Options for default minimum flow & allocation limits in Northland

Part 2: Technical report

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Executive summary

The National Policy Statement for Freshwater Management (NPSFM) requires regional councils to set freshwater objectives and water resource-use limits for all rivers (MfE 2011). Limits on water quantity must consist of at least a minimum flow (the flow below which no further water is to be taken for out-of-channel use) and a total allocation limit (the maximum quantity of water available for abstraction) for all water bodies in the country. Northland Regional Council (NRC) is responsible for setting these limits in Northland.

This project contributes to establishing regional default or interim minimum flow and allocation limits for all streams and rivers in the Northland region. The objective of these limits is to provide a specific level of environmental protection while also enabling out-of-channel water use at specified levels of availability and reliability.

The Environmental Flows Strategic Assessment Platform (EFSAP) is a tool to evaluate the consequences of setting different water resource-use limits across all parts of a catchment or region, including those for which detailed information is not available. It integrates scientific tools to enable the concurrent evaluation of consequences for instream physical habitat and reliability of supply for out-of-channel water uses, accounting for the interaction between the flow regime, minimum flow and total allocation limits at all locations.

In this study we used EFSAP to simulate the consequences of various potential sets of limits (i.e., minimum flows and total allocations) for all river and stream reaches in Northland with a mean flow greater than 10 L s^{-1}. A range of alternative scenarios, from more environmentally conservative to more resource-use enabling than the proposed National Environmental Standard for ecological flows and water levels (NES) rules, were simulated. The indicator species selected for assessment were banded kokopu (*Galaxias fasciatus*), common bully (*Gobiomorphus cotidianus*), shortfin eel (*Anguilla australis*) and longfin eel (*Anguilla dieffenbachii*). These were selected based on their presence and value in the Northland region.

For much of Northland, using the proposed NES default limits for small rivers (minimum flow equal to 90% of mean annual low flow (MALF); and total allocation 30% MALF), reliability at the management flow (where partial restrictions on abstraction begin) is predicted to exceed 90%. However, through the central part of the region, reliability is predicted to be slightly lower (80-90%), and there is an area to the east of Hokianga Harbour where the reliability of supply is predicted to be relatively low (40-70%).

For banded kokopu under the proposed NES minimum flow and allocation limit, the median change in physical habitat ranged across the region from a 100% loss of habitat in some reaches to a 75% increase in habitat at other reaches. Similar variation across the region was observed for the other fish species.

To reduce regional inequalities in outcomes, spatially discrete management units, with relatively uniform outcomes for each of the values, were defined based on river size and climate. For each of the three proposed management units, the consequences of multiple limit options were summarised for each value in decision-space diagrams. Once freshwater objectives have been set for each value, the decision space diagrams can be used by NRC to determine which combination of limits best satisfies the objective for each value. Once the subsets of limits that satisfy the objective for each individual value have been defined, they can theoretically be combined to find the set of limits which meet all objectives. In some cases, the defined objectives for all values will result in a combination of limit options that overlap. Water resource managers therefore have the choice of defining limits that satisfy all objectives. However, in some circumstances there will be no combination of limits that satisfies all objectives. In this situation, a compromise has to be found between the different values until an acceptable combination of limits can be agreed upon. The decision-space diagrams can assist in this trade-off process by illustrating to stakeholders and resource managers (i) how limits interact with each other and (ii) the relative consequences of alternative management decisions.

It must be recognised that EFSAP does not evaluate all values that may be relevant for a given location. It also does not explicitly consider flow variability or the temporal sequencing of flows. EFSAP is based on the assumption that instream physical habitat at low flows is limiting. These factors must therefore be considered when determining the most appropriate combination of limits. However, despite these limitations, EFSAP provides a robust, objective, and defensible approach to evaluating the relative merits of different combinations of limits and therefore will allow NRC to more transparently communicate and set water resource limits that meet their nominated objectives.

This second issue of the report includes an additional appendix reanalysing the EFSAP modelling results around proposed Freshwater Management Units for water quantity that are being developed as part of NRC's implementation of the NPS-FM.

1 Introduction

1.1 Background

Developing a sustainable water allocation framework is essential to ensuring that water resources are managed in a way that protects environmental values as well as allowing economic growth. The current allocation framework in Northland requires updating to provide security of water supply, protect environmental values and meet the requirements of the National Policy Statement on Freshwater Management (NPSFM) (MfE 2011).

Sustainable water allocation is listed in Northland Regional Council's Long Term Council Community Plan as a priority issue, and Northland Regional Council (NRC) is developing a new sustainable water allocation framework through the Sustainable Water Allocation Project. Setting minimum flows and allocation limits is critical to development of a sustainable water allocation regime.

Building on advice received under a previous Envirolink Small Advice Grant on appropriate methods for establishing ecological flows in Northland (Franklin 2010), this project seeks to go beyond business as usual by developing scientifically defensible and transparent default minimum flow and allocation limits appropriate for the Northland region. The establishment of defensible default water allocation limits is an essential foundation to sustainable water allocation, resulting in greater environmental protection and more efficient and equitable resource use.

1.2 Purpose

Out-of-channel water resource use is expanding in Northland, increasing pressure on aquatic ecosystems. The present water allocation regime in Northland does not afford sufficient protection to instream values or provide certainty to water users due to an absence of allocation limits. Limits are required by the NPSFM, and to avoid endangering aquatic ecosystems and expectations of being able to abstract water that is in reality not available. This project will contribute directly to establishing regional default minimum flows and allocation limits for all streams and rivers in the Northland region. It will also support and inform consultation with stakeholders.

The advice received as part of this project will support reform of NRC's approach to water allocation management, improving sustainability and enhancing understanding of the environmental consequences of limit setting. It will also assist NRC, water users and the community to understand the consequences of different minimum flow and allocation limits on instream physical habitat for fish and security of supply. Such understanding will lead to better informed decisions on council's water allocation/ water management policies and rules.

1.3 Scope

This project involved application of a strategic planning tool (Environmental Flow Strategic Assessment Platform; EFSAP) to assist in developing transparent options for default minimum flow and water allocation limits for all streams and rivers in the Northland Region. Newly developed by NIWA, EFSAP simulates the consequences of different minimum flow and allocation limits on fish habitat and reliability of water supply at a regional scale.

EFSAP was used to evaluate the expected outcomes of different water allocation limits across Northland for a range of environmental values and out-of-channel water resource uses. It was then used to develop a range of water allocation limit options to support establishment of environmentally appropriate default water allocation limits for the whole of the Northland Region.

Two reports were produced for this project. This report describes the model simulations and technical analyses. It also provides the scientifically derived options for regional scale default minimum flow and allocation limits in Northland with guidance on how the results can be used for policy making. The second report (Franklin et al. 2013) provides a non-technical summary of the results presented in this report.

2 Methods

2.1 EFSAP model description

EFSAP is a tool to enable planners and water allocation decision-makers to simulate and compare spatially explicit water management scenarios at catchment, regional and national scales. It is able to simulate the spatially explicit consequences of multiple takes on both out-of-stream and in-stream values, demonstrate the trade-off between environmental state and resource use, and allow comparison of different water allocation management scenarios. It is based on the application of generalized models applied across all locations in a spatial framework. Further details of the model structure are described below.

2.1.1 Spatial framework

The spatial framework for EFSAP is the River Environment Classification (REC; Snelder & Biggs 2002), which comprises a digital representation of the New Zealand river network and a classification system that are contained within a Geographic Information System (GIS). The river network representing the Northland region comprises 27,492 segments with an average length of c. 655 m. Each segment is associated with several attributes including the total catchment area, stream order, as well as the climatic, topographic, geological, and land-cover characteristics of the upstream catchment. The REC classifies all river and stream segments into classes at several levels of detail (Snelder & Biggs 2002). The first level of the REC groups each segments of the river network into classes that discriminate variation in upstream climate. The second level groups segments into classes that discriminate variation in climate and topography of the upstream catchment.

2.1.2 Hydrological data

EFSAP requires estimates of several hydrological characteristics including: mean annual low flow (MALF), mean flow (Qbar), and the shape of the flow duration curve (FDC). FDCs are a hydrological tool that is used to represent the percentage of time flows are equalled or exceeded for a particular river location (Vogel & Fennessey 1995) (Figure 2-1). This project required both annual (i.e., calculated across the entire year) and monthly (i.e., calculated for individual months) FDCs so that the consequences for availability and reliability of water supply for out-of-channel uses could be reported for the whole year and the most restrictive (summer) month. Approaches for estimating these hydrological characteristics are described by Booker et al. (2012). See Booker and Snelder (2012) for further technical details of the methods used to estimate FDCs. The methods with the lowest uncertainties have been used with EFSAP to undertake the simulation analyses for this project.

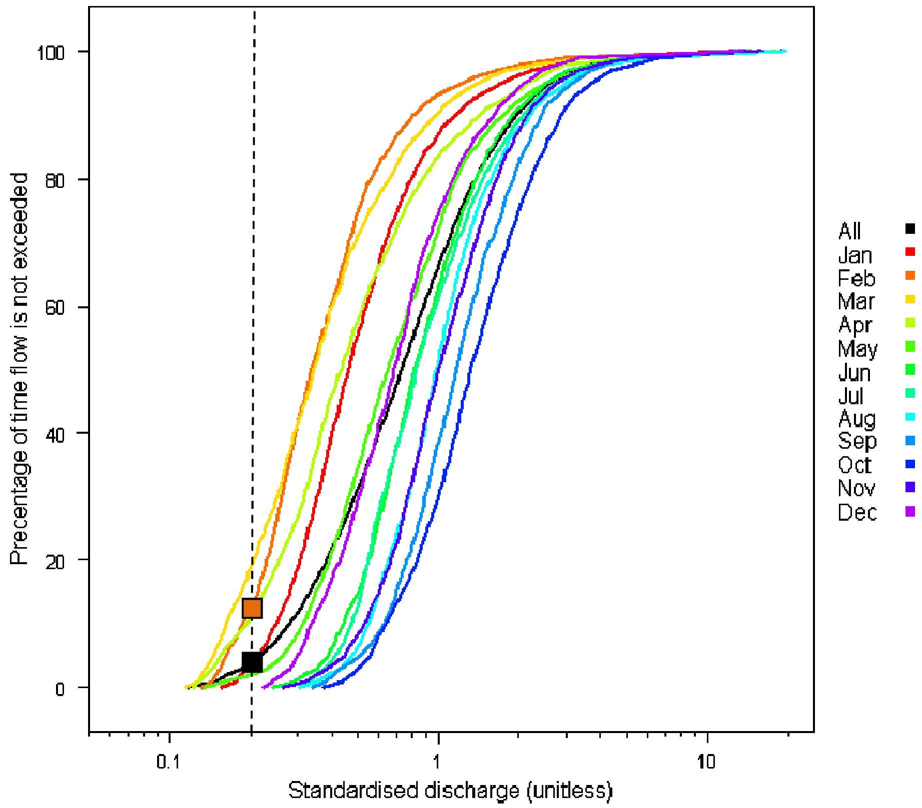


Figure 2-1: An example of annual and monthly FDCs for a network segment. Minimum flow is indicated by the vertical dashed line. Reliability for any given month is indicated by the point at which the FDC meets the dashed line. For example, the black square indicates reliability based on the annual FDC (restriction of 5% of the time equates to a 95% reliability), the orange square indicates reliability based on the February FDC (restriction of 15% of the time equates to an 85% reliability).

2.1.3 Generalized habitat v. flow relationships

EFSAP utilizes coupled generalized models of mean wetted width versus flow and habitat versus reach-averaged specific discharge (width/flow) to describe the relationship between habitat availability and flow at a site.

Estimating wetted width

Booker (2010) defines a power-law relationship between discharge, Q ($m^3\ s^{-1}$), and mean wetted width, W (m), for each river reach:

$$\log(W) = d_0 + d_1 \log(Q) + d_2 (\log(Q))^2 \quad (1)$$

$$d_0 = a_0 + a_1 \log(A) \quad (a)$$

$$d_1 = b_0 + b_1 \log(A) \quad (b)$$

$$d_2 = c_0 + c_1 \log(A) \quad (c)$$

where A is catchment area (km^2) and a, b, and c take values dependent on REC classes. All logs are to the base 10. These models are used in EFSAP to estimate width-flow relationships for all REC network segments.

Estimating instream physical habitat

Conventional instream physical habitat models link hydraulic model predictions with microhabitat-suitability criteria to predict the availability of suitable habitat at various discharge rates (e.g., RHYHABSIM; Clausen et al. 2004, Jowett 1996, Jowett & Biggs 2006). The availability of suitable physical habitat is commonly expressed as Weighted Usable Area (WUA) in m^2 per 1000m of river channel (Figure 2-2). WUA is an aggregate measure of physical habitat quality and quantity, and will be specific to a particular discharge and taxa/life stage. Instream physical habitat models can be used to assess WUA over a range of flows and therefore to make predictions of how habitat changes with changes in flow.

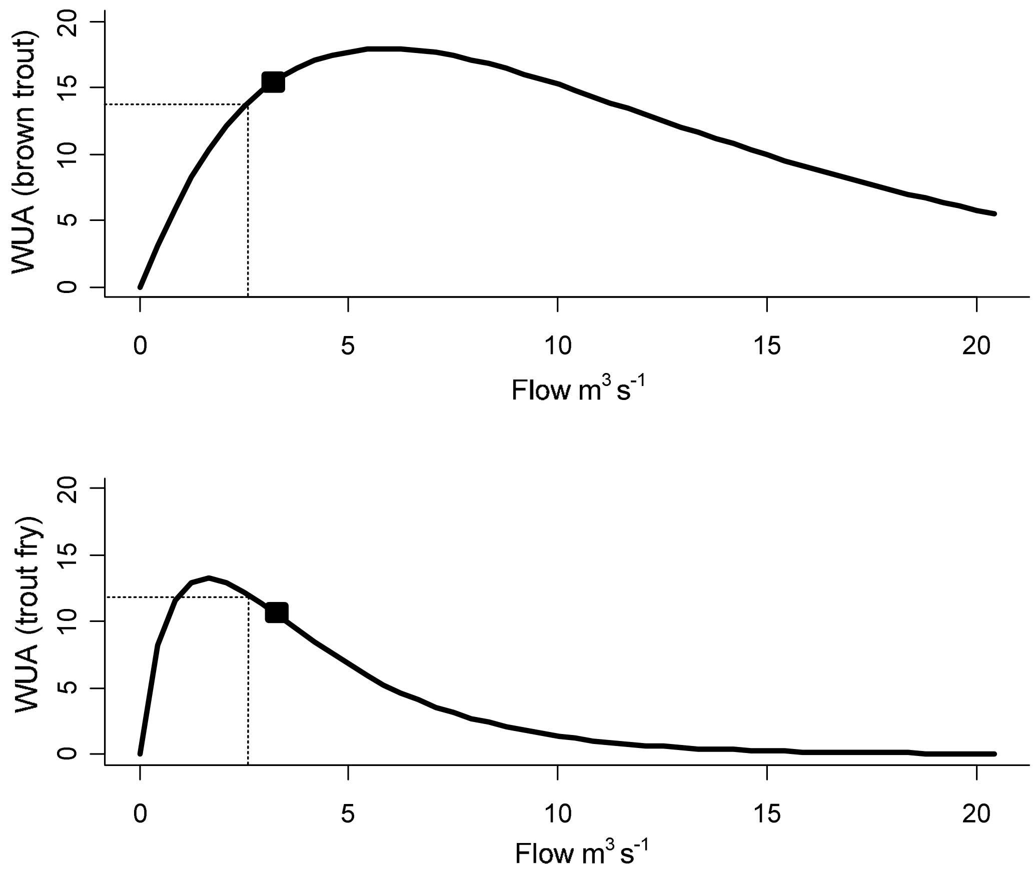


Figure 2-2: WUA versus flow curves for adult brown trout and brown trout fry for a network segment (mean flow = 20 $m^3 s^{-1}$). These curves were defined by combining equations 1 and 2. MALF for the segment (3.3 $m^3 s^{-1}$) is shown by the black square on the curve. WUA at the proposed NES minimum flow of 80% MALF are shown by the dashed lines. Note that WUA decreases between MALF and the minimum flow for adult brown trout, but increases for brown trout fry.

Criticisms of instream physical habitat models include lack of biological realism (Orth 1987) and failure of microhabitat-suitability criteria to reflect the detailed mechanisms that lead to density–environment associations (Booker et al. 2004, Lancaster & Downes 2010, Mathur et al. 1985). However, many microhabitat suitability models have a high degree of transferability between rivers and are therefore useful bases for the management of stream catchments (Lamouroux et al. 2010).

The models have been applied throughout New Zealand (Lamouroux & Jowett 2005) and the world (Dunbar & Acreman 2001), primarily to assess impacts of abstraction. PHABSIM in particular has become a legal requirement for many impact studies in the USA (Reiser et al. 1989) and RHYHABSIM (the New Zealand equivalent) a standard tool employed to define minimum flows in New Zealand (e.g., MfE 2008).

