Ministry for Primary Industries
Manatū Ahu Matua

National Environmental Standard- Plantation Forestry

Additional Fisheries Advice

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Growing and Protecting New Zealand

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1 Introduction

1.1 BACKGROUND

The Ministry for Primary Industries (MPI) is leading the development of the National Environmental Standard for Plantation Forestry (NES-PF). The objective of the NES-PF is to provide a suite of consistent rules for plantation forestry throughout New Zealand and to reduce the variation currently present in Regional and District Council rules. The proposed NES-PF covers eight aspects of plantation forestry:

- Mechanical land preparation;
- Afforestation;
- Earthworks;
- Forestry quarrying;
- River crossing;
- Pruning and thinning to waste;
- Harvesting; and
- Replanting.

The majority of these activities can affect water courses and the aquatic flora and fauna that reside in the water courses. Therefore, the draft NES-PF that was released for consultation on 17 June 2015 contained rules for working in and around water. The draft includes a number of rules for the protection of fish and fish spawning. Development of the rules was supported by information on fish spawning (Smith 2015) and fish distributions using the New Zealand Freshwater Fish Database (NZFFD) records and the River Environment Classification Predictive Fish Model (REC-FPM) (Crow et al 2014).

Submissions on the draft NES-PF commented on a number of issues relating to the fisheries information:

- Taxonomically indeterminate species have not been included in the rules, submitters have questioned whether these should be covered, particularly Galaxiid species that are regionally isolated;
- Whether the NZFFD and River Environments Classification (REC2) are sufficiently accurate as a basis for resource management regulation;
- Whether a national fish spawning calendar is capable of covering the full range of spawning times across New Zealand;
- The NES-PF rules currently only place restrictions on the peak spawning period, or where a peak period has not been identified through the spawning calendars a truncated spawning period of two months has been used at the centre of the species spawning range. Submitters have questioned whether this would be sufficient to allow for successful recruitment. Some have suggested that a wider window of risk should be used to allow additional time for successful egg and larval development; and
- Whether using a modelled probability of fish presence from the REC-FPM of 0.5 is appropriate.

1.2 SCOPE OF REPORT

This report has been commissioned to provide further information and assessment of the issues raised by submitters in the first four bullet points above. A literature review and NZFFD record comments were used to provide spawning information's and the indeterminate taxa, the GIS spatial layer and fish distributions where compared to existing data not included in the NZFFD to test the accuracy of the spatial layer. Recommendations for changes to the spawning protection timing where made to reflect the information in the literature review.

2 Freshwater Fish of New Zealand and the NES-PF

2.1 INTRODUCTION

When conducting the New Zealand threat ranking process, led by the Department of Conservation (DOC), Goodman et al (2014) classified 77 freshwater fish taxa. This compilation of freshwater fish includes one extinct species (grayling, *Prototroctes oxyrhynchus*); 56 native fish taxa (42 described species and fourteen indeterminate taxa) and 20 introduced and naturalised fish species. An additional two species, grass carp and silver carp, were not included in Goodman et al (2014). Therefore, there are a possible 79 fish taxa to include in the NES-PF rules (Appendix A).

For the NES-PF background information on fish spawning was collated by Smith (2015). This provides spawning and fish migration information and undertakes an impact assessment of forestry activities on fish spawning for 41 taxa, 34 native and seven introduced (Appendix A). The NES-PF used the data provided by Smith (2015) and the fish threat categories (Goodman et al (2014) to select 21 fish species for specific protection in the NES-PF. These fish taxa were selected as they were considered to be at high risk of impacts on spawning due to forestry activities (Smith 2015) and had a high threat category in Goodman et al (2014).

To provide guidance to forestry operators on the fish fauna present in streams in the forestry areas the NES-PF is accompanied by GIS with a spatial layer that has the distributions of the 21 fish species in the NES-PF across New Zealand. To develop the fish distribution layer, MPI used records from the NZFFD and the fish prediction model REC-FPM of Crow et al (2014) to map the likely distributions of the 21 freshwater fish across New Zealand. The NZFFD records were used to provide location data for fish across the New Zealand river network. However, NZFFD records were only considered appropriate records of fish occurrence for the survey site and for a distance of 1 km upstream and downstream from the NZFFD record site. For areas more than 1 km from NZFFD records the fish prediction model (Crow et al 2014) was used to predict which fish species are likely to be present. Crow et al (2014) maps the occurrence of 33 fish species, 27 native and 6 introduced fish and including 31 described species (determinate taxa) and two of the indeterminate taxa listed by Goodman et al (2014) in the predictive modelling (Appendix A). However, Crow et al (2014) do not provide predictions for the occurrence of all the fish species included in the NES-PF so for some species the spatial layer only uses the NZFFD records to map occurrence.

2.2 FISH SPECIES TO INCLUDE IN THE NES-PF

To select the fish species to include in the NES-PF spawning protection rules some simple exclusions from the 79 fish taxa were made. The extinct grayling was excluded from the NES-PF. Fifteen introduced fish taxa with a status of unwanted, noxious, pest, restricted and introduced fish of no status (e.g., goldfish) and an additional seven native and marine vagrant taxa that spawn in the marine environment (e.g., eels, triplefins) were all excluded from the spawning protection rules.

The Resource Management Act (1991) (RMA Part 2, Section 7 h) also requires the protection of habitat of trout and salmon, although the RMA does not define trout and salmon. The NES-PF includes fish of the *Salmo* and *Oncorhynchus* genera (five species, brown trout, Atlantic salmon, sockeye salmon, Chinook salmon and rainbow trout, all trout and salmon). The status of char species (*Salvelinus*) with respect to the RMA is not clear as these species belong to the wider salmonid group that includes salmon and trout but are not themselves trout or salmon. The NES-PF has currently included brook char in the spawning rules, but not lake char (mackinaw). A further fifteen native fish were included in the NES-PF based on risk assessment and current threat rankings (see Appendix A).

3 Indeterminate Taxa in the NES-PF

3.1 INTRODUCTION

Indeterminate taxa are populations of fish that have been separated from described species (determinate taxa) as they are now thought not to be part of the described species, or are taxa that have never been assigned to a species. Taxonomic revisions of the *Galaxias* genus have given rise to a number of indeterminate taxa that await formal species descriptions. Further background information on the taxonomic history of the New Zealand galaxiid fishes that form the majority of the indeterminate taxa is provided in Appendix B.

3.2 CURRENT TAXONOMIC ACTIONS

DOC hosted a one-day workshop on non-migratory galaxiid taxonomy in May 2013. This workshop discussed issues with the non-migratory galaxiid taxonomy and made decisions on how to address the indeterminate taxa. The workshop output (Bowie et al 2014) noted that the following indeterminate taxa should be investigated with the objective of formally describing them as distinct species:

- *G.* sp D, Clutha flathead galaxias, flathead populations from the Benger Burn and upstream in the Clutha River catchment (excluding the Teviot River);
- *G.* 'Teviot', the Teviot flathead found (to date) only in the Teviot River catchment;
- *G.* 'southern', a flathead galaxias found in Southland and Stewart Island;
- *G.* 'northern', a flathead galaxias found from the Maruia River, Motueka River and Marlborough; and
- *G.* 'Nevis', the roundhead galaxias from the Nevis River catchment.
- Limitations on the understanding of galaxiid populations in the lower Clutha River catchment and adjacent lowland rivers lead to the decision to name two new indeterminate taxa:
- *G.* 'Pomahaka', a flathead galaxias found in tributaries of the Pomahaka River; and
- *G.* 'lower Clutha', for galaxiids found in the lower Clutha River catchment and some adjacent lowland rivers.

Once formal description of these species is complete, this will reduce the area of South Island and Stewart Island with indeterminate taxa from the *G. vulgaris* group to just areas of the Clutha River catchment and lowland rivers adjacent to the Clutha catchment.

For the other indeterminate taxa further work will be required to assess and determine species status.

3.3 INDETERMINATE TAXA AND THE NES- PLANTATION FORESTRY

Submissions on the draft NES-PF noted that a number of indeterminate taxa have been omitted from draft. These taxa are not specifically mentioned in the NES-PF and were also absent from the GIS with the fish predictive model. The following six indeterminate taxa were noted as omissions in the submissions: lower Clutha galaxias, Clutha flathead galaxias, Teviot flathead galaxias, Nevis galaxias, Pomahaka galaxias and northern flathead galaxias. Goodman et al (2014) in the most recent freshwater fish threat rankings lists an additional 8 indeterminate taxa, including further galaxiid taxa: southern flathead galaxias, Waitaki lowland longjaw galaxias, Southland alpine galaxias, Manuherikia alpine galaxias, Waitaki upland longjaw, dune lakes galaxias, dwarf galaxias (northern) and one bully, *Gobiomorphus*, upland bully (West Coast and North Island). These taxa have been identified as potentially distinct from the described species but no formal descriptions have been made and therefore species status has not been conferred on them. Despite this some of these taxa have been recognised for nearly twenty years and have been treated independently from closely related species.

The NZFFD only records four indeterminate flathead galaxias taxa separately in the database: Clutha, southern, northern and Teviot flatheads. With two exceptions all other indeterminate taxa are included in the NZFFD within the records for determinate taxa (Table 1). The two indeterminate taxa, the Pomahaka galaxias and lower Clutha galaxias, are recorded as Clutha flatheads in the NZFFD. In all cases a geographic filter will separate the determinate and indeterminate taxa if required. The draft NES-PF does include six indeterminate taxa as they are currently included within the related determinate taxa in the spatial layer of the NES-PF (*Table 1*). However, it does not include five of the six named indeterminate taxa from the submissions.

Smith (2015) provides spawning data for a range of taxa including some indeterminate taxa as part of his assessment of the closely related determinate taxa. It is possible to use the existing spawning data to develop risk assessment scores for the majority of indeterminate taxa. As the majority of indeterminate taxa also have threat rankings it is possible to conduct the same ranking process to determine whether the individual indeterminate taxa should be included in the NES-PF.

The Crow et al (2014) fish prediction model provides the likelihood of fish presence for areas where no fish survey records are available. This modelling has also been conducted using the closely related determinate taxa for six indeterminate taxa. Crow et al (2014) has also developed distribution models for two indeterminate taxa, the northern flathead and Clutha flathead (*G.* 'northern' and *G.* sp D). However, the Clutha flathead model will be confounded as it uses NZFFD records that include the Pomahaka galaxias and lower Clutha galaxias records. Therefore, this prediction model will be using incorrect geographic boundaries for the geographically restricted model and the environmental, spatial and hydrological variables used in the model will come from a larger dataset that may not be appropriate for *G.* sp D, as set out by Bowie et al (2014) as part of the taxonomic review process for galaxiids in New Zealand.

3.4 INCLUDING THE INDETERMINATE TAXA IN THE NES-PLANTATION FORESTRY

From the simple biological perspective, the distinction between determinate and indeterminate taxa is a limited issue. This is because all of the indeterminate taxa are closely related to described species and the majority of these can be expected to have similar biological traits (*Table 2*). The key aspect of spawning timing may vary in the order of weeks for some of the different taxa but all information, published and anecdotal, can be used to provide a spawning timing period for these indeterminate taxa. Timing variations are more likely to be associated with water temperature that changes with latitude and altitude rather than with the identity of the closely related taxa.

Smith (2015) provided a risk assessment for plantation forestry impact on a suite of freshwater fish. For the indeterminate taxa some are included within assessment as there included with closely rated sister taxa and these risk scores can be used for the indeterminate taxa. For other taxa, the flathead galaxiids in the Clutha River catchment, there is less certainty that the risk assessment of Smith (2015) is a good fit. However, the two flathead species assessed by Smith (2015) had relatively high impact assessment scores and given all the Clutha River catchment flathead species are highly threatened and some populations of these fish have gone extinct in forestry areas the use of the high scores assessed for other flathead species is appropriate (*Table 3*). The exception to this is the Nevis galaxiid that is most closely related to the Gollum galaxias of Southland. Gollum galaxias has a moderate impact score of 39, it is unknown if this is appropriate for the Nevis galaxias. However, it is used as an interim score for the Nevis galaxias as the Nevis Valley is considered an extremely unlikely area for forestry activity and hence at extremely low risk of impacts occurring.

It is recommended that if there is a decision to include any indeterminate taxa in the NES-PF that a simple mapping exercise is undertaken using the NZFFD records and the REC-FPM. The data and model information could then be split along the geographic boundaries (*Table 1*) that are well recognised, to delineate between indeterminate taxa and the determinate taxa they have been split from.

The only problematic indeterminate taxa are the lower Clutha galaxias and Pomahaka galaxias. Data for lower Clutha galaxias (DOC unpublished data) indicates that populations of this taxon has been lost or suffered major declines in forestry areas in the last 20 years. The reasons for these losses are not understood but given this occurred in forestry areas, forestry activities are a potential cause. Therefore, this indicates (without conducting the assessment of Smith 2015) that this taxon is at risk. The geographic distribution of the Pomahaka galaxias is poorly understood but appears limited to just the Pomahaka catchment. Therefore, from a threat ranking perspective the limited geographic range will likely lead to a high threat ranking. The MPI process for determining the inclusion of fish taxa in the NES-PF spawning rules includes high threat rankings and high risk of forestry impacts. Both these indeterminate taxa appear to be likely candidates for inclusion. Despite limited knowledge of the two taxa the NZFFD holds over 100 records for non-migratory galaxiids in the area that can be used to define initial distributions for the lower Clutha galaxiid and Pomahaka galaxias. In addition, DOC has recently conducted new surveys in the lower Clutha area and has commissioned genetic analysis of the galaxiids collected. Once analysis of this data is complete further information on the taxa present and distributions will be available. Rules appropriate for spawning protection can be provided for the Pomahaka and lower Clutha galaxias by using general spawning information for non-migratory galaxiids from low attitude areas of Otago. While this may not provide full protection for all sites for all of the spawning season, it will provide substantially more protection above that currently provided in the draft NES-PF.

To initiate further work on the lower Clutha galaxias, data on populations in the lower Clutha River catchment and adjacent areas in the Catlins and Tokomairio River catchment that are in plantation forests can be revisited (as some are now believed to be extinct, DOC unpublished data) and current distributions can be refined. This work can be coupled with a review of the genetic information and if additional genetics samples are gathered (if required) that can be done during the fish survey work. This would lead to updated distribution information for forestry areas and an improvement in the taxonomic understanding of the lower Clutha galaxias, from which further decisions on work required and protection needs can be made.

3.5 RECOMMENDATIONS FOR INDETERMINATE TAXA

3.5.1 Short-term Recommendations

The following short term recommendations are made:

- Spatial distribution data held in the DOC GIS for the indeterminate taxa is used to map the occurrence of these taxa.

3.5.2 Long-term Recommendations

The following long-term recommendations are made to address the most outstanding issues with indeterminate taxa:

- Spawning information for the indeterminate taxa is acquired to confirm the spawning timings proposed for the NES-PF.
- The forestry impact risk assessment process is conducted for indeterminate species in the Clutha River catchment using data gathered from populations of the indeterminate species in this catchment
- Fish surveys are conducted to determine the distributions of the Pomahaka galaxias and the lower Clutha galaxias;
- MPI support efforts to resolve the taxonomic status of populations of *Galaxias* in the Pomahaka and lower Clutha galaxias taxa; and
- Research is conducted into the reasons for the loss of the lower Clutha galaxias in forestry areas and into the spawning biology of the Pomahaka and lower Clutha galaxias.

Table 1: Indeterminate taxa not recorded separately in the NZFFD and the determinate taxa the NZFFD uses to record their presence.

Indeterminate Taxa	Determinate taxa and NZFFD code	NZFFD Records to select for indeterminate taxa	Included in the NES-PF
G. paucispondylus "Manuherikia".	*G. paucispondylus,* alpine galaxias (galpau).	*G. paucispondylus,* Manuherikia River.	Yes, as *G. paucispondylus,* alpine galaxias
G. paucispondylus "Southland".	*G. paucispondylus*, alpine galaxias (galpau).	*G. paucispondylus*, Oreti, Mataura, Lochy, Rivers.	Yes, as *G. paucispondylus,* alpine galaxias
G. prognathus 'Waitaki'.	*G. prognathus,* upland longjaw (galpro).	*G. prognathus,* Waitaki River.	Yes, as *G. prognathus upland longjaw galaxias*
G. cobitinis 'Waitaki'.	*G. cobitinis* lowland longjaw (galcob).	*G. cobitinis,* Waitaki River.	Yes, as *G. cobitinis lowland longjaw galaxias*
Galaxias divergens 'Marlborough, North Island'.	*G. divergens*, dwarf galaxias (galdiv).	*G. divergens,* Motueka River, Marlborough, and North Island.	Yes, as *G. divergens d*warf galaxias
Galaxias gollumoides 'Nevis'.	*G. gollumoides,* Gollum galaxias (galgol.	*G. gollumoides,* Nevis River.	Yes, as *G. gollumoides,* Gollum galaxias
Lower Clutha galaxias.	*Galaxias sp D*, Clutha Flathead galaxias (galspd).	*G. sp D* records NOT in the following: Benger Burn and upstream in the Clutha River, Pomahaka galaxias sites. NOTE this includes lower Clutha includes sites outside the Clutha catchment.	No
Pomahaka Galaxias.	*Galaxias sp D*, Clutha Flathead galaxias (galspd).	Selected sites of *G sp D* in the Pomahaka River catchment.	No
G. gracilis Dune lakes galaxias.	*G. gracilis* Dwarf inanga (galgra).	*G. gracilis*, Kai Iwi Lakes, Northland.	No
Gobiomorphus breviceps 'West Coast, North Island'.	*G. breviceps,* upland bully (gobbre).	*G. breviceps,* West Coast, Nelson, Marlborough North Island.	No

Table 2: The reporting of indeterminate taxa in the NZFFD and their inclusion in the REC-FPM.

