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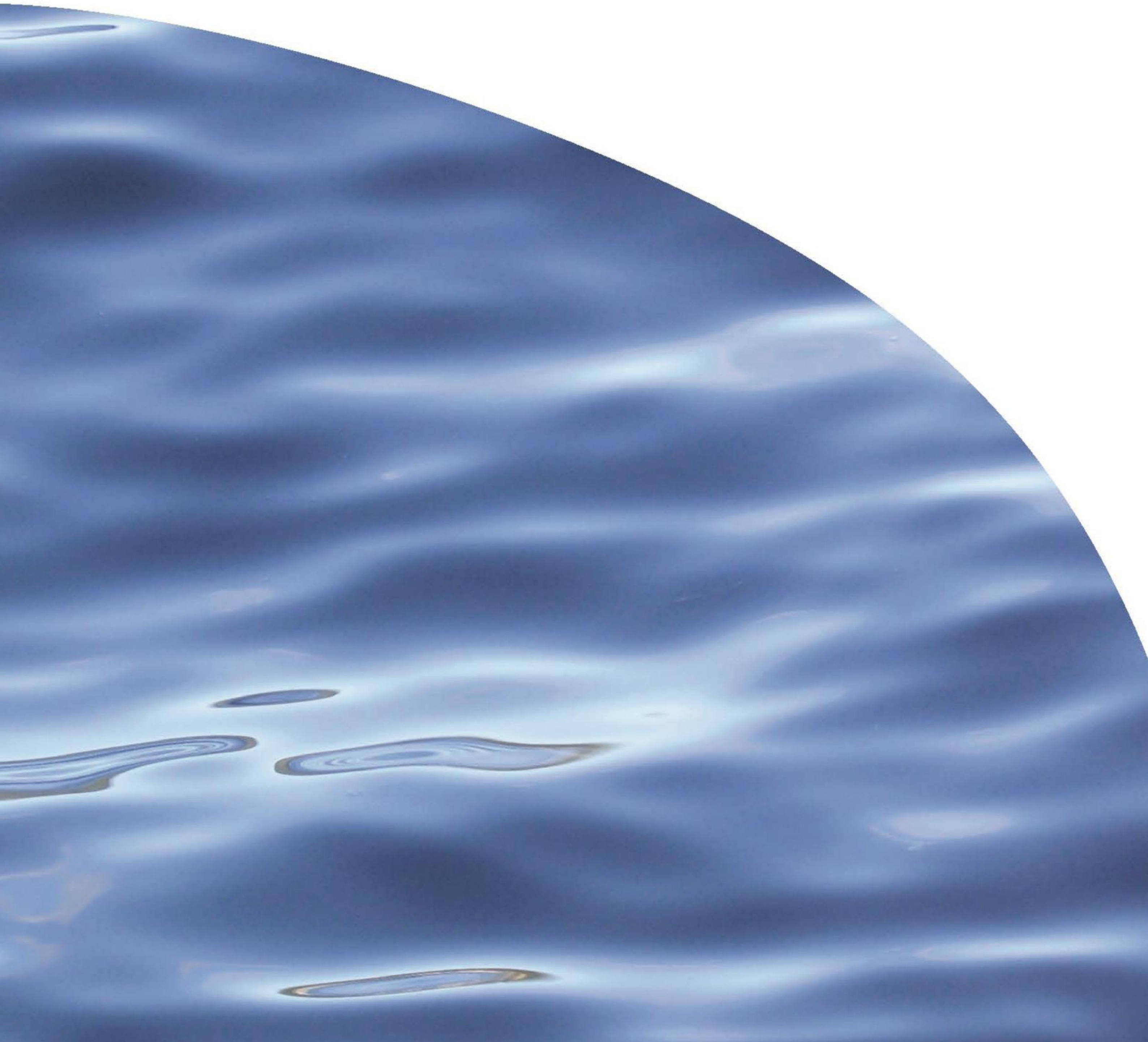
A REVIEW OF CONTEMPORARY SALMONID STOCKING PRACTICES IN NEW ZEALAND



A REVIEW OF CONTEMPORARY SALMONID STOCKING PRACTICES IN NEW ZEALAND

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Prepared for Fish & Game New Zealand

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EXECUTIVE SUMMARY

New Zealand's trout and salmon fisheries are becoming increasingly degraded from multiple pressures, including intensive land use, climate change and increased angling pressure. Consequently, there is renewed interest within some New Zealand Fish & Game regional councils to release hatchery-reared fish as a management response. In this report, I review the theory and international literature on salmonid stocking and discuss the potential effects of stocking on wild salmonid populations. I also provide a national overview of contemporary stocking programmes and present three regional case studies. I have focused on the ecological implications of hatchery stocking. Economic aspects were explicitly excluded from my scope.

Potential consequences of stocking

The success of stocking salmonids in lakes and ponds with limited or no spawning habitat is self-evident in terms of returns to anglers. However, in open river systems, with existing self-sustaining (wild) salmonid populations, most stocking programmes fail to enhance fisheries in the long term. Furthermore, in many cases, augmentation of salmonid populations with hatchery-reared fish can occur at the expense of natural production from the wild component of the population.

Releases of hatchery fish into systems already containing self-sustaining wild populations can:

1. reduce available resources for existing wild fish through competition
2. introduce domesticated fish genetics reducing overall population fitness
3. retard the process of local adaptation
4. place increased predation pressure on native fauna
5. inflame negative perceptions towards Fish & Game (and salmonids in general) because of the perceived impact of stocking introduced fish on native fish.

Salmonid stocking in New Zealand

Stocking salmonids is still wide spread in New Zealand and occurs in a range of waterbody types. In total, almost four million salmonids have been released into New Zealand's waterbodies within the last five years. Fish & Game regions have differing approaches to stocking. Salmonid releases in the Otago, Auckland, Wellington, Southland and Hawke's Bay Regions are largely limited to put-and-take fisheries in reservoirs, small lakes and ponds. In the North Canterbury, Northland, Taranaki and Nelson Regions, fish releases occur in small put-and-take lake fisheries as well as in various rivers and streams. The Eastern Region runs an intensive rainbow trout release programme across 13 large and small lakes. The Central South Island, North Canterbury, and to a lesser extent the West Coast regions, release large numbers of Chinook salmon smolts in an attempt to enhance sea-run fisheries.

Regional case studies

In our review of fish release practices in New Zealand, the demonstrable success of the Eastern Region's hatchery and fish release programme was unparalleled. Thirteen lakes of varying sizes are efficiently run as large put-and-take fisheries - through regular stocking with 180-mm rainbow trout. A high-quality monitoring program is in place which demonstrates high returns to anglers. The region's three main lakes support well over 100,000 angler days annually and approximately 70% of all fish caught in these lakes originate from the Ngongotaha hatchery.

In recent years the Nelson / Marlborough Region has undertaken substantial releases of large 'takeable'-sized (i.e. > 750 g) fish in Argyle Pond (a hydro-electric header reservoir) and the newly created 'fish-out' ponds on the Waimea River bermlands. The success of these initiatives in terms of returns to anglers is clear. Over the past two years, the Nelson region has also undertaken releases of takeable-sized brown and rainbow trout into a variety of rivers and streams throughout the region. Many of these fish releases have been unsuccessful. The exceptions are the releases of 100's of takeable-sized rainbow trout into spring-fed streams. These releases have increased total fish densities over a sub-annual time scale (determined through drift diving surveys) and appear to have benefited some anglers. In addition, the Trust Power-funded rainbow trout releases into the Branch-Leatham River system demonstrate that even moderately flood-prone rivers can be managed as put-and-take fisheries (at least during years with relatively stable flows). The success of this programme is due to regular releases of substantial numbers of takeable-sized rainbows - in the order of 200–400 large fish released biannually. The region is also releasing juvenile life-history stage salmonids (i.e. eye-ova and fingerlings) into a range of streams and rivers with existing fisheries. However, the region has no means of assessing the effectiveness of these juvenile salmonid releases. Generally, the potential negative consequences of fish releases into rivers and streams with existing wild salmonid populations appear to be disregarded.

Our investigation into the North Canterbury Region's hatchery release practices revealed substantial problems with their data collection and reporting. Particularly with respect to the Montrose hatchery, which produces salmon smolts in an attempt to enhance sea-run salmon populations in the South Islands east coast braided rivers. Not only is their current monitoring programme not fit-for-purpose, it is misleading. The last decade of reporting appears to be based on erroneous data, meaning that the Region's councillors and anglers are unaware of the actual performance of the hatchery release programme. Furthermore, it is possible that the current hatchery practices may be placing pressure on wild sea-run salmon population in the Rakaia during years when unfavourable ocean conditions result in weak spawning runs.

Key recommendations

The practice of releasing juvenile life-history stage trout into rivers and streams should be discontinued. In general, all trout hatchery release programmes should focus on creating 'put-and-take' style lake fisheries in waterbodies where it can be demonstrated that natural recruitment is limited. In particular, the success (and demand) for small put-and-take lake fisheries near population centres is clear.

Both history and science show that hatchery release programmes, based on releasing juvenile salmonids in open river systems, have a high chance of failure. Furthermore, there can be negative consequences for wild fisheries. We recommend that Fish & Game develops an inter-Regional peer-review process for all hatchery release programmes. Given the risks involved, the burden-of-proof should be placed on all release programmes to demonstrate that returns to anglers will outweigh any potential negative consequences.

A more extensive list of recommendations is provided at the end of this document.

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1. INTRODUCTION

New Zealand's internationally renowned salmonid fisheries were created from hatchery-reared fish. In the mid to late 1800s, the persistent efforts of acclimatisation societies eventually resulted in the establishment of naturalised and self-sustaining (wild) salmonid populations across New Zealand (McDowall 1994). By the mid-1900s, the three main salmonid sports fish species, brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*)[1], had largely expanded to their present-day distributions. Fish & Game now no longer seeks to expand the range of salmonids within New Zealand (Anon 2000). However, to this day, releases of hatchery-reared salmonids continue within their present range. The intention of these fish releases is to maintain, enhance, or create angling values (in the case of waterbodies without spawning habitat).

There is consensus amongst anglers, fishery managers and scientists that New Zealand's salmonid fisheries have declined alongside the expansion of urban and agricultural land uses. Moreover, the pace of fisheries decline has increased over the last three decades alongside the rapid growth of intensive agriculture. In addition, within the context of a changing global climate, warming river and ocean temperatures (alongside more extreme weather events) threaten to reduce populations and contract the range of salmonids. Populations in the warmer and more drought-prone areas of New Zealand are particularly at risk (Scott & Poynter 1991). An inevitable consequence of increasingly degraded fisheries, both here and overseas, is that those fisheries that remain in good health are being placed under increasing angling pressure (Unwin 2009). Because of all these threats there has recently been renewed interest within some of the regional Fish & Game councils to release hatchery-reared fish to maintain or enhance fisheries.

The base argument for releasing hatchery-reared salmonids into waterbodies is simple: it is assumed that if more fish are put into a waterbody there will be more fish for anglers to catch. Indeed, in closed-system waterbodies, without natural spawning habitat, the success of hatchery releases in terms of creating angling opportunities is self-evident. However, for rivers and streams with wild salmonid populations, the factors that led to the success or failure of hatchery releases are complex and generally returns to anglers are poor (Levin et al. 2001). Moreover, internationally respected salmonid scientists have been arguing for decades that traditional hatchery release programmes represent a major *threat* to wild migratory salmonid populations and fisheries. Some go further, suggesting that the scale of negative impacts from hatchery releases on wild salmon populations is comparable to dams, habitat loss and harvest (Ruckelshaus et al. 2002). More moderate views on the value of hatcheries have emerged recently, with the focus of hatcheries shifting from augmenting biomass

[1] This review will not consider other naturalised New Zealand salmonids species, such as brook trout or sockeye salmon, because they are seldom reared in hatcheries for supplementary stocking and they support minor fisheries.

to providing 'supportive breeding' programmes aimed at protecting locally endangered wild populations.