Generalised instream habitat models (Lamouroux & Jowett 2005) have been developed from the results of many individual habitat studies conducted throughout New Zealand. These models generalise the relationship between flow and habitat in natural stream reaches based on simple reach-average hydraulic characteristics (Lamouroux & Jowett 2005). Therefore, when linked with hydraulic geometry models (i.e., empirical models relating hydraulic parameters such as width, depth, and velocity to discharge), generalized habitat models make it possible to simulate the relationship between flow and habitat over whole river networks (see examples in Jowett 1998, Lamouroux 2008, Lamouroux & Capra 2002, Snelder et al. 2011). We used the generalized instream habitat models provided by Jowett et al. (2008) to estimate WUA as a function of reach-averaged specific discharge (width/flow). The flow-habitat relationships describe a unimodal shape that depends on two coefficients, *j* and *k*, that are specific to a taxa and *i*, which is specific to a reach:

$$WUA = i\left(\frac{Q}{W}\right)^{j} e^{-k\left(\frac{Q}{W}\right)} \qquad (2)$$

The ratio of WUA at two discharges depends only on discharge and the width-discharge relationship, but not on the reach coefficient *i*. Consequently, the width-flow relationship (Equation 1) can be combined with Equation 2 to estimate relative changes in habitat with changes in flow over a whole river network (Lamouroux & Souchon 2002).

2.1.4 Analysis options

EFSAP is based on the analysis and simulation of four key variables:

- Flow changes (c.f. total allocation) (ΔQ)
- Minimum flow (Q_min)
- Reliability of supply (R)
- Habitat change (ΔH)

When undertaking a simulation, any two of these variables may be specified and the other two will be calculated at all locations on the river network. For example, to simulate the consequences of the proposed NES minimum flow and total allocation limits for small rivers (described in Section 2.2.3 below), flow change (ΔQ) would be set as 30% MALF and minimum flow (Q_min) as 90% MALF, and reliability of supply (R) and habitat change (ΔH) for the target species would be calculated by the model for all locations.

EFSAP can be run in two modes: global and local. Global simulations are used to evaluate the spatial consequences of uniform rules or objectives across the river network. In this mode, all reaches are treated as independent and thus the spatial distribution of takes upstream of a site is not taken into consideration, and effects are not accumulated down the river network. The global mode was used for this project. The results can therefore be interpreted as representing the consequences of water allocation at each location independently of any upstream allocation. The local mode allows simulation of the cumulative effects of site specific takes. In this mode, the location, take volume (ΔQ) and minimum flow (Q_min) of every abstraction are specified and the effects are accumulated down the river network. This approach is more suitable for catchment specific investigations where good data are available on the location and characteristics of takes.

2.2 Applying EFSAP in Northland

2.2.1 Assumptions

This project takes a regional approach to simulating the consequences of different water allocation limits. The models upon which EFSAP is based are not calibrated for every location on the river network, but instead provide a generalised estimate that, when considered collectively, help to understand regional scale patterns. Results should therefore be evaluated and interpreted at a regional scale, and should not be used for assessments at specific locations on the river network.

Booker et al. (2012) showed that characteristics of the FDC can vary between months and monthly FDCs are different to the annual FDC. This means that for a given minimum flow and allocation limit, average reliability of supply for out-of-channel uses will vary between months, with the lowest reliability occurring in the month with the greatest frequency of low flows. To allow for this variability, EFSAP simulations for Northland have been run using the annual FDC and the FDC for February only. The February FDC was chosen for analysis because, on average, the greatest frequency of low flows occurs in this month and therefore it is the most resource limiting month (Susie Osbaldiston, NRC, personal communication). Since inter-annual variability was not considered, results produced using the February FDC should be interpreted as representing conditions on average over all Februarys.

Estimates of reliability of supply were based on the position of various proportions of the 7-day MALF on the flow duration curves. For this calculation, we had a choice of three different estimates of MALF to locate on the flow duration curve at each location on the REC network. These were: a) MALF from HUC (Hydrology of Ungauged Catchments projects); b) specific MALF estimated from a random forest regression model and then multiplied by catchment area; and c) the flow on each estimated flow duration curve that corresponded to the estimated position of MALF (as predicted by a random forest model of the proportion of time for which MALF is exceeded) on that flow duration curve. Given that there may be errors associated with both estimated MALF and estimated FDCs, we chose to apply the last of these three options, as it was the most likely to produce accurate estimates of reliability of supply. Comparisons of reliability of supply at 100% of MALF (results not shown) showed that there was little difference between our second and third methods of estimating MALF, but that the HUC method produced higher estimates of reliability of supply.

When simulating consequences for environmental state and reliability for out-of-channel uses, it is assumed that the full quantity of allocated water available is taken all of the time. This represents the worst case scenario (assuming all abstractions are consented and in the absence of permitted takes). In reality this is rarely the case, but greatest demand for out-of-channel uses typically occurs when the resource is most limited (i.e., dry summers) and therefore it is important that water resource use limits are designed to provide sufficient protection of environmental values and reliability of supply at full capacity.

EFSAP uses instream physical habitat as a measure of environmental state. The use of physical habitat is based on the assumption that habitat availability, rather than other factors such as water quality or migration barriers, is the primary limiting factor on the target species. Physical habitat is used as a surrogate for the suitability of a site to support the target species, but the availability of suitable habitat does not mean that a species will be present, and the quantity of suitable habitat does not necessarily correlate with species abundance. Factors such as water quality and migration barriers would be considered in a full and detailed analysis of the ecological impacts of flow setting scenarios.

2.2.2 Indicator species

Generalised habitat models are currently only available for a restricted number of species and life stages in New Zealand (Appendix A, Table A-1). The values for the model coefficients were derived by Jowett et al. (2008) from a dataset of 99 stream reaches in New Zealand. The ‘flow demand’ (in terms of optimal discharge per unit width; Appendix A, Table A-1) for some species is logical based on our understanding of the traits of the individual species, e.g., torrentfish (which prefer fast flowing riffle habitats) having the highest demand of the native fish species. However, the optimal discharges defined by the Jowett et al. (2008) models are less intuitively logical for other species, e.g., common bully (which have very flexible habitat requirements, but relatively high flow demand). It is possible that this is symptomatic of a sampling bias in the data used to derive the models towards daytime habitats in wadeable gravel rivers. Further work is required to validate the use of these models, and particularly their transferability across different river types. This research would help to reduce uncertainty in the models and their output. It would also be beneficial to expand the range of species and life stages included to provide more flexibility in selecting relevant target species.

The indicator species used for this assessment were determined with reference to both known (New Zealand Freshwater Fish Database; NZFFD) and predicted (Leathwick et al. 2008) fish distributions, and in consultation with NRC staff (Table 2-1).

Table 2-1: Indicator species used for EFSAP simulations in Northland.

Indicator species	Justification
Longfin eel (<30 cm)	Cultural value and conservation status
Shortfin eel (<30 cm)	Cultural value and broad distribution
Banded kokopu (juvenile)	Characteristic species of more natural streams
Common bully	Broad distribution

2.2.3 Scenarios

Uniform rules for water resource use can be defined as standardised, unvarying limits that apply equally to all sites in a class. The proposed NES default minimum flow and allocation limits are uniform rules, divided into two classes based on river size (small - mean flow <5 $m^3 s^{-1}$; large - mean flow ≥5 $m^3 s^{-1}$). Uniform rules are relatively easy to apply and manage, but can result in spatially varying consequences for both instream and out-of-channel water uses and consequent equity problems for stakeholders.

We first simulated the consequences of the proposed NES default minimum flow and allocation limits for small rivers (Q_min 90% MALF, ΔQ 30% MALF; MfE (2008)). We then simulated a range of scenarios encompassing both more environmentally conservative and more resource enabling limits than the proposed NES defaults. All scenarios were based on proportions of MALF (Q_min 10-100%

MALF; ΔQ 10-150% MALF in 10% increments) and were applied to all sites in the catchments of interest.

2.2.4 Analyses

Reliability of supply was determined for both the proportion of time that abstractions are partially restricted and the proportion of time that no abstraction is possible because natural flows are at or below the minimum flow. These two points were termed ‘reliability at the management flow’ and ‘reliability at the minimum flow’ respectively.

The availability of physical habitat was described in terms of the weighted usable area (WUA). The predicted change in habitat availability can be expressed in a number of ways. In this case, for every segment of the river network, we calculated WUA at MALF from the naturalised FDC and again from the flow at the same percentile on the modified FDC. To allow comparison of all network segments, we expressed the WUA from the modified FDC as a percentage of the WUA at MALF. This measure of habitat change integrates the effects of both the minimum flow and allocation limits on available habitat. It is based on the assumption that habitat is limiting at natural low flows and that fish communities are adapted to cope with that restricted quantity of suitable habitat for a certain proportion of the time (i.e., that which occurs naturally). When the flow regime is modified, the amount of suitable habitat available for that same proportion of time (i.e., same flow percentile) will change. The greater the difference between the two values, the greater the likely impact on WUA and therefore fish communities.

We analysed the spatial patterns of the consequences for reliability and habitat under the proposed NES scenarios. Results were initially mapped and visually inspected to identify likely drivers of any spatial differentiation in consequences. We then used REC reach attribute data, e.g., stream order or catchment geology, to try and distinguish spatial differences and subsequently define spatial classes or potential “management units” with relatively uniform consequences for reliability and habitat. If significant spatial differences could be identified and defined, results were split into spatial classes for further analysis, with the consequences for the full range of uniform rule scenarios summarised statistically and presented as a ‘decision space diagram’. This allows visual comparison of the range of potential outcomes for habitat and reliability resulting from different combinations of minimum flow and allocation limit for each management unit.

3 Results

3.1 Proposed NES rules

The proposed NES allocation rules for small rivers (minimum flow 90% of MALF and total allocation 30% of MALF) were applied to all reaches in the catchments of interest and used to evaluate the spatial patterns and variability in consequences for resource reliability and instream habitat for the four indicator fish species. Scenarios were run using both the annual and February flow duration curves to compare the consequences under average and summer low flow conditions.

Reliability at the management flow describes the proportion of time (on average) that the whole volume of water that has been allocated (i.e., all of the total allocation limit) is potentially available for use. The higher the value, the higher the reliability of supply for out-of-stream use. Figure 3-1 shows the reliability at the management flow based on the annual FDC and therefore represents the predicted average reliability of supply over multiple years. It can be seen that for much of Northland, reliability is high (>90%). However, through the central part of the region, reliability is predicted to be slightly lower (80-90%) and there is an area to the east of Hokianga Harbour where the reliability of supply under the proposed NES small river rules is predicted to be relatively low (40-70%). During the summer low flow period, reliability at the management flow is broadly predicted to be lower than over the annual FDC as expected (Figure 3-2).

Reliability at the minimum flow describes the proportion of time (on average) that at least some of the volume of water allocated for out-of-stream use is predicted to be available. Subtracting this value from 100% gives the proportion of time (on average) that all water takes must cease to meet the minimum flow requirements. The higher the reliability at the minimum flow, the lower the proportion of time when no water is available to be taken. Figure 3-3 and Figure 3-4 show the predicted reliability at the management flow for the annual and February FDCs respectively. It can be seen that for the annual FDC, reliability across the vast majority of Northland is high (>90%), but there are a few locations where reliability is as low as 50% (Figure 3-3). During February, reliability at the management flow across most of the region is still over 90%, but is lower in the central part of the region and to the east of the Hokianga Harbour (minimum c.50%).

The predicted consequences of the proposed NES small river rules for instream physical habitat of the four indicator fish species are broadly similar for both the annual and February FDCs (Figure 3-5 to Figure 3-12). For banded kokopu, instream habitat typically increased in larger rivers (particularly for the annual FDC), but on average declined and was almost completely lost in some of the small, headwater streams to the east of the Hokianga Harbour and to the west of Kerikeri (Figure 3-5 & Figure 3-6). Common bully showed a similar response, but compared to banded kokopu there was a less pronounced increase in physical habitat in larger rivers for the annual FDC (Figure 3-7 & Figure 3-8). The consequences for both eel species were very similar, with physical habitat for both species declining on average (Figure 3-9 to Figure 3-12). The spatial patterns in the response of the physical habitat variables were subsequently identified as a key driver to identifying and defining spatially discrete management units for setting default water limits.

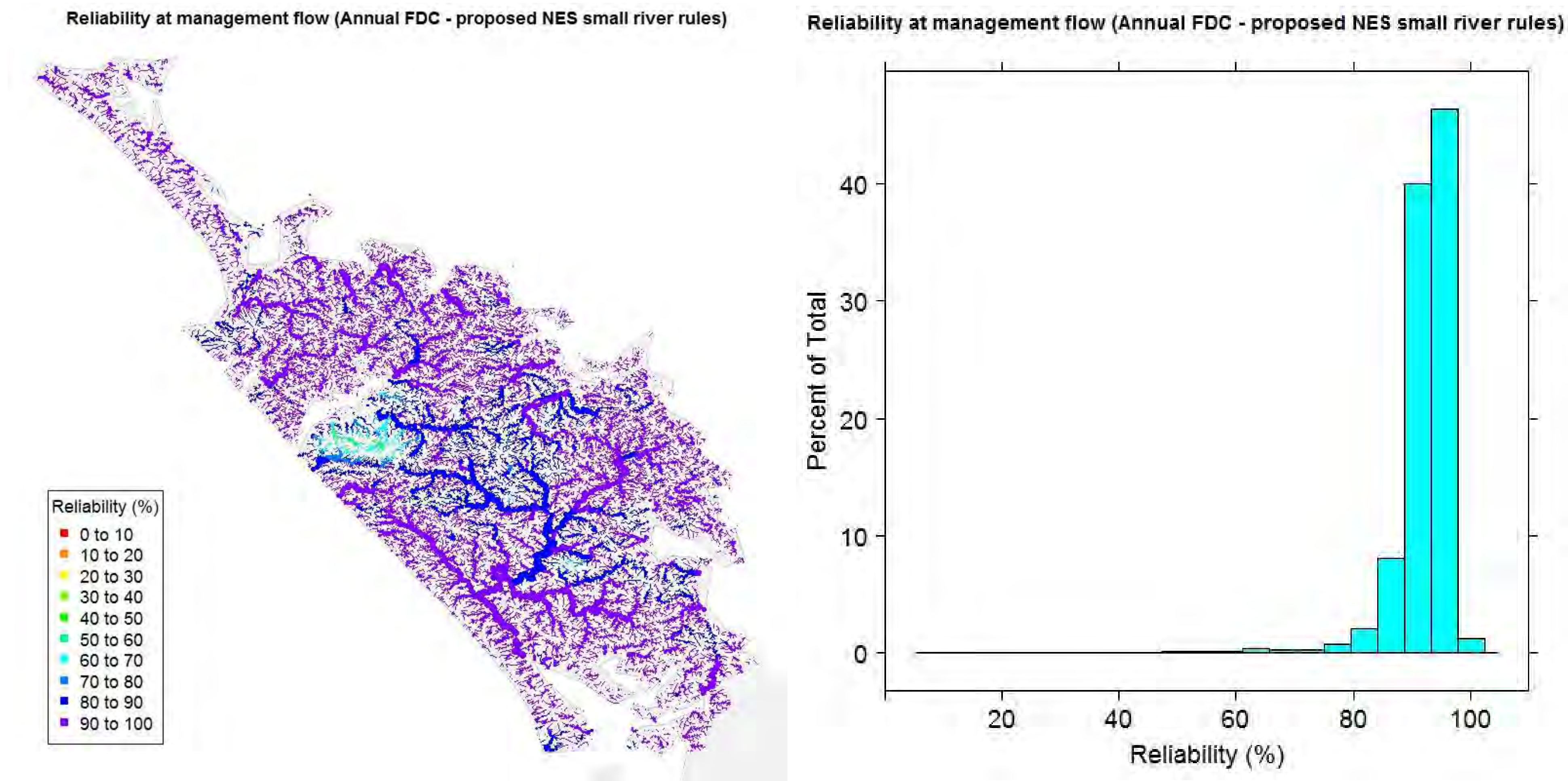
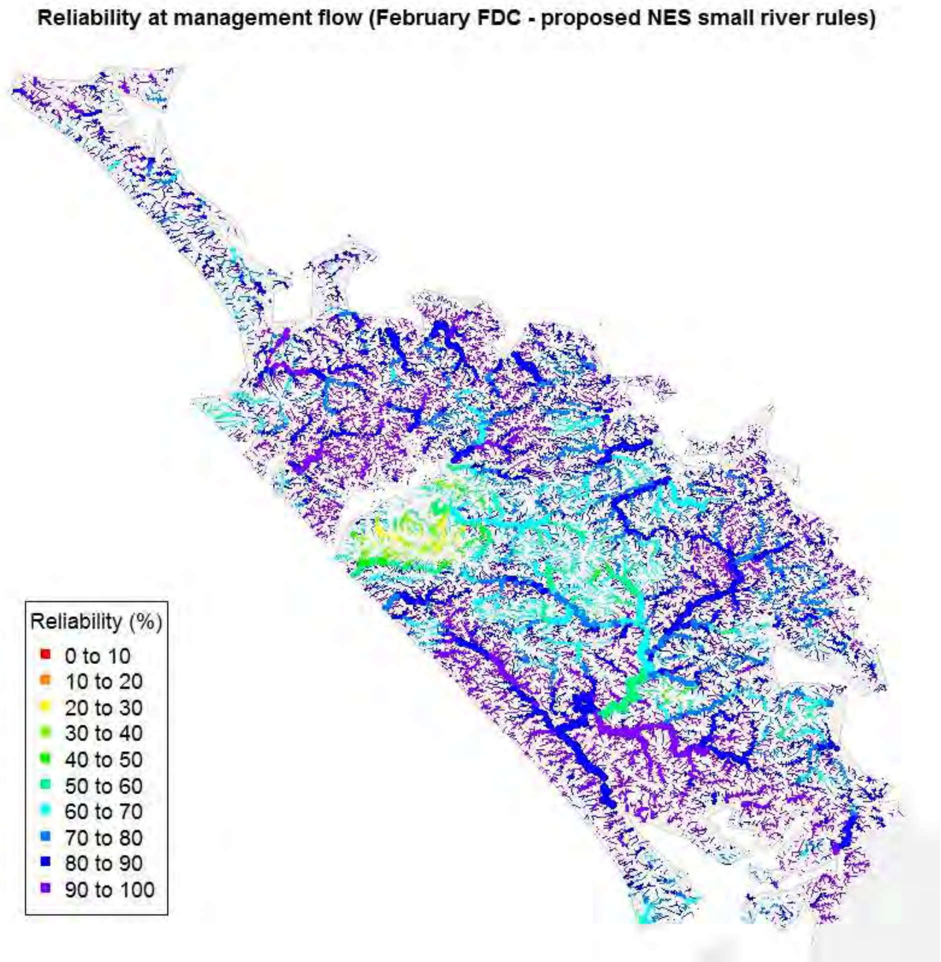


Figure 3-1: Mean annual reliability at the management flow for Northland under the proposed NES rules for small rivers.