Indeterminate taxa	Previous determinate taxa	Separately recorded in NZFFD	Modelled in REC-FPM	Likelihood of distinct spawning timing
Southern flathead	*G. depressiceps*[1]	Yes	No	Low

Northern flathead	*G. vulgaris*[1]	Yes	No	Low
Teviot flathead	*G. depressiceps*[1]	Yes	No	Low
Clutha flathead	*G. depressiceps*[1]	Yes	No	Low-moderate
Nevis galaxias	*G. gollumoides*[1]	No – *G. gollumoides*	Yes, as *G. gollumoides*	Moderate
Lower Clutha galaxias	*G. anomalus/G. depressiceps*[2]	Yes, as *G. anomalus*, and Clutha flathead	Majority not included	Low-moderate
Pomahaka flathead	*G. depressiceps*[2]	Yes, as Clutha flathead	No	Low
Lowland longjaw 'Waitaki'	*G. cobitinis*	No	Yes	Low
Alpine galaxias 'Southland'	*G. paucispondylus*	No	Yes	Low
Alpine galaxias 'Manuherikia'	*G. paucispondylus*	No	Yes	Low
Upland longjaw 'Waitaki'	*G. prognathus*	No	Yes	Low
Dwarf galaxias (Marl. NI)	*G. divergens*	No	Yes	Low
Dune lakes galaxiid	*G. gracilis*	No	No	Low
Upland bully (WC, Marl. NI)	*Gobiomorphus breviceps*	No	Yes	Low

[1]See Table 2, McDowall 2006.
[2]See Bowie et al (2014).

Table 3: Proposed forestry impact scores for indeterminate species.

Indeterminate taxa	Previous determinate taxa	Smith (2015) forestry effects ranking for determinate taxa	Proposed ranking for indeterminate taxa
Southern flathead	Taieri flathead	43	52
Northern flathead	Canterbury galaxias	43	52
Teviot flathead	Taieri flathead	43	52
Clutha flathead	Taieri flathead	43	52
Nevis galaxias	Gollum galaxias	39	39
Lower Clutha galaxias	Taieri flathead	43	52
Pomahaka flathead	Taieri flathead	43	52
Lowland longjaw 'Waitaki'	Lowland longjaw	52	52
Alpine galaxias 'Southland'	Alpine galaxias	52	52
Alpine galaxias 'Manuherikia'	Alpine galaxias	52	52
Upland longjaw 'Waitaki'	Upland longjaw galaxias	52	52
Dwarf galaxias (Marl. NI)	Dwarf galaxias	42	42
Dune lakes galaxiid	Dwarf inanga	16	16
Upland bully (WC, Marl. NI)	Upland bully	42	42

3.6 SUMMARY

Currently there are no limitations on spawning or distribution data that prevents the inclusion of the majority of indeterminate taxa in the NES-PF.

There is sufficient data available to allow distributions to be mapped in the NES-PF spatial layer. For some taxa this will be a simple process of splitting an existing determinate taxa into two or more taxa along well recognised geographic boundaries. For other taxa the distributions will need to be added to the spatial layer but this is considered a simple mapping task using the fish data available.

Spawning information required to set the NES-PF spawning rules for indeterminate taxa is available from the taxa themselves or closely related taxa and will be sufficient for use in the NES-PF.

The Pomahaka galaxias and lower Clutha galaxias are problematic as their distributions are not well understood and spawning information is limited. However, mapping can be conducted using existing data and spawning rules set using data from other galaxiids. It is recommended that fish surveys and research is conducted for these two taxa to refine the distributional data, to understand the risk forestry activities pose and to better understand spawning activities.

4 Spatial Layer Review

4.1 INTRODUCTION

To guide the plantation forestry industry on the presence of fish species in streams and the locations that where the NES-PF fish spawning rules will apply, MPI has developed a GIS layer with known and predicted fish distributions. This layer contains stream courses and indicates where fish species for which rules apply have been recorded or are expected to be present. Note it does not contain information on fish species for which the NES-PF rules do not apply. The layer uses fish records from the NZFFD to provide actual data on fish present. The map coordinates provided with the database records are used to place the database record on the stream network. The stream network is that used for the River Ecosystem Classification (REC) which is itself developed from a digital elevation data. For stream reaches more than 1 km from a NZFFD record the REC-FPM (Crow et al 2014) has been used to provide the probability that a fish species is present. The layer currently uses a 0.5 probability as the cut off between expected to be absent and expected to be present. This spatial layer then provides the locations of the 21 fish species across New Zealand that specific rules of the NES-PF apply to.

4.2 POTENTIAL ERRORS IN THE SPATIAL LAYER.

4.2.1 NZFFD coordinates

The NZFFD was established in the 1970s and has records extending back to the 1901. The database continues to collect records and as a result the map coordinates used and the methods to determine survey location have changed over time. The map coordinates were originally read from the NZMS 1 series empirical maps (inch to mile scale). With the conversation to metric units the coordinates where taken from NZMS 260 maps (2 cm to 1 km scale). Coordinates from both map series could be stored as three digit coordinates for eastings and northings. For the NZMS 260 series map this could lead to location inaccuracies of up to 50 m in each direction. This gives rise to a relatively small level of error in database records when coordinates where read from map sheets. An additional error has potentially been introduced when the empirical coordinates where converted to metric map coordinates. As the second generation topographic maps (NZMS 50) have come into use further map coordinate conversion errors may have been introduced to the database coordinates.

In the present day, site coordinates are likely to be gathered using GPS devices which have greater accuracy that the map sheet coordinates. However, there are still likely to be some coordinate conversion errors as different coordinate systems can be used on GPS devices.

For some sites such as braided rivers the topographic maps or digital elevation models do not show or define the river channels as they actually are. NZFFD submitters then have to choose between providing the actual fishing location even if this appears to be on dryland or placing the fish survey site at coordinates that are on a nearby water course.

Finally, the database records are for fish surveys along a reach of a water course and this reach is recorded as a point but is in fact an area with width and length. Therefore, the

coordinates represent the submitter's decision on where to take the site coordinates, at the upstream, downstream or at someplace along the reach. As some survey reaches extend well over 100 m, the site coordinates are an approximation for the location.
These potential errors can mean that NZFFD data records can be placed on the wrong stream when mapping the NZFFD sites on to the REC stream network in the GIS. However, the distances involved are small and are not expected to lead to major errors for site locations.

4.2.2 Data Age

The NZFFD records fish survey results for fish surveys dating back to 1901. This long time range for the records creates the issue of determining when a record represents the current location of fish species versus a historic record of the fish's presence. This entails some knowledge of fish passage, longevity, the presence and change in level of effect of any detrimental effects on the fish species, the speed with which these effects act, and the likelihood these effects will lead to local extinction in any given time frame.
For widespread species such as brown trout there may appear little likelihood of range contraction. However, changes in river flows due to abstraction and changes in water quality have led to changes in the distribution of brown trout and other fish species. For a number of threatened native fish species, range contraction is also very real. Therefore, a portion of the records in the NZFFD represent historic locations rather than present day locations for the fish species. An extreme example of this is the three NZFFD records for grayling that has been extinct since the 1930s.
The record age and whether it is historic or current first needs to consider fish longevity. For instance, eels may live to 100 years whereas inanga generally only survive for a year. As general guidance, the longevity of fish means that records for short lived species should be treated with more caution as the record becomes older. Older records may also be treated as historic is more recent records are available for the same sites. The most recent records can also be assessed for the presence of species known to eliminate vulnerable species, for instance when old records record a non-migratory galaxiid is present and the most recent records indicate brown trout are present, but no galaxiids, then it is highly likely the galaxiid has been eliminated as a result of the arrival of brown trout.
It is likely that if no filter on the age of the NZFFD records has been used in the construction the spatial layer associated with the NES-PF then it will include some historic data.

4.2.3 Identification Errors

Submitters to the NZFFD range from fisheries professionals to interested hobbyists, giving rise to a range of fish identification skills. Taxonomic changes amongst the native freshwater fish also means that old records have to be updated and people need to become familiar with the new species. There are also species pairs that are difficult to distinguish between. With respect to the NES-PF the species combinations of most concern are koaro and the various flathead species. The greatest difficulty is found when trying to distinguish between Canterbury galaxias and koaro and between northern flathead and koaro. NZFFD records for these species in these regions do have some errors. Given the different spawning timing of koaro and the flathead galaxiids this confusion can lead to the NES-PF rules being applied to the wrong species and/or stream reach. Another species pair that can be misidentified are the alpine galaxias dwarf galaxias pair, especially in Marlborough where the two species co-occur and a commonly used identification feature does not hold true (Allibone 2002).

4.2.4 Features Controlling Fish Distributions

A key feature controlling the distribution of many fish species in New Zealand is the presence of fish passage barriers. For migratory fish species, barriers to upstream movement represent the upstream limits of the fish species, regardless of the quality of habitat upstream of the barrier. Barriers can also limit the range of non-migratory fish and limit the distribution of introduced fish. Introduced fish, especially salmonids, have a major controlling influence on the distribution of galaxiid fishes. For many non-migratory galaxiids predation by salmonids, especially brown trout, brook char and rainbow trout, has led to local extinctions of the galaxiids. Townsend & Crowl (1991) showed in the Taieri River catchment that waterfalls that exclude brown trout from penetrating further upstream protect galaxiid populations. Even when suitable habitat exists downstream of the barrier if salmonids are present in the downstream reach then non-migratory galaxiids are generally absent. The most vulnerable species are dusky and Eldon's galaxias. Other vulnerable species outside of the Taieri catchment study include the various flathead species, Gollum galaxias and the three kokopu species, banded giant and shortjaw kokopu. Therefore, when mapping fish distributions from survey records and from predictive models the location of man-made and natural barriers is critical information.

With the spatial layer in the NES-PF the way NZFFD records are used to map fish present for up to 1 km upstream and downstream of the survey site limits the distance for any errors to a maximum of 2 km. For the predictive model the errors can be much greater as the model can predict fish occurrence over much longer reaches.

4.2.5 Fish Prediction Model Stream Locations

The REC-FPM model has been developed along the stream network in the REC2. The REC2 uses digital elevation information to develop a stream network. If the digital elevation model and stream network are inaccurate then stream course and fish locations in the spatial layer of the NES-PF will also be inaccurate. This is particularly an issue for low gradient streams, where the REC2 predictions of stream alignment become very inaccurate.

4.3 GIS LAYER COMPILATION

The compilation method first plotted the NZFFD records on the REC2 river network. For NZFFD records that did not fall directly on a water course those that were within 1000 m of a water course were mapped to the nearest water course. The fish reported at each NZFFD point were then mapped as present in the water course for 1 km upstream and downstream from the sample point. In water ways where the sample density is high this can lead to long continuous reaches with NZFFD records providing fisheries data for the spatial layer. However, this does require a sample point every two kilometres or less which is uncommon in most water ways.

For water ways with no fish sampling recorded in the NZFFD the spatial layer uses the fish prediction model of Crow et al (2014) to predict the fish species present. Crow et al (2014) use a range of environmental, hydrographic and geographic variables for the model. Given this is a modelling process some error can be expected and small differences in the modelled range and real range of fish species should be expected. Most importantly, Crow et al (2014) only use the locations of major fish passage barriers such as dams in the model. By far the majority of natural barriers (waterfalls) and small structures such as culverts are not included in the model. This has lead to the model predicting fish are present further upstream than they actually occur. In the case of salmonids, the model has, at times, predicted they are present in areas that are in fact occupied by threatened galaxiids. For the NES-PF spawning rules, this will lead to the use of incorrect spawning timing. However, if spawning and egg development times for salmonids are used as proposed in this report (see Section6.3.3), then greater restrictions on forestry activities may occur than if galaxiid spawning times were used.

For non-migratory fish species Crow et al (2014) also developed two models, one that had a geographic constraint on model predictions for non-migratory taxa and a second model with no geographic constraints. The unconstrained model predicts that many non-migratory fish are more widespread than they are at present. However, the NES-PF has used the constrained model that better reflects the current known distribution of the non-migratory galaxiids. This reflects the presence of suitable habitat in areas outside the current geographic range of the species and indicates potential sites to investigate for the presence of the fish species. However, the unconstrained model does not factor in biogeographic and migration limitations that mean the fish may not be able to access these additional areas of suitable habitat. The use of the unconstrained predictive model could be considered a conservative approach as it will include a greater number of water courses than the constrained model but may also lead to un-necessary restrictions on forestry activities.

4.4 TEST OF THE SPATIAL LAYER

To investigate the accuracy of the fish distributions in the spatial layer the following investigations were conducted:

- NZFFD records for sites where local extinctions have occurred were checked in the spatial layer;
- Areas of the spatial layer were checked for incorrect predictions of fish species present given the current knowledge of geographic ranges of fish species;
- The model predictions upstream of known barriers were compared to knowledge of the fish species upstream of the barrier (using the author's unpublished data);
- Fish survey datasets that have not been submitted to the NZFFD were used to compare the predicted fish present with the actual fish recorded; and
- Ad hoc checks of records submitted to the NZFFD by the author were conducted for NZFFD sites in the spatial layer to check these matched the site locations in the original fish survey.

Given the spatial layer covers all of New Zealand, these tests were conducted on a limited number of sites in the South Island and across water ways occupied by a range of the fish species for which the NES-PF has rules limiting forestry operations. The intent was to determine whether the above issues could be found and determine if they were likely to be common or rare in the spatial layer.

4.4.1 Local Extinction Sites

Populations of the roundhead galaxias in the Ewe Burn, Prices Creek and Spratts Creek in the Taieri River catchment are all believed to be extinct. However, NZFFD database records exist for these sites and these have been included in the spatial layer.
A series of sites for Eldon's galaxias in the Berwick Forest for which NZFFD records were submitted in 1996 are present in the spatial layer. The majority of these populations are all believed to be extinct since the mid-2000s (due to forest harvest effects).
Historic locations of dusky galaxias at Munros Dam Stream are recorded in the spatial layer. This population of dusky galaxias has been greatly reduced in range due to the expansion of brook char. If the population still exists, the continued expansion by brook char is expected to lead to its local extinction in the near future.
Goodman et al (2014) and previous DOC threat ranking publications show the majority of native fish in New Zealand are declining. Therefore, it can be expected that the extinction sites noted above are a sample of this decline and it is reasonable to expect that the NZFFD records for a range of species at a range of sites are now historic rather than current. The difficulty is to determine which records are still current. The extinctions observed can be related to climatic conditions (e.g., drought), the expansion of predatory introduced fish or activities relating to land use. There is no simple way to devise a rule to filter the NZFFD records. Expert opinion can be used for the rarer native fish that are subject to some monitoring by DOC and Regional Councils to filter out some records. Given the limited ranges of many of the native fish taxa this filtering task could be readily accomplished.

4.4.2 Incorrect Predictions

Sample regions in the Taieri River catchment and Rakaia River catchments were chosen to assess the prediction model.

The non-migratory galaxiids of the Taieri River are known to have near allopatric distributions and streams where more than one species occur are rare. In addition, these species rarely occur in the presence of brown trout and brown trout populations are generally only found downstream of the galaxiids. The exception to this is the roundhead galaxias that is very rarely found in streams free of brown trout or brook char.

Deep Creek, a lower Taieri River tributary, has the widely distributed population of Eldon's galaxias. The spatial layer using the fish prediction model places Taieri flatheads and dusky galaxias in this catchment, although neither have been recorded in this catchment. Taieri flatheads and dusky galaxias are also recorded in areas of the Lee Stream catchment where no records for these species exist. The predictive model has both dusky galaxias and Taieri flathead galaxias as widespread species in these catchments. It is most likely that these stream reaches are actually occupied by either by Eldon's galaxias or by brown trout or are fish free. Brown trout is also occasionally predicted to occur in the upper reaches of streams upstream of non-migratory galaxiids in areas it is known not to occur.

Approximately 200 fish survey records for the Rakaia River were used to assess the spatial layer in this catchment (Allibone et al 2012). Few fish survey records are available for any area in the upper Rakaia catchment (upstream of the Wilberforce confluence) in the NZFFD so the fish prediction model provides the majority of data for this area. The model indicates brown trout are widespread in the upper Rakaia, Mathias and Wilberforce catchments. However, fish surveys in these areas did not catch any salmonids and the upper reaches were populated predominately by alpine galaxias with localised populations of Canterbury galaxias, upland longjaw galaxias and upland bully (Allibone et al 2012). The model also predicts koaro are relatively common and this fish was rarely found in the upper Rakaia catchment. When present it was found in areas close to Lake Coleridge, the larval fish rearing habitat. In general, the lack of NZFFD records means there is little data to use in the spatial layer and also little information to train the fish prediction model and therefore the output is relatively poor.

Random checks of other sites in Southland and Marlborough also indicated these issues were present and it is expected that in areas with few NZFFD records the fish prediction model is limited.

4.4.3 NZFFD records at incorrect locations

An area of the Waipori River catchment was noted to have unexpected fish distributions. Allibone & McDowall (1997) and Allibone (1999) report fish distributions for part of this area and the findings of these reports do not match the spatial layer mapping. Eldon's galaxias was present in two streams, a small un-named tributary of Lake Mahinerangi and Post Office Creek, another larger tributary of Lake Mahinerangi. The spatial layer used a NZFFD records of Eldon's galaxias from Mill Creek, an adjacent stream, but a tributary of the lower Waipori River. The attribute table for this record gives the site locality as Post Office Creek (Figure 1) not Mill Creek. This may represent an example of the GIS process mapping a survey site to an incorrect stream reach if the record has been placed on Mill Creek as the nearest water course in a 1000 m radius. It is not possible to check this as the attribute table associated with the record in the spatial layer does not provide the NZFFD card number or other details (e.g. fish surveyor name) to allow the record to be checked.

In the same area brook char are shown to occur in three streams (Figure 1) and yet brook char have only been reported from one of these streams (Allibone & McDowall 1997). It is possible that the records of Allibone & McDowall (1997) are historic and brook char has been introduced to new streams, but this is considered unlikely given this is a closed forestry area and the streams are too small to provide any sports fishery of value. Therefore, the accuracy of these database records is of concern.