1.1. Report scope

In this report I consolidate the relevant theory and literature on salmonid stocking and discuss the potential effects of hatchery stocking on wild salmonid populations. Following this, I provide a national overview of contemporary stocking programmes and present three regional case studies. In the discussion section I provide an analysis of Fish & Game's current hatchery practices and present a rebuttal to some common arguments put forward in favour of hatchery releases to supplement wild populations. Finally, I provide some specific management recommendations regarding the future role of salmonid stocking in New Zealand.

To maintain a focus on recent practices, the national scale analysis is limited to hatchery releases occurring over the previous five years. In addition, my scope did not include an analysis of the economic aspects of hatchery releases or operational practices relating to fish rearing (i.e. animal husbandry).

1.2. Management reasons for hatchery releases

Before discussing the implications of different stocking practices and their potential effects, it is useful to define the different management contexts for stocking salmonids. Broadly, these fall into four categories:

1.2.1. 'Put-and-take' fisheries

Many waterbodies that provide suitable adult salmonid habitat have limited or no spawning habitat; for example, small lakes and ponds which lack substantial permanent tributaries. In these systems, the existence of a fishery can be entirely dependent on the release of hatchery reared fish. Fish are 'put' into the waterbody, either as juveniles or adults, for anglers to 'take' them out.

1.2.2. Fishery enhancement stocking (supplementary stocking)

I refer to supplementary stocking as the practice of releasing hatchery-reared fish to boost catch-rates and / or recruitment within an existing wild salmonid population. For example, Fish & Game and voluntary angler organisations regularly release 100s of thousands of salmon smolt into the South Island's east coast Chinook salmon rivers, such as the Rakaia and the Waitaki rivers.

1.2.3. Supportive breeding

The term supportive breeding refers to stocking practices to preserve stocks at risk of local extinction. Key elements of a supportive breeding programme are careful broodstock selection from wild populations, clear population objectives and an exit strategy for the discontinuation of the stocking programme. Supportive breeding programmes differ from supplementary stocking because fish are not being released primarily for anglers to catch, rather fish are released in an attempt to increase recruitment and the long-term viability of a wild, self-sustaining fishery.

1.2.4. Stocking for resource use mitigation

In some situations, the release of hatchery reared-fish is undertaken in recognition of the effects of a development (usually an impoundment) on a fishery. These may be required mitigation set by resource consent conditions. Alternatively, a developer may undertake fish releases voluntarily, to demonstrate good corporate citizenship, in partnership with fishery management agencies.

1.2.5. Stocking for research purposes

Stocking can be used as a tool for fisheries investigations. For example, releasing tagged fish and subsequently tracking their movement, growth and survival is one way to determine if a fishery is recruitment limited (or not). Such experiments assume that hatchery-reared fish are suitable models for wild fish.

2. FACTORS AFFECTING THE SURVIVAL OF STOCKED SALMONIDS

2.1. Habitat and carrying capacity

There are two key ecological concepts that need careful consideration before (and during) any fish release programme: the carrying capacity of the receiving environment and the related concepts of density-dependent and density-independent growth and survival. Carrying capacity is the term used to describe the upper limit to the number of organisms that can fit into an ecosystem. The upper limit in salmonid populations is not static but changes over time in response to limiting factors such as food and space availability, particularly in rivers with highly variable flow regimes (Cramer & Ackerman 2009). As any population approaches its carrying capacity, density-dependent factors increasingly constrain population growth until carrying capacity is reached. The logistic function in Figure 1 illustrates this concept.

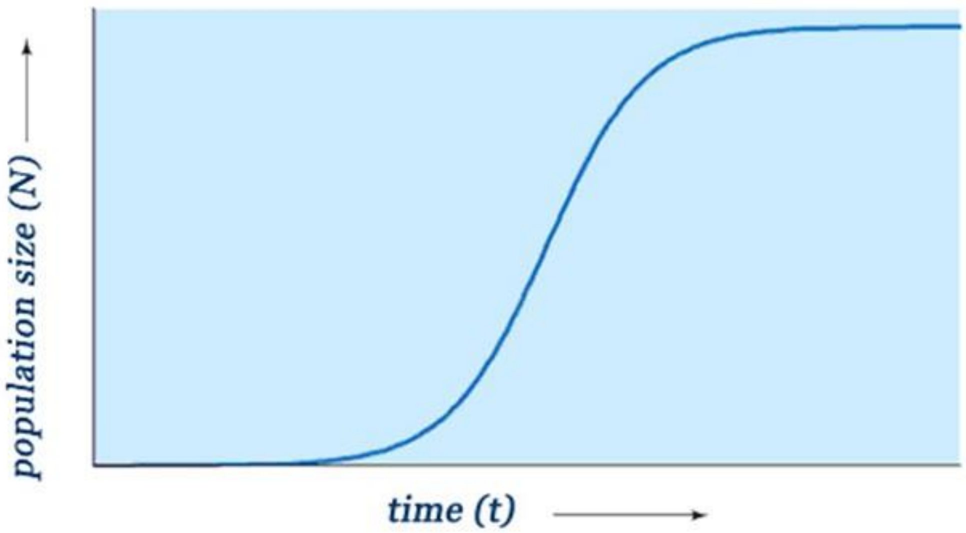

Figure 1. A typical logistic curve used in stock recruitment models. Initially, a population at low densities undergoes exponential growth, eventually population growth is increasingly constrained as carrying capacity is approached.

Food limitation is the most intuitive density-dependent constraint on population growth, although spawning habitat availability, juvenile rearing habitat, predation pressure and disease are other types of density-dependent controls that can increase in severity at high population densities (Armstrong et al. 2003). Inverse density-dependent control can also occur at very low population sizes. For example, the chances of finding a mate may be reduced at very low population densities and this can further reduce a population size (Courchamp et al. 1999). Typical examples of density-*independent* population control in salmonid populations are the effect of high temperatures or flooding in rivers (George et al. 2015; Elliott 1994). These factors are thought to slow growth or 'thin-out' a proportion of population irrespective of initial population size.

Understanding how close a population is to carrying capacity, and the degree to which a population is limited by density-dependent or density-independent factors, is critical to guaranteeing the success of any stocking programme (Alldredge et al. 2015). For example, if fish are stocked into systems where the initial population is limited by food availability, the stocked fish will either replace the existing fish biomass, migrate out of the system (if this is possible) or lose condition or die because there is not enough food production to support the additional biomass. However, if a waterbody is 'over stocked' there will always be a lag-phase before biomass is reduced to carrying capacity. Equilibration to carrying capacity may take days or weeks, if outmigration is possible, or months if outmigration is not possible and food limitation is in effect. In the later scenario, stocked juvenile fish will be unlikely to reach a size of interest to anglers (takeable size). If they do, it will be at the expense of total biomass within the wider population. Nevertheless, if a waterbody is 'over-stocked' with takeable-sized salmonids (e.g. > 750 gm), anglers can exploit the temporary increase in fish numbers, provided they act before fish eventually lose condition, die of natural causes or emigrate. Many small put-and-take lake fisheries are operated in this manner to ensure high catch rates for anglers. Fish releases are actively advertised to ensure anglers remove fish whilst they remain in good condition from weight gained in the hatchery.

Based on these concepts, hatchery releases will be more effective in natural systems that are well below their salmonid carrying capacity, for example, as a result of limited spawning habitat or intense angling pressure. However, in practice, defining the salmonid carrying capacity of streams and large lakes is a difficult and resource-intensive exercise. It is practically impossible in large river systems. Determining methods for defining salmonid carrying capacity in large rivers is currently a frontier in fisheries research (e.g. Wheaton et al. 2018).

2.2. Stocking practices

2.2.1. Size at release

Across all salmonid species, the larger the fish are at the time of release, the higher their survival rate in the wild (e.g. Saloniemi et al. 2004; Miyakoshi et al. 2001; Unwin 1997b). However, because all hatcheries have a limited biomass capacity, there is always a trade-off within a hatchery cohort between the size and the number of fish that can be produced. For example, during the 1970s, a substantial Chinook salmon long-term research programme was conducted at the Glenariffe fisheries research station in the Rakaia catchment (Quinn et al. 2001). Using various release strategies, it was determined that the optimised North American practice of releasing 90-day-old smolt (5-10 g) was not an efficient way to run salmon hatcheries in New Zealand. Common practice from 1981 onwards, has been to rear smolts for up to 15 months with release weights of between 10 and 80 g (Unwin 1997a).

For brown and rainbow trout it is not possible to determine broadly effective release strategies in relation to an optimum size / number trade-off. This is because habitat variables, such as the risk of flood displacement or predation pressure affects optimum release strategies and these factors are highly variable between waterbodies. The Ngongotaha Hatchery operated by Eastern Fish & Game Council is New Zealand's longest-running rainbow trout hatchery operation. There it has been determined that rearing fish to around 180 mm results in the best returns within the Rotorua lakes put-and-take fisheries (pers. comm., Mark Sherburn, Fish & Game Officer, Eastern Region). For fish to successfully establish in rivers, where they are vulnerable to mortality and displacement by floods, they probably should be larger than this. This is because flood-induced mortality is disproportionally high during early salmonid life history stages (Armstrong et al. 2003). For example, major flooding in six South Island East Coast rivers in March 1986 reduced small brown trout (100-200 mm) by 90–100%, medium browns (200–400 mm) by 62–87% and large browns (> 400 mm) by 26–57% (Jowett & Richardson 1989). Rainbow trout occurred in three study rivers but were not found in two them after the flood. In the third river the abundance of large rainbow trout had increased in the drift dive sections after the flood, but small rainbows decreased by 94%. The results of this study support the view that juvenile (small) trout up to 200 mm are highly vulnerable to flood-induced loss and that rainbow trout are more vulnerable than browns.

2.2.2. Release timing

For migratory Chinook salmon, release timing has a substantial influence on survival. Unwin and Gabrielsson (2018) reviewed data from 202 salmon releases from the Glenariffe research station on the Rakaia. By modelling both size and release timing, they found that releases around early March resulted in adult return rates about twice that of fish released in early August for fish of the same size (Unwin & Gabrielsson 2018). There is some evidence to suggest that Chinook salmon released during high rainfall years have relatively higher survival rates (Unwin 1997b). Chinook salmon are thought to suffer high mortality during smoltification in freshwater plumes running into the ocean due to the physiological challenge of adjusting to salt water and predation. Larger freshwater plumes, that result from frequent high flows, would provide smolts with more dilution and turbid water, to avoid detection from predators, over a wider area when they are dispersing.

For brown and rainbow trout, and landlocked salmon releases, timing is less critical than it is for ocean-going Chinook salmon, because outmigration is not an obligatory life history strategy. However, basic physicochemical water properties change with season. In particular, the temperature of the receiving environment will have a considerable effect on the behaviour and survival rates of liberated trout. After release, hatchery-reared salmonids require a period of adjustment to natural environments as they establish territories and learn to capture natural food (Jonsson & Jonsson 2006). During this period, they are vulnerable to stress. It follows that fish releases during high river temperatures in mid to late summer (e.g. > 17 °C) may be less successful than releases during cooler temperatures when fish will have lower energetic demands (Elliott et al. 1995).

2.2.3. Stability of the receiving environment

Mortality and loss rates of hatchery-reared fish are lower, the more benign and stable is the receiving environment. Put simply, survival (and by extension return to anglers) will be relatively high when salmonids are released into waterbodies that closely resemble hatchery conditions, such as ponds and lakes. Indeed, the generally high survival rates of large fish released into fish-out ponds is self-evident. Conversely, there is a substantial amount of evidence to show that releases of juvenile salmonids into dynamic rivers and streams is often unsuccessful (Jonsson & Jonsson 2009). For example, a comprehensive study of recent release strategies by the Victorian Fisheries Authority, which included a review of previous release strategies, found that substantial and extensive juvenile trout releases into rivers and streams throughout the region have been unanimously unsuccessful by any measure of success (Forster et al. 2017).