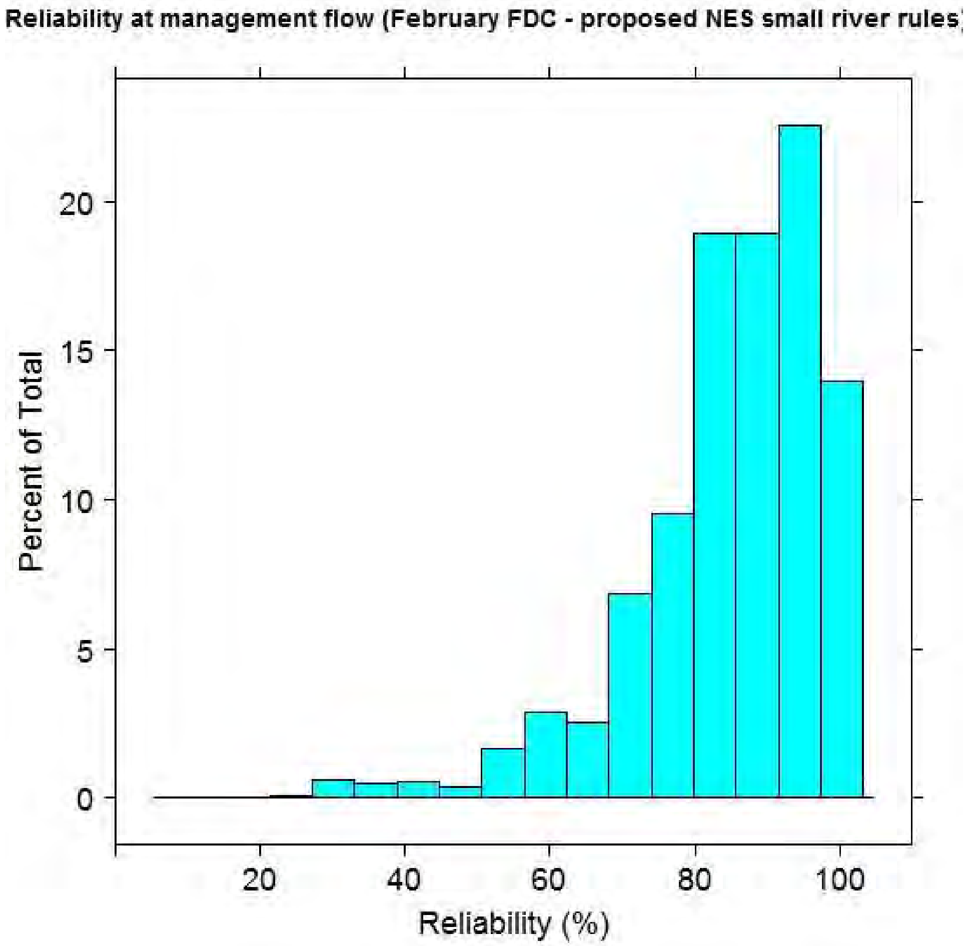


Figure 3-2: Mean February reliability at the management flow for Northland under the proposed NES rules for small rivers.

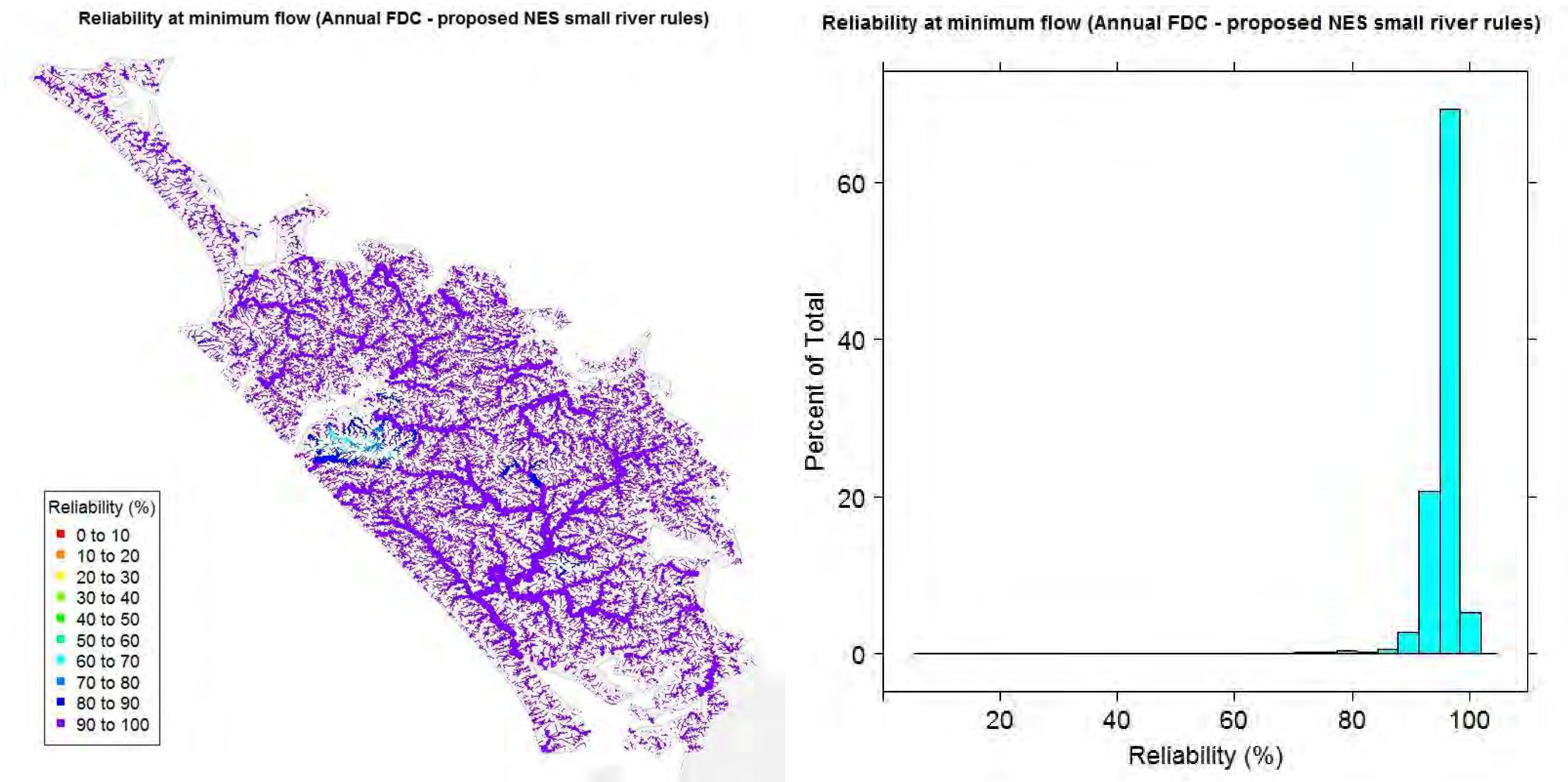
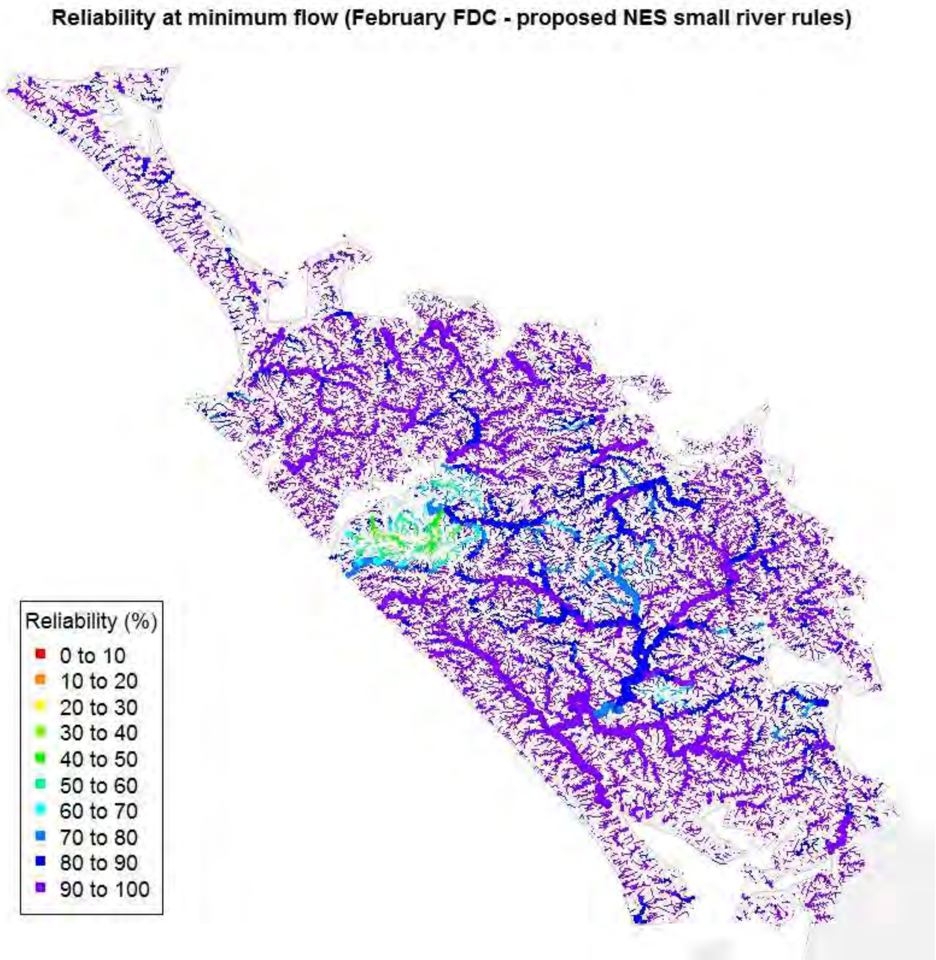


Figure 3-3: Mean annual reliability at the minimum flow for Northland under the proposed NES rules for small rivers.



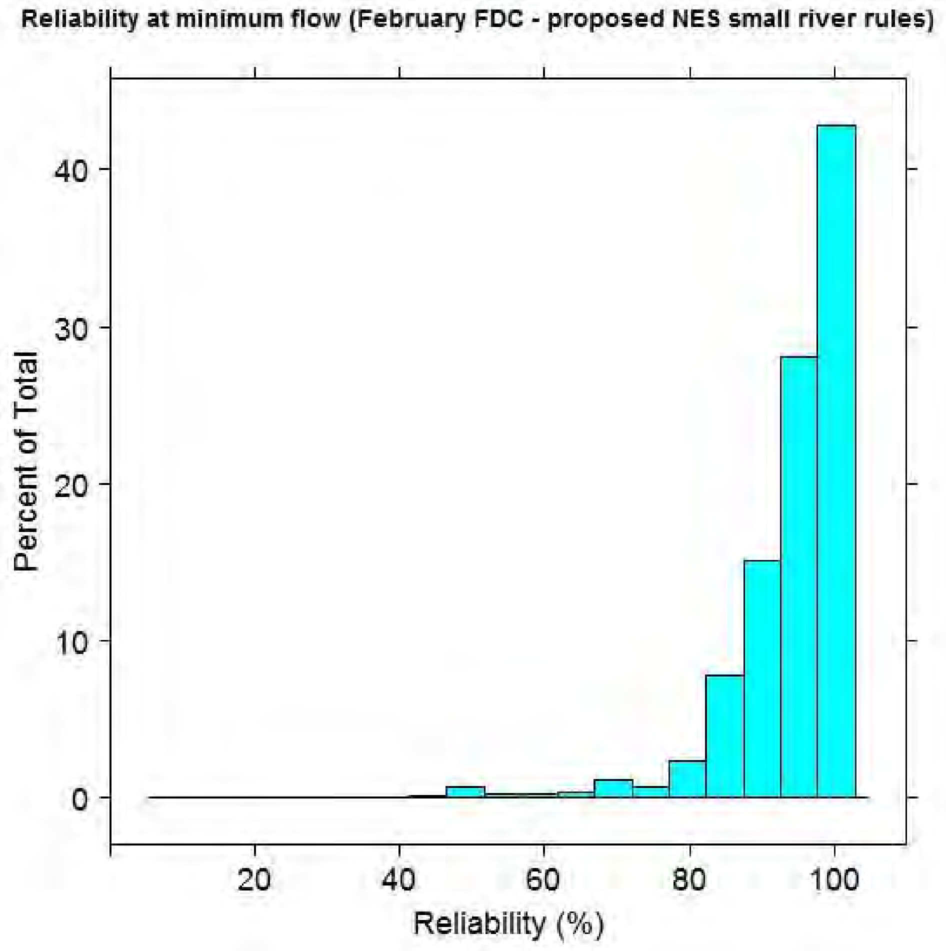
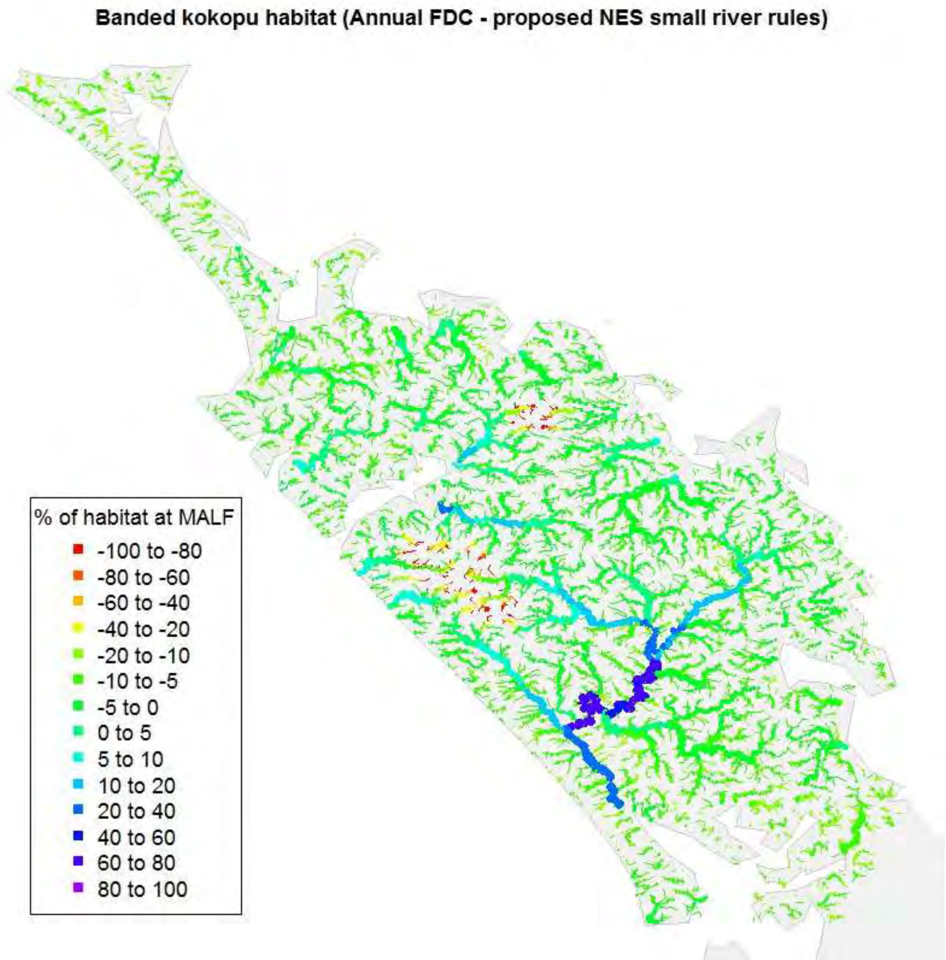


Figure 3-4: Mean February reliability at the minimum flow for Northland under the proposed NES rules for small rivers.