It is likely that in majority of cases the miss-matching of NZFFD records to water courses will be un-noticeable as the same fish species will occur in both water courses. The areas where errors will be apparent is at the geographic boundaries of the non-migratory fish distributions and in areas where small headwater streams occur in close proximity. Expert mapping of the non-migratory galaxiid distributions will aid in reducing this issue.

As expected other observations indicated that the 1 km zone upstream and downstream from NZFFD locations was, at times, too large and the range of fish along streams was greater than that actually occupied. This most frequently occurred when a NZFFD record was immediately upstream or downstream of a fish passage barrier and species were reported to occur upstream or downstream of the barrier when it was not actually present. Given the 1 km limit around NZFFD record sites the maximum distance the error can apply is limited to the 1 km distance.

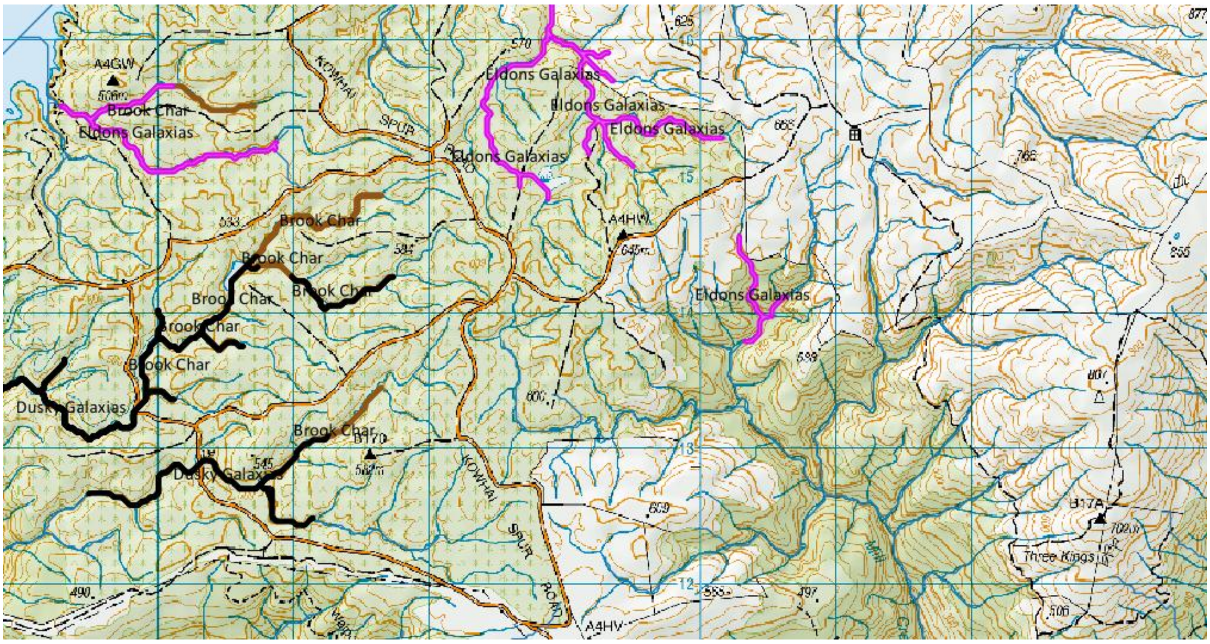

Figure 1: A forestry area in the Waipori River catchment with possibly incorrect fish locations.

4.4.4 Barrier Check

Some barriers appear to be recognised in the spatial layer and this coincides with good NZFFD records for the reaches around the barrier. However, some substantial barriers have not been detected and this results in some incorrect fish community predictions. For example, in the Taieri River a large rapid upstream of Canadian Flat excludes all fish aside from Taieri flathead galaxias from the upper reaches of the Taieri River and its tributaries. The REC-FPM has brown trout, brown trout and Taieri flatheads or Taieri flatheads present in reaches upstream of the rapid. All brown trout predictions are incorrect and in this case represent a substantial upstream increase in the range of brown trout. A similar issue was noted in the adjacent Waikouaiti River catchment, where brown trout are again predicted to occur well upstream of waterfall barriers and adjacent to reaches that NZFFD records indicate brown trout have not been caught.

Burgan Stream is a tributary of the Taieri River that descends from the Rock & Pillar Range over a high waterfall. Numerous fish surveys of the stream (University of Otago, DOC) have failed to locate fish in this stream. The fish prediction model has indicated Eldon’s galaxias is present in a section of this stream.

For the upper reaches of the Kye Burn, a major tributary of the Taieri River, the combination of NZFFD records and the predictive model have relatively accurately mapped the distributions of the brown trout, Taieri flathead galaxiids and roundhead galaxiids. This area has a relatively high density of NZFFD records, which appear to help define the location of barriers to fish movement.

As noted above, the test of the Rakaia River catchment predictions found brown trout were predicted to occur much more widely than they actually occur. River flow records and anecdotal reports of the flows in the Mathias, Rakaia and Wilberforce rivers indicate that heavily braided reaches of these river frequently go dry. In addition, the multiple braids present, many of which have shallows or cut-offs, can prevent upstream movement of large fish (e.g. large brown trout seeking spawning areas) and this appears to have been acting as a barrier to fish movement in the Rakaia.

It is not possible to map all barriers and this represents a difficult issue. Based on our examination of the Taieri and Rakaia River catchments, it appears the spatial layer is predominately including salmonids in areas that they are not present. It is also apparent other species occur outside the expected geographic range in areas were the FPM expects appropriate habitat to be present.

4.4.5 REC Stream Network Errors

The stream network and REC-FPM were investigated in the Mackenzie Basin area with special attention to the location of bignose galaxiid sites. General observations of the fish prediction model found that where the stream network was well controlled by the topography the accuracy of stream locations was very good. However, the accuracy of the REC across alluvial fans and very low gradient landforms was variable (Figure 2). At times, natural stream courses were not represented at all and at others multiple channels were mapped as a single channel. It was also noticeable that where land use activities have diverted water courses the REC (and topographic maps) did not reflect these changes (Figure 3). It is expected that the issues associated with low gradient, poorly defined water courses in the REC will occur nationally. However, for the majority of steeper gradient streams in New Zealand the REC will provide accurate stream locations.

It was also found when comparing the author's experience with areas in the Mackenzie Basin that the stream network included water courses that are ephemeral as fish habitat (Figure 4). This type of error will lead to the spawning rules being applied to areas where for the most part no fish or permanent water course exists. This effect is likely to occur in first and possibly second order streams as mapped on topographic maps sheets in arid areas of New Zealand. It is possible such areas have limited use for plantation forestry and the effect of this type of error may be limited. An important caveat for ephemeral streams are streams that are mudfish habitat. Mudfish are known to survive dry periods and some ephemeral habitats (streams and wetlands) are important habitat for these threatened fish. None of the mudfish species are currently included in the NES-PF spawning rules but there are mudfish populations known from streams in forestry areas. Therefore, the general exclusion of ephemeral streams from the spatial layer associated with the spawning rules can be considered appropriate, but only if the mudfish species are included in the species specific spawning rules and GIS layer.

Figure 2: Modelled streams along what appear to be dry stream courses, and some modelled streams cutting across the natural stream courses (bignose presence probabilities 0.4-0.6 light green line, 0.6-0.7 aquamarine line, 0.7-0.8 blue line).

Figure 3: A modelled stream course (with > 0.9 probability of bignose present) plotted across a flat irrigated paddock with no actual stream present.

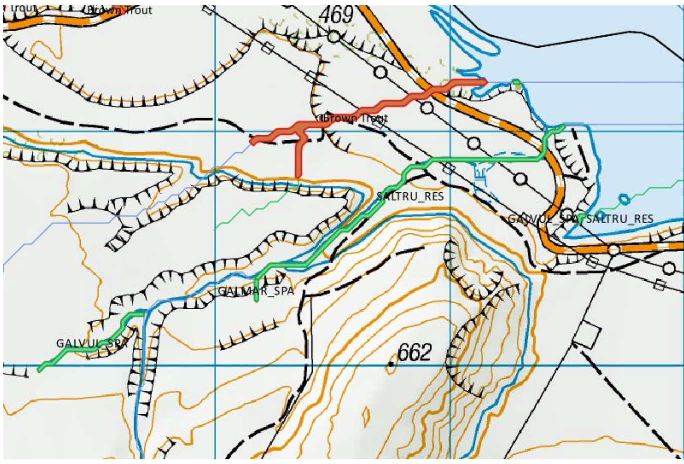

Figure 4: FPM outputs for a tributary of Lake Ruataniwha (left) and the dry stream bed (right), predicted to be brown trout, bignose galaxias and Canterbury galaxias habitat photographed in May 2014.

4.4.6 Species Specific Issues

Atlantic Salmon

Atlantic salmon are included in the 21 fish species in the NES-PF. However, the NZFFD records do not appear to have an Atlantic salmon category and neither is it included in the fish prediction model outputs in the spatial layer. This is a relatively minor issue as Atlantic salmon are restricted to the Waiau River Southland and few are thought to remain. The last captive stock was released into Lake Mistletoe about five years ago with little expectation they would even be seen again (Southland Fish & Game, pers. com.).

Chinook Salmon

The REC-FPM does not include predictions for Chinook salmon and as such the spatial layer only includes NZFFD records and the sections of river 1 km upstream and downstream of the records as Chinook salmon habitat. This has created a patch work of small river sections with and without Chinook salmon in areas where Chinook salmon are present (Figure 5). This is misleading with the majority of Chinook salmon habitat not included in the spatial layer. However, it is important to note that the majority of this habitat is the migration pathway for salmon to move from spawning areas to sea and back. Most importantly, as the spatial layer guides the implementation of spawning protection, the spawning areas of Chinook salmon need to be included and these areas are also only partially mapped.

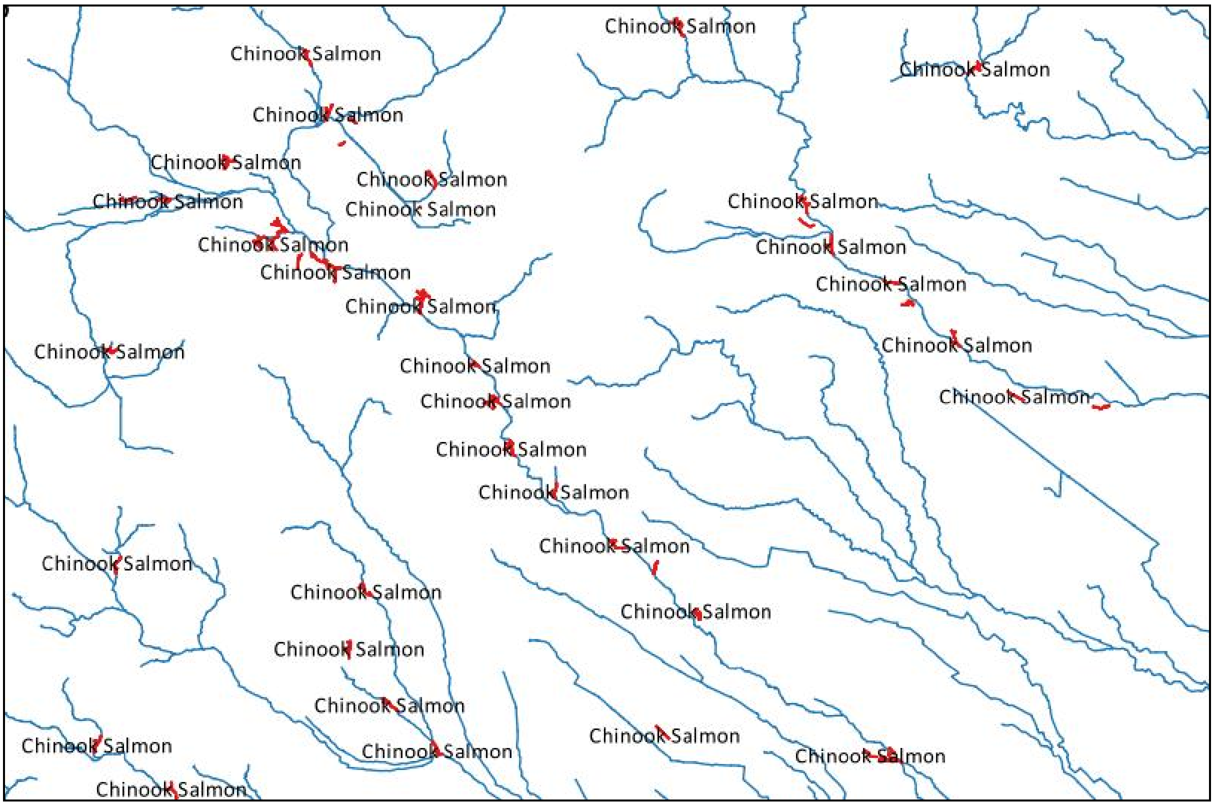

Figure 5: A patchwork of Chinook salmon areas from Canterbury rivers in the spatial layer.

To remedy this lack of data and poor mapping it is recommended that Fish & Game are asked to provide the locations of spawning habitat for Chinook salmon and that these locations are manually entered into the spatial layer. The migration pathways, if required, can then be mapped as these will be the river reaches downstream of the spawning areas.

Brown Trout

The spatial layer predicts brown trout are more widespread than expected, at least in part due to the limited information on barriers in the model. Currently the spatial layer uses a Kappa Cohen value cut-off of 0.5, with values over 0.5 indicating presence and values under 0.5 as absence. However, Crow et al (2014) indicate that the Kappa Cohen value for the cut-off should be 0.3. Lowering the cut-off value will increase the occurrence of brown trout in the spatial model, increasing the likelihood of incorrect presence prediction in areas upstream of barriers.

It should be noted that the spatial layer is mapping all brown trout habitat, observed and predicted. However, the NES-PF is developing rules for the protection of spawning areas and brown trout spawning habitat is a subset of this wide habitat area mapped in the spatial layer.

4.4.7 Historic verses current data

As noted above the NZFFD contains both current and historic data and consideration should be given to whether the use of older database records is appropriate. However, to simply discard all records of a selected age and older will both discard useful dataand retain some data that is not current. This is because fish distribution changes for a variety of reasons and individual fish species are affected by events in different ways. For instance, the creation of a fish passage barrier will prevent migratory fish species migrating upstream and the populations upstream of the barrier will be lost over time. For bully species with a life span of five years this loss will be rapid but long-lived species such as kokopu will still be present 15 to 20 years after the fish passage barrier was created. In addition, non-migratory species upstream of the barrier will not decline and may in fact increase as the migratory species decline. Conversely, if a drought or flood eliminates fish in a stream, migratory fish can rapidly recolonise via the recruitment of juveniles from the ocean. However, non-migratory fish may not be able to recolonise at all if no other local populations are present in adjacent streams. These effects can lead to individual NZFFD records containing both current and historic data.

For the spatial layer in the NES-PF maintaining an up-to-date layer presents some issues. Records older than a certain date can simply be deleted from the data used and the deletion process repeated at set time intervals to update the spatial layer. However, this may increase the reliance of the spatial layer on the REC-FPM if data is eliminated from areas infrequently surveyed. However, to manually assess whether the NZFFD data is current requires a good knowledge of the fish populations to review records. Such a review would require a panel of experts with a good combined knowledge of fish distributions for all of New Zealand. It is unlikely that such knowledge exists for all of the country, rather such expert knowledge will be patchy. A possible solution is to use expert opinion for intensively monitored species such as the threatened non-migratory galaxiids of Otago and to use a database cut-off for widespread species such as salmonids and redfin bully. This will rely on DOC or other parties continuing to monitor the localised rare species and general fisheries surveys to continue to be conducted across New Zealand to maintain up-to-date records. An appropriate cut-off date for NZFFD records should reflect the longevity of the species of interest and some judgement reflecting the rate of change. For the initial phase to set up the spatial layer, the removal of data older than 30 years can be trialled.

4.5 PROCESS TO UPDATE SPATIAL LAYER

The updating of the spatial layer can be timed to match the DOC threatened fish ranking process that is now expected to occur once every five years. The DOC process reviews taxonomic status and the distribution of fish in New Zealand and will provide a very useful review of data for the spatial layer. Coordinating the DOC threat-ranking process with the MPI spatial layer review will also provide a joint government department data set and ensure different branches of government are in sync.

It will be important to note that, for native fish, adult fish habitat is the spawning habitat for all species aside from eels, lamprey and inanga. For salmonids, the spawning areas are a subset of the total range of the species and ideally the spatial layer data should reflect spawning areas not the wider adult habitat.

The update process should take the following steps:

1. Call for submission from interested parties to provide data on fish distributions that do not match the current spatial layer and recommend fish species for inclusion in the spatial layer;
2. Remove data from the NZFFD records that is considered historic;
3. Update the NZFFD and spatial layer with any taxonomic changes;
4. Update distributions of species with localised geographic ranges using expert opinion (a process most likely completed or partially completed by DOC in the threat-ranking process), using information provided in submissions and NZFFD;
5. Use existing spawning area data and any additional data for salmon species;
6. Check brown and rainbow trout spawning area data;
7. Add REC-FPM, including fish distribution model and any salmonid spawning habitat models and overlay to the spatial layer to fill data gaps;
8. Produce new spatial layer and gazette new layer.

Additional tasks can be added to this update. A review of the species included in the spatial layer can be conducted prior to the update process and included in the submissions process. This review can revise the inclusions and exclusions of fish from the spawning rules using changes to the DOC threat status and any data demonstrating plantation forestry activities have greater or lesser impact than currently expected.

Updates to the REC and the REC-FPM can also be included as part of Step 5 allowing improvements to the REC and fish prediction model to be incorporated into the spatial layer. This will include any updates to the barrier information available for the model.

