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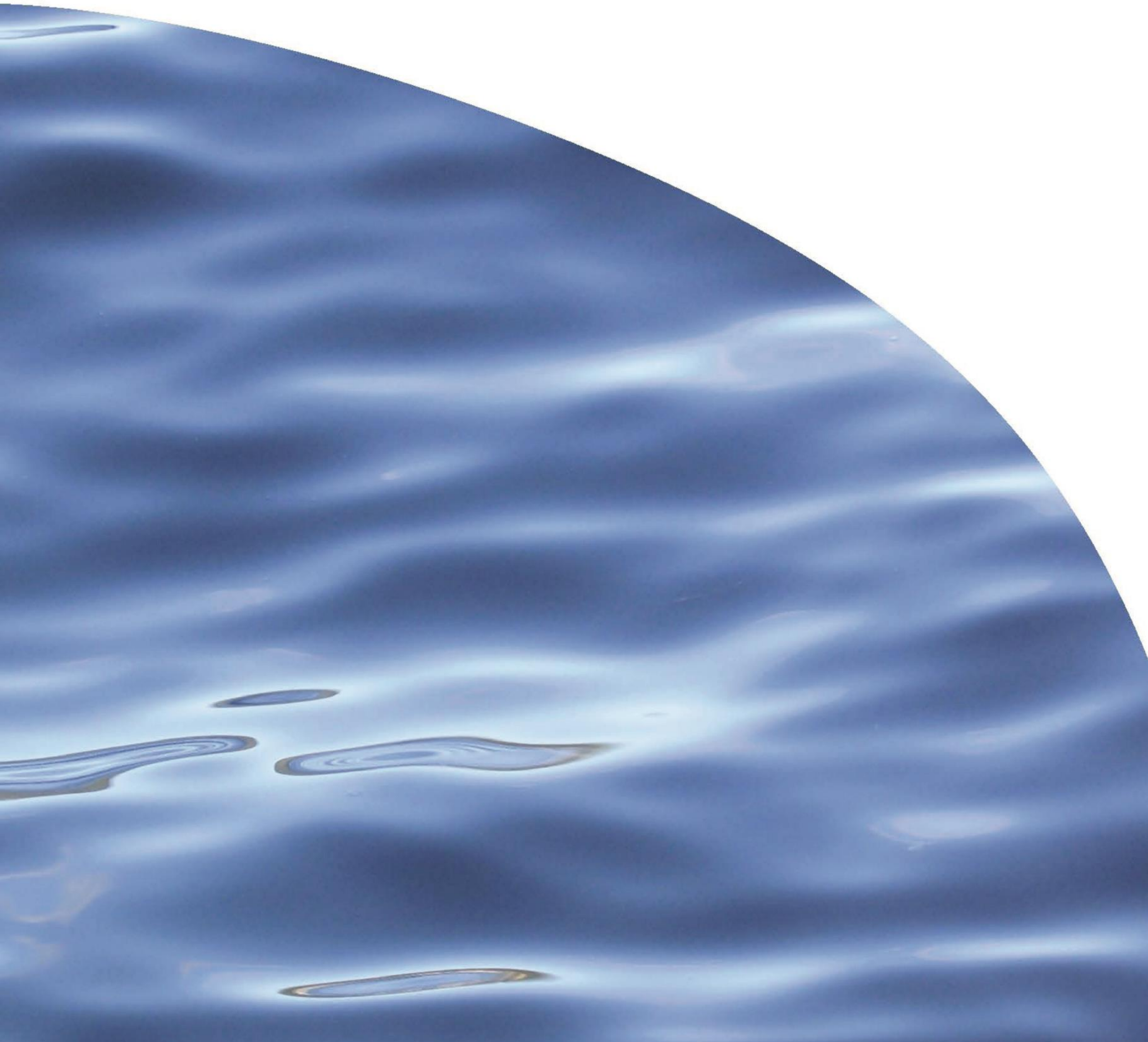
REVIEW OF HISTORICAL HATCHERY RELEASES OF CHINOOK SALMON IN NEW ZEALAND



REVIEW OF HISTORICAL HATCHERY RELEASES OF CHINOOK SALMON IN NEW ZEALAND

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EXECUTIVE SUMMARY

The operating consent for the Roxburgh Dam requires a salmon fishery mitigation and enhancement programme. However, attempts to meet this requirement by releasing yearling Chinook salmon sourced from hatcheries outside the Clutha catchment have not resulted in any significant increase in salmon runs since the programme began in 2010. This report, commissioned by Contact Energy, reviews salmon returns to the Clutha River / Mata-Au (hereafter Clutha) and assesses historical data for releases into other New Zealand rivers to determine guidelines for improving the performance of Contact Energy's salmon fishery mitigation programme.

We used data on percentage survival to adulthood for 541 releases of salmon from 36 locations in 13 catchments on the east coast of the South Island to characterise variation in survival in relation to factors such as year of spawning (brood year); river of origin; age and size at release; and release location. These data were dominated by releases from Glenariffe Stream in the upper Rakaia River, but also included 56 releases into the lower Clutha.

Return rates[1] ranged from 0 to 7.55%, with a median of 0.33%. Survival was strongly skewed towards lower values, with 30% of releases yielding return rates below 0.1%.

Return rates for releases from Glenariffe Stream showed a strong tendency to increase with mean release weight, partly offset by a tendency to decline for release dates later in the calendar year. Survival varied by a factor of 93 among brood years. After adjusting for the influence of size and date at release, we estimate that survival rates for Clutha releases were 14.6 times lower (median value) than Glenariffe releases over the 12-year period of common record for both locations.

New Zealand release programmes that used established local hatcheries and broodstock sourced from locally returning adults tended to be more successful than programmes lacking an established hatchery and / or strong natural spawning runs.

Based on these findings, we recommended that Contact Energy:

- continues to develop concept plans, an operating framework, and a budget to establish a salmon hatchery near the Roxburgh Dam capable of sustaining well-targeted experimental release of salmon smolt annually (150,000–200,000) during a 10-year hatchery establishment phase
- in consultation with fishery managers and other stakeholders, revises its expectations of survival rates likely to be achievable on the lower Clutha River. Anticipated survival rates exceeding 1% may be achievable in an exceptional year, but a more realistic target would be 0.1–0.2% in an average year, and as low as 0.01% in a poor year

[1] The terms 'return rate', 'survival rate', and 'survival' are used as synonyms throughout this report, according to context, to refer to the number of returning adults from a given release expressed as a percentage of the total number of fish released.

- ensures that all releases are batch marked, and that returns are monitored via appropriate harvest surveys, thereby enabling the results of differing release strategies to be measured and compared
- quantifies the relationships between survival to adulthood, and size and age at release, with the dual aims of (a) characterising the extent to which survival varies among brood years, and (b) informing cost-benefit analyses of competing release strategies
- establishes a locally adapted, Clutha-specific broodstock by sourcing ova from adult salmon returning to the lower Clutha
- reviews the success of hatchery releases (and any other associated fishery enhancement activities) after 10 years, to determine how and to what degree hatchery releases can enhance the lower Clutha sea-run salmon population.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Adipose fin	Soft fleshy fin just in from of the tail fin.
Anadromous	Migrating from the marine to the freshwater environment to spawn.
Carrying capacity	Maximum population size that can be supported (indefinitely) by a particular environment.
Enhance	To increase in quality, value, etc.
Fecundity	Fertility or the ability to produce an abundance of offspring.
Fitness	Average number of progeny (offspring) per natural spawning adult.
Genotype	The genetic constitution of an organism, as opposed to its physical appearance (phenotype).
Homing	To return to the place of origin, e.g. the return of salmon from the ocean to the same river where they were born (hatched).
Imprinting	A process of rapid learning of highly specific information (e.g. chemical odours of a stream) during a critical time period, e.g. juvenile rearing / smolt stage.
Phenotype	The physical observable appearance of a specific genotype in conjunction with the environment influences. Variation in phenotype is an important element in evolution.
Philopatric	Homing to their natal stream.
Recover	To get back or regain.
Redd	A nest dug into gravel in a stream bed by an adult female salmon / trout while spawning.
Rehabilitate	To re-establish good health.
Restore	To bring back to a previous or healthy condition.
Smolt	A silvery young salmon that is physiologically adapted for the marine environment.
Stocking	The release of hatchery fish in a natural river system.
Supplementation	A hatchery programme operated with the objective of increasing abundance of natural production.
TAS	Time And Size at release experiments that released fish tagged to identify the date and mean size (weight) at release.

1. INTRODUCTION

1.1. Background

Hydro-electric power stations have adversely affected the Clutha / Mata-Au River (hereafter Clutha) sports fishery for sea-run Chinook salmon (*Oncorhynchus tshawytscha*). Consequently, resource consents for operating the Roxburgh Dam require the consent holder (Contact Energy Ltd., hereafter Contact Energy) to implement a sports fisheries mitigation and enhancement programme. Specifically, Clause 17(a) of Resource Consent 2001.394 states: Discharge Permit to operate the Roxburgh Dam requires Contact Energy in consultation with the Otago Region of Fish & Game New Zealand (FGNZ) to manage sport fisheries in the lower Clutha from Roxburgh to the sea so that:

> *(i) A self-sustaining population of salmon with a target spawning run of approximately 5,000 salmon is established, and*
>
> *(ii) Sports fish habitat is generally enhanced.*

Since 2010, Contact Energy has attempted to meet the first of these requirements by releasing yearling Chinook salmon smolts, sourced from hatcheries outside the Clutha catchment, into the lower Clutha River, in the hope of boosting stocks of returning adults. A total of 895,000 fish have been released to date, increasing from 30,000 in 2010 to 200,000 in 2016 (Table 1). However, angler catch rates and spawning surveys indicate that returns of adult fish remain small, below expectations of a 0.5-1% survival to adulthood and total annual returns of up to 5,000 fish. A recent Fish & Game New Zealand review of the current release programme notes that 'Despite some promising signs particularly in the 2014 season, results from the past two seasons indicate that enhancement efforts have not resulted in any significant increase in salmon harvest, even with increasing numbers of salmon smolt released' (Trotter 2016).

Table 1. Chinook salmon smolt released into the Clutha River from 2010 to 2016.

Year	Number released	Number fin clipped	Proportion marked	Source	Estimated % return*
2010	30,000	30,000	100%	North Canterbury Fish & Game	0.02-0.20
2011	80,000	30,000	37.5%	North Canterbury Fish & Game	0.03-0.30
2012	110,000	30,000	27.3%	North Canterbury Fish & Game	0.05-0.43
2013	150,000	30,000	20%	North Canterbury Fish & Game	0.01-0.10
2014	150,000	30,000	20%	Aoraki Salmon Limited	0.00-0.03
2015	175,000	52,500	30%	Aoraki Salmon Limited	n/d
2016	200,000	60,000	30%	Aoraki Salmon Limited	n/d

**Estimated return rates (supplied by Otago Fish & Game) generated by assuming 10-90% of all returning hatchery fish harvested by anglers; n/d = no data.*

Many potential factors, singly or collectively, may have contributed to the ongoing poor returns. These include (but are not limited to):

- unsuitability of the lower Clutha River as a target for enhancement
- sub-optimal release strategies
- highly variable survival rates from year to year
- reliance on non-local stock rather than local stock sourced from the lower Clutha River
- effects of transport and handling stress on post-release mortality.

1.2. Scope of this report

This report was commissioned by Contact Energy as a first step towards to gaining a better understanding of the salmon fishery enhancement potential of the lower Clutha River. Firstly, we evaluate the success of historical (1977–1990) releases of hatchery-reared Chinook salmon into the Clutha and other South Island rivers, and review returns to the Clutha River in a broad historical context, based on extensive data sets collected by the former Ministry of Agriculture and Fisheries (MAF) and now held by NIWA (see Section 2.2). Secondly, we characterise the relative success rates of different release strategies used in New Zealand, including a comparison of return rates for Chinook smolts released at different weights, dates and in their natal catchment compared with fish originating from other catchments.

