariffe Stream (a major spawning tributary of the Rakaia River) was 522 - 2887 over the same period. Low-run and high-run years in Glenariffe Stream coincided closely with those in Winding Creek.

The mid-point of the Winding Creek run was about 15-16 May, some two weeks later than in Glenariffe Stream, and about 10 days later than the mid-point of the run into Silverstream hatchery in the lower Waimakariri basin. The mid-point of the entry of salmon into the Waimakariri River from the sea appeared to be the middle of March, indicating a mean migration time of about eight weeks from the coast to Winding Creek.

The age structure of Waimakariri quinnat salmon was generally similar to that found in other east coast salmon rivers, with 3-year-old fish comprising the dominant age class and no fish over five years old. Salmon in Winding Creek were of similar size to those recorded at Glenariffe.

Examination of scales from angler-caught salmon from the mainstem of the Waimakariri River, and from fish trapped in Winding Creek, showed a high incidence of "stream type" nuclei. This type of scale nucleus is found in fish that spent most, or all, of their first year of life in fresh water, before migrating to sea. Almost two-thirds of all scales collected from Waimakariri salmon have this type of nucleus. Scales from Waitaki River salmon show an incidence of scale type similar to that of Waimakariri salmon. In contrast, the majority of scales taken

from salmon in the Rakaia and Rangitata Rivers have "intermediate" type nuclei, indicating that, as juveniles, these salmon spent only a few months in fresh water. These differences may reflect differences in the relative stability of the river habitat occupied by juvenile salmon before they migrate.

Salmon spawning in the Waimakariri basin is distributed over a number of tributaries, mostly small, but which collectively comprise about 42% of all known spawning areas. Winding Creek and streams on the Poulter River flats account for the remainder. However, there are tributaries of the Waimakariri where spawning has never been assessed accurately. The relative importance of these streams for salmon spawning must vary from year to year, because access to them is changeable depending on conditions in the main river.

1. HISTORICAL BACKGROUND

In the period 1875-1878, four importations of quinnat salmon (*Oncorhynchus tshawytscha* (Walbaum)) eggs - then popularly known as "California salmon" - were made into New Zealand from the United States Fish Commission's McCloud River salmon breeding station in northern California (Stone 1885, 1896; Thomson 1922). They were distributed to acclimatisation society hatcheries throughout New Zealand and to a government hatchery in Southland. Fry and juvenile salmon were liberated in numerous waters in both the South and North Islands (Thomson 1922).

In early 1877, 20 000 fry were released into the Waimakariri River from a shipment of eggs hatched in the Gardens Hatchery of the Canterbury Acclimatisation Society in Christchurch. A further 10 000 fry were released into the river from a second shipment of eggs received at the end of 1877. Releases also were made into the Rakaia and Rangitata Rivers (Thomson 1922, Lamb 1964).

A view has been expressed by Thomson (1922), Allen (1956), and McDowall (1978) that these first introductions were unsuccessful, because they were scattered in distribution and involved relatively small numbers of fish. However, occasional specimens of adult quinnat salmon were reputedly caught by anglers and in nets in the lower

Waimakariri River before the turn of the century. Their identity was established locally by people familiar with the species back in California. One of three fish sent from the Waimakariri to the South Kensington Museum, London in 1884 was identified by Dr A. Gunther as a quinnat salmon (Farr 1885, Lamb 1964), the other two were brown trout (Salmo trutta Linnaeus). L.F. Ayson (1899), later responsible for further introductions, mentioned the presence of quinnat salmon in the Waitaki River at that time in a report to the New Zealand government.

In 1901, the New Zealand Marine Department began a second, systematic attempt to establish the species. A hatchery was constructed on the Hakataramea River (a tributary of the Waitaki River) to which shipments of quinnat eggs came from the Sacramento River, California, from 1901 until 1907 (Ayson 1910, Thomson 1922). Although liberations of the juveniles hatched and reared from these eggs were made solely into the Waitaki River system, the fish soon began to spread up the east coast and had reached the Waimakariri before 1916 (Allen 1956).

Winding Creek, or, as it was once called, Windy Creek, is a tributary of Broken River, which is itself a tributary of the Waimakariri River, North Canterbury. A pioneer study of the natural reproduction of quinnat salmon was carried out in Winding Creek, Slovens Creek, and Broken River (all Waimakariri River tributaries) by D.F. Hobbs during 1932/33 (Hobbs 1937). From this study came the first documented report of adult quinnat salmon from the upper Waimakariri River system. Mr J.H. Kidd of Avoca wrote to Hobbs in November 1933 reporting "I first saw quinnat salmon in Broken River two years after I came to Avoca, in very small numbers". This would be in 1922, for Mr Kidd stated that he had lived at Avoca for 13 years.

Kidd's report does not necessarily mean that 1922 was the first time that sea-run quinnat salmon had entered the area. It is remote and mountainous country, lightly populated (even today), and in Kidd's day was occupied mainly by a scattering of people working a few high country pastoral runs (like him), or involved with maintenance of the crude road linking Canterbury with the West Coast via two alpine passes (Porters and Arthurs), or with operation of the Midland railway line, which was completed in 1923.

During the early 1920s, there was conjecture in acclimatisation society circles as to whether quinnat salmon could pass through the upper Waimakariri into the river's higher reaches. At Easter 1926, one councillor, G. Bryant Hobbs, had an adventurous trip with his brother down the river from Cora Lynn to Whites Bridge. He saw no sign of salmon in the upper river, despite crystal-clear water conditions. Because of the steepness and turbulence of several rapids encountered in the upper gorge, he believed it improbable that salmon would be able to pass through, although he conceded that there had been reports of their presence in the upper river (Hobbs, cited in Holden 1984). While the rapids and turbulent whirlpools of the rock-girt upper gorge impressed and bothered river travellers, no waterfall or cataract impeding or obstructing the passage of salmon existed. It is possible that salmon had passed into the upper river in earlier years, but either had not been noticed or not been remarked upon, and that by 1922 they were already utilising the same waters throughout the Waimakariri system as they do today.

No further liberations of quinnat salmon into the Waimakariri River occurred until 1963, when the North Canterbury Acclimatisation Society (NCAS) began a project to enhance the spawning run into Slovens Creek. Over four years (1963, 1964, 1965, and 1968) a total of 154 850 hatchery-reared juvenile salmon, obtained from eggs collected from the Rangitata and Rakaia Rivers, were released into Lake Hawdon. No results from this project have been reported, and it is not known if any enhancement eventuated.

2. WAIMAKARIRI CATCHMENT

The Waimakariri River system has been described extensively by Speight (1928), Dalmer (1971), and the North Canterbury Catchment Board and Regional Water Board (1986). It is an alluvial river, which flows about 150 km from its headwaters on the eastern slopes of the Southern Alps to discharge into the Pacific Ocean in Pegasus Bay (Fig. 1). Of its 3564 km² total catchment, 2490 km² are in the mountainous headwaters and are drained by the major contributory rivers Waimakariri, Bealey, Hawdon, Andrews, Poulter, Esk, and Broken. For much of its upper reaches, the mainstem Waimakariri occupies a wide, braided, gravel bed

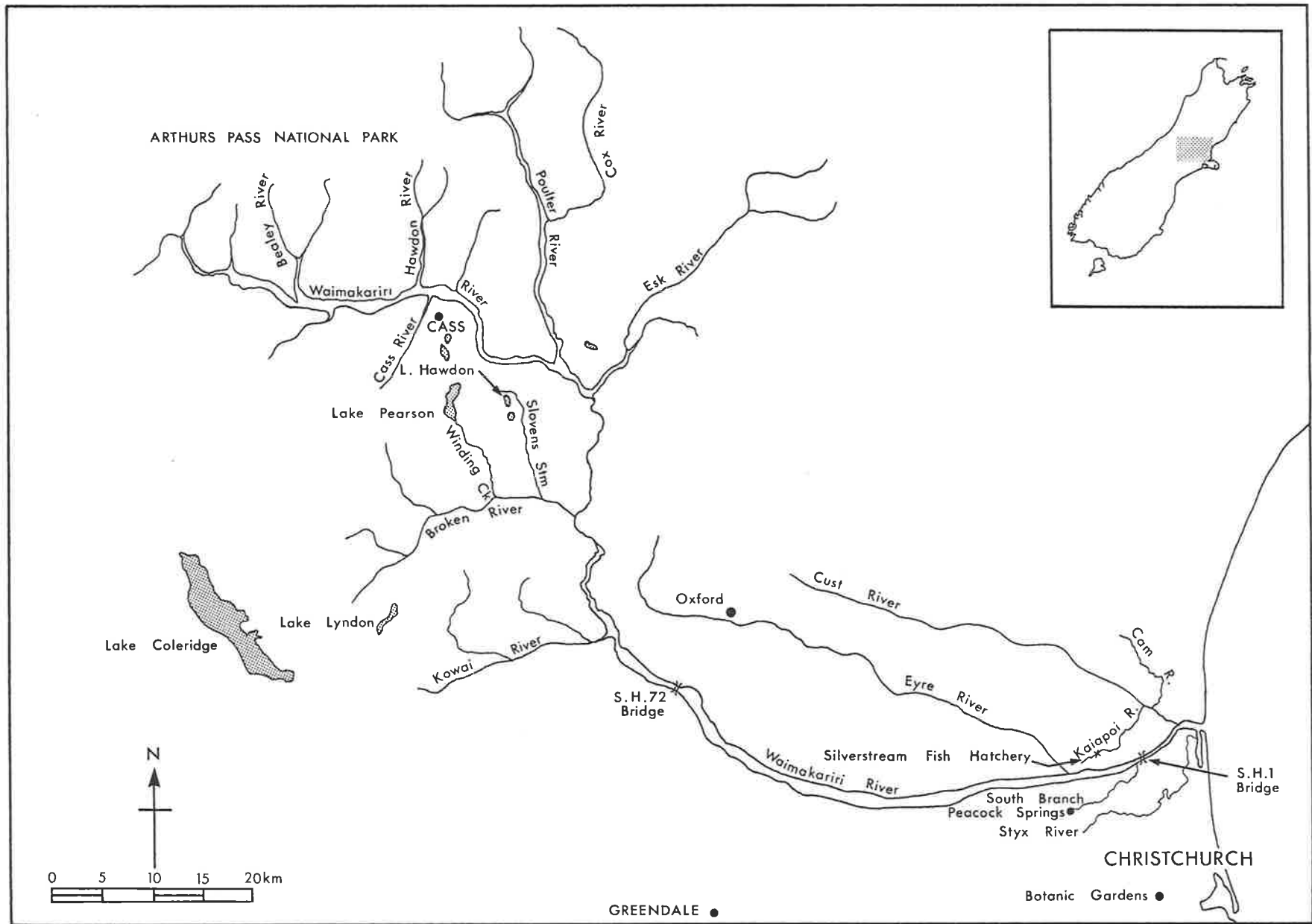


FIGURE 1. Location map, showing localities mentioned in the text.

within a region known as the Waimakariri basin, where there are several significant lakes (Pearson, Grasmere, Sarah, Hawdon, Marymere, and Letitia).

The Waimakariri leaves its upper catchment by a steep-sided, rock-walled (100 m high) gorge bisecting the Torlesse and Puketeraki mountain ranges. The lower, middle (Otarama), and upper gorges comprise some 51 km of the river's total length. Between the middle and lower gorges, the last mountain catchment tributary, the Kowai River, enters. From the lower gorge downstream, the river flows in a wide (1.5 km), multi-channelled, braided, gravel flood bed across the Canterbury Plains to the coastal lowland, where the South Branch, Kaiapoi River, and three minor tributaries join. Unusually among Canterbury alluvial rivers, the Waimakariri has a 5.5 km long estuarine reach and associated coastal lagoon (Brooklands). The river discharges through a permanent mouth to the sea.

The river gradient in the Waimakariri basin averages about 6.6 m/km. In the gorge, the gradient reaches about 4.0 m/km, whereas across the plains it is about 5.3 m/km, until, some 16 km from the sea, it reduces gradually to reach about sea level at the head of the tidal reach (Speight 1928).

The mean annual flow of the Waimakariri River at the old Highway Bridge gauging site is 119 ± 6 m³/s (1967-1983). A daily minimum low of 22 m³/s was recorded on eight occasions in late summer/autumn of 1971, when, for 71 consecutive days, the discharge remained below 40 m³/s. Within the period of record, a flood with a maximum daily discharge of 1830 m³/s occurred in 1984 (North Canterbury Catchment Board and Regional Water Board 1986). A flood with a maximum instantaneous discharge of 4250 m³/s was recorded in 1957 (Griffiths 1979). Historically, floods of greater magnitude probably have occurred.

The Waimakariri's discharge is governed largely by the frequency and amount of precipitation on the Main Divide, which is brought principally by strong west and north-westerly winds (Speight 1928). The periods of lowest flow tend to occur more often in late summer, and through into autumn. Heavy winter snow in the mountains, and the associated freezing conditions, retard runoff and reduce flows. However, snow melt in the

spring, usually assisted by an increased frequency of north-west rain, increases mean discharge, and there tend to be more freshes and floods in this season. Nevertheless, freshes and floods may occur in any season, as shown by the long-term discharge record. While major floods do not result solely from westerly or north-west precipitation, heavy north-easterly rain is uncommon. These climatic conditions are a consequence of New Zealand's geographic location in the prevailing westerly wind system of the south 40's latitude.

2.1 Broken River

Broken River is an alluvial tributary, which enters the Waimakariri near the head of the middle gorge, about 83 km from the sea. Its mean annual discharge is 12 m³/s (North Canterbury Catchment Board and Regional Water Board 1986). It flows from a mountainous catchment of about 400 km², bounded to the east by the Torlesse Range and to the south-west by the Craigieburn Range, each of these ranges being about 2000 m in height. The catchment lies to the east, within the rain shadow of the Main Divide, and so is less influenced by north-westerly rains than other headwater tributaries, tending to higher flows in the winter from south-westerly rain and from snow melt in the spring. It has been observed to have quite low flows in summer, autumn, and early winter.

For about 4 km upstream from its junction with the Waimakariri, Broken River flows through a steep, narrow gorge. Throughout its approximately 26 km length, the river alternates between narrow gorge sections (about 9 km in total), and open, alluvial, flood bed. There are no significant obstacles to salmon passage, except for one short reach near the confluence with Cave Stream, where the channel is down-cut through a limestone ridge. At low flows, this reach may be impassable, but, so far as is known, the possibility has not been investigated. However, a small number of adult sea-run salmon is known to spawn in a spring stream in the headwaters of the Porter River (North Canterbury Acclimatisation Society Annual Reports, personal observation).