4.6 RECOMMENDATIONS FOR THE SPATIAL LAYER

4.6.1 Short-term recommendations

Currently the spatial layer has errors associated with both the NZFFD records and the REC-FPM. To address these issues the following is recommended:

- DOC spatial data for non-migratory galaxiids is used as the primary data for the layer. For any taxa with no spatial mapping data available the distributions can be mapped using the DOC process (for consistency) and incorporated into the NES-PF spatial layer;
- Undertake a gap analysis to find areas of limited or no fisheries data. These areas can be assessed against current and likely plantation forestry activity to determine if the gaps are present in areas where plantation forestry may occur;
- For Chinook and sockeye salmon Environment Canterbury has a spatial layer called salmon spawning areas (https://data.canterburymaps.govt.nz/layer/7620-salmon-

spawning-sites/) that provides the locations of salmon spawning in Canterbury. This will cover major salmon spawning areas foe Chinook salmon and all sockeye salmon spawning. Additional information can be sought from Fish & Game Councils for areas such as the Clutha River catchment and West Coast areas.
- Fish & Game Southland are requested to designate Atlantic salmon spawning areas for the spatial layer.
- A spawning area prediction model should be developed and used to replace the general brown trout distribution used in the GIS spatial layer. This layer also tests whether spawning habitat is limited to streams from first to fourth order.

4.6.2 Long term recommendations

- It is recommended that MPI and Fish & Game develop a method to map spawning areas of brown trout, rainbow trout and brook char. Known spawning areas should be directly mapped into the spatial layer and supplemented by the spawning habitat models if these can be developed by NIWA.
- MPI develops a spatial layer revision programme to update the spatial layer. This process can be timed to complement the DOC threatened fish ranking process that occurs every five years. Both processes require data on the distribution of fish and changes to their occurrence so the same data can be used. The update process can also include:
    - Fish passage barrier information from DOC, Fish & Game, and other parties that have fisheries data associated with barriers. This information can be used in the spatial layer to remove REC-FRM predictions that indicate fish species are present upstream of barriers that actually exclude them. Data collection for fish passage barriers is being developed by the New Zealand Fish Passage Advisory Group and this can be added to MPI's existing barriers information.
    - MPI develops a process for the submission of corrections to the spatial layer so that incorrect fish data and inaccurately mapped water course (e.g., ephemeral water courses mapped as permanent fish habitat) are corrected and updated. Of critical importance is the occurrence of these errors in areas of current and likely plantation forest and these could be targeted for the revision.
    - The update process removes historic NZFFD records and includes the most recent database records submitted to the NZFFD since the last spatial layer update.
- MPI should support a research objective to determine if the NZFFD records older than 30 years can be deleted from use in the spatial layer. This should include an assessment of the data lost and whether this is useful data, redundant due to more recent surveys or data that is now incorrect. The spatial layer should also be assessed to determine regions where records will become sparse or absent and provide a list of areas for surveys to fill the data gaps in plantation forestry regions.

5 Spawning Timing for Freshwater Fish

5.1 INTRODUCTION

Knowledge on the biology, particularly the spawning, of freshwater fish is varied and ranges from very well known (e.g., brown and rainbow trout) to very poorly known (e.g., giant bully). For the 21 fish species included in the NES-PF the spawning biology, location and behaviours of the introduced salmonids is well known. However, for the native fish the spawning biology is less well understood and there are few studies available to provide guidance. Therefore, it is very important to note the data used to provide information on native spawning is sparse and further investigations may provide different information to that presented here.

The NZFFD does provide extra information when the comments section notes the spawning status of captured fish. The most important information are the reports of ripe female fish as this indicates spawning is imminent, whereas ripe males can be present for some months and they are a less precise indictor of spawning timing. In addition, a key factor for all fish is the egg development time and this is controlled by water (or air) temperature. For eggs laid in cold water development times can be considerably longer than in warmer water. Therefore, the duration of spawning and egg development is very much temperature dependent and fixed periods of protection may be insufficient or well exceed the required egg development time in different streams.

5.2 SPAWNING CALENDARS.

To aid the understanding of fish spawning periods spawning calendars have been developed (e.g., Smith 2015, Hamer 2007). For the NES-PF the spawning protection rules can include regional variation in spawning if appropriate.

The NES-PF currently includes 21 fish species of which five, giant kokopu, koaro, redfin bully, brown trout and rainbow trout are widespread, and may require regional spawning periods to be recognised. The other sixteen species have more restricted distributions and regional spawning calendars are not considered necessary. However, for all of the species an additional consideration is the effect of altitude on spawning timing. Therefore, spawning protection times for the various fish are discussed further below for each species and summarised in Table 3.

5.3 SPAWNING INFORMATION

5.3.1 Galaxiid spawning biology

Galaxiids have some varied spawning habits and several distinct features are present, including the fact that a number of species spawn amongst the riparian vegetation rather than in the water. They access the vegetation during floods or at high tide when the areas are inundated. For these species, while spawning timing can be determined, it will be influenced by rainfall and flood flows. Spawning has the potential to be delayed in years when no significant rain falls during the expected spawning period. Eggs laid in these riparian areas then develop and hatch when they are resubmerged. There are some hatching triggers (McDowall & Charteris 2006) that influence hatching so that larval fish hatch during a flood or at high tide, not just when it rains. In the absence of floods, the eggs can remain amongst the riparian vegetation, waiting to hatch for up to 60 days. However, larval fish development in the egg is generally complete in about 15-30 days depending on air temperature. For the whitebait species once they hatch, they are rapidly flushed out to sea, in hours or a day or two depending on how far upstream they hatched. The rate of movement downstream is increased by hatching occurring during floods or retreating tides that speed the downstream transport of the larval fish. For these species spawning protection involves keeping the riparian zone well vegetated so the eggs can remain damp. If vegetation and shade is removed eggs can desiccate in just a few hours.

Other galaxiids spawn in the stream, under rocks and amongst vegetation root mats. These eggs remain submerged throughout the development period. Some species of non-migratory galaxiid appear to have flexible spawning strategies with nests found both in the riparian vegetation and amongst rocks in the stream bed. For stream bed spawners, clean rock substrates are important and low levels of suspended sediment are required to prevent smothering of the eggs. A further specialisation of the aquatic spawning galaxiids is the use of springs as spawning areas. A small number of galaxiids have been found to use spring heads and upwelling areas in braided river beds as spawning areas. These areas appear to provide clean water with no suspended sediment allowing the eggs to avoid smothering by sediment.

In general, spawning is well synchronised with most individuals in a population spawning within a month of one another. Ripe male fish can be found over longer time periods than ripe females, meaning the presence of ripe and spent females provide the best guidance on spawning timing. The egg development period is expected to take approximately 30 days. All galaxiids hatch as small larval fish that vary in length with species from about 6 mm to 10 mm at hatching. All of the galaxiids aside from inanga spawn in adult fish habitat. Therefore, site records for a galaxiid also represents a site record for spawning. However, spawning habitat will be more specialised than the general habitat used by adult fish and sites associated with riparian vegetation more vulnerable to disturbance than the general fish habitat as recovery after disturbance requires the recovery of the riparian vegetation, which can take years.

Koaro

There are eight publications and one unpublished observation describing koaro spawning and/or larval fish migrations to sea (Appendix C). The locations of these spawning observations range from the Central North Island lakes to Stewart Island and range in altitude from near sea level to 1000 m. The observations also come from landlocked and diadromous populations and provide good information regarding contrasting spawning times for landlocked and diadromous populations. In addition, the comments section of the NZFFD provides eleven additional observations. These observations are again split across landlocked and diadromous populations (Appendix C).

The observations for diadromous populations indicate that spawning at high altitude (Otira River at Arthurs Pass) begins in February with larval fish observed drifting downstream in March (McDowall & Suren 1995). A spawning site located in March on Stewart Island and spawning in late April and May on Mt Taranaki (Katikara Stream) indicate spawning occurs over several months for the diadromous populations. The only site with more than one observation is Katikara Stream on Mt Taranaki where spawning commenced in late April and May each year observed. Allibone & Caskey (2000) also note spent koaro were common at a second site on Mt Taranaki, the Waiwhakaiho River, in early May 1999. This would indicate relatively consistent spawning on Mt Taranaki.

For the landlocked populations, observations of ripe and spent fish indicate spawning is occurring in late spring and summer. The timing appears to vary between lakes, with the Lake Taupo population possibly spawning the latest, in January, and other lake populations earlier in the summer. Observations in the hydro-electric lakes in the Waitaki River and Lake Matiri in the Buller system indicate a December spawning time. Observations of ripe fish in the natural lakes, Chalice and Christabel, in mid-winter indicate these lake populations are spawning well after diadromous populations that spawn February to May but the time of spawning is unknown. Further evidence of different spawning timing for landlocked populations comes from the historic whitebait fishery in tributaries of Lake Wanaka that was reportedly undertaken in March and April (McDowall 1990) rather than September and October for the sea run whitebait

Setting a spawning period for any river or area of New Zealand will require more information than just the presence of koaro. The migratory behaviour will need to be confirmed and some consideration of the effects of latitude and altitude on water temperature, the probable spawning cue for spawning, would be ideal. However, even if spawning is cued by water temperature the cue for diadromous populations will be a falling water temperature as autumn progresses, whereas December spawning for landlocked populations will be occurring as water temperatures rise. Therefore, the limited information on timing represents an information gap and spawning timing for different areas may be approximated but this may require a period longer than the two months in the draft NES-PF to ensure the spawning period is contained within the months specified.

To progress the NES-PF and rules for koaro the following work is recommended. An additional attribute is added to the koaro information in the spatial layer, indicating whether a stream contains a diadromous or landlocked koaro population. For many areas of New Zealand this will simply require populations of koaro upstream of lakes to be classified as landlocked (e.g. Lake Taupo, Lake Wakatipu) and koaro in catchments with no lakes as diadromous. The landlocked category is expected to include hydro-electric storage dams such as Lake Mahinerangi and Lake Dunstan. The classification of streams would benefit from a workshop with experts on koaro biology and MPI staff (including GIS staff) to develop an agreed classification of koaro populations. Some issues may be present regarding natural lakes that are close to the coast that may include diadromous and landlocked stocks. However, it is also possible the majority of these are in conservation estate and of limited concern to the NES-PF. For spawning timing, the current limitations on data limit the development of regional spawning calendars and it is recommended that a South Island/North Island split is introduced for diadromous populations with spawning for the South Island running from March to May and the North Island April to June. Landlocked populations are more problematic, but an initial spawning protection period of November to January is recommended. It is also recommended that this spawning period split is included in the workshop agenda with koaro experts.

Giant kokopu

Franklin et al (2015) reports the first observed spawning sites for giant kokopu from a stream in Hamilton. Spawning was found to occur on a number of occasions in May and early June, all on days with high flows to allow spawning amongst the riparian vegetation. Franklin et al (2015) also determined egg development took approximately 25 days at mean ambient air temperature. McDowall & Kelly (1999) aged giant kokopu whitebait using daily growth rings in the otoliths. From these ages and an estimated egg development period of 28 days they estimated giant kokopu caught on the West Coast, South Island were spawned in a period from early June to early August. McDowall & Kelly (1999) also note some observations of ripe and spent fish in June and August respectively for sites in the lower South Island. Bruno David (Environment Waikato fisheries biologist, pers. comm.) noted that spawning appeared to be relatively late for giant kokopu populations in tributaries of Lake Waihola, South Otago, with spawning possibly occurring in August and September. This may be attributed to this population being predominately lake rearing and the spawning timing is linked to lake productivity.

For the NES-PF, spawning protection needs to consider both the timing of spawning and the spawning habitat. Riparian protection is important to retain appropriate vegetation and bank conditions to support spawning. Franklin et al (2015) note that giant kokopu spawn on gentle bank slopes of 15˚ or less and among dense low stature vegetation that will retain a damp environment for eggs. This vegetation is expected to protect the eggs from both desiccation and from frosts. Therefore, riparian setbacks to prevent damage to riparian vegetation for giant kokopu streams would be appropriate. Spawning timing is variable and a three-month period is considered appropriate to cover this variation, with a June to August period in place for the South Island and a mid-April to mid-July period for the North Island.

One caveat with this assessment is that spawning timing may have greater variation than assessed here as giant kokopu frequently form partially or completely landlocked populations. As noted above koaro have quite distinct spawning periods for landlocked and diadromous populations and the observations for the populations associated with Lake Waihola indicate a later spawning than might be expected for diadromous populations. Therefore, it is recommended that the NES-PF have a long-term research goal to determine if landlocked populations have distinct spawning period when compared to diadromous populations. To date information on spawning timing for such populations is extremely limited. However, some landlocked populations are known from lakes such as Lake Brunner, and Lake Kaniere on the South Island's West Coast, and from man-made ponds such as populations in gold mining dredge ponds in the Waikawa River catchment, Southland. For the initial NES -PF the NES can list the known landlocked populations and apply the above recommended spawning protection period to landlocked populations and then support the long-term research goal to confirm the spawning timing at a number of landlocked sites. For the short-term goal, fisheries researchers around New Zealand can be approached to provide any information on the location of landlocked populations that they are aware of. When further information for the long-term research goal is available the NES-PF can then be updated with appropriate spawning protection periods if required.

Roundhead galaxias

Allibone & Townsend (1997) report spawning observations for roundhead galaxias from two streams over three years, 1992 to 1994. In each year spawning commenced in August and continued through to mid-September. Egg development was estimated to take approximately 30 days and hatching occurred from mid-September through to mid-October. Currently, the NES-PF has a protection period of September October. This will protect the majority of the spawning and egg development season. However, an extension to protect spawning in August is recommended as the fish eggs are vulnerable to sedimentation effects to a greater extent than larval fish.

Gollum galaxias

Little published information exists on the spawning timing of Gollum galaxias. Ripe females were observed in July in a central Southland stream (Allibone pers. obs.). Spawning was expected to occur in late July or August as the female fish were running ripe, which indicated spawning would occur in the near future. This is similar to the timing observed by Dunn (2011) who found spawning occurring from August to October.
Given Gollum galaxias is restricted to Southland and Stewart Island and to relatively low altitudes (excluding fish from the Nevis River catchment) it can be expected that water temperature effects are similar across the fish's range and that spawning timing is also similar. Therefore, without any further information, a spawning timing of August is expected, with larval fish hatching in September.
It is recommended that spawning period in the NES-PF is adjusted from September October to August to October.

Nevis galaxias

The Nevis River galaxiid is currently included in the NES-PF as Gollum galaxias. There are few observations of spawning for this fish and to date these have found that spawning occurs in mid-October (DOC unpublished data). This is substantially different to the lowland Gollum galaxias populations and if Nevis galaxiid is retained in the NES-PF as part of the Gollum galaxias taxa then a separate spawning period of October November is recommended for galaxiids in the Nevis catchment.
However, the Nevis River is a high altitude valley over the 600 m altitude limit that forestry activity is conducted in Otago. The valley is also known for its very cold winters and the valley has only dry weather road access that further limits any forestry potential. Therefore, while the recommendation from spawning protection for October and November is made in this case it is not expected to be required.

Taieri Flathead Galaxias

Taieri flathead occurs in the Taieri River catchment and coastal catchments to the east, including the Waikouaiti River and Akatore Creek. The altitudinal range of these populations is approximately 1200 m as populations occur from near sea level in Akatore Creek to over 1200 m in streams on the Rock & Pillar Range. This exposes these galaxiids to a wide range of environmental conditions, including significantly different water temperature and flow regimes.

Allibone & Townsend (1997) report spawning commencing in August in a population at approximately 200 m elevation and in mid- to late-October at sites between 600 to 850 m. Larval fish were observed approximately a month later in both streams. Further investigations by DOC staff (DOC unpublished data) found the high altitude populations on the Rock & Pillar Range commenced spawning in November and larval fish hatched in December. It is also possible the Akatore Creek population, the lowest attitude population known, spawns earlier than others due to its very low altitude (30 – 100 m) and coastal location.

The common factor for Taieri flathead spawning observations is that spawning and egg development at any one site took place over approximately two months. Therefore, for any site, a two-month period for spawning protection is expected to provide protection for spawning and egg development. However, the full time range for spawning and egg development is at least five months (August to December).

Currently, MPI consider plantation forestry in Otago is possible up to an altitude of 600 m. Excluding spawning activities for populations over the 600 m altitude limit, it is recommended that the spawning period is increased from September October to August to October. This will protect all spawning activity in the low altitude areas up to 400 m and provide at least partial protection for spawning at high altitudes. This is considered reasonable as the higher altitude populations are often present on DOC estate or in areas where no forestry activity is undertaken (e.g., Rock & Pillar Range and Rough Ridge)

Canterbury galaxias

Spawning studies of Canterbury galaxias have been conducted at a number of sites in Canterbury and North Otago. Cadwallader (1976) reported spawning occurred in August and early September in the Glentui River. Benzie (1968) and Dunn (2003) found that spawning occurred from October to early December (and on occasion possibly January) further inland in the Cass River. Allibone (unpublished data) found spawning in September and October in the Maerewhenua River in North Otago. Both Benzie (1968) and Cadwallader (1976) found water temperature was the key factor cueing spawning as warmer sites had earlier spawning activity. Benzie (1968) also noted the source of flow and degree of shading were important as these factors influenced water temperature in her study streams. In general, these data indicate that spawning occurs over two to three months at any one location but altitude, latitude and source of flow all affect spawning timing by influencing water temperature.

The NES-PF has set a spawning protection period of September October for Canterbury galaxias. This will provide some protection in the egg development period for warm water areas such as lowland rivers, but not the spawning period. The time period will provide reasonable protection for spawning in some areas, although this is not well defined with respect to where in the geographic range of Canterbury galaxias this is. The NES-PF will provide very little protection of the cool water areas Canterbury galaxias occupies as the majority of the spawning and egg development occurs later than October.

It is recommended an analysis is conducted of the overlap between likely areas for plantation forestry and the range of Canterbury galaxias. Areas of Conservation Estate should be included in this analysis so that the range of populations of Canterbury galaxias within areas suitable for plantation forestry can be determined. Then two or three-month spawning protection periods should be set for spawning areas, extending from August to an appropriate month, depending on the above analysis and the expected spawning period of Canterbury galaxias.