3. POTENTIAL EFFECTS OF HATCHERIES ON SALMONIDS AND WILD POPULATIONS

3.1. Effects of hatcheries on salmonids

Traditional hatcheries are simplified and benign environments compared to natural systems. Temperatures and flows are optimised and are often relatively homogeneous. Plentiful, energy-dense food rains from the sky at predictable intervals and there are no, or few, predators. High mortality rates during the egg and fry stages are a defining feature of wild salmonid populations (Levin et al. 2001; Armstrong et al. 2003). However, the science of rearing salmonids has advanced to the point where hatcheries can now effectively bypass the massive mortally rates of early life-stages by about two orders of magnitude (Maynard et al. 1995; Levin et al. 2001; Lichatowich et al. 2001). As a result, densities in hatcheries far exceed those experienced by fish in natural waterbodies. As might be expected, rearing within the profoundly different hatchery environment can affect fish behaviour and morphology (Towle 1983).

Einum and Fleming (2001) reviewed the behavioural changes associated with a range of hatchery-reared salmonids. From a range of independent studies, they identified that (relative to wild salmonids) after release the hatchery-reared fish had:

1. a tendency to be more aggressive towards conspecifics
2. a reduced tendency to avoid predators
3. higher metabolic rates
4. a tendency to be more active higher in the water column
5. altered out-migration timing
6. lower feeding efficiency
7. inferior camouflaging
8. a reduced fear of people.

All these changes could theoretically result in reduced 'fitness' for hatchery fish when compared with wild fish. Indeed, there is now overwhelming evidence to show that hatchery-reared fish have lower survival rates in natural environments relative to their wild counterparts. This occurs during all life history stages including: downstream migration (e.g. Melnychuk et al. 2014), somatic growth periods (Kurt et al. 2018), at sea (e.g. Howell 1994) and during reproduction (e.g. Christie et al. 2014). Out of 24 studies of differential survival rates of hatchery and wild salmonid species (including various studies on rainbow trout, brown trout, Atlantic salmon and brook trout), 22 studies found that hatchery-origin fish had reduced survival rates compared with wild fish of the same species (Einum & Fleming 2001).

Over subsequent generations, hatchery fish diverge genetically from wild populations—a process termed domestication. At the extreme end of the scale are the commercial hatchery strains of Atlantic salmon which are the product of intensive selective breeding programmes. Gross (1998) suggests that Atlantic hatchery salmon have become so domesticated that escaped farmed salmon should be treated as an *exotic* species within their native range. Commercial Chinook salmon have also been selectively bred for desirable market traits in New Zealand (Camara & Symonds 2014), although they have had a relatively short period of domestication, and far less investment in selective breeding programmes, within our own salmon aquaculture industry. Nevertheless, as the industry progresses, selective breeding programmes are set to intensify, and commercially farmed Chinook broodstock will diverge rapidly from wild fish (pers. comm., Dr. Jane Symonds, Cawthron).

Domestication also occurs inadvertently in hatcheries intended to support wild fisheries (Ford 2001; Christie et al. 2015). Furthermore, unintended domestication can occur rapidly. For example, Christie et al. (2012) showed measurable adaptation to hatchery conditions occurred in a *single* generation within a hatchery population of migratory rainbow trout (steelhead). More recently, evidence is emerging that epigenetic changes cause reduced fitness in first-generation hatchery-reared fish (i.e. progeny of wild origin fish reared in a hatchery) (Luyer et al. 2017).

3.2. Effects of hatcheries on wild populations

At this stage the ‘so what’ question needs to be asked. Does it matter that hatchery-origin fish perform relatively poorly in natural environments if they still add to the overall size of a population? The answer is yes, if hatchery fish exclude wild fish from obtaining resources, through competition, then the wild fishery will be negatively affected (see Section 2.1). An even more problematic issue is the potential for the progeny of hatchery origin fish to have relatively low fitness. For example, if hatchery fish breed with wild fish, and the progeny have lower fitness, then the initial population boost from hatchery releases could result in a net reduction in the reproductive potential of a wild population (Reisenbichler & Rubin 1999; Araki et al. 2008; Willmes et al. 2018).

Christie et al. (2012) demonstrated that wild-born first-generation hatchery fish had substantially reduced fitness when compared to the progeny of wild origin fish in a steelhead (sea-run rainbow trout) population. Similarly, Miller et al. (2004) showed that the progeny of hybrids between hatchery and wild rainbow trout had a relative survival rate of just 59% when compared to progeny of wild x wild type pairings.

At the population level, Chilicote et al. (2010) found a negative relationship between the proportion of hatchery fish in the spawning population and the reproductive performance of natural populations of steelhead rainbows, Coho, and Chinook salmon. Productivity estimated from recruitment models suggested that the reproductive performance for a population comprising entirely hatchery fish would be just 13% of a population comprising entirely wild fish. The effect of hatchery fish was the same among all three species. Furthermore, Chilicote et al. found that the impact of hatchery fish from 'wild type' hatchery broodstocks was no less adverse than hatchery fish from traditional (potentially domesticated) hatchery broodstocks. Chilicote et al. recommend that, in most cases, measures that minimise the interactions between wild and hatchery fish will be the best long-term conservation strategy for wild populations.

A study by Levin et al. (2001) titled 'The road to extinction is paved with good intentions' tested the hypothesis that hatchery releases contributed to the decline in spring-run strength of Snake River Chinook salmon (Pacific Northwest USA). They found that continuous hatchery augmentation was apparently exacerbating the effect of periods of unfavourable ocean conditions on population viability. Similarly, Morita et al. (2006) found that, although the release of 1.2 billion salmonids annually along the coast of Hokkaido (Japan) supported substantial commercial fisheries, hatchery-based catches were also accompanied by declines in wild-based fishery returns. Within New Zealand, Unwin (1997a) suggested that the number of salmon added to the population from the Glenariffe Hatchery, over its 10-year period of operation, was accompanied by roughly proportional reductions in the population elsewhere in the Rakaia. In other words, hatchery fish may simply have been replacing wild fish. This pattern was consistent with density-dependent constraints acting on a post-release life-history phase (for example, either on juveniles rearing in tributaries or main river, or on smolts within the limited extent of the Rakaia River ocean plume).

I found few studies that report a positive effect of hatcheries on wild fish populations, beyond the initial boost in fish numbers—which is then followed by decline. Exceptions included a study by Araki et al. (2007) which showed that, when using wild broodstock, there was no discernible difference in progeny survival rates of wild-type hatchery-reared crosses when compared with progeny of wild x wild crosses in steelhead population. Similarly, Hess et al. (2012) showed that wild-origin steelheads, when reared in a hatchery, performed well after release with no detectable loss of fitness. They conclude that overall, a supportive breeding approach can boost fish populations without affecting the fitness of wild salmon populations.

3.2.1. Local adaptation in relation to sea-migratory salmonids

Local adaptation is defined by a population that has differentially evolved in response to natural selection pressures associated with localised conditions, when compared to other populations within their species. Examples of local adaptation are wide-ranging and are most commonly documented in plants (Blanquart et al. 2013). Salmonids have been suggested to show rapid local adaptation across relatively small spatial scales. For example, Frazer et al. (2011) show that local adaptation can manifest quickly, in just 6–30 generations and that on average, locally adapted populations have 1.2 times (20%) more fitness relative to the performance of foreign populations in new environments.

Some of the best evidence for rapid local adaptation within salmon populations comes from studies of migratory Chinook salmon in New Zealand. Examination of historical salmon records prior to the early 1990s showed that Waitaki salmon tended to be older and larger (because they had a higher proportion of 4-year old fish), Waitaki and Waimakariri salmon tended to spawn later than other rivers while Rakaia salmon spent the least time rearing in freshwater (mostly ocean-type, which migrate to sea in their first year) (Unwin 1999). This prompted subsequent scientific studies of life-history and genetic differences between salmon populations. These showed that local adaptation and divergence of genetically-linked migratory behaviours and life-history traits between salmon populations in South Island east coast rivers have occurred in less than 30 generations (Quinn et al. 2001). Unwin et al. (2003) undertook an experiment by translocating fish between the Glenariffe Stream and the Hakataramea River (Waitaki catchment). They demonstrated that a substantial 'home-court advantage' existed for fish released in their natal environment—in the order of a 1.5- to 3-fold increase in survival rates compared to translocated fish. In a related study, Quinn et al. (2001) showed differentiation in heritable migratory strategies between salmon originating from the upper Waimakariri in relation to other east coast salmon populations. Salmon that migrated further (to Glenariffe Stream, Rakaia) had smaller eggs than those with a shorter migration route (Hakataramea River, Waitaki) (Kinnison et al. 2001). Differences in juvenile growth rate and length of stream residence (proportion of ocean-type versus stream-type fish) between populations were also confirmed (Unwin et al. 2000).

3.2.2. Local adaptation in relation to landlocked fishery releases

Localised adaptation in isolated trout populations has received less scientific attention. Nevertheless, hybridisation of hatchery fish with genetically distinct strains of trout within their native ranges is a critical and ongoing conservation concern (e.g. Hayes et al. 1996). This issue is less relevant in New Zealand where trout do not have native biodiversity values. However, trout life history strategies and behaviour can be distinctly different between and within catchments. For example, Kristensen and Closs (2008) found differences in growth and aggression rates between fish from an isolated upstream population and lower segments of the same stream. They speculate that these differences may have arisen because of different genetic backgrounds. Like salmon, trout populations can rapidly genetically diverge. For example, brown trout released in two rivers in the Subantarctic Kerguelen Islands rapidly colonised other rivers via the ocean and diverged into separate genetic units in neighbouring rivers in less than 20 years (Ayllon et al. 2006).

It is reasonable to expect that brown and rainbow trout may be vulnerable to the same potential problems of interbreeding with fish from hatcheries and / or other catchments as salmon. A precautionary approach would be to treat isolated stocks of trout within different catchments as discrete populations and develop release strategies that avoid the potential for translocation of fish between populations, so as not to erode the work of natural selection for favourable traits that improve the productivity and resilience of wild fish populations over time.

3.3. Food web dynamics

Stocking waterbodies with juvenile salmonids (e.g. < 180 mm) will provide prey for wild salmonid populations and native predators, such as longfin eels and cormorants. Conversely, stocking a waterbody with takeable-sized salmonids may increase predation pressure on wild juvenile salmonids and native fish. The flow-on consequences to food-web dynamics may be complex and will vary widely between waterbodies and catchments. I am unaware of any food-web studies on the effects of stocking salmonids in New Zealand into waterbodies where they are already present. Nevertheless, if a waterbody is stocked then additional predation pressure will be placed on native fish (McIntosh et al. 2010). Depending on the degree to which a waterbody is stocked, prey resources will be reduced for wild salmonids.

Overseas studies have shown that large-scale hatchery releases can create aggregations of salmonid predators (Collis et al. 2011). The response of predators to hatchery releases in New Zealand is undocumented within the scientific literature. However, it has been speculated that mass releases of Chinook salmon could attract, or create, aggregations of marine predators such as kahawai around the South Island East Coast river plumes. In addition to providing prey for large trout, stocked juvenile salmonids will also be eaten by longfin eels and cormorants (see for example this video of brown trout and longfin eels eating juvenile Chinook salmon https://www.youtube.com/watch?v=ZNaL1DkD4As).

3.4. Biosecurity

Transporting hatchery fish represents a biosecurity risk: that of spreading unwanted pathogens and organisms within and between catchments. New Zealand salmonid populations are relatively disease-free compared with overseas populations. In part this is because they were introduced into the country as eggs. As a result, the parasites and diseases that affect later life-history stages were left behind within the source populations (Hobbs 1948). In addition, our isolation from native salmonid populations means there is a relatively low risk of novel pathogens being introduced into our fisheries.

I found no evidence of hatchery releases definitively spreading unwanted pest organisms or pathogens, although the whirling disease pathogen, *Myxobolus* *cerebralis*, has been recorded from locations where salmonids have been released from infected hatcheries (Boustead 1993), which suggests a 'smoking gun'.