The goal is to identify strategies which are likely to (a) be more effective than those which have been conducted to date; and (b) yield a better understanding of the lower Clutha River fishery.

1.3. Report structure

This report is divided into five sections. First, we briefly review the introduction of Chinook salmon to New Zealand, the development of hatchery supplementation during the late 1970s and 1980s, and the associated development of the marking programmes which were used to obtain robust hatchery-specific estimates of survival to adulthood. Second, we use these data to review survival rates for Chinook salmon released into the lower Clutha River from 1977 to 1989. Third, we reanalyse data for returns of hatchery fish to the former MAF research hatchery on Glenariffe Stream in the headwaters of the Rakaia River, focussing on: the relationships between smolt age and size at release and the age, size, and survival rate of returning adults from each release; and inter-annual variation in brood year survival rates. Fourth, we use the updated Glenariffe Stream analyses to interpret the Clutha River return data in a broader perspective by taking into account (and where possible adjusting for) differences in release practices between the two enhancement programmes. We conclude with a discussion and recommended guidelines for managing future supplementary releases into the lower Clutha River in ways that will contribute to a better understanding of the fishery.

2. CHINOOK SALMON IN NEW ZEALAND

2.1. Acclimatisation and distribution

Chinook salmon are the largest members of a group of fishes known as Pacific salmonids (family Salmonidae) and are native to the North Pacific rim from California to northern Japan (Healey 1991). They are a cool water species with their latitudinal distribution strongly related to ocean temperatures. They are strongly anadromous (i.e., migrating from the marine to the freshwater environment to spawn), philopatric (i.e., homing to their natal stream), and semelparous (i.e., dying after spawning), with spawning and juvenile rearing occurring in fresh water, and the remainder of the life cycle at sea.

Stocks from the upper Sacramento River in California were introduced to the lower Waitaki River from 1901 to 1905, and by c. 1915 had self-colonised all major catchments on the east coast of the South Island between the Waitaki River and the Waimakariri River. Chinook did not self-colonise the Clutha River, but established there by c. 1920 after liberations starting in 1917 (McDowall 1994).

The most abundant New Zealand stocks are those of the large, glacier-fed, braided east coast rivers draining the South Island main divide, primarily the Waimakariri, Rakaia, Rangitata, and Waitaki (Quinn & Unwin 1993), which historically supported annual spawning populations of up to 20,000 fish (West & Goode 1987). Smaller runs occur in the Clutha River, having been greatly reduced in number after completion of the Roxburgh Dam in 1956 (Jellyman 1987), and in non-glacial east coast rivers such as the Waiau, Clarence, Hurunui, and Opihi. Sporadic runs are recorded well outside this range (McDowall 1990), particularly on the South Island West Coast where spawning populations of up to several hundred fish return to the tributaries of Lake Paringa and Lake Mapourika.

2.1.1. The lower Clutha salmon fishery

Estimates of annual run strength in the Clutha River before completion of the Roxburgh Dam are unavailable[2], but anecdotal reports of totals ranging from 10,000 to 20,000 fish are plausible, and consistent with estimates of 5,000–20,000 for the Rakaia River over four years from 1973 to 1976 (West & Goode 1986, 1987). Post-Roxburgh figures are also sparse, but the limited angler catch and spawning survey data available are consistent with runs which are generally in the hundreds but may exceed one to two thousand in a good year (Jellyman 1987).

[2] Otago Acclimatisation Society reports for the late 1950s, immediately after the dam was commissioned, note that “large numbers of salmon were caught below the dam” but do not specify a figure (Pack 1988). A figure of 40,000 fish is sometimes quoted, but appears to be apocryphal.

Estimated annual angler usage of the lower Clutha River, based on FGNZ angler surveys conducted at seven-year intervals since 1994, range from 12,550 to 23,420 angler-days (Unwin 2016). Of this the most recent (2014) survey gives an estimate for salmon fishing only of 6,760 angler-days, which represents 29% of the total angler usage for the lower Clutha in that year (see Unwin 2016). The 2014 figure represents a level of effort well below that of the most popular salmon fisheries for the same year (Waimakariri River: 42,690 angler-days; Rakaia River: 34,180 angler-days; Rangitata River: 19,840 angler-days), and somewhat below the Waitaki River (9,560 angler-days), but comparable to the lower Hurunui River (6,790 angler-days), and roughly three times higher than the figure for the Waiau River (2,280 angler-days).

Recent FGNZ surveys of the lower Clutha confirm that current annual run strength is in the order of a few hundred fish. Annual angler harvest over the seven years from 2010 to 2016 ranged from 20–86 fish, with estimated total runs from 2010 to 2014 (assuming a 33% angler capture rate) of 190–264 fish (Trotter 2016).

The decline in run strength since the Roxburgh Dam was commissioned is almost certainly related to the lack of suitable spawning areas in the lower Clutha River (Jellyman 1987). In the Waimakariri, Rakaia, and Rangitata rivers spawning is primarily confined to clear, stable spring-fed headwater tributaries, such as Glenariffe Stream in the upper Rakaia River, the Poulter River in the upper Waimakariri River, and Deep Creek in the Rangitata headwaters (Unwin 1986; Quinn & Unwin 1993; Davis & Unwin 1989; Unwin et al. 2000). Run strength in the Waitaki River is thought to have declined markedly since completion of the Waitaki Dam at Kurow in 1934, and further in recent decades due to increasing water abstraction pressures on lower river side tributaries like the Hakataramea River. Yet side braids of the lower Waitaki River below Kurow provide spawning gravels of sufficient quality and quantity that a reduced run has remained viable. By contrast, the lower Clutha River is primarily confined to a single channel, with mainstem spawning limited to a few gravel bars in areas such as near Beaumont and Clydevale. Tributaries such as the Teviot, Beaumont, Waitahuna and Tuapeka appear to be used lightly if at all, although the Pomahaka catchment does provide fragmented spawning opportunities (Trotter 2016). Most of the small residual run of adult wild salmon returning to the lower Clutha River are thought to be derived from juveniles which have migrated downstream from the upper Clutha source lakes. Attempts to quantify the natal origin of salmon caught by recreational anglers from the lower Clutha show that > 60% can be the progeny of lake-rearing populations land-locked above hydro-power dams, and that a further 20–25% likely originated from the Pomahaka River sub-catchment (for details see Gabrielsson 2015).

2.2. Hatchery supplementation and marking programmes

Beginning in the late 1970s considerable effort went into developing a commercial ocean ranching[3] industry based on Chinook salmon. Between 1977 and 1997, 46 million hatchery salmon were released into South Island rivers, peaking at 6.6 million in 1987 (Deans et al. 2004). Most of the fish released (71%) were associated with commercial farms, with a further 25% released as part of research programmes led by NIWA or its predecessor organisations. Angler-funded programmes aimed at enhancing the sports fishery made up 4% of the total. Releases took place from 55 locations in 21 catchments (Figure 1).

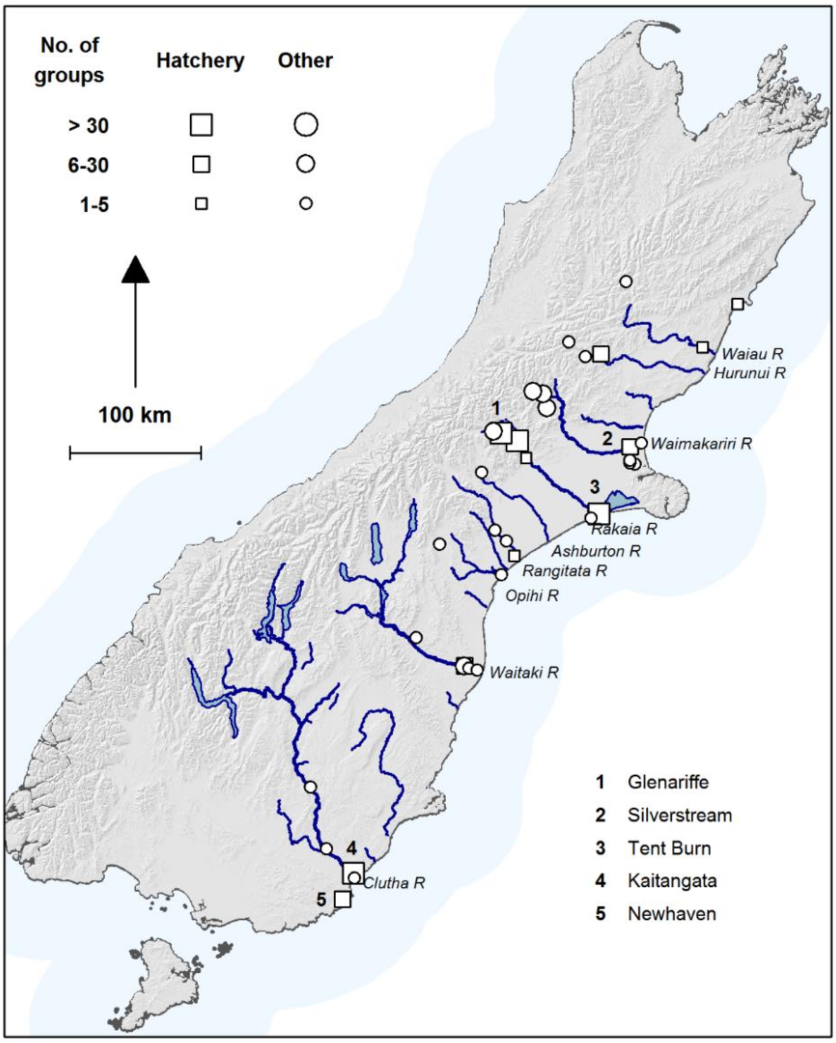

Figure 1. Map of the South Island illustrating the location, origin (i.e. from a local hatchery or other source) and size of Chinook salmon releases over 14 years, 1977 to 1990.

[3] The practice of raising young salmon in a hatchery for some, or all, of their first year of life, and releasing them to the ocean in the hope that enough adults will survive and return to the point of release to generate a viable business.

Coded-wire microtags (Jefferts 1963) were used throughout this period to mark a proportion of the fish released from each location. These tags, (1.25 mm lengths of fine stainless steel wire engraved with bar codes which can be read under a microscope), are injected into the nose cartilage and can be used to mark juvenile hatchery Chinook as small as 5 g (80 mm). The puncture wound left by the tagging needle heals quickly, with over 99% of tags remaining in place as the fish grows to adulthood. The tags cannot be seen once implanted, so tagged fish were also marked externally by removal of the adipose fin.

Recovering tags from returning adults (up to four years after their release) involved recognising the absence of an adipose fin, removing the head (or at least the upper jaw), and forwarding this to a central laboratory for dissection until the tag was located (Unwin et al. 1987). The tag recovery rate was essentially 100% for salmon returning to a hatchery or commercial salmon farm, where staff were aware of the need to check for a missing adipose fin, but was potentially lower for salmon taken in the recreational fishery as they migrated upriver. To maximise the return from anglers, the tagging programme was supported by a network of ‘head depots’ located near all rivers where tagged salmon were likely to be caught, and by a publicity campaign alerting anglers to the need to look for fin-clipped fish and encouraging them to return the head to the nearest depot. Definitive estimates of the proportion of tagged fish recognised as such by anglers for specific rivers and years are unavailable, but a figure of 65–75% is consistent with spawning counts and angler catch estimates for the Rakaia River during the 1970s and early 1980s (West & Goode 1987; Unwin & Davis 1983; NIWA unpublished data). Tags were also recovered from spent carcases recorded during foot surveys of recognised spawning streams, and miscellaneous sources such as fish salvage operations (e.g. Unwin et al. 2000).