Eldon's galaxias, Dusky galaxias

The majority of spawning observations for Eldon's galaxias have been made in Whare Creek, near Dunedin, at sites around 340-360 m altitude. In this stream the fish has been found to commence spawning in October (Allibone & Townsend 1997, DOC unpublished data) with larval fish emerging in November. In other streams at higher altitude and further inland spawning has been observed in October and into mid-November (Allibone & Townsend 1997 DOC unpublished data). Nests of eggs can be found in the stream amongst rocks in riffle habitat and amongst the riparian vegetation. Despite populations being found over an altitudinal range of approximately 800 m, spawning timing has a relatively small range of two months.

Dusky galaxias has been reported to spawn in October and egg hatching occurs in November (Allibone & McDowall 1997). DOC monitoring has also found spawning to occur in October. The spawning habitat is often in riffles at the stream edge, with eggs laid under overhanging root mats or in shallow water with dense overhanging vegetation.

Spawning site protection for Eldon's and dusky galaxias is considered more important than for some other galaxiids. These two species have relatively low fecundity and limited ability to recover from population declines. Monitoring studies undertaken by DOC and research on their spawning biology (Jones 2015) show both the adult and larval fish do not disperse any great distances during their life. Tagged fish tracked over periods of five years or more have remained in the same section of stream for the whole period. It has also been observed that areas of streams occupied by these species can often have few if any resident fish, and population recovery after removal sampling is slow, indicating the ability to recolonise areas is limited. Relatively low egg production means the ability of populations to recover via juvenile fish recruitment is also slow. These fish are also capable of residing in very small streams, small first-order streams in the order of 20-30 cm wide. Habitat, including riparian spawning areas, in these very small streams can be easily damaged during forest harvesting operations. In the past, forest harvesting is believed to have led to the loss of a number of dusky and Eldon's galaxias populations, and forestry may be a major contributor to the increase in threat ranking for these species.

Therefore, it is recommended that the NES-PF spawning period is changed from September October to October November. It is also recommended that disturbance of the riparian zone of streams inhabited by these species is prohibited, with a no-go zone of 5 m on slopes less than 30˚ and 10 m on steeper slopes. This will reduce the potential for suspended sediment inputs and damage to important riparian zone vegetation that is used for spawning.

Upland longjaw galaxias

There is limited knowledge of spawning biology for upland longjaw galaxias. However, a key factor for spawning is the strong association with springs. Eggs of lowland longjaw galaxias have been discovered amongst the substrate in springs up to 30 cm under the surface of the stream or in the underground water of the spring. Bonnett (1992) investigated the spawning biology and timing for upland longjaw galaxias and considered spawning took place in spring, October to November, and also possibly in autumn between March and May. Subsequent anecdotal observations as part of general fish surveys have not found more evidence of the March to May spawning (e.g., Allibone et al 2012).

It is recommended the NES-PF spawning period for upland longjaw galaxias is adjusted from September October to October November. Currently, with no further information to support the March to May spawning period this is not included in the spawning protection provisions. It is also recommended that any springs in areas occupied by upland longjaw galaxias are protected with a 10 m exclusion zone to protect the key habitat from damage.

Lowland longjaw galaxias

DOC (unpublished info.) observations of the spawning of lowland longjaw in the Kauru River, North Otago found eggs in June and July. However, the presence of larval fish in June would indicate spawning commences in May and continues through to August. In addition, there is evidence of occasional spawning at other times of year. DOC also found lowland longjaw spawning occurred in one site in the upper Waitaki in August. Observations at other sites in the upper Waitaki indicate varied spawning timing appears to commence in August and extend to December.

It is recommended that the spawning period in the NES-PF for lowland longjaw galaxias in the Kauru and Kakanui rivers is set for May to September. This long period allows for the full spawning period observed and for an additional 30 days for eggs to develop and larval fish to hatch. For population of lowland longjaw galaxias in the Waitaki River catchment the August to December period is the recommend protection period. Given the uncertainty around the spawning timing for the lowland longjaw in the Waitaki River catchment, further work is recommended to determine spawning timing. It is also recommended that any springs in areas occupied by lowland longjaw galaxias are protected with a 10 m exclusion zone to protect the key habitat from damage.

Bignose galaxias

DOC staff (DOC unpublished data) have located bignose spawning nests on two occasions in August indicating a spawning period possibly commencing in July and extending through August. One of these spawning sites was found at a spring head where lowland longjaw galaxias were also spawning. Little else is known about spawning for bignose galaxias.

It is recommended that the spawning period for bignose galaxias in the NES-PF is changed from September October to July to September.

Alpine galaxias

Bonnett (1992) from a study in the upper Rangitata River found that alpine galaxias spawned between August and October, with August and September being the main spawning months. Dunn & O'Brien (2007) undertook spawning surveys in the upper Waimakariri River catchment in mid-October and found a small number of alpine galaxias eggs. This would indicate a mid- to late-September spawning event. This matches with earlier spawning work by Dunn (2003) where a spawning period between September and November was reported. The habitat alpine galaxias use for spawning is unknown.

It is recommended that the spawning protection period for alpine galaxias is extended from September October to August to October in the NES-PF. This caters for the majority of the observed spawning periods and, in the absence of further data, the inability to determine a core spawning period. It is also noted that the high altitude inland sites with spawning occurring in November will generally be in DOC estate at altitudes above those well-suited for plantation forestry.

It is important to note that no studies have been conducted on the Southland alpine galaxias. Therefore, it is recommended that MPI consider undertaking investigation into spawning timing for these areas to determine if the proposed spawning timings above are appropriate.

Dwarf galaxias

Hopkins (1971) reports an extended spawning period for dwarf galaxias, with larval fish present from late September to early March in a Wairarapa stream. This would indicate spawning from August to February. Hopkins (1971) attributed this extended spawning to early spawning by three-year-old females and a later spawning peak of two-year-old females. However, in a second year of the study this lengthy period of larval emergence was not apparent and spawning was likely to have been more synchronous in spring. This would match the observations of Graynoth (1979) who noted spawning occurred in spring in tributaries of the Motueka River, with larval fish found in October.

A further consideration for dwarf galaxias is that the geographic range of the species is large, from near Hokitika to the Waihou River in the Waikato. This very extended geographic range could affect spawning timing if it is cued by water temperature. However, it is not easily predictable as stream size, source of flow, and degree of shading will complicate any assessment. For instance, the Waihou River population is centred near the spring source of the Waihou River that is a constant 11˚C (DOC unpublished data) and generally cooler than rain fed streams. Other sites are well shaded or are in completely unshaded braided streams. Therefore, a simple latitudinal change in water temperature and spawning period is not expected.

With the current data the spawning timing in the NES-PF of September October appears appropriate for protecting a core spawning period but is not expected to provide protection for all populations for the full spawning season.

5.3.2 Redfin bully spawning

Redfin bully are considered a relatively widespread species in New Zealand and can be found in rivers on both main islands Stewart and Chatham Islands and smaller islands. However, Allibone et al (2010) noted that this species appears to be undergoing a widespread decline with the frequency with which it has been reported in NZFFD records in the decade 2000-2009 being 50% of that in all previous decades. This declining trend was also apparent in the riffle dwellers koaro, torrentfish and bluegill bully. The underlying causes for the decline are unknown but the decline is considered serious due to the relative large decline and that more than one species is showing the same trend.

McDowall (1965) provides a very good description of the spawning of redfin bully. He found spawning commenced in late July and continued through to the end of November with eggs still present in the stream until late December. Importantly he found individual female bullies prepared two batches of eggs for spawning each year and both batches were spawned over the spawning period. This means that, to protect redfin bully spawning, the protection period needs to include the first spawning and egg development period, the time taken for females to mature the second batch of eggs and then the second spawning and egg development period. McDowall (1965) reported that larval redfin bullies hatched between 14 and 30 days after spawning and also showed the time for maturing the second batch of eggs for spawning exceeds a month. For full spawning protection the period needs to include the first spawning event followed by the period for the second batch of eggs to mature, the second spawning event and subsequent 14 to 30 day egg development period. This is expected to be a period of three months or more and it can be expected to be extended as individual fish will commence their spawning season at different times.

If spawning protection is restricted to two months (as in the draft NES-PF), then it is highly likely either the first or second batch of eggs spawned by many females will occur outside the spawning protection period.

The NES-PF currently has a spawning protection period for redfin bully of September and October. This period excludes all early spawning in July and August and also late spawning and egg development in November and December. The proposed September and October spawning protection period is therefore considered inadequate. Early spawning activities are not catered for and these nests could be lost in July and August prior to protection conditions becoming active. Nests spawned during October and November will also have reduced protection while developing in the stream during November and December. Only eggs laid in September and early October are likely to be spawned and hatch in the protection period. It is also possible that if the bulk of redfins conduct their first spawning in late July and August they will spend the majority or all of the spawning protection period maturing the second batch of eggs to spawn in late October and November. Therefore, for these fish the spawning protection period will fall in the period between their two spawning events for a year.

At a minimum it is recommended that the spawning protection period in the NES-PF is increased to four months with the addition of August and November to the spawning protection period. This will allow much greater protection of the redfin bully spawning than currently provided.

5.3.3 Stokell's smelt

Stokell's smelt occurs across a limited geographic range, only being found in lowland Canterbury Rivers. As such there is very limited scope for geographic or altitudinal effects to lead to variations in spawning timing. Spawning timing is reported to be in late spring and summer (McDowall 1990). The NES-PF spawning protection that is set for December and January will include the majority of the spawning season and appears appropriate.

5.3.4 Salmonid spawning biology

The various salmonid species in New Zealand all have some very similar spawning habits. Adults of nearly all species conduct spawning migrations to spawning areas. Adult fish resident in the ocean (salmon) or lower reaches of rivers (trout) migrate upstream to spawning areas. Therefore, spawning areas are generally considered to be only a portion of the total area of river system that salmonids may be encountered in. Exceptions to this are many populations of small stream-resident brown trout and brook char populations, where the adults are resident in the same reaches year round and there is no difference between adult, juvenile and spawning habitat on the reach scale. Populations of these resident brown trout and brook char can be found in many first- and second-order and possibly third-order streams around New Zealand.

Generally salmonids (aside from lake char) lay their eggs in excavations in the stream bed and, once the eggs are fertilised, bury the eggs. Occasionally, lake populations of salmonids use lake shore areas for spawning if tributary stream habitat is not available. These nests are generally called redds and they have some important features that provide for the eggs while they are buried. The stream needs to have clean gravels and cobbles with little if any fine sediment. This allows water to flow through the gravels to keep the eggs oxygenated. Of particular note is that, as the eggs develop, the associated oxygen requirements increase (Quinn 2005). Therefore, for protection of eggs in the redd it is important to consider the period just before hatching as an important period to maintain high dissolved oxygen levels. Small partially developed fish called alevins hatch from the eggs and these also remain in the redd, sheltering amongst the gravel and cobble. The alevins have a large yolk sac when they hatch and this provides food for the alevin for several weeks. This allows the alevins to develop and grow into a fully formed fry before emerging from the redd. Alevins, like the eggs, require clean flowing water to be passing through the redd to provide oxygen and to remove wastes. Without clean, well oxygenated water, egg and alevin mortality can be very high. Therefore, to protect salmonid spawning the period from egg laying to alevin emergence is important. For spawning streams, it is also important to keep the spawning areas relatively clean from fine sediments. Regardless of the time of year activities occur, if the activity results in significant fine sediment deposition, the spawning areas can become unsuitable for successful egg and alevin development.

At present the NES-PF has spawning protection rules in place for the spawning period for salmonids. However, the time period does not include the egg or alevin development periods.

Brown trout

Brown trout have a range of life history types in New Zealand. Some areas have populations of sea run brown trout in which adults feed either at sea or in lower river estuaries and migrate upstream to spawn and then return to feeding areas. Other stocks are riverine migratory stocks with adults feeding in the larger rivers and again migrating upstream to tributaries to spawn. In small streams there are stream resident populations that feed and spawn in the same reaches. These small stream-resident populations are often referred to as stunted populations, as the adult fish do not reach the large sizes found in the large river and sea run populations. For the migratory populations, upstream runs generally occur in April and May and spawning is conducted in late May and June. For the stream resident populations, no migration occurs and the spawning period is also May and June. The eggs are laid in redds and develop over winter and fry emerge in early spring (McDowall 1990). Some variation on this hatch timing can be expected as cooler water temperatures will slow egg development and delay hatching and emergence.

The NES-PF currently provides spawning protection in May and June. Spawning generally commences in May, so the NES-PF period includes two to three weeks in May when spawning is unlikely. The egg and alevin development period occurs from June to September so little of this period is included in the spawning protection period. Therefore, it is recommended that a spawning protection period runs from mid-May to the end of October to provide good protection for brown trout spawning.

The NES-PF currently puts in place spawning protection across the full geographic range of brown trout. Given spawning occurs in only a portion of the range of brown trout, the NES-PF provides greater protection than required to protect spawning and spawning habitat. To achieve spawning protection, the spatial layer with brown trout areas could be reduced from all brown trout habitat to brown trout spawning habitat. To achieve this four methods are available:

- the designation of spawning streams from knowledge of spawning areas used;
- the development of a brown trout spawning habitat predictive model similar to the fish prediction model of Crow et al (2014);
- A rule-based stream selection process where streams of a selected width or stream order are excluded from the spawning habitat protection layer. NIWA has developed a stream width model and the REC contains stream order information, so these methods can be applied from existing data; and
- A combination of designated streams and exclusion of streams by order or width.

Atlantic salmon

Atlantic salmon are restricted to the Waiau River, Southland and most likely to just a few areas in the system. The spawning biology of Atlantic salmon is nearly identical to brown trout. The two species have very similar spawning timing and spawning biology. The adult fish spawn amongst river bed gravels in late autumn, early winter and the eggs develop over the winter months. Eggs then hatch as alevins and these remain living in the river bed gravels for another 30-60 days as they feed off their yolk sac and grow before emerging as fry.

Any spawning protection for brown trout that encompasses the full period of spawning, egg development and alevin life history stage will also protect Atlantic salmon spawning. Brown trout is also present throughout the Waiau River catchment, including the locations Atlantic salmon have been released, and they should utilise the same spawning reaches. Therefore, the NES-PF can provide spawning protection by default to Atlantic salmon via the brown trout spawning protection.

Rainbow trout

Rainbow trout occur widely in New Zealand although they are more abundant in the North Island, especially when associated with lakes and their tributaries. Adult fish tend to reside in the lakes or large rivers and migrate upstream to spawn in smaller tributaries. The timing of spawning runs to the tributaries spreads generally over a longer period and is more variable than for brown trout. Runs occur in autumn, winter and early spring with spawning occurring from June through to October (McDowall 1990, Hamer 2007). MacLean (2011) discusses some of the variation in upstream runs especially for Lake Taupo and he notes early runs (June-August) often occur when freshes occur and rainbow trout will wait for these freshes before continuing to migrate upstream. During the late run rainbow generally run "ripe" and the importance of freshes is not as important. Male fish also run earlier than female fish and may spend a period of weeks at spawning areas waiting for females to arrive. Fish in the spawning runs that occur later in winter tend to move continuously upriver to the spawning grounds so the migration is faster (Dedual and Jowett 1999). These variations in run behaviour all lead to the general spawning time of late winter and spring. McDowall (1990) indicates June, July and August, Hamer (2007), for the Waikato region, indicates river populations spawn in winter, June – August and stocks from Lake Taupo in late winter and spring. The timing of the run is closely related to the average size of the fish returning to spawn. The smaller the fish, the later the run. There is also a slight tendency for the run to be late when the run is small (Figure 6).

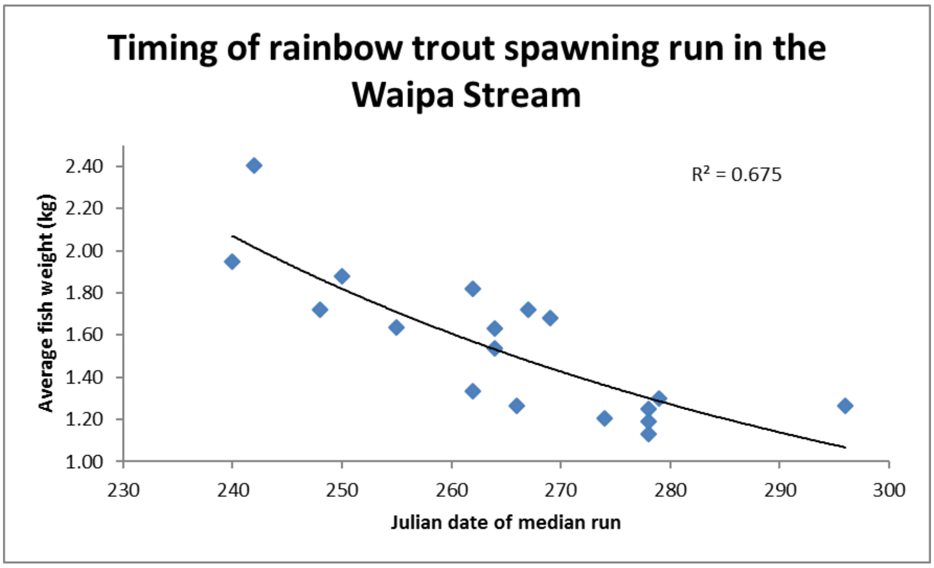

Figure 6: Rainbow trout spawning timing in the Waipa Stream, North Island.

Overlap between all spawning periods is greatest in August and September in the Waikato. Eggs and alevin development takes approximately two months, with time varying depending on water temperature, but fry are present in the water column by December.

The NES-PF sets a spawning protection time of April and May for rainbow trout. This does not include any part of the wider spawning period of June to November and provides no protection for rainbow trout spawning. It is recommended the time is adjusted to June to November. As rainbow trout have well known spawning migrations to spawning streams, the spawning protection does not need to be applied to all areas rainbow trout are reported from, rather just to the spawning streams. For the NES-PF a spawning stream database is required and consultation with Fish and Game and the DOC Taupo fisheries group is recommended to develop this database. An alternative to the broad spawning protection period is to determine local spawning timing and set in place shorter time frames that are appropriate for local rainbow trout populations.