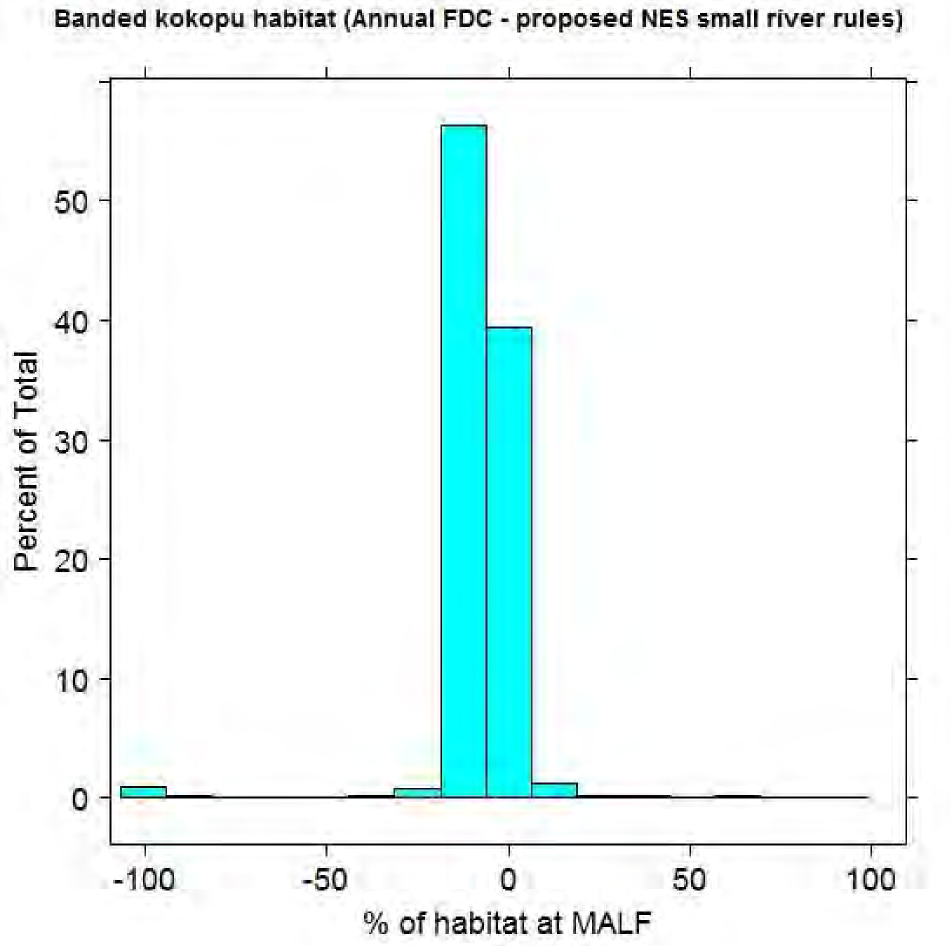


Figure 3-5: Mean annual change in banded kokopu habitat for Northland under the proposed NES rules for small rivers.

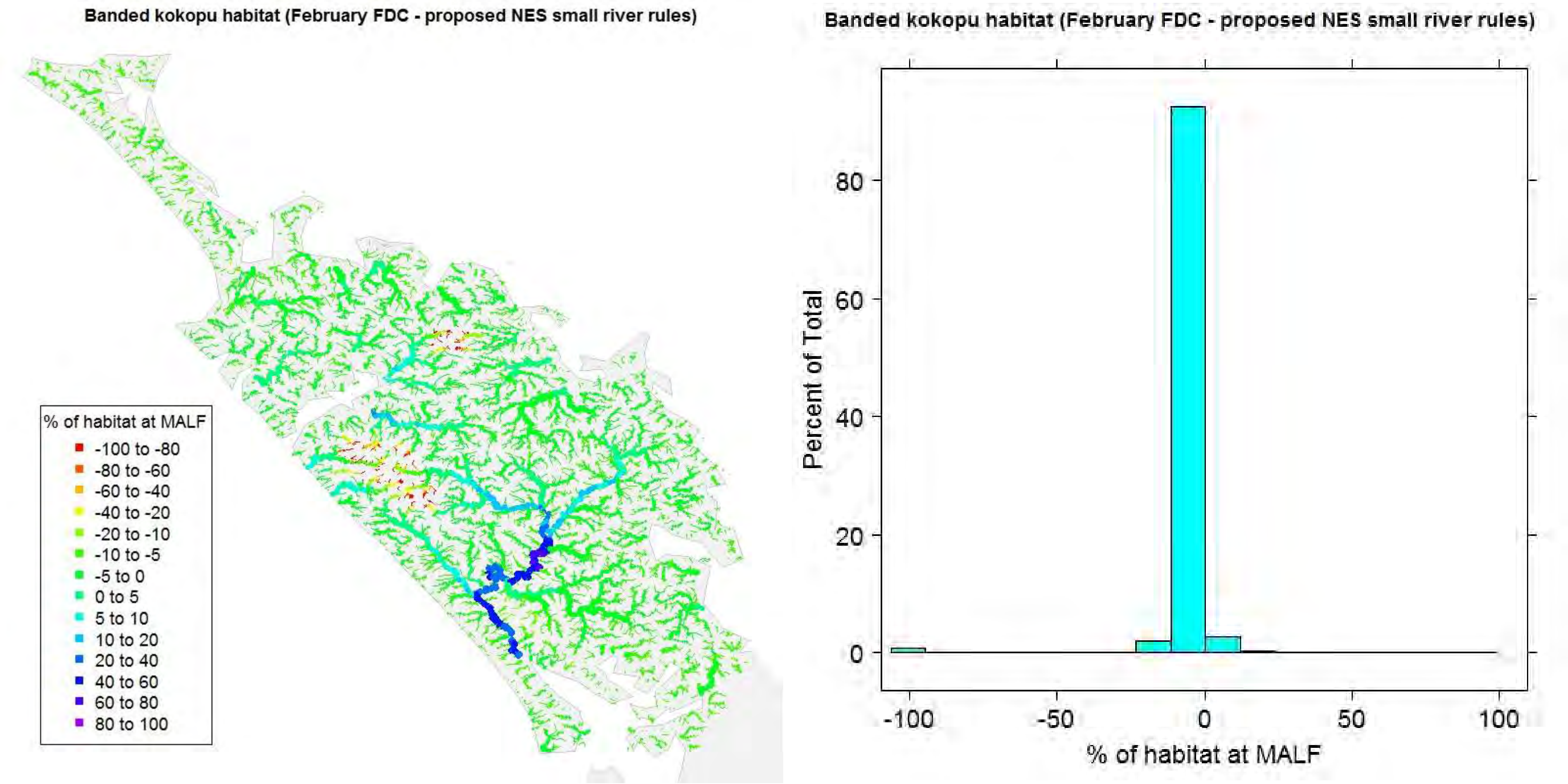
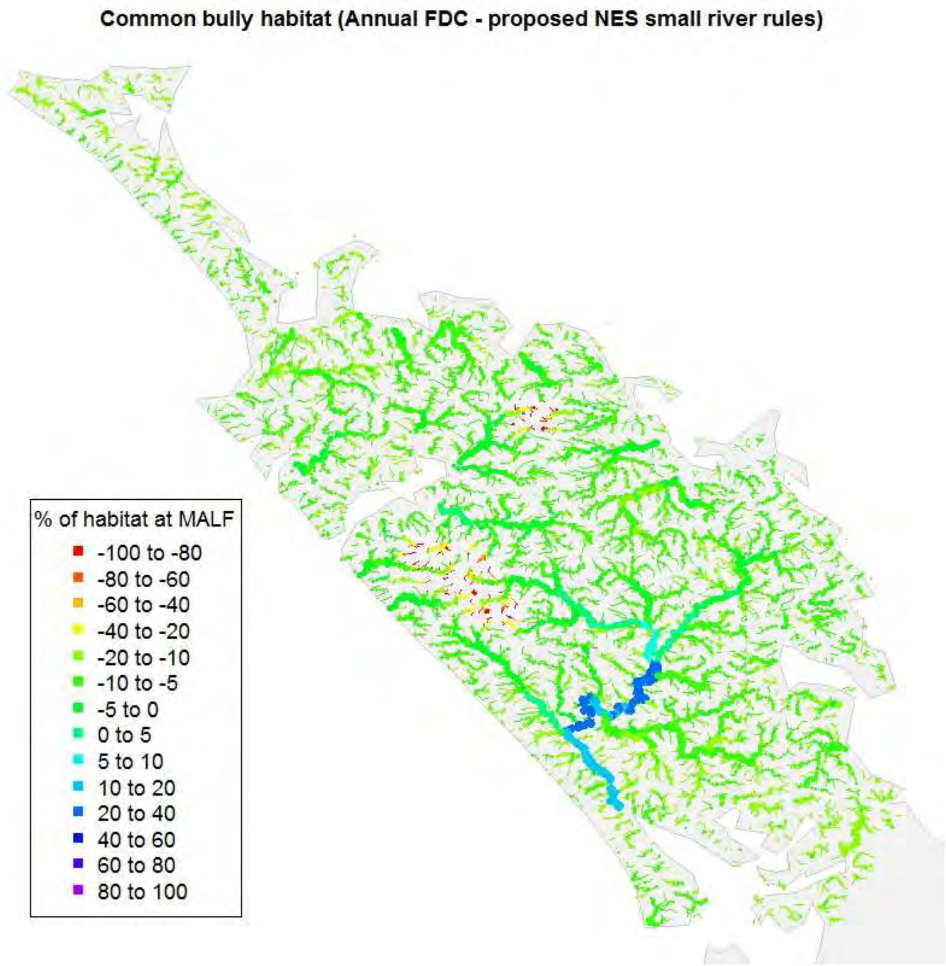


Figure 3-6: Mean February change in banded kokopu habitat for Northland under the proposed NES rules for small rivers.



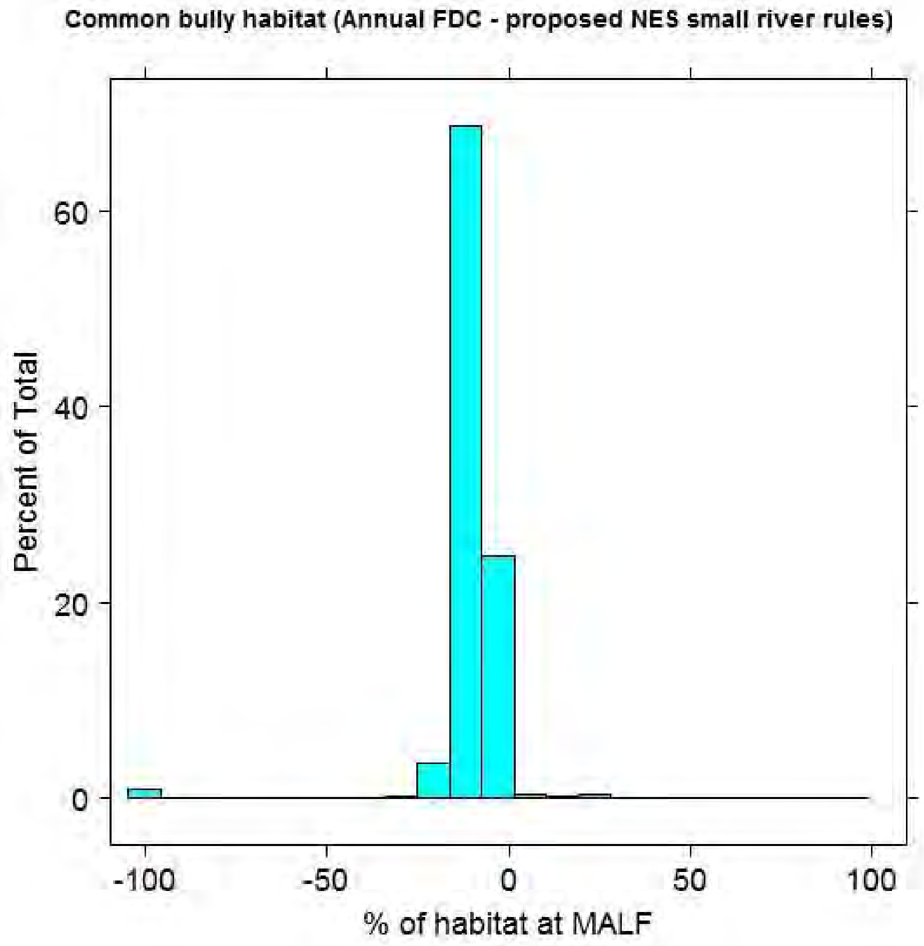
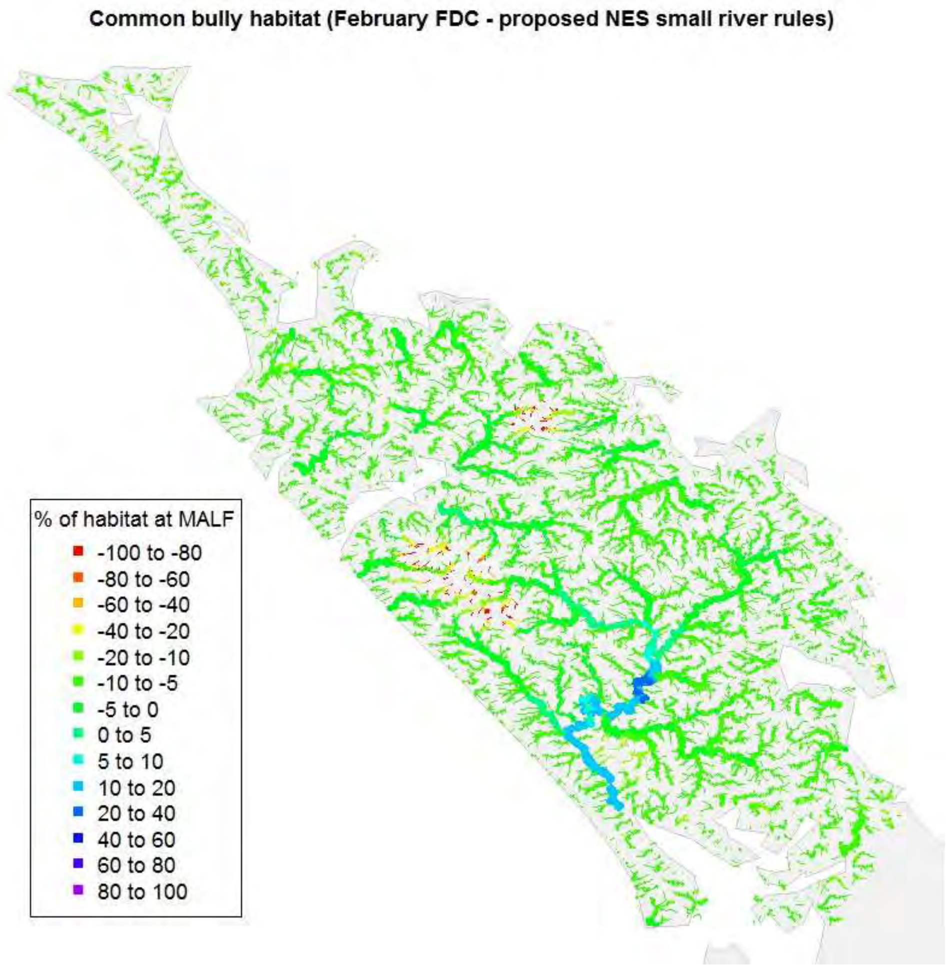


Figure 3-7: Mean annual change in common bully habitat for Northland under the proposed NES rules for small rivers.



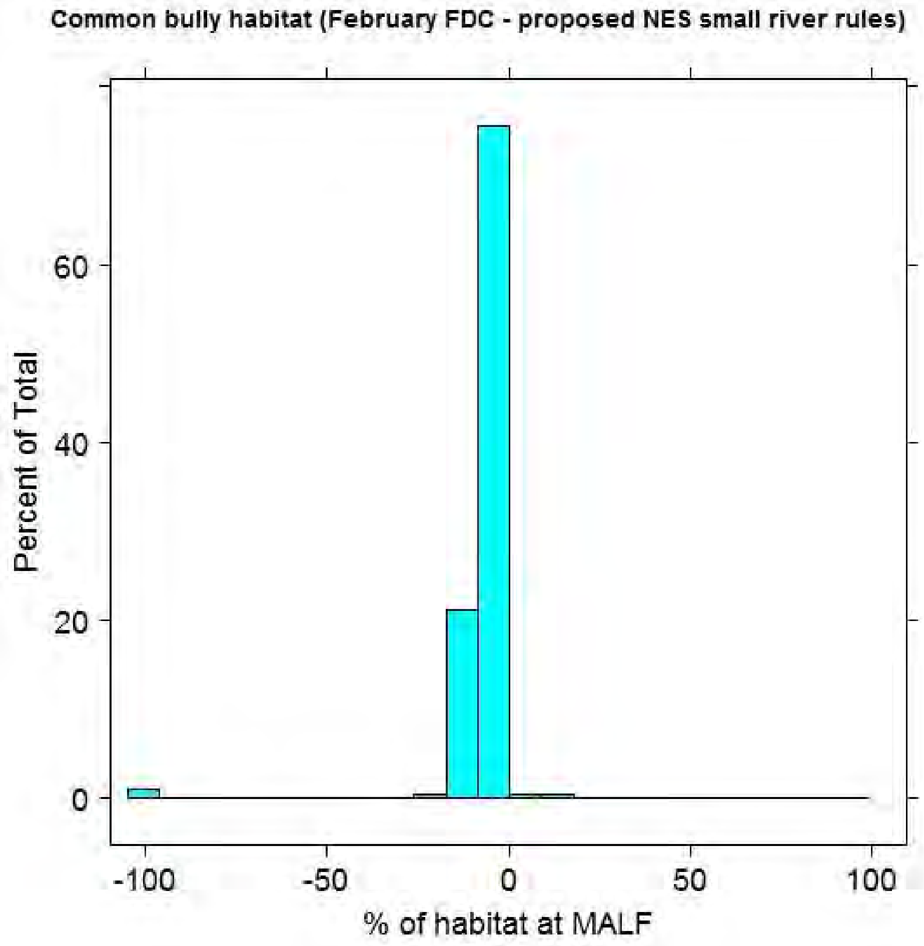


Figure 3-8: Mean February change in common bully habitat for Northland under the proposed NES rules for small rivers.