Any fish release represents some element of risk for transporting unwanted organisms between waterbodies and fish populations, no matter what biosecurity procedures are in place. Consequently, the spread of unwanted organisms should be factored into any risk / benefit assessment before undertaking a hatchery release.

3.5. Social licence issues associated with salmonid releases

Many freshwater anglers view hatchery releases positively. However, other sectors of New Zealand society do not. The 'introduced predator free' movement in New Zealand started with the protection of native birds. This ethic has now extended to include freshwater ecosystems. When people who support this principle learn that trout are not a native species, and that they are predators, it is a short logical step to determine that they eat native species and that this is undesirable. Indeed, there is clear evidence that trout have negative impacts on native aquatic fauna (McDowall 2006; McIntosh et al. 2010).

In my opinion, an increasing number of New Zealanders view salmonids as a threat to native biodiversity and by extension as an undesirable species. The comments section below this recent Stuff.co article provide an example of the polarised views of interested members of the public with respect to salmonids in New Zealand: https://www.stuff.co.nz/the-press/news/100983463/beloved-brown-trout-damage-native-fish-insects-and-waterways accessed 26 June 2018). Moreover, my 10 years of experience in both native and sports-fish management suggests that these views are not limited to the general public. Many of my scientific peers, as well as influential water managers, see the protected 'sports-fish' status of salmonids (under Schedule 1 of the 1983 Freshwater Fisheries Regulations) as an inappropriate privilege afforded to the species largely by way of New Zealand's colonial history.

It is a hard ask to counter the simple idea that 'trout are an introduced predator and therefore a pest' with the more nuanced and complicated arguments that underpin the 'anglers for habitat conservation' narrative, which is typically presented as follows… 'anglers value the presence of salmonids in waterbodies and the fisheries they support, in turn, this leads to passionate and practical advocacy to protect aquatic ecosystems—for example thorough investing in Water Conservation Order applications. Overall, this results in a net benefit for freshwater ecosystems (despite the clear negative impact of trout on native fish populations)'. This narrative is widely used to justify the value of salmonids to non-anglers.

Resources devoted to salmonid releases contribute nothing to Fish & Game's contemporary 'anglers for habitat conservation' narrative. On the contrary, rightly or wrongly, continued salmonid stocking risks linking the modern Fish & Game organisation with the outdated historical practices of the preceding acclimatisation societies; for example, the latter groups' introductions of salmonids to the detriment of native fisheries in Lake Taupo, or the abhorrent widespread eel and cormorant eradication programmes. These actions are a substantial grievance for some Iwi (McDowall 2006).

The impact of fish releases on community attitudes will vary greatly from place to place. It will depend on the value of salmonid fisheries to the local communities and Iwi, the composition and threat status of native fauna in a given waterbody and the various management policies and legal frameworks in place. Before stocking a waterbody with salmonids, the potential cost of degrading local and national societal attitudes towards Fish & Game should be considered very carefully.

4. SUPPLEMENTARY SPORTS FISH STOCKING PRACTICES IN NEW ZEALAND

In this section I provide an overview of salmonid release practices in New Zealand over the past five years. Subsequently, the release practices of the North Canterbury, Nelson-Marlborough and Eastern Fish & Game regions are documented in more detail.

4.1. National overview

To gain a national overview of salmonid release practices, all Fish & Game regions were contacted and asked to provide information on:

1. how many salmonids they had released over the last five years?
2. what species were they?
3. when and where they were released?
4. what was the size and age at the time of release?
5. were they tagged and how?
6. how were the releases monitored?

Only the Eastern region responded with data that adequately addressed all six questions. There were numerous omissions and missing fields in the data provided by other regions (e.g. specific locations or fish size data were non-existent in some cases). In addition, some release numbers were obviously estimated figures. Furthermore, some salmonid releases, that were administered as mitigation by hydroelectric companies, appear to have been omitted from the data I received. With this in mind, the analysis presented below should be considered as an estimate of fish released over the last five years, rather than a total census. Nevertheless, once consolidated, the data were of sufficient accuracy to present an analysis at the national scale.

Stocking salmonids is still a widespread exercise in New Zealand and occurs in a wide range of waterbodies. In total, close to four million salmonids have been released into New Zealand waterbodies within the last five years (n = 3,868,210). A breakdown of the last five years of fish releases by species and region is shown in Table 1. By far, the majority of fish releases occurred in the Central South Island, North Canterbury and Eastern Fish & Game regions. Substantial numbers were also released in the West Coast and Otago regions. Fewer than 30,000 fish were released in the remaining regions (Figure 2).

Table 1. Total number of rainbow trout, Chinook salmon and brown trout released by New Zealand Fish & Game regions over the past five years.

Region	Species	Number	Region	Species	Number
Northland	Rainbow trout	27,880	West Coast	Rainbow trout	35,682
	Chinook salmon	0		Chinook salmon	177,860
	Brown trout	1,200		Brown trout	14,020
	Total	29,080		Total	227,562
Auckland Waikato	Rainbow trout	35,900	North Canterbury	Rainbow trout	160,500
	Chinook salmon	0		Chinook salmon	955,000
	Brown trout	400		Brown trout	174,000
	Total	36,300		Total	1,389,500
Eastern	Rainbow trout	433,514	Central South Island	Rainbow trout	105
	Chinook salmon	0		Chinook salmon	1,737,360
	Brown trout	3,680		Brown trout	0
	Total	437,194		Total	1,737,465
Taranaki	Rainbow trout	28,132	Otago	Rainbow trout	56,939
	Chinook salmon	0		Chinook salmon	0
	Brown trout	1,983		Brown trout	0
	Total	30,115		Total	56,939
Wellington	Rainbow trout	11,550	Southland	Rainbow trout	2,900
	Chinook salmon	0		Chinook salmon	1,000
	Brown trout	0		Brown trout	0
	Total	11,550		Total	3,900
Nelson Marlborough	Rainbow trout	4,504			
	Chinook salmon	3,362			
	Brown trout	739			
	Total	8,605			

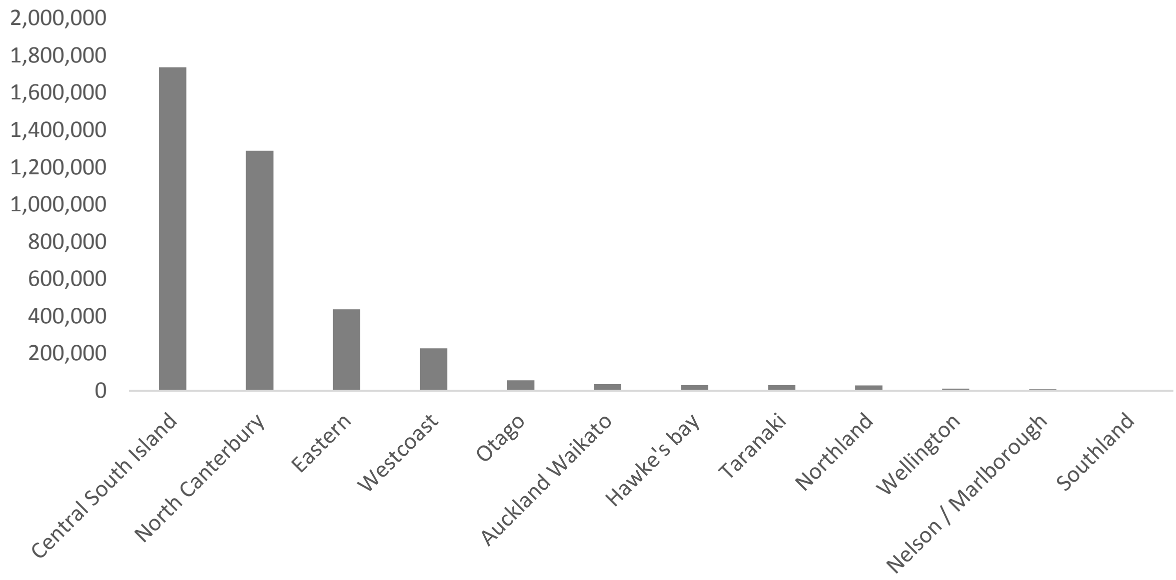

Figure 2. The total number of salmonids released by New Zealand Fish & Game regions over the past five years.

By species, Chinook salmon releases by the Central South Island, North Canterbury and to a lesser extent the West Coast regions comprised most salmonids released into New Zealand waterbodies. Rainbow trout were liberated extensively across the country with brown trout releases being relatively limited (Figure 3).

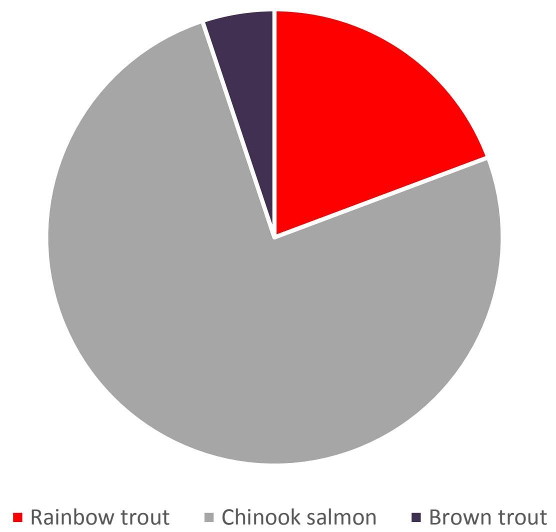

Figure 3. The proportion of salmonid species released into New Zealand waterbodies over the past five years (Chinook salmon n = 2,874,582, rainbow trout n = 733,826, brown trout n = 194,422).

At this point it should be noted that the numbers of each fish species released will not accurately represent the resources devoted to hatchery rearing for each species or by each region. This is because Chinook salmon releases, to support sea-run populations, are typically undertaken when fish are about one year of age, whereas it is common practice to grow rainbow trout to a takeable size (which requires more resources).

A breakdown of the types of waterbodies that salmonids, excluding Chinook salmon to support sea-run populations, were released into is given in Figure 4. Most of these releases were in large lakes, primarily trout releases in the Eastern Region. Small lakes (i.e. less than *c.* 10 ha), which includes various fish-out ponds, were the next most common waterbody type to receive hatchery fish. Surprisingly, a substantial proportion of the releases (*c.* 15%) were into rivers and streams. These were mainly in North Canterbury, Taranaki, Northland and Nelson-Marlborough regions.

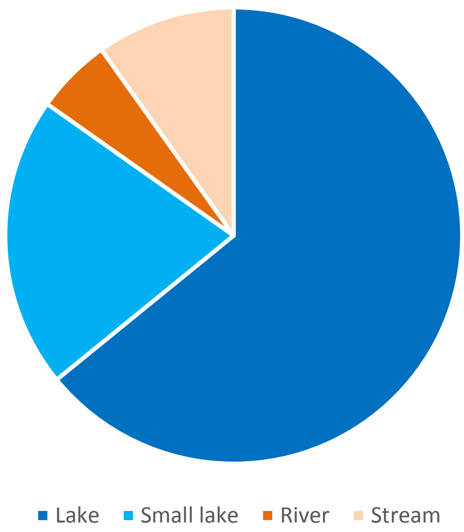

Figure 4. Number of salmonids released into different water types (large lake n = 1,326,069, small lake n = 427,585, Stream n = 203,408, River n = 111,185). Chinook salmon releases to support sea-run populations were excluded from this analysis. Small lakes were defined as being < 10 ha, rivers were defined as being non-wadable around median flows, streams were defined as being as wadeable. Waterbodies were assigned subjectively into categories by the author.