Chinook salmon

Currently the NES-PF provides spawning protection for Chinook salmon spawning in all river reaches that Chinook salmon have been reported from. This provides protection over much greater areas of riverine habitat than is required for spawning protection. Chinook salmon generally spawn in stable flow tributaries of the Canterbury Rivers. Some exceptions exist, such as spawning in the Waitaki River downstream of Waitaki Dam and in the Clutha River below Roxburgh Dam. However, for the most part spawning occurs in relatively small areas of each river system that Chinook salmon occupy. The areas downstream of spawning reaches are habitat for juvenile salmon as they feed and move downstream to the ocean or, along which adult Chinook salmon, migrate back to the spawning areas. Spawning for Chinook salmon occurs from April to June with egg and alevin development occurring over winter.

It is recommended that for the NES-PF to provide spawning habitat protection for Chinook salmon the spawning areas are used (See ECan spatial layer) in the spatial layer rather than all areas Chinook salmon have been reported from in the NZFFD. Fish & Game Councils have good records of spawning areas as these areas are regularly surveyed to determine the spawning success and run size of Chinook salmon, often on an annual basis (e.g., Terry 2012). As by far the majority of Chinook salmon return to their natal streams to spawn, it is not expected that the number and distribution of spawning areas will change over time. It is also recommended that the period for which protection is applied is extended from April-May to April-September, to allow for protection of eggs and alevins in the redds for the full incubation and growth period.

Sockeye salmon

Sockeye salmon were established in the upper Waitaki catchment in Lake Ohau and Lake Benmore. The fish originally appear to have restricted successful spawning to tributaries of Lake Ohau and were dispersing downstream as far as Lake Benmore. The adults then migrated back upstream to natal streams to spawn. Graynoth (1995) found Larch Stream, a tributary of Lake Ohau, was the only significant spawning stream for sockeye salmon and that spawning occurred in March, egg hatching to alevins occurs in May and sockeye salmon fry emerge in June. However, sockeye salmon were also declining as migrations between Lake Ohau and Lake Benmore were prevented by hydro-electric power scheme developments. However, more recently (Otago Daily Times 2010) sockeye appear to have established new spawning areas in tributaries of Lake Benmore and the Twizel and Tekapo Rivers, and the population is now increasing and spreading in the Waitaki River catchment. Graynoth (1995) noted that the spawning timing of sockeye salmon that was suitable for North American rivers and climate appeared poor for New Zealand conditions. The current increase in range and abundance may indicate the sockeye have developed spawning behaviour more appropriate for New Zealand conditions. Therefore, it is recommended that the March spawning and June emergence timing reported by Graynoth (1995) should be confirmed as still correct before being used in the NES-PF. It is likely that Fish and Game Central South Island can confirm the details of the current spawning activity and the timing for spawning protection can then be adjusted in the NES-PF if necessary.

Brook char

Brook char are generally restricted to small headwater streams in New Zealand. Many of the populations are composed of small fish less than 30 cm long and are present in stream less than 1 m wide and are not considered sports fishery populations. Exceptions include the upper reaches of the Manuherikia River and Nevis River in Otago and the only North Island population in the Moawhango catchment in the central North Island, where sports fishery populations are present. The Moawhango population is centred on Lake Moawhango (a hydro-electric lake) and is on New Zealand Army-administered land in the Waiouru training area, an area unlikely to have plantation forestry activities. Therefore, the need for protection of brook char populations is centred in Canterbury and Otago.

It is not known if brook char in New Zealand migrate to spawning sites, but the majority of populations occur in very small headwater streams and upstream migrations of any great distance are not possible. Therefore, unlike most salmonids it is reasonable to assume that, for New Zealand brook char, adult habitat is also spawning habitat.

Brook char spawning occurs in May and June, eggs develop over winter in the redds, and the alevins emerge from the redds in October. Egg development times are generally long as the fish are present in cold or very cold water headwater streams.
To provide protection for the spawning and egg development period, the NES-PF needs to extend the spawning protection period from May and June to May to October. It is also recommended that Fish and Game are approached to determine whether all brook char populations require protection and, rather than protecting small headwater populations of no fishery value, the extended spawning protection period is set for designated sports fishery populations. Furthermore, as brook char often occur in high country streams, brook char streams may be outside the areas considered for plantation forestry, and also potentially in conservation estate.

5.4 PROCESS TO UPATE THE SPAWNING DATA

The spawning information above demonstrates that the knowledge of spawning behaviour for native fish in New Zealand is incomplete. The spawning timing of koaro is highly variable and other species, while less variable, have uncertainties associated with the timing and the location of spawning. In addition, as taxonomic revisions are completed information is likely to be gathered on the spawning biology of newly described species. Furthermore, reviews of the NES-PF may determine additional species need to be included in the spawning protection rules. Therefore, a process of updating the spawning timing for the NES-PF spawning rules is required.

1. Call for submissions for information on spawning timing to submit to the review
2. Review submissions and any new publications on the spawning biology of fish species of interest and determine if the spawning timing observed falls within the spawning protection period in the NES-PF.
3. Review NZFFD records submitted since the previous review for additional observation on spawning biology. This review should include new NZFFD records dated since the last review and any older records that have been submitted to the NZFFD after the last review. This is because some fish survey records reach the NZFFD years after the actual fish surveys were conducted. The review should record all NZFFD records used so existing and new records can easily be identified in later reviews (see Appendix C for example of possible record keeping).
4. For the purposes of determining spawning timing the following priorities for observations should apply:
    a. Actual observations of fish spawning provide a spawning date;
    b. Observations of ripe and spent males and female indicate spawning is occurring at this time;
    c. Observations of running ripe female fish that indicate spawning is likely to occur in the next week or two as females releasing eggs indicates spawning is imminent;
    d. Actual observations of fertilised fish eggs developing instream or on the riparian margin that indicate spawning has occurred recently for native fish or at some time in the past few months for salmonids. These observations need to be accompanied by egg identification (e.g., genetic analysis, and/or fish survey) to determine which fish species has produced the eggs;
    e. Presence of spent males and females indicate spawning has occurred but timing is uncertain as the recovery of fish condition can be influence by a variety of factors;
    f. Presence of ripe males indicate spawning possible in the next two months as many observations indicate male fish are running ripe well before the spawning period commences; and

   g. Gravid females indicate spawning may occur anytime in the next four or five months as native fish, especially non-migratory galaxiids many develop eggs in autumn for spawning in spring.
5. Determine if new data available requires an adjustment to the spawning timing for a species or for a life history type (e.g. landlocked populations).
6. Gazette any new spawning timing rules as appropriate.

5.5 SUMMARY OF RECOMMENDATIONS

5.5.1 Short-term recommendations

The following short term recommendations are made:

- MPI establish a project to establish the spawning timing of alpine galaxias in the Manuherikia River catchment. This population occurs in a small area of the river system and plantation forestry is present in this area. It is likely that the results of this work will take two or more spawning seasons to complete. Therefore commencing this work in the near future will ensure data is available for the first review of the spawning rules if not available at the initial release of the NES-PF.
- Fish & Game Otago are approached to designate important brook char populations for which the spawning rules will apply. Confirm whether other Fish & Game Councils (Southland, Canterbury) have any brook char populations to include in spawning rules.
- Confirm with Fish & Game Central South Island that sockeye salmon spawning areas have been correctly identified.
- Confirm with Fish & Game Southland that Atlantic salmon spawning will be protected by the spawning rules for brown trout.

5.5.2 Long term recommendations

The following long-term recommendations are made:

- A spawning database for rainbow trout is established in conjunction with DOC Taupo and Fish & Game that records spawning areas and spawning timing for each spawning area. This will allow more accurate mapping in the spatial layer and confirm spawning timings that appear to vary at sites around New Zealand.
- A spawning database for rainbow trout is established in conjunction with Fish & Game that records spawning areas and spawning timing for each spawning area. This will allow more accurate mapping in the spatial layer and reduce the reliance on general brown trout occurrence data rather than spawning location data.
- MPI support spawning research for the lowland longjaw galaxias, koaro and giant kokopu. For the latter two migratory species the objective should be to better establish the spawning timing around New Zealand, including differences among landlocked populations and between the landlocked and sea run populations.

5.6 SUMMARY OF SPAWNING PROTECTION TIMING, CURRENT AND RECOMMENDED

Recommended changes to the spawning protection times from the draft NES-PF are outlined below, together with the draft NES-PF times (*Table 4*). Recommendations of any splits in spawning timing are also summarised.

Table 4: Summary of spawning timing and recommended protection.

Taxa*	Common name	Draft NES-PF spawning protection period	Recommendation for split spawning periods	Recommended spawning protection period(s)	Additional protection recommendations
Galaxias anomalus	Central Otago roundhead	1 September to 31 October	No	1 August to 31 October	
Galaxias argenteus	Giant kokopu	1 May to 30 June	Sea run North Island Sea run South Island Landlocked	15 April to 15 July 1 June to 31 August 1 May to 31 August#	Full riparian protection to protect spawning habitat
Galaxias brevipinnis	Koaro	1 April to 30 May	Sea run North Island sea-run South Island Landlocked	1 April to 30 June# 1 March to 30 May# 1 November to 31 January#	
Galaxias cobitinis	Lowland longjaw galaxias	1 September to 31 October	No	1 May to 30 September	Protection of springhead spawning areas
Galaxias cobitinis 'Waitaki'	Lowland longjaw galaxias 'Waitaki'	1 September to 31 October	No	1 August to 31 December	Protection of springhead spawning areas
Galaxias depressiceps	Taieri flathead	1 September to 31 October	No	1 August to 31 October	
Galaxias divergens	Dwarf galaxias	1 September to 31 October	No	1 September to 31 October	
Galaxias divergens 'Marlborough, North Island'	Dwarf galaxias 'Marlborough, NI'	1 September to 31 October	No	1 September to 31 October	
Galaxias eldoni	Eldon's galaxias	1 September to 31 October	No	1 October to 30 November	Full riparian protection to protect spawning habitat
Galaxias gollumoides	Gollum galaxias	1 September to 31 October	No	1 August to 30 September	
Galaxias gollumoides 'Nevis'	Nevis galaxias	1 September to 31 October	No	1 October 30 November	
Galaxias macronasus	Bignose galaxias	1 September to 31 October	No	1 July to 30 September	
Galaxias paucispondylus	Alpine galaxias	1 September to 31 October	No	1 August to 30 October	

Taxa*	Common name	Draft NES-PF spawning protection period	Recommendation for split spawning periods	Recommended spawning protection period(s)	Additional protection recommendations
Galaxias paucispondylus "Manuherikia'	Alpine galaxias	1 September to 31 October	No	1 August to 30 October[#]	
Galaxias paucispondylus "Southland'	Alpine galaxias	1 September to 31 October	No	1 August to 30 October[#]	
Galaxias prognathus	Upland longjaw galaxias	1 September to 31 October	No	1 October to 30 November	Protection of springhead spawning areas
Galaxias prognathus 'Waitaki'	Upland longjaw galaxias 'Waitaki'	1 September to 31 October	No	1 October to 30 November	Protection of springhead spawning areas
Galaxias pullus	Dusky galaxias	1 September to 31 October	No	1 October to 30 November	Full riparian protection to protect spawning habitat
Galaxias vulgaris	Canterbury galaxias	1 September to 31 October	No	1 August to 31 October[#] [ii]	
Gobiomorphus huttoni	Redfin bully	1 September to 31 October		1 August to 31 October[#]	
Stokellia anisodon	Stokells smelt	1 December to 31 January	No	No change	
Oncorhynchus mykiss	Rainbow trout	1 April to 31 May	Possible[#]	1 July to 30 November[#]	Select spawning areas
Oncorhynchus nerka	Sockeye salmon	1 March to 31 March	Reduce area	1 March to 30 June	Select spawning areas
Oncorhynchus tshawytscha	Chinook salmon	1 April to 31 May	No	1 April to 31 September	Select spawning areas
Salmo salar	Atlantic salmon	1 May to 30 June		15 May to 15 September	
Salmo trutta	Brown trout	1 May to 30 June	No	15 May to 15 September	Select spawning areas
Salvelinus fontinalis	Brook char	1 May to 30 June	No	1 May to 31 October	

*indeterminate taxa are included in this table for taxa that are currently included in the NES-PF as part of the closely related determinate taxa.

[#] Requires further work to confirm spawning period

[i] For populations under 500 m altitude

[ii] For populations under 600 m altitude

6 Summary

The NES-PF is intended to provide national guidance and rules for the management of plantation forestry activities and to manage the effects on the environment. Within the draft NES-PF there are rules for activities that may impact on the spawning of 21 freshwater fish species.

Submissions received on the draft NES-PF indicated submitters were concerned about a number of issues regarding the fish spawning protection rules including:

- Whether a national fish spawning calendar is capable of covering the full range of spawning times across New Zealand;
- The NES-PF rules currently only place restrictions on the peak spawning period, or where a peak period has not been identified through the spawning calendars a truncated spawning period of two months has been used at the centre of the species spawning range. Submitters questioned whether this would be sufficient to allow for successful recruitment. Some have suggested that a wider window of risk should be used to allow additional time for successful egg and larval development;
- Whether the New Zealand Freshwater Fish Database (NZFFD) and River Environments Classification (REC2) are sufficiently accurate as a basis for resource management regulation; and
- Taxonomically indeterminate species have not been included in the rules, submitters have questioned whether these should be covered, particularly Galaxiidae species that are regionally isolated.

A review of the indeterminate taxa found that six indeterminate taxa are included in the NES-PF spawning protection rules. An additional six indeterminate taxa can be included in the NES-PF and the forestry impact assessment should be conducted for these taxa to determine if spawning protection is required. Distributional data and spawning data can be obtained for all indeterminate taxa relatively easily, allowing the NES-PF's spatial layer to indicate where these taxa are present and for the NES-PF to set spawning protection periods.

The NES-PF spatial layer provides relatively good data on fish locations using data from the NZFFD, but it has substantial errors in the areas with little fish sampling. The REC-FPM appears to over predict the presence of common salmonid species and also some native fish. In part this is due to a lack of data on barriers to fish movement in the REC-FPM. Other errors are due to a lack of data on fish presence. It is possible to more accurately map the distribution of the majority of native fish in the spatial layer, to remove some errors by reviewing the data, and to also refine the distribution of brown trout. Therefore, it is expected that the spatial layer can be improved, but it will still have errors for areas with little survey data. It is recommended that if error-prone areas can be identified by gap analysis that streams in these areas are targeted for fish survey prior to any new plantation forestry being undertaken. It is also noted that the REC layer that underlies the REC-FPM model has some errors with the location of river channels as the digital elevation model cannot accurately resolve the location of rivers and streams in very low gradient environments.

The fish spawning times and protection periods in the NES-PF were reviewed using available data on fish spawning. Modifications to the fish spawning times have been provided in this report for the majority of taxa in the NES-PF. The most extensive change recommended is the extension of the spawning protection period for salmonids so that it includes the spawning, egg and alevin development periods rather than just the spawning period. This will improve the protection and survival of eggs while developing in the bed of streams. It was also noted that the spatial layer provides protection for salmonid spawning habitat across the full range of the species rather than just the spawning habitat, which is a smaller portion of the habitat occupied by these species. Therefore, the spatial layer could be modified with the salmonid species locations reduced to better represent the spawning areas rather than their general habitat.

For native fish, the diadromous galaxiids are the most problematic to provide spawning protection periods for, due to changes in spawning timing related to latitude, altitude and whether populations are diadromous or landlocked. To allow for this variation some regional and life history related splits in spawning timing have been recognised and provided for in the recommended spawning protection periods. Additional research is also recommended for a number of native fish species to better understand the spawning timing and protection requirements.

7 References

Allibone, R. M. (1999). Impoundment and introductions: impacts on the native fish community of the upper Waipori River, New Zealand. *The Journal of the Royal Society of New Zealand*, 29(4), 291-299.

Allibone, R. M. (2002). Dealing with diversity dwarf galaxias style. *Water & Atmosphere*, 10(1), 18-19.

Allibone, R. M., & Caskey, D. (2000). Timing and habitat of koaro (*Galaxias brevipinnis*) spawning in streams draining Mt Taranaki, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 34: 593-595.

Allibone, R.M., Charteris, S., Elkington, S. (2012). *Fish communities of the upper Rakaia River catchment.* New Zealand Freshwater Science Conference, Dunedin 2012.

Allibone, R. M., Crowl, T. A., Holmes, J. M., King, T. M., McDowall, R. M., Townsend, C. R., & Wallis, G. P. (1996). Isozyme analysis of *Galaxias* species (Teleostei: Galaxiidae) from the Taieri River, South Island, New Zealand: a species complex revealed. *Biological Journal of the Linnean Society*, 57, 107-127.

Allibone, R. M., & McDowall, R. M. (1997). *Conservation ecology of the dusky galaxias, Galaxias pullus (Teleostei: Galaxiidae)* Conservation Sciences Publication 6. Department of Conservation, Wellington. 48p.

Allibone, R. M., & Townsend, C. R. (1997). Reproductive biology, species status, and taxonomic relationships of four recently discovered galaxiid fishes in a New Zealand river. *Journal of Fish Biology*, 51, 1247-1261.

Allibone, R. M., & Wallis, G. P. (1993). Genetic variation and diadromy in some native New Zealand galaxiids (Teleostei: Galaxiidae). *Biological Journal of the Linnean Society*, 50, 19-33.

Benzie, V. (1968). The life history of *Galaxias vulgaris* Stokell, with a comparison with *G. maculatus attenuatus*. *New Zealand Journal of Marine and Freshwater Research*, 2, 628-653.

Bonnett, M. L. (1992). Spawning in sympatric alpine galaxias (*Galaxias paucispondylus* Stokell) and longjawed galaxias (*G. prognathus* Stokell) in a South Island, New Zealand, high country stream. *New Zealand Natural Sciences*, 19, 27-30.