Tags were typically used to batch mark groups of 5,000–10,000 juveniles with a common binary code, so that tallying all recovered tags from each batch yields a direct estimate of percentage survival from juvenile to adult (Unwin et al. 1988). These estimates are potentially conservative due to under-reporting of tagged fish caught by anglers, but otherwise provide a consistent basis for comparing survival rates within and between rivers, seasons, and hatchery rearing strategies. Specifically, we assume that annual variation in return rates is dominated by variation in marine survival rather than by variation in angler interception rates among seasons and rivers.

Hatchery rearing and release strategies varied widely over the 14-year period of record. From 1977 to 1980 most hatcheries followed the conventional North American practice of releasing ‘90-day smolt’ weighing 5–10 g (c.f. Hardy 1988). However, uniformly poor returns from these releases, and an isolated return of 2.6% from an experimental release of 35-g yearlings from Glenariffe Stream in August 1979, led to increasing acceptance that 90-day smolt did not appear to be viable in New Zealand, and by 1981 most hatcheries had abandoned the practice. Subsequent hatchery programmes involved holding smolt for up to 15 months and attaining weights of up to 190 g, although most releases lay within a broad band spanning weights of 10–50 g in March, increasing to 30–80 g in September.

2.3. Data sources

2.3.1. Coded-wire tag recoveries

We used the database of coded-wire tag release and recovery programmes compiled by NIWA and its predecessor agencies to extract a data set representing recaptures from 541 releases of salmon over the 14 years from 1977 to 1990, a period when most hatchery research programmes were devoted to exploring the effects of differing rearing and release strategies on survival to adulthood. For the purposes of this report we limited our analyses to releases from catchments on the east coast of the South Island to focus on those most relevant to the Clutha River. A total of 4.25 million tagged fish were released from 36 locations in 13 catchments from the Kahutara River (10 km south of Kaikoura) to the Owaka River (on the Catlins River estuary 20 km south of the Clutha River mouth). Most releases were made into the Rakaia, Tent Burn, Clutha, and Waimakariri catchments, which collectively accounted for 86% of all releases, 87% of the fish tagged, and 96% of the recoveries. Metadata available for these releases generally included date of release (recorded for 95% of releases), and mean weight at release (recorded for 92% of releases). We used these data to estimate mean juvenile growth rate (as % body weight per day) up to the day of release, mean age at return, and sex ratios at return for each age class. A final descriptor added to the data set was a flag to differentiate between releases from an established hatchery, where the fish were released directly into their natal stream, and those released at other locations after being transported from their natal stream by fish tanker.

2.3.2. Glenariffe Stream releases and returns

From 1983 to 1985, releases from the former Ministry of Agriculture and Fisheries (MAF) research hatchery at Glenariffe Stream in the headwaters of the Rakaia River were devoted to systematically exploring the relationships between mean weight at release, date of release, and survival to adulthood (Unwin et al. 1989). Juvenile Chinook were released every 30 days, at ages ranging from 8 to 15 months post-hatch. On each release date fish were further stratified by body weight, to yield three discrete size groups (notionally categorised as small, medium, and large), with three replicate tag codes used to mark each size class. In the remainder of this report we use the term TAS (for Time And Size at release experiment) to refer to these fish and their associated data sets.

Between 1984 and 1988 a total of 10,789 adults from the TAS releases returned to Glenariffe Stream. Data recorded for all fish included age, sex, fork length in mm, and date of return. We used these data to estimate mean age, mean length, and sex ratio for each release group, and hence to relate date of release and mean weight at release to the demographics of the corresponding adult cohort.

When presenting our results, we use the term 'brood year' to refer to the year in which a specific annual cohort or release group was spawned and incubated. For example, fish from the 1980 brood year were the progeny of adults which matured in autumn 1980, and were incubated and hatched during winter and early spring 1980. This does not necessarily correspond to the calendar year in which they were released, which coincides with the brood year only for releases which occurred before 31 December. We also use the terms 'sub-yearling' and 'yearling', respectively, to refer to releases made before and after 1 July, on the basis that date of hatch for most hatcheries involved in large scale releases was generally within a week or two of the end of June.

3. RESULTS

3.1. Clutha River returns

3.1.1. Survival rates

A total of 56 groups of coded-wire tagged Chinook salmon were released into the lower Clutha River or its catchment between 1977–1989, most of which originated from the former ICI / Wattie hatchery at Kaitangata in one of the earliest attempts at commercial ocean ranching (Gillard 1985). Of these, 48 are represented in the NIWA database by essentially complete records which include the number of fish tagged, release location, date of release, mean weight at release, and number of returning adults by year (Table 2). These 56 releases fall naturally into three discrete time periods: brood years 1977-1980, representing the first four years of the ICI / Wattie programme; 1981-1985, when the hatchery focussed on releases of larger (up to 190 g) smolt until its closure in 1985; and 1986–1989, when a series of small-scale releases into the Waitahuna River were sponsored by the Otago Branch of the New Zealand Salmon Anglers Association.

Table 2. Summary data for 56 groups of coded-wire tagged Chinook salmon released into the lower Clutha River, 1977–1989. Successive columns for each release are the ID number in NIWA's tag database (ID); brood year; release location; number of tagged and untagged fish released; mean release weight in g; release date expressed as a calendar date (D/M/Y) and as days from 1 October; release agency; mean growth rate up to the day of release, expressed as % body weight per day; number of returning adults at ages 2, 3, 4, and totalled over all ages; % return; and mean age at return. Odd-numbered brood years are shaded blue to facilitate comparisons among years and rearing seasons.

ID	Brood year	Release location	Number released		Release weight (g)	Release date		Agency	Growth rate (%/d)	Number of returning adults				% return	Mean age at return
			Tagged	Untagged		D/M/Y	Days from 1 Oct			Age 2	Age 3	Age 4	Total		
259	1977	Kaitangata	9,508	2,620	7.6	19/12/77	79	ICI/Wattie	0.84	1	0	0	1	0.01	2.00
260	1977	Kaitangata	7,319	72,000	4	12/11/77	42	ICI/Wattie	0.93	0	0	0	0	0.00	
265	1978	Kaitangata	3,155	31,000	7.2	27/10/78	26	ICI/Wattie	1.34	0	0	0	0	0.00	
266	1978	Kaitangata	3,418	31,000	7.2	27/10/78	26	ICI/Wattie	1.34	0	0	0	0	0.00	
267	1978	Kaitangata	3,221	31,000	7.2	7/10/78	6	ICI/Wattie	1.74	0	0	0	0	0.00	
271	1978	Kaitangata	4,477	37,836	10.7	21/11/78	51	ICI/Wattie	1.14	0	0	0	0	0.00	
296	1979	Kaitangata	10,244	82,481	8.1	30/10/79	29	ICI/Wattie	1.34	0	0	0	0	0.00	
299	1979	Kaitangata	10,025	82,681	6.2	23/10/79	22	ICI/Wattie	1.34	0	0	0	0	0.00	
342	1980	Kaitangata	30,998	39,550	5.4	17/12/80	77	ICI/Wattie	0.77	0	2	0	2	0.01	3.00
350	1981	Kaitangata	11,482	0	170	17/08/82	320	ICI/Wattie	0.49	57	76	3	136	1.18	2.60
352	1981	Kaitangata	5,659	0	170	17/08/82	320	ICI/Wattie	0.49	26	53	3	82	1.45	2.72
354	1981	Kaitangata	3,437	0	170	17/08/82	320	ICI/Wattie	0.49	18	32	1	51	1.48	2.67
358	1981	Kaitangata	11,456	11,346	15	14/12/81	74	ICI/Wattie	1.02	0	0	0	0	0.00	
359	1981	Kaitangata	10,178	61,672	15	17/12/81	77	ICI/Wattie	0.99	0	0	0	0	0.00	
360	1981	Minzion Burn	5,292	0	104	28/07/82	300	ICI/Wattie	0.49	49	41	4	94	1.78	2.52
361	1981	Kaitangata	1,323	0	190	22/12/82	447	ICI/Wattie	0.37	2	6	1	9	0.68	2.89
364	1981	Kaitangata	10,578	8,596	6	17/12/81	77	ICI/Wattie	0.80	0	0	0	0	0.00	
371	1981	Kaitangata	10,370	0	170	30/10/82	394	ICI/Wattie	0.41	93	85	6	184	1.77	2.53
384	1982	Minzion Burn	2,971	0	60	26/07/83	298	ICI/Wattie	0.47	8	58	20	86	2.89	3.14
385	1982	Kaitangata	5,782	6,863	68	12/07/83	284	ICI/Wattie	0.49	81	62	1	144	2.49	2.44
387	1982	Kaitangata	5,489	17,930	68	12/07/83	284	ICI/Wattie	0.49	97	66	2	165	3.01	2.42
432	1982	Minzion Burn	11,158	5,799	64	24/04/83	205	ICI/Wattie	0.63	24	25	5	54	0.48	2.65
434	1982	Kaitangata	10,667	0	76.2	26/07/83	298	ICI/Wattie	0.48	98	234	79	411	3.85	2.95
436	1982	Kaitangata	10,650	37,599	70	24/04/83	205	ICI/Wattie	0.64	83	49	2	134	1.26	2.40
438	1982	Minzion Burn	10,412	0	50	8/06/83	250	ICI/Wattie	0.53	25	91	20	136	1.31	2.96
440	1983	Kaitangata	5,252	16,150	65	11/06/84	254	ICI/Wattie	0.54	9	8	0	17	0.32	2.47