4.2. Regional summary of releases to support landlocked fish populations

Excluding Chinook salmon releases to support sea-run populations, the various Fish & Game regions have different approaches to stocking landlocked fisheries. Otago undertakes extensive releases in numerous small put-and-take lake fisheries across the region (e.g. municipal water supply reservoirs and irrigation ponds). Larger lakes, rivers and streams are not generally stocked. The Auckland, Wellington, Southland and Hawke's Bay regions undertake limited releases, almost exclusively in small put-and-take lake fisheries that are close to population centres. Eastern's release practices are characterised by intensive and regular rainbow trout releases across large and small lakes in the region. West Coast fish stocking is largely limited to medium-sized reservoirs and small put-and-take lakes—although some releases to streams occur. The Central South Island region releases large numbers of Chinook salmon to support landlocked fisheries in large lakes. These fish are sporadically donated from salmon farms. The Northland, Taranaki and Nelson-Marlborough regions release fish into small put-and-take lake fisheries as well as into various rivers and streams across the regions. In recent years, Taranaki appears to be scaling back fish releases in rivers and streams, whereas, Nelson-Marlborough is increasing such releases. North Canterbury release Chinook salmon, brown and rainbow trout, in relatively large numbers, across all waterbody types in the region.

4.3. Regional case studies

Three regions were selected to study their salmonid release practices in more detail. The case studies presented below were chosen to be representative of the breadth of fish release programme-types in New Zealand (identified during the national scale analysis): 1) large-scale releases into lakes (Eastern Region), 2) small scale releases into a variety of waterbody types (Nelson-Marlborough region) and 3) hatchery releases to support the sea-run Chinook salmon fisheries (North Canterbury region). The case studies were intended to be high-level overviews of recent practices in the regions and not a detailed audit of operations. However, inconsistencies with the data and narratives supplied by the North Canterbury Fish & Game Council meant a more detailed analysis of their practices was necessary to determine how their hatchery stocking programmes are operated.

The key questions put to the three regions were:

1. why do you have a release programme?
2. what are your salmonid release strategies?
3. how do you monitor effectiveness?
4. what is the return to anglers?

4.3.1. North Canterbury region

The North Canterbury region has the most popular Chinook sea-run salmon fisheries in New Zealand (Unwin 2016). In addition, North Canterbury has important landlocked salmonid fisheries that can be roughly divided into five main types:

1. mixed species high country lake fisheries
2. backcountry brown trout fisheries

3. braided river fisheries (including some flood plain springs)
4. lowland plain streams and spring creek fisheries
5. put-and-take 'fish-out' ponds.

North Canterbury staff and councillors were visited on 16 February 2018 and interviewed about their salmonid release practices (by the author of this report). A tour of the hatcheries in the region was also conducted.

Why does North Canterbury have a salmonid release programme?

North Canterbury has been described as 'ground zero' in terms of the impact of intensive agriculture on fisheries. Hatchery releases are now considered necessary by some staff, councillors and anglers, to maintain and / or re-establish fishery values in some waterbodies. Furthermore, hatchery releases are seen as a key tool to enhance the South Island east coast Chinook salmon fisheries—which are currently considered to be at crisis point. It was apparent from discussions with the North Canterbury Fish & Game councillors and staff, that the wider angling community feel very passionate about hatcheries and view salmonid releases in the region as an appropriate use of Fish & Game resources.

Several social outreach projects are run as part of the hatchery release operations. For example, organised fishing events are administered where junior anglers and hospital out-patients are provided with volunteer support to catch takeable-sized trout from small put-and-take lake fisheries close to Christchurch—such as The Groins and Isaac's Pond. These events are well patronised. Staff and councillors see these events as a positive way for North Canterbury Fish & Game to contribute to the local community.

Fish releases also occur regularly in the popular high-country lake fisheries, for example Lakes Coleridge, Georgina, Evelyn and Selfe. Although these lakes are largely unaffected by intensive land use development, it is thought that natural recruitment is insufficient to meet angler demand. An example of the extent to which different waterbodies that are stocked within North Canterbury is provided in Appendix 1.

What are North Canterbury's hatchery practices?

There are currently three hatcheries operating in North Canterbury (excluding those associated with commercial salmon farms). These are the Montrose hatchery, Peacock Springs hatchery and the recently created Whiskey Creek hatchery. The Montrose hatchery is located just above the lower Rakaia Gorge and produces yearling Chinook salmon, primarily to supplement the wild sea-run salmon populations in the Rakaia and Waimakariri rivers. Brown and rainbow trout are also reared here. Peacock Springs is run by the Isaac Conservation and Wildlife Trust, with assistance from North Canterbury Fish & Game. This hatchery is used to grow salmonids to a takeable size for stocking put-and-take fisheries, both within and outside the region. Whiskey Creek is located on the Rakaia bermlands upstream of the Montrose Hatchery, adjacent to the Trust Power Lake Coleridge tailrace. It is intended to provide additional capacity to produce Chinook salmon smolts to support the sea-run populations in the Rakaia River.

North Canterbury's release strategies are diverse. Fish are released at all life-history stages and into all waterbody types. For its landlocked fisheries, takeable-sized rainbows are released into small closed systems, such as The Groins fish-out ponds. Variable numbers of brown trout, at various life-history stages, are released into degraded lowland stream fisheries in parallel with habitat enhancement initiatives. In the high-country lakes, large numbers of rainbow trout and Chinook salmon (some of which are sourced from commercial salmon farms) are released annually, mostly as yearlings.

In addition to the release of yearlings, there have been several releases of takeable-sized brown trout (e.g. 1-3 kg) to support existing river fisheries, for example, in the Upper Selwyn River. In addition, recently, approximately two hundred large brown trout of various sizes were released into spring creeks associated with the lower Rakaia River. These releases were undertaken in response to angler concerns over declining sea-run brown trout catches.

Large numbers of salmon and trout ova are planted in 'scottie boxes' in various degraded streams around the region. Scottie boxes are essentially artificial redds comprising slabs of multi-celled plastic, each egg being housed in a plastic cell where it can incubate till emergence (Purchase et al. 2018). These ova plantings are intended to increase production and / or re-establish salmon runs and trout fisheries in areas of catchments where spawning habitat is degraded but juvenile rearing habitat still exists. We could not determine the extent of this practice because accurate records of the ova planting sites were not be supplied despite being requested.

With the intention of supporting the Chinook sea-run salmon fisheries, around 90,000 smolt are released from the Montrose hatchery annually in June–July, at a target weight of 50 g each. About 60,000 of these fish are released into the Rakaia River, directly from the Montrose hatchery. The remaining 30,000 smolt are transported to infrastructure associated with the commercially-run Silverstream salmon farm-hatchery complex in the lower Waimakariri River catchment. Here smolt undergo a short acclimatisation / imprinting period before release into the Silverstream (spring creek). In addition to releases within the Rakaia, variable numbers of smolt and eggs are transported to other catchments both within and outside the region (e.g. to West Coast and Nelson-Marlborough).

No salmon broodstock are maintained at North Canterbury's hatcheries. According to the hatchery, ova from about 100 to 150 hen salmon are required to meet the demand for smolt production within Montrose hatchery. Hen salmon are procured from various sources; about 20% come from the 'headwaters', 40% come from 'salvage' and 40% come from returns to two salmon traps operated in the region (Appendix 2). One salmon trap is operated on the stream exiting the Montrose hatchery (in the Rakaia catchment) the other is below the Silverstream hatchery (in the Waimakariri catchment). Based on these figures, up to 90 hens may be sourced from salvage and the headwaters each year (i.e. 60% of 150). This represents about 5–10% of the total wild spawning population in the Rakaia during the recent low return years of 2015, 2016 and 2017 (Appendix 3). Precise information on the number of hens (or jacks) used each year (to supply hatchery production), and information on where the hens were sourced from, were not provided to us despite repeated requests for these data.

In addition to fish released by North Canterbury hatcheries, it is estimated that between 50,000 and 200,000 yearling Chinook salmon are released from commercial salmon farm hatcheries in the region. Standard practice in the commercial hatcheries is to raise surplus 'insurance stock' to ensure that salmon farms are provided with enough fish to grow-on to meet market demands. If any insurance stock is not required, it is released. Most releases occur in the Waimakariri in association with the Silverstream hatchery. North Canterbury was not able to supply accurate information on the numbers or timing of insurance salmon releases. Occasionally, insurance salmon are gifted to North Canterbury; these fish are apparently stocked into Lake Coleridge. Again, exact numbers were not provided.

How does North Canterbury monitor the effectiveness of their release strategies?

For trout, anecdotal reports of anglers catching hatchery-origin fish, and high levels of angler satisfaction resulting from hatchery releases, were discussed as measures of success during the site visit. However, within the North Canterbury Fish & Game annual reports, the only measure provided for meeting the region's objective of supplementing stocks with hatchery fish is the number of fish released per year (Appendix 1). No information is provided on the efficacy of rainbow and brown trout releases in the region in terms of survival rates, returns to anglers or improvements to wild fishery production.

For Chinook salmon, hatchery-reared fish are adipose-fin clipped to differentiate them from wild fish for monitoring purposes. In addition, salmon anglers are telephone surveyed and asked about the number of fish caught and if any fish caught were fin clipped. However, only total angler catch data is used from the telephone surveys for annual reporting. The number or ratio of fin clipped fish caught by anglers (i.e. confirmed to be of hatchery origin) is not reported. This is because it is assumed that most anglers will not recognise a missing adipose fin (Terry 2016). Consequently, the number of salmon returning to the Montrose and Silverstream traps, in combination with estimates of salmon spawning in the wild (from helicopter surveys) and total angler catch rates, are the only data used to determine the performance of the Chinook salmon hatchery releases.

Inconsistencies were apparent within the data supplied to us with respect to the Montrose hatchery operation. For example, initially I was told by email that tagging salmon by adipose fin clipping had been undertaken on 30% of fish released during 2014 and 2013. Later this figure was amended to 100% for those years. No data spreadsheets relating to fish tagging were supplied. Based on the latest figures supplied, apparently 100% of fish are fin clipped except in years when operational issues at the hatchery require early releases of up to half the fish (as occurred in 2016 and 2015).

Major discrepancies were apparent regarding the census data for annual salmon returns to the Montrose hatchery trap. Table 2 shows the total number of salmon returning annually to the Montrose trap for the same period from two different sources. In the top row are hatchery data (supplied by email on 01 July 2018), on the bottom row are the figures presented in the 2017 Salmon Management Report (Terry 2017). Different figures for the total numbers of salmon found in the trap are apparent during every year for the duration of the record (Table 2).

Table 2. Census figures for the total number of salmon returning to the Montrose Hatchery trap for the same years according to two different sources. On the top row are figures from the hatchery . In the bottom row are the figures presented in Appendix 3 of the 2017 North Canterbury Salmon Management report (Terry 2017).

Data source	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Hatchery data	750	900	203	227	250	83	197	421	133	17	20
2017 Salmon Management Report	180	250	450	112	257	210	250	500	130	21	21

There are clear inconsistencies between these two sets of figures. The hatchery suggested the data presented in the Salmon Management reports are consistently inaccurate because in some years salmon continue to arrive into the Montrose trap after the trap census data are supplied to be analysed for the report. However, this explanation fails to account for the fact that some of the trap return figures in the data provided are *lower* than the numbers of salmon reported for the same years in the Salmon Management reports (for example see years 2017, 2016 and 2014 in Table 2). The result is that there are clear inconsistencies in the two data sets; it appears that the annual Salmon Management Reports have been produced based on data that is highly inaccurate. There was no explanation as to why the conflicting data presented in the Salmon Management Reports have not been corrected for inaccuracies during the last decade of annual reporting.

The apparent inconsistencies in these data have had wide ramifications. For example, the source data presented in the Salmon Management reports have been used by North Canterbury Fish & Game and North American fisheries scientists to assess the sustainability of salmon harvest rates in the Rakaia. Furthermore, the Salmon Management Report source data have been used to produce figures in a recent high profile New Zealand scientific publication (Deans et al. 2016).

In addition to the above issue, data from the Silverstream trap is potentially confounded by returns of ‘insurance release salmon’. As it is currently reported in the Salmon Management reports, returning salmon of commercially farmed origin are not separated from any returns from the annual release of the 30,000 smolt from the Montrose hatchery (i.e. those fish that are translocated to the Silverstream hatchery from the Montrose hatchery before release). This omission could have a substantial effect on the reported success rates of the Montrose hatchery operations. This is because insurance salmon releases may out-number Montrose hatchery origin releases at the Silverstream site by a factor of six on any given year.