Bowie, S., Pham, L., Dunn, N., Allibone, R. M., Crow, S. K. (2014). *Freshwater fish taxonomic workshop: Focussing on New Zealand non-migratory galaxiid issues. Proceedings of a workshop 14 May 2013, Dunedin.* Unpublished Department of Conservation publication, Christchurch

Burridge, C. P., McDowall, R. M., Craw, D., Wilson, M. V. H., & Waters, J. M. (2011). Marine dispersal as a pre-requisite for Gondwanan vicariance among elements of the galaxiid fish fauna. *Journal of Biogeography*, 39(2), 306-321.

Cadwallader, P. L. (1976). Breeding biology of a non-diadromous galaxiid, *Galaxias vulgaris* Stokell, in a New Zealand river. *Journal of Fish Biology*, 8, 157-177.

Charteris, S., Allibone, R. M., & Death, R. G. (2003). Spawning site selection, egg development, and larval drift of *Galaxias postvectis* and *G. fasciatus* in a New Zealand stream. *New Zealand Journal of Marine and Freshwater Research*, 37: 493-505.

Crow, S., Booker, D., Skyes, J., Unwin, M., Shanker, U. (2014). *Predicting distributions of New Zealand freshwater fishes*. NIWA Client Report CHC2014-145. Prepared for the Department of Conservation.

Crow, S. K., & McDowall, R. M. (2010). Ontogenetic changes in morphology of flathead galaxiid fishes (Osmeriformes: Galaxiidae) in South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 45(4), 689-707.

Crow, S. K., Waters, J. M., Closs, G. P., & Wallis, G. P. (2009). Morphological and genetic analysis of *Galaxias* 'southern' and *G. gollumoides*: interspecific differentiation and intraspecific structuring. *Journal of the Royal Society of New Zealand*, 39(2), 43-62.

Dedual M, Jowett IG. 1999. Movement of rainbow trout (*Oncorhynchus mykis*s) during the spawning migration in the Tongariro River, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 33, 107–17.

Duffy, C. A. J. (1996). Pre-spawning mortality of koaro (*Galaxias brevipinnis*) in Apias Creek, north-east Ruahine range, North Island, New Zealand (Note). *New Zealand Journal of Marine and Freshwater Research*, 30: 403-405.

Dunn, N.R. (2003). The effects of extremes in flow on alpine (*Galaxias paucispondylus*) and Canterbury (*G. vulgaris*) galaxias. Unpublished M.Sc. thesis, University of Canterbury, Christchurch. 174 p.

Dunn, N., & O'Brien, L. (2007). Possible divergent reproductive strategies in New Zealand riverine non-migratory *Galaxias* fishes. *New Zealand Natural Sciences*, 32, 13-20.

Esa, Y. B., Waters, J. M., & Wallis, G. P. (2000). Introgressive hybridization between *Galaxias depressiceps* and *Galaxias sp D* (Teleostei: Galaxiidae) in Otago, New Zealand; secondary contact mediated by water races. *Conservation Genetics*, 1, 329-339.

Franklin, J. F., Smith, J., Baker, C. F., Bartels, B., & Reeve, K. (2015). First observation on the timing and location of giant kokopu (*Galaxias argenteus*) spawning. *New Zealand Journal of Marine and Freshwater Research*.

Goodman, J. M., Dunn, N., Ravenscroft, P., Allibone, R. M., Boubee, J.A.T., David, B. O., Griffiths, M., Ling, N., Hitchmough, R., Rolfe, J. R. (2014). *Conservation status of New Zealand freshwater fish, 2013*. New Zealand Threat Classification Series 7. Department of Conservation, Wellington.

Graynoth, E. (1979). Effects of logging on stream environments and faunas in Nelson. *New Zealand Journal of Marine and Freshwater Research*, 13(1): 79-109.

Graynoth, E. (1995). Spawning migrations and reproduction of landlocked sockeye salmon (*Oncorhynchus nerka*) in the Waitaki catchment, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29: 257-269.

Hopkins, C. L. (1971). Life history of *Galaxias divergens* (Salmonoidea: Galaxiidae). *New Zealand Journal of Marine and Freshwater Research*, 5(1), 41-57.

Hamer, M. P. (2007). *The freshwater fish spawning and migration calendar report*. Environment Waikato Technical Report 2007/11. 17p.

Johnson, W. S., Mace, J. T., & Tuner, A. S. (1976). *Fisheries Survey of Lake Christabel, West Coast Acclimatisation Society, South Island*. Fisheries Technical Report 144. MAF, Wellington.

Jones, P. (2015). Life history of non-migratory Central Otago *Galaxias*. Unpublished PhD thesis, Department of Zoology, University of Otago.

Kusabs, I. A. (1989). The biology and general ecology of the koaro (*Galaxias brevipinnis*) in some tributary streams of Lake Taupo. Unpublished MSC thesis, University of Waikato, Hamilton, New Zealand. 141p.

Maclean, G. (2011). *Assessment of rainbow trout spawning in the upper Makaroro River 2011*. Technically Trout Client Report TT 2011-01, produced for the Hawkes bay Regional Council. 23p.

McDowall, R. M. (1965). Studies of the biology of the red-finned bully *Gobiomorphus huttoni* (Ogilby) II.-Breeding and life history. *Transactions of the Royal Society of New Zealand*, 5(14), 177-196.

McDowall, R. M. (1970). The galaxiid fishes of New Zealand. *Bulletin of the Museum of Comparative Zoology*, 139(7): 341-431.

McDowall, R. M. (1990). *New Zealand freshwater fishes: a natural history and guide*. (2 ed.). Auckland: Heinemann Reed.

McDowall, R. M. (1997). Two further new species of *Galaxias* (Teleostei: Galaxiidae) from the Taieri River, southern New Zealand. *Journal of the Royal Society of New Zealand*, 27(2), 199-217.

McDowall, R. M. (1998). *Diadromy in fishes: migration between freshwater and marine environments*. London: Croom Helm.

McDowall, R. M. (2006). *The taxonomic status, distribution and identification of the Galaxias vulgaris species complex in the eastern/southern South Island and Stewart Island*. NIWA client report prepared for the Department of Conservation. 41p.

McDowall, R. M., & Chadderton, W. L. (1999). *Galaxias gollumoides* (Teleostei: Galaxiidae), a new fish species from Stewart Island, with notes on other non-migratory freshwater fishes present on the island. *Journal of the Royal Society of New Zealand*, 29(1), 77-88.

McDowall, R. M., & Charteris, S. C. (2006). The possible adaptive advantages of terrestrial egg deposition in some fluvial diadromous galaxiid fishes (Teleostei: Galaxiidae). *Fish and Fisheries*, 7, 153-164.

McDowall, R. M., & Hewitt, J. (2004). *Attempts to distinguish morpho-types of the Canterbury-Otago non-migratory Galaxias species complex*. DOC Science Internal Series Report 165. 18p.

McDowall, R. M., & Kelly, G. R. (1999). Date and age at migration in juvenile giant kokopu *Galaxias argenteus* (Gmelin) (Teleostei: Galaxiidae) and estimation of spawning season. *New Zealand Journal of Marine and Freshwater Research*, 33(2), 263-270.

McDowall, R. M., & Suren, A. M. (1995). Emigrating larvae of koaro, *Galaxias brevipinnis* Gunther (Teleostei: Galaxiidae), from the Otira River, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 29: 271-275.

McDowall, R. M., & Wallis, G. P. (1996). Description and redescription of *Galaxias* species (Teleostei: Galaxiidae) from Otago and Southland. *Journal of the Royal Society of New Zealand*, 26(3), 401-427.

Meredyth-Young, J. L., & Pullan, S. C., (1977). *Fisheries Survey of Lake Chalice, Marlborough Acclimatisation District, South Island*. Fisheries Technical Report 150. MAF, Wellington.

Mitchell, C. P., & Scott, D. (1979). Muscle myogens in the New Zealand Galaxiidae. *New Zealand Journal of Marine and Freshwater Research*, 13(2), 285-294.

Otago Daily Times (11 May 2010). Once vanished sockeye make return.

Quinn, T.P. 2005. *The Behaviour and Ecology of Pacific Salmon & Trout*. University of Washington Press, Seattle.

Rowe, D.K., Konui, G., Christie, K.D. (2002). Population structure, distribution, reproduction, diet, and relative abundance of koaro (*Galaxias brevipinnis*) in a New Zealand lake, *Journal of the Royal Society of New Zealand*, 32:2, 275-291, DOI:10.1080/03014223.2002.9517695.

Smith, J. (2015). Freshwater Fish Spawning and Migration Periods. Ministry of Primary Industries Technical Paper No: 2015/17.

Stokell, G. (1949). The systematic arrangement of New Zealand Galaxiidae: II Specific classification. Transactions of the Royal Society of New Zealand, 77: 472-496.

Stokell, G. (1959). Notes on galaxiids and eleotrids with descriptions of new species. *Transactions of the Royal Society of New Zealand*, 87(3-4): 265-269.

Terry, S. (2012). 2011/12 Salmon Management Report, North Canterbury Region. Internal Report, North Canterbury Fish & Game Council.

Townsend, C. R., & Crowl, T. A. (1991). Fragmented population structure in a native New Zealand fish: an effect of introduced brown trout. *Oikos*, 61, 347-354.

Waters, J. M., Craw, D., Youngson, J.H., Wallis, G.P. (2001). Genes meet geology: fish phylogeographic pattern reflects ancient, rather than modern, drainage connections. *Evolution*, 55(9), 1844-1851.

Waters, J. M., & Wallis, G. P. (2001a). Mitochondrial DNA phylogenetics of the *Galaxias vulgaris* complex from South Island, New Zealand: rapid radiation of a species flock. *Journal of Fish Biology*, 58, 1166-1180.

Waters, J. M., & Wallis, G. P. (2001b). Cladogenesis and loss of the marine life-history phase in freshwater galaxiid fishes (Osmeriformes: Galaxiidae). *Evolution*, 55(1), 587-597.

Waters, J. M., Wallis, G. P., Burridge, C. P., & Craw, D. (2015). Geology shapes biogeography: Quaternary river-capture explains New Zealand's biologically 'composite' Taieri River. *Quaternary Science Reviews*, 120, 47-56.

Appendix A: Freshwater fish of New Zealand.

Table A1.: Freshwater fish of New Zealand and their threat rankings (Goodman et al 2014), forestry risk assessment scores (Smith 2015), availability of distribution models (Crow et al 2014) and basic biological information.

Taxa	Common name	Status	Goodman et al (2014)	Smith (2015)[#]	Crow et al (2014)*	NES-PF	Life history(s)[#]	Spawning location	NZ Geographic Range
Aldrichetta fosteri	Yelloweyed mullet	Native	Not threatened	Not scored	No	No	Marine	Marine	NZ
Anguilla australis	Shortfin eel	Native	Not threatened	22	Yes	No	Catadromous	Oceanic	NZ
Anguilla dieffenbachii	Longfin eel	Native	At Risk, Declining	22	Yes	No	Catadromous	Oceanic	NZ
Anguilla reinhardtii	Spotted eel	Native	Non-resident, native	Not scored	No	No	Catadromous	Oceanic	West coast of North Island
Cheimarrichthys fosteri	Torrentfish	Native	At Risk, Declining	31	Yes	No	Amphidromous	Freshwater	NZ
Fosterygion nigripenne	Estuarine triplefin	Native	Not threatened	Not scored	No	No	Estuarine/Marine	Marine	NZ
Galaxias 'northern'	Northern flathead	Native	Nationally vulnerable	Not scored	Yes	No	Non-migratory	Freshwater	Marlborough, Nelson, West Coast
Galaxias anomalus	Central Otago roundhead	Native	Nationally endangered	52	Yes	Yes	Non-migratory	Freshwater	Otago
Galaxias argenteus	Giant kokopu	Native	At Risk, Declining	37	Yes	Yes	Amphidromous	Freshwater and riparian	NZ
Galaxias brevipinnis	Koaro	Native	At Risk, Declining	36	Yes	Yes	Amphidromous	Freshwater	NZ
Galaxias cobitinis	Lowland longjaw galaxias	Native	Nationally critical	52	No	Yes	Non-migratory	Freshwater	Kakanui River
Galaxias cobitinis 'waitaki'	Lowland longjaw galaxias 'Waitaki'	Native	Nationally critical	52[#]	No	Yes	Non-migratory	Freshwater	Waitaki River

Taxa	Common name	Status	Goodman et al (2014)	Smith (2015)[#]	Crow et al (2014)*	NES-PF	Life history(s)[#]	Spawning location	NZ Geographic Range
Galaxias depressiceps	Taieri flathead	Native	Nationally vulnerable	43	Yes	Yes	Non-migratory	Freshwater	Otago
Galaxias divergens	Dwarf galaxias	Native	At Risk, Declining	52	Yes	Yes	Non-migratory	Freshwater	West Coast and Nelson
Galaxias divergens 'Marlborough, North Island'	Dwarf galaxias 'Marlborough, NI'	Native	At Risk, Declining	52[#]	Yes, with dwarf galaxias	Yes	Non-migratory	Freshwater	Marlborough and North Island
Galaxias eldoni	Eldon's galaxias	Native	Nationally endangered	43	No	Yes	Non-diadromous	Freshwater and riparian	Otago
Galaxias fasciatus	Banded kokopu	Native	Not threatened	44	Yes	No	Amphidromous	Freshwater and riparian	NZ
Galaxias gollumoides	Gollum galaxias	Native	Nationally vulnerable	39	Yes	Yes	Non-migratory	Freshwater	Southland, Catlins and Stewart Island
Galaxias gollumoides 'Nevis'	Nevis galaxias	Native	Nationally endangered	Not scored	Yes* with Gollum galaxias	Yes	Non-migratory	Freshwater	Nevis River
Galaxias gracilis	Dwarf inanga	Native	At Risk, Declining	16	No	No	Non-diadromous	Freshwater	Northland
Galaxias lower Clutha galaxias	Lower Clutha galaxiid	Native	Data deficient	Not scored	Yes* with Clutha flathead	No	Non-migratory	Freshwater	Otago
Galaxias macronasus	Bignose galaxias	Native	Nationally vulnerable	52	Yes	yes	Non-migratory	Freshwater	Waitaki River
Galaxias maculatus	Inanga	Native	At Risk, Declining	25	Yes	No	Amphidromous	Freshwater and riparian	NZ
Galaxias paucispondylus	Alpine galaxias	Native	Naturally uncommon	52	Yes	Yes	Non-migratory	Freshwater	Canterbury, Marlborough

Taxa	Common name	Status	Goodman et al (2014)	Smith (2015)[#]	Crow et al (2014)*	NES-PF	Life history(s)[#]	Spawning location	NZ Geographic Range
Galaxias paucispondylus 'Manuherikia'	Alpine galaxias	Native	Nationally endangered	52[#]	Yes*	Yes	Non-migratory	Freshwater	Manuherikia River
Galaxias paucispondylus 'Southland'	Alpine galaxias	Native	Nationally vulnerable	52[#]	Yes*	Yes	Non-migratory	Freshwater	Southland, and Lochy River, Otago
Galaxias 'Pomahaka'	Pomahaka galaxias	Native	Nationally endangered	Not scored	No	No	Non-diadromous	Freshwater	Pomahaka River
Galaxias postvectis	Shortjaw kokopu	Native	Nationally vulnerable	44	Yes	No	Amphidromous	Freshwater and riparian	NZ
Galaxias prognathus	Upland longjaw galaxias	Native	Nationally vulnerable	52	Yes	Yes	Non-migratory	Freshwater	Canterbury
Galaxias prognathus 'Waitaki'	Upland longjaw 'Waitaki'	Native	Nationally vulnerable	52	Yes*	Yes	Non-migratory	Freshwater	Waitaki River
Galaxias pullus	Dusky galaxias	Native	Nationally endangered	52	No	Yes	Non-diadromous	Freshwater and riparian	Otago
Galaxias 'southern'	Southern flathead	Native	At Risk, Declining	Not scored	No	No	Non-diadromous	Freshwater	Southland, Stewart Island
Galaxias sp D	Clutha flathead	Native	Nationally critical	Not scored	Yes	No	Non-migratory	Freshwater	Otago
Galaxias 'Teviot''	Teviot galaxias	Native	Nationally critical	Not scored	No	No	Non-diadromous	Freshwater	Teviot River
Galaxias vulgaris	Canterbury galaxias	Native	At Risk, Declining	43	Yes	Yes	Non-migratory	Freshwater	Canterbury
Galaxias gracilis 'dune lakes'	Dune lakes galaxias	Native	Naturally uncommon	16[#]	No	no	Non-diadromous	Freshwater	Kai-Iwi Lakes, Northland
Geotria australis	Lamprey	Native	Nationally vulnerable	17	Yes	No	Anadromous	Freshwater	NZ

Taxa	Common name	Status	Goodman et al (2014)	Smith (2015)[#]	Crow et al (2014)*	NES-PF	Life history(s)[#]	Spawning location	NZ Geographic Range
Gobiomorphus alpinus	Tarndale bully	Native	Naturally uncommon	16	No	No	Non-migratory	Freshwater	Marlborough
Gobiomorphus basalis	Cran's bully	Native	Not threatened	35	Yes	No	Non-migratory	Freshwater	North Island
Gobiomorphus breviceps	Upland bully	Native	Not threatened	42	Yes	No	Non-migratory	Freshwater	Southland, Otago, Canterbury
Gobiomorphus breviceps 'West Coast, North Island'	Upland bully	Native	Not threatened	42[#]	Yes	No	Non-migratory	Freshwater	West Coast, Nelson Marlborough, North Island South Island
Gobiomorphus cotidianus	Common bully	Native	Not threatened	33	Yes	No	Amphidromous	Freshwater	NZ
Gobiomorphus gobioides	Giant bully	Native	Not threatened	26	Yes	No	Amphidromous	Freshwater	NZ
Gobiomorphus hubbsi	Bluegill bully	Native	At Risk, Declining	31	Yes	No	Amphidromous	Freshwater	NZ
Gobiomorphus huttoni	Redfin bully	Native	At Risk, Declining	40	Yes	Yes	Amphidromous	Freshwater	NZ
Mugil cephalus	Grey mullet	Native	Not threatened	Not scored	No	No	Catadromous	Marine	North Island
Neochanna apoda	Brown mudfish	Native	At Risk, Declining	25	No	No	Non-diadromous	Freshwater	West Coast, SI, and lower North Island
Neochanna burrowsius	Canterbury mudfish	Native	Nationally critical	25	No	No	Non-diadromous	Freshwater	Canterbury, North Otago
Neochanna diversus	Black mudfish	Native	At Risk, Declining	25	No	No	Non-diadromous	Freshwater	Northland, Auckland, Waikato
Neochanna heleios	Northland mudfish	Native	Nationally vulnerable	25	No	No	Non-diadromous	Freshwater	Northland