Table 2, continued

ID	Brood year	Release location	Number released		Release weight (g)	Release date		Agency	Growth rate (%/d)	Number of returning adults				% return	Mean age at return
			Tagged	Untagged		D/M/Y	Days from 1 Oct			Age 2	Age 3	Age 4	Total		
441	1983	Kaitangata	5,604	7,244	36	26/04/84	208	ICI/Wattie	0.58	0	3	0	3	0.05	3.00
452	1983	Kaitangata	9,647	36,206	43	30/03/84	181	ICI/Wattie	0.66	2	0	0	2	0.02	2.00
453	1983	Kaitangata	10,083	67,637	43	30/03/84	181	ICI/Wattie	0.66	0	0	0	0	0.00	
454	1983	Kaitangata	10,432	17,255	25	30/03/84	181	ICI/Wattie	0.62	0	1	0	1	0.01	3.00
455	1983	Kaitangata	10,145	2,082	45	30/03/84	181	ICI/Wattie	0.67	3	11	0	14	0.14	2.79
456	1983	Kaitangata	9,116	8,166	28	28/02/84	150	ICI/Wattie	0.72	4	4	0	8	0.09	2.50
507	1983	Kaitangata	5,428	15,879	57	11/06/84	254	ICI/Wattie	0.53	4	9	0	13	0.24	2.69
521	1983	Kaitangata	5,597	0	25	26/04/84	208	ICI/Wattie	0.55	0	2	0	2	0.04	3.00
534	1984	Kaitangata	4,981	14,547	81	10/06/85	252	ICI/Wattie	0.55	0	0	0	0	0.00	
535	1984	Kaitangata	4,961	14,320	96	10/06/85	252	ICI/Wattie	0.56	0	0	0	0	0.00	
536	1984	Kaitangata	5,085	9,471	100	8/07/85	280	ICI/Wattie	0.52	3	0	0	3	0.06	2.00
537	1984	Kaitangata	5,058	9,472	100	8/07/85	280	ICI/Wattie	0.52	5	0	1	6	0.12	2.33
538	1984	Kaitangata	5,125	5,009	50	27/02/85	149	ICI/Wattie	0.78	2	1	0	3	0.06	2.33
539	1984	Matau Mouth	4,992	0	50	27/02/85	149	ICI/Wattie	0.78	0	0	0	0	0.00	
540	1984	Kaitangata	5,101	56,491	45	20/03/85	170	ICI/Wattie	0.70	0	0	0	0	0.00	
541	1984	Kaitangata	5,128	84,309	45	20/03/85	170	ICI/Wattie	0.70	0	0	0	0	0.00	
591	1985	Kaitangata	1,739	0	50	10/03/86	160	Southland Salmon	0.74	0	0	0	0	0.00	
595	1985	Kaitangata	5,060	0	50	10/03/86	160	Southland Salmon	0.74	0	0	0	0	0.00	
619	1985	Kaitangata	5,021	0				ICI/Wattie		0	0	0	0	0.00	
620	1985	Kaitangata	5,051	0				ICI/Wattie		0	0	0	0	0.00	
621	1985	Kaitangata	5,036	0				ICI/Wattie		0	2	0	2	0.04	3.00
622	1985	Kaitangata	5,027	0				ICI/Wattie		0	0	0	0	0.00	
623	1985	Kaitangata	5,135	0				ICI/Wattie		0	2	0	2	0.04	3.00
624	1985	Kaitangata	5,097	0				ICI/Wattie		0	0	0	0	0.00	
625	1985	Kaitangata	2,552	0				ICI/Wattie		0	0	0	0	0.00	
626	1985	Kaitangata	2,575	0				ICI/Wattie		0	0	0	0	0.00	
699	1986	Waitahuna R	2,341	5,759	35	27/05/87	238	NZSA (Otago)	0.52	3	3	5	11	0.47	3.18
747	1987	Waitahuna R	2,086	8,000	80	23/06/88	266	NZSA (Otago)	0.53	9	14	0	23	1.10	2.61
754	1988	Waitahuna R	2,178	4,812	45	5/05/89	216	NZSA (Otago)	0.58	0	0	0	0	0.00	
823	1989	Waitahuna R	2,600	12,500	50	6/02/90	128	NZSA (Otago)	0.87	0	0	0	0	0.00	

Returns from the 1977–1980 releases were uniformly poor, and—in seven out of nine instances—non-existent. Of 82,300 coded-wire tagged fish released over this period only three were ever recovered as adults, representing a mean return rate of 0.004%. Similar results for a second commercial operation on the lower Waitaki River, and only slightly higher returns to MAF's Silverstream Hatchery on the lower Waimakariri River, led to increasing acceptance amongst the fledgling ocean-ranching industry that the conventional North American practice of releasing '90-day smolt' weighing 5–10 g (Hardy 1988) did not appear to be viable in New Zealand. Following a 2.6% return from an experimental release of 35 g yearlings from Glenariffe Stream in August 1979, Kaitangata (and most other hatcheries) devoted most of their efforts to yearling releases as from 1981.

The 1981 and 1982 brood year releases were, by any standards, spectacularly successful. For six groups of yearlings released at ages of 10–15 months, at weights of 104–170 g, return rates ranged from 0.68% to 1.78%, with a mean of 1.48%. Returns from the 1982 brood were even higher ranging from 0.48% to 3.85% across seven release groups and averaging 1.98%. Three of these releases were made into the lower Minzion Burn, 85 km upstream from Kaitangata, in the hope of encouraging returning adults to home to the release where they might be more easily recovered. By contrast, returns from the 1983, 1984, and 1985 brood year releases were only slightly better than those for 1977-1980. Returns totalled 60 adults from 71,300 tagged smolt in 1983 (0.08%); 12 adults from 40,400 tagged smolt in 1984 (0.03%), and 4 adults from 42,300 tagged smolt in 1985 (0.01%), although interpretation of the 1985 figure is clouded by the lack of data on age and size at release for 8 of the 10 tag groups.

The 1986–1989 releases also had mixed success, achieving returns of 0.47%, 1.10%, 0%, and 0%, in successive years. Sporadic releases continued into the early 1990s, but none of these included coded-wire tagged fish and we do not consider them further in this report.

Excluding the 1977–1980 releases, mean survival for the remaining 46 releases was 0.56%, although this figure is strongly influenced by the high success rate for the 1981 and 1982 broods. By contrast, median survival—which is a more robust measure of central tendency for such a highly skewed data set—was 0.04%.

3.1.2. Age at return

Returning adults from the ICI / Wattie releases tended to be younger than those associated with naturally spawning populations elsewhere in New Zealand, which have a modal age at maturity of three years and are typically distributed 15%, 70%, 15% among 2-, 3-, and 4-year-old fish, respectively. By contrast, mean age at maturity for the 27 lower Clutha release groups which generated non-zero returns ranged from 2.0 to 3.18 years, with an average of 2.67 and a median of 2.66. This compares with mean ages for 44 annual cohorts representing five naturally spawning populations of 3.05 years for males and 3.21 for females (Quinn & Unwin 1993). The 1981 brood year was particularly striking in this respect, with the 556 adults which returned to the lower Clutha distributed 44.1%, 52.7%, and 3.2% among 2-year-olds, 3-year-olds, and 4-year olds, respectively.

3.2. All returns

Survival to adulthood for the 541 groups of tagged Chinook salmon described in Section 2.3.1 ranged from zero to 7.55%, with a median of 0.33% (Table 3). Figures for individual release groups were skewed towards lower values (i.e., positively skewed), with mean survival (0.74%) more than double the median (0.33%). A total of 164 releases (30% of the total) yielded survival rates less than 0.1%, including 71 (13% of the total) with zero returns.

Table 3. Survival to adulthood (%) by brood year (1977-1990) for the same dataset shown in Figure 2. Successive columns show median, mean, minimum, and maximum survival for each brood year.

Brood year	Number of releases	Survival (%)			
		Median	Mean	Minimum	Maximum
1977	15	0.00	0.05	0.00	0.38
1978	25	0.04	0.24	0.00	2.60
1979	23	0.01	0.09	0.00	0.39
1980	27	0.07	0.15	0.00	1.04
1981	33	0.30	0.85	0.00	5.12
1982	55	1.24	2.01	0.03	7.55
1983	81	1.20	1.38	0.00	6.03
1984	68	0.87	0.94	0.00	3.81
1985	60	0.08	0.23	0.00	1.83
1986	33	0.39	0.45	0.00	1.27
1987	42	0.38	0.60	0.02	2.48
1988	34	0.32	0.40	0.00	1.82
1989	31	0.14	0.21	0.00	0.91
1990	14	0.07	0.07	0.00	0.20
All years	**541**	**0.33**	**0.74**	**0.00**	**7.55**

Survival was uniformly low (< 0.13%) for releases made before the end of December, and only rarely exceeded 0.5% for releases in January and February (Figure 2a). The earliest release date for which survival exceeded 1% was 6 March, represented by 11 releases from Glenariffe and one from the former New Zealand Salmon Company hatchery on the Lake Coleridge tailrace between 1982 and 1985. Survival rates of between 1% and 2% were more common for autumn and winter releases (March to August), representing fish aged 6–12 months as measured from hatching date. Survival rates above 2% were rare irrespective of release date, accounting for 54 (10%) of the 541 release groups.

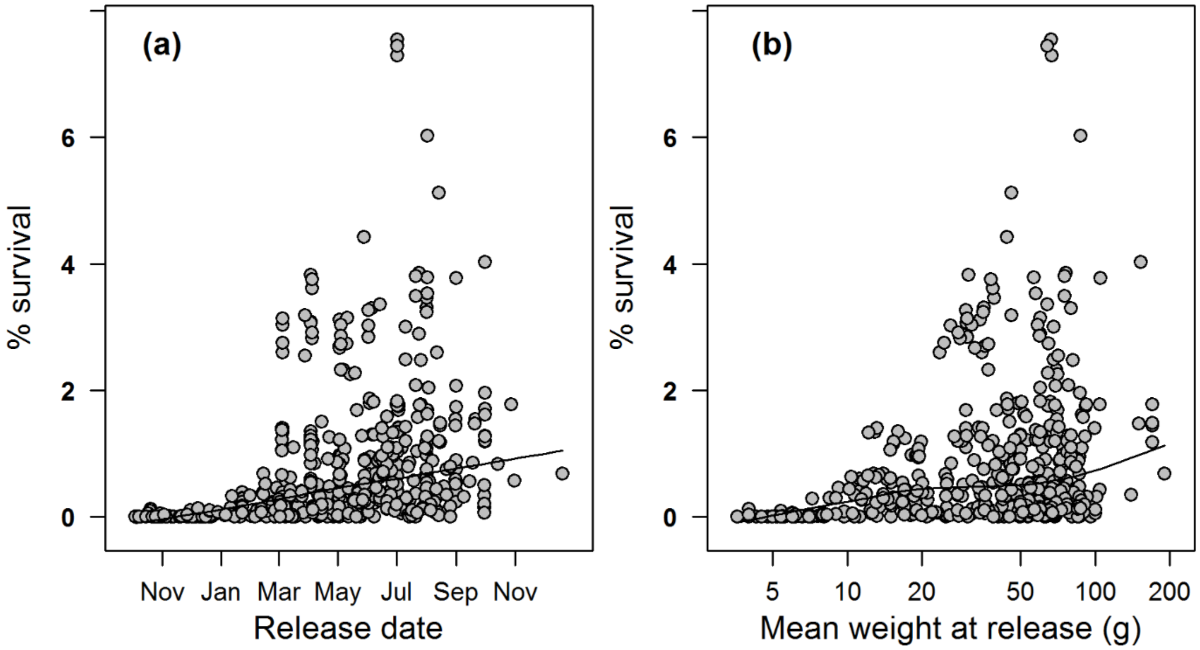

Figure 2. Return rates (% survival) vs. (a) release date, and (b) mean release weight for 541 releases of juvenile Chinook salmon from 36 locations on South Island east coast rivers between 1977 and 1991. Solid lines represent lowess smoothers.

Variation in survival relative to mean weight at release was broadly consistent with the pattern described in the previous paragraph: survival was uniformly low (and often zero) for sub-yearling groups averaging less than 10 g at release, and less than 2% (and generally below 1%) for groups averaging 10–20 g at release (Figure 2b). Return rates tended to increase for mean release weights above 20 g but also became increasingly variable, ranging from 0% to 3.8% for release weights of 30–40 g, and from 0% to 7.7% for release weights of 50–80 g. Return rates for yearling releases (median 0.78%, mean 1.22%) were higher than for sub-yearling releases (median 0.24%, mean 0.59%).

Analysis of expanded returns[4] for selected enhancement programmes on major east coast South Island rivers highlights the extent to which the success of these programmes—as indexed by total returns—has varied among brood years and river of origin (Table 4). We defer a more detailed review of these results until Section 3.4, but note in passing that the programmes which achieved the most consistent and sustained success rates over the period of record were for releases into the Waimakariri River and the Rakaia River, both of which sustain large, naturally spawning populations, and were associated with established hatcheries using broodstock sourced from returning adults. By contrast, enhancement programmes in rivers lacking an established hatchery and / or strong natural spawning runs, including the lower Clutha River, were generally less successful.

[4] The term "expanded returns" refers to estimated total returns for a release, or group of releases, in which not all fish in each release were tagged. In such cases, the number of untagged fish returning is estimated assuming that untagged fish had the same survival rate as the tagged fish. To give a specific example, one of the 1982 brood year releases into the lower Clutha River totalled 48,250 fish, comprising 10,650 tagged fish and 37,600 untagged fish. A total of 134 tagged fish were recovered, representing a survival rate of 1.26%. Expanded returns for this release were therefore 48,250 x 1.26%, i.e., 607 fish. Such estimates make no allowance for tagged fish which were not recovered or otherwise returned unreported, so tend to be conservative.

