Spatial prioritisation strategy for the recovery of migratory galaxiids on the South Island's West Coast

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Department of Conservation
Migratory Species Recovery Programme

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Contents

Executive summary

A range of literature was reviewed and summary information compiled to support the development of a conservation prioritisation strategy for two migratory fish species (īnanga and shortjaw kōkopu) on the South Island's West Coast. This strategy will support the development of migratory species recovery plans under the government-funded Bio18 programme being implemented by the Department of Conservation. Existing datasets were evaluated and a desktop assessment completed to provide an initial characterisation of conservation value and threat intensity at regional scale. Recommendations are provided for a progressive conservation prioritisation strategy using the best available data. Results of the desktop assessment are presented in this summary report and include a set of spatial data and maps prepared for the use of operational staff who will lead implementation of this project in the coming years.

Findings of the desktop analyses included the characterisation of existing information on conservation value and the distribution of threats to the security of these species. Spatial disparities between species distribution models (SDMs) produced on different versions of the River Environment Classification were identified and are described. Model discrepancies may indicate the influences of differences in environmental predictor variables, areas of heightened uncertainty due to environmental conditions, or both.

Since both models were able to simulate training data with high levels of accuracy, the uncertainties relate mostly to their ability to extrapolate into new spatial domains. This suggests a useful role for targeted ground-truthing surveys, both within areas of model congruence and also model discrepancy, and is recommended for inclusion in the Bio18 operational work.

For the purposes of prioritising actions, these results also indicate challenges for the adoption of model predictions as indicators of conservation value. To address this, a linked-model approach is proposed that takes into account both data sources.

A four-tier 'priority class' classification is assigned based on the strength of evidence for species presence, as described by the following classes:

Priority Class	Description
Class 1	Presence confirmed by the results of field surveys
Class 2	Presence predicted by both of the available SDMs (model congruence)
Class 3	Presence predicted by one of the available SDMs but not the other (model discrepancies)
Class 4	No evidence for presence (as judged by SDM probabilities of capture below the modelled threshold for presence, and the absence of confirmed sightings)

Using this approach, conservation value is assigned primarily on the basis of the evidence for species presence within planning units. However, they may be further ranked using species abundance data available within the New Zealand Freshwater Fish Database (NZFFD), or by modelled probabilities of capture. Within the present project, this classification was utilised for an initial characterisation of spatial priority for each species across a set of 3rd order subcatchment planning units for the region (n = 2367). The co-occurrence of conservation values and threats was further explored using nine indicators of anthropogenic pressure for which region-wide data were available, despite some limitations in currency with regards to recent land-use change.

Further development of the prioritisation strategy will occur within the Bio18 operational programme. The key next steps include ground-truthing areas of predicted conservation value, and conducting updated threat assessments to inform the identification of practical interventions for conservation gains.

Priority class 2 areas are considered to be the most important locations for ground-truthing to confirming species presence (or otherwise). Threat assessments will be conducted as an element of site-led investigations in a parallel line of work. The expected outcomes of this process are the sequential identification of sites for inclusion in migratory species recovery plans (MSRP). More detailed site-level prescriptions will be developed within MSRPs to create a set of management plans, in consultation with land-owners and other key stakeholders.

In comparison to more traditional systematic conservation planning, the objectives of this programme are less oriented towards the expansion of formal ‘protected areas’. Instead, the suggested prioritisation strategy is more oriented towards identifying those sites at which the most positive difference can be made from a combination of resources and opportunities. As such, the programme will incorporate interactive components in the form of targeted future investigations and information from stakeholder participation that can be encouraged through workshops and other knowledge-gathering events. These activities create a feedback loop within the prioritisation strategy and will assist with the design of management interventions for inclusion in the MSRP.

1. Introduction

1.1 Background

Species-based conservation and threatened species recovery makes an important contribution to biodiversity conservation and wider environmental management goals (Mace et al. 2008). The need for improved conservation outcomes has come into sharp focus in recent years due to high rates of species and habitat loss that are indicative of a biodiversity crisis worldwide (Pereira et al. 2012; Singh 2002). Aquatic systems, which are the focus of this project, have been among the most severely affected (Abell 2002; Albert et al. 2020).

Despite having a relatively short history of human occupation (Wilmshurst et al. 2008), New Zealand's experience epitomises these trends, with extinctions having occurred at alarming rate (Craig et al. 2000). Although there has, arguably, been a greater focus on New Zealand's terrestrial biodiversity, aquatic ecosystems are no exception. For example, 22 indigenous freshwater fish were classified as 'threatened' in the most recent assessment (Dunn et al. 2018), according to the New Zealand Threat Classification System criteria (Townsend et al. 2008). A further 11 species were assessed as 'declining' and only 12 species were assigned to the 'not threatened' category from a total of 78 taxa assessed (Dunn et al. 2018). Recent evidence points to an ongoing aquatic degradation trend (Ministry for the Environment 2017; Ministry for the Environment & Stats NZ 2019).

Many threats to aquatic environments are associated with land-use development patterns, and the impacts of invasive species (Collen et al. 2014; Strayer & Dudgeon 2010). Looking ahead, climate change introduces further challenges associated with physical alterations to hydrological systems that will changing species' distributions, and drive new interactions with human activities such as land and water use (Dudgeon et al. 2006; Orchard et al. 2020). Addressing existing and potential threats, and ensuring the protection of important sites, are among the practical interventions that can be incorporated within species recovery plans.

1.2 Migratory species recovery

This project addresses the conservation of two migratory fish species, īnanga (*Galaxias maculatus*) and shortjaw kōkopu (*G. postvectis*). Both species exhibit an amphidromous life cycle (McDowall 2007). Although spawning occurs within the river system, larvae are typically washed out to sea where they develop for a period of ca. six months before migrating back into fresh water to mature into adults (McDowall & Eldon 1980). These characteristics have pronounced implications for conservation around the need to ensure connectivity between life stages and their associated the habitat requirement, which are susceptible to changes over time (McDowall 1992, 1999; Orchard et al. 2018b)..

The migrating juvenile fish contribute to New Zealand's iconic 'whitebait' fishery along with New Zealand's three other migratory galaxiid species (*G. fasciatus*, *G. argenteus*, and *G. brevipinnis*) (McDowall 1984). Īnanga is the most abundant species in the whitebait catch in most regions, though the relative proportions of each may vary between rivers and months (McDowall 1965; Yungnickel et al. 2020). Shortjaw kōkopu are the most threatened of the whitebait species, creating a particular focus for management.

In the most recent conservation status assessment, īnanga was assessed as 'At Risk – Declining', and shortjaw kōkopu as 'Threatened – Nationally Vulnerable' under the New Zealand Threat Classification System (Dunn et al. 2018). In this context, both the recovery of fish populations and continued sustainability of the whitebait fishery are desired outcomes of management.

For the purposes of this project, fishery management options are treated separately from other pressures, and are the subject of additional considerations. Instead, the Department of Conservation (DOC) is establishing Migratory Species Recovery Plans where the focus is oriented towards targeted conservation investments for the management of other pressures. Currently, this programme of work has targeted the above galaxiid species and longfin eel (*Anguilla dieffenbachia*), for attention as part of the as part of the government-funded Bio18 initiative. This contributes to a wider process of prioritisation for the management of threatened and at-risk species and ecosystems (Goodman 2018) and builds on earlier migratory species recovery plans (Department of Conservation 2005).

2. Objectives

This desktop study has been commissioned to provide initial support to the Bio18 Migratory Species Recovery Programme on the South Island's West Coast.

This report has three key objectives:

- Review and summarise the DOC information base, and relevant literature for development of a conservation prioritisation strategy for *G. maculatus* and *G. postvectis* on the South Island's West Coast.
- Recommend options for progressing the conservation prioritisation strategy in collaboration with DOC technical staff.
- Provide an initial characterisation of 3rd order subcatchment planning units, based on the above, using desktop analysis methods. This assessment has the objective of providing initial guidance and recommendations for ground-truthing surveys to be implemented by DOC operational staff.

In addition to this report, a set of spatial data and operational maps have been produced to support the project, as detailed in Appendix 1.

3. Methods

A selection of relevant literature was identified in collaboration with DOC technical staff and complemented with a wider literature review on approaches to conservation prioritisation and spatial ecology of the species. The results were compiled into a summary suitable for operational staff and with a focus on providing context to the prioritisation strategy.

Prioritisation options were evaluated following the review of available datasets provided by the Department. Geospatial analyses and workflows were completed in QGIS v3.4.15 (QGIS Development Team 2020). Specific details of recommended workflows are included in the sections below.

The overall objectives of the desktop assessment can be summarised as follows:

- Define areas of interest within each catchment for purposes of improving security.
- Characterise sites within the range of each species across the region, with aim of identifying a list of sites for security improvement based on the available data.
- Apply appropriate metrics to help decide on importance of areas for the security improvement, to include:
    - fish density per river segment.
    - presence of high quality habitat and/or critical life stages [and related proxies where fish density data are lacking].
    - combined benefits for more than one target species.
- A draft set of these sites is first identified using desktop methods (this assessment) for subsequent ground-truthing within the programme.

4. Literature review

4.1 Approaches to conservation prioritisation

The topic of conservation prioritisation recognises that a range of factors are relevant to the planning of conservation actions, of which the likelihood of loss (e.g., extinction risk) is only one (Berg et al. 2014). Other considerations may include efficiency of the proposed protection measures (Pressey et al. 2004), cost to implement (Wilson et al. 2007), and a range of measures of diversity that may warrant conservation work (Tucker et al. 2012).

Traditional approaches to prioritisation have focussed on reserve design concepts with the objective of identifying the optimal sites for protection (Rodrigues & Gaston 2002). Systematic conservation planning (*sensu*. Margules & Pressey 2000), optimises site selection based on complementarity and is typically assessed on the basis of current biodiversity values (Pressey et al. 2004). This basic idea may be extended to metrics such as species richness to guide decisions on biodiversity value. More recent studies have further extended this general line of thinking to assign conservation priority to other measures of community and ecosystem-level biodiversity (Arponen et al. 2008; Leathwick et al. 2010).

Each of these approaches is challenged by the need for information on the spatial distribution of the values at stake. This has led to a proliferation of modelling approaches with the objective of simulating the distribution of species or habitats (as the case may be), to address empirical data deficiencies. Although the benefits of such models are attractive due to the desirability of generating data 'for everywhere', there is an inevitable degree of uncertainty to be considered in practical applications (Collen 2015). Independent tests of model accuracy are required ideally, although appropriate data for these purposes may not always be available (Elith & Leathwick 2009; Zurell et al. 2010).

In reconciling these aspects, there is some debate over the composition and importance of the relevant considerations. This has spurred the development of an increasingly complex range of systematic approaches to account for the contributions of an increasing range of factors, supported by technical tools such as new algorithms and software. Examples include the incorporation of alternative land uses (Moilanen et al. 2011), and habitat connectivity in aquatic systems (Moilanen et al. 2008; Weeks 2017) within systematic analyses.

On the other hand, there are also alternative conceptual approaches that have the potential to add value to the objective of identifying priority areas for conservation. Those highlighted here include a family of approaches where the focus is on recognising conservation 'opportunity' (Knight et al. 2010). These have the potential to help address the implementation gap between conservation planning and real action on the ground (Arlettaz et al. 2010). In practice, both systematic and opportunistic lines of enquiry are likely to be useful and are potentially complementary. However, both rely on continual improvement of knowledge on key topics such as the location of conservation values and distribution of threats. These aspects are often difficult to ascertain at the scales needed for effective management indicating a need for improved monitoring (Pereira et al. 2012), and the pace of environmental change also suggests the need for regular reassessment over time (Pressey et al. 2007).

4.2 Spatial ecology of īnanga and shortjaw kōkopu

Īnanga

Īnanga are found throughout New Zealand and are the most abundant species in the annual whitebait migration in most rivers nationwide (McDowall 1984). They are predominantly a lowland fish due to having relatively weak climbing abilities (Doehring et al. 2012; Mitchell 1989) that influence their ability to bypass obstacles such as steep rapids and waterfalls (Baker 2014).

The reduction of lowland aquatic habitat through historical drainage (Ausseil et al. 2008; Larned et al. 2018), has undoubtedly contributed to īnanga decline. Īnanga are also reliant on riparian habitat for spawning (Benzie 1968), and this contributes to their vulnerability to land-use change (Hickford et al. 2010; Hickford & Schiel 2011; Orchard et al. 2018b). Important considerations for the recovery of īnanga populations in the contemporary environment include the condition and accessibility of instream habitat for adult fish, and the protection of spawning grounds as critical habitat for this particular life stage.

Many of the known spawning sites are located close to the upstream limit of salt water in lowland tidal waterways (Burnet 1965; Taylor 2002). Recent research has found that spawning may occur over a relatively large salinity range (Orchard et al. 2018b). In some rivers this increases the size of the area that requires protection for spawning (Orchard & Hickford 2020), and is also reflected in the spatio-temporal dynamics of spawning locations which may 'move around' within a rivermouth system. This can create difficulties for reliable detection (Orchard & Hickford 2018; Orchard et al. 2018a), and drive new interactions with disturbance threats such as vegetation clearance, mowing, and grazing (Orchard et al. 2018b). On the other hand, it could also be used to advantage when planning for the restoration of spawning sites alongside other land uses by offering more potential 'room to move' (Orchard 2017; Orchard & Hickford 2016). Spawning grounds have been recently characterised in non-tidal rivers where they are also found near the rivermouth (Orchard & Schiel 2020).

As a predominantly annual species (one year life cycle), human impacts have the potential to cause immediate impacts on īnanga since the total fish population depends largely on the survival of each year's eggs and juvenile fish. Potentially, this fast-feedback cycle might also be used proactively to boost numbers through threat removal and associated habitat restoration work.

Shortjaw kōkopu

Shortjaw kōkopu are the least abundant of New Zealand's five migratory galaxiids based on indicators such as catch composition of whitebait fishery (McDowall 1965; Yungnickel et al. 2020). They are typically found in small to medium-sized rivers with bouldery substrates and abundant riparian cover (Bowie & Henderson 2002; Goodman 2002; McDowall 1990). They also have a preference for podocarp / hardwood catchments, and are seldom found in beech forest (McDowall et al. 1996).

Shortjaw kōkopu have a nationwide distribution typical of diadromous species, although most of the known populations are found on the west coast in both islands (McDowall et al. 1996). The South Island's West Coast is home to several key populations that are important as national strongholds (Goodman 2018). Causes of decline are thought to include habitat degradation and predation by introduced fish species (Department of Conservation 2005; Goodman 2002; Jack et al. 2001; McIntosh et al. 2010).

