Recommendations for Addressing Declines in Chinook Salmon Abundance in New Zealand

David Willis
Hatchery Section Head
Salmonid Enhancement Program
Department of Fisheries and Oceans Canada
David.Willis@dfo-mpo.gc.ca
May 2018

Table of Contents

1. Executive Summary
2. Introduction
3. Recommendations
    a. Hatchery Management
    b. Fishery Management
    c. Stock Assessment
    d. Habitat and Water Management
4. References

Executive Summary

This report recommends a series of hatchery management actions combined with stock assessment and fishery management actions to better utilize the hatcheries of the South Island of New Zealand to increase the abundance and productivity of Chinook salmon populations, as well as to allow for maintained or increased fishery benefits and license sales. Recommendations are based on over 40 years of investigations and learning in the Canadian Salmonid Enhancement Program, as well as the latest scientific literature from Canada, the US and elsewhere.

Introduction

In November 2017 I travelled to New Zealand to learn more about the Chinook salmon of the South Island so that I could constructively provide advice and input on recommendations to help address recent declines in abundance that have had a negative effect on the fishery. During my trip I accompanied Steve Terry, Fish and Game officer for North Canterbury region. We visited several hatchery facilities, including McKinnon's, Silverstream, Isaac's, Whiskey Creek, and Montrose. We also toured the fishery areas and spawning streams by air, visiting the Waimakariri, Rakaia, and Rangitata systems as well as the lower reaches of the Ashburton. Near the end of my trip I was able to speak at the "Turning the Tide" Salmon Symposium, held in Ashburton. During my talk I described some approaches that have been used successfully in Canada for rebuilding salmon populations, as well as some of the emerging science on hatcheries and their utility in contributing to salmon rebuilding. In this report I will expand upon some of my recommendations, specifically as they may apply to the New Zealand situation. My recommendations are based upon our experience operating a large Chinook salmon hatchery program in Canada, as well as on the latest scientific literature from the US and elsewhere.

Recommendations

During the salmon symposium in November 2017, a wide variety of topics were covered by many expert speakers. In this report, I will limit my recommendations to three areas in which I have a fair amount of direct experience:

- Hatchery Management
- Fishery Management
- Stock Assessment

Hatchery Management

The salmon hatcheries of the South Island provide an excellent opportunity to achieve several objectives related to improving the status of natural populations. They allow for augmentation of natural runs to allow for increased harvest and spawning, they provide a platform for research and monitoring activities to improve understanding of salmon populations and their limiting factors, and they are effective in engaging local communities and fostering a stewardship ethic. In this section, I will outline 6 recommendations for better utilizing the hatcheries the Central South Island and North Canterbury to improve salmon population status, as well as increasing fishery opportunities. I have restricted my recommendations to hatchery planning and evaluation; the recommendations and resources provided by Don MacKinlay in 2009 for actual fish culture still hold true today.

1) Clearly identify specific objectives for all hatchery programs

This recommendation sounds simple and obvious, but the North American experience has shown this to be much more elusive that would be expected, and has also shown that the lack of specific objectives can seriously impair a hatchery program's ability to improve salmon population status, and in fact can result in unintended negative consequences for the status and productivity of natural populations.

The designation of a hatchery program as harvest-focused or conservation-focused can then inform the strategies that are used to best meet the objectives. For example, in a hatchery program that is primarily for the purpose of increasing salmon abundance for fishery harvest, releasing juveniles in a location near the fishery zone may result in the returning adults remaining vulnerable to a fishery for a longer period of time. Another example of a strategy aimed at a fishery program would be to use a size at release that may promote a higher survival rate at the expense of a natural age and sex ratio at return. Conversely, designating a hatchery program as conservation-primary would consider employing strategies that would promote the return of spawners to the spawning grounds that are most likely to be successful in giving rise to fish in the next generation (see Recommendation 3 below).

The basis behind this recommendation is that in order to achieve objectives, one must be very clear about exactly what that objective is. Hatcheries can be an effective tool for a number of objectives, but if the objective is unclear then it is less likely that efforts and resources dedicated to the hatchery will deliver the return on investment that is desired.

For more information on this topic, see www.hatcheryreform.us.

2) Design hatchery programs to maximize fishery & conservation benefits

This recommendation builds on the previous one, and takes the next step in designing the hatchery program to best deliver on its objectives. Once a hatchery program has been designated as fishery-primary or conservation-primary, there are several different strategies that can be employed to best meet objectives.