2.2 Winding Creek

Winding Creek (Fig. 2) is a tributary of Broken River, and has a mean annual discharge of 2.5 m³/s (North Canterbury Catchment Board and Regional Water Board 1986). The upper reaches occupy the floor of an open, glaciated, partly terraced, mountain-rimmed valley, towards the head of which lies Lake Pearson. The outlet from the lake flows intermittently, with the first 3.5 km of Winding Creek usually being dry. From this point downstream, Winding Creek has a permanent flow contributed by small tributaries (e.g., Rata and Bernard Streams) which bring underflow from the talus fans of Broken Hill and the St Bernard ranges.

As a salmon spawning stream, Winding Creek may be considered in two parts. The upper reach, from the point of permanent flow downstream for about 2 km, follows an extremely sinuous course occupying part of the bed of a receded glacial lake (Speight 1939). It has numerous ox-bow bends, deep slow pools and runs, and stretches of shallower, gravel riffles. Overall, the gradient is moderate. At the end of the reach, the creek encounters a ridge of moraine where the valley narrows. The principal upper Winding Creek salmon spawning grounds consist of about a 1600 m length of this reach.

Passing through a gap in the moraine ridge, the stream cuts along the toe of a steep talus watercourse plunging down from Broken Hill. Debris brought down the watercourse by heavy runoff sometimes partially dams the creek, ponding water upstream until it is cleared by the flow. From the ridge downstream to Broken River, the valley progressively narrows, confining Winding Creek in a straighter course with its gradient gradually steepening to descend about 100 m in 3.6 km. On its approach to Broken River, the valley narrows appreciably, passing through scrub and beech forest. The bed of the creek then drops quickly through short, rocky pitches, with large boulders, creating a series of low cascades and rapids. This is the second reach. Where it leaves the valley, the river often follows a course parallel to Broken River for some distance, but separated from it by a gravel berm.

Hobbs (1937) considered both reaches to be attractive to spawning salmon. In this study, it was found that, while moderate numbers of salmon spawned in the lower reach, particularly towards its upper end

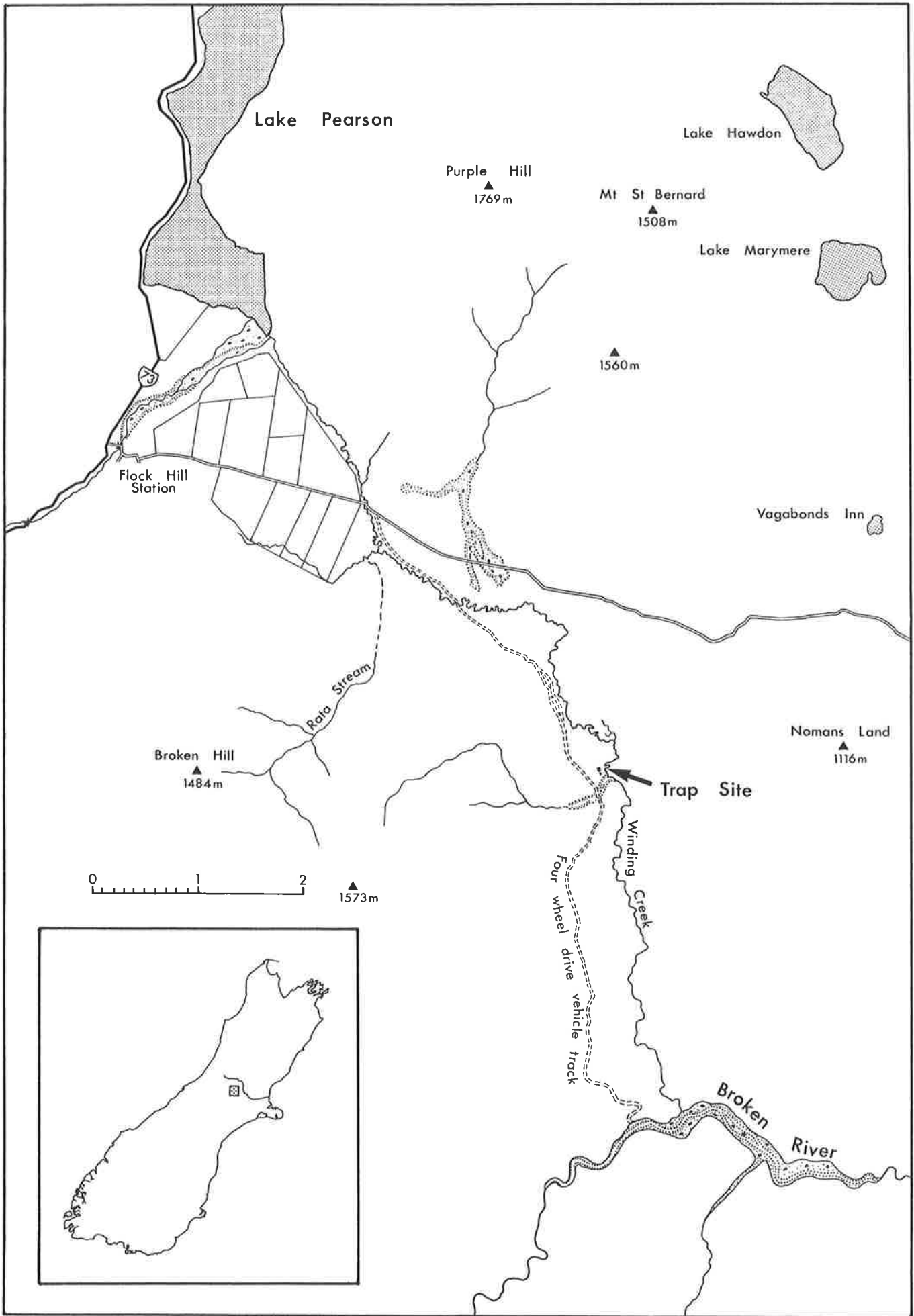


FIGURE 2. Winding Creek, showing location of the trap site.

where there were extensive gravel riffles interspersed with pools and runs, most of the salmon ascended to the upper reach.

3. QUINNAT SALMON TRAPPING IN WINDING CREEK

In 1962, the North Canterbury Acclimatisation Society (NCAS) decided "to improve the salmon potential of Lake Hawdon", which drains via Slovens Stream into Broken River (Fig. 1). An attempt was made to trap fish below a cataract in Slovens Stream (which denies salmon access to most of its length), to obtain eggs for hatchery propagation. (It was planned to modify the cataract later to ensure fish passage, but it remains unmodified.) The attempt was unsuccessful since no female salmon entered the creek. The next year, a trap was placed in Winding Creek to secure eggs. It was abandoned because of sudden spates, which caused weed accumulation, and the absence of sufficient males for fertilisation of ova. Netting carried out in Winding Creek in May 1967 secured only a small number of fish.

Trapping Winding Creek between 20 April and 10 May 1968 provided enough eggs to hatch 20 000 quinnat fry at the NCAS Greenpark hatchery. Eleven female quinnat salmon were trapped from Winding Creek in 1970 and stripped of 59 000 eggs for use in a trial of a jar system of incubation, which had been newly installed in the NCAS Silverstream fish hatchery (Hardy 1972, Henderson 1972). No further trapping was carried out in Winding Creek until 1976, when mature salmon began to be taken to provide ova for the induced-run project (Hardy 1988).

3.1 Silverstream Hatchery Induced-run Project

In 1972, the South Island Salmon Committee (Cunningham 1972) approved the establishment of a project, based on the Silverstream fish hatchery, to induce a return run of adult sea-run quinnat salmon to the hatchery for egg-taking and fishery development purposes. The project began in 1973/74 with the release of juvenile salmon into the upper Kaiapoi River.

Eggs for the project were obtained from a number of salmon spawning streams in the Rakaia, Rangitata, and Ashburton River catchments, but

none were collected from Winding Creek until 1976. By this time, the control of Silverstream and its programmes had passed to the Ministry of Agriculture and Fisheries (MAF). However, obtaining mature fish for ova production continued to be carried out co-operatively between MAF's Silverstream staff and the acclimatisation societies.

In 1976, a trap was erected by MAF and NCAS staff at the lower end of upper Winding Creek to intercept the salmon spawning run. It was operated by field officers of the NCAS. MAF staff were responsible for transporting the mature salmon back to the hatchery to be ripened for egg-taking, and for taking and fertilising eggs at the trap site for incubation at Silverstream (Table 1).

TABLE 1. Number of adult salmon from Winding Creek used to provide eggs for hatchery production at Silverstream, 1976-1981.

Year	No. of females	No. of males	Comments
1976	79	29	transported live to Silverstream
1977	166	25	transported live to Silverstream
1978	103	-	transported live to Silverstream
1979	147	+	stripped at Winding Creek trap
1980	81	+	stripped at Winding Creek trap
1981	139	+	stripped at Winding Creek trap

- = Silverstream males used for fertilisation.

+ = number of males used for fertilisation not recorded.

Because the NCAS was concerned that the quantity of fish or eggs taken from Winding Creek should not reduce future natural spawning in the creek, and because it was unnecessary to obtain all the eggs for the induced-run project from this source, the trap was only fished now and again during the spawning season. Most of the time, the fish had free access to their spawning grounds. No attempt was made to count the total number of fish, although an approximate check was made on abundance by carrying out spawning surveys during the 1976, 1977, and 1978 spawning seasons.

In total, about 3.2 million salmon eggs (715 females x an average of 4500 eggs* (Field-Dodgson and Galloway 1985)), or about 536 000 eggs each season, were obtained from Winding Creek stock.

3.2 Census Trapping

A change in the trapping was instituted in 1979. As well as collecting eggs for the hatchery, an attempt was made to obtain a total count of the sea-run salmon entering upper Winding Creek each year until 1984, and to examine each fish for the absence of an adipose fin. (This absence indicated that the fish was probably tagged with a coded-wire nose tag.) The recovery of tagged fish was important to the collection of data for a tagging programme being carried out throughout the salmon fishery by MAF (Unwin *et al.* 1987). Large numbers of juvenile salmon produced and released by the Silverstream hatchery were part of that programme (Hardy 1988).

3.2.1 Trap Site

Whereas the site of the traps used in previous years had been variable over a 500 m length of the creek, in 1979 the position of the trap was fixed (map reference S66:289019) about 100 m upstream from the moraine ridge which marks the start of the upper Winding Creek spawning grounds (Fig. 2). There, a deep run and pools often were used by salmon as a holding area, prior to ascending further.

The trap consisted of a barrier rack, set across the full width of the stream, with fish-holding pens and a trap attached to the downstream face. Converging wings leading from each stream bank led fish upstream through a non-return "V" entrance inserted into the trap. Downstream inclined screens were placed along the top of the lead-in

*Hobbs (1937) listed the number of ova per fish from data provided from the Hakataramea hatchery for 20 female quinnat (size range 4.1-10.5 kg) from the Waitaki River. The average number derived from his Table 2 was about 5800. Galloway (cited in Hawke 1978) counted ova in 12 female salmon from the upper Rakaia River, which had a mean length of 73.3 cm (range 65.2-80.5 cm), a mean weight of 4.8 kg (range 3.5-5.7 kg), and a mean number of 4400 eggs. In 1982, eggs were stripped from 26 adult females returning to the Silverstream hatchery. The mean length of the females was 64.6 cm (range 43.0-80.5 cm), and the average number of eggs per female was 4360 (Hardy 1988).

wings, to prevent fish jumping over them, and to divert fish towards the "V" trap entrance.

The barrier rack was about 8.5 m long and the stream was about 6 m wide. The trap measured 2.12 m by 3.0 m, with three holding pens, each about 2.12 m deep by 1.5 m wide. The lead-in wings were of unequal length, the longest being about 6.4 m long.

Because the structure was pre-fabricated, and the timber sub-frame was left in place from year to year, erection of the trap to full working order occupied a team of four people for one day. At the end of a season, it was dismantled and stored in half a day.

Although the trap site was remote (about 6 km distance from State Highway (S.H.) 73), there was public access through the area, which was used by trampers, hunters, and anglers. To forestall any possible interference with the salmon, the trap was staffed continuously. NCAS field officers alternated week about with MAF's Silverstream staff.

3.2.2 Trap Operation

Each year, the trap was installed as close to 1 April as possible. Observations in previous years had established that few salmon entered the spawning grounds before this date. The trap was then operated continuously until it was apparent from daily catches that the run had finished, usually during last week in June (Table 2).

TABLE 2. Duration of trapping at Winding Creek, 1979-1984.

Year	Trapping		No. of days operated
	Start	Finish	
1979	3 Apr	25 Jun	84
1980	2 Apr	27 Jun	87
1981	30 Mar	26 Jun	89
1982	29 Mar	14 Jun	78
1983	5 Apr	27 Jun	84
1984	29 Mar	25 Jun	90

The trap was cleared daily, and each fish was sexed, measured, and examined for absence of the adipose fin. Fish with a missing adipose fin were killed and the heads kept for tag recovery in the laboratory. In 1983 and 1984, samples of scales were taken for ageing. Fish required for egg taking and fertilisation were placed in holding pens. Otherwise, fish were immediately released upstream.

3.2.3 Water Temperatures

During the 1979-1984 trapping periods, water temperature was recorded daily using a maximum/minimum thermometer submerged in the stream at the trap site. Several different thermometers were used over the years. None was calibrated to a standard, so that the records are indicative rather than necessarily accurate. Data for the 1983 trapping season are given as an example (Fig. 3). Although the daily water temperatures differed in detail, the pattern was similar in all years. Daily air temperatures ranged from 24°C to 3.5°C during the day, and 9.5°C to -10°C overnight.