In general, there has been a lack of studies on many aspects of their spatial ecology such as variation between locations, regional structuring, egg production trends, and timing (Department of Conservation 2005). Many of the existing records involve the occurrence of just one or two fish in sporadic surveys which makes the drawing of conclusions difficult (Allibone et al. 2003). For these reasons, addressing information gaps is an important aspect of current conservation needs and also contributes to uncertainty when assessing their conservation status.

For example, McDowall et al. (1996) noted:

> "*There have been very few objective data that suggested that the species is in danger of imminent decline or extinction, but then not enough has been known to give any assurance that it is adequately protected either*".

Although there is very limited information on spawning, Charteris et al. (2003) have established that it occurs on the riparian margins of streams during flood events. At the catchment scale, there has been no evidence to suggest adult migration to specific spawning areas is required (as is the case for īnanga), with eggs have being found within previously established adult habitat (Charteris et al. 2003). Other studies have also found juveniles in the same location as adults, indicating a lack of separation between adult and juvenile habitat (Allibone 2003; Goodman 2002). Despite this, there is evidence for patchy recruitment in comparison to other migratory species, and this suggests that connectivity issues between life stages may require attention (Bowie & Henderson 2002; McDowall 2010).

For both īnanga and shortjaw kōkopu, spatial dimensions of the life cycle translate to a wide variety of potential interactions with people. Priority areas for conservation action priorities can be expected to include critical habitat for the different life stages and the migration routes required for successful movement.

5. Existing data sources

5.1 Waters of National Importance (WONI)

The Waters of National Importance (WONI) project was established under the Sustainable Development Programme of Action for Freshwater to support decisions on water conservation and competing demands. WONI assessments were made for tourism, irrigation, energy generation, industrial uses, recreation, natural heritage and cultural heritage.

DOC contributions included the identification of nationally important physical and biological freshwater systems (Chadderton et al. 2004). This assessment was based on identifying the minimum set of catchment units that could represent the full range of indigenous freshwater biodiversity in New Zealand. The catchment units were defined using five hierarchical levels of the River Environment Classification (REC) (Snelder & Biggs 2002), resulting in a total of 4706 assessment units (Chadderton et al. 2004). This assessment did not use direct measures of biodiversity value to identify the importance of each assessment unit, with the exception of information of the percentage of natural land cover. Instead, the importance concept was related to the degree of anthropogenic pressure. Consequently, this rationale regarded the least disturbed systems as being the highest priorities for protection. The assessment framework was used to rank the importance of catchment units within 29 biogeographical regions (15 in the North Island, and 13 in the South Island, plus Stewart Island) that were delineated according to the boundaries of major river catchments (Chadderton et al. 2004).

Subsequent work by Leathwick et al. (2007) identified a new framework of 19 biogeographical units, based on the distribution of historic events such as glaciation and volcanism that are likely to have been major influences on contemporary biodiversity patterns. In a separate project, a biologically-tuned classification of freshwater environments was produced based on multivariate models of macroinvertebrates and fish (Leathwick et al. 2008b). These models were subsequently combined using generalised dissimilarity modelling to produce a classification of biological similarities between sites (Leathwick et al. 2008b; Leathwick et al. 2011). This approach used 23 environmental variables that were chosen for their relevance to freshwater biodiversity, and was applied to 567000 river and stream segments as defined by the REC. In developing the models, the environmental variables were related to presence of freshwater fish as recorded in the New Zealand Freshwater Fish Database (NZFFD) and macroinvertebrate data from 2475 sites. The results provide a description of New Zealand river environments with complete spatial coverage from a training dataset of biological data that represents only around 1 % of REC segments nationwide (Leathwick et al. 2008b; Leathwick et al. 2011). The classification is oriented towards discriminating between different river environments that are important for these taxonomic groups. The significance of these for any one species is a separate line of enquiry that was progressed in other work.

5.2 Species distribution models

Although several previous studies have modelled the distribution of New Zealand's freshwater fish (e.g., Leathwick et al. 2005; Joy & Death 2004), this brief review concentrates on the most recent models produced for the REC network version 1 and 2 (hereafter referred to as REC1 and REC2). Outputs from both models are available in the Freshwater Environments of New Zealand (FENZ) database administered by DOC. In both models, NZFFD records are used as the training dataset.

A species distribution model (SDM) for freshwater fish was developed by Leathwick et al. (2008c) for the REC1 network, using the same 23 environmental predictor variables mentioned above. Model fitting used Boosted Regression Trees to generate probabilities of capture for 15 diadromous and 15 non-diadromous species by relating the environmental predictor variables to presence records in the NZFFD. Since the majority of these records come from wadeable streams using electro-fishing as the sampling method, predictions were restricted to wadeable non-saline environments and are best related to electro-fishing probabilities of capture (Leathwick et al. 2008a; Leathwick et al. 2008c). Thresholds for the relating modelled probabilities of capture to presence/absence were calculated from a cross-validation routine using hold-out data.

A similar SDM for the REC2 network was developed by Crow et al. (2014). A component of this project also involved reassigning NZFFD records to the REC2 network segments which feature some typographical updates that reflect improved spatial information obtained since the development of REC1 (Crow et al. 2014). The predictive model was trained using NZFFD records for 33 fish species, but selected records according to the fishing method. For both īnanga and shortjaw kōkopu, electro-fishing was the method chosen for the final model as it accounted for the majority of NZFFD records. This differs from the approach of Leathwick et al. (2008c), who included fishing method as an explanatory variable in the model.

For model fitting, Crow et al. (2014) used a Regularised Random Forest approach that considered 44 environmental, 34 additional hydrological variables, and a selection of spatial variables. These included most of the environmental variables used by Leathwick et al. (2008c), and a new set of hydrological variables developed by Booker & Woods (2014). Thresholds for relating modelled probabilities of capture to predicted presence/absence were calculated using Cohen's Kappa.

Section 5 provides a comparison of the outputs from the models for īnanga and shortjaw kōkopu on the West Coast.

5.3 Pressure indicators

Data layers describing pressure indicators are available in the FENZ database from the earlier work of Leathwick & Julian (2007) who calculated pressures for REC1 catchment units reflecting human-induced disturbance in relation to seven measures.

These address the following pressures:

- loss of native vegetation cover
- proportion of impervious surface cover
- downstream dam effects
- upstream dam effects
- nitrogen loads
- mines and other point source pollution
- presence of exotic fish

A combined pressure measure was also calculated that reflects the expected influence of the above seven factors on the ecological integrity of the environment for freshwater fish.

Advantages of these data layers include their spatial coverage which includes all New Zealand river and stream ecosystems. Out of necessity, some simplifying assumptions were made in designing the metrics used to model the intensity of these pressures across the landscape, all of which rely on transformations of the underlying empirical data to yield 'ecological integrity' scores (Leathwick & Julian 2007).

For the purposes of this project, recent information from surveys of fish passage barriers by NIWA and DOC was compiled by DOC staff and includes a five-point rating of the severity of the barriers observed. Although this dataset is not yet comprehensive, it provides useful information to flag the location of known fish passage issues.

5.4 NZFFD records and National Īnanga Spawning Database

As at 20 June 2020 the NZFFD contains 479 records for īnanga and 247 for shortjaw kōkopu within the DOC West Coast region.

The īnanga records span a date range of 1961 – 2014 and represent 80 catchments with an altitude range of 0 – 194 m. However most of the records are from sites of altitude < 100 m.

The National Īnanga Spawning Database (NISD) was established in the late 1980s and maintained until the early 2000s. Although the database currently requires updating to include more recent records, it does contain a useful record of confirmed spawning sites (as evidenced by eggs) and other observations of spawning and pre-spawning activity (Taylor 2002).

The shortjaw kōkopu records span a date range of 1950 – 2019 and represent 38 catchments with an altitude range of 0 – 395 m. Most of the records are from sites of altitude < 200 m.

6. Comparison of species distribution models

To assist the development of a prioritisation approach, differences between the REC1 and REC2 SDMs were assessed for each target species on the basis of probabilities of capture and presence/absence estimates. In general, the predicted probabilities of capture are lower in the REC2 model outputs. Examples are shown in the Bruce Bay area for īnanga (Fig. 1), and Westport area for shortjaw kōkopu (Fig. 2).

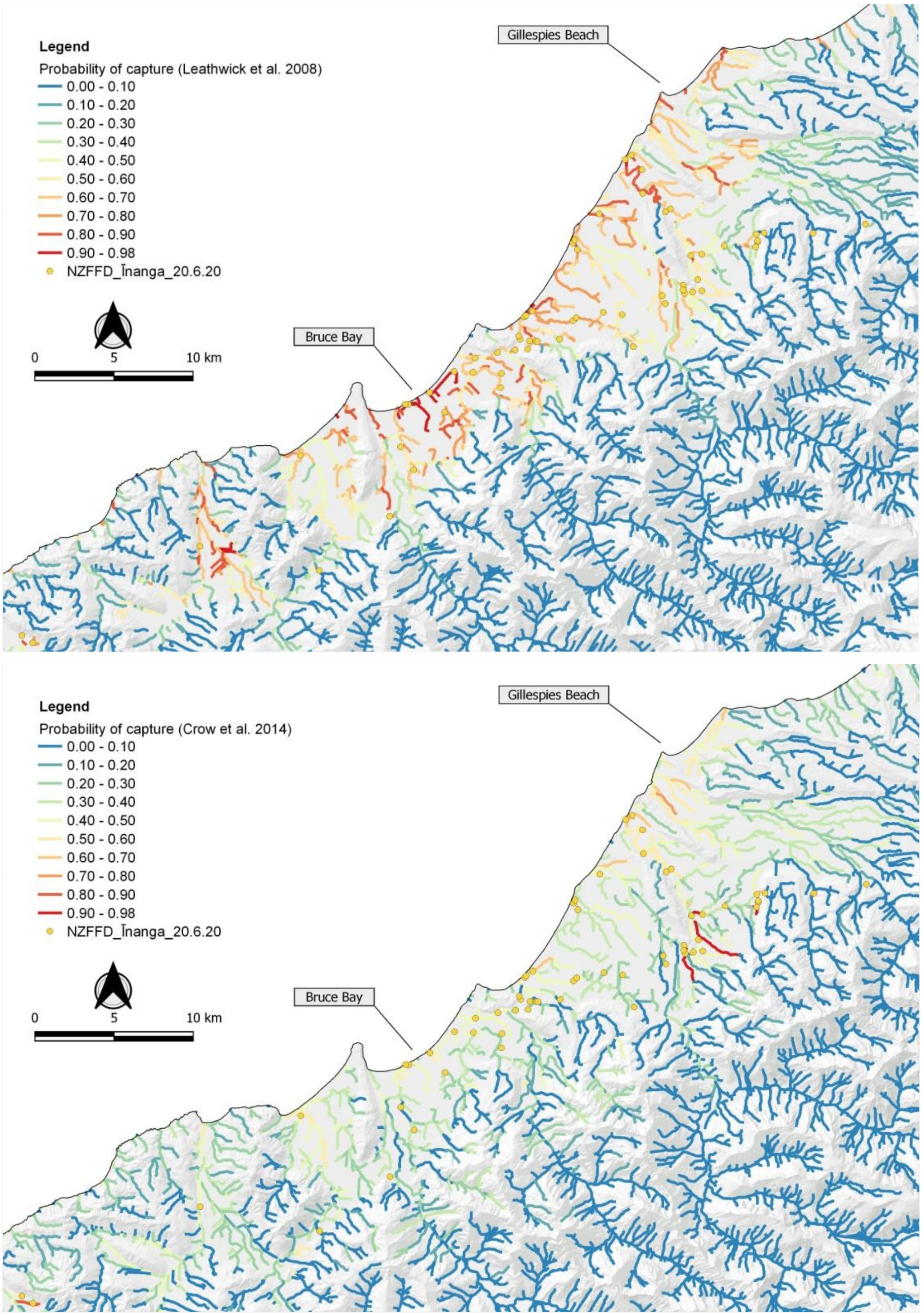

Fig. 1. Modelled probabilities of capture for īnanga (*Galaxias maculatus*) near Bruce Bay. (a) As calculated by Leathwick et al. (2008c). (b) As calculated by Crow et al. (2014).

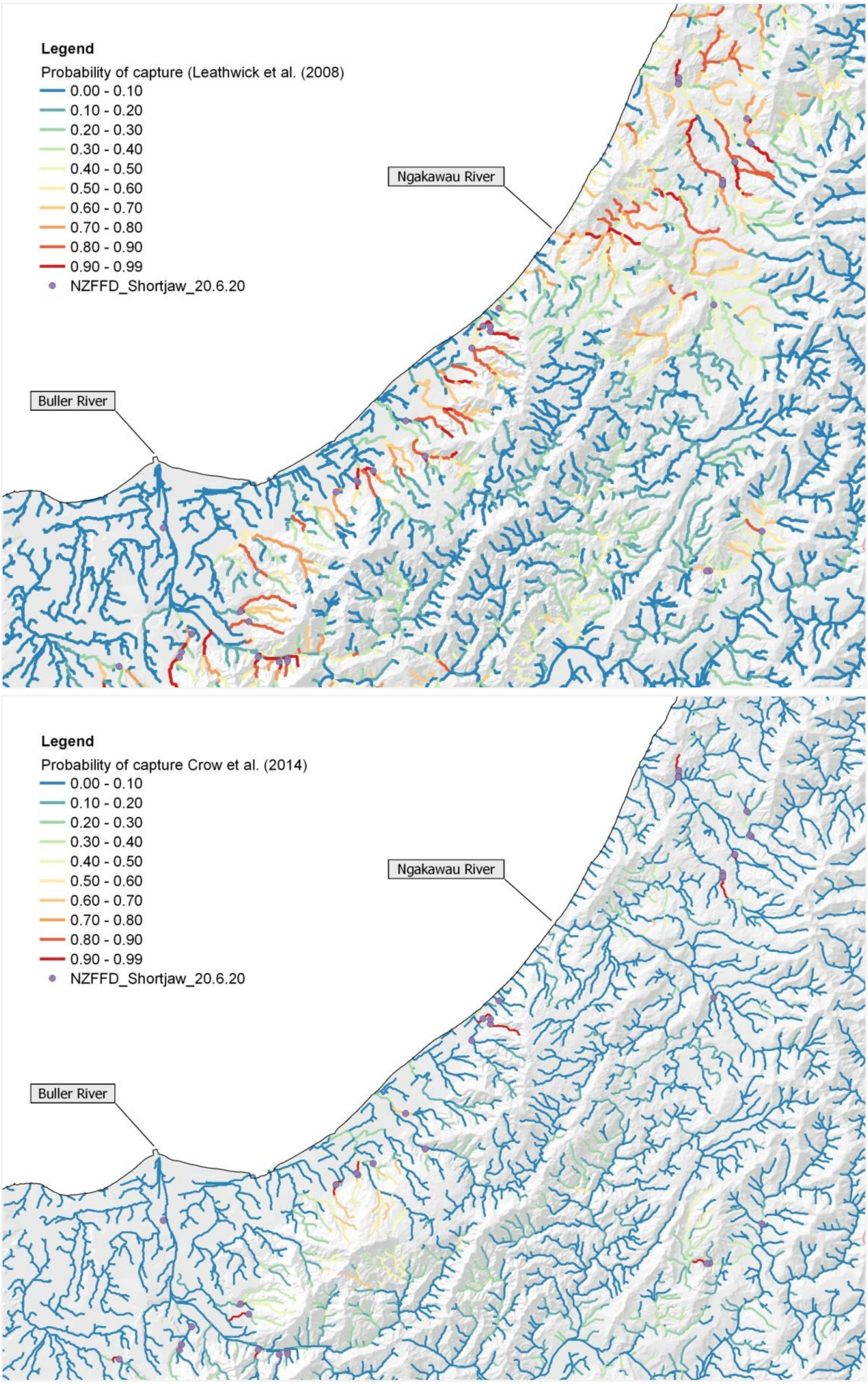

Fig. 2. Modelled probabilities of capture for shortjaw kōkopu (*Galaxias postvectis*) near Westport. (a) As calculated by Leathwick et al. (2008c). (b) As calculated by Crow et al. (2014).