For fishery-primary hatcheries, I would recommend the following strategies:

- Externally marking all released salmon to allow for identification in fisheries

- Using hatchery fish culture techniques to maximize early growth and achieve greater release numbers earlier
- Releasing hatchery salmon in locations that will promote their vulnerability in high effort fishery zones (through use of lower river hatcheries, or by offsite transport and releases)

For conservation-primary hatcheries, I would recommend the following strategies:

- Releasing juveniles at or near high quality spawning habitat to increase homing back to spawning grounds
- Use of natural origin broodstock (i.e. from native watershed)
- Exclusion of aquaculture surpluses in releases
- Use of hatchery rearing and release strategies that promote a natural age and size at maturity

The specific application of these recommendations to New Zealand hatcheries will allow for hatchery programs that have clear objectives and performance measures, and that can be adaptively managed to best meet the management goals for the watersheds.

3) Use release strategies that provide the highest return on investment and that mirror natural salmon life histories

In Canada, the Chinook salmon hatchery program predominantly uses an ocean-type, or "90 day special" strategy. Eggs are incubated over the winter, ponded in late winter/early spring, and reared for ~3 month prior to release as ~4-8g smolts in the spring, when the natural juveniles are migrating to sea. In some specific circumstances (e.g. in rivers that are far from the coast and that have natural populations of stream-type Chinook salmon), a yearling release strategy is used where salmon are reared in the hatchery for a year and released in their second spring at a size of ~18-25g. Through several decades of trial and error, these two classes of strategy have been demonstrated to be the most effective in terms of total adult production. Survival rates from release to adult return can be quite variable based on environmental conditions, but at the major Canadian hatcheries a recent survival rate of 1-2% has been observed.

As the hatcheries on the South Island are not of the same size and scale as those in Canada, available rearing water and containers are frequently a limiting factor. Generally, hatchery capacity is measured either in load rate (kg/m^3) or load per flow (kg/m^3/L/Min). In order to maximize the return of adult salmon from relatively small and space-limited hatcheries, I would strongly recommend exploring an experimental approach of increasing the number of eggs taken, significantly increasing the number of juveniles released, and significantly decreasing the size at release. For example, instead of rearing and releasing 60,000 salmon at 100g each (6,000 kg of biomass in hatchery), rearing and releasing 600,000 salmon at 10g each would give a superior adult return as long as the survival rate was at least 10% or greater of the 100g release.

In addition to a likely increase in total adult return, I recommend using a spring release if hatcheries are able to achieve a size of at least 4-8 g by the summer solstice. Primary production in the marine environment is likely higher in the spring and early summer than it is in the winter, and matching ocean entry to a period of increased food abundance for juvenile salmon will likely promote a higher marine survival rate.

Lastly, I recommend strongly considering reducing ova plants, and using the eggs to supplement increased releases of 4-8 g fry. Survival from this strategy is known to be very poor when used in Canada, and is no longer used on any kind of a production scale. Use these eggs to increase production of fry and smolts from hatcheries, with more releases at a smaller size, but an equal total biomass to current production.

4) Conduct or support further research into the genetic population structure of wild and farmed salmon populations in order to better understand effects of domesticated salmon on natural populations

New Zealand salmon are unique in that they are all descended from a single source transplant in the early 20th century, from the McCloud River in California. Despite this single founder population, Chinook salmon were observed to have colonized virtually all rivers on the South Island in their present day range within 10 years, and today exhibit highly variable run timing, body size and shape, and habitat usage that would indicate significant phenotypic divergence has occurred (Quinn, 2001). It is this adaptation to local environments that provides the genetic principal upon which population rebuilding is most likely to occur.

I recommend that some preliminary work on developing a genetic baseline for population identification be initiated. The assumption that all Chinook salmon in New Zealand are interchangeable carries considerable risk to the success of rebuilding natural populations if that assumption is proven to be incorrect. Through genetic stock identification work to identify potential differences in populations, hatchery and fishery management actions can be informed to protect genetic diversity where it may be important. If significant genetic diversity is identified, those populations should be protected to ensure that they retain those adaptive characteristics. Without current knowledge on the population structure of New Zealand Chinook, informed decisions on how best to manage populations, specifically around the movement and transplants of hatchery salmon, cannot be undertaken in an effective manner.