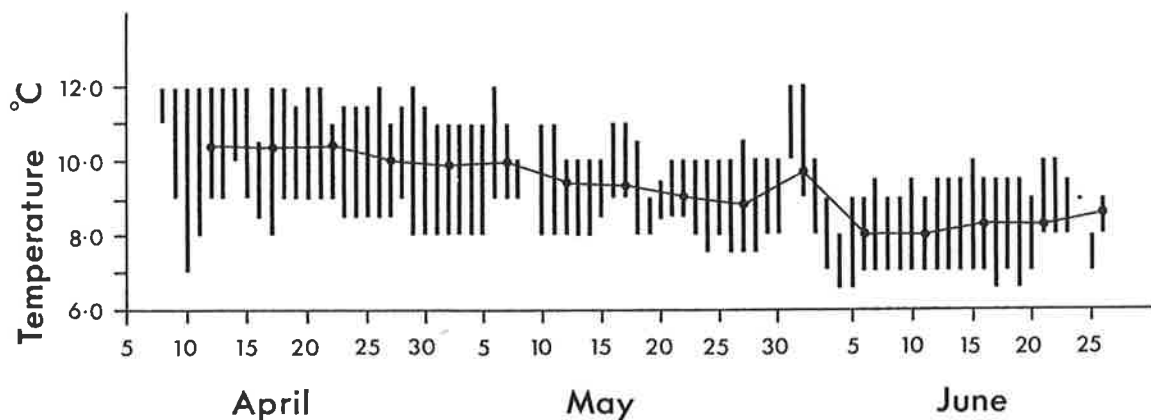


FIGURE 3. Maximum and minimum daily water temperatures at Winding Creek, April-June 1983.

No water temperature recordings are available for other months of the year, but a series has been recorded for Deep Stream (Rangitata), from April 1983 to April 1984 (Davis *et al.* 1986) and for Glenariffe Stream (Rakaia) for 1980 (Unwin 1986). Their water temperature regimes

appear similar to that for Winding Creek, and suggest that the water temperature in Winding Creek could become slightly lower in July, and then begin to rise in August.

3.2.4 Water Clarity

Winding Creek was usually clear and uncoloured. Only after continuous, heavy rain in the catchment did the stream rise or become discoloured. The discolouration usually arose from runoff of surface water from the several talus fans, from bank slumpage in the upper reaches, or, rarely, when the Craigieburn River overflowed directly into Winding Creek during a flood.

In early May 1979, there was a period of about 14 days when the stream rose and was dirty to discoloured. The level of Lake Pearson rose, and its water overflowed into the head of Winding Creek. It was the only time that this occurred during the six trapping seasons. The creek also rose and was discoloured for about eight days in mid June 1980, and for three days and four days, respectively, in early and late May 1983. In other years, it remained clear for the whole trapping period. Winter floods are also uncommon in the Broken River system.

4. TRAPPING RESULTS

Because trapping was carried out in the same three months each year, some early or late arriving salmon may not have been caught. However, from experience of trapping quinnat salmon both at the Silverstream fish hatchery (Hardy 1988) and at the Glenariffe salmon trap (S.P. Hawke pers. comm.), it is considered that the number of such fish is likely to be small. A survey of the upper Winding Creek spawning grounds at the time of trap installation each year never revealed more than a handful of salmon present. In 1979, for example, about 30 salmon were present when trapping started, and a few were still running when the trap was removed. The run that year was exceptionally large (Table 3). During the six years trapped, run size varied by a factor of 18.

TABLE 3. Number and sex of salmon trapped at Winding Creek, 1979-1984.

Year	Males	Females	Total
1979	1 585	1 460	3 045
1980	530	401	931
1981	555	535	1 090
1982	118	51	169
1983	461	157	618
1984	726	525	1 251
Total	3 975	3 129	7 104
Mean			1 184
Standard deviation			989

4.1 Comparison with Other Canterbury Spawning Runs

Comparison of the Winding Creek quinnat salmon spawning runs with those into Glenariffe Stream, which has been trapped annually since 1965 (Flain 1982, Field-Dodgson and Galloway 1985), and Deep Stream, which was trapped in 1983 and 1984 (Davis *et al.* 1986), demonstrates striking similarities in trends in run size from year to year (Table 4). In 1979, both Winding Creek and Glenariffe Stream had high numbers; both had low numbers in 1982. In the other years, and in Deep Stream in 1983 and 1984, the numbers were roughly similar, despite each of the waters being a major spawning stream in separate river systems. Although limited to a small number of consecutive years, this comparison suggests that whatever factors govern the size of the annual spawning escapement (e.g., freshwater juvenile survival, marine survival, reproductive success of a brood year, angling effort and success), there is a degree of similarity in their effect on the number of salmon returning to these three waters.

Run size in Winding Creek varied by a factor of 18, whereas it was about eight in Glenariffe Stream. While these variations are probably significant, no explanation can be offered as to why they occur. The occurrence of severe floods at the time of fry emergence from the gravels, and during juvenile migration to the sea, has been given as a cause for the reduced adult return to Glenariffe Stream in 1967 and 1970. However, an inexplicable reduction in the adult return also

occurred in 1971, when river conditions for that brood year were stable (Flain 1970, 1982).

TABLE 4. Comparison of the size of quinnat salmon runs into Winding Creek, Glenariffe Stream, and Deep Stream, 1979-1984.

Year	Winding Creek	Glenariffe Stream ⁺	Deep Stream
1979	3 045	2 887	-
1980	931	1 381	-
1981	1 090	1 819	-
1982	169	522	-
1983	618	713	757 + 167*
1984	1 251	896	1 076 <u>+</u> 150*

+ = in each respective year, 4, 152, 611, 536, 853, and 1727 hatchery-produced salmon also were trapped (Field-Dodgson and Galloway 1985). The figures shown here are only the naturally-produced adults.

- = no data.

* = estimates were calculated from the number of adults trapped and tagged, and from the recovery of tagged and untagged carcasses (Davis et al. 1986).

The mean annual discharge of the Rakaia River is almost twice that of the Waimakariri, and the minimum daily discharge is almost four times greater. Thus, there is undoubtedly more habitat available for juvenile salmon rearing in the Rakaia (Glova and Duncan 1985, Hopkins and Unwin 1987), and this may explain the apparently greater salmon production of the Rakaia. Flood discharges in both rivers have a short duration, with peak discharges usually occurring within a day and flows returning to pre-flood levels within a week. When flood discharges of similar magnitude occur in these rivers during downstream juvenile salmon migration, or during river residence, the substantially greater water volume present during steady and low flow conditions in the Rakaia may buffer the impact that flood flows may have in forcing involuntary downstream migration. Put another way, if the juvenile salmon are distributed over a wide area of river channel habitat, as they may be in the Rakaia, and are more concentrated when there is less area of river habitat, as may be the case in the Waimakariri, their exposure to sudden flood discharges in the Rakaia may be reduced and the effect attenuated, making them less susceptible to being flushed out to sea.

4.2 Timing and Duration of the Run

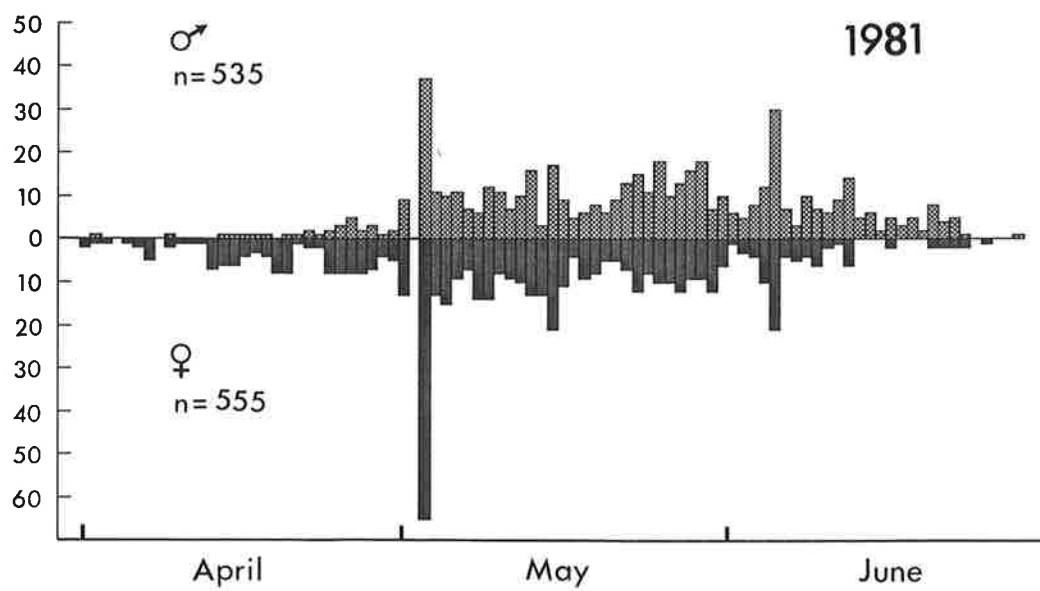
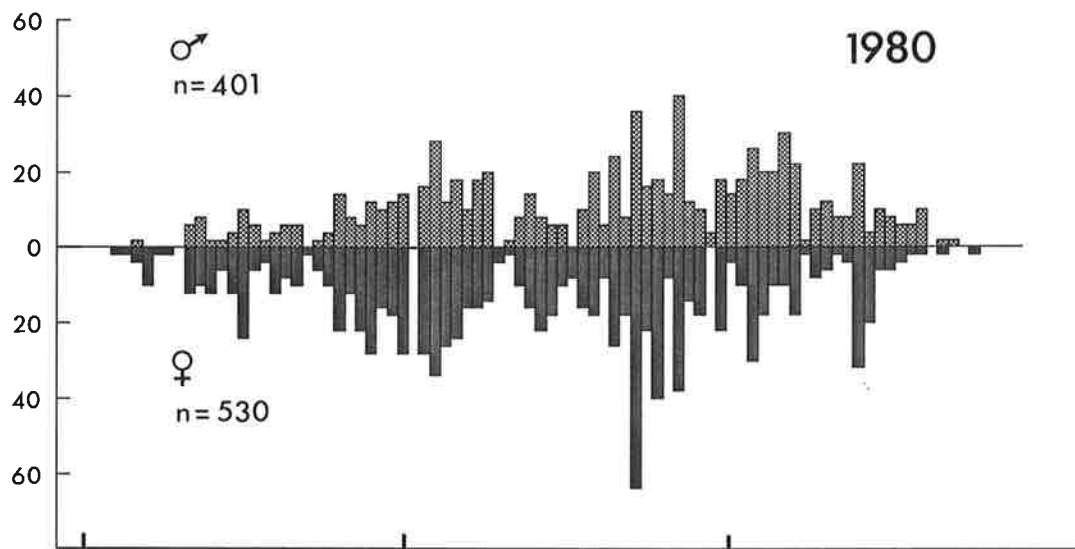
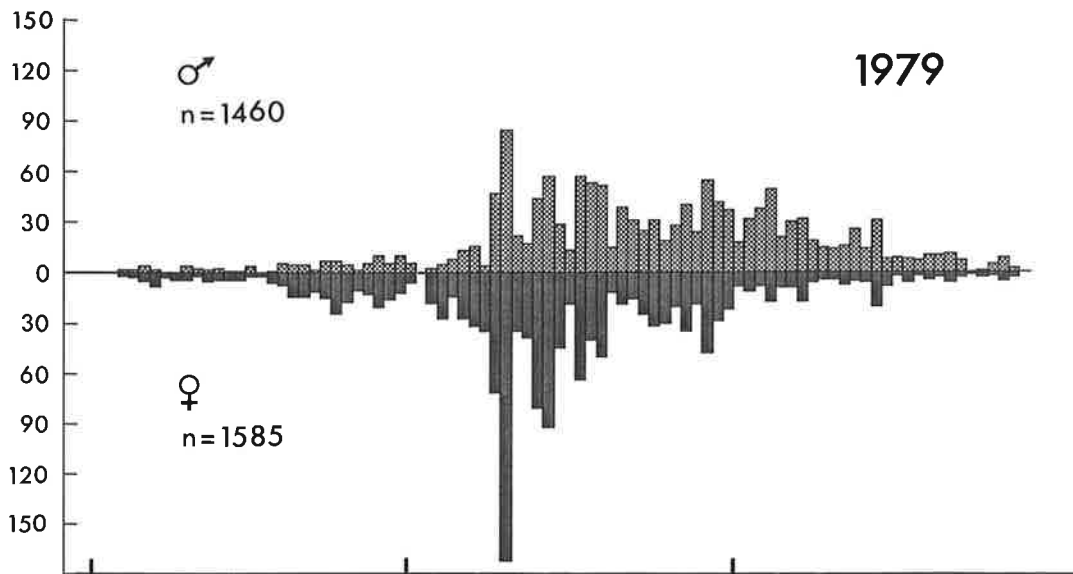
In all years, more males than females arrived on the spawning grounds in April. Large numbers of fish of both sexes arrived in May, and, in four of the six seasons monitored, noticeably more females than males reached the grounds in June (Table 5). Daily catches of trapped salmon are shown in Figure 4.

TABLE 5. Percentage of males, females, and of the total run trapped at Winding Creek during April, May, and June, 1979-1984.