Although the probabilities of capture calculated by Crow et al. (2014) are generally lower than those predicted by Leathwick et al. (2008c), the predicted 'presence' thresholds also differ between the models. Applying these thresholds to visualise the predicted distribution of fish presence provides a more direct comparison. Examples are shown in the Bruce Bay area for īnanga (Fig. 3), and shortjaw kōkopu (Fig. 4). As is generally evident throughout the region, predicted presence is similar between models for īnanga, but much reduced for shortjaw kōkopu in the REC2 model.

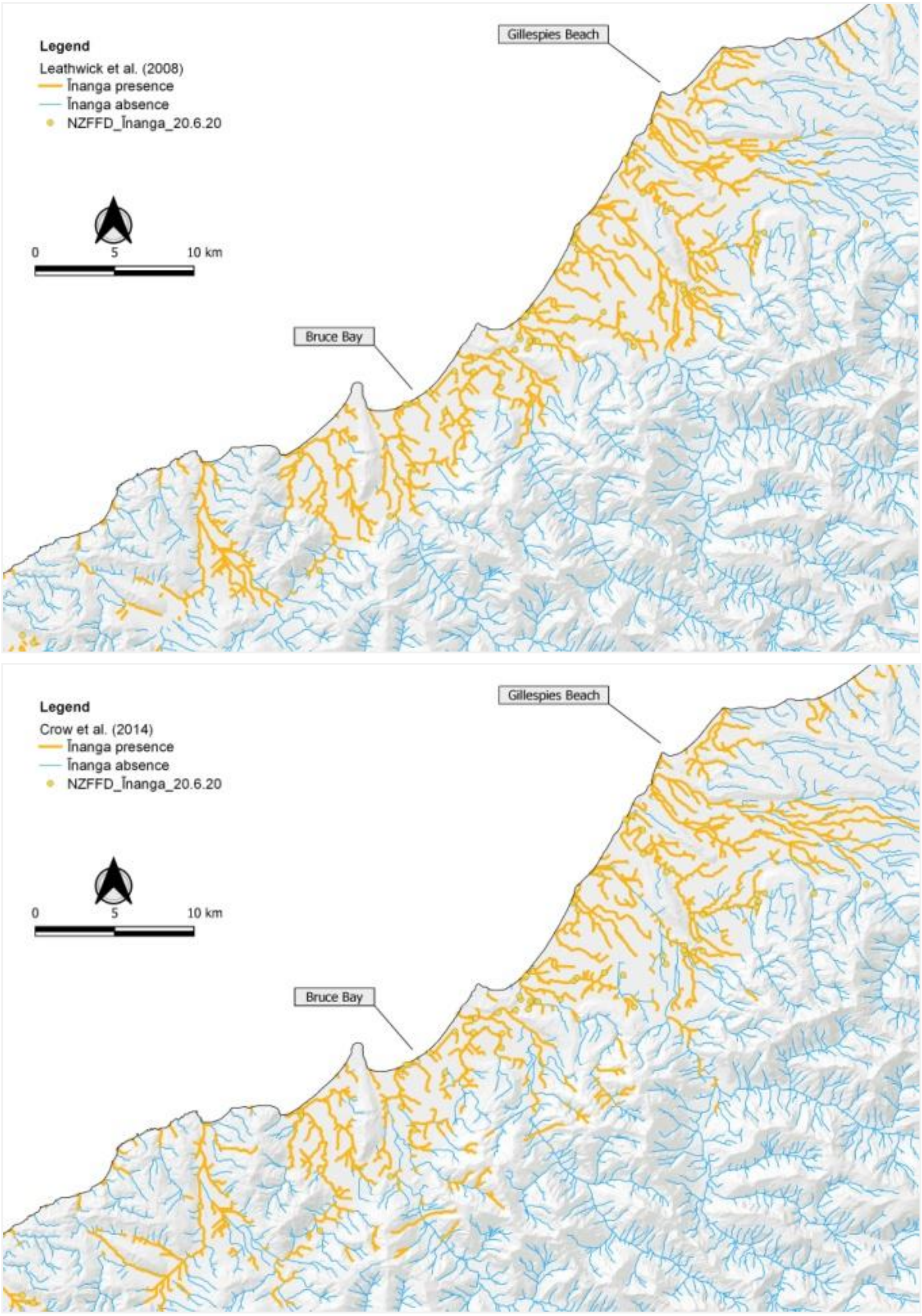

Fig. 3. Predicted presence īnanga (*Galaxias maculatus*) near Bruce Bay. (a) As calculated by Leathwick et al. (2008c). (b) As calculated by Crow et al. (2014).

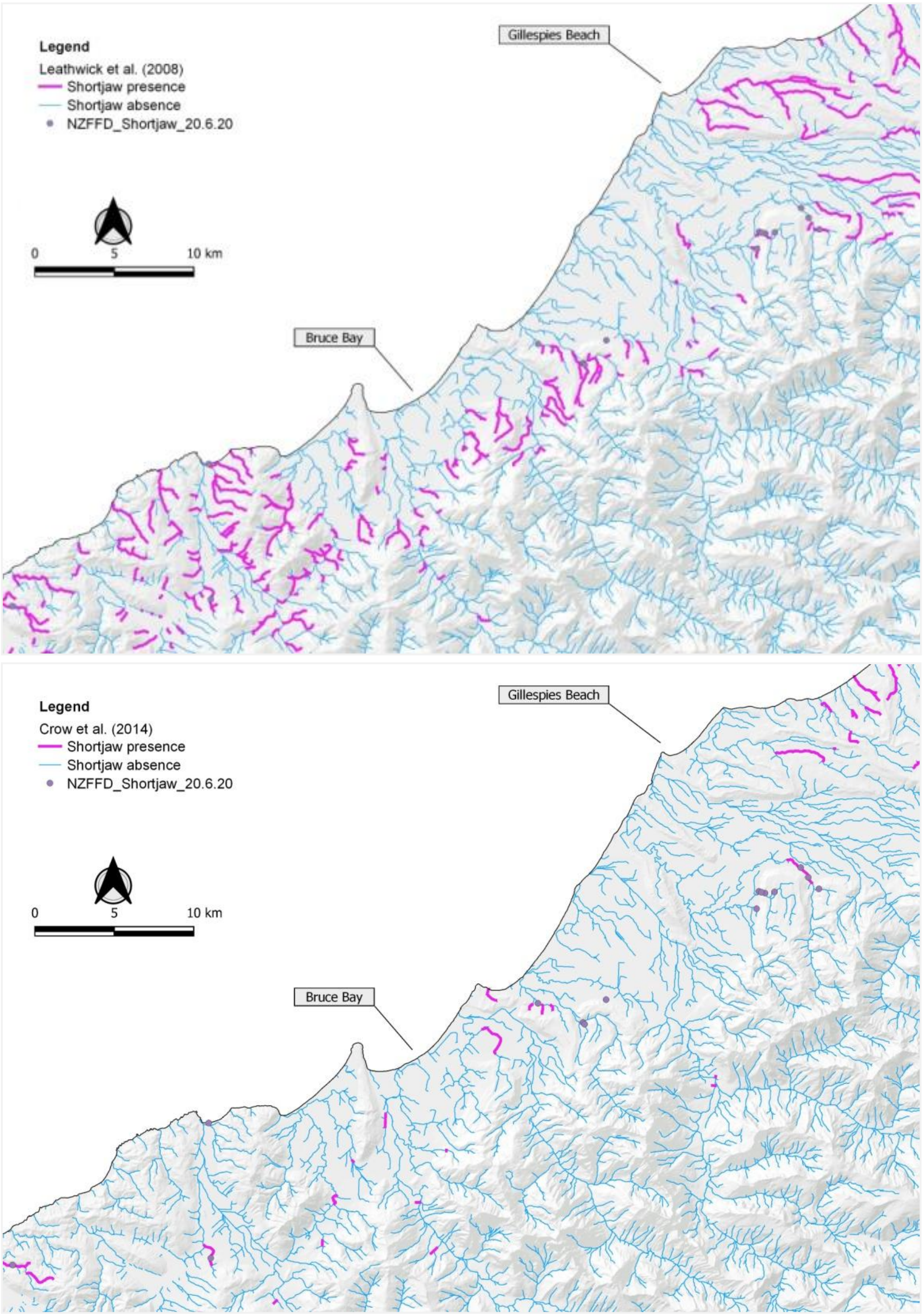

Fig. 4. Predicted presence of shortjaw kōkopu (*Galaxias postvectis*) near Brice Bay. (a) As calculated by Leathwick et al. (2008c). (b) As calculated by Crow et al. (2014).

A summary of model differences is provided in Table 1. For īnanga this shows higher probabilities of capture for the REC1 model, but the modelled threshold is also higher in comparison to the REC2 model, resulting in a reduced predicted distribution overall. This difference amounts to approximately 2% of the REC network, or around 600 km of waterways (Table 1a).

For shortjaw kōkopu, the difference between models is more dramatic. The REC1 model predicts much high probabilities of capture and a lower presence threshold. This translates to around a 9-fold increase in predicted presence in comparison to the REC2 model as measured by the number of REC segments or reach length. Of particular note, the REC2 model predicts shortjaw kōkopu presence in only 1% of the waterway network considered within the model, whereas the for REC1 model this figure is 12% (Table 1b). This results in a markedly different view of spatial priorities. A targeted programme of ground-truthing surveys to address this is therefore a key recommendation for inclusion in the current project.

It is important to note that both models were able to simulate training data with high levels of accuracy based on the area under the curve (AUC) measure for receiver operating characteristic (ROC) curves. This measure compares model performance against the prediction of presence/absence simply by chance (which by definition has a probability of 0.5), and is calculated by comparing confirmed observations (i.e., from the NZFFD) to the modelled results.

Table 1. Comparison of species distribution model outputs for the REC1 model (Leathwick et al. 2008c) and REC2 model (Crow et al. 2014) for īnanga and shortjaw kōkopu on the South Island's West Coast.

(a) Predictions for īnanga (*Galaxias maculatus*).

	REC1 model	REC2 model
Predicted probability of capture		
Mean	0.078	0.069
Median	0.010	0.006
Standard Deviation	0.175	0.136
Minimum	0.000	0.000
Maximum	0.981	0.996
Presence threshold	0.32	0.26
Predicted presence		
Segment count	4467	5315
Total segment length (km)	3493	4091
Proportion of REC network	0.10	0.12

(b) Predictions for shortjaw kōkopu (*Galaxias postvectis*).

	REC1 model	REC2 model
Predicted probability of capture		
Mean	0.070	0.045
Median	0.014	0.022
Standard Deviation	0.154	0.072
Minimum	0.000	0.000
Maximum	0.986	0.982
Presence threshold	0.21	0.335
Predicted presence		
Segment count	4631	545
Total segment length (km)	3953	411
Proportion of REC network	0.12	0.01

7. Prioritisation strategy

7.1 Recommended approach

Conceptual framework

The terminology used here, that of a progressive prioritisation 'strategy', denotes the idea of identifying important sites within an interactive work programme in preference to reliance on desktop exercises which are constrained by the availability and accuracy of information sources at the time. This assessment is intended to be the starting point of that process and additional aspects are already built into the operational roles earmarked for the DOC Bio18 programme. These include the ground-truthing of areas of predicted conservation value, and conducting updated threat assessments to inform the identification of practical interventions for conservation gains.

Spatial units

For this project, a set of 3rd order subcatchment planning units (PLUs) have been supplied by DOC (D. West, pers. comm.). Each PLU is a polygon derived from the catchment boundaries of 3rd order tributaries. Note that there are a small number of higher order mainstem units within this classification, but in all cases these represent only the remaining mainstem unit after all 3rd order subcatchments have been subtracted from it. There are also a small number of 1st and 2nd order stream catchments included where small streams are located close to the coast. This classification results in a total of 2367 PLUs that collectively cover all of the West Coast region as defined using the DOC operational boundaries.

Although REC segments can also be used to visual the location of priority sites, this set of PLUs has been used for previous threat assessments now recorded in the FENZ database, that include calculation of the pressure metrics detailed in Leathwick & Julian (2007). This provides a good starting point for threat assessments to support the current project, and is a convenient scale for the planning of ground-truthing surveys and site investigation work.

7.2 Estimation of conservation value

For evaluating the conservation value of each PLU for the two target species, the best information sources are considered to be the NZFFD, and the SDMs developed by Leathwick et al. (2008c) and Crow et al. (2014). In considering the SDM results, both models were able to simulate training data with high levels of accuracy (AUC > 0.9), and therefore the differences between models relates mostly to their ability to extrapolate into new spatial domains. This has important consequences for the use of SDM results to identify conservation value in those areas, especially since there is a large proportion of the REC network that has yet to be surveyed for these species (shortjaw kōkopu in particular). These uncertainties highlight the strengths of a progressive prioritisation approach as detailed above, including the important role of ground-truthing surveys in helping to confirm species presence and better understand their overall distribution. A targeted campaign of such surveys is recommended for inclusion in the operational work, and with a particular focus on shortjaw kōkopu.

The spatial prioritisation framework shown below will assist the planning of these surveys by identifying areas of model congruence and discrepancy, and using these to guide the survey effort (e.g., following a strategy of surveying the most likely areas first).