5) Strongly consider discontinuing releases of surplus fish farm salmon into natural salmon-bearing rivers

As anyone who has spent time working with wild and farmed salmon will know, fish that come from fish farms are different. The adaptive environment in captivity will select for different traits than the natural environment will. Salmon bred for size, growth and fat content are far less likely to perform well in the natural environment where the ability to forage for food, swim upstream, dig a redd, and avoid predators will all be critical to their reproductive success. Releasing surplus farmed salmon is highly unlikely to have significant net benefit on overall salmon population abundance, due to poor expected fitness in the natural environment.

In addition to expected poor performance, there is increasing evidence in the field of epigenetics that changes in the expression of genes can occur after as little as one generation in captivity, and that these changes can be passed down across generations. This has recently been observed in hatchery coho salmon in British Columbia that spent only a year in captivity (Le Luyer, 2017). If epigenetic changes have occurred in farmed salmon, it is possible that their offspring in the natural environment could pass these changes on to naturally-produced salmon, with potential deleterious effects on the overall productivity of the population (Withler et al, 2018).

Unless the returning adults from surplus fish farm releases can be removed from naturally spawning populations with a high degree of certainty, I would strongly recommend discontinuing this practice. Alternative uses for surplus salmon may be in landlocked fishery locations (lakes), or at offsite release locations far from any potential natural spawning stream.

6) Continue to use hatcheries as a tool to engage community and foster a stewardship ethic

This recommendation is not for any change, but is intended to reinforce the good work that the South Island hatcheries do in raising the profile of salmon conservation issues with the public, as well as instilling a stewardship ethic in the general public. Hatcheries provide an excellent opportunity to educate younger generations on salmon, their habitat, and the healthy ecosystems upon which they depend. Through the use of hatcheries as a tool to educate and inform, a future generation of fishermen, streamkeepers, and volunteers can be recruited to look after the resource.

Fishery Management

Although there are several "levers" that can and should be used in rebuilding salmon populations (harvest, hatcheries, habitat and water management/hydro), fishery management measures generally have the most immediate impact and benefit in terms of increasing the number of adult salmon returning to the spawning grounds. Habitat, hatchery and water management/entrainment issues can provide benefit in as early as one generation, but an increase in spawners through fishery management measures can serve to accelerate the pace of rebuilding in the early stages.

With particular focus on the Rakaia and Waimakariri, I believe there is evidence to indicate that current rates of fishery removals are accelerating the rate of decline of the populations, and may significantly impede rebuilding in the short term and potentially long term.

1) Decrease harvest rate on Rakaia and Waimakariri salmon returns during the current period of decreased productivity

In November 2017 I reviewed stock-recruitment data that had been compiled by Steve Terry and analysed by Steve Fleischman of Alaska. This data was based on the long term escapement and harvest estimate dataset, and was used to estimate the mean productivity of the population aggregates and the subsequent sustainable harvest rates for the populations. This is a standard fishery management approach and one that has been used extensively in North America, in fact the Ricker stock-recruitment model is named after Bill Ricker, who worked for the Department of Fisheries and Oceans Canada in Nanaimo, British Columbia. In Canada, recent declines in salmon abundance have been linked to a decrease in productivity (recruits per spawner) in recent years. Although long term stock-recruitment models indicate harvest rate at maximum sustainable yield to be 31% for the Rakaia and 45% for the Waimakariri, when only recent years of known poor productivity are included (post-2007) it becomes apparent that harvest rates are likely contributing to delayed rebuilding or even accelerated declines.

For the datasets of the Rakaia and Waimakariri, this trend was apparent to me as well. Although salmon populations appeared to follow a cyclical pattern of lower abundance followed by higher abundances (Fig. 1), this appears to have broken down in the last two generations, which corresponds with the observed declines that have led to the recent concerns in New Zealand. This decline was stronger in the Rakaia, where the mean recruits/spawner value barely reached above one in the years 2007-2014. Simply put, in most recent years the populations are just barely replacing themselves (i.e. one fish back for every spawner), which means that any removals via fisheries will cause or accelerate declines in abundance.