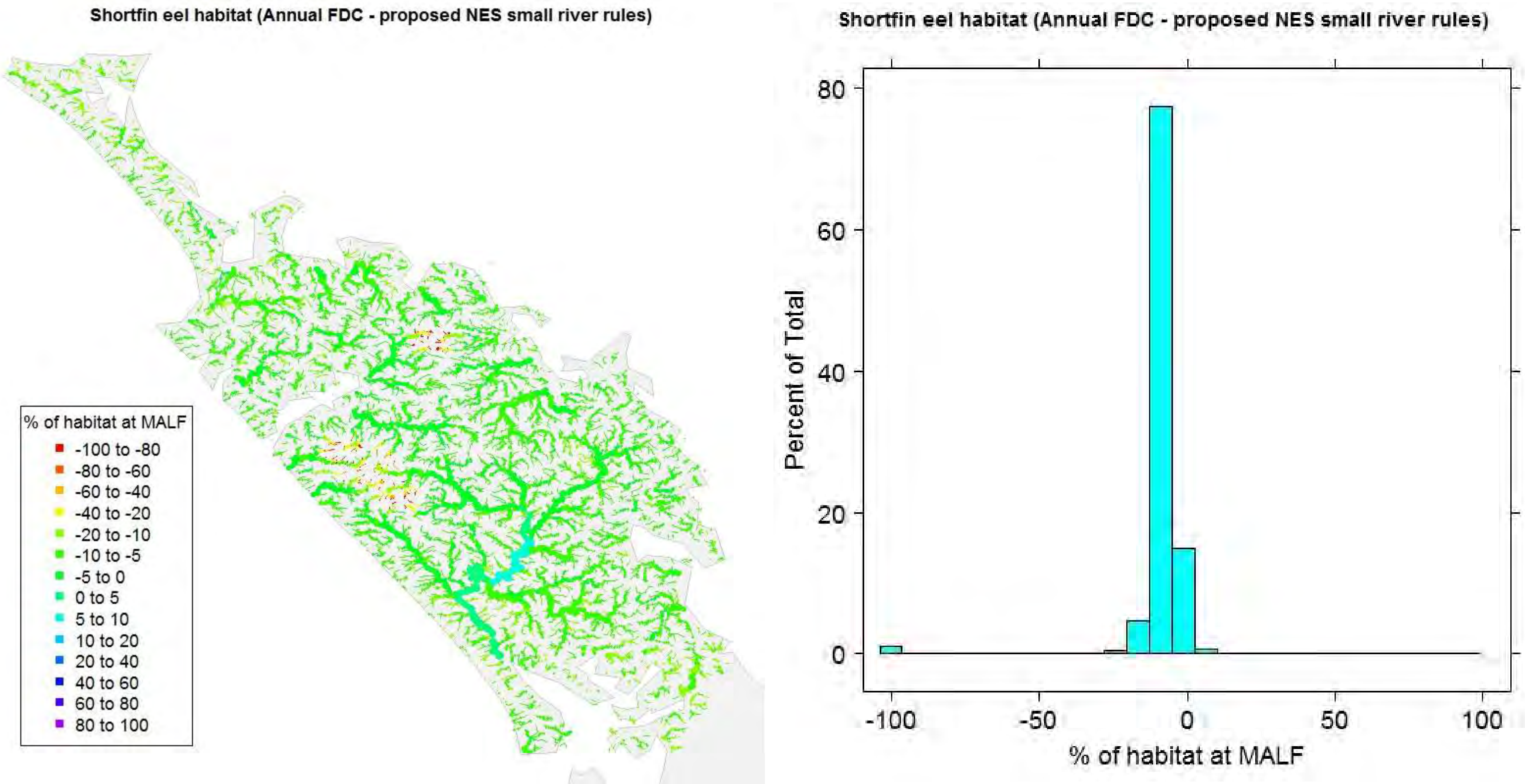


Figure 3-9: Mean annual change in shortfin eel habitat for Northland under the proposed NES rules for small rivers.

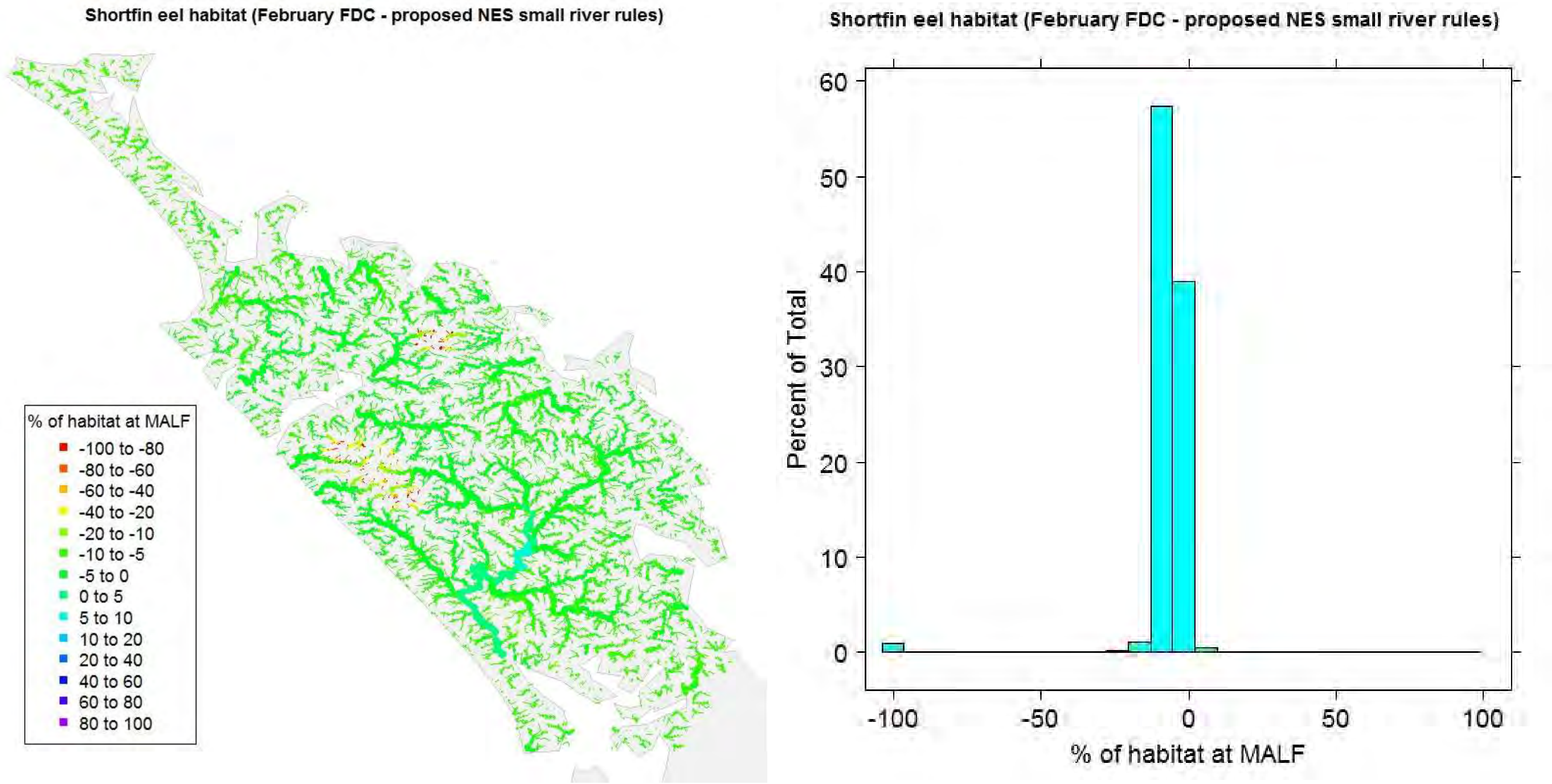


Figure 3-10: Mean February change in shortfin eel habitat for Northland under the proposed NES rules for small rivers.

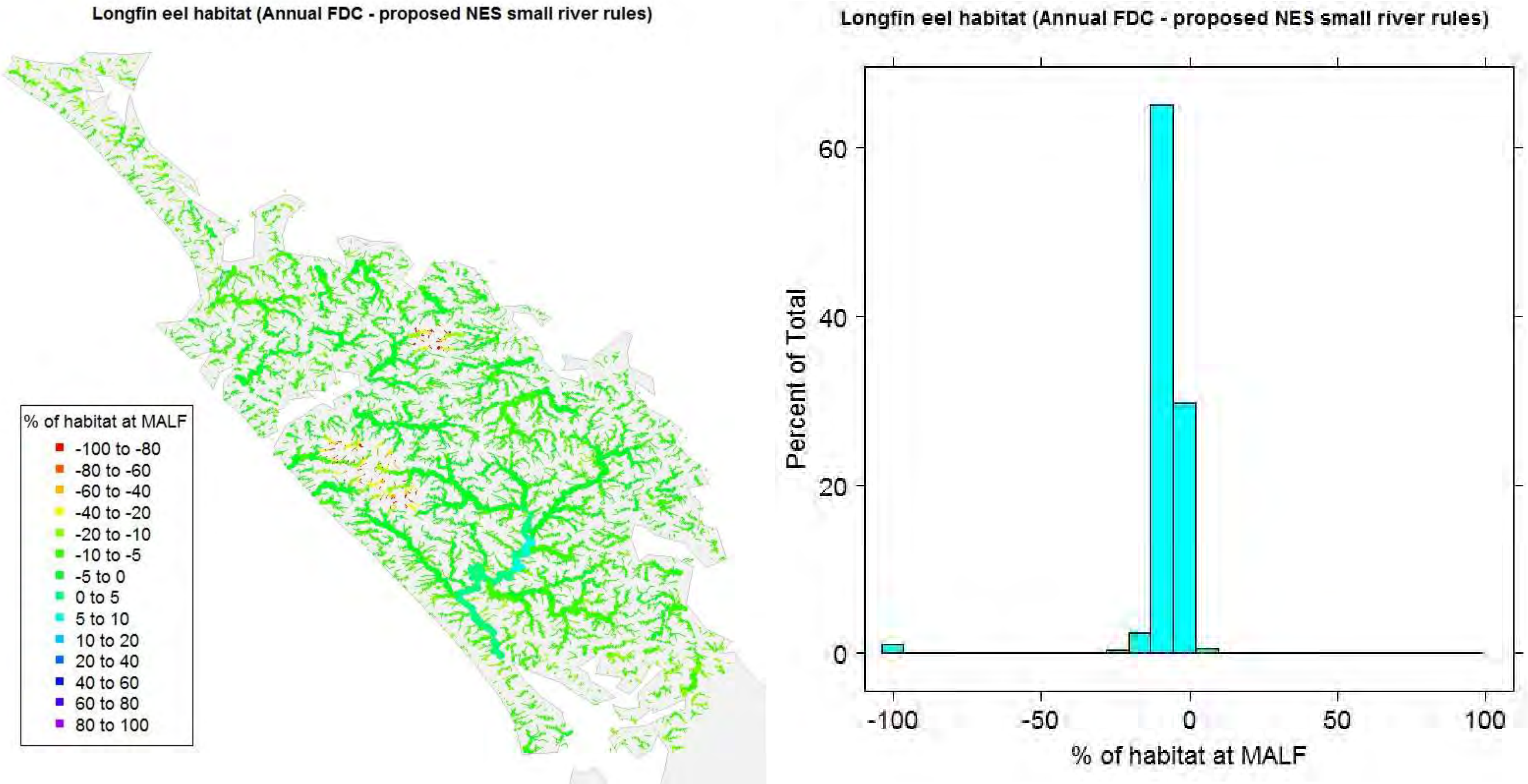


Figure 3-11: Mean annual change in longfin eel habitat for Northland under the proposed NES rules for small rivers.

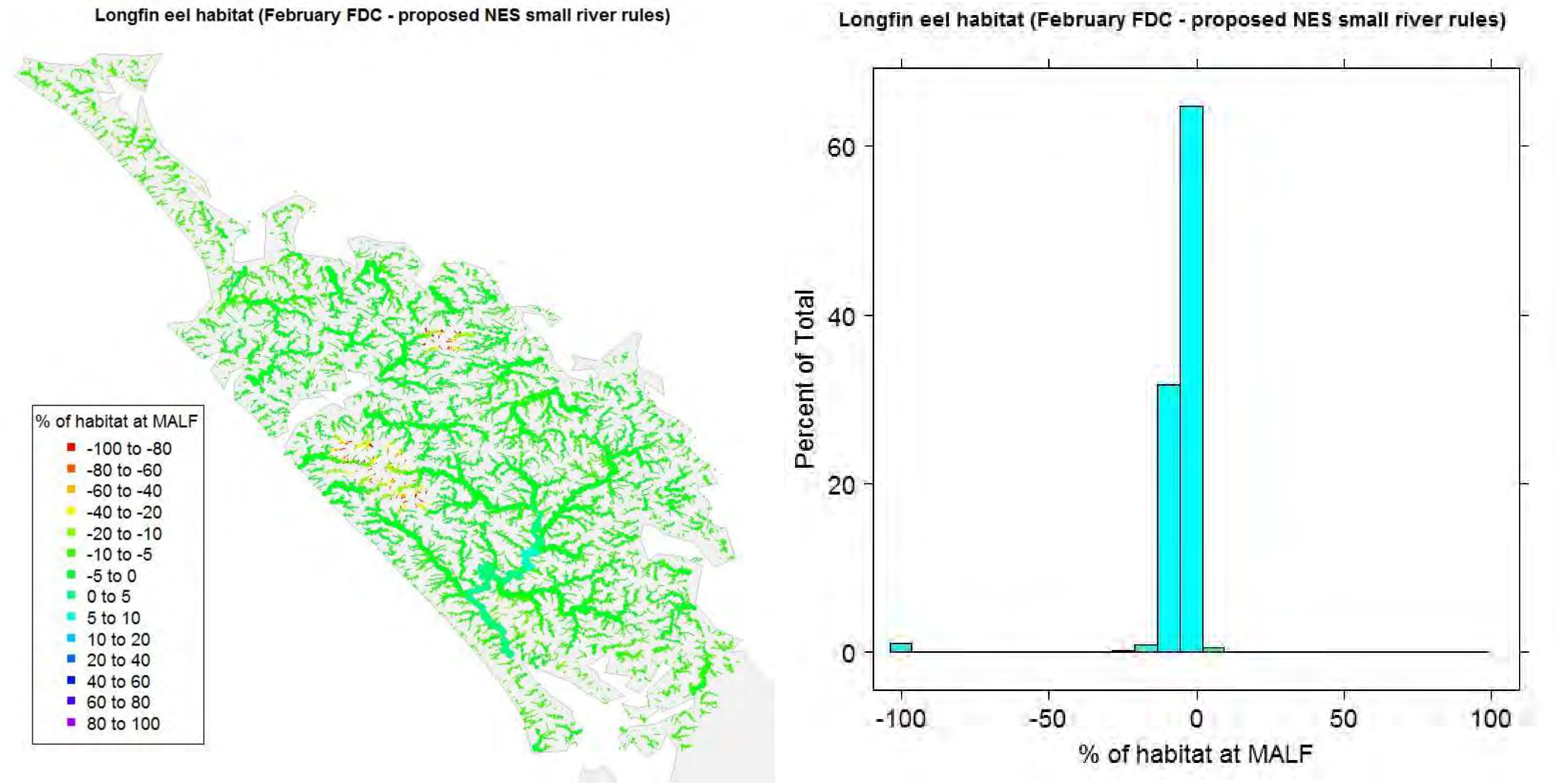


Figure 3-12: Mean February change in longfin eel habitat for Northland under the proposed NES rules for small rivers.

3.2 Spatial patterns

In order to reduce the variability in both instream and out-of-stream consequences, and thus improve equitability for stakeholders, we attempted to define spatially discrete management units with relatively uniform outcomes for each of the values. Exploratory data analysis was carried out using REC classes to differentiate spatial groupings. In most cases, little differentiation was observed between the REC classes. The exception was the association between the REC WX (warm extremely wet) climate class and the areas of significant physical habitat decline in the areas east of Hokianga Harbour and to the west of Kerikeri. Separating reaches from this REC class significantly reduces the variability in consequences for the remaining reaches, therefore all streams in the REC WX climate class were grouped into a separate spatial management unit (Table 3-1; Figure 3-13).

For the remaining river reaches, it was recognised that river size was an important variable in differentiating the consequences for instream physical habitat, especially for banded kokopu and common bully. A threshold based on mean flow was identified that broadly separated those reaches where physical habitat was predicted to increase (relative to MALF) under the proposed NES small river rules from those where physical habitat was predicted to decline (relative to MALF) (Table 3-1; Figure 3-13).

The differences in predicted consequence between the three proposed spatial management units are illustrated for each indicator variable in Figure 3-14 to Figure 3-19. It is recognised that currently there remains a relatively broad range of variability in consequences within the 'Warm extremely wet' management unit (Figure 3-14 to Figure 3-19), broadly reflecting a distinction between the main stem and small, first order tributaries. However, this management unit accounts for a large proportion of the regional variability in consequences for each of the values at a regional scale. As a consequence of separating these reaches into a separate management unit, variation in the other two management units (which account for the majority of river reaches in the region) is considerably lower. There is also a bi-modal distribution in the reliability results in the large river unit for the February FDC. It appears that this reflects the influence of the Manganui River on the lower reaches of the Wairoa River. It is recognised that using Table 3-1 to categorise management units may create practical difficulties because, for example, they do not coincide with catchment boundaries or existing water management units. More detailed analyses at a higher spatial resolution or based on catchment boundaries could help to distinguish management sub-units with more uniform outcomes, but is beyond the scope of this project. The observed variability will have implications for defining appropriate rules to meet objectives in all locations and for equitability between stakeholders. However, because the aim of this project is to support definition of regional scale default allocation limits, rather than catchment and site specific rules, we consider that this level of variability is acceptable.