Prioritisation framework

A four-tier 'priority class' classification is proposed based on the strength of evidence for species presence (Table 2). This linked-model approach takes into account both of the available SDM data sources, as well as observations from the NZFFD.

Table 2. Classification of spatial priority using a combination of field data and species distribution model (SDM) results. The SDMs provide predicted distributions of īnanga and shortjaw kōkopu on the REC1 network (Leathwick et al. 2008c) and REC2 network (Crow et al. 2014) for the South Island's West Coast.

Priority Class	Description
Class 1	Presence confirmed by the results of field surveys
Class 2	Presence predicted by both of the available SDMs (model congruence)
Class 3	Presence predicted by one of the available SDMs but not the other (model discrepancies)
Class 4	No evidence for presence (as judged by SDM probabilities of capture below the modelled threshold for presence, and the absence of confirmed sightings)

Using this approach, conservation value is assigned primarily on the basis of the evidence for species presence within planning units. However, they may be further ranked using species abundance data available within the New Zealand Freshwater Fish Database (NZFFD), or by modelled probabilities of capture.

Table 3 provides a summary of the classification result for all 3rd order subcatchment planning units in the region (n = 2367).

Table 3. Number of PLUs within each priority class (as defined in Table 2) for īnanga and shortjaw kōkopu based on NZFFD records as at 20 June 2020.

Priority classes (3rd order PLUs)	Species	
	Īnanga (*Galaxias maculatus*)	**Shortjaw kōkopu** (*Galaxias postvectis*)
Class1	174	84
Class 2	412	426
Class 3	159	378
Class 4	1622	1479
Total	2367	2367

Figure 5 shows the distribution of each priority class across the region for both species using NZFFD records obtained on 20 June 2020. Figures 6 and 7 show examples of ranking PLUs. Priority class 1 PLUs are ranked using species abundance data available within the NZFFD (red colour ramp). Appendix 3 provides a list of these rankings for priority 1 PLUs. For the remaining PLUs (priority class 2 – 4), a similar ranked exercise can be done using the probabilities of capture calculated by Leathwick et al. (2008c). The same could be also done using the Crow et al. (2014) probabilities of capture, or using an average-rank that combines the two.

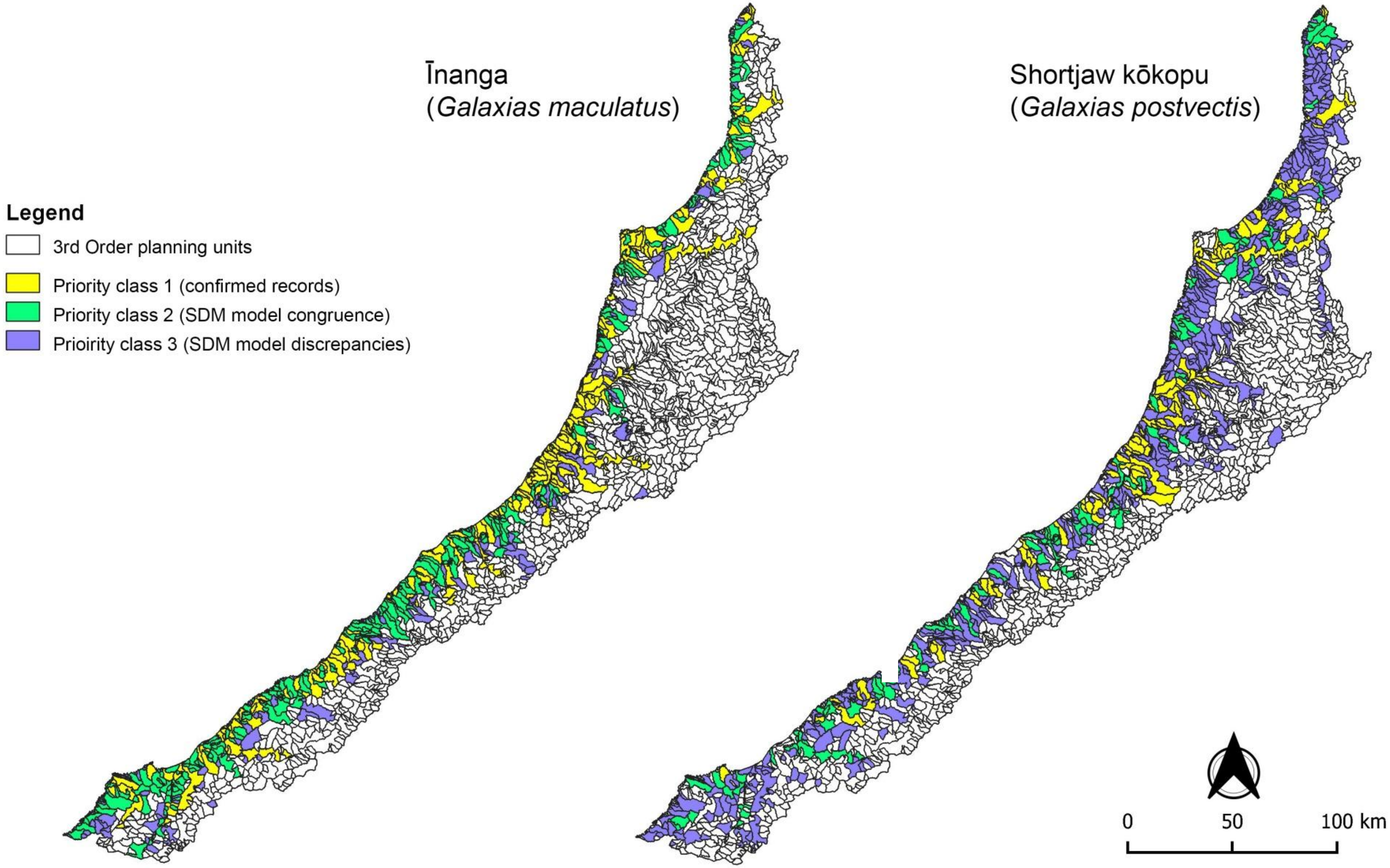

Fig. 5. Distribution of four priority classes applied to 3rd order subcatchment planning units for īnanga and shortjaw kōkopu on the West Coast.

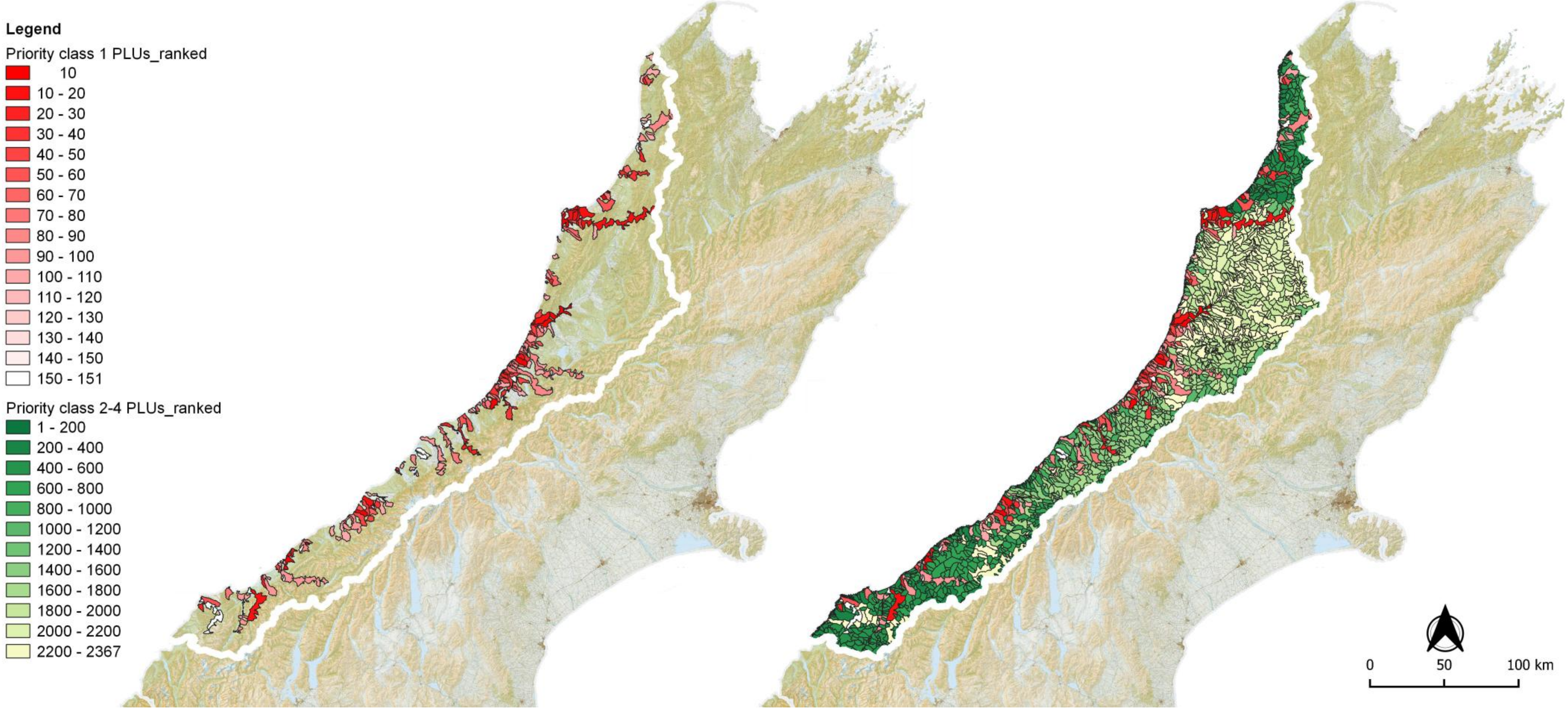

Fig. 6. Examples of ranking of planning units for īnanga (*Galaxias maculatus*) on the West Coast. (a) Priority class 1 PLUs ranked by species abundance based on NZFFD records as at 20 June 2020. (b) remaining PLUs (priority class 2 – 4) ranked by probabilities of capture from Leathwick et al. (2008c).

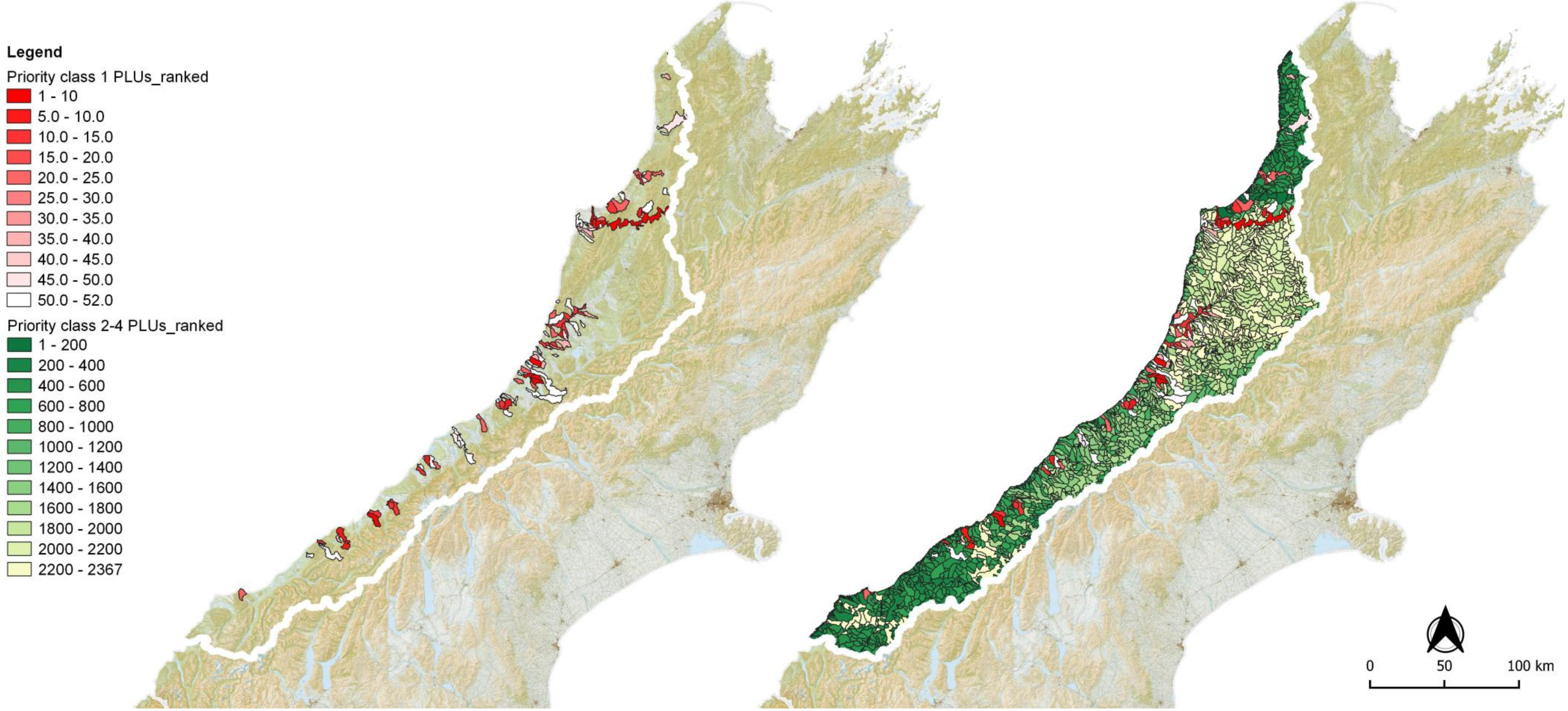

Fig 7. Examples of ranking of planning units for shortjaw kōkopu (*Galaxias postvectis*) on the West Coast. (a) Priority class 1 PLUs ranked by species abundance based on NZFFD records as at 20 June 2020. (b) remaining PLUs (priority class 2 – 4) ranked by probabilities of capture from Leathwick et al. (2008c).

7.3 Critical habitat considerations

The above approach does not explicitly consider the idea of 'critical habitat' for particular life stages. Since the classification units are treated equally based on the evidence for adult fish presence, there is the potential to miss or underestimate the importance of areas such as migration pathways and spawning grounds. Two key recommendations to address these aspects are outlined below.

Protection of spawning grounds

- Identify and prioritise the protection of spawning sites as a separate exercise from that of adult fish habitat.
- For shortjaw kōkopu, very few spawning sites are known, but those that have been found are in the vicinity of adult habitat. Therefore it would be reasonable to use adult fish presence as an indicator of potential spawning sites. When assessing threats it may be beneficial to give particular regard to spawning threats at the same sites, which suggests attention to seasonal disturbances and favourable environmental conditions such as riparian cover.
- For īnanga, a spawning site prioritisation method is already available that identifies priority areas based on known spawning sites which are typically located near rivermouths. This method identifies priority planning units for the protection of spawning sites and data gaps where there is a known fish population but the spawning location has yet to be found (Orchard 2019). An intersection of National Īnanga Spawning Database (NISD) records and the 3rd order PLUs identifies 38 PLUs where spawning sites have been found (Fig. 8). These PLUs should be prioritised for immediate attention (i.e., to assess potential threat). Establishing the location of spawning sites in other catchments where īnanga are found is also important to ensure that critical habitat is identified and assessed.