Year		Apr	May	Jun
1979	male	15.0	74.9	10.1
	female	7.3	65.8	26.9
	total	11.3	70.5	18.2
1980	male	28.5	54.1	17.4
	female	17.5	54.1	28.4
	total	23.7	54.2	22.1
1981	male	23.2	63.5	13.3
	female	7.3	64.1	28.6
	total	15.4	63.8	20.8
1982	male	17.8	76.3	23.7
	female	5.9	86.3	13.7
	total	14.2	79.3	20.7
1983	male	25.4	62.9	11.7
	female	9.6	62.4	28.0
	total	21.4	62.7	15.9
1984	male	19.7	61.3	38.7
	female	9.3	73.9	26.1
	total	15.3	66.6	33.4

4.2.1 Migration from the Sea to the Spawning Grounds

In 1928, the N.Z. Marine Department fished an experimental net in the Waimakariri estuary from 6 February until 28 April. The first salmon was taken on the first day of netting and the last on 12 April (Parrott 1971). This netting established that salmon were present in the estuary by early February, but it is not clear whether they ceased running after 12 April or whether river conditions changed after this



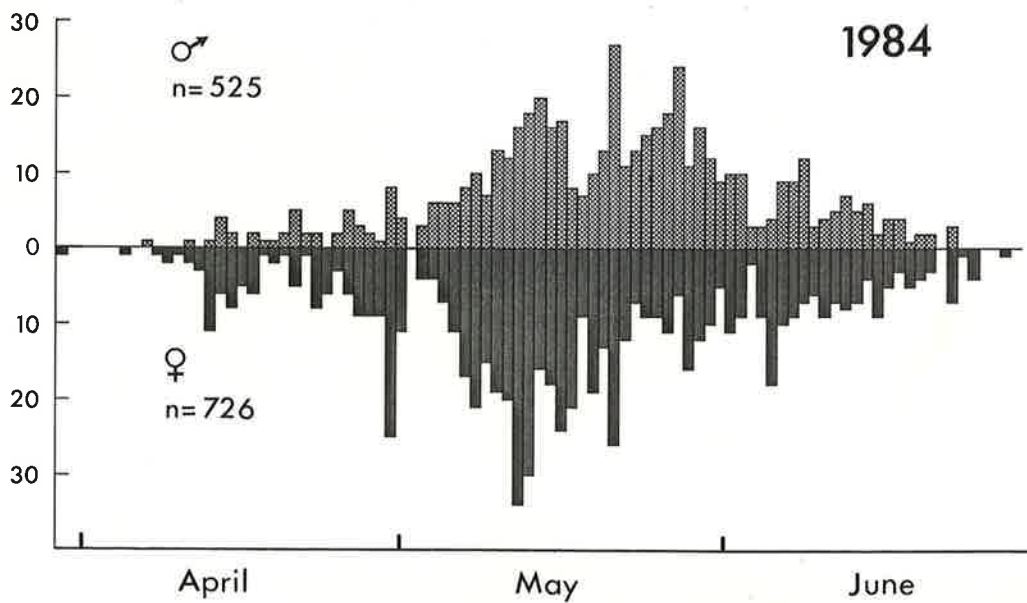
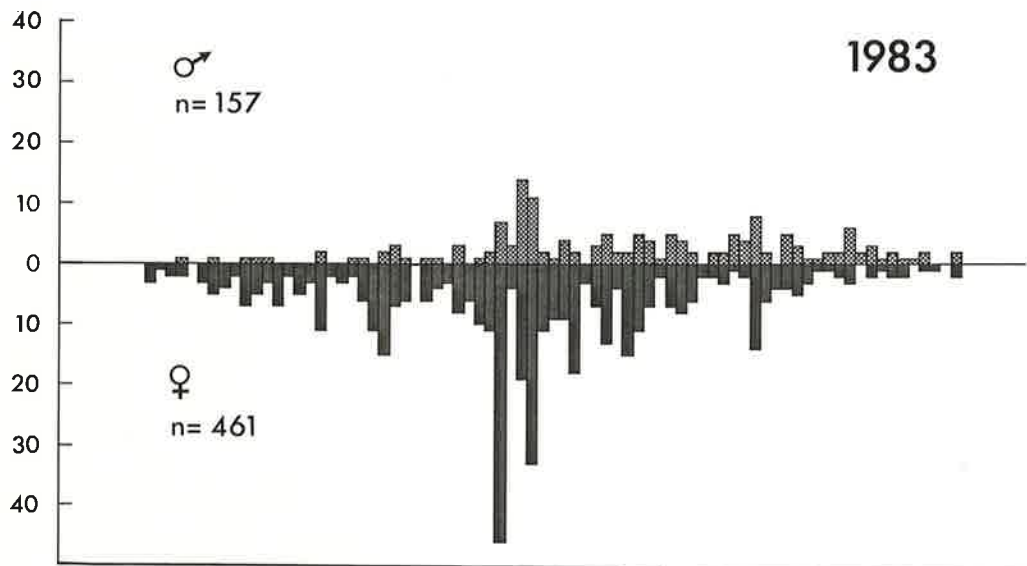
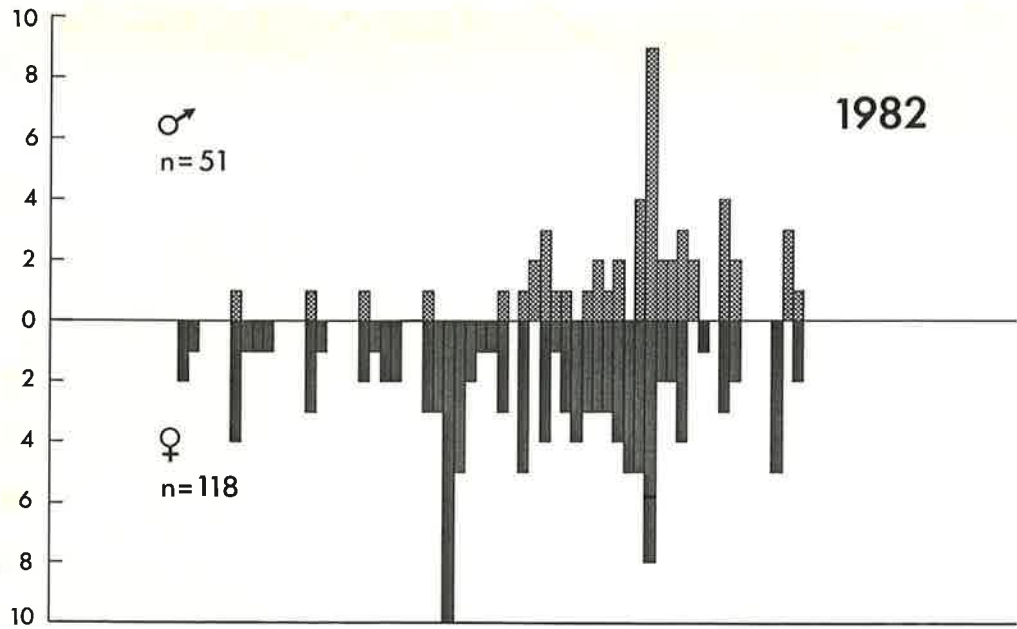


FIGURE 4. Daily catches of salmon in the Winding Creek trap, 1979-1984.
New Zealand freshwater fisheries report no. 114 (1989)

time, and fish could no longer be caught, since Parrott (1971) said the "netting was favoured by fine weather and a low river until the last fortnight of the season". A total of 454 salmon was netted, with the catch reaching a peak at the middle of March (Flain 1984).

In 1933, Hobbs (1937) assumed that it took, on average, about 7.5 weeks for a salmon to ascend the Waimakariri from the sea to the mouth of Broken River, a distance of about 83 km (i.e., a mean rate of travel of about 1.5 km/day). This assumption was based on the time relationship of the following events:

1. netting returns in the estuary for 1932 showed that fish were present from 19 January until 6 April, with half the catch being landed by 15 March;
2. salmon were first seen 1.6 km up Broken River on 10 April, and they continued to enter the stream until 26 May;
3. live, mature fish were present in the Broken River system for about 6.5 weeks, with numbers peaking between 20 and 30 April.

The evidence for a peak or mid-point in the run of salmon into the Waimakariri River from the sea is circumstantial. However, experienced anglers who have fished the lower Waimakariri and mouth for upwards of 50 years consider the peak of the run to occur about 17 March each year (P. Osborne pers. comm.).

The mid-point of the run of male salmon into Winding Creek varied by six days over the six years, with a mean of about 11 May (Table 6). This was about 10 days earlier than the mid-point of the female salmon run, which varied within four days over the six years, i.e., it was close to 21 May each year. The mid-point of the total run varied over six days, with a mean of 15-16 May. This is about a fortnight later than the mid-point of the Glenariffe run.

Assuming 15 March to be the mid-point of the run in from the sea (as indicated above), the migration period from the estuary to the upper Winding Creek spawning grounds is about eight weeks. This agrees well with Hobbs (1937) assumption of 7.5 weeks to the mouth of Broken River, allowing for an additional 12 km from there to the Winding Creek trap site.

TABLE 6. Mid-point of the male, female, and total adult quinnat salmon run into upper Winding Creek, 1979-1984.

Year	Males	Females	Total run
1979	11 May	20-21 May	15 May
1980	13 May	20-21 May	18 May
1981	8-9 May	21 May	13-14 May
1982	14 May	22-23 May	17-18 May
1983	10 May	20 May	10-11 May
1984	13-14 May	19 May	15-16 May

A similar mid-March peak for the run into the Rakaia River was given by Flain (1972), with peak salmon numbers usually occurring at the Glenariffe trap in mid-April. From these data, it was calculated that the fish cover approximately 112 km in 30 days, an average of 3.73 km per day. This is more than twice the maximum daily rate estimated for salmon migrating up the Waimakariri to Winding Creek. However, if the mid-point of the run at the Rakaia River mouth is earlier (in February, as suggested by Field-Dodgson and Galloway 1985), then estimates of the daily progress rate for the two rivers are similar.

4.2.2 Salmon Appearance as an Indicator of Duration of River Passage

It is considered by anglers and workers with sea-run salmon that the colouration of a fish indicates how long it has spent in fresh water. Salmon running in from the sea are typically bright silver in colour, and their scales are easily detached. After entering fresh water, the body colour assumes an increasingly bronzy hue, its intensity being related to the time that the fish has been in the river, and the scales become increasingly embedded in the epidermis. As the fish approaches sexual maturity, the bronzing often changes to a more charcoal colouration, and reddish blushes become prominent along the flanks of some fish - usually males. The scales become very well embedded and changes occur in the body shape (e.g., development of prominent teeth and a kype in males, roundness and softness in the belly of females).

Since most of the salmon arriving at the Winding Creek trap are sexually mature (particularly males), it would be reasonable to expect them all to have the dark colouration and other features associated with ripe fish. However, this was not always the case.

During 1980, the Winding Creek trap catch (as well as that at Silverstream) was assessed subjectively for market quality. Appearance and body colouration on arrival at the trap were taken into account. Clean, bright, silvery salmon comprised only 0.2% of the 929 fish assessed. Fish that were a dull silvery colour, or had a lightly bronzed hue and clean, firm appearance, amounted to 6.5% of the run. In the next category, comprising 39.5% of the total, the fish had a darker body colour, and exhibited signs of spawning colouration, evidence of approaching sexual maturity. These fish were judged to be in the minimum general condition acceptable to anglers. The predominant group, comprising 53.8%, were sexually mature (eggs or milt could be freely expressed); sexual dimorphism was evident, and frayed fins and white body patches were obvious. These fish were judged to be salmon which would be rejected by anglers. Most were darkish in colour but, surprisingly, there were also numerous males and females with light body colouration, similar to those in the second category.

If increasing darkening of body colour is directly related to the length of time spent in upstream passage to the spawning grounds, then this subjective assessment indicates that there is considerable variation in passage time among adult salmon. The impression is that, using body colouration and general body condition as criteria, some salmon (ripe or unripe) travel rapidly, perhaps measured in days, whereas others, possibly the majority, spend a longer but variable time in up-river migration, which may take several weeks.

4.2.3 Radio Tracking of Up-river Migration of Salmon

In 1985, 34 sea-run quinnat were netted in the lower Waimakariri River, close to the mouth of the Kaiapoi River (Fig. 1), between 18 March and 16 May. These were tagged by inserting battery-powered radio transmitters into the gut. Each tag transmitted on an individual frequency so that its signal could be identified on a directional-search receiver (Docherty 1984). The intention was to follow the tagged fish through the braided mainstem Waimakariri up to the gorge bridge, to determine the effect of river flows on their passage (Glova and Docherty 1986). Determining passage time from their entry from the sea to the spawning grounds was not intended.

Only 14 of the fish were tracked successfully, and the results were inconclusive. Of the salmon tracked up the mainstem during low flows (<30 m³/s), the mean rate of progression upstream was 3.5 ± 1.9 (S.D.) km per day (range 1.0-6.0 km per day). During a fresh at the end of April (flow approximately 110 m³/s), the mean rate of progress was 5.7 ± 5.9 km per day (range 0.1-21.6 km per day). Some fish lingered for days at a time in one or more of the holes along the length of the river, whereas others kept moving upstream at a more or less steady rate.

4.2.4 Influence of Waimakariri River Discharge on Salmon Migration

There is no indication that Waimakariri River flows influenced the timing of the mid-point of the salmon spawning run into upper Winding Creek during the six years of census. The mid-point occurred close to the same date each year, even though discharge in the Waimakariri varied during the period of upstream salmon migration (Table 7).

4.3 Size of Adult Salmon

Comparison of mean fork lengths of fish trapped at Winding Creek (Table 8) with those trapped in Glenariffe Stream on the upper Rakaia River (Flain 1982) shows that the two populations are similar in size (Table 9), despite the different period of record and possible variations in age structure between the two streams.

There are some historical data on sizes of Waimakariri salmon. Finlay (1931) provided size data for a sample of 56 sea-run salmon taken from the Waimakariri in 1927. Their average length was 86.8 cm, and the average weight was 7.5 kg. A sample of 450 salmon taken from the estuary in 1928 by the N.Z. Marine Department consisted of fish aged 2, 3, 4, and 5 years. The average length of the males (n = 179) was 69.6 cm, whereas the females (n = 271) averaged 74.2 cm (Finlay n.d.). (N.B. These lengths were reported in whole inches.) The total weight of these salmon was 2221 kg, giving an average weight of 4.9 kg (Parrott 1971). This was slightly less than the average weight of 5.1 kg reported in the N.Z. Marine Department's annual report to Parliament that year, for 2514 salmon (total weight 12 730 kg) taken from the estuary by four nets (including the department's net).

TABLE 7. Mean monthly discharges (m³/s) in the Waimakariri River at the old Highway Bridge, January to June, 1979-1984. (Data are from North Canterbury Catchment Board and Regional Water Board 1986.)

Year	Jan	Feb	Mar	Apr	May	Jun
1979	79	98	92	116	226	89
1980	225	134	141	121	99	136
1981	69	75	123	92	82	113
1982	139	68	59	48	142	112
1983	163	54	81	142	201	117
1984	105	120	96	53	56	53
Mean	130	92	99	95	134	103
Mean*	101	72	81	106	114	94

* = mean for the years 1967 to 1984 inclusive.

TABLE 8. Mean and range in fork length (cm) of male and female quinnat salmon trapped at Winding Creek, 1979-1984.

Year	Males		Females	
	Mean	Range	Mean	Range
1979	74.7	33.0 - 103.0	76.2	47.0 - 95.0
1980	71.0	34.0 - 96.0	73.8	51.0 - 93.5
1981	74.8	56.0 - 94.5	72.0	59.0 - 91.5
1982	70.3	45.0 - 93.5	73.9	63.0 - 89.5
1983	66.2	43.0 - 100.0	71.1	54.5 - 92.5
1984	77.6	37.0 - 99.5	77.0	51.0 - 95.5

TABLE 9. Mean fork length (cm) of all quinnat salmon (male and female) trapped at Winding Creek (1979-1984) compared with those trapped at Glenariffe Stream (1965-1978) (Flain 1982).