Table 3-1: Definition of spatial management units for default allocation limits in Northland.

Management unit	Spatial definition
Large river	Mean flow ≥ 20 $m^3 s^{-1}$
Small river	Mean flow < 20 $m^3 s^{-1}$
Warm extremely wet	REC WX climate class

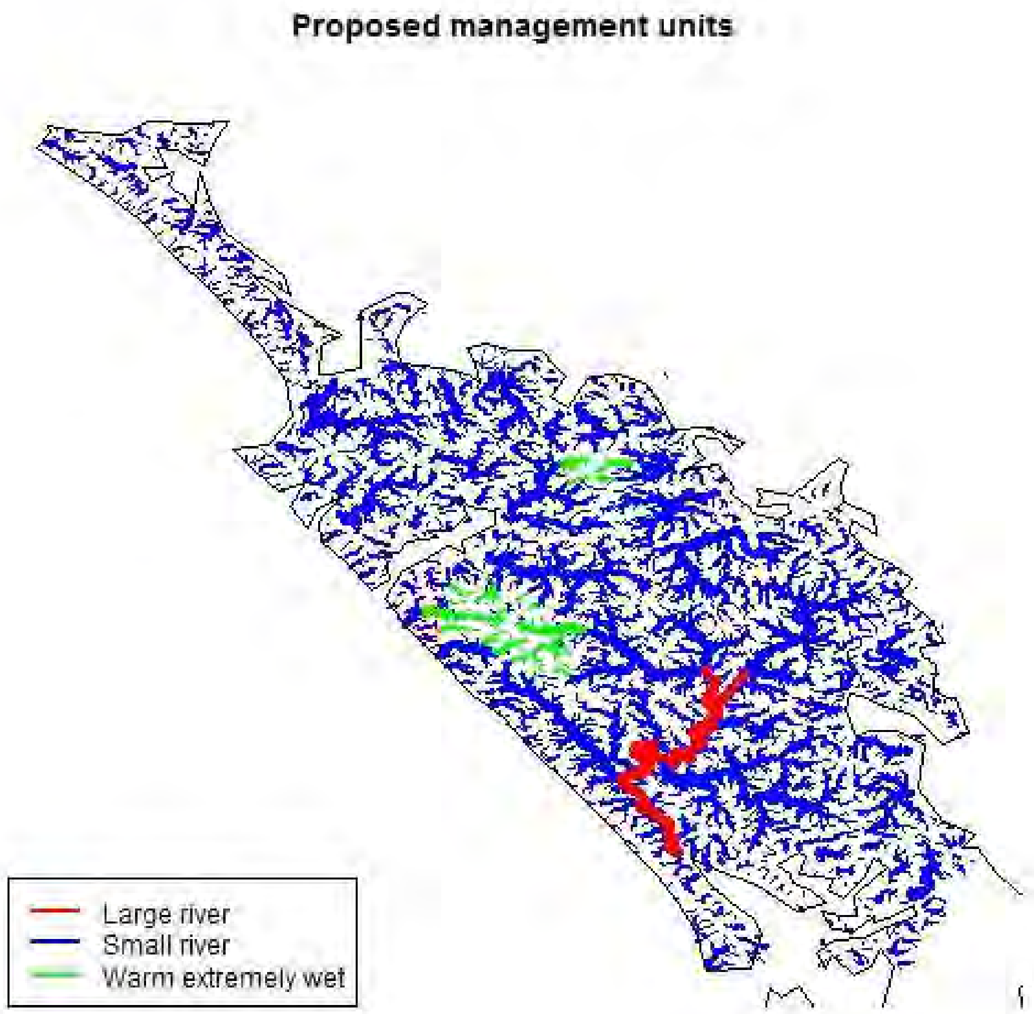


Figure 3-13: Location of the three proposed management units.

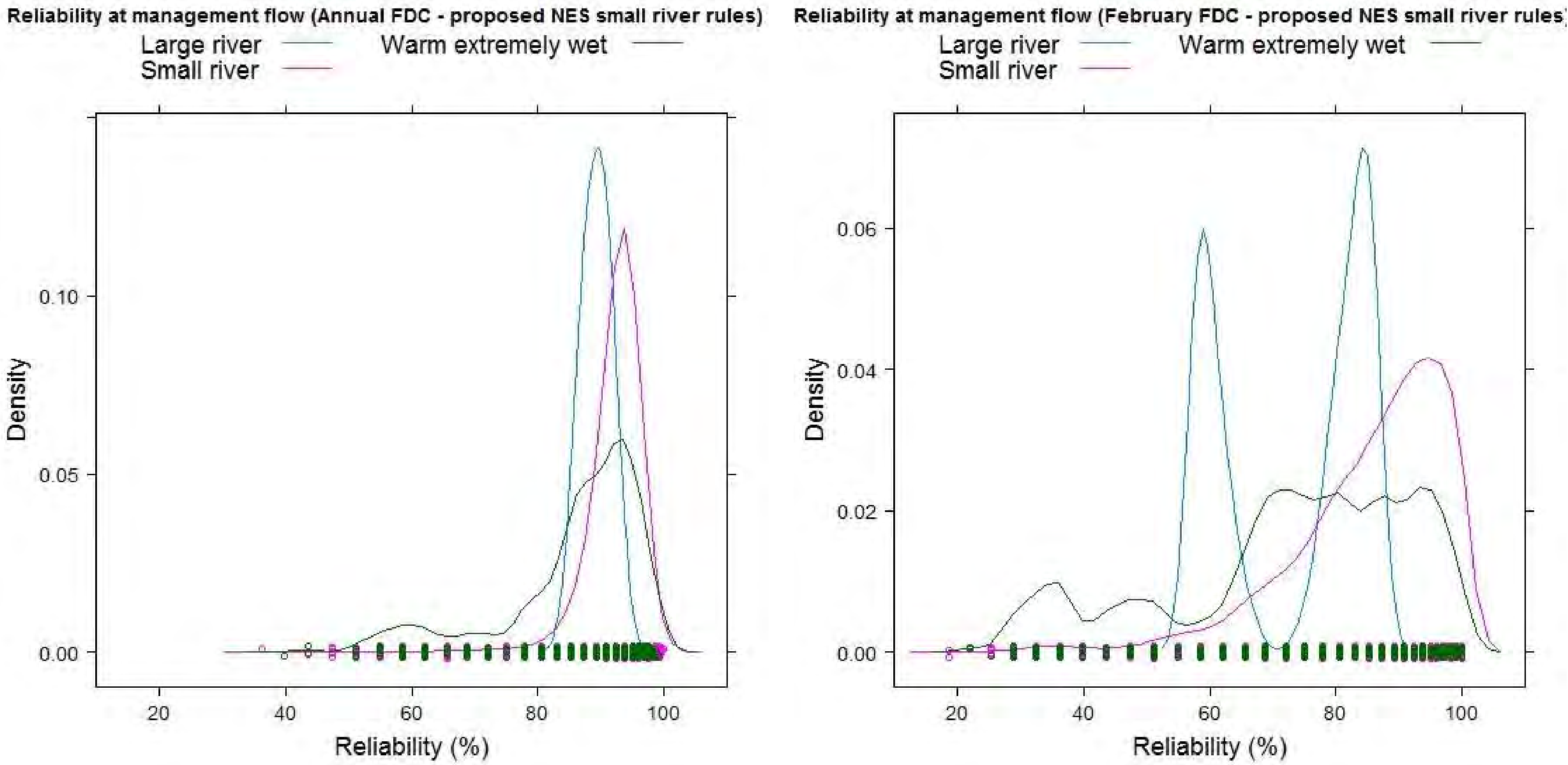


Figure 3-14: Density plots showing variation in reliability at the management flow within and between the three management units. Left: Annual flow duration curve; Right: February flow duration curve. The higher the density, the greater the proportion of reaches with that reliability.

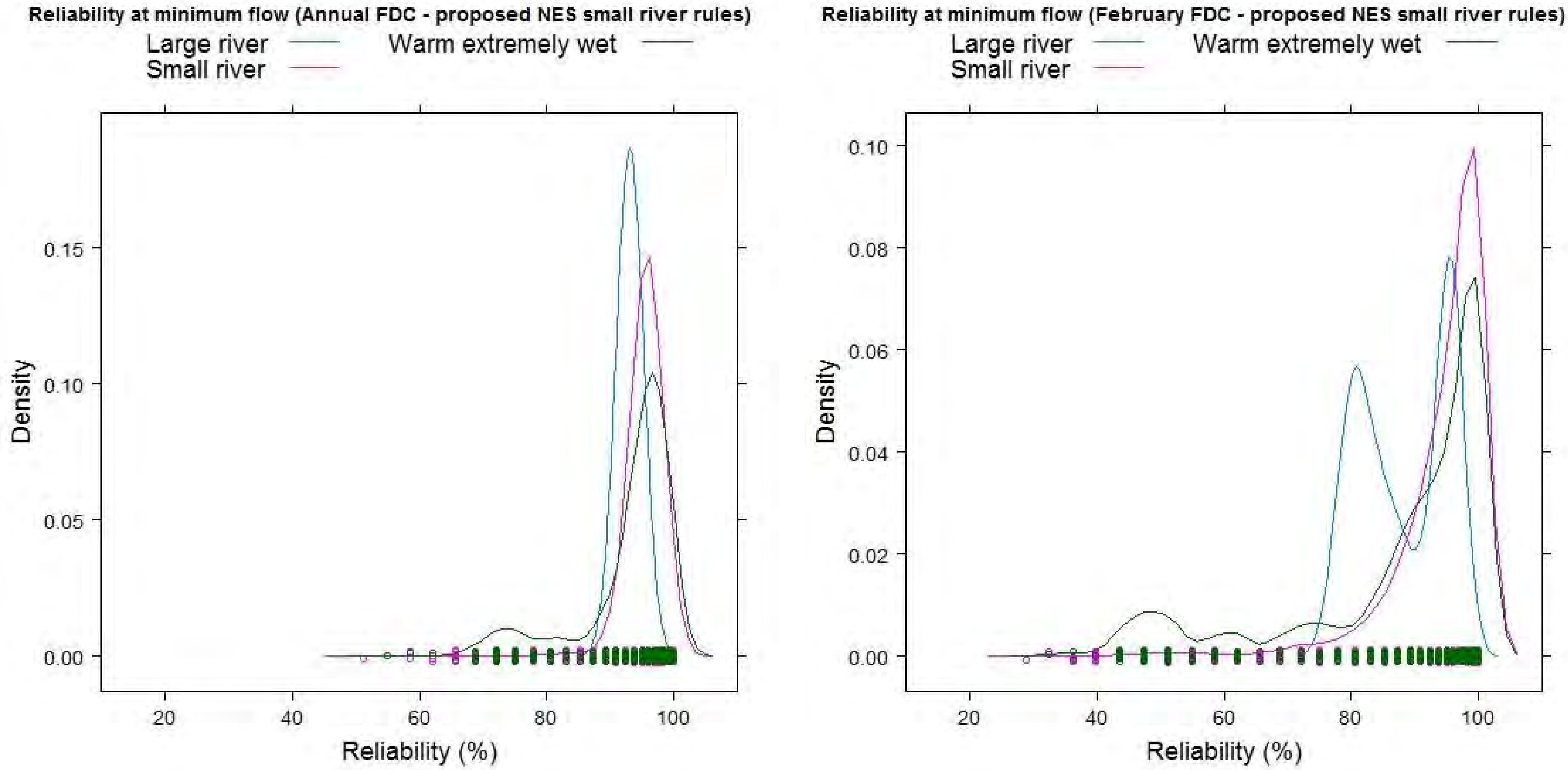
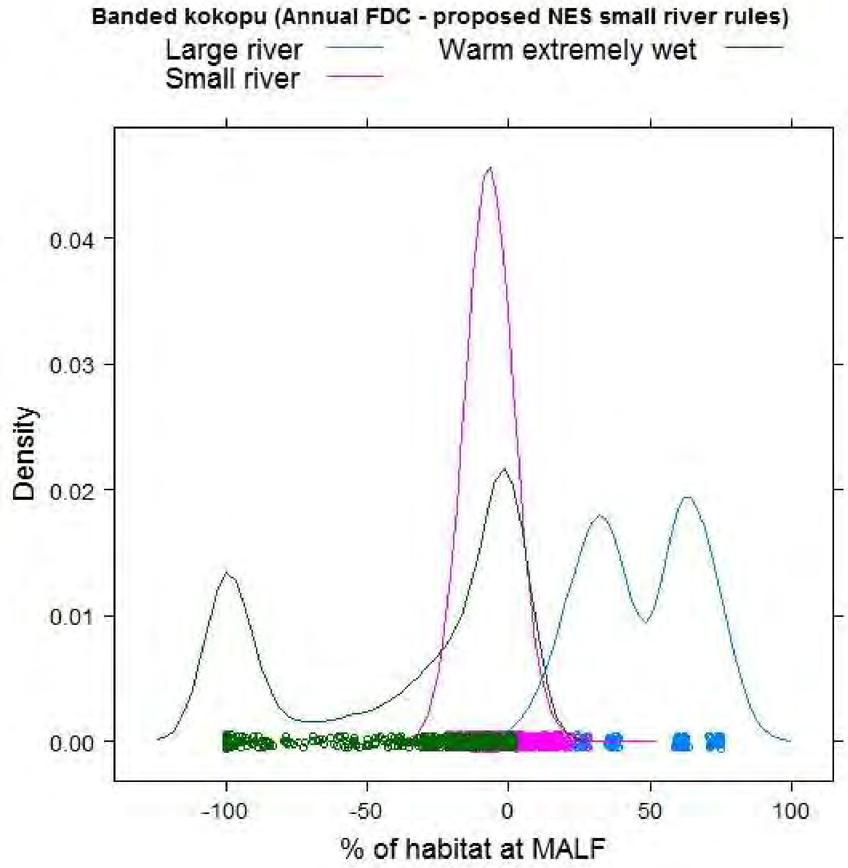


Figure 3-15: Density plots showing variation in reliability at the minimum flow within and between the three management units. Left: Annual flow duration curve; Right: February flow duration curve.



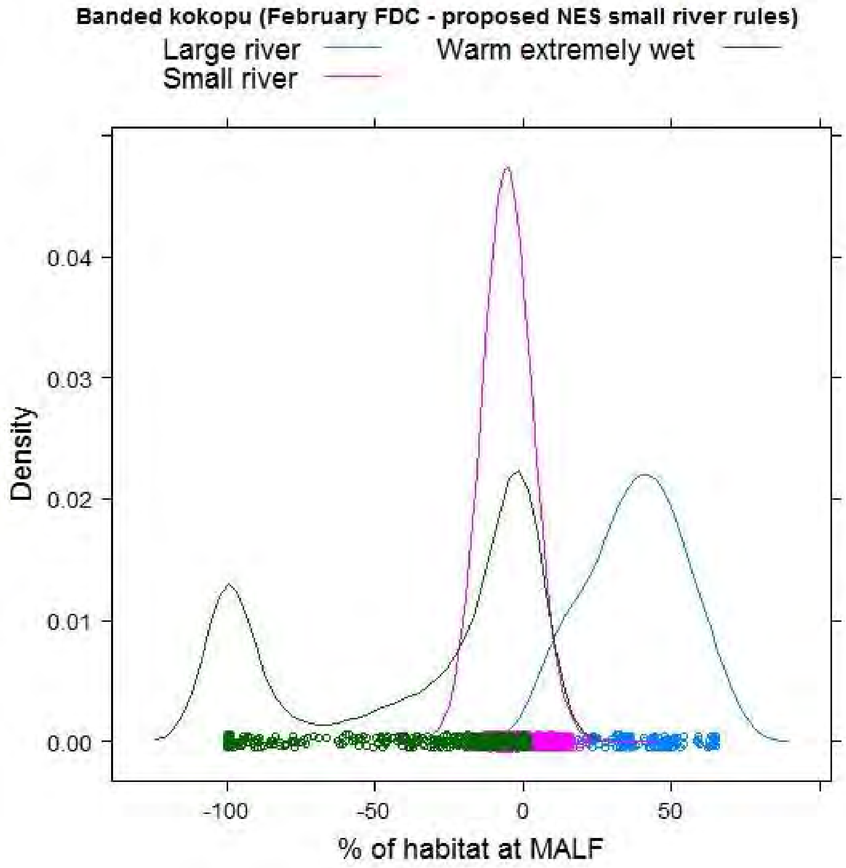


Figure 3-16: Density plots showing the variation in consequences for banded kokopu instream physical habitat within and between management units. Left: Annual flow duration curve; Right: February flow duration curve.