Protection of migration pathways

- Conducting threat assessments in all PLUs downstream of priority sites for adult fish is likely to be beneficial. However, this approach will tend to miss legacy issues (e.g., existing fish barriers) that may be responsible for the lack of adult fish presence in otherwise suitable habitat upstream. For these reasons, a systematic approach to identifying and solving fish passage issues is recommended.
- In prioritising the remediation of known barriers, predictions from the SDM models may be useful, especially where the models are tuned to remove the effect of fish barriers as an explanatory variable. Following this approach, the model outputs could be used to indicate where there is an abundance of 'potential habitat' upstream. This information may assist with decisions on investment priorities for barrier removal or remediation within an ongoing programme of work.

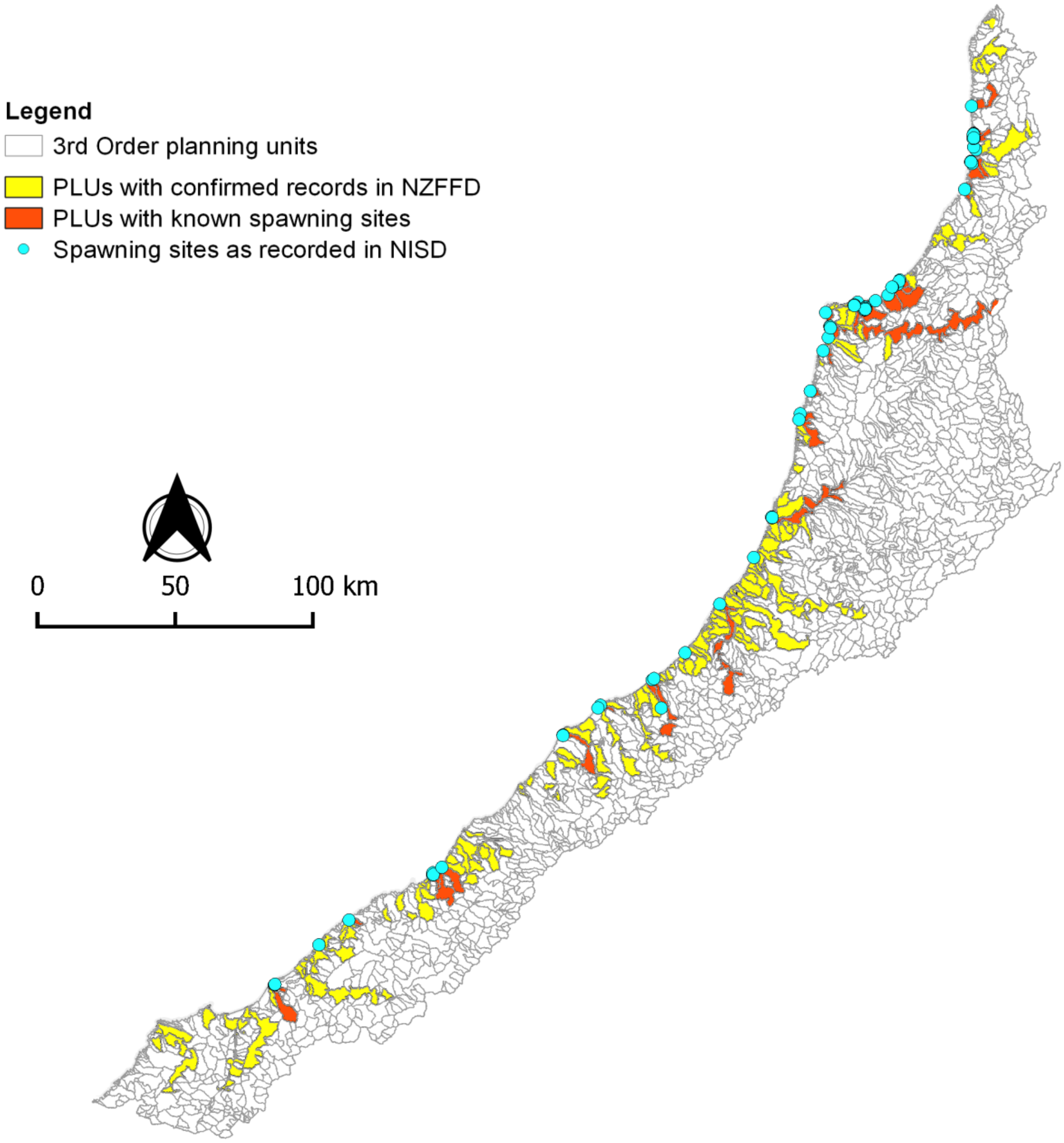

Fig. 8. Location of 3rd order PLUs with known īnanga spawning sites (red) compared with all PLUs where īnanga have been recorded in the NZFFD (yellow) for the South Island's West Coast.

7.4 Estimate of anthropogenic pressures

A two-step workflow can be used to make a desktop assessment of threats at any selection of sites. First select the sites of interest by conservation value (e.g. by priority class), and then assess the distribution of all threats individually across those sites (Fig. 9).

A set of maps were produced that characterise the distribution of threats in this way (see Appendix 1 for details), using nine indicators of anthropogenic pressure for which region-wide data were available and includes one measure of 'combined pressures' (Appendix 2). The most threatened sites for each threat type can be easily identified and short-lists made. This provides an initial indication of the intensity of individual threats across all PLUs, despite some limitations in currency of the underlying data with regard to recent land-use change.

Fig. 9. Workflow for a desktop assessment of threats at high value sites.

7.5 Summary of workflow

In summary, the suggested workflow is based on the idea of decoupling the assessment of conservation value from the assessment of threats. This creates a relatively simple approach that is suited to recovery planning. A flow chart covering the main steps is shown in Fig. 10.

Although some of the factors responsible for the current distribution of these species relate to existing threats and legacy effects (e.g., fish barriers and riparian vegetation clearance) these aspects can be partly overcome using the SDMs. Even without tuning the SDM outputs towards to prediction of 'potential habitat', they identify a considerable number of PLUs with predicted presence versus the number of PLUs where presence has been actually confirmed. It is expected that ground-truthing at these sites will help to further improve the understanding of conservation value and also shows the usefulness of the SDMs in helping to direct survey effort despite the differences between models.

Treating the threat assessment separately has several practical advantages. Instead of a threat or 'integrity' score being embedded within the concept of priority and assessed using desktop exercises, this approach invites updated threat assessments that are prioritised according to the measures of value. In turn, the threat assessments are oriented towards identifying practical opportunities for improvements. Although some threat types may not be easily solved, others will be amenable to interventions that can help conserve these species. This approach is expected to generate tangible results for inclusion in recovery plans.

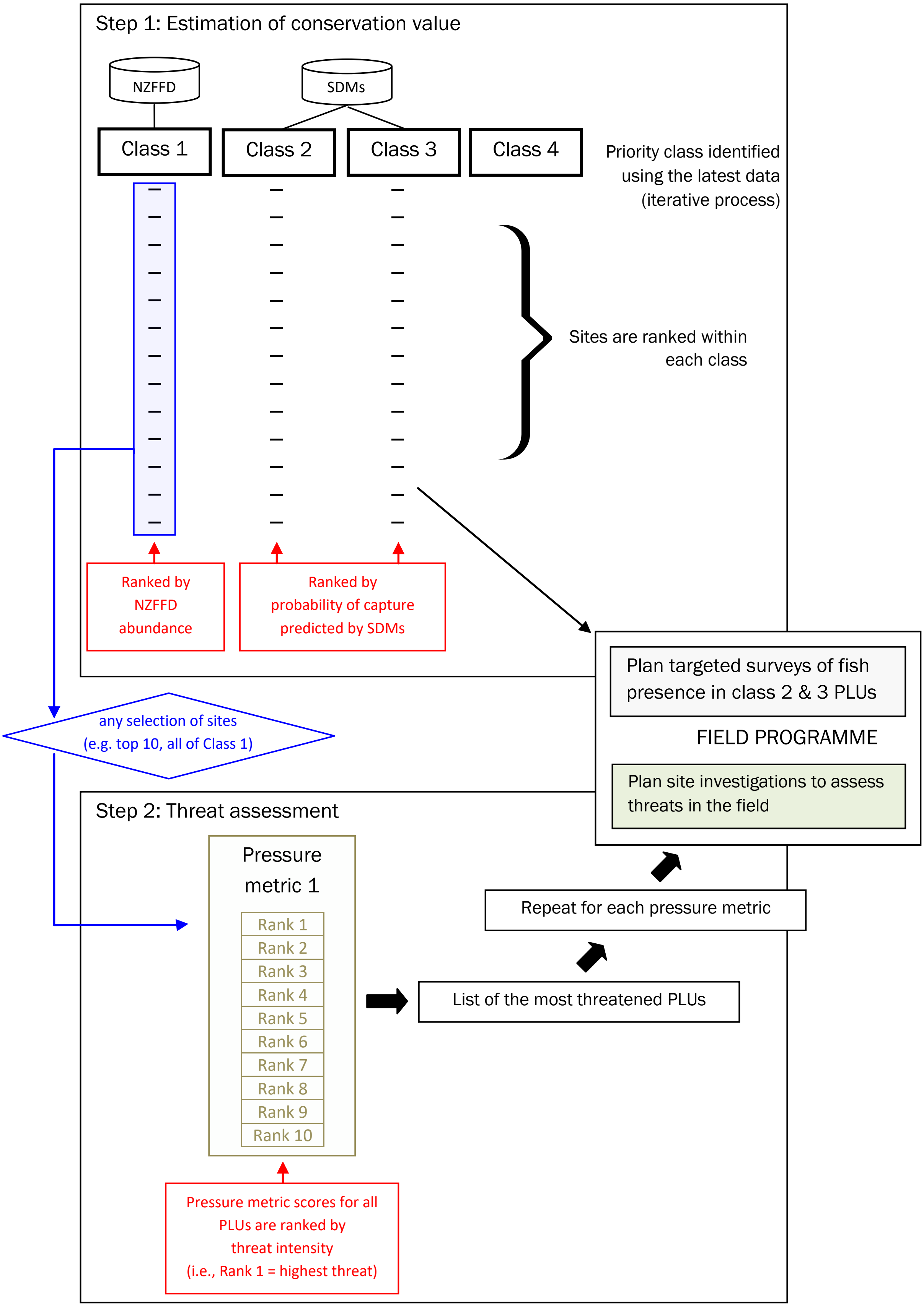

Fig. 10. Flow chart of steps to help guide decisions on spatial priority when planning site investigations to support the development of recovery plans.

8. Next steps

There is an iterative aspect to further development of the recommended prioritisation strategy as results from the ground-truthing activities are fed back into the classification of priority areas, especially where field surveys are able to confirm the presence of new populations. Priority class 2 areas are considered to be the most important locations for ground-truthing to confirming species presence (or otherwise) based on the results of the SDMs. Threat assessments will be conducted as an element of site-led investigations in a parallel line of work. The expected outcomes of this process are the sequential identification of sites for inclusion in migratory species recovery plans (MSRP). More detailed site-level prescriptions will be developed within the MSRP to create a set of management plans, in consultation with land-owners and other key stakeholders.

In comparison to more traditional systematic conservation planning, the objectives of this programme are less oriented towards the expansion of formal 'protected areas'. Instead, the prioritisation strategy is more oriented towards identifying those sites at which the most positive difference can be made from a combination of resources and opportunities. As such, the programme incorporates interactive components in the form of targeted future investigations and information from stakeholder participation that can be encouraged through workshops and other knowledge-gathering events. These activities create a feedback loop within the prioritisation strategy and will assist with the design of management interventions for inclusion in the MSRP.

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10. References

Abell, R. (2002). Conservation Biology for the Biodiversity Crisis: A Freshwater Follow-up. *Conservation Biology, 16*(5), 1435-1437. doi:10.1046/j.1523-1739.2002.01532.x

Albert, J. S., Destouni, G., Duke-Sylvester, S. M., Magurran, A. E., Oberdorff, T., Reis, R. E., . . . Ripple, W. J. (2020). Scientists' warning to humanity on the freshwater biodiversity crisis. *Ambio*. doi:10.1007/s13280-020-01318-8

Allibone, R. (2003). Egg cannibalism by inanga (*Galaxias maculatus*). *New Zealand Journal of Marine and Freshwater Research, 37*(4), 763-765.

Allibone, R., Caskey, D., & Miller, R. (2003). Population structure, individual movement, and growth rate of shortjaw kokopu (Galaxias postvectis) in two North Island, New Zealand streams. *New Zealand Journal of Marine and Freshwater Research, 37*(3), 473-483. doi:10.1080/00288330.2003.9517182

Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T. S., Sierro, A., James, E. M. W., & Braunisch, V. (2010). From publications to public actions: When conservation biologists bridge the gap between research and implementation. *Bioscience, 60*(10), 835-842. doi:10.1525/bio.2010.60.10.10

Arponen, A., Moilanen, A., & Ferrier, S. (2008). A successful community-level strategy for conservation prioritization. *Journal of Applied Ecology, 45*(5), 1436-1445. doi:10.1111/j.1365-2664.2008.01513.x

Ausseil, A. G., Gerbeaux, P., Chadderton, W. L., Stephens, T., Brown, D., & Leathwick, J. (2008). *Wetland ecosystems of national importance for biodiversity: criteria, methods and candidate list of nationally important inland wetlands*. Landcare Research Contract Report LC0708/158, 174 pp.

Baker, C. F. (2014). Effect of ramp length and slope on the efficacy of a baffled fish pass. *Journal of Fish Biology, 84*(2), 491-502. doi:10.1111/jfb.12298

Benzie, V. (1968). Some ecological aspects of the spawning behaviour and early development of the common whitebait *Galaxias maculatus attenuatus* (Jenyns). *Proceedings of the New Zealand Ecological Society, 15*, 31-39.

Berg, C., Abdank, A., Isermann, M., Jansen, F., Timmermann, T., & Dengler, J. (2014). Red Lists and conservation prioritization of plant communities – a methodological framework. *Applied Vegetation Science, 17*(3), 504-515. doi:10.1111/avsc.12093

Booker, D. J., & Woods, R. A. (2014). Comparing and combining physically-based and empirically-based approaches for estimating the hydrology of ungauged catchments. *Journal of Hydrology, 508*, 227-239. doi:10.1016/j.jhydrol.2013.11.007

Bowie, S., & Henderson, I. M. (2002). *Shortjaw kokopu (Galaxias postvectis) in the northern Tararua Ranges: distribution and habitat selection*. DOC Science Internal Series Vol. 30. Department of Conservation, Wellington, N.Z. 21pp.