	Winding Creek		Glenariffe Stream	
	Mean fork length	n	Mean fork length	n
Males	73.6	3 975	73.8	12 951
Females	75.0	3 129	75.4	12 932

Government's purpose in introducing the California salmon to New Zealand was to establish a commercial fishery, and hopefully a salmon canning industry. To this end, from 1925, the taking of quinnat salmon for sale was permitted by issuing licences to professional fishers to net fish from the rivers, and by permitting licensed trout anglers to purchase an additional salmon fishing licence, and to sell fish caught on the rod. While trials were made on several east coast rivers, it was found possible to net successfully only in a limited part of the tidal Waimakariri River estuary. With the exceptions of 1929, 1930, and 1941, a small, variable number of commercial nets fished each year from 1925 until 1952. Rod selling began on the Waimakariri in 1929, and was carried out on a number of rivers. The authorisations permitting rod selling and commercial netting were revoked in 1951 and 1952 respectively (Cunningham 1972).

Annual returns of the catch by the N.Z. Marine Department listed the number of nets and rods, the number of salmon caught, the total weight of salmon taken, and the average weight. The rod selling returns were reported by river. An occasional footnote mentioned that part of the catch was gutted, so that weights given do not always represent the true weight of fish. With this reservation, the data can be treated as comparable.

For 20 of the 28 years fished between 1925 and 1952, the number and weight of salmon taken was reported. In these years, the Waimakariri nets took 11 568 fish, with an average weight of 5.3 kg. The average weights varied between years ranging from 4.3 kg (1952, n = 90) to 6.0 kg (1932, n = 157; 1933, n = 928).

A comment in the department's 1933 annual report, concerning the average weights of rod-caught salmon reported from the Waimakariri, Rakaia, and Rangitata Rivers, said "in accordance with the general rule the average size is greater for the southern rivers than for those in the north". In 11 of the years between 1929 and 1946, there were annual returns of salmon taken from these three rivers by commercial rods and from the Waimakariri by nets. Rods took 1202 fish from the Rangitata (average weight 7.9 kg), 1654 fish from the Rakaia (average weight 6.9 kg), and 200 fish from the Waimakariri (average weight 6.9 kg). Net catches from the Waimakariri totalled 5809 fish, with an

average weight of 6.2 kg. In five of these years, rod-selling catches also were reported from the Waitaki River, and a comparison of the average weight can be made with the Rangitata, Rakaia, and Waimakariri rod catches, and the Waimakariri nets, for the same years. The average weights were: Waitaki 8.7 kg, n = 143; Rangitata 8.0 kg, n = 471; Rakaia 7.1 kg, n = 663; Waimakariri rod 7.0 kg, n = 107, and nets 5.4 kg, n = 3879. These generalised data indicate a trend towards larger salmon being taken in the more southern Waitaki and Rangitata Rivers than in either of the more northern Rakaia or Waimakariri Rivers.

4.4 Recovery of Coded-wire Tagged Salmon

The tagged juvenile salmon released into Winding Creek came from two sources:

1. salmon with tag codes 63/11/03 and 63/58/03 were produced from eggs taken from adults returning to the Silverstream hatchery during the induced-run project (Hardy 1988);
2. salmon with tag code 63/38/03 were produced at Silverstream from eggs taken from Winding Creek.

Between 1981 and 1984, 21 coded-wire tagged adult salmon were recovered at Winding Creek (Table 10). Twelve of these tagged fish were strays from the Rakaia catchment, and salmon from these tag groups also were recovered elsewhere. Details of the release data for the tag codes of fish recovered at Winding Creek during the trapping period are given in Table 11. Information on the coded-wire tagging project and details on the recovery of tagged fish have been reported by Anon (1980), Lucas (1980, 1981), Unwin and Lucas (1982, 1983, 1984, 1986) and Unwin *et al.* (1987, 1988).

4.5 Age Composition of Spawning Runs

Aging that has been done on east coast, South Island, sea-run adult quinnat salmon (e.g., from the Waimakariri River (Finlay n.d., Flain 1982), the Rangitata River (Flain 1972, Davis *et al.* 1986), the Rakaia River (Flain 1982), and the Waitaki River (James and Deverall 1987)) has established that no salmon older than five years return to fresh water.

TABLE 10. Coded-wire tagged salmon recovered at Winding Creek.

Year recovered	Brood year	Tag code	Where released	Age at recovery	How recovered
1981	1978	63/20/02	Glenariffe*	3	trap
1982	1980	63/17/03	Lake Coleridge+	2	angler
1983	1981	63/58/03	Winding Creek	2	angler
1983	1981	63/58/03	Winding Creek	2	trap
1983	1981	63/58/03	Winding Creek	2	trap
1983	1980	63/11/03	Winding Creek	3	trap
1984	1982	63/36/31	Glenariffe	2	trap
1984	1982	63/36/32	Glenariffe	2	trap
1984	1982	63/36/32	Glenariffe	2	trap
1984	1982	63/36/33	Glenariffe	2	trap
1984	1982	63/36/33	Glenariffe	2	trap
1984	1982	63/36/41	Glenariffe	2	trap
1984	1982	63/36/42	Glenariffe	2	trap
1984	1982	63/54/03	Lake Coleridge	2	trap
1984	1982	63/54/03	Lake Coleridge	2	trap
1984	1982	63/56/03	Lake Coleridge	2	trap
1984	1981	63/20/04	Silverstream†	3	trap
1984	1981	63/38/03	Winding Creek	3	trap
1984	1981	63/38/03	Winding Creek	3	trap
1984	1981	63/58/03	Winding Creek	3	carcass
1984	1981	63/58/03	Winding Creek	3	trap

* = MAF hatchery located in the upper Rakaia River.

+ = N.Z. Salmon Co. Ltd. hatchery located adjacent to the Coleridge power station outfall into the upper Rakaia River.

† = MAF hatchery located on a tributary of the lower Waimakariri River.

TABLE 11. Date, size, and number at release of coded-wire tagged salmon recovered at Winding Creek.

Tag code	Brood year	Date released	Size at release (g)	No. tagged	No. not tagged
63/20/02	1978	14.08.79	35.0	7 333	0
63/11/03	1980	04.12.80	5.5	9 728	8 926
63/17/03	1980	24.07.81	47.0	10 513	34 290
63/58/03	1981	04.11.81	8.0	21 626	81 558
63/38/02	1981	22.12.81	18.0	10 598	0
63/20/04	1981	09.03.82	21.0	20 368	0
63/36/33	1982	03.08.83	39.2	8 606	0
63/54/03	1982	13.05.83	60.0	10 443	47 557
63/56/03	1982	16.06.83	64.0	10 670	55 830
63/36/41	1982	04.07.83	66.9	9 245	0
63/36/42	1982	04.07.83	64.1	10 153	0
63/36/31	1982	03.08.83	35.5	9 445	0
63/36/32	1982	03.08.83	35.3	9 764	0

Most adult fish return at three years of age (the dominant age) or as 4-year-olds, with the proportion of these two year classes varying between years. James and Deverall (1987) found that the combined proportions of 3-year-old and 4-year-old salmon were remarkably constant in the Waitaki River, and comprised 92% of all adults sampled over a period of 11 years (1976-1983). Five-year-old salmon were uncommon (approximately 2% of all samples reported), and 2-year-olds comprised the remainder, their proportions varying widely between years. Most 2-year-olds were males.

From 1967 to 1978, the salmon spawning run into Glenariffe Stream totalled 22 131 adults (Flain 1982); the age structure is shown in Table 12. Finlay (n.d.) examined the scales from 450 salmon caught in an experimental net in the Waimakariri River estuary in 1928, and Flain (1982) reported the age structure of a sample of 453 quinnat salmon taken from the Waimakariri River in the 1969/70 season (Table 12). Scale samples also were taken in 1983 and 1984 to age the run through the Winding Creek trap (Table 12).

TABLE 12. Age structure of Waimakariri salmon compared with data from Glenariffe trap, Rakaia River.

Location	Year	Sample size	Age class (%)			
			2	3	4	5
Glenariffet	1967-1978	22 131	12.5	71.6	15.8	0.1
Waimakariri R. ^o	1928	450	2.9	80.4	14.9	1.8
Waimakariri R. [†]	1970	453	4.4	59.2	36.4	0
Winding Ck. [#]	1983	220	47.3	51.8	0.9	0
Winding Ck. [#]	1984	411	7.3	87.8	4.9	0

† = after Flain (1982).

^o = from Finlay (n.d.).

= MAFFish unpublished data.

The age structure of the 1983 Winding Creek sample is completely different from either Finlay's or Flain's samples from the Waimakariri River, and from the 1984 Winding Creek sample. Except for this oddity, the Waimakariri salmon age structures are similar to the age structures obtained from Glenariffe Stream (1967 to 1978), the Rangitata River (Davis et al. 1986), and the Waitaki River (James and Deverall 1987).

In the Waimakariri samples, 3-year-old salmon dominate, but in two of the four samples, the 4-year-old age class is poorly represented. If 4-year-olds are consistently poorly represented in the Waimakariri runs, it would be an anomaly compared to the runs into Glenariffe Stream, and the Rangitata and Waitaki Rivers. However, sample sizes were not large, and do not encompass a range of years. A more extensive examination of the age structure of Waimakariri salmon is required.

4.6 Juvenile Life History Obtained from Scale Readings

Three juvenile life history types have been identified in natural populations of quinnat salmon in New Zealand, based on interpretation of the number and spacing of the circuli (or rings) laid down in the scale nucleus (Flain 1982). The circuli in the nucleus form a particular pattern, characteristic of the environment(s) in which the first year's growth is attained (Gilbert 1914; Rich 1920, 1925; Flain 1982). The types are summarised by Unwin (1981) as:

- 1 ocean - little or no freshwater residence;
- 2 intermediate - part of the first year spent in fresh water;
- 3 stream - over one year spent in fresh water.

Although Finaly (n.d.) recognised the nuclear patterns for the ocean and stream growth categories described by Rich (1920) for Pacific Northwest chinook (quinnat) salmon, and knew of a third type which indicated part stream and part ocean growth within the first year (termed "composite nuclei" by Rich and Holmes 1929), he did not attempt this classification, and recognised only ocean and stream nuclei (types 1 and 3 above). Flain (1972) re-examined 433 samples from this scale set and found 1.2% ocean, 69.0% stream, and 29.8% intermediate type growth.

The scale samples taken at the Winding Creek trap in 1983 and 1984 (Table 12) were examined to identify the juvenile life histories (Table 13). The relative percentages of each growth type agreed closely with those from the 1928 sample. Two-thirds, or more, of each of the samples had stream-type nuclei, which were a feature of the 3-year-old and 4-year-old fish (Table 13). Ocean-type nuclei were either absent or negligible.

TABLE 13. Age frequency (%) of scale nucleus types in samples from Winding Creek trap, 1983 and 1984.

Year	Age	Sample size	Hatchery*	Intermediate	Scale nucleus type Stream	Ocean
1983	2	104	6.7	44.2	49.0	0
	3	114	4.4	15.8	79.8	0
	4	2	0	0	100.0	0
	Total	220	5.5	29.1	65.5	0
1984	2	30	6.7	83.3	10.0	0
	3	361	0.6	16.1	83.4	0
	4	20	0	15.0	85.0	0
	Total	411	1.0	20.9	78.1	0

* = a growth pattern associated only with hatchery-reared fish, readily distinguishable from the growth patterns found in the scales of wild fish (D.H. Lucas pers. comm.).

Scales collected from angler-caught quinnat salmon in the Rakaia River between 1967 and 1976 (Flain 1982), and from the Rangitata River between 1973 and 1984 (Davis *et al.* 1986), had a different incidence of scale nucleus types (Table 14). The percentage of intermediate and stream nuclei is the reverse of that found for the 1927 and 1982 Waimakariri River estuary samples, and for the 1983 and 1984 Winding Creek trap samples. The incidence of ocean type nuclei is low in the Rakaia and Rangitata River samples, non-existent in the Winding Creek samples, and negligible in the 1982 Waimakariri estuary sample.

TABLE 14. Mean incidence of scale nucleus types in angler-caught quinnat salmon from the Rakaia, Rangitata, and Waitaki Rivers. (Data are from Flain 1982, Davis *et al.* 1986, and James and Deverall 1987.)

River	No. in sample	Scale nucleus type (%)		
		Ocean	Intermediate	Stream
Rakaia	1 397	0.4	76.4	23.2
Rangitata	1 285	0.6	71.2	28.2
Waitaki	1 090	1.9	46.2	51.9

The ratio of scale nucleus types reported by James and Deverall (1987) from angler-caught quinnat salmon from the Waitaki River between 1976 and 1983 (Table 14) are more similar to those found in the Waimakariri samples, in that most fish exhibited stream-type juvenile life histories. By contrast, in the Rangitata and Rakaia Rivers, most adults exhibited an intermediate-type juvenile life history. In all four rivers, only a very minor proportion of adults exhibited an ocean-type juvenile life history.

Early workers overseas (e.g., Gilbert 1922, Rich and Holmes 1929, Clark 1929) and Davis et al. (1986) found evidence, from the ages and sex of fish with different juvenile growth types, of a correlation between age at maturity (as measured by age at adult return to fresh water) and juvenile life history. Broadly, the evidence suggests an earlier age at maturity for quinnat salmon with ocean-type, or intermediate-type nuclei, and an older age at maturity for fish with stream-type nuclei.

One might therefore expect to find a relatively high proportion of 4-year-old salmon in the Waimakariri River, where stream-type nuclei predominate. However, scale reading results from Waimakariri sea-run salmon do not support this hypothesis. Four-year-old salmon were poorly represented in both the 1983 and 1984 Winding Creek trap samples (Table 13). In 1983, the two 4-year-old fish, both with stream nuclei, comprised only 1.4% of all salmon with stream nuclei in the sample. In the 1984 sample of 20 4-year-old fish, 17 had stream nuclei, but they comprised only 5.3% of all salmon with stream nuclei in the sample. This evidence does not support the expectation of a relatively high incidence of 4-year-old quinnat salmon in the Waimakariri run.

5. SPAWNING SURVEYS OF WINDING CREEK

A detailed spawning survey of 2.4 km of Winding Creek was first made by NCAS councillors and field staff on 7 May 1964 and 400 salmon were counted. In 1966, 267 spawning fish were counted. A count in May 1967 gave 670 live and 76 dead spawners. In a 1.6 km section, 1350 live and dead salmon were counted in 1968. (This survey may have been made while a trap was installed between 20 April and 10 May for the purpose

of collecting salmon eggs.) A reported count of between 250 and 300 spawning salmon over "a two-mile observation" was made in 1969 by NCAS honorary rangers. No date for the survey was given. The next count of 250 salmon was in late April 1971, over the "threequarters of a mile [1.2 km] used each year". A spawning survey was reported in the 1973 NCAS Annual Report where, on 17 May 1973, 70 salmon, 17 redds, and some fresh-run fish were recorded in Winding Creek. No further surveys were reported until 1978.