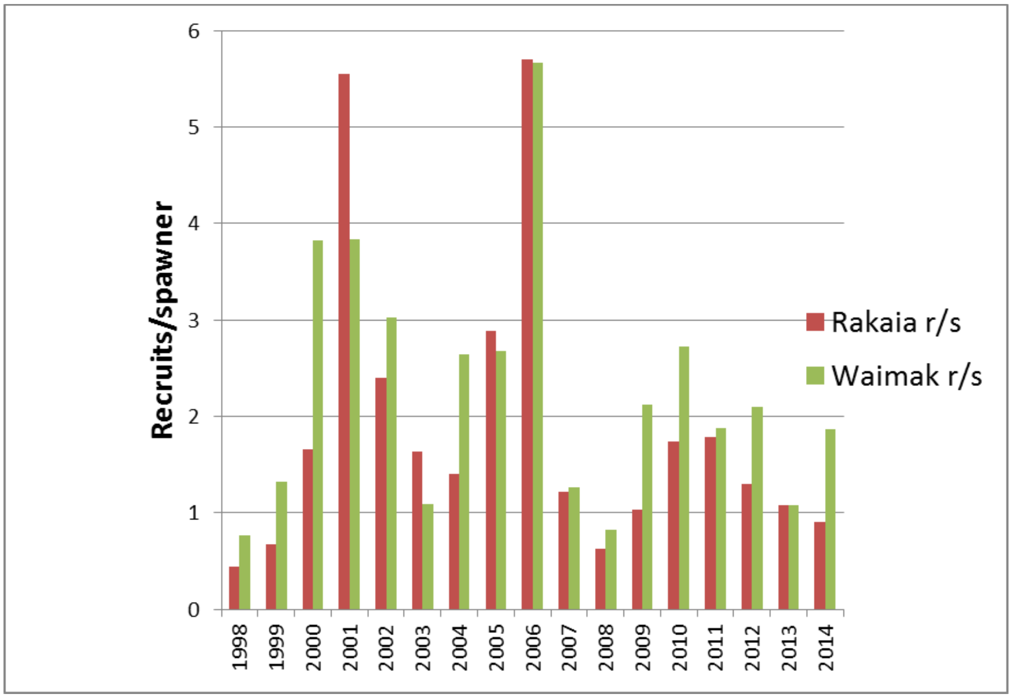

Figure 1. Recruits per spawner by brood year, Rakaia & Waimakariri rivers

Although there is significant uncertainty in the stock-recruit data, one thing that is certain is that fewer salmon caught in fisheries will translate directly into more salmon spawning. For this reason, I recommend pursuing fishery management actions that will reduce the overall impact on salmon populations for one generation, while maintaining fishery opportunity. Some potential managements actions (all of which are actively in use in Canada) that could be considered include:

- Annual catch limits. Work done by O. Houdayer (unpub.) for NZ F&G in 2010 reported that implementation of annual catch limits on the Rakaia and Waimakariri Rivers could be an effective tool in reducing overall fishery impacts. It should be noted that in Canada an annual limit of 30 from the entire coast, with water-specific limits of 10, 15 and 20 for specific waters.

- Daily limit decrease. A reduction in the daily retention limit. In Canada, typical daily limit in freshwater is 1 adult salmon/day.

- Slot limits. Limiting retention of salmon to a certain size range (e.g. 65cm-75cm) will allow larger salmon to pass through to the spawning grounds, and ultimately will reduce overall harvest rate. In addition to decreasing the harvest rate, the salmon that are removed will be disproportionately the smaller fish that are less fecund, and will allow the larger more fecund females to spawn.

- Single Barbless Hook. In Canada 100% of salmon fishing (freshwater and saltwater) requires only a single barbless hook to be used. When combined with other fishery management measures, it will decrease the mortality of caught and released salmon significantly (Patterson et al, 2017)

- Decreasing harvest of juvenile salmon in non-target fisheries (Lake Heron & Lake Sumner)

The chart in Figure 2 demonstrates a simplified alternative management approach whereby harvest rates on the Rakaia River are either maintained at the recent averages (red and green lines), or are decreased to 25% annually (blue and purple). The 25% scenario assumes that the progeny of the 2015 brood year (2018 returns) were the first generation to undergo a reduced harvest rate, which would have resulted in increased spawners and subsequent natural production. While this is an overly simplified model that does not take into account stochasticity or other time-varying parameters, it is intended to make clear that if the low productivity that has been observed since 2007 does not change, a significant decrease in spawners and returns should be expected under current harvest rates. A precautionary approach would aim to reduce harvest impacts on wild salmon, while other actions such as habitat and hatchery work are undertaken to increase the abundance and productivity of the watersheds for the longer term.