Burnet, A. M. R. (1965). Observations on the spawning migrations of *Galaxias attenuatus*. *New Zealand Journal of Science, 8*, 79-87.

Chadderton, W. L., Brown, D. J., & Stephens, R. T. (2004). *Identifying freshwater ecosystems of national importance for biodiversity: Criteria, methods, and candidate list of nationally important rivers. Discussion document.* Wellington, N.Z.: Dept. of Conservation. 112pp.

Charteris, S. C., 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*(3), 493-505. doi:10.1080/00288330.2003.9517184

Collen, B., Whitton, F., Dyer, E. E., Jonathan, E. M. B., Cumberlidge, N., William, R. T. D., . . . Böhm, M. (2014). Global patterns of freshwater species diversity, threat and endemism. *Global Ecology and Biogeography, 23*(1/2), 40-51. doi:10.1111/geb.12096

Collen, B. (2015). Conservation prioritization in the context of uncertainty. *Animal Conservation, 18*(4), 315-317. doi:10.1111/acv.12222

Craig, J., Anderson, S., Clout, M., & Creese, B. (2000). Conservation issues in New Zealand. *Annual Review of Ecology and Systematics, 31*, 61.

Crow, S., Booker, D., Sykes, J., Unwin, M., & Shankar, U. (2014). *Predicting distributions of New Zealand freshwater fishes*. Report prepared for the Department of Conservation. NIWA, Christchurch. 100pp.

Department of Conservation. (2005). *New Zealand large galaxiid recovery plan, 2003-13: shortjaw kokopu, giant kokopu, banded kokopu and koaro*. Retrieved from Wellington:

Doehring, K., Young, R. G., & McIntosh, A. R. (2012). Facilitation of upstream passage for juveniles of a weakly swimming migratory galaxiid. *New Zealand Journal of Marine and Freshwater Research, 46*(3), 303-313. doi:10.1080/00288330.2011.639787

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z.-I., Knowler, D. J., Lévêque, C., . . . Sullivan, C. A. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews of the Cambridge Philosophical Society, 81*(2), 163-182. doi:10.1017/S1464793105006950

Dunn, N. R., Allibone, R. M., Closs, G. P., Crow, S. K., David, B. O., Goodman, J. M., . . . Rolfe, J. R. (2018). *Conservation status of New Zealand freshwater fishes, 2017*. *Zealand Threat Classification Series 24*. Wellington: Department of Conservation. 11 pp.

Elith, J., & Leathwick, J. R. (2009). Species Distribution Models: Ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics, 40*(1), 677-697. doi:10.1146/annurev.ecolsys.110308.120159

Goodman, J. (2018). *Conservation, ecology and management of migratory galaxiids and the whitebait fishery. A summary of current knowledge and information gaps*. Nelson: Department of Conservation. 39pp.

Goodman, J. M. (2002). *The ecology and conservation of shortjaw kokopu (Galaxias postvectis) in Nelson and Marlborough.* M. Sc. thesis. University of Canterbury. Department of Zoology.

Hickford, M. J. H., Cagnon, M., & Schiel, D. R. (2010). Predation, vegetation and habitat-specific survival of terrestrial eggs of a diadromous fish, *Galaxias maculatus* (Jenyns, 1842). *Journal of Experimental Marine Biology and Ecology, 385*(1-2), 66-72. doi:10.1016/j.jembe.2010.01.010

Hickford, M. J. H., & Schiel, D. R. (2011). Population sinks resulting from degraded habitats of an obligate life-history pathway. *Oecologia, 166*(1), 131-140. doi:10.1007/s00442-010-1834-7

Jack, D. C., Barrier, R., & Goodman, J. (2001). *Short-jawed kokopu (Galaxias postvectis): conservation status in Nelson/Marlborough : year three interim report, 2001*. Department of Conservation, Nelson/Marlborough Conservancy.

Joy, M. K., & Death, R. G. (2004). Predictive modelling and spatial mapping of freshwater fish and decapod assemblages using GIS and neural networks. *Freshwater Biology, 49*(8), 1036-1052. doi:10.1111/j.1365-2427.2004.01248.x

Knight, A. T., Cowling, R. M., Difford, M., & Campbell, B. M. (2010). Mapping human and social dimensions of conservation opportunity for the scheduling of conservation action on private land. *Conservation Biology, 24*(5), 1348-1358. doi:10.1111/j.1523-1739.2010.01494.x

Larned, S., Booker, D., Dudley, B., Moores, J., Monaghan, R., Baillie, B., . . . Short, K. (2018). *Land-use impacts on freshwater and marine environments in New Zealand*. Report prepared for the Ministry for the Environment. NIWA, Christchurch. 291pp. .

Leathwick, J., & Julian, K. (2007). *Production of pressures estimates for New Zealand river catchments*. Report prepared for the Department of Conservation. NIWA, Hamilton. 13pp.

Leathwick, J., Chadderton, W. L., Elith, J., Rowe, D., & Hastie, T. (2008a). Dispersal, Disturbance and the Contrasting Biogeographies of New Zealand's Diadromous and Non-Diadromous Fish Species. *Journal of Biogeography, 35*(8), 1481-1497. doi:10.1111/j.1365-2699.2008.01887.x

Leathwick, J., Julian, K., Elith, J., Chadderton, L., Ferrier, S., & Snelder, T. (2008b). *A biologically-optimised environmental classification of New Zealand rivers and streams: reanalysis excluding human impacts variables*. Report prepared for the Department of Conservation. NIWA, Hamilton. 47pp.

Leathwick, J., Julian, K., Elith, J., & Rowe, D. (2008c). *Predicting the distributions of freshwater fish species for all New Zealand's rivers and streams*. Report prepared for the Department of Conservation. NIWA, Hamilton. 56pp.

Leathwick, J. R., Rowe, D., Richardson, J., Elith, J., & Hastie, T. (2005). Using multivariate adaptive regression splines to predict the distributions of New Zealand's freshwater diadromous fish. *Freshwater Biology, 50*(12), 2034-2052. doi:10.1111/j.1365-2427.2005.01448.x

Leathwick, J. R., Collier, K. J., & Chadderton, L. (2007). *Identifying freshwater ecosystems with nationally important natural heritage values: development of a biogeographic framework*. Wellington: Department of Conservation. 30pp.

Leathwick, J. R., Moilanen, A., Ferrier, S., & Julian, K. (2010). Complementarity-based conservation prioritization using a community classification, and its application to riverine ecosystems. *Biological Conservation, 143*(4), 984-991. doi:10.1016/j.biocon.2010.01.012

Leathwick, J. R., Snelder, T., Chadderton, W. L., Elith, J., Julian, K., & Ferrier, S. (2011). Use of generalised dissimilarity modelling to improve the biological discrimination of river and stream classifications. *Freshwater Biology, 56*(1), 21-38. doi:10.1111/j.1365-2427.2010.02414.x

Mace, G. M., Collar, N. J., Gaston, K. J., Hilton-Taylor, C., AkÇAkaya, H. R., Leader-Williams, N., . . . Stuart, S. N. (2008). Quantification of Extinction Risk: IUCN's System for classifying threatened species. Cuantificación del Riesgo de Extinción: Sistema de la UICN para la Clasificación de Especies Amenazadas. *Conservation Biology, 22*(6), 1424-1442. doi:10.1111/j.1523-1739.2008.01044.x

McDowall, R. M. (1965). The composition of the New Zealand whitebait catch, 1964. *New Zealand Journal of Science, 8*(3), 285-300.
McDowall, R. M., & Eldon, G. A. (1980). The ecology of whitebait migrations (Galaxiidae: *Galaxias* spp.). *New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Bulletin, 20*, 1-172.
McDowall, R. M. (1984). *The New Zealand whitebait book.* Wellington: Reed.
McDowall, R. M. (1990). *New Zealand freshwater fishes: A natural history and guide*. Auckland: Heinemann Reed.
McDowall, R. M. (1992). Particular problems for the conservation of diadromous fish. *Aquatic Conservation: Marine and Freshwater Ecosystems, 2*(4), 351-355. doi:10.1002/aqc.3270020405
McDowall, R. M., Eldon, G. A., Bonnett, M. L., & Sykes, J. R. E. (1996). *Critical habitats for the conservation of shortjawed kokopu, Galaxias postvectis Clarke*. Department of Conservation, Wellington, N.Z. 30pp.
McDowall, R. M. (1999). Different kinds of diadromy: Different kinds of conservation problems. *ICES Journal of Marine Science, 56*(4), 410-413. doi:10.1006/jmsc.1999.0450
McDowall, R. M. (2007). On amphidromy, a distinct form of diadromy in aquatic organisms. *Fish and Fisheries, 8*(1), 1-13.
McDowall, R. M. (2010). *New Zealand freshwater fishes: an historical and ecological biogeography* (Vol. 32). New York: Springer.
McIntosh, A. R., McHugh, P. A., Dunn, N. R., Goodman, J. M., Howard, S. W., Jellyman, P. G., . . . Woodford, D. J. (2010). The impact of trout on galaxiid fishes in New Zealand. *New Zealand Journal of Ecology, 34*(1), 195-206.
Ministry for the Environment. (2017). *National Policy Statement for Freshwater Management 2014 (amended 2017)*. Wellington: Ministry for the Environment.
Ministry for the Environment & Stats NZ. (2019). *New Zealand's Environmental Reporting Series: Environment Aotearoa 2019*. Wellington: Ministry for the Environment and Stats NZ. 125pp.
Mitchell, C. P. (1989). Swimming performances of some native freshwater fishes. *New Zealand Journal of Marine and Freshwater Research, 23*(2), 181-187. doi:10.1080/00288330.1989.9516354
Moilanen, A., Leathwick, J., & Elith, J. (2008). A method for spatial freshwater conservation prioritization. *Freshwater Biology, 53*(3), 577-592. doi:10.1111/j.1365-2427.2007.01906.x
Moilanen, A., Anderson, B. J., Eigenbrod, F., Heinemeyer, A., Roy, D. B., Gillings, S., . . . Thomas, C. D. (2011). Balancing alternative land uses in conservation prioritization. *Ecological Applications, 21*(5), 1419-1426. doi:10.1890/10-1865.1
Orchard, S., & Hickford, M. J. H. (2016). *Spatial effects of the Canterbury earthquakes on īnanga spawning habitat and implications for waterways management*. Report prepared for IPENZ Rivers Group and Ngāi Tahu Research Centre. Waterways Centre for Freshwater Management and Marine Ecology Research Group. Christchurch: University of Canterbury. 37pp.
Orchard, S. (2017). *Response of īnanga spawning habitat to riparian vegetation management in the Avon & Heathcote catchments.* Report prepared for Christchurch City Council. 35pp.
Orchard, S., & Hickford, M. J. H. (2018). Census survey approach to quantifying īnanga spawning habitat for conservation and management. *New Zealand Journal of Marine and Freshwater Research, 52*(2), 284-294. doi:10.1080/00288330.2017.1392990.
Orchard, S., Hickford, M. J. H., & Schiel, D. R. (2018a). Use of artificial habitats to detect spawning sites for the conservation of Galaxias maculatus, a riparian-spawning fish. *Ecological Indicators, 91*, 617-625. doi:10.1016/j.ecolind.2018.03.061
Orchard, S., Hickford, M. J. H., & Schiel, D. R. (2018b). Earthquake-induced habitat migration in a riparian spawning fish has implications for conservation management. *Aquatic Conservation: Marine and Freshwater Ecosystems, 28*(3), 702-712. doi:10.1002/aqc.2898
Orchard, S. (2019). *Conservation prioritisation methodology for īnanga spawning sites*. Report prepared for the Department of Conservation, November 2019. 47pp.
Orchard, S., & Hickford, M. J. H. (2020). Protected area effectiveness for fish spawning habitat in relation to earthquake-induced landscape change. In R. Maiti, H. G. Rodríguez, C. A. Kumari, D. Mandal, & N. C. Sarkar (Eds.), *Sustainable bioresource management: Climate change mitigation and natural resource conservation. (Chpt 22)*: Apple Academic Press. 526pp.
Orchard, S., Hughey, K. F. D., & Schiel, D. R. (2020). Risk factors for the conservation of saltmarsh vegetation and blue carbon revealed by earthquake-induced sea-level rise. *Science of the Total Environment, 746*, 141241. doi:10.1016/j.scitotenv.2020.141241
Orchard, S., & Schiel, D. R. (2020). Whitebait conservation and protected areas at non-tidal rivermouths: integrating biogeography and environmental controls on īnanga (*Galaxias maculatus*) spawning grounds. *bioRxiv*, 2020.2011.2006.372243. doi:10.1101/2020.11.06.372243

Pereira, H. M., Navarro, L. M., & Martins, I. S. (2012). Global biodiversity change: The bad, the good, and the unknown. *Annual Review of Environment and Resources, 37*(1), 25-50. doi:10.1146/annurev-environ-042911-093511

Pressey, R. L., Watts, M. E., & Barrett, T. W. (2004). Is maximizing protection the same as minimizing loss? Efficiency and retention as alternative measures of the effectiveness of proposed reserves. *Ecology Letters, 7*(11), 1035-1046. doi:10.1111/j.1461-0248.2004.00672.x

Pressey, R. L., Cabeza, M., Watts, M. E., Cowling, R. M., & Wilson, K. A. (2007). Conservation planning in a changing world. *Trends in Ecology & Evolution, 22*(11), 583-592. doi:10.1016/j.tree.2007.10.001

QGIS Development Team. (2020). *QGIS Geographic Information System. Open Source Geospatial Foundation Project.* http://qgis.org.

Rodrigues, A. S. L., & Gaston, K. J. (2002). Optimisation in reserve selection procedures—why not? *Biological Conservation, 107*(1), 123-129. doi:10.1016/S0006-3207(02)00042-3

Singh, J. S. (2002). The biodiversity crisis: A multifaceted review. *Current Science, 82*(6), 638-647.

Snelder, T. H., & Biggs, B. J. F. (2002). Multi-scale river environment classification for water resources management. *Journal of the American Water Resources Association, 38*, 1225-1240.

Strayer, D. L., & Dudgeon, D. (2010). Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society, 29*(1), 344-358. doi:10.1899/08-171.1

Taylor, M. J. (2002). *The national inanga spawning database: trends and implications for spawning site management. Science for Conservation 188.* Wellington: Department of Conservation. 37pp.