The usefulness of these counts is limited. None gives a true indication of the size of the spawning run in any year. For the most part they appear to be single surveys, undertaken in the earlier part of the spawning season. They suggest that there may have been a relatively large spawning run into upper Winding Creek in 1968 and a small one in 1973.

A more comprehensive survey was undertaken in 1978, and similar surveys have been continued thereafter as a routine part of the assessment of spawning in selected upper Waimakariri salmon spawning tributaries. From 1979 to 1984, the spawning survey counts for Winding Creek can be compared with the counts of salmon passing through the trap (Table 15). (No surveys were carried out in 1983.)

On first inspection of the data, there appears to be little relationship between the number of salmon counted and the number that had passed through the trap prior to the survey, although there is some correlation between the number of female salmon recorded at the trap and the number of redds counted. It is apparent that when there was a relatively large spawning run (e.g., in 1979 and 1981), the number of redds counted reached a plateau at about 250, with multiple redds prominent, despite the presence of a much larger number of females than usual on the spawning grounds.

Wing (1972) reported the results of seven years of spawning surveys (1965-1971) in Glenariffe Stream, where the counts of live and dead salmon and redds were compared with the numbers of salmon that had passed through the trap onto the spawning grounds. In 1966, when 929 adult salmon had been recorded, a survey made by three experienced personnel counted 464 live and dead salmon - a counting efficiency of 50%.

TABLE 15. Comparative counts of salmon in Winding Creek from spawning surveys and trapping, 1978-1984. (Trap counts show the total number of salmon and number of females counted up to and including the date of the survey.)

Date	Survey counts			Trap counts	
	No. live salmon	No. dead salmon	No. of redds	Total no. salmon	No. of females
<u>1978</u>					
03 May	210	-	60	-	-
10 May	214	-	75	-	-
19 May	428	-	194	-	-
18 Jun	74	-	190	-	-
<u>1979</u>					
22 Apr	152	0	21	173	54
23 Apr	154	0	50*(8)	204	61
22 Jun	184	97	259*(74)	3 021	1 443
<u>1980</u>					
17 Apr	76	0	29	75	21
30 Apr	134	6	57	221	70
16 May	106	20	118*(1)	441	158
29 May	151	25	161*(5)	702	271
12 Jun		stream dirty		897	379
<u>1981</u>					
30 Mar	0	0	0	trapping not started	
24 Apr	71	0	13	90	14
14 May	260	0	175*(5)	557	206
27 May	173	65	232*(6)	813	354
11 Jun	146	65	244*(4)	1 037	493
05 Jul	51	40	214*(4)	trapping completed	
<u>1982</u>					
1 Apr	0	0	0	0	0
22 Apr	14	0	5	15	2
4 May	10	0	8	41	4
14 May	24	6	16	71	12
28 May	41	6	37*(2)	147	41
11 Jun	23	12	30*(2)	trapping completed	
01 Jul	2	3	35*(3)		
<u>1984</u>					
25 Apr	40	0	4	111	31
09 May	76	0	128*(60)	381	120
04 Jul	88	148	203*(95)	trapping completed	

- = no data.

* = the number of multiple redds counted is given in brackets.

The relationship between the number of redds counted and the number of female salmon that had passed through the trap also was examined. The range of efficiency of counting varied from 59% to 115%. The comment was made that these variations "can be traced directly to the experience of the counting personnel" (Wing (1972)); the same people did not conduct all the surveys, and personnel changed from year to year, comprising a mix of experienced and inexperienced people. Factors such as river conditions, light conditions, and algal growth also had an effect (Wing 1972). Even so, despite the wide variations in annual counting efficiency, there was a more positive relationship between the number of females through the trap and the number of redds counted by survey, than between the total number of salmon through the trap and the number of live and dead salmon counted on the spawning grounds.

In Winding Creek, in May 1980, an experienced field officer counted 171 live and dead adult salmon when 680 had passed through the trap - a counting efficiency of 25%. In this instance, the surveyor felt that the following reasons contributed to the discrepancy (Fitzgerald 1980):

- a) only one person surveying;
- b) salmon were not seen under banks and vegetation, or in deep holes;
- c) discoloured water;
- d) unfavourable weather (wind, rain).

Table 15 indicates that the number of redds counted did not increase substantially when increasingly high numbers of female salmon were present above the trap. The data were examined by regression analysis. A square root transformation of the numbers of female salmon trapped versus redd counts gave a reasonably linear relationship:

$$\text{no. of females} = (2.4 + 0.0922 (\text{no. of redds}))^2 \quad (r^2 = 0.83).$$

Linearity was improved further by deleting the 22 June 1979 data point of 259 redds as an outlier:

$$\text{no. of females} = (3.37 + 0.718 (\text{no. of redds}))^2 \quad (r^2 = 0.94).$$

Therefore, in upper Winding Creek, counts were reliably related to the number of female salmon that had passed through the trap prior to the survey date, until the number of redds reached 245. As the number

of redds increased to the maximum count of 259, when many more female salmon were present (Table 15), linearity and reliability decreased. This may have been due to the increasing incidence of multiple redds, or to the unavailability of spawning sites precluding some females from spawning (with the subsequent death of unspawned females). These effects have not been measured but either would result in a significant under-estimation of the number of female salmon present (M.J. Taylor pers. comm.).

The upper Winding Creek salmon spawning grounds usually extend about 1600 m upstream from the trap site, the upper limit of permanent flowing water varying by up to 200 m according to the dryness of the season. From 1981 to 1984, Canterbury endured severe drought conditions with annual rainfalls in all districts well below average. In 1979, when Lake Pearson overflowed, and again in 1982, when the Craigieburn River altered course to flow into the top end of Winding Creek, there was a greatly extended length of stream available for spawning. However, surveys by NCAS field officers showed that very few salmon moved upstream to utilise the extended area.

It is possible that some adult salmon may continue upstream and spawn in Craigieburn Stream when the outflow from Lake Pearson is continuous, but such spawning has not been reported. However, from time to time, salmon do occur in the lake, sometimes growing to reach angling size (25 cm). These fish probably develop from juveniles moving upstream from Winding Creek into the lake when the outlet is flowing, and becoming landlocked when the outflow dries up. A dry outlet may persist for several years.

Only a proportion of the spawning reach of Winding Creek offers suitable substrate for spawning (i.e., riffles and runs with gravels of appropriate size and composition). The principal areas utilised for spawning are the riffles with faster flows at the tails of pools and flats, along the shoulders of deeper runs, and in shallower, fast-flowing runs. According to Hobbs (1937), the gravels utilised contain material mostly no larger than 76 mm in diameter, although occasional small cobbles and boulders may be present. In areas where boulders are more numerous, the female may construct her redd in the patches of smaller gravels that occur amongst them. Figure 5 is a

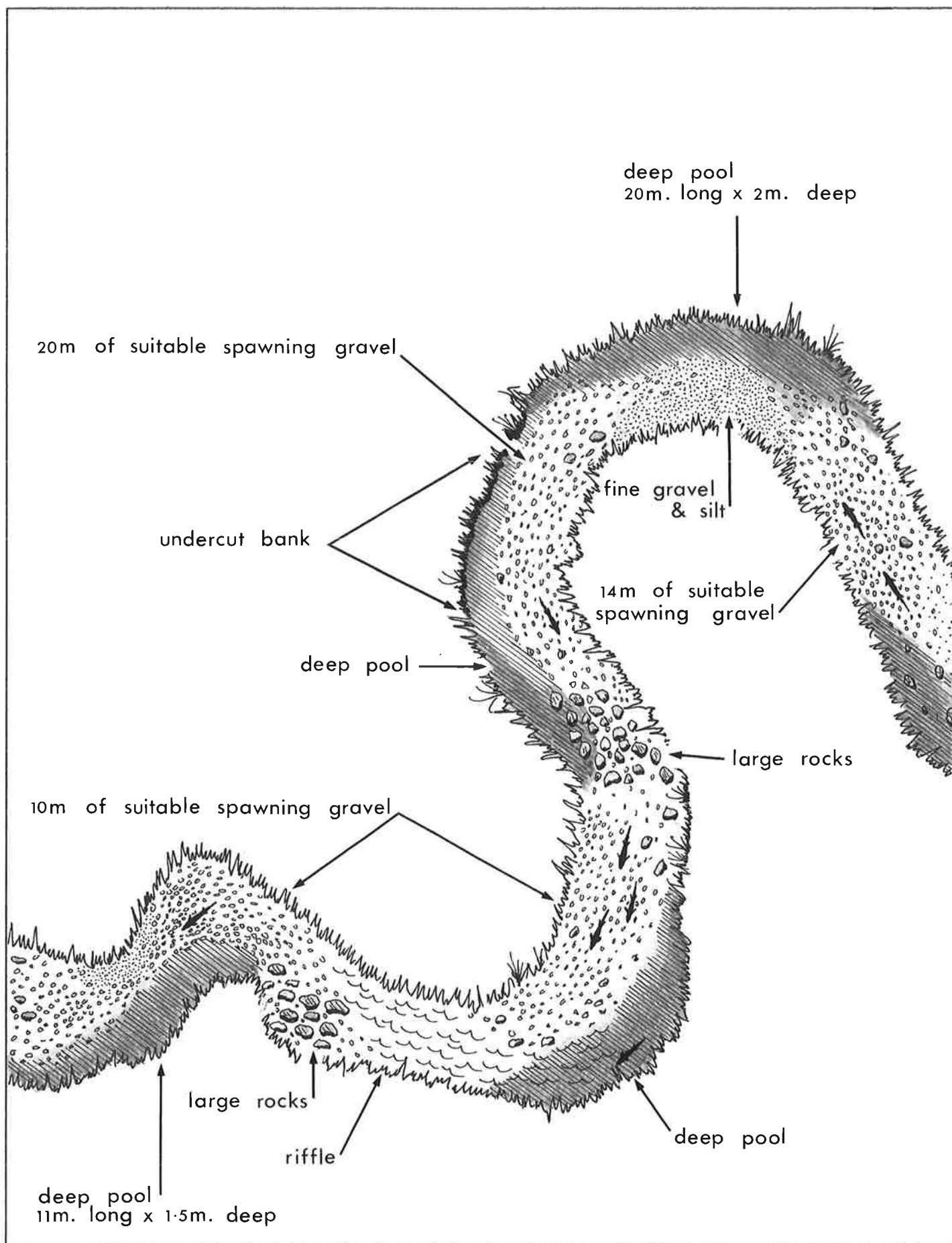


FIGURE 5. Sketch map, illustrating the nature of the upper Winding Creek spawning grounds.

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sketch map of a typical reach of upper Winding Creek, illustrating its character as assessed subjectively by observation (G. Kelly pers. comm.).

Within the spawning reach there are particular areas more favoured for spawning than other areas. These may be used by a succession of female salmon in a season, resulting in superimposition of redds (Hobbs 1937). Superimposition poses a problem for surveyors, as it is usually impossible to assess how many redds may have been constructed in these situations. All that can be recorded is the presence of a multiple redd, which is the result of the efforts of some unknown number of female salmon.

6. QUINNAT SALMON SPAWNING WATERS IN THE WAIMAKARIRI CATCHMENT

Hobbs (1937) described what was then known about quinnat salmon spawning in the Waimakariri system. Nothing was known of spawning between the Waimakariri mouth and the gorge bridge (58 km upstream), except that mature salmon had been reported very early in the Cust River (a Kaiapoi River tributary) (Fig. 1). From the gorge bridge to Springfield (about 8 km), fish were reported to spawn in very large numbers. A more limited amount of spawning occurred in the middle gorge, near Staircase and the Broken River confluence. Hobbs felt that if redds were present at all in the upper gorge (between Broken River and the Esk River), it was improbable that they were numerically significant. From the top of the gorge to the junction of the Bealey and Waimakariri Rivers, in the open, braided reaches of the upper river (a distance of 35 km), considerable spawning occurred, but began to decline noticeably upstream from the Cass River confluence.

Spawning surveys were undertaken in the Waimakariri catchment in the 1950s by University of Canterbury field parties, and by staff of the N.Z. Marine Department (Bullivant et al. 1955, Cranfield 1959). However, as Wing (1972) noted, because different survey methods were used and different areas had been surveyed, little use can be made of the data collected.

Areas within the Waimakariri catchment where quinnat salmon spawning has been identified are shown in Figure 6. In some cases the locations

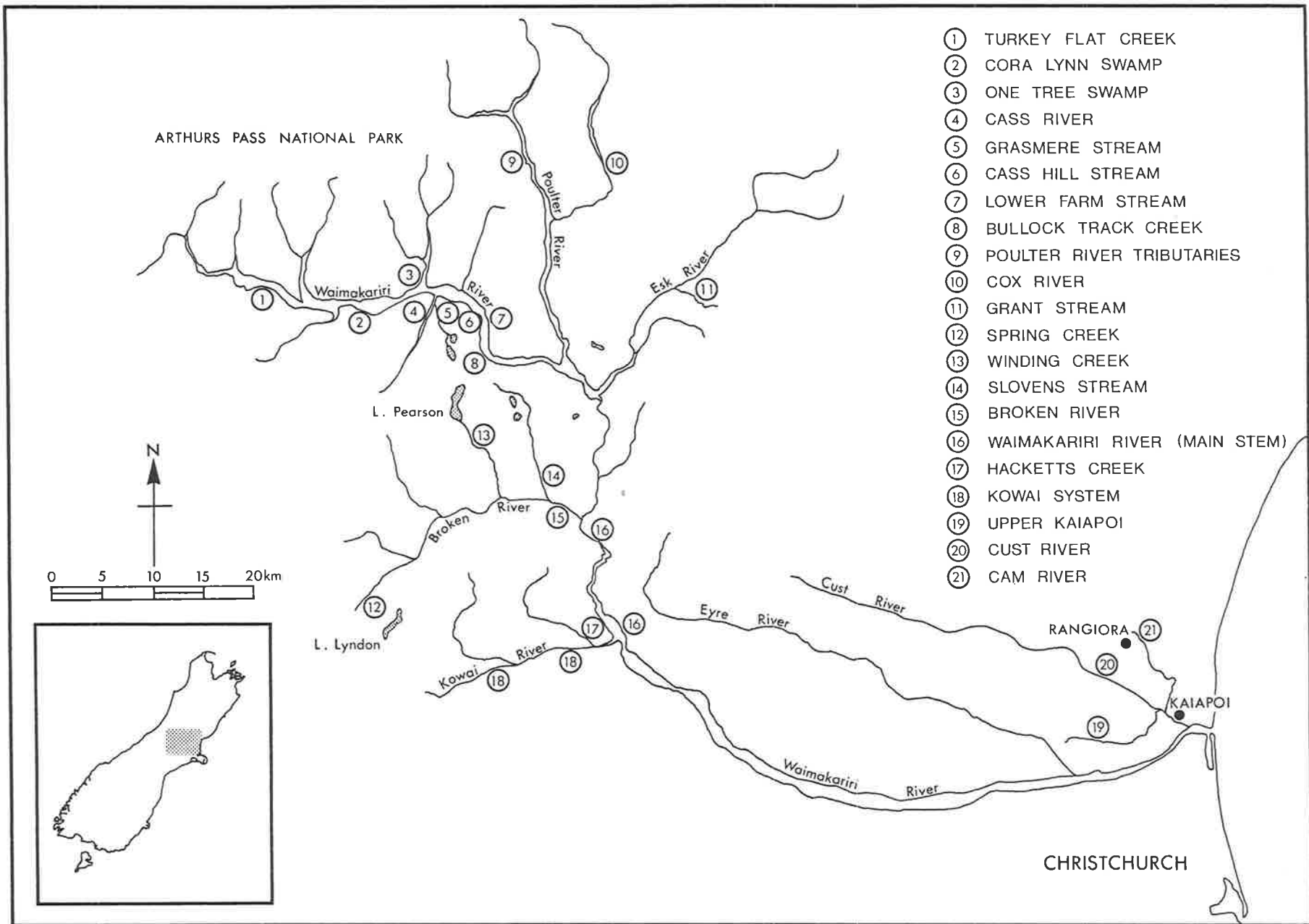


FIGURE 6. Location of salmon spawning areas in the Waimakariri River system.