Table 4. Estimated total returns by brood year and origin for selected rivers, 1977-1990. Figures show total releases of tagged and untagged fish summed over all tag groups (in italics) by year and river, and expanded returns (underneath release figure, not italicised) assuming the same survival rate for tagged and untagged fish in each group.

	River / Origin								
			Rakaia						
Brood Year	Hurunui	Waimakariri	Coleridge Hatchery	Glenariffe Hatchery	Ashburton	Rangitata	Opihi	Waitaki	Clutha
1977	*4,000* 0	*533,700* 594		*26,200* 30				*159,800* 0	*91,400* 1
1978	*7,900* 0	*512,800* 449		*123,300* 724			*25,100* 10	*135,000* 0	*145,100* 0
1979	*21,000* 0	*612,400* 35	*197,000* 673	*247,100* 617	*89,800* 10		*9,100* 0	*98,100* 0	*185,400* 0
1980	*203,700* 158	*500,100* 239	*237,500* 1,246	*384,000* 557			*36,600* 24	*25,500* 9	*70,500* 5
1981	*291,500* 150	*630,700* 809	*255,700* 5,402	*336,800* 2,583	*10,500* 17		*11,500* 2		*151,400* 556
1982	*58,000* 192	*10,600* 14	*222,800* 7,667	*369,900* 7,393					*125,300* 2,341
1983			*205,300* 3,516	*552,900* 8,796				*90,000* 762	*241,900* 173
1984	*10,100* 4	*18,100* 151	*121,273* 1,391	*644,100* 6,166		*35,200* 1,284		*59,600* 371	*234,000* 32
1985	*10,200* 6	*9,600* 151	*289,900* 460	*223,700* 587		*33,000* 426		*98,800* 122	*42,300* 4
1986			*199,000* 704	*328,700* 1338				*176,500* 990	*8,100* 38
1987		*110,600* 960	*355,400* 1,004	*575,000* 3,993					*10,100* 111
1988		*52,700* 290	*27,200* 66	*395,900* 1,470		*69,600* 510		*5,400* 11	*7,000* 0
1989		*190,600* 550	*154,200* 235	*504,900* 754		*96,700* 457	*17,700* 82	*70,500* 190	*15,100* 0
1990		*190,500* 90	*151,400* 0	*464,000* 242				*99,600* 0	

3.3. Glenariffe Hatchery

3.3.1. Influence of release weight and date on % survival

Variation in survival rates for releases described in the previous section span a range of release locations, and are potentially confounded by variation among rivers and hatchery practices. To elucidate the relationship between release date, mean release weight, and survival without these confounding factors, we conducted a separate analysis for a subset of 202 releases from Glenariffe Stream over the 13 brood years from 1978 and 1990. These comprised the 133 TAS releases plus a further 69 releases spanning the 1978-1981 and 1985-1990 brood years. Collectively, the 202 TAS and non-TAS releases spanned release dates from January to November, and mean release weights from 5 g to 150 g (Figure 3). The TAS releases totalled 1.07 million tagged Chinook, covering release dates from April 1983 to October 1985. Releases for the three brood years totalled 370,000 fish in 40 groups in 1983, 553,000 fish in 62 groups in 1984, and 152,000 fish in 31 groups in 1985. Mean weight at release ranged from 10 g to 152 g. with a median of 40.6 g.

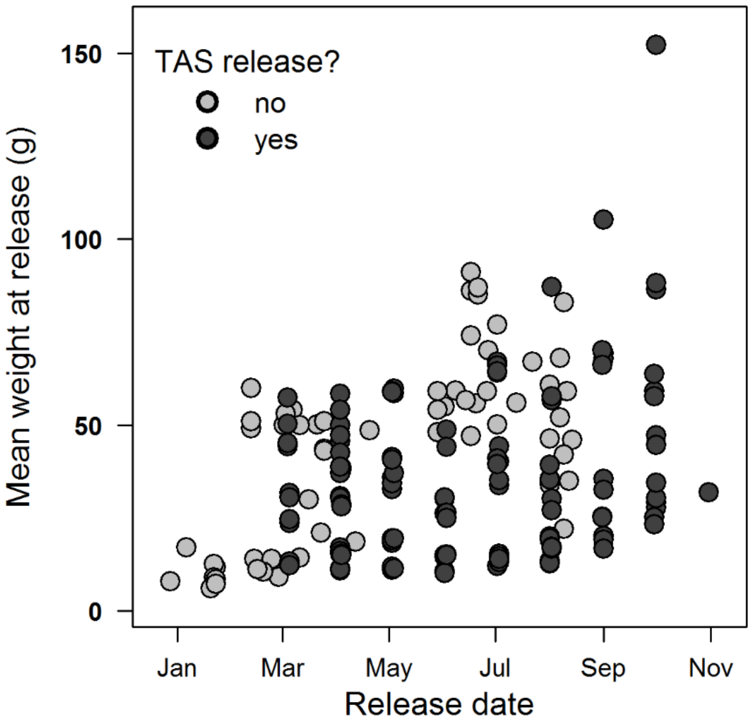

Figure 3. Mean weight at release vs. release date for 202 groups of coded-wire tagged Chinook salmon released from Glenariffe Hatchery, 1978-1990. TAS = Time And Size at release experiments: released fish tagged to identify date and mean size (weight) at release.

We used these data to characterise variation in log-transformed survival (S) as a function of mean release weight (W_{rel} g), release date (days from 1 October; D), and brood year (BY), via the model:

$$\log_{10}(S) = a_0 + a_1 \times \log_{10}(W_{rel}) + a_2 \times D + BY_k \quad (1)$$

This choice of model was motivated by the general tendency for survival rates to be log-normally distributed (Bradford 1995), and follows an earlier analysis of the same data set which modelled log(S) as a linear function of log(W_{rel}) together with a series of constant terms representing the influence of each brood year[5] or annual cohort (c.f. Unwin 1997a). However, it improves this model by including release date, the effects of which were not included in the 1997 analysis.

The resulting model (Table 5, Figure 4) provided a very satisfactory fit to the raw data, accounting for 84% of null deviance. Mean release weight, release date, and brood year all contributed significantly to the observed variation in survival. Consistent with the 1997 analysis, the coefficient of W_{rel} was positive, confirming a strong tendency for survival to increase with increasing mean weight at release. The revised model represents a 2.68-fold increase in survival for each twofold increase in release weight, a slightly faster rate than the 2.5-fold increase reported in the 1997 analysis.

[5] We emphasise here that ‘brood year’ is essentially a catch-all term for all remaining variation in survival which cannot be directly modelled by time and size at release. As such, it represents total variation across the freshwater and marine environments, without regard to which of these two environments has the biggest influence on survival.

Table 5. Fitted coefficients for model (1) applied to survival data for 202 releases from Glenariffe Stream, 1978-1990. Significance levels for each coefficient are indicated as n.s. (not significant); * (p < 0.05); ** (p < 0.01); and *** (p < 0.001). The first brood year coefficient (BY_{1978}) is defined to be zero, thereby providing a reference point against which the remaining 12 brood years are measured.

Model term	Coefficient ± Std. Error	t value (p, significance)
Constant	-1.520 ± 0.123	-12.36 (< 0.001 ***)
$\log_{10}(W_{rel})$	1.422 ± 0.072	19.79 (< 0.001 ***)
Day of year (D)	-0.00197 ± 0.000256	-7.68 (< 0.001 ***)
BY_{1979}	-0.750 ± 0.124	-6.03 (< 0.001 ***)
BY_{1980}	-0.581 ± 0.130	-4.47 (< 0.001 ***)
BY_{1981}	0.041 ± 0.130	0.32 (0.752 n.s.)
BY_{1982}	0.256 ± 0.099	2.59 (0.011 *)
BY_{1983}	0.035 ± 0.099	0.35 (0.724 n.s.)
BY_{1984}	-0.494 ± 0.105	-4.73 (< 0.001 ***)
BY_{1985}	-0.972 ± 0.114	-8.54 (< 0.001 ***)
BY_{1986}	-0.807 ± 0.127	-6.33 (< 0.001 ***)
BY_{1987}	-0.598 ± 0.126	-4.74 (< 0.001 ***)
BY_{1988}	-0.886 ± 0.122	-7.25 (< 0.001 ***)
BY_{1989}	-1.472 ± 0.131	-11.20 (< 0.001 ***)
BY_{1990}	-1.711 ± 0.134	-12.71 (< 0.001 ***)

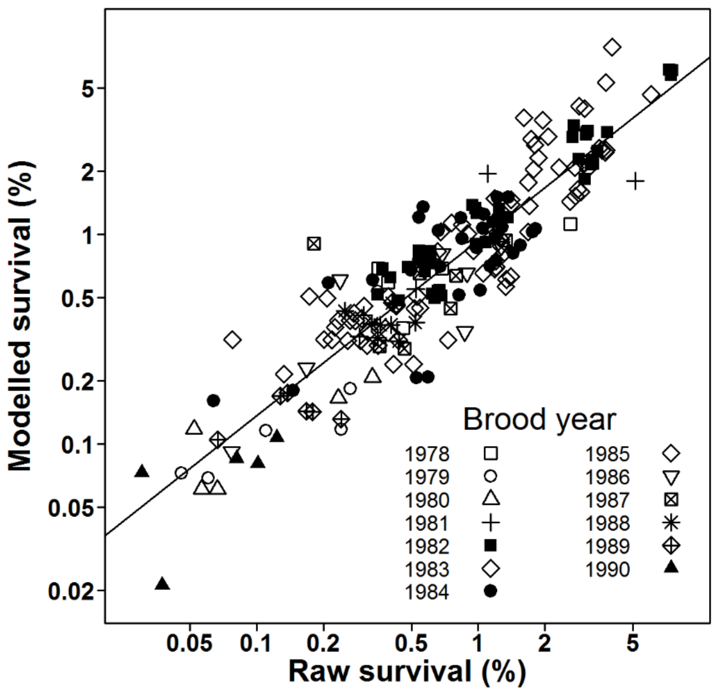

Figure 4. Observed (raw) vs. modelled survival for 202 releases from Glenariffe Stream, 1978-1990. The diagonal line represents a linear regression of modelled survival on raw survival (note axes have Log scales).

By contrast, the negative coefficient for release date represents a tendency for survival to decrease as for release dates later in the calendar year. The effect is modest for small delays in release date, amounting to a 13% reduction in survival over 30 days, but becomes increasingly significant over longer periods. For a given release weight, the drop in survival averages 24% over 60 days; 34% over 90 days; 42% over 120 days; and 49% over 150 days. To give a representative example, a survival rate of 1% for a group of 40 g fish released on 1 March would fall to 0.5% for a second group of 40 g fish released on 1 August.

The coefficients for successive brood years confirm the results of the 1997 analysis that, when standardised to a given release weight and date, survival to adulthood varies by nearly a factor of 100 from year to year (Figure 5, for details see Unwin 1997a). The current model shows a similar pattern of variation, with high survival (> 1%) for brood years 1978, 1981, 1982, and 1983; intermediate survival (0.2–1%) in 1980, 1984, and 1987; and poor survival (< 0.2%) in 1979, 1985, 1986, 1988, 1989, and 1990. Standardised survival for the 1982 brood year (which was the highest of the 13 years on record) was 93 times higher than for 1989, the poorest year on record.