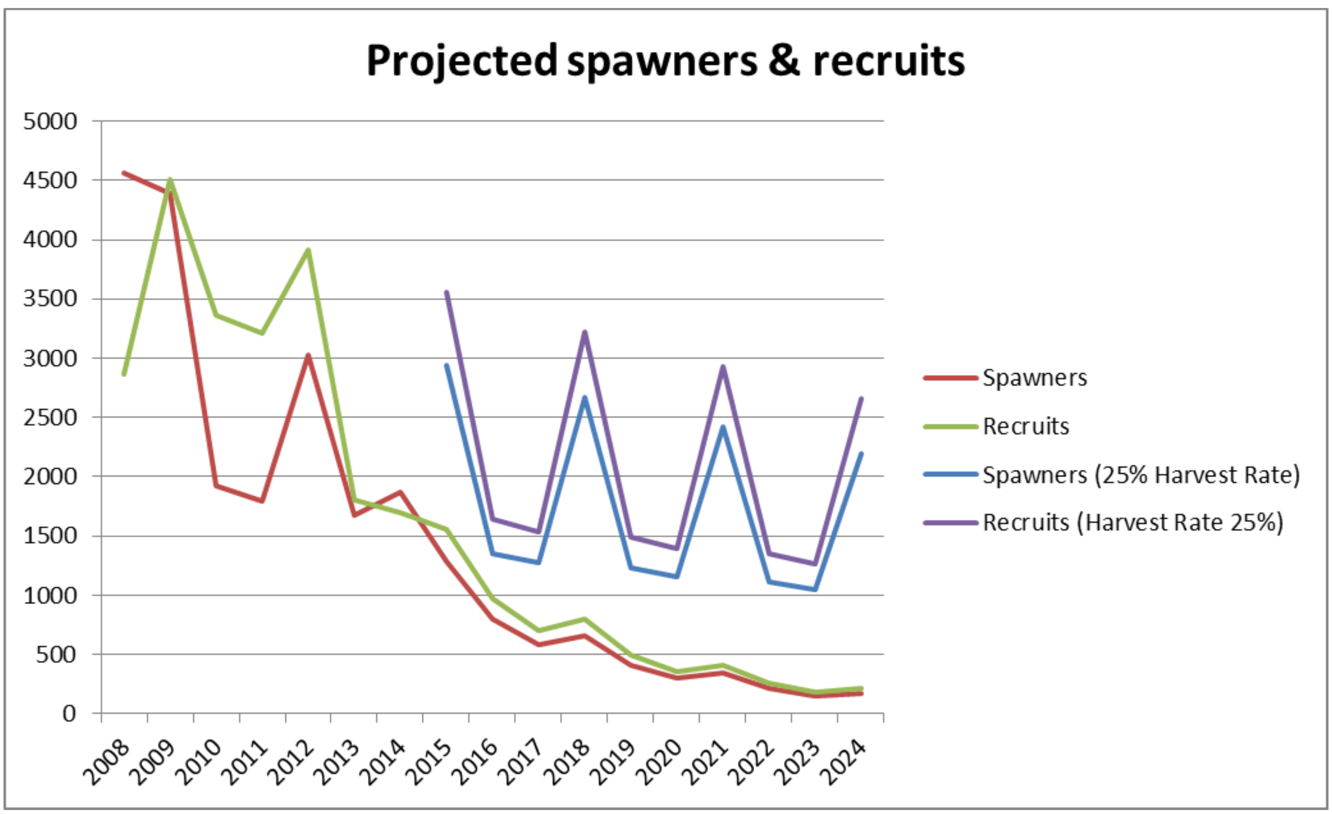

Figure 2. Projected recruits and spawners for the Rakaia River, under recent harvest rates and under a modelled 25% harvest rate

2) Shift harvest pressure from wild salmon to hatchery salmon

This strategy links hatchery production and release strategies with fishery management strategies. If hatchery salmon are externally marked (e.g. removal of the adipose fin clip), fishery retention regulations can be designed to allow increased harvest of hatchery salmon while conserving wild-origin salmon through catch and release. Some potential approaches could be:

- Daily limits that allow more harvest of hatchery salmon (e.g. 2 fish total, only one of which may be wild)
- Annual limits that allow more harvest of hatchery salmon (e.g. 5 wild salmon per year, no limit on hatchery)
- Release hatchery salmon in areas where they will be more vulnerable to fishing (e.g. in the lower reaches of the Rakaia and Waimakariri) and focus fishing effort on these areas.