The issues described above raise serious doubts about North Canterbury Fish & Game reporting on the efficacy of its hatchery operations. Moreover, previous assessments of the sustainability of the current recreational salmon harvest rates are now potentially invalidated. Resource constraints were cited as the reason for not undertaking a robust post-release monitoring programme. However, as a basic minimum requirement, any hatchery operation should collect data on the number of fish returning to hatchery traps, their sex, age, length, weight and whether they are tagged. Only the number and sex of the fish appear to be recorded at the traps but as outlined above there are serious issues with how these data are reported. Collecting basic information about individual fish that arrive in the fish traps would require minimal resources given these salmon are already handled to supply eggs for hatchery production. However, age determination from scales or otoliths can be more time demanding, but can be done by staff, or students with a little training when not in the field.

What is the return to anglers?

North Canterbury Fish & Game has a policy of supplementing angler catches of sea-run salmon with hatchery fish by 10%. Based on the analysis presented in Terry (2016), this target has been met or exceeded during most of the previous 13 years. The total contribution of the Montrose hatchery releases to the Rakaia salmon run is determined by multiplying the Montrose fish trap census data by the percentage of the total salmon run that are caught by anglers (see analysis methods detailed in Terry 2016).

If the data provided in the 2017 Salmon Management Report are taken at face value, and the number of hen fish required to supply the Montrose hatchery’s production are accounted for, some concerning figures are apparent. A cursory analysis of the source data for the report shows that during the 2015–2017 period, returns to both the Montrose and Silverstream traps (combined) were too low to meet the Montrose Hatchery demands for hen fish to supply eggs for smolt production. As stated before, this is approximately 100–150 hens. For example, a total of 200, 141, and 48 fish returned to both the Montrose and Silverstream traps combined during the 2015, 2016 and 2017 spawning runs respectively (Appendix 3). During these years at least, broadly similar trap return numbers were apparent in the hatchery figures provided during the preparation of this report (Table 2). If it is assumed that half of these fish were hens, then up to 50, 79 and 126 hens were required, from sources other than trap returns, to meet the hatchery's demands for eggs. These figures are broadly consistent with the approximate hatchery figure supplied, of around 90 hens (on average) coming from 'headwaters and salvage' (Appendix 2). Consequently, even if angler catch is accounted for (for example by adding 40% to the trap return figures) it appears that the number of hen salmon that were salvaged / harvested from the catchment (i.e. 90 each year) is broadly equivalent to the total number of salmon produced by the hatchery releases over the 2015–2017 period as a result of the Rakaia and Waimakariri smolt releases (i.e. a total run of 280, 141, 67 over the 2015–2017 period respectively, accounting for an angler interception rate of 40%). Moreover, these figures are calculated *before* salmon returns to the Silverstream trap are partitioned between salmon of Montrose Hatchery origin (from the 30,000 smolt transported and released there annually from Montrose) and Silverstream salmon farm hatchery origin (50,000–200,000 'insurance' smolt released annually). Partitioning between these two potential sources of fish at the Silverstream trap is not possible based on the available data (Table 2).

It was reported by the hatchery that low flows in the Montrose hatchery stream were the reason for the poor returns to the trap during 2015 and 2016 years. This would imply a high degree of straying in those years. However, it was also suggested that hatchery-reared fish (i.e. fin clipped fish) have never been observed spawning within the Rakaia River headwater streams. For example, it was anecdotally reported that a wild salmon DNA sampling effort in 2018, in association with an ongoing genetics survey, has found no fish of hatchery origin in the headwaters. The hatchery has reportedly *not* used salmon of commercially farmed origin to supply eggs for Montrose Hatchery production since about 2007. If this is correct, then productivity may be being transferred from the wild headwater population into a separate put-and-take fishery associated with the Montrose hatchery in the mid-lower river. The justification that salvaged fish used to supply eggs 'would have died anyway' assumes that live fish, with apparently viable eggs, could not be transported to prime headwater spawning streams, which have been underutilised by salmon in recent years, to spawn successfully. A further consideration is that substantial numbers of smolt and eggs have been supplied to other catchments both within and outside the North Canterbury region (e.g. West Coast and Nelson-Marlborough). Therefore, some salmon productively from the Rakaia may have been exported to other catchments at a time when stocks in the Rakaia are considered to be at crisis point.

It must be noted that my ‘back-of-the-envelope’ calculations are based on questionable data for the reasons outlined above. Therefore, I am not confident in the analysis based on them. Nevertheless, I have presented these calculations to demonstrate the possibility that, during years when cohorts have experienced poor ocean survival, the Montrose hatchery could effectively represent zero gains, or even a net loss, to the wild component of the fishery. The analysis highlights the problems that can arise for stocking operations and fisheries management, when accurate record keeping, which is a critical aspect of good hatchery practice, is not undertaken. The only performance measure presented in the Salmon Management reports is the ‘percentage of the Rakaia run that is of hatchery origin’. Councillors and anglers are likely to be unaware of this shortcoming and the potential adverse consequences for sustainable management of their salmon fishery.

4.3.2. Eastern Region

Why does Eastern have a salmonid release programme?

The Eastern region has been running a hatchery at Ngongotaha Stream since the early 1900s, spanning back to when the region was administered as an Acclimatisation Society. The region has 13 lakes of varying sizes that are regularly stocked with rainbow trout. The justification for stocking is that most of the region’s lakes have non-existent or very limited amounts of spawning habitat. Furthermore, across the region, stream substratum is characterised by highly mobile pumice gravels. Consequently, ova and alevins are extremely vulnerable to displacement during floods. Therefore, in the few lakes that do have substantial tributaries, natural recruitment is periodically very low during seasons with substantial winter and spring floods. This justification for stocking sounds entirely plausible and intuitive and will be is self-evident for some of the regions smaller lakes (which lack inflowing tributaries). However, I found it difficult to find any quantitative evidence for the assumption that the larger lakes with spawning streams (such as Lake Tarawera) are limited by recruitment. The research leading to this narrative may have occurred decades ago and may be limited to physical copies of reports. Resource constraints for this project prohibited a more dedicated search for these data (if they exist).

What are Eastern’s hatchery practices?

For the last 20 years, the region has run a selective breeding programme. Broodstock are selected according to pre-defined ‘desirable’ traits including large size (length), high condition factor and late maturation. Most broodstock are collected from Lake Tarawera, and occasionally fish from other lakes, such as Rotorua, are incorporated into the breeding programme to maintain genetic diversity.

In the hatchery, fish are grown to a target length of 180 mm before release. The frequency and number of fish released is varied across the region’s lakes in an attempt to maintain satisfactory angler catch rates and provide a diverse range of angling experiences. Some lakes are stocked at relatively high densities to provide high catch rates (e.g. Lake Rotoiti). Other lakes receive minimal stocking to allow a greater accumulation of biomass across a smaller number of fish in order to provide ‘trophy trout’ opportunities for anglers who are less concerned with catch rates (e.g. Lake Okataina). Fish releases are staggered and occur during spring.

How does Eastern monitor the effectiveness of their release strategies?
All fish that are released are tagged using one of three fin clipping patterns so that cohorts can be tracked for three successive years through to maturity. The Eastern region has maintained a fishing season opening day survey, as well as a winter creel monitoring programme on Lakes Rotoiti, Okataina and Tarawera for at least 20 years. Anglers are surveyed by boat and their catch is aged, measured, weighed and assessed for tags. Angers are also interviewed to determine the time spent fishing and if any fish were released. Angler satisfaction surveys are also undertaken. From these data, a record is maintained of fish size and condition, as well as a synthesised catch per unit effort (CPUE) estimate (Osbourn 2016). Any changes to release practices are compared against this long-term data in terms of its effects on key performance indicators such as average fish size, CPUE, and angler satisfaction. This monitoring programme is well documented in biannual annual reports (e.g. Eastern Fish & Game 2016, Eastern Fish & Game 2017).

What is the return to anglers?
Roughly 70% of the fish caught in Eastern’s lakes, year by year, are of hatchery origin. Between 65–80% of fish caught by anglers in Lakes Tarawera and Rotoiti over 2009–2016 were of hatchery origin. Catch rates are relatively high compared to national averages (Osbourn 2016). Furthermore, the percentage of anglers that were satisfied or highly satisfied with their summer’s fishing exceeded 90% over 2011–2017 in Lakes Rotoiti, Tarawera, Rotorua and Okataina (with the exception of the 2010–2011 summer, where satisfaction dropped slightly in some lakes) (Eastern Fish & Game 2017).

4.3.3. Nelson-Marlborough Region

The Nelson office was visited on 8 May 2018 and staff were interviewed about hatchery releases in their region.

Why does Nelson-Marlborough Fish & Game have a salmonid release programme?
Hatchery releases are undertaken in response to declining trout abundances, determined from drift-dive data and anecdotal angler reports. There is also perception among the Council and staff that there is a lack of opportunity for novice and junior anglers within the region. The region’s fisheries are predominantly clear-water brown trout river fisheries, which are considered more suitable for expert or guided anglers. Rainbow trout releases are intended to provide some ‘easy fish’ for juniors and beginner anglers to catch, the experience and perception being that rainbows are easier to catch. A third justification was that hatchery releases in the region will

provide data to determine what is limiting wild fish production. It is hoped that this will help guide appropriate management actions.

What are Nelson-Marlborough's hatchery practices?

In recent history very limited fish releases occurred, the exception being regular releases of takeable-sized rainbow trout (e.g. > 750 g) into the Branch / Leatham River system since 2010. These releases are funded by Trust Power as mitigation for the adverse effects on trout passage over the hydropower weir in the Branch River (approximately 1 km upstream of its confluence with the Wairau River). The fish passes constructed at this structure have been largely ineffectual, so Trustpower purchases adult rainbow trout to augment the impacted brown trout river fishery upstream.

Recently, particularly over the last two years, extensive releases of both brown and rainbow trout have been undertaken in various rivers and streams throughout the Nelson-Marlborough region. In addition, a volunteer-run hatchery in the Wairau catchment was being developed at the time of writing this report. When Nelson-Marlborough staff were questioned about their fish release strategies, the response was that currently they are in an 'exploratory phase' to determine which rivers will respond well to releases and which release strategies will be most effective. Both brown and rainbow trout are released at a range of sizes and life history stages (from large fish > 750 g to eyed ova plantings). Releases have occurred in a broad swath of rivers and streams.

During the past two years, fish have been released into 17 rivers and streams across the main river catchments in the region—including the Pelorus, Waimea, Motueka, Wairau and Takaka rivers. In addition to these supplementary / experimental releases, two put-and-take fisheries are operated in the region. These include Argyle Pond, part of the Branch hydropower scheme, and the newly created Waimea fishing park. The latter consists of a series gravel-pits constructed to serve as fish-out ponds. The ponds were created to provide a resource for junior anglers. People over 17 years old are prohibited from fishing. The fish for these releases are sourced from the North Canterbury hatcheries, as well as the newly created, local Wilhelmus hatchery situated in the Wairau catchment.

How does Nelson-Marlborough monitor the effectiveness of their release strategies

Fish & Game staff have undertaken drift dives, foot surveys and angler interviews to determine the effectiveness of their fish releases. They have also assessed licence sales in response to Facebook posts and other media coverage on fish releases.

What are the returns to anglers?

Drift-dive counts in the Branch / Leatham rivers over the last 10 years show clear increases in rainbow trout abundance following the releases of 200–400 takeable-sized fish biannually. Anglers are reporting excellent fishing in the catchment and it appears that the rivers are now being targeted by local fishing guides (pers. comm. Rhys Barrier, Nelson-Marlborough Fish & Game Council Manager). The Riwaka River and Spring Creek releases also appear to have increased trout abundance; although, in the Riwaka the increase in abundance was temporary because of large floods in the months following the releases. Conversely, releases of large trout into a range of tributaries of the Motueka, Waimea, Pelorus and Takaka catchments did not result in a demonstrable increase in numbers (Nelson-Marlborough Fish & Game Council 2017).