A salient feature of this analysis is that the 1981 and 1982 brood years, the most successful years of the ICI / Wattie programme, occurred at a time when survival rates for both wild and hatchery fish of Glenariffe Stream origin were also unusually high. By contrast, the later (1983–1989) releases took place over a period when survival rates were more closely aligned to the long-term (1965–1990) average. This pattern is also reflected in the expanded returns shown in the previous section (Table 3), in that the early 1980s were characterised by higher returns of adult salmon, most notably to the two large-scale hatcheries operating on the Rakaia River (Glenariffe Stream and Coleridge) than was the case over the latter part of the same decade. In particular, the 1981 and 1982 brood year releases into the lower Clutha River, which yielded expanded returns of 556 and 2,341 adults, respectively, were the only two of the 13 annual cohorts for which data are available to yield more than 200 returning fish.

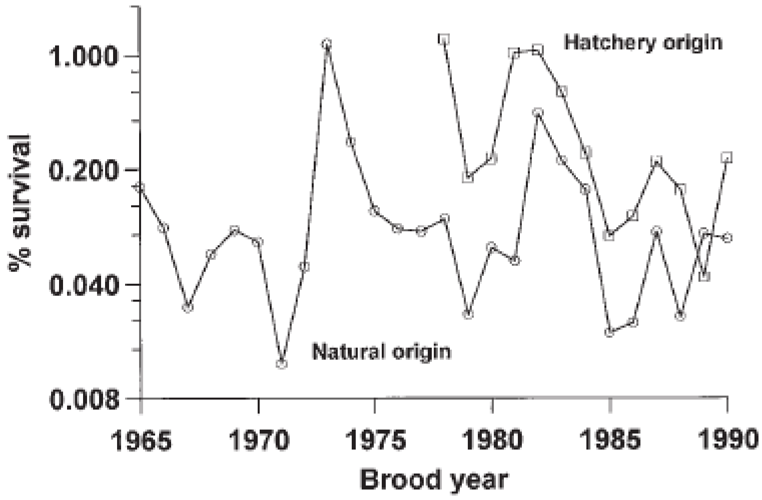

Figure 5. Annual survival rates (log scale) for Chinook salmon of natural (fry-to-adult) and hatchery (smolt-to-adult) origin from Glenariffe Stream, 1965-1990 (source: Unwin 1997a).

3.3.2. Application of Glenariffe survival model to the lower Clutha releases

To gain further insight into the performance of the lower Clutha releases relative to those from Glenariffe Stream, we used the Glenariffe survival model developed in the previous section to estimate survival to adulthood for all Clutha releases for which age and size at release were known, over the period which overlapped with the Glenariffe record (1978–1989). Essentially, this analysis asked the question "What would have been the expected survival of these fish had they been released from Glenariffe Stream on the same date, at the same mean release weight, as they were in the lower Clutha?".

With one exception, modelled survival rates for the hypothetical Glenariffe releases exceeded the survival rates observed for their Clutha counterparts (Table 6)[6]. Expressed as a ratio, the median difference between the two sets of survival rates was 14.6, and ranged from 0.5 (representing the sole exception to the general trend, for a 1986 brood year release into the Waitahuna River) to more than 300 (for a 1983 brood year release of 43 g smolt from Kaitangata). Median ratios for the 12 brood years from 1978 to 1989 were, respectively, 15.4; 8.0; 9.5; 9.7; 2.4; 35; 51; 13.8; 0.5; 1.1; 7.2; and 3.9.

[6] For Clutha releases which yielded zero returns the modelled/actual ratios listed are a minimum estimate, based on the assumption that exactly one adult had returned.

Table 6. Percentage survival for 46 groups of Chinook salmon released into the lower Clutha River, 1978-1989, vs. modelled survival for fish of the same age and size released from Glenariffe Stream. The final column (Modelled / Actual) represents the ratio between modelled and actual survival, i.e., the ratio by which survival for the hypothetical Glenariffe releases would have exceeded their Clutha counterparts (see text for further details).

ID	Brood year	Release location	Number tagged	Release weight (g)	Age at release (d)	Survival (%)		Modelled / Actual
						Actual	Modelled	
265	1978	Kaitangata	3,155	7.2	26	0.00	0.44	> 14.0
266	1978	Kaitangata	3,418	7.2	26	0.00	0.44	> 15.2
267	1978	Kaitangata	3,221	7.2	6	0.00	0.49	> 15.7
271	1978	Kaitangata	4,477	10.7	51	0.00	0.70	> 31.2
296	1979	Kaitangata	10,244	8.1	29	0.00	0.09	> 9.4
299	1979	Kaitangata	10,025	6.2	22	0.00	0.07	> 6.5
342	1980	Kaitangata	30,998	5.4	77	0.01	0.06	9.5
350	1981	Kaitangata	11,482	170	320	1.18	11.53	9.7
352	1981	Kaitangata	5,659	170	320	1.45	11.53	8.0
354	1981	Kaitangata	3,437	170	320	1.48	11.53	7.8
358	1981	Kaitangata	11,456	15	74	0.00	1.11	> 127.7
359	1981	Kaitangata	10,178	15	77	0.00	1.10	> 111.9
360	1981	Minzion Burn	5,292	104	300	1.78	6.28	3.5
361	1981	Kaitangata	1,323	190	447	0.68	7.60	11.2
364	1981	Kaitangata	10,578	6	77	0.00	0.30	31.6
371	1981	Kaitangata	10,370	170	394	1.77	8.24	4.6
384	1982	Minzion Burn	2,971	60	298	2.89	4.75	1.6
385	1982	Kaitangata	5,782	68	284	2.49	6.05	2.4
387	1982	Kaitangata	5,489	68	284	3.01	6.05	2.0
432	1982	Minzion Burn	11,158	64	205	0.48	7.94	16.4
434	1982	Kaitangata	10,667	76.2	298	3.85	6.67	1.7
436	1982	Kaitangata	10,650	70	205	1.26	9.01	7.2
438	1982	Minzion Burn	10,412	50	250	1.31	4.56	3.5
440	1983	Kaitangata	5,252	65	254	0.32	3.91	12.1
441	1983	Kaitangata	5,604	36	208	0.05	2.08	38.8
452	1983	Kaitangata	9,647	43	181	0.02	3.03	146.0
453	1983	Kaitangata	10,083	43	181	0.00	3.03	> 305.1
454	1983	Kaitangata	10,432	25	181	0.01	1.40	146.0
455	1983	Kaitangata	10,145	45	181	0.14	3.23	23.4
456	1983	Kaitangata	9,116	28	150	0.09	1.89	21.6
507	1983	Kaitangata	5,428	57	254	0.24	3.24	13.5
521	1983	Kaitangata	5,597	25	208	0.04	1.24	34.7
534	1984	Kaitangata	4,981	81	252	0.00	1.59	> 79.4
535	1984	Kaitangata	4,961	96	252	0.00	2.03	> 100.7
536	1984	Kaitangata	5,085	100	280	0.06	1.89	32.1
537	1984	Kaitangata	5,058	100	280	0.12	1.89	16.0
538	1984	Kaitangata	5,125	50	149	0.06	1.28	21.9
539	1984	Matau Mouth	4,992	50	149	0.00	1.28	> 63.9
540	1984	Kaitangata	5,101	45	170	0.00	1.00	> 51.1
541	1984	Kaitangata	5,128	45	170	0.00	1.00	> 51.4

Table 6, continued.

ID	Brood year	Release location	Number tagged	Release weight (g)	Age at release (d)	Survival (%)		Modelled / Actual
						Actual	Modelled	
591	1985	Kaitangata	1,739	50	160	0.00	0.41	> 7.1
595	1985	Kaitangata	5,060	50	160	0.00	0.41	> 20.5
699	1986	Waitahuna R	2,341	35	238	0.47	0.25	0.5
747	1987	Waitahuna R	2,086	80	266	1.10	1.16	1.1
754	1988	Waitahuna R	2,178	45	216	0.00	0.33	> 7.2
823	1989	Waitahuna R	2,600	50	128	0.00	0.15	> 3.9

3.3.3. Size and age at return

Mean age and length of coded-wire tagged adult Chinook salmon returning to Glenariffe Stream were strongly influenced by mean weight at release and / or release date. Mean age at return was negatively correlated with mean release weight ($r = -0.645$, $N = 162$, $p < 0.001$; Figure 6). A weaker ($r = -0.489$) but still significant ($p < 0.001$) correlation was also apparent between age at return and mean growth rate during the period of hatchery rearing, expressed as % body weight per day. Both results are consistent with the general tendency for salmonid age at maturity to be inversely correlated with growth rate (Thorpe 1986), a trait often referred to informally as 'live fast, die young'.

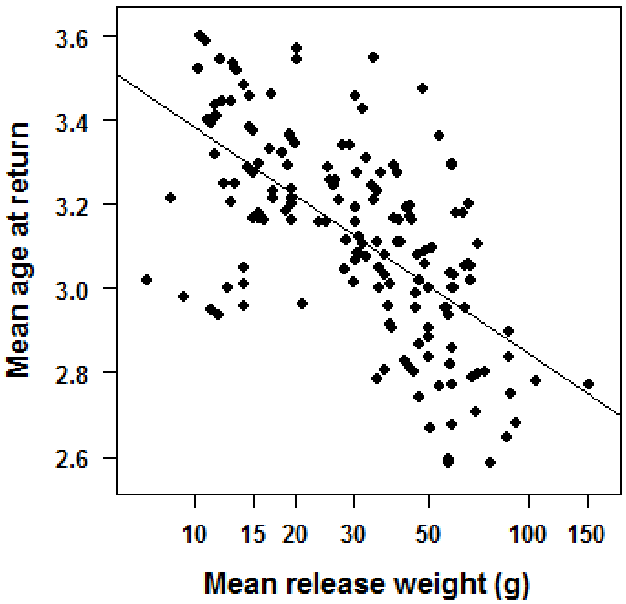

Figure 6. Mean age at return vs. mean weight at release (log scale) for coded-wire tagged adult salmon returning to Glenariffe Stream, 1978-1990. The underlying data set is limited to releases for which total returns exceeded 20 fish.

Mean length at return was negatively correlated with release date (Figure 7). The correlation was strongest for 2-year-old fish ($r = -0.774$, $N = 155$, $p < 0.001$); moderate for 3-year-old fish ($r = -0.559$, $N = 203$, $p < 0.001$); and weakest (but still highly significant) for 4-year-old fish ($r = -0.280$, $N = 176$, $p < 0.001$). Returning adults also tended to be smaller than wild adults (i.e., those derived from naturally spawning stocks) of the same age.

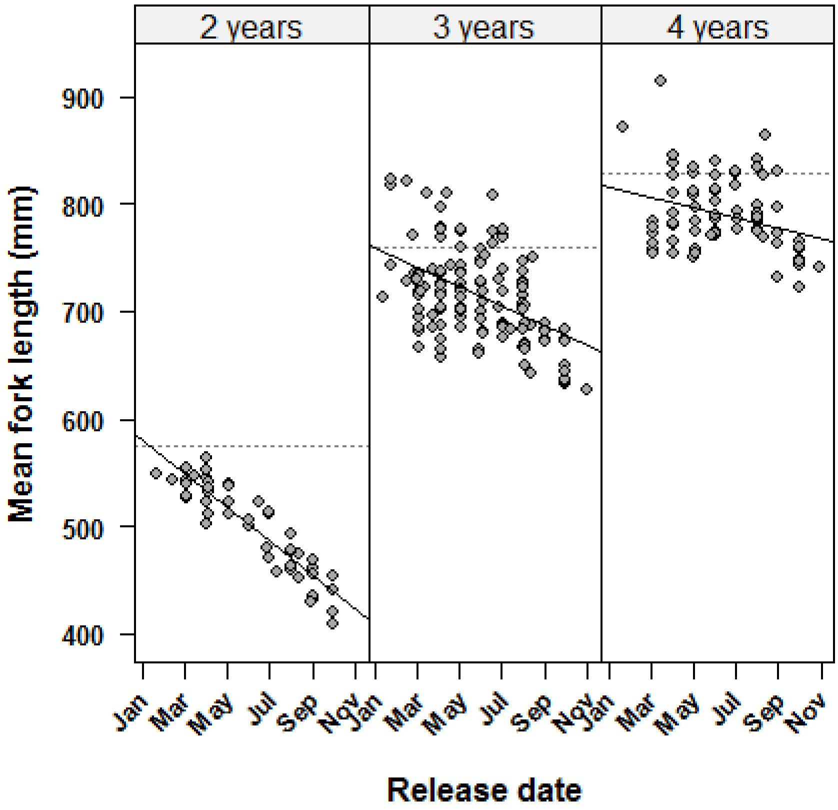

Figure 7. Mean fork length at return vs. release date for coded-wire tagged adult Chinook salmon returning to Glenariffe Stream, 1978-1990, for the same data set as in Figure 6. The horizontal dashed line in each panel represents the mean fork length of wild Chinook for the corresponding age class, based on the long-term average for Glenariffe Stream from 1967 to 1980. Solid diagonal lines represent linear regression fits.