Townsend, A. J., de Lange, P. J., Duffy, C. A. J., Miskelley, C. M., Molloy, J., & Norton, D. A. (2008). *New Zealand threat classification system manual*. Wellington, Department of Conservation. 35pp.

Tucker, C. M., Cadotte, M. W., Davies, T. J., & Rebelo, T. G. (2012). Incorporating geographical and evolutionary rarity into conservation prioritization. *Conservation Biology, 26*(4), 593-601. doi:10.1111/j.1523-1739.2012.01845.x

Weeks, R. (2017). Incorporating seascape connectivity in conservation prioritisation. *PloS one, 12*(7), e0182396. doi:10.1371/journal.pone.0182396

Wilmshurst, J. M., Anderson, A. J., Thomas, F. G. H., & Worthy, T. H. (2008). Dating the Late Prehistoric Dispersal of Polynesians to New Zealand Using the Commensal Pacific Rat. *Proceedings of the National Academy of Sciences of the United States of America, 105*(22), 7676-7680. doi:10.1073/pnas.0801507105

Wilson, K. A., Underwood, E. C., Morrison, S. A., Klausmeyer, K. R., Murdoch, W. W., Reyers, B., . . . Possingham, H. P. (2007). Conserving biodiversity efficiently: what to do, where, and when. *PLoS Biology, 5*(9), e223. doi:10.1371/journal.pbio.0050223

Woods, R., Elliot, S., Shankar, U., Bidwell, V., Harrise, S., Wheeler, D., . . . Parfitt, R. (2006). *The CLUES Project: Predicting the effects of land-use on water quality - Stage 2.* NIWA Client Reprot MAF05502.

Yungnickel, M. R., Hickford, M. J. H., & Schiel, D. R. (2020). Spatio-temporal variation in species composition of New Zealand's whitebait fishery. *New Zealand Journal of Marine and Freshwater Research*, 1-16. doi:10.1080/00288330.2020.1745854

Zurell, D., Berger, U., Cabral, J. S., Jeltsch, F., Meynard, C. N., Münkemüller, T., . . . Grimm, V. (2010). The virtual ecologist approach: simulating data and observers. *Oikos, 119*(4), 622-635. doi:10.1111/j.1600-0706.2009.18284.x

Appendix 1. Specifications of operational maps and spatial data

Table A1. Maps of threat distribution based on ThreatRank for 3rd order subcatchment PLUs.

Conservation priority classes (3rd order PLUs)	Description	Threat types	Mapset	Number of maps
Priority1	Confirmed presence (NZFFD records)	Pressure Sum LogN concentration Impervious Exotic Fish Upstream Dam Downstream Dam Coal Mine Other Mine	Karamea Buller Grey Glaciers Haast	40
Priority2	Presence predicted by both REC1 and REC2 SDMs (model congruence)	Pressure Sum LogN concentration Impervious Exotic Fish Upstream Dam Downstream Dam Coal Mine Other Mine	Karamea Buller Grey Glaciers Haast	40
Priority3	Presence indicated by one SDM model only (model discrepancies)	not mapped	-	0
Priority4	No evidence of presence (all remaining PLUs)	not mapped	-	0

Appendix 2. Description of pressure indicators

Table A2. Pressure indicators calculated by Leathwick & Julian (2007) using FENZ data and REC1, and a fish passage status indicator derived from recent NIWA and DOC survey data.

Pressure indicator	Range min	Range max
Loss of native vegetation cover Proportional cover of native vegetation in the catchment surrounding each REC segment from Land Cover Database 2 imagery	0	1
Impervious cover Proportional cover of impervious surfaces in the catchment surrounding each REC segment with area weighting reflecting the upstream position of the segment.	0	1
Downstream dam effects Segments affected by downstream dams where effects on species richness exceed 0.5 species modelled on electric fishing capture rates.	0	1
Upstream dam effects Score reflecting the number of dams in segments upstream of the assessment unit, each weighted by the average flow contributions of non-dammed tributaries in the segments in between.	0	9.4
Nitrogen loads Regional N-leaching model implemented within a catchment framework (Woods et al. 2006). Concentration values are log10 transformed in units of parts per million.	-4.1	3.1
Mine effects Score reflecting the number of point discharge locations upstream of the assessment unit, each weighted by the average flow contributions of non-dammed tributaries in the segments between (as used for upstream dam effects).	0	1
Exotic fish The weighted sum of probabilities of capture for ten introduced fish species obtained from boosted regression trees models, expressed on a scale of zero to one.	0	1
Pressure sum An overall pressure index calculated from the above metrics, each transformed to a scale of zero to one to reflect the predicted relationship of the metric and declines in ecological integrity. Further details in Leathwick & Julian (2007).	0	1
Fish barrier status A score reflecting the severity of fish passage barriers in REC segments with each 3rd order PLU. A rank between 1 (severe) and 5 (negligible) is assigned to all surveyed barriers and the status of the most severe barrier is applied to the PLU. Note this does not necessarily indicate that all potential fish barriers have been assessed with the PLU and this needs to be evaluated separately. A score of zero is used to denote unsurveyed areas.	1	5

Appendix 3. PLU rankings for īnanga based on NZFFD abundance

PLU_ID	Nzreach	Rank	CPUE	Count	Waterway	WoniUnit	Order	Area (Ha)	SpatialPro	RiverPro
29289	12027924	1	231	22	Grey River Mawheranui	Grey-Buller	7	7741	0.241	0.278
11334	12008353	2	228	7	Jones Creek	Northwest Nelson-Paparoa	3	906	0.417	0.162
7687	12050071	3	170	5	Waita River	Westland	5	547	0.706	0.488
11788	12009638	4	151	4		Northwest Nelson-Paparoa	4	560	0.256	0.179
8724	12031766	5	135	20	Waimea Creek	Westland	3	2935	0.303	0.331
8715	12033385	6	125	4		Westland	3	380	0.155	0.343
11781	12011918	7	124	9		Northwest Nelson-Paparoa	4	2855	0.055	0.272
8450	12046119	8	120	10	Hunt Creek	Westland	3	2128	0.258	0.345
8922	12035768	8	120	10	Totara River	Westland	4	2878	0.710	0.788
7678	12050716	10	113	5	Maori River	Westland	3	2405	0.995	0.652
10660	12027925	10	113	3		Grey-Buller	3	366	0.000	0.190
29282	12027932	12	107	7	Coal Creek	Grey-Buller	3	4387	0.341	0.512
11290	12010257	13	97	4		Northwest Nelson-Paparoa	3	1871	0.318	0.288
11304	12009875	14	95	9		Northwest Nelson-Paparoa	3	4731	0.332	0.295
11925	12012173	15	91	22	Orikaka or Mackley River	Grey-Buller	5	23311	0.606	0.407
8697	12035468	16	89	3	Monts Creek	Westland	3	598	0.968	0.299
11291	12010256	17	87	6	Bradshaws Creek	Northwest Nelson-Paparoa	3	2485	0.173	0.305
8872	12045072	18	83	12	Ohinetamatea River (Saltwater Creek)	Westland	4	3340	0.892	0.523
7693	12053045	19	78	5	Waiatoto River	Westland	5	9885	0.925	0.882
8723	12031773	20	76	4	Sawyers Creek	Westland	3	1220	0.276	0.326
7675	12051984	21	75	1		Westland	4	1231	0.766	0.544
7679	12049427	21	75	8	Ship Creek	Westland	4	1013	0.930	0.414
7746	12031613	21	75	1		Westland	1	82	0.278	0.326
7527	12054973	21	75	1	Barn River	Westland	3	1231	1.000	0.526
8942	12038565	21	75	2		Westland	5	6685	0.899	0.716
10801	12007920	21	75	3		Northwest Nelson-Paparoa	2	110	0.212	0.315
11427	12004728	21	75	2	Tidal Creek	Northwest Nelson-Paparoa	3	1789	0.897	0.256
11514	12000532	21	75	1		Northwest Nelson-Paparoa	3	750	0.952	0.451
8714	12033491	21	75	3	Fishermans Creek	Westland	3	1162	0.042	0.326
11051	12021683	21	75	3	Lawson Creek	Northwest Nelson-Paparoa	3	1005	0.812	0.490

29110	12028873	21	75	1	Mill Creek	Westland	3	608	0.320	0.326
50051	0	21	75	1		Westland	0	242	0.992	-1.000
8695	12035676	33	73	10	Totara Lagoon	Westland	3	2315	0.244	0.326
8982	12033313	33	73	12	Hokitika River	Westland	6	9013	0.588	0.600
7807	12042704	35	70	2		Westland	2	341	0.246	0.326
8460	12045662	36	61	5	Black Creek	Westland	3	1433	0.982	0.672
10734	12007908	37	55	1		Northwest Nelson-Paparoa	1	110	0.433	0.377
10797	12010069	37	55	1	Marris Creek	Northwest Nelson-Paparoa	2	194	0.000	0.014
8932	12031251	39	54	2		Westland	4	1807	0.271	0.326
8928	12033491	40	40	4	Fishermans Creek	Westland	3	819	0.224	0.326
11919	12005907	40	53	22	Mokihinui River	Northwest Nelson-Paparoa	6	5838	0.577	0.682
7475	12046712	41	50	2		Westland	2	288	0.934	0.688
11261	12011800	41	50	3	Omanu Creek	Grey-Buller	3	1268	0.748	0.490
8934	12033854	43	49	10	Kaniere River	Westland	5	3642	0.622	0.429
8449	12046138	44	48	8	Manakaiaua River	Westland	3	3659	0.701	0.807
29112	12027931	45	47	5		Grey-Buller	3	2047	0.392	0.303
8709	12034244	46	44	7	Cowan Creek	Westland	3	1490	0.102	0.326
29287	12026554	47	42	6	Seven Mile Creek/Waimatuku	Northwest Nelson-Paparoa	4	1786	0.243	0.356
8985	12045488	48	41	7	Karangarua River	Westland	6	3930	0.764	0.654
7608	12050789	49	40	3	Crikey Creek	Westland	3	1024	0.833	0.326
7540	12054367	51	39	4	The Old Man	Westland	3	3653	1.000	0.613
11326	12008808	52	39	6	Waimangaroa River	Northwest Nelson-Paparoa	3	5638	0.555	0.763
8656	12037638	53	38	3	Duffers Creek	Westland	3	3316	0.593	0.643
8719	12032271	54	36	4		Westland	3	470	0.000	0.326
8916	12037008	54	36	6		Westland	0	701	0.114	0.326
10736	12008136	54	36	2		Northwest Nelson-Paparoa	1	37	0.333	0.014
8463	12045644	57	35	1	Gordon Creek	Westland	3	1179	0.974	0.326
8650	12037951	57	35	2	Te Rahotaiepa River	Westland	3	2421	0.261	0.331
10794	12010809	57	35	1		Northwest Nelson-Paparoa	2	351	0.233	0.150
10795	12010188	57	35	1		Northwest Nelson-Paparoa	2	245	0.349	0.296
11839	12000458	57	35	1	Gunner River	Northwest Nelson-Paparoa	4	1923	0.980	0.612
8682	12036710	57	35	5	Black Creek	Westland	3	777	0.888	0.707
8703	12034956	57	35	2	Whites Creek	Westland	3	631	0.120	0.570
29127	12030053	57	35	5		Westland	4	2619	0.068	0.330
8722	12032159	65	34	3	Flowery Creek	Westland	3	1264	0.209	0.326

8708	12034492	66	27	7		Westland	3	982	0.487	0.326
8440	12046474	67	25	5		Westland	3	778	0.770	0.692
8694	12035789	68	22	6	Woolhouse Creek	Westland	3	1208	0.409	0.473
11250	12012213	69	22	5	O'Malley Creek	Northwest Nelson-Paparoa	3	748	0.444	0.326
7774	12042122	70	19	1		Westland	1	68	1.000	0.326
8454	12045888	70	19	5	Border Creek	Westland	3	1719	0.472	0.663
11401	12005951	70	19	3	Stillwater Creek	Northwest Nelson-Paparoa	3	1934	0.591	0.232
11740	12020602	70	19	3	Punakaiki River	Northwest Nelson-Paparoa	4	3740	0.872	0.762
11769	12013722	70	19	4	Tailings Creek	Northwest Nelson-Paparoa	3	2773	0.771	0.690
11343	12007951	75	18	2	Kerr Stream	Northwest Nelson-Paparoa	3	1508	0.635	0.595
8688	12036327	75	18	7	Donnelly Creek	Westland	3	1771	0.867	0.758
29111	12028351	75	18	4	Omotumotu Creek	Grey-Buller	3	1950	0.403	0.323
8717	12032848	78	17	9	Houhou Creek	Westland	3	1797	0.187	0.347
7562	12053122	79	15	7	Smoothwater River	Westland	3	2326	0.966	0.818
7806	12042838	79	15	1	Neils Creek	Westland	2	473	0.109	0.326
11527	12000004	79	15	1	Kahurangi River	Northwest Nelson-Paparoa	3	795	1.000	0.676
8907	12038791	79	15	2	Poerua River	Westland	4	6521	0.758	0.697
11219	12013722	79	15	1	Tailings Creek	Northwest Nelson-Paparoa	3	1687	0.910	0.700
11445	12003679	84	10	2	Blackwater Creek	Northwest Nelson-Paparoa	3	2191	0.332	0.168
11918	12003209	84	10	6	Karamea River	Northwest Nelson-Paparoa	6	14006	0.885	0.763
29125	12032245	84	10	13	Arahura River	Westland	4	11514	0.031	0.738
7681	12048388	87	9	6	Moeraki River (Blue River)	Westland	4	896	0.929	0.827
8706	12034665	88	8	5	Raft Creek	Westland	3	1453	0.296	0.497
7680	12048484	89	7	11	Whakapohai River (Little River)	Westland	4	2340	0.998	0.803
8568	12041559	89	7	6		Westland	3	1837	0.758	0.436
29131	12030412	89	7	11		Westland	6	13731	0.736	0.630
8729	12029683	92	6	9		Westland	3	2734	0.097	0.333
8951	12046384	92	6	11	Makawhio River (Jacobs River)	Westland	5	4603	0.756	0.807
29034	12046923	92	6	3	Makatata Stream	Westland	3	1448	0.252	0.664
8667	12037298	95	5	2		Westland	3	604	0.833	0.326
8683	12036511	95	5	4		Westland	3	463	0.313	0.331
8727	12030673	95	5	5	Serpentine Creek	Westland	3	688	0.549	0.326
10790	12014919	95	5	4	Deep Creek	Northwest Nelson-Paparoa	2	422	0.833	0.350
8693	12035837	95	5	4	Gows Creek	Westland	3	1029	0.072	0.356
3274	15000252	100	4	2		Westland	1	121	1.000	0.827