When fishery management approaches are combined with hatchery planning, it is possible to continue to maintain or increase fisheries while shifting pressure away from wild salmon that are required for spawning and population rebuilding.

Stock Assessment

Effective fishery management is based upon a foundation of sound stock assessment information. Given the limited resources available, the stock assessment programs in North Canterbury and Central South Island are to be saluted for their effectiveness. The following recommendations are both support for existing programs, and potential additions that could be implemented relatively easily within the current monitoring frameworks.

1) Maintain extensive surveys, expand if possible

The salmon escapement monitoring program currently conducted in North Canterbury and Central South Island is critical to the understanding of population dynamics and status, and fundamental to the effective management of sustainable fisheries. In recent years, both the Peak Count and the Area Under the Curve (AUC) methods have been used to calculate spawning escapements. As has been documented in recent Salmon Management Reports (Terry, 2016) there are advantages and disadvantages to both techniques, but the ability to monitor trends and detect changes in productivity is critical (see Rec 1, Fishery Management), and can be delivered by both methods.

I recommend maintaining and ideally expanding the extensive monitoring program for South Island spawning streams. It is also critical to ensure that the historic data set has been calibrated to ensure that changes in methodology are accounted for. Specifically, AUC and peak count estimates should be standardized across years based on correction factors from those years with both counts to ensure that stock-recruit relationships are as accurate as possible. The most important component of a long term monitoring project is the ability to detect trends, which requires that inter-annual estimates are as comparable as possible.

2) Maintain and improve fishery monitoring program

As with the escapement monitoring program, the annual telephone fisher survey is critical to the understanding of the fishery and the overall population status. This survey, which provides broad data across multiple fisheries and which is conducted very economically, provides a structured approach for maintaining a comparable dataset across years. I recommend maintaining this structured approach, as it supports the annual population monitoring framework for the South Island.

If there are specific fisheries in which a greater degree of resolution is desired, (e.g hatchery mark rates, etc), I recommend implementing specific studies that are designed in a manner to deliver rigorous data that will allow for effective fishery management. For example, voluntary reporting programs will likely deliver different results than a program such as the telephone survey. If multiple sampling or survey programs are conducted in an overlapping manner, I recommend calibrating the results if both programs are designed in a statistically sound manner. Otherwise, anecdotal results from voluntary reporting programs should be taken as qualitative data, with the structured survey providing the quantitative data used in fishery management decisions.

In British Columbia, the Department of Fisheries and Oceans has developed an app in collaboration with the Sport Fishing Institute (SFI), a non-profit anglers advocacy group. Use of app-based approaches or other web-based techniques have the ability to significantly reduce the annual operating costs of fishery monitoring, while having the ability to provide data that would otherwise not be available to managers (e.g. harvest data of other species). The code for the app in use in Canada, called FishingBC, may be available for use by New Zealand Fish and Game. I have reached out to Owen Bird, chairman of the SFI, and he has expressed willingness to discuss sharing the code with NZF&G if there is interest. Contact information is available upon request.

Habitat and Water Management

During my time on the South Island, it was very apparent that while there is a great deal of pristine spawning and rearing habitat in the major east coast rivers, that habitat degradation and water management issues were likely to be one of several causal factors in salmon population declines. As I do not have specific training nor a great deal of experience working on habitat-related issues I will refrain from providing specific recommendations on these topics. However, I can comment in general on two areas in which New Zealand is already well versed, if only to reinforce the good work that is ongoing.