Under the current monitoring programme, only the release of takeable-sized fish can be assessed. Nelson-Marlborough are not collecting data in a manner that will enable them to assess the effectiveness of the various ova placements, fry and juvenile releases that have been undertaken during the last two years.

5. DISCUSSION

Over the course of reviewing the scientific literature for this project I was struck by the overwhelming amount of recent international research discussing the potential negative aspects of hatchery releases. However, discontent with salmonid hatchery practices within the global fisheries science community is not a recent phenomenon (Lichatowich 1999; Ruckelshaus et al. 2002). A similar theme is also apparent within the history of New Zealand's fishery science. For example, Derisley Hobbs devoted a substantial portion of his career to investigating whether hatcheries improved upon established fisheries. In 1948 he suggested: 'Trout and salmon hatcheries should no longer be regarded in New Zealand as a means of increasing stocks… they are sometimes useful in lakes in the absence of good spawning grounds' (Hobbs 1948). He then spent several years communicating his findings to acclimatisation societies trying to get them to relinquish wasteful stocking practices. Fifty years later, Robert (Bob) McDowall, the Southern Hemisphere's most respected freshwater fish ecologist wholeheartedly agreed with Hobbs. In 2001, in Edition 33 of Fish & Game New Zealand magazine, he somewhat cantankerously suggested that... 'most people want hatchery releases because it makes them feel better, if they can afford it fine but don't waste my licence money on it' (McDowall 2001). John Hayes methodically outlines the problems with releasing fish into open river systems in the fisheries management chapter of his book 'The Artful Science of Trout Fishing' (Hayes & Hill 2005). Finally, Martin Unwin, who is the authority on the South Island East Coast Chinook salmon fisheries, has expressed concerns that hatcheries may have had a negative impact on wild sea-run Chinook salmon populations here (Unwin 1997a).

Despite these scientists calling for hatchery releases to be limited to the special situations in which they are most likely to be beneficial (e.g. best in lakes with minimal natural recruitment and high fishing pressure), approximately 800,000 salmonids are still released annually in New Zealand, across a wide range of waterbodies. Moreover, some regions are actively expanding their release programmes in rivers and streams, including flood-prone ones.

5.1. Critical analysis of stocking programmes and the future role of hatcheries in New Zealand

Put simply, the smaller and more hydraulically-stable the release site, the more effective the salmonid release will be. All waterbodies sit along a spectrum of hydraulic stability, on one end there are small ponds with no tributaries, on the other, there are large flood-prone rivers. Larger lakes and spring-fed streams sit somewhere near the middle of this spectrum. The second most critical determinant of an effective release programme is the size of fish at release. Again, put simply, the larger the fish are at the time of release, the more likely they are to survive until they are caught.

Assuming that a receiving environment is below its salmonid carrying capacity, from an angling enhancement perspective, releases of takeable-sized fish into small lakes will result in greatest benefits to anglers. Releases of juvenile fish into lakes is likely to result in some benefit but releases of juvenile fish into rivers and streams is very unlikely to result in meaningful benefits to anglers (Table 3).

Table 3. A conceptual risk assessment matrix to help visualise the likelihood of a salmonid release resulting in a benefit to anglers in relation to waterbody type. Habitat is assumed to be suitable and held as equal quality across all waterbody types.

Life history stage at release	Small lake (closed system)	Large lake	Stream / small river with stable flow regime	Large river with unstable flow regime
Eyed ova	Very unlikely	Very unlikely	Very unlikely	Very unlikely
Fry	Unlikely	Very unlikely	Very unlikely	Very unlikely
0-1 years old	Possibly	Unlikely	Very unlikely	Very unlikely
1-2 years old	Likely	Possibly	Unlikely	Very unlikely
Takeable size	Highly likely	Likely	Possibly	Unlikely

5.1.1. Ova planting, fry, and juvenile (yearling) releases

Egg-to-fry survival rates in natural redds can be increased by about 50% through using *in situ* artificial egg incubators (e.g. Scottie boxes) (Purchase et al. 2018). This approach to salmonid stocking may have some merit because survival from the egg to the fry stage can be doubled but the negative effects of hatchery rearing on individual fitness will be non-existent. However, determining if increasing the egg to fry survival rates in New Zealand salmonids will transfer through to higher adult return rates is yet to be demonstrated. In his recent report on salmon management in North Canterbury, Willis (2018) suggests that the practice of ova planting should be discontinued in New Zealand—because it has been shown to be an ineffective stock enhancement practice in Canada. However, published research either for or against his assertion was not easy to find. Nevertheless, two questions are pertinent to ova planting: 1) are the numbers planted large enough to make a difference, and 2) *where* are the eggs coming from to support ova planting programmes? With respect to the latter question, mining eggs from depleted wild stocks should be avoided / minimised, and care should be taken not to 'dilute' wild genetics with genetics influenced by hatchery broodstock.

If eggs are sourced from wild salmon, then the practice effectively amounts to relocating salmonid production to streams which may have sub-optimal spawning or juvenile rearing habitat. The majority of returning adults will home to their ova planting site, effectively funnelling reproductive potential into sub-optimal habitat. It is plausible that such wild-stock ova mining could reduce the net productivity of the wider catchment population. If the eggs are sourced from surplus returns to hatcheries or from commercial salmon farms, then the risks associated with spreading domesticated fish genetics widely throughout a catchment will apply. In any case, at present there are no monitoring programmes in place within New Zealand that are capable of determining if ova plantings are an appropriate salmonid fishery enhancement action. Some such research is being done in Australia, by the Victorian Fisheries Authority.

There is clear evidence to show that releases of juvenile trout into rivers and streams will generally result in paltry returns for anglers (Chinook salmon releases to support sea-run populations are discussed separately in Section 5.1.5). The minimal returns to anglers from this practice should be considered against the potential risks to the genetic integrity of wild stocks, the potential for transferring disease or pest organisms, the potential effects on food web dynamics (including increased predation pressure on native fish) and the potential to inflame anti-trout sentiment among New Zealand's native fish and aquatic biodiversity proponents. In my opinion, it is not necessary to invoke the costs of administering a salmonid release, to determine that juvenile trout releases into open river systems is not advisable. I believe that this practice represents a departure from evidence-based fisheries management.

5.1.2. Releasing takeable-sized trout into streams and rivers

Recent releases of large takeable-sized trout into a range of wadeable rivers and streams in the Nelson-Marlborough region (in the order of 100s of fish at a time), demonstrate that using streams and rivers as put-and-take can sometimes work. Releasing takeable-sized fish into the Branch-Leatham River system (moderately flood-prone), and some of the region's stable spring-fed creeks, have resulted in increased abundance (determined through drift diving) and, anecdotally, increased catch rates. On the other hand, releases of takeable-sized fish into several other rivers and streams in the region have been unsuccessful.

Of particular note is the success of the Branch-Leatham River fish releases. The improved fishery as a result of these releases can be considered counter to the risk assessment presented in Table 3, because this river system is moderately flood prone. However, the sheer number of large fish released into the system over the past decade, in the order of 200 to 400 large rainbows (> 750 g) biannually, shows that, unsurprisingly, if lots of large takeable-sized fish are put into any moderate-sized river with suitable habitat, this will create good fishing during years with stable flows. At some point, the cost of stocking rivers in such a manner needs to be considered. Although in the case of the Branch-Leatham releases, the cost is worn by Trust Power (in recognition of the adverse effects that its hydropower scheme has had on the wild brown trout fishery).

5.1.3. Trout released within large lakes

In my review of fish release practices in New Zealand, the demonstrable success of Eastern Fish & Game's Rotorua Lakes hatchery release programme was unparalleled. Over a dozen lakes of varying sizes are effectively run as large put-and-take fisheries. No fish releases occur in the region's rivers and streams. Approximately 70% of fish caught in the region's stocked lakes are produced by the Ngongotaha Hatchery. Ngongotaha Hatchery fish clearly support a substantial amount of fishing effort. For example, during the 2014–15 fishing season, approximately 122,000 angler days of effort were estimated for in the region's three main stocked lakes (Tarawera, Rotorua and Rotoiti) (Unwin 2016). The intensive long-term monitoring programme has provided high quality information, which is fed back into the region's hatchery rearing and release practices using an adaptive management approach. Eastern's fishery managers are now in the position where they can accurately predict the average length of fish in angler's creels, based on the number of fish released during previous years. The monitoring programme shows that the lakes are being operated near their biomass carrying capacity. This knowledge enables the different lakes to be managed to provide a range of angling experiences. Anglers are clearly satisfied with the results.

The success or failure of releases into other large lakes in New Zealand cannot be determined based on the available data.

5.1.4. Trout releases in small lakes and fish-out ponds

The success of the numerous small put-and-take small-lake and pond fisheries around the country is self-evident. From a risk-benefit perspective (i.e. excluding economic factors), fish releases into these waterbodies are a better use of resources than releases into larger open systems. This is because:

1. Native fish values are generally low in small reservoirs and constructed ponds, meaning that salmonid releases will have relatively little impact on biodiversity and are unlikely to inflame anti-trout sentiment amongst the non-angling public.
2. Biosecurity risks are of less concern in environments with relatively low native biodiversity values. Any issues that do emerge will be more easily contained.
3. Concerns around the potential effects of hatchery releases on wild fisheries are non-existent in lakes that lack sufficient natural recruitment.

In my opinion, across all Fish & Game regions, any future expansion of hatchery releases should be focused on small put-and-take lake fisheries. The demand for these types of fisheries near population centres is clear. For example, the North Canterbury fish-out ponds and the newly created Waimea fish-out ponds in Nelson are a resounding success by all accounts.

5.1.5. Releases to support sea-run salmon populations

My brief investigation into current North Canterbury hatchery release practices (to support sea-run salmon populations in the Rakaia and Waimakariri rivers, and export salmon to other regions (e.g. West Coast) revealed alarming inconsistencies in their data collection and reporting practices. Not only is the monitoring programme not fit-for-purpose, it is misleading. The last decade of reporting appears to be based on erroneous data meaning that the Region's councillors and anglers are not aware of the true performance of the hatchery programme. Furthermore, the Montrose hatchery, as it is currently operated, may be placing pressure on the wild salmon population during years with poor ocean survival. There is a possibility that the hatchery programme may be contributing to the decline in the wild salmon fishery, either by way of mining the depleted wild population, replacement of wild fish, or by altering the genetics of wild fish and undermining population productivity and resilience.

Some general recommendations in regard to hatchery release practices to support South Island East Coast sea-run salmon fisheries are provided in Section 5.2. However, currently it is not possible to provide recommendations for the management of the Montrose hatchery without a better understanding of how the operation is currently run. For example, precise information on the numbers and sources of hen salmon used to supply the hatchery with eggs is needed. In addition, the relative proportions of Montrose and commercial-farm derived insurance release salmon, that make up the returns to the Silverstream trap, are required. Consequently, I recommend that the operation's data collection, management and analysis procedures be independently audited.

5.2. A critique of common arguments put forward in support of hatchery releases into open river systems

Over the course of this investigation, eight arguments were repeatedly put forward by individuals in support of supplementary hatchery releases. In the interests of fostering an evidence-based approach to fisheries management, I felt compelled to list these and provide some critique. The critiques below apply only in the context of hatchery releases in systems that already maintain self-sustaining wild fisheries. They do not apply in the context of fish releases in lakes that are obviously recruitment limited.

1. **There are two sides or 'camps' to the debate regarding the merits of supplementary hatchery releases to augment wild salmonid populations. Therefore, arguments against hatchery releases as just as likely to be invalid as they are valid.**

   It is true that fishery scientists and hatchery proponents have polarised views on the role of hatcheries within fisheries management. However, this fact is unrelated to the inherent merits of data-driven arguments based on evidence and scientific theory. The 'two camps' line of critique is used in a broad range of disciplines to manufacture doubt in the consensus views of relevant experts. For example, this tactic is commonly employed by climate change denialists. Equal weight should not be given to opinions based on emotion, intuition, vested interest, isolated studies or anecdotal evidence. The science 'on both sides' of the hatchery debate is not balanced but heavily weighted towards the consensus opinion that, in most cases, hatcheries releases in open systems are at best, an expensive way to temporarily increase angler catch rates and at worst, damaging to wild fisheries.