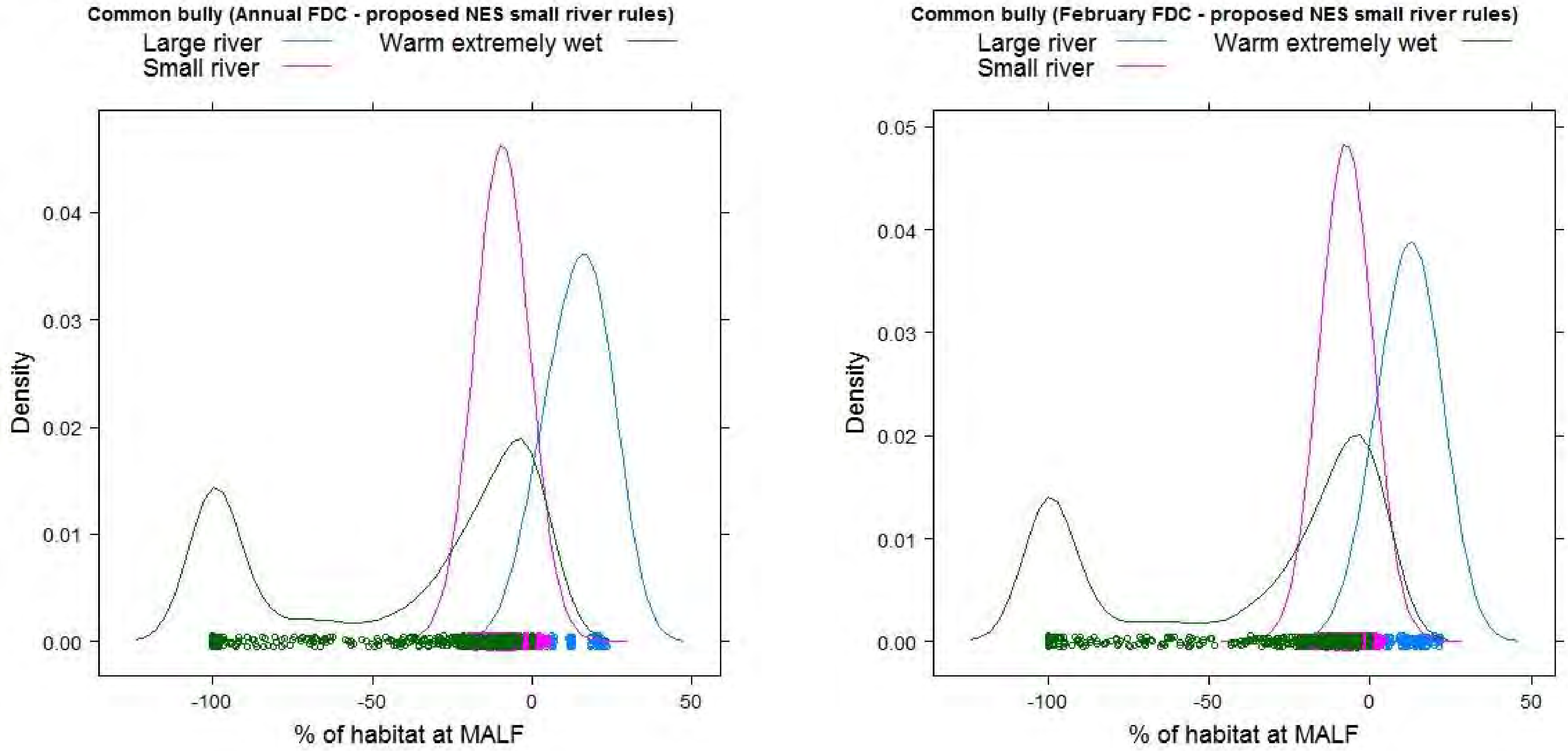


Figure 3-17: Density plots showing the variation in consequences for common bully instream physical habitat within and between management units. Left: Annual flow duration curve; Right: February flow duration curve.

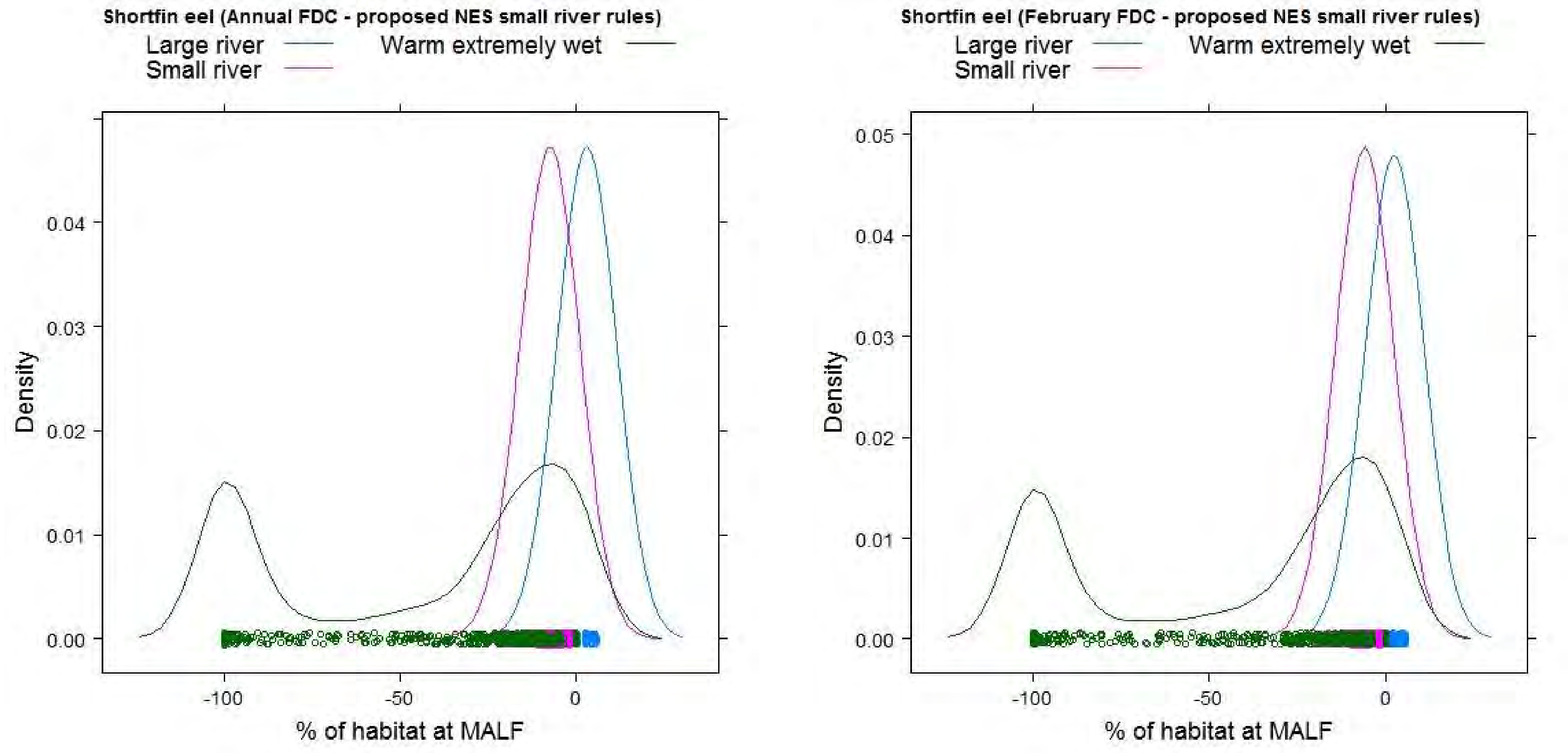


Figure 3-18: Density plots showing the variation in consequences for shortfin eel instream physical habitat within and between management units. Left: Annual flow duration curve; Right: February flow duration curve.

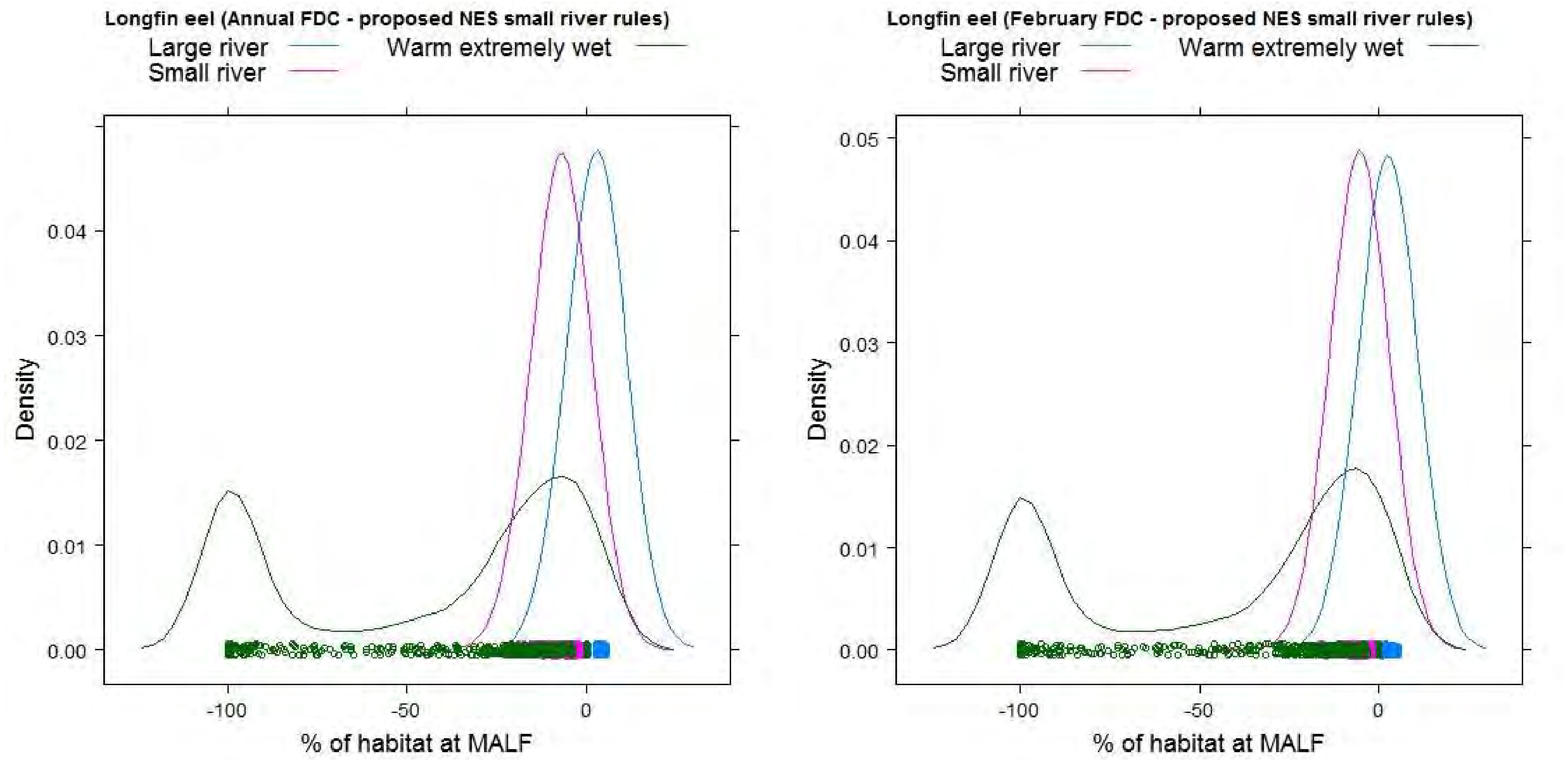


Figure 3-19: Density plots showing the variation in consequences for longfin eel instream physical habitat within and between management units. Left: Annual flow duration curve; Right: February flow duration curve.

4 Decision space diagrams

A range of allocation scenarios were simulated for the Northland region using EFSAP, for both the annual and February FDCs. The consequences for each value for the full range of simulated scenarios were then summarised in a decision space diagram. Here we present decision space diagrams that encompass minimum flows ranging from 10% to 100% of MALF, and total allocation limits that range from 10% to 150% of MALF, each in 10% increments. The full range of scenarios presented do not represent a 'recommended' range of options and may not be considered acceptable in all circumstances. They are presented only to provide information regarding the predicted trade-offs between the assessed values for consideration in the limit selection process, which must also account for additional values.

The decision space diagrams for reliability at management flow, reliability at minimum flow and for instream physical habitat for the four indicator fish species are presented for both the annual and February FDCs, for each of the three proposed management units. Table 4-1 summarises where the decision space diagrams for each value and each management unit can be found. Guidance on how these diagrams can be used to inform the limit setting process can be found in the discussion (Section 5.2).

Table 4-1: Summary of decision space diagrams presented. Diagrams are shown for both the annual and February FDCs.

Management unit	Reliability at management flow	Reliability at minimum flow	Banded kokopu habitat	Common bully habitat	Shortfin eel habitat	Longfin eel habitat
Large river	Figure 4-1	Figure 4-2	Figure 4-3	Figure 4-4	Figure 4-5	Figure 4-6
Small river	Figure 4-7	Figure 4-8	Figure 4-9	Figure 4-10	Figure 4-11	Figure 4-12
Warm extremely wet	Figure 4-13	Figure 4-14	Figure 4-15	Figure 4-16	Figure 4-17	Figure 4-18

Reliability is generally higher in the large and small river management units, compared to the warm extremely wet climate management unit. There is also less variability in consequences between different combinations of limits in the large and small river management units. In the large river management unit, large increases in Weighted Usable Area (WUA; a measure of the quantity of suitable habitat) for banded kokopu are predicted for many limit combinations. For the other fish species, the WUA increases in the large river management unit are predicted to be smaller, or slightly decreased. In the other management units predicted WUA for all fish species declines under all limit combinations. In general, the higher the allocation limit and the lower the minimum flow limit, the greater the reduction in predicted physical habitat (WUA), particularly in the warm extremely wet climate management unit.

4.1 Large river management unit

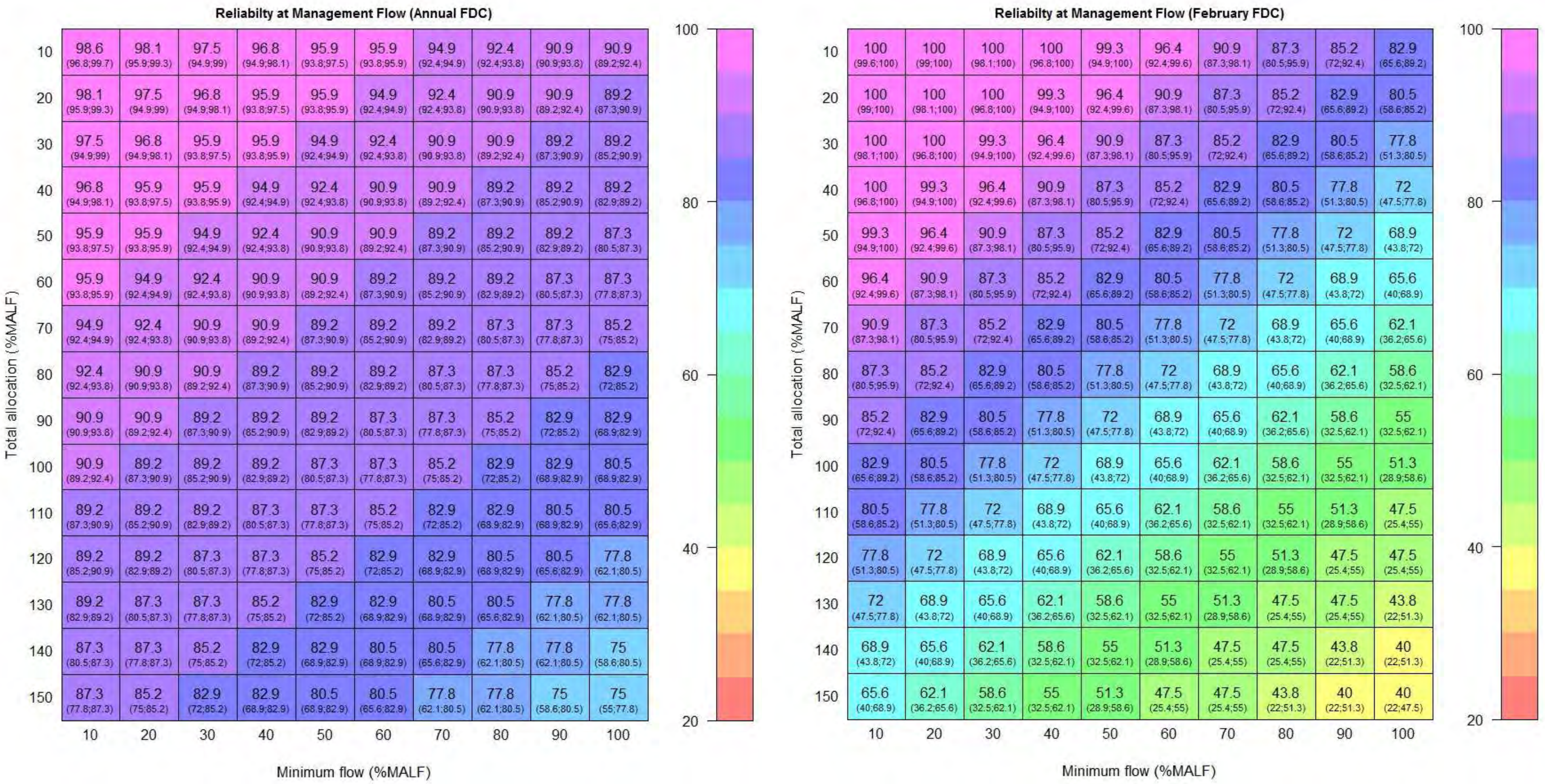


Figure 4-1: Large river (mean flow ≥ 20 $m^3 s^{-1}$) decision space diagrams for reliability at management flow. The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