3.4. Influence of release location

To compare the performance of fish released at their natal hatchery with those released at another location (not necessarily within the same catchment) after being carried to their release point via a fish transporter, we screened the pooled coded-wire tag database for catchments where there had been enough release groups in both categories to justify a comparison. This identified six such catchments: the Rakaia River (12 non-natal hatchery releases out of 260); the Clutha River (9 of 56 releases); the Waimakariri River (21 of 47 releases); the Waitaki River (14 of 21 releases); the Hurunui River (6 of 17 releases); and the Rangitata River (3 of 8 releases). We show these data as scatter plots of survival to adulthood vs. release date, to compare % survival for the two release groups (local vs. transferred) while allowing (as much as possible) for the potentially confounding effects of variation in mean release weight, release date, and brood year (Figure 8).

Percentage survival for releases from hatcheries tended to be somewhat higher than for releases from other locations, although the results are partially confounded by variation among brood years, and by the large number of data points for releases between 1977 and 1980 which were based on 90-day smolt. Results for the Hurunui River are therefore inconclusive, but results for March to October releases in the Rakaia River, Rangitata River, Waimakariri River, and Waitaki River are all consistent with a general tendency towards lower survival for transferred releases.

By contrast, results for the Clutha River are more equivocal, with some releases into the lower Minzion Burn performing relatively well (refer Table 2). A single pair of results for two groups of fish released from two locations on the same day (24 April 1983) at very similar mean weights (Kaitangata: 70 g; Minzion Burn: 64 g) provide the only direct comparison available. Survival rates for these two releases were 1.26% and 0.48%, respectively, confirming that the Kaitangata release outperformed the Minzion Burn release by a factor of 2.6.

A caveat to the results described above is that all transferred releases into the lower Clutha River were sourced from stocks of Clutha origin, and had been reared at the Kaitangata hatchery. By contrast, releases into the Hurunui River, Rangitata River, and Waitaki River, were sourced from non-native stock of Rakaia or Silverstream origin, carried to their release point by fish transporter. For this reason, the Hurunui / Rangitata / Waitaki release programmes provide a more direct comparison with Contact Energy's current release programme than do the historical releases into lower Clutha tributaries such as the Minzion Burn and Waitahuna River. We therefore conclude that the reliance on source stock from a non-local population, and the inability to rear these at a local hatchery, are likely to have contributed significantly to the poor returns from the 2010-2016 Contact Energy releases.

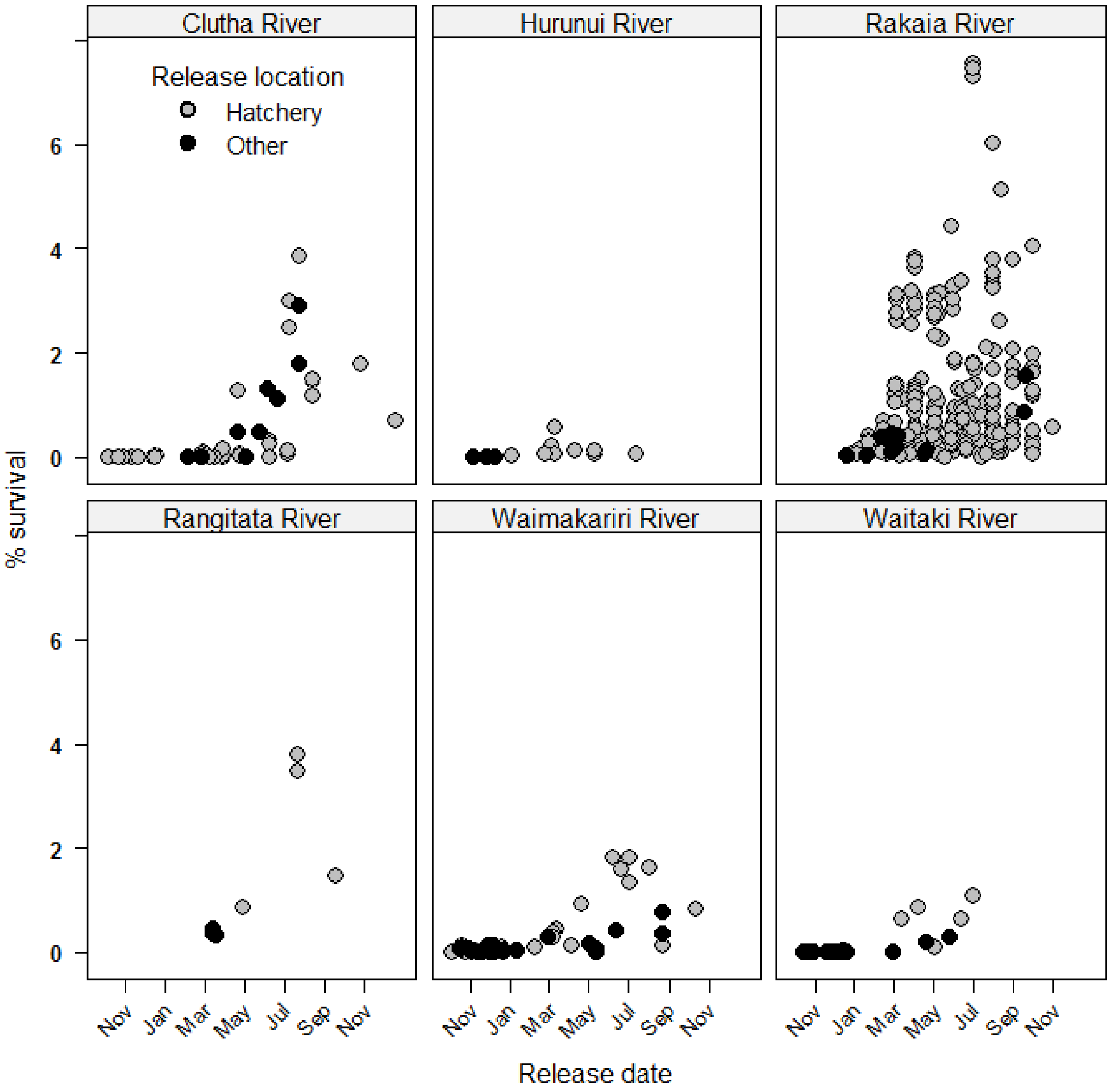

Figure 8. Survival (%) for Chinook salmon smolt released from their hatchery of origin (grey symbols) vs. those released from other locations (black symbols), for six major South Island catchments.

3.5. Comparison of returns from historical and recent Fish & Game hatchery releases

Salmon monitoring has been under-resourced since the mid 1990s; as a result, the few available datasets on current outcomes from hatchery releases are inadequate for conducting a robust comparative analysis against historical data. However, a coarse comparison of the variation in return rates for 'yearling size' hatchery release strategies from historical releases (i.e. smolt > 50 g released between June–August) to available survival estimates from more recent hatchery releases, conducted either by Contact Energy or other Fish & Game regions was attempted. This included using coarse estimates of cohort survival rates for yearling salmon smolt releases from McKinnon's Creek hatchery on the lower Rangitata River (run by volunteers but overseen by Central South Island Fish & Game), along with previously mentioned survival 'guesstimates' from recent releases made into the Clutha River by Contact Energy (2010–2016, see Table 1). Tagging rates of both hatchery releases are generally low, around 30–50% of fish released, and rely on adipose fin clipping only rather than a mixture of coded-wire tag and fin clips, or comparable mass-marking methods. As such they may be influenced by straying of hatchery fish from releases into other rivers nearby, which would amplify survival estimates.

Estimated cohort survival rates for recent hatchery releases of yearling salmon smolt from McKinnon's Creek (mean weigh 65–97 g) typically range from 0.2 to 2.6% (2006–2014 brood years). These estimates are broadly comparable to mean cohort survival rates from historical hatchery releases on rivers with established hatcheries using local origin broodstock (such as the Clutha, Waimakariri and Rakaia rivers, see Table 3). However, they are much higher than 'guesstimated' return rates from recent hatchery releases (2010–2016) into the Clutha, (range 0.03%–0.4%) under a best-case scenario (Helen Trotter, Otago Fish & Game, pers. comm.). This strengthens the conclusion that the use of non-local source stock has contributed to the poor returns from the 2010-2016 releases funded by Contact Energy.

4. DISCUSSION

Fishery managers worldwide use releases of hatchery-reared juvenile salmon to compensate for losses of natural fish production due to human use of rivers. These artificial breeding programmes are typically motivated by a strong desire, and at times a legal requirement, to increase wild salmon populations and recreational harvest opportunities. Acceptance that hatchery releases are a viable fishery enhancement tool is based on the belief that the number of returning adult salmon is primarily related to the number of smolts produced per catchment. Hence human impacts on rivers and wild salmon populations can, at least conceptually, be mitigated by artificially increasing the number of salmon smolt that reach the ocean.

Yet detailed evidence of the long-term benefits to wild populations from extensive releases of hatchery fish is often lacking. This is partly because hatcheries seldom mark or tag all fish prior to release, but also reflects a lack of commitment to appropriate post-release monitoring programmes (Lichatowich & Williams 2009). When monitoring data are available the outcomes of hatchery releases are often highly variable, mainly because a large number of factors contribute to the ultimate success of hatchery release programmes (e.g. broodstock origin and variable survival related to rearing, release and inshore / marine conditions etc.). This has led to a growing recognition that the evolution of population life histories that are locally adapted to freshwater spawning and rearing habitats is a fundamental aspect of salmon ecology (Lichatowich 2013).

The target spawning run of approximately 5,000 salmon as specified in Contact Energy's resource consent for the Roxburgh Dam is very ambitious. If achieved, it would be New Zealand's largest and most successful long-term enhancement programme since the original liberations of Sacramento River stock into the Waitaki River in the early 1900s, generating adult returns equal to or exceeding the most successful supplementation programmes of the early to mid-1980s.

Other than the obvious fact that it has failed so far to meet its target, the most striking outcome of the current release programme is that—despite releases totalling close to 900,000 fish over a seven-year period—the releases have failed to generate information that will help identify options for implementing a more successful programme.

The analyses presented in this report identify five considerations which we believe should be given priority when developing a revised enhancement strategy for the lower Clutha River. These are:

- establish a purpose built salmon hatchery on the lower Clutha
- set realistic goals and expectations for run strength
- enable evaluation of enhancement actions

- identify links between release strategy and survival rate
- establish a broodstock specific to the lower Clutha.