7696	12050778	100	4	9	Haast River	Westland	6	12649	0.873	0.779
7689	12051932	100	4	7	Turnbull River	Westland	5	5169	0.570	0.816
8983	12039911	100	4	2	Whataroa River	Westland	6	9379	0.417	0.604
11058	12021127	100	4	5	Hibernia Creek	Northwest Nelson-Paparoa	3	923	0.708	0.306
8718	12032717	100	4	2	Little Houhou Creek	Westland	3	788	0.000	0.326
28935	12053421	100	4	6	Arawhata River	Westland	6	5834	0.969	0.765
29281	12028293	100	4	3	Racecourse Creek	Grey-Buller	3	1096	0.184	0.326
7416	12049578	108	3	1		Westland	1	93	0.684	0.326
7463	12050590	108	3	1		Westland	2	176	0.981	0.326
7813	12037964	108	3	1	Te Rahotaiepa River	Westland	2	807	0.241	0.481
7419	12050494	108	3	1		Westland	1	94	0.976	0.827
7547	12053894	108	3	1	Dismal Creek	Westland	3	1147	0.994	0.751
7610	12050567	108	3	2		Westland	3	380	1.000	0.678
7641	12048034	108	3	3	Blackwater Creek	Westland	3	727	1.000	0.920
7646	12047113	108	3	2	Power Creek	Westland	3	1615	1.000	0.717
8464	12045602	108	3	9	Ohinetamatea River (Saltwater Creek)	Westland	3	3092	0.990	0.861
8549	12042253	108	3	1		Westland	3	668	0.994	0.326
8668	12037297	108	3	1		Westland	3	333	0.073	0.326
8681	12036778	108	3	2		Westland	3	354	0.966	0.179
8725	12030973	108	3	6		Westland	3	937	0.538	0.326
8950	12044695	108	3	1	Cook River	Westland	5	2874	0.871	0.711
10781	12023994	108	3	3		Northwest Nelson-Paparoa	2	149	0.087	0.326
10804	12006239	108	3	1	Patten Stream	Northwest Nelson-Paparoa	2	444	0.697	0.248
10836	10001410	108	3	1	Lagoon Creek	Northwest Nelson-Paparoa	2	324	0.707	0.229
10991	12024177	108	3	1	Bakers Creek	Northwest Nelson-Paparoa	3	968	0.947	0.815
11526	12000036	108	3	2	Moutere River	Northwest Nelson-Paparoa	3	1377	1.000	0.658
11883	12000635	108	3	4	Heaphy River	Northwest Nelson-Paparoa	5	5072	0.907	0.529
11904	12018145	108	3	1	Fox River	Northwest Nelson-Paparoa	5	910	0.586	0.600
10827	12000002	108	3	1		Northwest Nelson-Paparoa	2	464	1.000	0.633
11449	12003623	108	3	2	Granite Creek	Northwest Nelson-Paparoa	3	1688	0.769	0.263
11450	12003602	108	3	3	Kimberley Creek	Northwest Nelson-Paparoa	3	717	0.521	0.292
11817	12004563	108	3	1	Tidal Creek	Northwest Nelson-Paparoa	4	420	0.222	0.090
11885	12002776	108	3	2	Oparara River	Northwest Nelson-Paparoa	5	1503	0.493	0.225
8700	12035149	108	3	2	Duck Creek	Westland	3	2104	0.439	0.479
8707	12034493	108	3	7	Mahinapua Creek	Westland	3	2227	0.173	0.326

8721	12032176	108	3	3	Duffers Creek	Westland	3	1248	0.489	0.328
8728	12030455	108	3	2	Fuchsia Creek	Westland	3	599	0.504	0.326
8890	12042969	108	3	4		Westland	3	1320	0.826	0.470
8930	12031691	108	3	1	Waimea Creek	Westland	4	7	0.000	0.326
10769	12022414	108	3	2		Northwest Nelson-Paparoa	1	40	0.000	0.326
11236	12012956	108	3	1	Ohikaiti River	Grey-Buller	3	2202	0.997	0.870
29025	12046598	108	3	1	Te Naihi Creek	Westland	2	337	0.929	0.688
29041	12046717	108	3	5	Mahitahi River	Westland	5	4399	0.759	0.837
29054	12029125	108	3	1		Westland	2	177	0.000	0.326
29099	12033031	108	3	3		Westland	3	1800	0.355	0.495
29102	12032111	108	3	3	Clear Creek	Westland	3	1454	0.194	0.463
29235	12028293	108	3	1	Racecourse Creek	Grey-Buller	3	1018	0.286	0.326
29253	12027792	108	3	5	Stillwater Creek	Grey-Buller	4	1690	0.197	0.325
50081	0	108	3	1		Westland	0	394	0.018	-1.000
10735	12007838	150	2	1		Northwest Nelson-Paparoa	1	75	0.550	0.377
3275	15000271	151	1	1		Westland	1	86	1.000	0.827
7425	12053022	151	1	1		Westland	1	79	0.571	0.827
7692	12053044	151	1	4		Westland	5	810	0.972	0.718
7594	12051847	151	1	1		Westland	3	542	0.324	0.896
7632	12048955	151	1	2	Mathias Creek	Westland	3	755	1.000	0.864
10798	12010040	151	1	1	Gibsons Creek	Northwest Nelson-Paparoa	2	354	0.000	0.326
11768	12013344	151	1	1	Little Totara River	Northwest Nelson-Paparoa	4	344	0.129	0.531
11889	12004539	151	1	1		Northwest Nelson-Paparoa	5	1126	0.353	0.164
11462	12003073	151	1	1	Baker Creek	Northwest Nelson-Paparoa	3	1826	0.547	0.127
8577	12041170	151	1	2	Oroko Creek	Westland	3	1657	0.966	0.384
8580	12041086	151	1	2		Westland	3	2268	0.849	0.384
8674	12037165	151	1	1	Ferguson Creek	Westland	3	521	0.778	0.326
8712	12034044	151	1	5	Taminelli Creek	Westland	3	1127	0.680	0.523
10783	12022281	151	1	1		Northwest Nelson-Paparoa	2	147	0.000	0.326
28931	12054310	151	1	4	Cascade River	Westland	5	8955	0.784	0.797

Appendix 4. PLU rankings for shortjaw kōkopu based on NZFFD abundance

PLU_ID	Nzreach	Rank	CPUE	Count	Waterway_N	WoniUnit	Order	Area (ha)	SpatialPro	RiverPro
11925	12012173	1	39	22	Orikaka or Mackley River	Grey-Buller	5	23311	0.606	0.407
8711	12034079	2	18	5	Kennedy Creek	Westland	3	1677	0.737	0.326
8934	12033854	2	18	10	Kaniere River	Westland	5	3642	0.622	0.429
8724	12031766	4	17	20	Waimea Creek	Westland	3	2935	0.303	0.331
8449	12046138	4	17	8	Manakaiaua River	Westland	3	3659	0.701	0.807
11278	12011025	6	16	2	Pensini Creek	Grey-Buller	3	1546	0.920	0.313
7686	12047230	7	15	3	Paringa River	Westland	5	5550	0.836	0.700
8568	12041559	7	15	6		Westland	3	1837	0.758	0.436
29229	12028579	9	13	3	Clear Creek	Grey-Buller	3	1043	0.932	0.326
8922	12035768	10	12	10	Totara River	Westland	4	2878	0.710	0.788
11261	12011800	10	12	3	Omanu Creek	Grey-Buller	3	1268	0.748	0.490
8688	12036327	12	10	7	Donnelly Creek	Westland	3	1771	0.867	0.758
11809	12006180	13	9	2	Chasm Creek	Northwest Nelson-Paparoa	4	1204	0.465	0.445
8544	12042365	14	8	3	Company Creek	Westland	3	1696	1.000	0.536
11316	12009259	15	7	3	Whareatea River	Northwest Nelson-Paparoa	3	3822	0.706	0.451
29289	12027924	15	7	22	Grey River Mawheranui	Grey-Buller	7	7741	0.241	0.278
8450	12046119	15	7	10	Hunt Creek	Westland	3	2128	0.258	0.345
8460	12045662	15	7	5	Black Creek	Westland	3	1433	0.982	0.672
29127	12030053	15	7	5		Westland	4	2619	0.068	0.330
7681	12048388	15	7	6	Moeraki River (Blue River)	Westland	4	896	0.929	0.827
8464	12045602	15	7	9	Ohinetamatea River (Saltwater Creek)	Westland	3	3092	0.990	0.861
29253	12027792	15	7	5	Stillwater Creek	Grey-Buller	4	1690	0.197	0.325
7562	12053122	23	6	7	Smoothwater River	Westland	3	2326	0.966	0.818
29106	12030354	24	5	4	Cariboo Creek	Westland	3	1493	0.379	0.326
11268	12011622	25	4	5	Coal Creek	Grey-Buller	3	1514	0.471	0.276
8556	12042092	25	4	3	Zalas Creek	Westland	3	1313	0.178	0.535
8710	12033854	25	4	5	Kaniere River	Westland	5	1172	0.956	0.489
11919	12005907	25	4	22	Mokihinui River	Northwest Nelson-Paparoa	6	5838	0.577	0.682
8709	12034244	25	4	7	Cowan Creek	Westland	3	1490	0.102	0.326
29287	12026554	25	4	6	Seven Mile Creek/Waimatuku	Northwest Nelson-Paparoa	4	1786	0.243	0.356
11326	12008808	25	4	6	Waimangaroa River	Northwest Nelson-Paparoa	3	5638	0.555	0.763

8656	12037638	25	4	3	Duffers Creek	Westland	3	3316	0.593	0.643
8682	12036710	25	4	5	Black Creek	Westland	3	777	0.888	0.707
29111	12028351	25	4	4	Omotumotu Creek	Grey-Buller	3	1950	0.403	0.323
8717	12032848	25	4	9	Houhou Creek	Westland	3	1797	0.187	0.347
11518	12000467	36	3	3	Ryan Creek	Northwest Nelson-Paparoa	3	1394	1.000	0.510
10923	12027502	36	3	3	Woolley Creek	Grey-Buller	3	391	0.761	0.540
10947	12026299	36	3	3	Callaghans Creek	Grey-Buller	3	1755	0.676	0.366
11241	12012716	36	3	1	Okari River	Northwest Nelson-Paparoa	3	872	0.778	0.341
29108	12030118	36	3	10	New River	Westland	3	3463	0.512	0.340
7682	12047707	36	3	3	Hall River	Westland	4	972	0.996	0.661
8723	12031773	36	3	4	Sawyers Creek	Westland	3	1220	0.276	0.326
11769	12013722	36	3	4	Tailings Creek	Northwest Nelson-Paparoa	3	2773	0.771	0.690
10827	12000002	36	3	1		Northwest Nelson-Paparoa	2	464	1.000	0.633
8721	12032176	36	3	3	Duffers Creek	Westland	3	1248	0.489	0.328
10735	12007838	36	3	1		Northwest Nelson-Paparoa	1	75	0.550	0.377
11395	12006210	47	2	3	Coal Creek	Northwest Nelson-Paparoa	3	1088	0.692	0.438
8614	12039534	47	2	6	Hinatua River	Westland	3	2637	0.999	0.361
29228	12028587	47	2	5	Stillwater Creek	Grey-Buller	3	1416	0.393	0.326
8694	12035789	47	2	6	Woolhouse Creek	Westland	3	1208	0.409	0.473
11918	12003209	47	2	6	Karamea River	Northwest Nelson-Paparoa	6	14006	0.885	0.763
7622	12049688	52	1	3	Ship Creek	Westland	3	1123	1.000	0.675
30300	12048388	52	1	4	Moeraki River (Blue River)	Westland	4	5963	0.917	0.860
8945	12041582	52	1	10	Okarito River	Westland	5	2630	0.877	0.655
11283	12010748	52	1	2	New Creek	Grey-Buller	3	3845	0.880	0.804
11393	12006230	52	1	2	Podge Creek	Northwest Nelson-Paparoa	3	426	0.865	0.300
11801	12007828	52	1	2		Northwest Nelson-Paparoa	3	1436	1.000	0.841
8543	12042366	52	1	1	Five Mile Creek	Westland	3	829	1.000	0.359
8671	12037203	52	1	9	Totara River	Westland	3	1871	0.995	0.821
8920	12036148	52	1	1		Westland	4	697	0.193	0.715
10927	12027412	52	1	1	Sunday Creek	Grey-Buller	3	648	0.794	0.311
10944	12026448	52	1	4	Blackball Creek	Grey-Buller	3	2605	0.773	0.851
11212	12013942	52	1	3	Little Totara River	Northwest Nelson-Paparoa	3	2109	0.966	0.788
11242	12012716	52	1	1	Okari River	Northwest Nelson-Paparoa	3	1068	0.763	0.535
11243	12012488	52	1	1	Nine Mile Creek	Grey-Buller	3	567	1.000	0.740
29286	12024925	52	1	1	Thirteen Mile Creek	Northwest Nelson-Paparoa	3	374	0.931	0.713

29096	12036210	52	1	8	Styx River	Westland	3	6553	0.936	0.898
29126	12031563	52	1	1	Greenstone or Big Hohonu River	Westland	4	406	0.955	0.326
29237	12027513	52	1	12	Ongionui or Twelve Mile Creek	Grey-Buller	3	2707	0.315	0.331
8715	12033385	52	1	4		Westland	3	380	0.155	0.343
11781	12011918	52	1	9		Northwest Nelson-Paparoa	4	2855	0.055	0.272
29282	12027932	52	1	7	Coal Creek	Grey-Buller	3	4387	0.341	0.512
29110	12028873	52	1	1	Mill Creek	Westland	3	608	0.320	0.326
8932	12031251	52	1	2		Westland	4	1807	0.271	0.326
8722	12032159	52	1	3	Flowery Creek	Westland	3	1264	0.209	0.326
11343	12007951	52	1	2	Kerr Stream	Northwest Nelson-Paparoa	3	1508	0.635	0.595
11527	12000004	52	1	1	Kahurangi River	Northwest Nelson-Paparoa	3	795	1.000	0.676
8907	12038791	52	1	2	Poerua River	Westland	4	6521	0.758	0.697
29125	12032245	52	1	13	Arahura River	Westland	4	11514	0.031	0.738
8683	12036511	52	1	4		Westland	3	463	0.313	0.331
8727	12030673	52	1	5	Serpentine Creek	Westland	3	688	0.549	0.326
11450	12003602	52	1	3	Kimberley Creek	Northwest Nelson-Paparoa	3	717	0.521	0.292
8700	12035149	52	1	2	Duck Creek	Westland	3	2104	0.439	0.479
8728	12030455	52	1	2	Fuchsia Creek	Westland	3	599	0.504	0.326