Habitat management can be broken into two main components; protection of existing critical habitats, and restoration of degraded habitats. As the spawning streams of the South Island that I visited appeared to be in relatively good shape, preservation and protection of the spawning and rearing areas should remain a priority. Habitat restoration can also be a very effective tool, although it can be more difficult to identify the most important projects to undertake. One approach to narrow the options is to identify the critical life history stages for salmon rebuilding, and focus efforts on projects to address those limiting factors. Through the use of a simple life history model it will quickly become apparent that the relative gain made from improvements in survival at the early life history stages can have a dramatic effect on overall adult abundance. Using the hypothetical life stage model below (Fig. 3), one can make adjustments at various life stages based on potential management actions to model potential benefits to adult production. Two things become clear, that improvements at the earlier stages can have very dramatic relative effects, and that even small improvements at those stages with the highest mortality (e.g. at-sea mortality) can have very significant effects. My recommendation on this point is to explore multiple options to improve freshwater and downstream migration survival, as well as to increase the number of returning adults via fishery management measures and hatchery production. Specifically, if major causes of mortality can be isolated and addressed, such as any potential major entrainment in water abstraction diversions, these may have major effects on reducing immediate mortality as well as subsequent mortality if juveniles passing through water diversions or through poor quality water are compromised upon entering the sea. Habitat restoration work in areas utilized just prior to ocean entry has been demonstrated to increase marine survival in the Cowichan River, British Columbia, so if there are candidate activities to remediate or restore critical habitat for outmigrating juveniles, these should be strongly pursued as part of a long term rebuilding plan.

Life Stage	Ecosystem Unit	Mortality	Abundance	Mortality	Abundance
Migrating Adults	Mouth to spawning streams	10%	5280	10%	5280
Spawners	Spawning streams		4800		4800
Eggs Laid	Spawning streams		8400000		8400000
Fry Hatched	Spawning streams	60%	3360000	60%	3360000
Smolts out	Mainstem river to ocean	75%	840000	50%	1680000
Adults Produced	Ocean	99%	8400	99%	16800
Caught in ocean	Ocean	1%	8316	1%	16632
Terminal run	Ocean to lower river		8316		16632
Caught in river	Mainstem	50%	4158	50%	8316

Figure 3. Hypothetical life stage model that can be used to model potential benefits to production from various management actions

Lastly, water management should remain an area of focus for New Zealand salmon management. As can be seen in Figure 3, improvements in survival during the fry and smolt stages can have large benefits for overall adult production. Continued efforts at working to reduce mortality of smolts into unscreened irrigation systems are likely to realize significant benefits to salmon populations.

Acknowledgements

I would like to thank all those who offered me such wonderful hospitality and helped me learn so much during my time in New Zealand. Steve Terry generously offered his time touring me all over Canterbury to learn all about the salmon populations and hatcheries, Mark Webb and Hamish Stevens provided excellent insight into the salmon management situation in the Central South Island region, Dirk Barr and Tony Hawker shared their vast knowledge and experience with the salmon hatcheries and rivers in the North Canterbury region, and Richard Cosgrove for greeting me upon my arrival and giving me the insider's tour and introduction to Christchurch. Last but certainly not least, thanks to Don MacKinlay for making this opportunity possible, as well as sharing his insights and experience from his time in New Zealand in 2009.

References

Hatchery Scientific Review Group (HSRG). 2014. On the science of hatcheries: an updated perspective on the role of hatcheries in salmon and steelhead management in the Pacific Northwest.

Le Luyer, J., M. Laporte, T.D. Beacham, K.H. Kaukinen, R.E. Withler, J.S. Leong, E.B. Rondeau, B.F. Koop and L. Bernatchez. 2017. Parallel epigenetic modifications induced by hatchery rearing in a Pacific Salmon. Proceedings of the National Academy of Sciences U.S.A. 114: 12964-12969.

Patterson, D.A., Robinson, K.A., Raby, G.D., Bass, A.L., Houtman, R., Hinch, S.G., and Cooke, S.J. 2017. Guidance to Derive and Update Fishing-Related Incidental Mortality Rates for Pacific Salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/011. vii + 56 p

Quinn, T.P., Kinnison, M. T., Unwin, M. J. 2001. Evolution of chinook salmon (*Oncorhynchus tshawytscha*) populations in New Zealand: pattern, rate, and process. Genetica 112-113: 493-513.

Unwin, M. J., Glova, G. J. 1997. Changes in life history parameters in a wild population of chinook salmon (*Oncorhynchus tshawytscha*) associated with releases of hatchery-reared fish. Canadian Journal of Fisheries and Aquatic Sciences 54:1235-1245.

Withler, R.E., Bradford, M.J., Willis, D.M., and Holt, C. 2018. Genetically Based Targets for Enhanced Contributions to Canadian Pacific Chinook Salmon Populations. DFO Can. Sci. Advis. Sec. Res. Doc. 201019. xii + 88 p.