These considerations will help inform future decisions about the long-term continuation of the hatchery programme irrespective of the consented target salmon return levels. The remainder of this discussion is devoted to elaborating on these points, followed by our recommendations.

4.1. Establish a purpose-built hatchery

The tendency for the most successful long-term supplementation release programmes to be associated with hatcheries such as Glenariffe and Silverstream, coupled with the generally poor performance of fish imported from other catchments, suggests that a purpose-built hatchery on the lower Clutha River will be essential if long-term success is to be achieved. Given the poor returns to date we do not assume that such a hatchery will guarantee success, but we strongly believe a release programme that does not include a locally-based hatchery will inevitably fail.

We therefore recommend that Contact Energy continues to develop concept plans, an operating framework, and a budget to establish a lower Clutha salmon hatchery capable of sustaining well-targeted experimental releases of 150,000–200,000 salmon smolt annually for a minimum period of 10 years. Establishing such a hatchery usually requires a formal catchment-wide scoping exercise to identify and evaluate alternative siting options, and finalise design specifications, but at least one potential site has been identified at Lake Roxburgh village (Gabrielsson 2018). Following a 10-year establishment period, we would envisage a review to identify viable long-term options.

4.2. Expectations from future hatchery releases

Expectations of long-term mean survival rates of, or exceeding, 1% appear to be based on an over-optimistic extrapolation from hatchery returns to the lower Clutha River in the early 1980s, and are unrealistic. Survival rates in the Rakaia and other east coast rivers at this time were unusually high, and—with the benefit of 30 years hindsight—now appear as outliers. Long-term data sets for Glenariffe Stream confirm that annual survival rates vary by a factor of 100 among brood years, and are approximately log-normally distributed (Bradford 1995)[7]. Survival rates exceeding 1% may indeed be achievable in an exceptional year, but will more typically be closer to 0.1–0.2% in an average year, and as little as 0.01% in a poor year.

[7] Log-normal distributions typically arise when the variable of interest, in this case survival, can be represented as a product of multiple factors each of which varies independently. Such distributions are characterised by preponderance of low values offset by a few high outliers, and a median which is much lower than the mean. Household incomes are a familiar example.

Median survival across all hatchery releases reviewed in this report was very low (< 0.035%). This figure is conservative as it includes many releases over 1977–1982 of '90-day smolt' weighing 5–10 g, which consistently failed to produce returns. However even after excluding those releases median survival rates for most rivers were typically well below 0.5%. The Glenariffe Stream record (Figure 5) hints at a tendency for periods of higher survival to cluster together, perhaps at intervals of 10-15 years, but simulations based on a randomly varying log-normal model (not reported here) reveal that the observed variation is essentially random and unpredictable. This does not preclude the possibility of a link between survival rates and oceanic cycles (Pearcy 1992), which could potentially be indexed through variables such as sea surface temperature (SST; Uddstrom & Oien 1999). However, SST data for New Zealand waters were not collected routinely until the early 1990s, and do not overlap with the Glenariffe record.

For the purposes of managing future expectations for enhancement releases into the lower Clutha River, and hence to ensure that all parties involved are comfortable that these are realistic and achievable, we suggest that projected return rates can be expected to fall broadly into three blocks representing, respectively, low survival (< 0.2%); intermediate survival (0.2–1%); and high survival (> 1%). Low survival essentially equates to below median survival, and can be expected to occur approximately half the time. Intermediate survival can be expected to occur around 40–45% of the time, and high survival at most 5–10% of the time.

The above guidelines do not allow for recent changes to ocean conditions, which have seen near-record high sea surface temperatures around much of New Zealand. While the impacts or longevity of these changes remain unknown, they are likely to present many new challenges for cool water species such as Chinook salmon.

4.3. Enabling evaluation of fishery enhancement actions

We consider a robust marking programme to be the second essential requirement of any future enhancement strategy. The analyses conducted in this review are, we hope, sufficiently detailed and compelling to leave consent holders, fishery managers, and hatchery operators in no doubt as to the benefits of a structured marking programme. In the absence of such a programme it is not possible to identify specific outcomes of differing release strategies, and to isolate these effects from variation in brood year survival. Influences on survival which can potentially be quantified through a suitably structured marking programme include, but are not limited to: size and time of release, release location, broodstock origin, and effects of transport. Over time, this information may also yield new insights into the influence of uncontrolled factors such as catchment hydrology.

Information from such a programme would also help to inform cost-benefit analyses of differing release strategies. For example, assuming a primary goal is to produce the largest number of returning fish for the least cost, is it more cost-effective to release a large number of fish at a relatively low mean weight, or a smaller number of larger fish? Nor should it be overlooked that factors other than raw survival rate can potentially be manipulated to advantage, particularly for release strategies focussed on maximising returns to the angler. The Glenariffe data show convincingly that traits such as age at return, and size at age, are directly related to size and time at release. Fishery managers may favour a release strategy which accepts some reduction in overall survival in exchange for a higher incidence of larger 3-year and 4-year-old fish which are preferred by anglers.

We therefore recommend that future releases of salmon into the lower Clutha River should ensure all fish are identifiably marked, preferably by release strategy / batch, and that marking records and monitoring data are compiled into a national database. A range of easy to apply, cost-effective and accurate mass-marking methods are available to fishery managers, and suitable to monitor the success of fishery enhancement via releases of hatchery-reared salmon smolt. For further details regarding available options for mass-marking techniques see Warren-Myers et al. (2018) and Gabrielsson (2015).

4.4. Links between release strategy and likely survival rate

For historical releases into Glenariffe Stream the relationships between survival and release date / weight followed well-defined trajectories which persisted across brood years. The corresponding relationships for releases into the lower Clutha will not necessarily align with those observed for Glenariffe Stream, but are likely to be equally robust. A third priority is therefore to quantify these relationships for the Clutha River. As noted in the previous section, understanding these relationships is fundamental to developing a release strategy which balances the potentially competing aims of maximising returns, maximising cost-effectiveness, and meeting angler expectations.

Although survival rates in Glenariffe Stream were positively associated with increasing smolt size, the resulting increase in survival was partially offset by a weaker but still highly significant tendency for survival to decrease as fish were held for longer periods. This suggests that an optimal release strategy may involve a trade-off between size and age at release, particularly when cost-benefit analysis is taken into account. Indeed, the Glenariffe results strongly suggest that under the conditions which applied there in the 1980s, a better strategy may have been to focus on growing fish as quickly as possible, so that they could reach a specified target weight (e.g., 30 g) and be released as early as possible. The possibility that a similar strategy may be appropriate for the lower Clutha, including the release of even smaller (e.g., 20 g) fish, deserves further exploration.

Marine conditions are an important factor that influences growth, age at maturity and run size of salmon populations. There is a strong tendency for runs of wild adult salmon in the four main salmon-producing rivers (i.e., the Waitaki, Rangitata, Rakaia and Waimakariri) to follow parallel trends (FGNZ, unpublished data). A high correlation between annual survival rates for wild and hatchery-origin fish provides additional evidence that cohort strength of both groups is often largely driven by marine conditions, presumably shortly after ocean entry. However, while variation in marine conditions is clearly an important driver of variation in salmon production, smolt survival and run size can in some years also be heavily influenced by freshwater environmental conditions. For example, flood pulses in the Rakaia River during spring (indexed by the ratio of mean to median flows during October and November) corresponded with increased cohort survival, possibly because large offshore freshwater plumes may help buffer the transition from fresh to saline waters (Unwin 1997b). Although turbid flood waters may also increase survival by reducing visibility and decreasing losses to inshore marine predators such as kahawai (*Arripis trutta*). These findings are supported by research overseas which also demonstrate a relationship between adult returns and the river flows experienced as juveniles (Sturrock et al. 2015), and that differences in survival between wild and hatchery-reared salmon can at times be largely determined shortly after release during downstream migration (Melnychuk et al. 2014). Taken together these findings suggest it is sensible to confirm hatchery fish are ready for release by conducting saltwater readiness tests (Kinnison et al. 1998a); and secondly that experimental investigation of how release time, flow history and freshwater migration distance relates to smolt-to-adult survival would be beneficial.

4.5. Establishing a Clutha River broodstock

New Zealand Chinook salmon stocks have diverged significantly from their Sacramento River ancestors, in both phenotype and genotype, since the first liberations into the Waitaki River 110 years ago (Quinn et al. 2001). This divergence led to marked inter-population differences within New Zealand in traits such as age at maturity and size at age (Quinn & Unwin 1993), reproductive output (Kinnison et al. 2001; Kinnison et al. 1998b), migration timing (Quinn et al. 2011) and duration of freshwater residence (Unwin et al. 2000). Integrating these traits into survival from release to return, salmon of Glenariffe Stream origin released into their natal stream outperformed Waitaki River stock released at the same location by a factor of 1.7 in 1994, and 2.9 in 1995 (Quinn et al. 2001), providing direct evidence of a ‘home court’ advantage for the locally adapted stock.

These results, together with best practice guidelines for North American hatchery operations (Willis 2018), provide a compelling case for basing future enhancement releases into the lower Clutha River on locally sourced stock. As well as boosting survival rates, using a locally adapted brood stock would eliminate the confounding effects of population of origin when evaluating survival data across brood years. Perhaps more importantly, it would also minimise (if not eliminate) negative impacts on wild stocks in the lower Clutha River due to loss of genetic fitness (Willis 2018 and references therein).

4.6. Adjusting hatchery enhancement strategies for the Clutha River

As previously mentioned river flows shortly before, during and after release may in some years have an important influence on cohort survival. This suggests gains can be made by rearing fish to an appropriate size and then releasing them in batches coinciding with high flow events so they may benefit from a freshwater plume into the ocean. Based on the knowledge gained from the revised analysis presented in this report we recommend restructuring future hatchery releases into three broad categories: late summer releases of > 30 g smolt (mid-March onwards), along with a small number of monitoring releases of 50–80 g smolt during autumn / winter (May onwards), and some very large smolt (> 150 g) released late winter / spring (August–December).

The two primary benefits of adopting a more diverse ‘portfolio’ of release strategies is that (1) that if coupled with a comprehensive marking and monitoring programme it will contribute to a better understanding of the fishery, facilitating adaptive management of the sports fishery enhancement efforts and strategy; and (2) it may also help partly reduce the high interannual variability in return rates common to hatcheries that rely on a single release strategy, though a buffering ‘portfolio effect’. Considerable cost savings can also be made over the longer term (consent period) by beginning to release hatchery fish earlier each year (e.g. 15 March onwards) than has previously been the case (July–September).

5. RECOMMENDATIONS

Based on the findings of this report we recommend that Contact Energy:

- continues to develop concept plans, an operating framework, and a budget to establish a salmon hatchery near the Roxburgh Dam capable of sustaining well-targeted experimental release of salmon smolt annually (150,000–200,000) during a 10-year hatchery establishment phase
- in consultation with fishery managers and other stakeholders, revises its expectations of survival rates likely to be achievable on the lower Clutha River. Anticipated survival rates exceeding 1% may be achievable in an exceptional year, but a more realistic target would be 0.1–0.2% in an average year, and as low as 0.01% in a poor year
- ensures that all releases are batch-marked, and that returns are monitored via appropriate harvest surveys, thereby enabling the results of differing release strategies to be measured and compared
- quantify the relationships between survival to adulthood, and size and age at release, with the dual aims of (a) characterising the extent to which survival varies among brood years, and (b) informing cost-benefit analyses of competing release strategies
- establishes a locally adapted, Clutha-specific broodstock by sourcing ova from wild adult salmon returning to the Clutha River
- reviews the success of hatchery releases (and any other associated fishery enhancement activities) after 10 years, to determine how and to what degree hatchery releases can enhance the Clutha River sea run salmon population.

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