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are specific, in others they are general. The figure does not purport to identify every place within the system where salmon may, or do, spawn. For example, no spawning is shown for the mainstem Waimakariri between the mouth and the lower gorge bridge, yet spawning has been reported around the mouth of the Eyre Diversion (D. Anderson pers. comm.), and a few redds have been sighted in side braids some kilometres below Browns Rock. Similarly, spring and underflow seepages about, and downstream from, the mouth of the Kowai River are invariably used for spawning, but are not identified separately on the figure. They are within the reach between the lower gorge bridge and Springfield where Hobbs (1937) mentioned spawning was reported in the 1930s, and where spawning has been observed recently (see later this section). There are other places where spawning has been noted, but where access is dependent on river discharges. It is known that in 1980, 1982, and 1984, lack of rain in the headwaters caused the mainstem Waimakariri between Cora Lynn and the Bealey to flow beneath the surface gravels on occasions during the spawning season, thereby preventing salmon access to Turkey Flat, and restricting access to waters such as Lower Farm Creek, One Tree Swamp, Cass Hill, and the Cass River/Grasmere system (North Canterbury Acclimatisation Society Annual Reports).

Although salmon are known to spawn in tributaries of the Kaiapoi River, and have probably utilised these waters for many years (Hobbs 1937), they have not been surveyed systematically, and knowledge of these spawning grounds is fragmentary (Hardy 1988). Spawning in the Ohoka Stream, Cust Main Drain, Cust River, and the Northbrook branch of the Cam River has been observed.

Surveys in the Waimakariri basin have been carried out by experienced NCAS field officers, usually working singly, or, infrequently, with a companion. Different field officers conducted the surveys in various years. The methods employed were to survey a water at intervals over each spawning season, identifying and counting redds, and live or dead salmon, and recording factors affecting the survey. An effort was made to visit each water at a similar time each year, although this was not always possible. Neither was it always possible to maintain the same frequency of visits. Similar areas were surveyed from year to year, but sometimes surveys extended beyond these areas, with counts of the regular and extended areas being combined or not

clearly separated in the records. Other factors (e.g., weather, poor visibility, droughts, floods) influenced the efficiency of surveys and numerous variables complicate the records. In addition to the problems of multiple redds, or extensively spawned-over areas, and the demonstrated limitations of visual surveys in giving reliable counts of salmon, these variables make a detailed analysis of the records extremely difficult, if not impossible.

Nevertheless, the surveys provide an approximation of the relative annual spawning abundance and relative importance of each of the spawning waters (Table 16). The data show a general correspondence in spawning abundance between all the Waimakariri spawning waters in the same year, i.e., in 1979, when the number of females trapped at Winding Creek was highest, the overall redd count in the other waters was also highest, and in 1982, when the number of females trapped at Winding Creek was lowest, the overall redd count in the other waters was also the lowest. This suggests that whatever factor, or factors, affect spawning abundance in any season (measured as number of females or redds counted), spawning areas in the Waimakariri catchment are all affected similarly.

The stable, spring-fed streams of the Poulter River, together with Winding Creek, are the most significant quinnat salmon spawning grounds in the Waimakariri catchment. (It is noteworthy that neither area offers the extent of spawning available in either the Glenariffe Stream or Hydra Waters of the upper Rakaia River.) The next most significant areas, Cass Hill and Cora Lynn, lie within the flood bed of the Waimakariri, and are, from time to time, affected by the vagaries of the river's floods or droughts. Cass Hill is particularly vulnerable to damage from large floods spilling over into the system. Spring Creek is a minor spawning area, seldom supporting more than a small number of fish. Access may be limited by low flows in the upper reaches of Broken River during drought conditions. Turkey Flat also seems to support only a small number of spawners. Periodic cessation of surface flow in the Waimakariri above Cora Lynn may sometimes deny fish access. The NCAS field officers' reports describe problems with heavy aquatic weed growth in some seasons, and with grazing cattle trampling the spawning gravels. Cattle pastured out on unfenced river flats (e.g., at Cora Lynn and Cass Hill), trample and damage spawning grounds, and have

TABLE 16. Maximum redd counts recorded in North Canterbury Acclimatisation Society (NCAS) annual surveys of spawning waters in the Waimakariri catchment, 1979 to 1986. (Source: NCAS Annual Reports.)

Location	1979		1980		1981		1982		1983		1984		1985		1986	
	s*	m*	s	m	s	m	s	m	s	m	s	m	s	m	s	m
Cass Hill	153	8	146	12	110	3	52	2	50	5	117	16	182	1	208	3
Grasmere	83	7	24	-	62	-	17	-	23	3	65	2	61	-	37	-
Slovens Stream	36	-	75	-	51	1	5	-	9	3	30	-	25	-	22	-
Cora Lynn	210	1	98	-	184	2	34	3	86	8	162	12	172	4	200	1
One Tree	123	7	108	4	119	6	48	5	34	18	59	16	176	5	72	1
Lower Farm	38	-	62	-	32	-	3	-	7	4	49	-	2	-	26	-
Turkey Flat	48	-	18	-	25	-	4	-	2	-	12	-	16	-	7	-
Spring Creek	7	-	7	-	30	-	NS	-	14	-	24	-	2	-	-	-
Winding Creek	280	74	154	5	240	4	32	3	NS	-	108	95	223	4	SA	-
Poulter (spring-fed)	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	800	-	559	-
	978	97	692	21	853	16	195	13	225	41	626	141	1659	14	1131	5
Winding Creek trap counts (females)	1460		401		535		51		157		525		NS		NS	

s* = number of single redds.

m* = number of multiple redds.

- = none.

NS = no survey.

SA = survey abandoned, owing to bad weather.

concerned the NCAS for some time. With the co-operation of the runholder and the (former) Lands and Survey Department, fencing of spawning areas susceptible to cattle entry at Cora Lynn has been initiated recently (NCAS Annual Report 1986).

Overall, quinnat salmon spawning in the Waimakariri catchment is distributed over a number of tributary streams, most of which are minor waters, supporting variable, generally small, numbers of breeding fish in a season, and most having periodic limitations on their use, owing to drought or low flows. Collectively, this aggregation of minor waters comprises about 42% of the spawning occurring in all the surveyed waters, with the Poulter River flats spring-fed streams (35%) and upper Winding Creek (23%) accounting for the remainder. How much this represents of the total quinnat salmon spawning occurring in the entire Waimakariri River system has not been determined. NCAS field officers have reported redds in mainstem sections of the Waimakariri adjacent to the surveyed waters, but usually only in times of low flow. Whether mainstem spawning takes place in all years, but is only observable at low, clear flows, is an open question. How successful it is, is also unknown.

One other apparently important spawning area is the Kowai River system, in particular Hackets Creek, and the flood bed of the Waimakariri around and downstream from the Kowai River mouth. Occasional visits have been made to the area, but salmon spawning activity has not been surveyed regularly. In May 1983, MAF staff noted quinnat salmon spawning in the lower Rubicon River (a small spring-fed stream entering the Kowai River), Hackets Creek, the "lead in" to Hackets Creek, around the mouth of the Kowai, and in seepage streams emanating from Cabbage Tree Flat (adjacent to the Kowai mouth) and flowing into the Waimakariri flood bed. MAF staff visited Hackets Creek on 26 May 1986, during a search for tagged salmon carcasses. In an incomplete survey of the length of the creek, 104 redds, 105 live salmon, and 303 dead salmon were counted. A large proportion of the redds were multiple redds.

Hackets Creek is very difficult to survey. Parts of the lower reaches are overhung with thick scrub, the middle reaches are deep and narrow, and the upper reaches, where most spawning seems to occur, have

heavily sedimented and weedy gravels. Carcasses are quickly obscured by sediment, and separate redds are not easy to identify. In recent years, the flow regime and substrate character of Hackets Creek have been adversely modified by swamp drainage and land development in the upper reaches, and by misguided "stream improvement" work, purportedly to improve the stream for salmon spawning.

Clearly, the area about Kowai Bush has considerable importance for salmon spawning in some years. Personal observations of the area at times of low flow in the Waimakariri River indicate a tendency for the mainstem channel to occupy the flood bed on the northern (true left) side of the river, well away from the mouth of the Kowai River. Perhaps an abundance of salmon spawning activity in the Kowai Bush area is dependent on the Waimakariri River mainstem channel occupying the south side of the flood bed, or on higher river discharges, to attract salmon to the area.

7. SPAWNING ENHANCEMENT OF SLOVENS STREAM

In Section 3, mention was made of an NCAS project to improve the spawning potential of Slovens Stream, and of the existence of a cataract that denied salmon access. The project, involving the planting of hatchery-reared juvenile salmon in Lake Hawdon, was carried out from 1962 to 1968, but was apparently unsuccessful.

The problem of the cataract denying fish access to approximately 11 km of creek, which contains potentially usable spawning gravels, had not been resolved by 1979. The NCAS then decided on a six year trial period involving the annual transfer of 100 pairs of spawners from Winding Creek to the area upstream of the cataract in Slovens Stream, to see if they would spawn successfully. Because of a late decision to proceed, only 29 male and 33 female salmon were transferred from the Winding Creek trap to Slovens Stream by NCAS and MAF staff on 4 June 1979. Inspections on 22 and 26 June showed that eight redds had been made. Only 25 pairs were transferred into Slovens Stream between 7 and 9 May 1980, because of the small spawning run into Winding Creek (Table 4). A survey made on 20 May revealed that 10 redds had been constructed in the release area. In 1981, a further 30 pairs were

transferred and released about 1 km below the Craigieburn Homestead. Eleven redds were later counted there.

No transfers were made in 1982 or 1983 because the spawning run into Winding Creek was again low (Table 4). However, the NCAS was now satisfied that successful spawning could take place in the hitherto inaccessible upper reaches of Slovens Stream, and turned its attention to investigating the provision of unimpeded access over the cataract for salmon. In April 1984, an NCAS/volunteer working party endeavoured, with partial success, to reduce the height of the cataract, but later surveys found no evidence that any adult salmon had managed to ascend to the upper reaches.

In January 1984, a further attempt was made to enhance the Slovens Stream salmon run by releasing 36 000 juvenile salmon (average weight 21 g) reared by MAF at Silverstream. These fish were liberated near the Craigieburn Homestead. They were not marked, so that their success would only be discernible from a significant increase in the numbers of salmon surveyed on the spawning grounds in the lower reach (downstream from the cataract to the junction of Slovens Stream with Broken River) in subsequent years. No significant increase has been observed. Subsequent surveys have shown no more than a high annual variability in the number of salmon spawning, similar to the variability observed in earlier years. However, during the 1986 spawning season, MAF staff collected eight adult quinnat salmon carcasses from the lower reach. An examination of the scale nuclei found that five of these fish had a hatchery-type juvenile life history (T. Washbourne pers. comm.). This interesting observation does not, however, establish which hatchery or release these adults originated from.

Following the transfer of salmon to Slovens Stream between 1979 and 1982, a small number of quinnat salmon occurred in anglers' catches in Lake Hawdon during the 1983 and 1984 fishing seasons. Quinnat salmon do not normally occur in the lake, and it is presumed that those caught had migrated upstream as juveniles to become short-term residents in the lake.

8. DISCUSSION

An examination of the characteristics of the Sacramento River quinnat salmon transplanted into New Zealand waters may provide some understanding of the nature of the Waimakariri stock. The eggs imported into New Zealand from the McCloud River salmon breeding station (Baird hatchery) during 1875-1878, were from what was then termed a "summer run", i.e., the adults entered from the sea in the spring and early summer, migrated through the warm waters of the lower Sacramento River to the cool, upper tributaries such as the McCloud to hold over the summer, and spawned in late summer/early autumn (Stone 1885, 1896; Green 1887). Since that time, this run in the Sacramento has been re-defined as a "spring run" (Clark 1929, Hallock and Fry 1967), since the classification is now applied to the season of entry from the sea and not the season in which the fish spawn. The Sacramento River then, as now, had three distinct runs of salmon: a fall run, which was by far the most numerous, a spring run of lesser abundance, and a minor winter run. These three runs still exist in the same relative proportions (Hallock and Fry 1967), but are much depleted in numbers and in distribution as a result of commercial exploitation and radical modification of their environment by European settlement and land development. Because the spring run migrated through San Francisco Bay and into the two Central Valley rivers (Sacramento and San Joachin) in good weather and steady river-flow conditions, and was present for an extended period, it was the principal run fished commercially. This catch sustained the world's first large-scale salmon canning industry (Clark 1929).