2. **Even if salmonid releases in rivers are unlikely to be successful, hatchery fish are reasonably inexpensive. Therefore, it's worth a try.**

   It may be the case that Fish & Game's regional operational budgets are sufficient to buy fish and / or allocate staff time to facilitate fish releases into open river systems, despite a low chance of success. In many cases, the cost of hatchery fish production may be subsidised by donations of volunteer time or money. However, this view point fails to account for the multiple risks associated with hatchery releases that are unrelated to financial cost of undertaking them (i.e. the potential negative outcomes relating to biodiversity, social licence, biosecurity risks or the potential negative effects on wild salmonid populations). There is also a potential 'opportunity cost' with regards to donated money or volunteer time which could be put to more effective use.

3. **The implications of overseas research on salmonid hatchery releases are not relevant to New Zealand. This is because our rivers and fish are fundamentally different.**

   It is true that there are substantial differences between our aquatic environments and salmonid populations when compared with those of other countries (particularly the continents). Generally, our rivers have more variable flows, and extreme high and low river-flows are less predictable by season than in the continents. In addition, with respect to sea-run salmonid productivity, our ocean survival rates are far lower than overseas populations. In light of these differences, hatchery releases ought to be less successful in New Zealand than they have been in North America. This hypothesis has not been disproven, despite 20 years of attempts by commercial ranching operations and a decade of local research undertaken at the Glenariffe research station (Quinn et al. 2001).

4. **Salmonids have only been in New Zealand for 150 years, this is not enough time for them to have evolved to be genetically different between catchments. Therefore, transferring stocks between catchments will have no negative genetic effects.**

   It is unclear to me where the perception comes from that fish require more than 150 years to adapt to changing environmental conditions. There is evidence from multiple fish species that evolution can happen over similar, and shorter time scales. For example, many species show slower growth or precocious maturation in response to size-selective capture by modern industrial fishing techniques (e.g. Jorgensen et al. 2009). There is also clear evidence that local adaptation can occur New Zealand Chinook salmon in response to differing catchment conditions—in less than 30 generations (i.e. 90 years) (Unwin 1999; Unwin et al. 2000; Kinnison et al. 2001; Quinn et al. 2001; Unwin et al. 2003; 2004). And there is evidence from the Subantarctic Kerguelen Islands that brown trout populations can genetically diverge within 20 years (Ayllon et al. 2006).

5. **Introducing fish from different catchments will introduce genetic diversity into a population. Genetic diversity is beneficial to wild salmonid populations. Therefore, hatchery releases will be beneficial.**

This argument is a version of the above argument. Vague notions of 'hybrid vigour' within selective breeding programmes do not apply to wild populations that display localised adaptation to individual catchment conditions. Research from both here and overseas shows that there can be a 'home court advantage' for locally adapted salmonid populations that increases their survival (fitness) (Quinn et al. 2001). Introducing genetic diversity from another catchment is likely to result in a reduction in fitness of the wild population, if hatchery reared fish compete or interbreed with wild fish.

6. **Anglers view hatchery releases favourably and want them to occur, therefore, we should do what they want.**

Hatchery releases are a tangible and highly visible way to demonstrate the use of licence fees. In addition, hatchery releases are undoubtably viewed favourably by many anglers. However, most anglers do not have the time, means or inclination to obtain the information required to understand the complicated issues that can arise as a result of hatchery releases. Furthermore, if fishery managers are advocating for fish releases, then there is no reason for anglers to consider that there may be any potential pit falls to investigate. Fishery managers (Fish & Game councillors and staff) have a responsibility to educate themselves and each other about the risks of hatchery releases on wild populations and to pass this knowledge on to anglers. Undertaking hatchery releases purely in response to pressure from licence holders represents a departure from evidence-based management. It risks being ultimately wasteful of anglers' license fees and damaging wild stocks.

7. **Given the inherent uncertainty of salmonid monitoring data, it is impossible to prove that hatchery releases *do not* provide population benefits.**

It is true that freshwater fisheries science is rife with uncertainty, more so than most ecological disciplines. Even when research outcomes are based on well-resourced long-term data collection programmes that are meticulously administered (such as occurred in the Glenariffe research station), they are often couched within substantial caveats. However, the overwhelming weight of evidence, accumulated over the last century, suggests that hatchery release programmes in open systems are *usually* unsuccessful. Furthermore, some have resulted in bad outcomes for wild fisheries. Therefore, the burden-of-proof sits squarely on each individual hatchery / fish release operation to demonstrate that first they will do no harm, and second, they will succeed in augmenting a wild population where most have failed.

8. Our fish releases will provide useful data on the wild fishery.

Hatchery releases can provide valuable data on wild fishery dynamics. However, under New Zealand's current research funding climate, I do not believe that the resources are available to successfully undertake a project of this kind. It is tempting to speculate that some fish releases are ostensibly occurring under the mantle of a data-gathering exercise to placate reservations of scientists, when in fact, the true motivations are an attempt to supplement a fishery despite scientific evidence or advice to the contrary.

5.3. Management recommendations

1. Develop national guidelines for undertaking hatchery releases that include a requirement for all fish release projects to demonstrate that they will result in benefits to anglers and will not put wild salmonid populations at risk.
2. In relation to recommendation one, develop an inter-Fish & Game Regional Council peer-review process for all hatchery release programmes / projects proposals.
3. Develop region-specific hatchery release monitoring programmes to enable an evidence-based management approach. The capability to do this clearly exists within the Eastern Fish & Game Council. I suggest facilitating an exchange of expertise between the Eastern region and other regions that are intent on maintaining substantial hatchery release programmes. This will help develop fit-for-purpose monitoring programmes and hatchery release strategies.
4. Undertake an audit of all South Island east coast Chinook salmon hatchery release programmes. Particular attention should be given to data collection, data management and reporting methods / protocols.
5. Stop the regular harvest of hen salmon from headwaters, during years of poor wild runs, to supply hatcheries for smolt production. Any 'salvaged' wild fish (e.g. from drying hydropower raceways) should be relocated to the vicinity of existing prime spawning grounds.
6. Stop the release of commercially farmed 'insurance salmon' into rivers with wild sea-run salmon populations. Excess insurance salmon from commercial farms should be used to stock put-and-take fisheries, that are isolated from wild sea-run salmon fisheries, or go to landfill. Unless it can be proven that these fish do not interbreed with wild-origin fish, these releases represent a risk to the genetic

integrity of wild stocks. This recommendation is consistent with that provided by Willis (2018).

7. Stop transferring salmon progeny between catchments that have existing wild salmon fisheries, either through egg planting or through hatchery releases.
8. Stop releasing juvenile trout into rivers and streams. Instead, refocus hatchery release programmes into put-and-take lake fisheries, such as constructed fish-out ponds, reservoirs or irrigation ponds.
9. Undertake a review of the ova planting programmes within the country to determine the current extent of this practice. Undertake a review of the relevant science around this practice to assess its scope for use as a fishery enhancement tool in New Zealand.
10. Undertake an education programme to inform Fish & Game Staff, Councillors and anglers about the potential risks of undertaking hatchery release programmes.
11. If it isn't broken don't fix it. Hatchery releases in open river systems should only be considered as a 'last resort' for 'at risk' populations or those affected by hydropower development. Chinook salmon runs in the Waiau, Hurunui, Clarence and Wairau have remained productive and relatively consistent during recent years—in contrast to the salmon runs in the rivers to the south. This is despite, and perhaps because of, minimal interventions by way of supplementary stocking.

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7. APPENDICES

Appendix 1. Excerpt from North Canterbury Fish & Game 2017 annual report showing the objective relating to hatchery release, the relevant performance measure and the number of fish released into various waterbodies in the region.

Objective 1.1.4.1

To supplement stocks of sports fish by operating a hatchery to raise salmon, rainbow and brown trout for release.

Objective 1.1.4.1 Performance Measure

Operate a Fish & Game hatchery program based at facilities at Montrose Station and Peacock Springs.

Objective 1.1.4.1 Actual Result

From the three F&G managed hatcheries, Montrose and Whiskey Creek on the Rakaia River & Isaacs adjacent to the Waimakariri River, salmon and trout were bred and released as follows:

Salmon Production.

- 60,000 x 50g smolt from Montrose into the Rakaia River.
- 30,000 x 50g smolt from Whisky Creek into the Rakaia River.
- 30,000 x 50g smolt imprinted for one month and released from Silverstream Hatchery.
- 10,000 x 50g smolt into Lake Coleridge tributaries including Harper River.
- 30,000 x 7-10g smolt transferred from Montrose and released into Whiskey Creek, then into the Rakaia River.
- 800 x 750g two-year olds - Isaac TAKF Sponsorship.
- 2,000 x 750g two-year olds – Groynes Lakes.
- Surplus ova for ova planting - 100,000.

Rainbow Trout production (21,500 released) lakes and rivers combined

- 15,000 fingerlings for North Canterbury High Country Lakes.
- 5,500 x fingerlings released into North Canterbury Rivers (Harper/Avoca).
- 1,000 held until two years and available for sale to other regions for regional TAKF days with surplus available for the Groynes young angler program.

Brown Trout production (16,500 released)

- 3,000 x fingerlings into the upper Selwyn River.
- 2,000 x fingerlings into Lake Ellesmere tributaries.
- 1,000 x fingerlings into the upper Okuku River (partly sponsored release)
- 1,000 x fingerlings into Lake Guyon.
- 1,000 x fingerlings into the upper Waipara River.
- 1,000 x fingerlings into upper Waikari River.
- 1,500 x fingerlings to be held until two years for release into lower Rakaia tributaries.
- 2,000 x fingerlings into the Avon/Heathcote Rivers.
- 2,000 x fingerlings into the Cam/Styx/Silverstream Rivers.
- 2,000 x fingerlings into Lake Georgina & Lake Lyndon.

Lakes Stocked with Rainbows

Lyndon 1,500, Georgina 1,000, Evelyn 500 Selfe 1,500, Henrietta 200, Ida 500, Catherine/ Monck 1,000, Pearson 4,000, Grasmere 1,500, Letitia 600, Sarah 500, Hawdon 1,000, Guyon 1,000.

Appendix 2. Excerpt from an email reply received 15 May 2018 from the North Canterbury Hatchery in response to a question about specific sources of salmon eggs:

Report author's question (sent via email):

> "You replied that the fish that are stripped for eggs to supply the hatchery come from various sources (wild headwater fish, salvage, hatchery returns and farmed origin). Can you please be a bit more specific about the proportion/percentage of eggs/salmon obtained from these sources over the last 5 years?"

Response:

> "On average it probably is about 20% headwater, lots of salvage from many catchments annually, about 40% usually but 90% last year due to a large stranding. Quiet this season as flows have been high, some trapped by rivers changing course, some trapped by power scheme flows, some by irrigation leads and failing fish barriers. We have 2 harvest trap locations, 1 on the Waimak and one on the Rakaia. They are both used annually and would make up the remaining 40%."

Appendix 3. Data for the Montrose and Silverstream hatchery traps and the total estimated wild spawning run in the Rakaia. Data have been extracted from the source data used for North Canterbury Fish & Game's Salmon Management reports.

Year	Montrose Trap Census	Silverstream Trap Census	Wild spawning escapement in Rakaia
2003	120	600	1243
2004	110	205	2706
2005	850	300	1818
2006	110	170	1123
2007	180	275	2673
2008	250	360	4313
2009	450	360	3945
2010	112	60	1817
2011	257	60	1538
2012	210	240	2813
2013	250	340	1430
2014	500	350	1366
2015	130	70	2140
2016	21	120	1015
2017	21	27	837