Taxa	Common name	Status	Goodman et al (2014)	Smith (2015)[#]	Crow et al (2014)*	NES-PF	Life history(s)[#]	Spawning location	NZ Geographic Range
Neochanna rekohua	Chatham Island mudfish	Native	Naturally uncommon	Not scored	No	No	Non-diadromous	Freshwater	Chatham Island
Prototroctes oxyrhynchus	grayling	Native	Extinct	Not scored	No	No	Amphidromous	Freshwater	NZ
Retropinna retropinna	Common Smelt	Native	Not threatened	27	Yes	No	Anadromous	Freshwater	NZ
Rhombosolea retiaria	Black flounder	Native	Not threatened	Not scored	Yes	No	Catadromous	Marine	NZ
Stokellia anisodon	Stokell's smelt	Native	Naturally uncommon	22	No	Yes	Anadromous	Freshwater	Canterbury
Oncorhynchus mykiss	Rainbow trout	Sports fish	Introduced and naturalised	43	Yes	Yes	Non-diadromous	Freshwater	NZ
Oncorhynchus nerka	Sockeye salmon	Sports fish	Introduced and naturalised	43	No	Yes	Non-diadromous	Freshwater	Waitaki River
Oncorhynchus tshawytscha	Chinook salmon	Sports fish	Introduced and naturalised	43	Yes	Yes	Anadromous	Freshwater	Canterbury
Perca fluviatilis	Perch	Sports fish	Introduced and naturalised	Not scored	No	No	Non-diadromous	Freshwater	NZ
Salmo salar	Atlantic salmon	Sports fish	Introduced and naturalised	43	No	Yes	Non-diadromous	Freshwater	Lake Mistletoe and Waiau River
Salmo trutta	Brown trout	Sports fish	Introduced and naturalised	40	Yes	Yes	Non-diadromous	Freshwater	NZ
Salvelinus fontinalis	Brook char	Sports fish	Introduced and naturalised	43	Yes	Yes	Non-diadromous	Freshwater	South Island and Moawhango River, N.I.
Savelinus namaycush	Mackinaw	Sports fish	Introduced and naturalised	16	No	No	Non-diadromous	Freshwater	Lake Pearson

Taxa	Common name	Status	Goodman et al (2014)	Smith (2015)[#]	Crow et al (2014)*	NES-PF	Life history(s)[#]	Spawning location	NZ Geographic Range
Tinca tinca	Tench	Sports fish	Introduced and naturalised	Not scored	No	No	Non-diadromous	Freshwater	NZ
Scardinius erythrophthalmus	rudd	Sports fish/ noxious fish	Introduced and naturalised	Not scored	No	No	Non-diadromous	Freshwater	NZ
Ctenopharyngodon idella	Grass carp	Restricted	N/A	Not scored	No	No	Non-diadromous	Freshwater	Where stocked
Hypophthalmichthys molotrix	Silver carp	Restricted	N/A	Not scored	No	No	Non-diadromous	Freshwater	Where stocked
Cyprinus carpio	Koi carp	Noxious, Unwanted	Introduced and naturalised	Not scored	No	No	Non-diadromous	Freshwater	North Island
Gambusia affinis	Gambusia	Unwanted	Introduced and naturalised	Not scored	Yes	No	Live bearer	Freshwater	North Island, Nelson, Marlborough
Ameiurus nebulosus	Brown bullhead catfish	Pest	Introduced and naturalised	Not scored	No	No	Freshwater	Freshwater	North Island, and Lake Mahinapua
Leuciscus idus	Orfe	Pest	Introduced and naturalised	Not scored	No	No	Non-diadromous	Freshwater	Auckland
Arenigobius bifrenatus	Bridled goby	N/A	Introduced and naturalised	Not scored	No	No	Estuarine/Marine resident	Marine	North Island
Carassius auratus	Goldfish	N/A	Introduced and naturalised	Not scored	Yes	No	Non-diadromous	Freshwater	NZ
Gobiopterus semivestitus	Glass goby	N/A	Non-resident, native	Not scored	No	No	Estuarine/Marine resident	Estuarine/Marine	Northland
Parioglossus marginalis	Dart goby	N/A	Non-resident, native	Not scored	No	No	Estuarine/Marine resident	Estuarine/Marine	Northland, Great Barrier Island

Taxa	Common name	Status	Goodman et al (2014)	Smith (2015)#	Crow et al (2014)*	NES-PF	Life history(s)#	Spawning location	NZ Geographic Range
Phalloceras caudimaculatus	Caudo	N/A	Introduced and naturalised	Not scored	No	No	Non-diadromous	Live bearer	Northland
Poecilia latipinna	Sailfin molly	N/A	Introduced and naturalised	Not scored	No	No	Non-diadromous	Live bearer	Waikato
Poecilia reticulata	Guppy	N/A	Introduced and naturalised	Not scored	No	No	Non-diadromous	Live bearer	Waikato
Xiphophorus helleri	Swordtail	N/A	Introduced and naturalised	Not scored	No	No	Non-diadromous	Live bearer	Waikato

Appendix B: A Brief Taxonomic Background to New Zealand Galaxiids and the Indeterminate Taxa.

The taxonomic investigation of New Zealand's galaxiids commenced in the 1800s with a number of species described with little knowledge of life histories, distributions and other taxonomists' work. These studies used morphological techniques to assess specimens and the taxonomic relationships among them. Subsequently, Gerald Stokell from the 1930s and 1960s named a number of galaxiid and bully species and began to rationalise the taxonomy of New Zealand's freshwater fish. His species descriptions included his 1949 description of a non-migratory galaxiid from Canterbury, *Galaxias vulgaris* (Stokell 1949), and in 1959 another non-migratory galaxiid from the Manuherikia catchment in Central Otago, *G. anomalus* (Stokell 1959).

McDowall (1970) continued the taxonomic investigations and published a review of galaxiid taxonomy in which he reduced the number of described galaxiids to eleven. These galaxiids included five migratory (whitebait) species: inanga, banded kokopu, shortjaw kokopu, giant kokopu and koaro, and five non-migratory species: alpine galaxias, dwarf galaxias, longjaw galaxias, dwarf inanga, *G. usitatus* (now recognised as inanga, *G. maculatus*), and common river galaxias. McDowall (1970) considered G. anomalus and G. vulgaris to be a single species, *G. vulgaris* the common river galaxias, but did note that this species was morphologically variable and widespread throughout the South Island, aside from the West Coast. McDowall (1970) also noted that one population from Otago (called the Linn Burn in McDowall (1970) but actually from Munros Dam Stream) was distinct, with a lower than usual principal caudal fin ray count of 14, rather than the 16 principal caudal fin rays that other *G. vulgaris* populations had. No further revisions of the galaxiid taxonomy occurred until the 1990s.

Genetic investigations into the structure of galaxiid populations began in the 1970s with the Mitchell & Scott (1979) study of muscle myogens. This study found that significant structure existed within *G. vulgaris* and it queried whether the status of *G. anomalus* needed to be reconsidered. However, the paper did not stimulate any taxonomic revisions. Allibone & Wallis (1993) conducted a second genetic study into population structure of migratory and non-migratory galaxiids, again finding significant genetic structuring among *G. vulgaris* population at a level that often characterised differences among species. This investigation coincided with a major research programme in the Taieri River that was encountering non-migratory galaxiids with differing morphological features. Genetic investigations of galaxiids from the Taieri and Clutha River catchment were undertaken to compare the non-migratory galaxiids present in these Otago rivers with G. vulgaris from its type locality in Canterbury. This genetic study (Allibone et al 1996) found four distinct non-migratory galaxiids were present in the Taieri River. One group matched G. vulgaris from Canterbury, while the second group matched fish from the *G. anomalus* type locality in Central Otago. Two further galaxiids were simply referred to as *Galaxias* sp B and *Galaxias* sp D. McDowall & Wallis (1996) proceeded to redescribe *G. anomalus* and describe *Galaxias* sp B and called this species *G. depressiceps*. Further survey work in the Taieri River catchment failed to find any further populations of Galaxias sp D that came from one stream, Totara Creek on Rough Ridge.

McDowall (1997) used morphological data to describe two further species from the Taieri River catchment, *G. eldoni* and *G. pullus*. *G. eldoni* populations were included in the Allibone et al (1996) study but had not been distinguished from G. vulgaris in their genetic work. However, McDowall (1997) found significant morphological differences that he considered sufficient to warrant species status and this has subsequently been supported by further genetic investigations (e.g., Waters & Wallis 2001a). One population of *G. pullus* from Munros Dam Stream was included in the study by Allibone et al (1996), but the authors did not distinguish it from *G. eldoni* or *G. vulgaris*, whereas McDowall (1997) found significant morphologic differences (including samples from Munro Dam Stream). Again, subsequent genetic analyses have supported this species description (Allibone & McDowall 1997, Water & Wallis 2001a, b). This suite of research outputs also recognised two distinct groups within the *G. vulgaris* group as it was termed, the flathead and roundhead forms. Flatheads were *G. depressiceps* while G. vulgaris and roundheads were *G. anomalus*, *G. eldoni* and *G. pullus*. Some of the common names given to these species reflected this split in the morphology of the fish (e.g., roundhead galaxias, Taieri flathead galaxias).

In response to the discovery of the new fish species in the 1990s, the taxonomy of non-migratory galaxiids across the South Island and Stewart Island was in question. Information in the NZFFD that recorded *G. vulgaris* throughout the South Island and on Stewart Island needed to be updated to match the species descriptions. Therefore, DOC in conjunction with the University of Otago set out to identify non-migratory galaxiids of the *G. vulgaris* group and samples were collected for genetic analysis whenever new populations were located or old sites of *G. vulgaris* were revisited. This work is ongoing and has extended across the South Island and Stewart Island since 1996. McDowall also revisited collections of non-migratory galaxiids in the NIWA fish collection to see if any historic collections provided useful taxonomic specimens. The upshot of the reassessment of the fish collection was the discovery of an unusual roundhead galaxias from southern Stewart Island. New collections from Stewart Island were made and genetic and morphological studies lead to the description of *G. gollumoides* (McDowall & Chadderton 1999). This discovery and subsequent genetic work on Southland roundhead populations lead to all roundhead galaxiids in Southland being recognised as Gollum galaxias rather than *G. anomalus*, which became restricted to Central Otago (and now sometimes called the Central Otago roundhead galaxiid).

Genetic and morphological work recognised three additional flathead lineages – southern flathead in Southland, Teviot flathead in the Teviot River, Otago, and northern flathead from Marlborough and the Maruia and Motueka Rivers. *Galaxias* sp D was also found in much of the upper Clutha River catchment and was given the common name Clutha flathead. These studies also found that some galaxiid populations were hybrids including Munros Dam Stream (*G. pullus* - *G. eldoni* hybrids), and Totara Creek (*G. depressiceps – G.* sp D, hybrids; Esa et al. 2000). While lineages had become more apparent, some doubts still existed over the status of some populations. Most notable of these doubts was the status of *G. gollumoides* in the Nevis River, Otago, and populations of galaxiids in the lower Clutha River, the Pomahaka River and some coastal catchment in South Otago and the Catlins region.

McDowall & Hewitt (2004) and McDowall (2006) used morphological methods to attempt to find morphological characters to aid identification of the various lineages and to provide evidence for species descriptions. However, this work failed to provide useful morphological characters, in part due to a lack of simple morphological differences between flathead types and also at times incorrect groupings of populations.

Crow et al (2009) conducted morphological and genetic analysis on populations of *G. gollumoides* and *G. 'southern'*. This confirmed the genetic differences and also the distinct morphologies of the roundhead type *G. gollumoides* and the flathead type of G. 'southern'. Crow & McDowall (2010) then investigated morphological changes with growth for four flathead lineages and while differences where apparent, the paper did not consider differences sufficient for species identifications at the time.

The Kawarau Water Conservation Order Amendment (KWCO) hearings between 2010 and 2012 focused attention on the non-migratory galaxiid of the Nevis River catchment. This galaxiid had been recognised as a distinct genetic and geographic outlier of the *G. gollumoides* group (Wallis & Waters 2001a, b and Burridge et al 2011). Geological investigations (Waters et al 2001) showed that 500,000 years ago the Nevis River was the headwaters of the Nokomai River and it flowed south into the Mataura River. Uplift along the Nevis/Cardrona fault line led to tilting of the river valley until a saddle rose in the upper Nokomai River and the northern portion of the river was cut-off and changed its flow direction from south to north, forming the present day Nevis River that flows into the Kawarau River. This "river capture event" isolated the galaxiid present in the upper Nokomai River from other populations of *G. gollumoides* in Southland. Fisheries evidence at the KWCO hearings generally concluded that the Nevis galaxiid was a separate taxon to *G. gollumoides* and the Nevis galaxias was not found anywhere else in Southland or Otago. Most recently, geological investigations have provided some explanations for the origins of the Teviot flathead. Waters et al (2015) used geological evidence to show that the Taieri River tributary, Kye Burn, used to flow into the Clutha River. This connection was broken by uplift of the Lammerlaw Ranges and the most southerly section of the Kye Burn that entered the Clutha River became the Teviot River. During this process flathead galaxias from the proto-Taieri River catchment became isolated in the mid-Clutha River catchment and became the Teviot flathead.

Recognition of Indeterminate Taxa

Recognition of the indeterminate taxa stems from Allibone et al. (1996), who first used the term *Galaxias* sp B and *G.* sp D. As noted above, *Galaxias* sp B was subsequently described as *G. depressiceps*. *G*. sp D has remained undescribed but the name and, with increasingly knowledge, the distribution of this galaxiid is understood and accepted. Other indeterminate taxa have been named in scientific publications and DOC reports, resource consent and special tribunal hearings. To date three indeterminate taxa have been discarded as new data indicated they were not distinct from existing described species. All of the indeterminate taxa now recognised have some history and acceptance in the general freshwater fisheries science and management community, and all appear in the DOC freshwater fish threat listing (e.g., Goodman et al 2014) and when appropriate feature in Resource Management Act consent applications and Regional Council Plans. In addition, the recognition of these taxa stems from over twenty years of fisheries surveys and research, which has been restricted by limited resources to complete formal taxonomic descriptions.

The NZFFD includes four of the indeterminate taxa, northern, southern, Clutha and Teviot flatheads, in the database records under these common names. Currently the Clutha flathead group in the NZFFD includes galaxiids that are either Clutha flatheads (from the upper Clutha, Benger Burn and upstream), lower Clutha galaxiids or Pomahaka galaxiids. Distribution data is also available for all other indeterminate taxa, as all are defined by geographical boundaries.

Appendix C: Background Information Sources for Koaro Spawning Timing.

Table B1: Koaro studies that provide information on spawning timing and or downstream larval movements.

Source	Site	Landlocked	Observation date	Forest region	Altitude (m)	Observations	Spawning date*	Larval fish migration[#]
Allibone & Caskey 2000	Katikara Stream, Mt Taranaki,	No	21/05/1999	SNI	400	Spawning site found	Early May	Late May- June
	Waiwhakakiho River, Mt Taranaki	No	4/05/1999	SNI	460	Spent Koaro common	Early May	Late May- June
Rowe et al 2002	Lake Rotoaira	Yes	September 1998 April 1999 January 199 April 1999	CNI	564	September – adults maturing, rare spent April – majority of adults spent January – Larval fish common and small April – Larval fish rare and large	November -December?	December – January?
Johnson et al 1976	Lake Christabel	Yes	10-14 June 1974	WC	660	Gravid females	?	?
Meredyth-Young & Pullan, (1977).	Lake Chalice	Yes	29 June – 1 July 1974	NM	750	Near ripe, no spent koaro	?	?
Kusabs 1989	Lake Taupo	Yes	June 1988- May 1989	CNI	370	Ripe and spent adults November to April and downstream larval drift in February	December- January	February
McDowall & Suren 1995	Otira River	No	27 March 1994	WC	800-1000	Larval koaro drifting downstream	Late February	Late March
Duffy 1996	Apias Ck, Ngaruroro River	No	8 March 1995	HB	800	Ripe female koaro	April	May
Charteris et al 2003	Katikara Stream	No	26, 27 May and 17 June 2001	SNI	350-400	Larval koaro drifting downstream	Late April, May	Late May, June
Allibone unpublished data	Maori River, Stewart Island	No	Late March	n/a	20	Eggs mass in stream	March	April

*Estimated from condition of the eggs (e.g., eyed, not eyed) or from observations of ripe and spent fish or 30 days prior to downstream migration.

[#] Estimated to occur 30 days after spawning.

Table B2: NZFFD records with information on koaro spawning.

NZFFD card No.	River system	Observation date	Forest region	Altitude (m)	Observations	Landlocked
1293	Buller	24/09/1979	WC	345	Both sexes ripe	Yes
1297	Buller	25/09/1979	WC	340	Both sexes ripe	Yes
2124	Waitaki	11/12/1991	C	430	Possibly spawning	Yes
7929	Arahura	6/04/1987	WC	70	Ripe and spent	No
7999	Totara	18/03/1987	WC	160	Ripe females	No
8000	Totara	18/03/1987	WC	161	Ripe females	No
8816	Tukaekuri	18/05/1988	HB	930	Spent fish	No
13033	Oparau	2/06/1993	CNI	380	Spent fish	No
13034	Oparau	3/05/1993	CNI	340	Ripe fish	No
17707	Oakura	21/04/1998	SNI	410	Ripe and spent fish	No
21280	Waitaki	18/08/1980	C	500	Ripe fish	Yes