As the term implies, the "fall run" entered the river in autumn and early winter. These quinnat did not linger in their migration, but travelled swiftly through the mainstem river as it rose with commencement of the annual rains in the headwaters, arriving on the spawning grounds fully mature and depositing their eggs without delay. In the McCloud River, fall-run spawning began two to three weeks after the spring run had finished. In the period of operation of the Baird hatchery reported by Stone (1885), only the spring run was propagated artificially. Although the fall run comprised many more salmon than the spring run, it could not be fished effectively because fresh and flood

flows in the river were too strong to operate nets and traps. Because the fall run was regarded as the "seed run" in the river, it was also protected by a closed fishing in the peak migration month (California State Fisheries Commission Biennial Report 1876-77).

The eggs imported into New Zealand between 1901 and 1907 were from a fall run. (Ayson (1910) called this a winter run, since the bulk of the spawning takes place in early winter.) Although these importations are credited as having come from Baird hatchery (e.g., Thomson 1922), there is doubt that they were from the McCloud River fall run. It is more probable that they came from another, larger, U.S. Fish Commission hatchery on Battle Creek, renowned for the tens of millions of eggs collected annually from its fall run. Battle Creek is a Sacramento River tributary, some 70 km closer to the sea than McCloud River. Battle Creek hatchery was visited and described by Ayson in his report to the New Zealand Government (Ayson 1899) on an evaluation of overseas sources of exotic fish species that could be introduced into New Zealand.

In general, spring-run quinnat salmon enter fresh water in prime condition, their bodies fully stored with fats to sustain them through the many weeks, or several months, waiting in the river until they spawn (Hagen 1953). At the time of entry into fresh water, the female's eggs are small and immature. By comparison, fall-run quinnat usually have passed peak body condition when they enter from the sea; the quality of their flesh is deteriorating and sexual development is advanced, since spawning occurs within days, or, at the most, within a few weeks.

Green (1887) reported that fry hatched from eggs taken from the spring run, and planted out into the McCloud in the autumn, remained in the river until the following autumn when, at a length of 100-175 mm, they disappeared sea-ward on a rain-swollen river. Rutter (1904) studied the natural history of Sacramento River quinnat salmon, reporting "many [young salmon] ... probably 10 000 to the mile ... remain in the pools in the headwaters all summer and fall" until December, when the rivers rose and the major sea-ward migration of fry occurred, reaching "brackish water when three to five months old, according to the distance they have to go". Wales and Coots (1954)

examined fall-run quinnat spawning in Fall Creek, a tributary of the Klamath River, Northern California. They found that the juveniles emigrated from the creek, some as yolk-sac fry, but mostly as fry and fingerlings (27.5-57.5 mm in length), within three months of emergence.

These observations, and others elsewhere, indicate that spring-run quinnat juveniles mostly spend one year, or more, in fresh water before migrating to sea (i.e., they have stream-type scale nuclei), and fall-run juveniles mainly enter the sea within the first year of life; those entering within days or weeks of emergence have ocean-type scale nuclei, those entering after some months have intermediate-type scale nuclei. Spring-run quinnat also are considered to be the fish that run farthest upstream in large rivers to spawn (e.g., 2500 km in the Columbia River), whereas most fall-run quinnat spawn within about 300 km of the sea, often in streams only a short distance above salt water (Hagen 1953). In the Sacramento River, winter, spring, and fall runs utilise the upper tributaries (i.e., Little Sacramento, McCloud, and Pit Rivers), within about 500 km of the salt waters of San Francisco Bay. Several lower tributaries (e.g., Feather River, Butte Creek, Battle Creek) also have both spring and fall runs. Thus, it seems reasonable to assume that the distance that the Sacramento runs migrate from the sea to the spawning grounds is not the principal reason for the difference in run timings.

Nothing is known about the age structure of the particular spring or fall run populations that our stocks originated from. The method of aging fish by reading the growth history recorded in their scales was not then in use. After Gilbert (1914) applied the method to Pacific salmon, Clark (1929) was able to report on the age structure and juvenile life history of a composite sample of 456 Sacramento-San Joachin adult quinnat salmon collected by netting in 1919, and another sample of 1291 fish collected in 1921. Four-year-old fish were the most abundant age class (49% in 1919 and 44% in 1921), followed by 5-year-old fish (24% and 49%), 3-year-old fish (22% and 12%), 6-year-old fish (4% and 0.7%), and 2-year-old fish (0.2% and 2%). The age structure of quinnat salmon transplanted into New Zealand waters has one less year class (no 6-year-old fish have been recorded), with dominance biased towards 3-year-old fish, but shifting between 3-year-olds and 4-year-olds, rather than between 4-year-old and 5-year-old fish, as in Clark's (1929) samples.

There is almost no information about the size of the salmon stripped at Baird hatchery, except that Stone (1886) mentioned that the average weight handled "in the last few years is estimated at about 13 lbs [5.9 kg] each", and he recorded the average weight of 82 fish after they had been spawned in August 1878 as 8.25 lbs [3.75 kg]. (It is not clear whether the 13 lb weight mentioned related to the weight of fish before or after spawning; from the context I suspect it was before spawning.) In Clark's 1921 net samples (which he considered to be more reliable because it was a bigger sample than that taken in 1919), the mean fork lengths of the age classes identified were (number of fish in sample in parentheses): 2-year-old = 54.6 cm (28); 3-year-old = 73.1 cm (148); 4-year-old = 94.5 cm (572); 5-year-old = 103.6 cm (534); 6-year-old = 106.7 cm (6). These mean lengths are quite similar to those determined for 2-year-old, 3-year-old, and 4-year-old age classes returning to Glenariffe Stream (Flain 1982), but data for 5-year-olds are too few for comparison.

Ninety percent of Clark's (1929) adult salmon samples had an ocean-type juvenile life history, which, in the convention of the time, included nuclei showing estuarine and ocean growth and nuclei showing intermediate-type growth.

Stream-type and ocean-type nuclei were considered by Rich (1925) to represent separate life histories, created by different environments, with higher proportions of the stream-type indicating a "harsher" environment. Northern rivers and headwater tributaries were thought to be harsher environments than southern rivers and lowland tributaries. Healey (1983) proposed that, because of evidence of "consistent differences between stream and ocean type chinook [quinnat] in adult run timing, in the distribution of their spawning populations along the coast and within river systems, and in their ocean distribution and migration", an evaluation of the available evidence indicated that the two life history types appeared to be distinct races. The matter is unresolved.

Assuming that stream-type and ocean-type life histories do represent genetically-different spawning runs, such as spring and fall runs, a possible reason for the occurrence of the high proportion of stream-type scale nuclei in the Waimakariri River samples (Table 13), Waitaki River

samples, and, albeit at a lower incidence, in the Rangitata and Rakaia samples (Table 14), may be that this type of life history represents spring-run juveniles. This then begs the question of the continued existence of a spring-run stock, since it is generally considered that the initial introduction of quinnat salmon into New Zealand failed (e.g., Thomson 1922). Stokell (1962) questioned what seems to be more an assumption of failure than a factual evaluation, since there appears to be more evidence supporting the presence of quinnat prior to the N.Z. Marine Department's 1901-1907 introductions, than evidence proving failure. I concur with this view.

The apparently high incidence of stream-type nuclei in the Waimakariri scale samples, compared with those from the Rakaia and Rangitata Rivers, could be no more than an artefact resulting from a relatively small sample of scales examined over a widely-separated period of years. However, this seems unlikely, since James and Deverall (1987) have demonstrated a high incidence of stream-type nuclei in the Waitaki River, that differs significantly from the incidence in the two mid Canterbury rivers (Table 14).

Possibly, the incidence of stream-type nuclei has nothing whatsoever to do with racial characteristics, but is the product of differing environmental conditions, e.g., those affecting juvenile residence. It may reflect the relative stability or instability of the habitats utilised within each river for juvenile rearing, or the seasonal influence of variable flows acting differentially upon these habitats, i.e., the "harshness" factor suggested by Rich (1925).

Presumably, if large floods are a significant factor in stream residence time, or on survival of migrating juveniles, these would act upon the juveniles in the Rangitata, Rakaia, and Waimakariri Rivers in a similar manner, and would have the greatest effect where these rivers are swiftest and most unstable, i.e., in the braided alluvial plains reaches between the primary spawning tributaries and the sea, rather than the harsh headwater tributary environmental conditions postulated by Rich (1925) for quinnat in their native range. If juveniles with both stream-type and intermediate-type nuclei are produced in these reaches, floods must have a differential effect on the various juveniles then in residence, or, alternatively, the juveniles in residence at any

one time are affected differently to those in residence at some other time. This is quite possible, since any juvenile migration period will usually alternate variably between fresh/flood and steady-state flow conditions, allowing the juveniles periods of poor or good growth before entering the sea. While this situation would permit the formation of an intermediate-type juvenile life history, those juveniles that produce stream-type nuclei must endure all the freshes and floods occurring in the reach over a full year. As they grow bigger, they may be able to withstand the effect of these more effectively, and remain in situ. Alternatively, stream-type life histories may develop in juveniles that remain either within the stable spawning tributaries, or in some other reach, or reaches, of the river system where floods have least effect over the year.

Information from the Glenariffe Stream (Unwin 1981) indicates that the proportion of juveniles that emigrate as yearlings is quite small. Projected over the whole array of stable tributary waters in the Rakaia system, would this level of juvenile yearling production equate with the incidence of stream-type life histories recorded for the river? If it was the case, then a similar but greater array of stable waters for yearling survival should exist in the Waimakariri River system to account for the significantly higher incidence of stream-type life histories recorded (Table 13). It is by no means clear that such an array exists in the Waimakariri tributary system, unless the extensive gorge reaches, with their permanently-formed pools and deep runs of significantly less gradient than the headwater and plains reaches, provide some part of it.

The other Canterbury river with a known, high incidence of stream-type nuclei, the Waitaki River, has no gorge. The length of river utilised for salmon spawning and juvenile rearing is, in the main, composed of alluvial, braided reaches. However, the Waitaki is extensively developed for hydro-electric power generation in its middle and upper reaches. A series of mainstem dams provide considerable water storage under controlled release, thus significantly reducing flood peaks and discharges, and creating a steadier flow regime in the lower part of the river. This may contribute to the high incidence of stream-type scale nuclei found there.

Apart from the historical record of the early liberations, and the incidence of stream-type nuclei, the occurrence of adult salmon returning to east coast Canterbury rivers from mid-November onwards in some years (Davis et al. 1986) also supports the existence of spring-run quinnat. Further, it is well known that adult salmon accumulate in the higher river and gorge pools during summer, presumably holding until the onset of full maturity before moving into the tributaries and onto other grounds to spawn. Stone (1896) and Hagen (1953) both mentioned the severe difficulties and mortalities often experienced in holding sexually immature spring-run quinnat in confinement, to enable them to ripen for use in artificial propagation. This also has been experienced at the Silverstream hatchery, in attempting to hold small numbers of adults which arrived before the end of March (Hardy 1988). Similarly, a small number of salmon arrive at the Glenariffe trap early in the season, and an unduly high rate of mortality has been observed in them (S.P. Hawke pers. comm.).

However, other than the occurrence of small numbers of early-arriving salmon, there is no evidence of any separation in spawning that would identify spring or fall runs. A possible reason may be that such evidence has not been looked for. Very few of our spawning runs have been examined as closely as those into Glenariffe Stream and Winding Creek. Even there, the emphasis has been on obtaining information about the fish as they arrive at the spawning grounds, rather than on a detailed examination of the timing and duration of spawning, which would reveal any discontinuity attributable to distinct racial spawning. The Glenariffe quinnat spawning run is regarded as being essentially a fall or autumn run (Field-Dodgson and Galloway 1985). It is clear from the trapping records in Winding Creek, Glenariffe Stream, and Deep Stream (upper Rangitata River) (Davis et al. 1986), that mid autumn to mid winter is the time that most salmon enter these grounds and spawn. Possibly there is a need to look further afield to identify the presence of a spring run. For example, do the spawning runs into the Poulter River spring-fed streams, or the Cox/Poulter, or other Rakaia spawning tributaries (e.g., Goat Hill Stream, Wilberforce River; Harrison's Bight Stream, Lake Heron) exhibit different, perhaps earlier, timings? At present this is not known. From Green's (1887) and Stone's (1885, 1896) observations of the time-separation of spring-run and fall-run spawning in the McCloud River, the hiatus is quite brief - a matter of

two to three weeks. In this report, evidence has been given that there is more than two week's mean difference in the mid points of the Winding Creek and Glenariffe Stream spawning runs. Why this should be so is difficult to explain, if both runs were derived from the same parent stock and spawn in co-joining, and essentially physically similar, river systems. Since such a difference does exist, it follows that spawning runs elsewhere in Canterbury/Otago rivers also may exhibit different timings that may have some significance. Perhaps, if spring-run quinnat salmon do exist, there are too few to distinguish them from the mass. In their native habitat, spring runs are numerically smaller than fall runs.

In the Waimakariri, the assessment of run timing, the pattern of entry from the sea, and the migration time upstream to the spawning grounds is empirically based on angler observations, on an experimental netting undertaken in the Waimakariri estuary in 1928, and on footnotes to the 1933, 1934, and 1935 netting returns reported by the N.Z. Marine Department. In 1928, 33.3% of the experimental net catch of 454 salmon was taken over five days between 1 March and 21 March. In 1933 and 1934, the nets were fished from about the middle of January until about the middle of April, with 2-3% of the catch taken in January, 17-34% in February, 62-79% in March, and 2-19% in April. In 1935, the distribution of the catch was similar, except that floods in April prevented any netting. Flooding from mid April 1934 also curtailed that year's netting.

These catches support the view that most fish run in from the sea in autumn, particularly in March. Operation of the nets frequently was constrained by floods, which may occur in any month and may persist for long or short periods. Since catching an adequate number of salmon each season affected the livelihood of the netters, it is possible that experience taught them it was not worth the effort to fish earlier than mid January or after mid April, even when river conditions were suitable. Certainly, observations reported by the N.Z. Marine Department from various rivers in those times generally indicated that the main runs occurred in autumn, but also that it was not uncommon for numbers of salmon to be running in late spring and early summer and, less frequently, in winter, until June.

The river and ocean environments occupied by the Waimakariri quinnat salmon stock (and other Canterbury/Otago river stocks) are different from the environments occupied by the parent Sacramento stock. It is probable that our transplanted stock is evolving as it adapts to the new environment, and therefore has characteristics that identify it specifically to New Zealand. Clearly, there is much yet to be learned about the life history and behaviour of quinnat salmon in this country, particularly the marine phase of the life cycle.

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