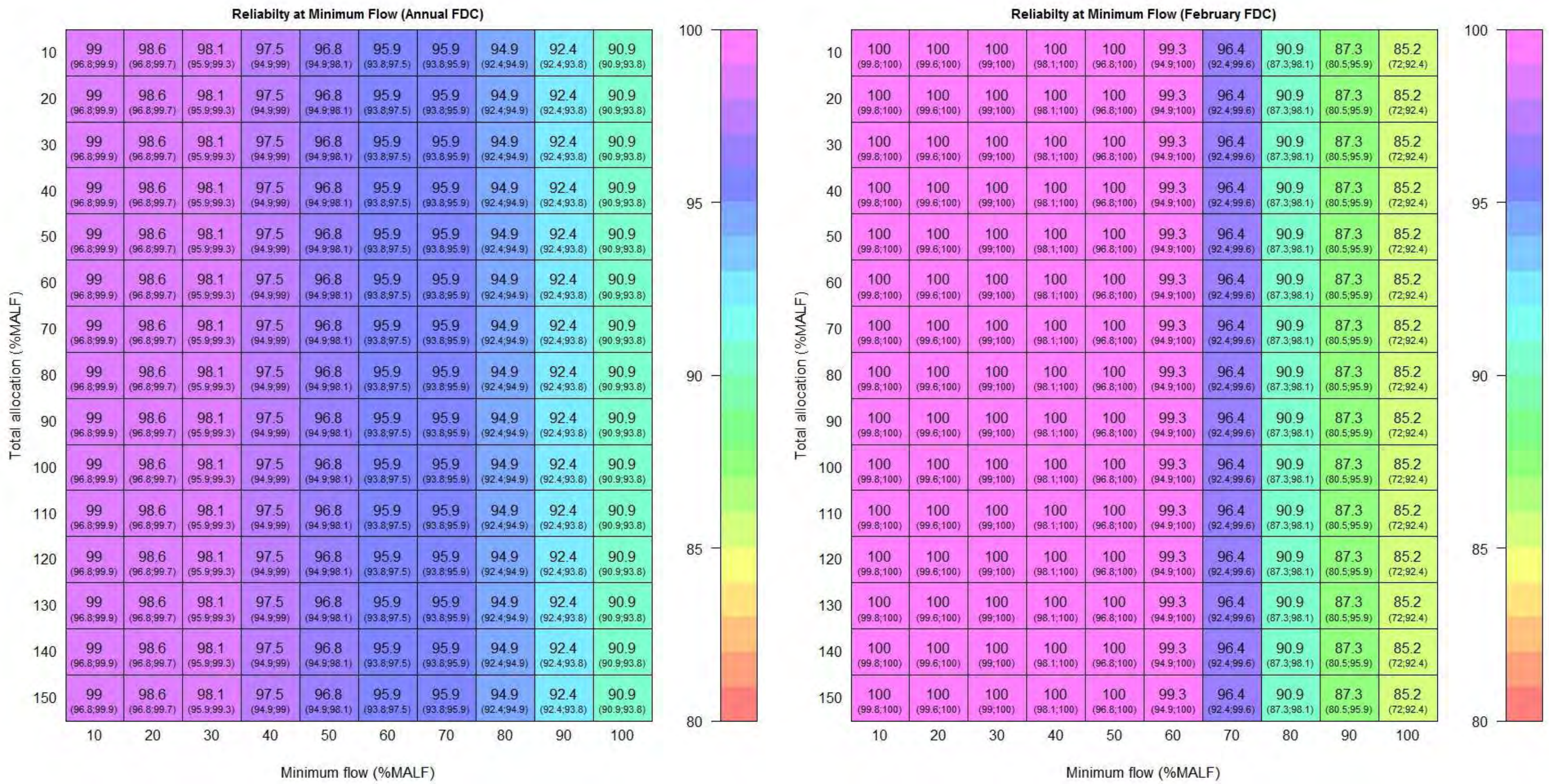


Figure 4-2: Large river (mean flow ≥ 20 $m^3 s^{-1}$) decision space diagrams for reliability at minimum flow. The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

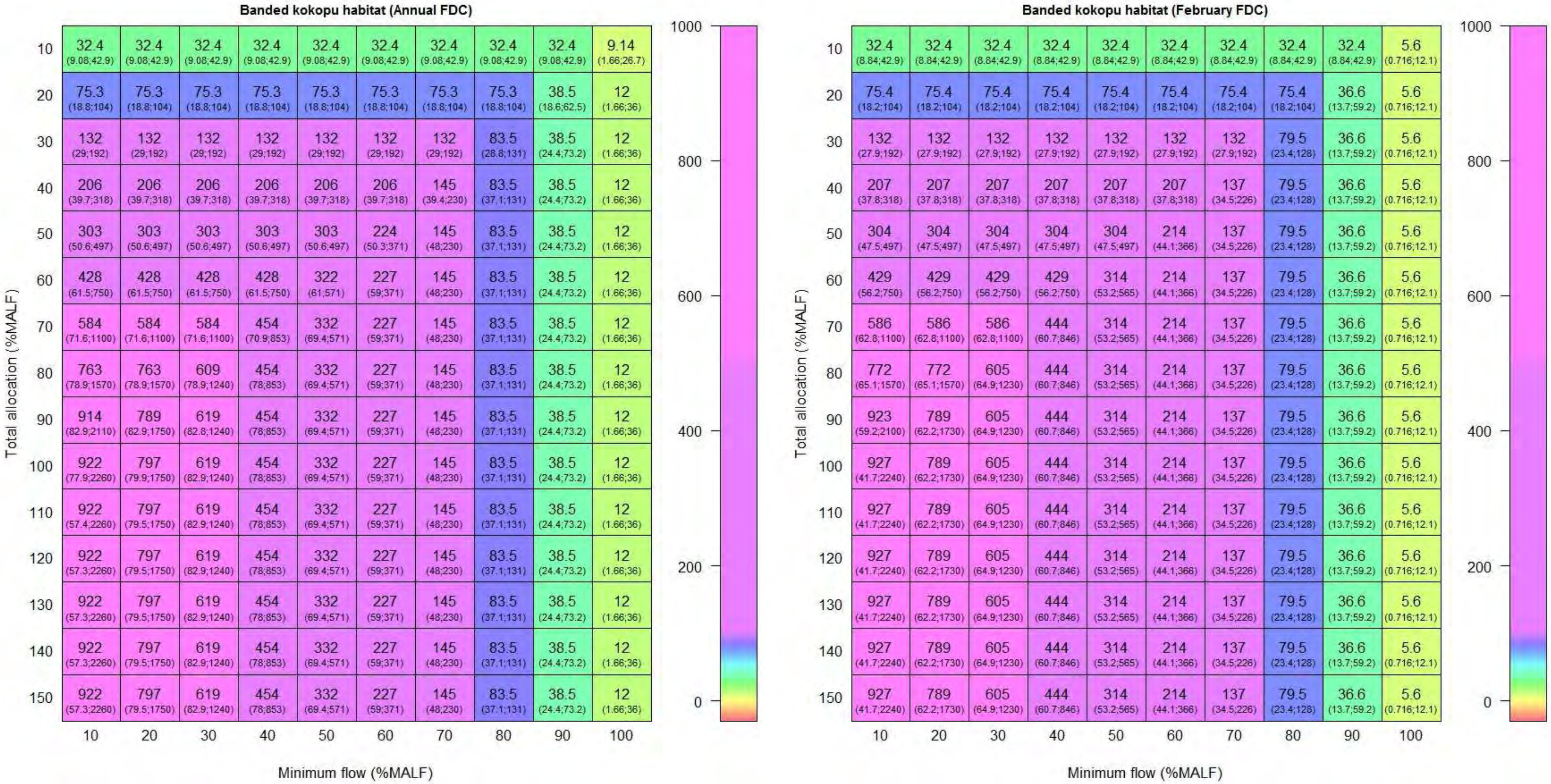


Figure 4-3: Large river (mean flow ≥ 20 m^3 s^{-1}) decision space diagrams for change in banded kokopu habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

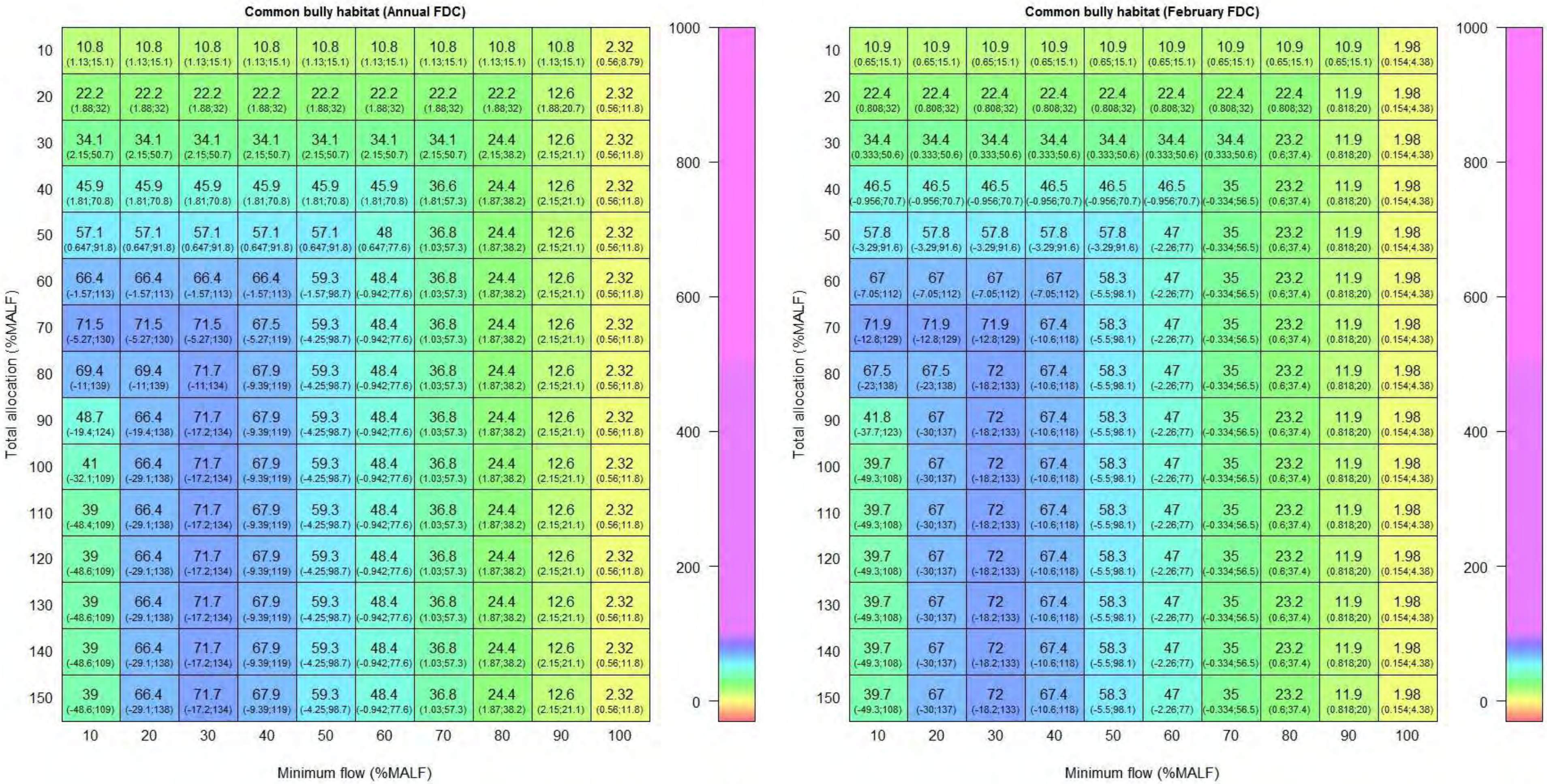
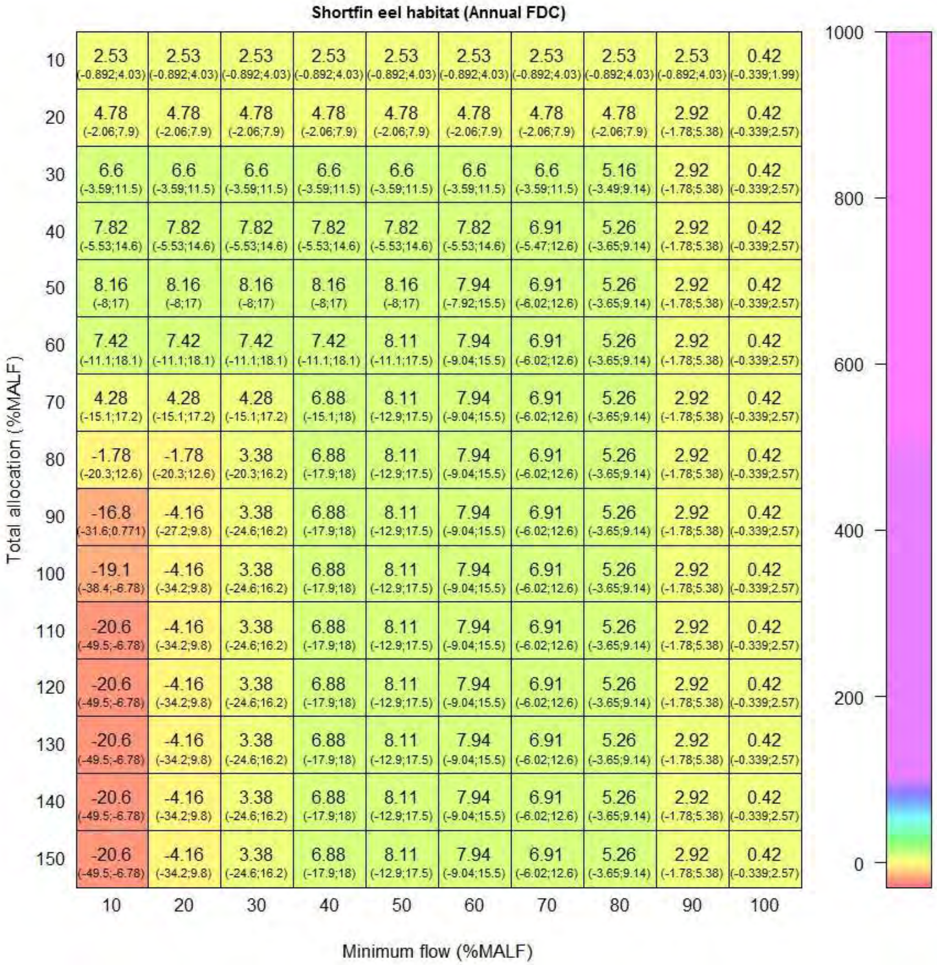


Figure 4-4: Large river (mean flow ≥ 20 $m^3 s^{-1}$) decision space diagrams for change in common bully habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.



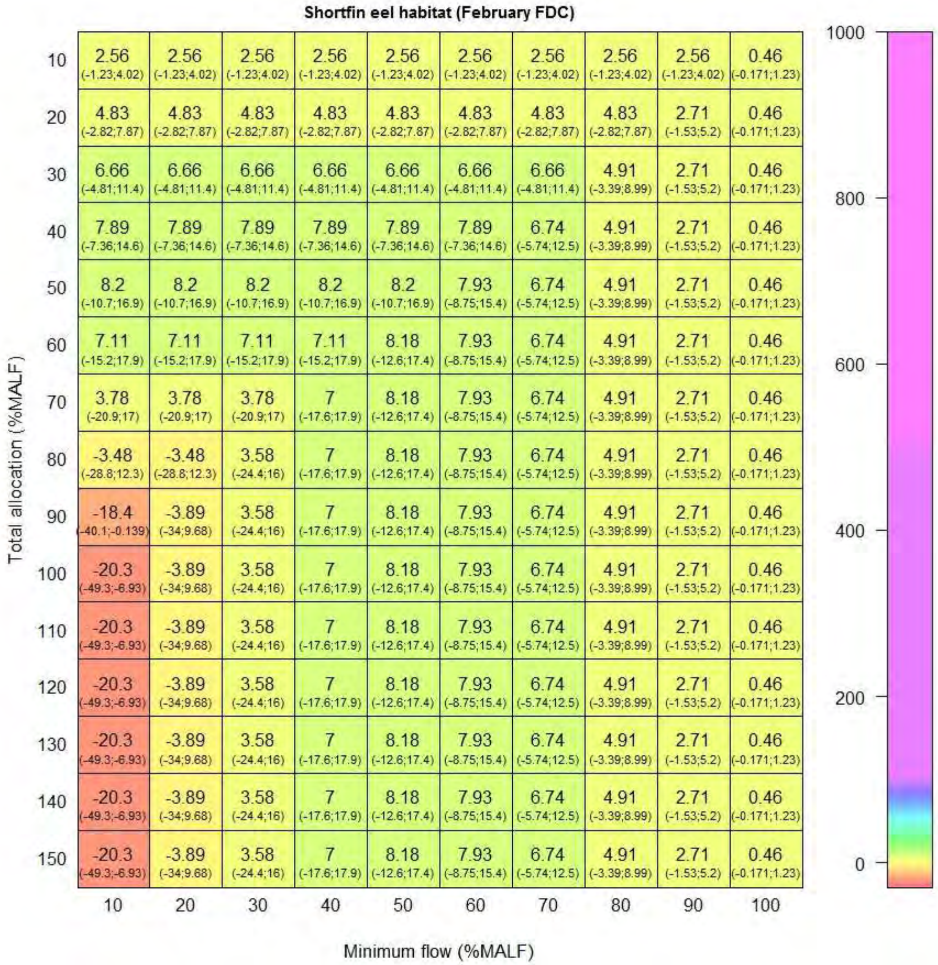


Figure 4-5: Large river (mean flow ≥ 20 $m^3 s^{-1}$) decision space diagrams for change in shortfin eel habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

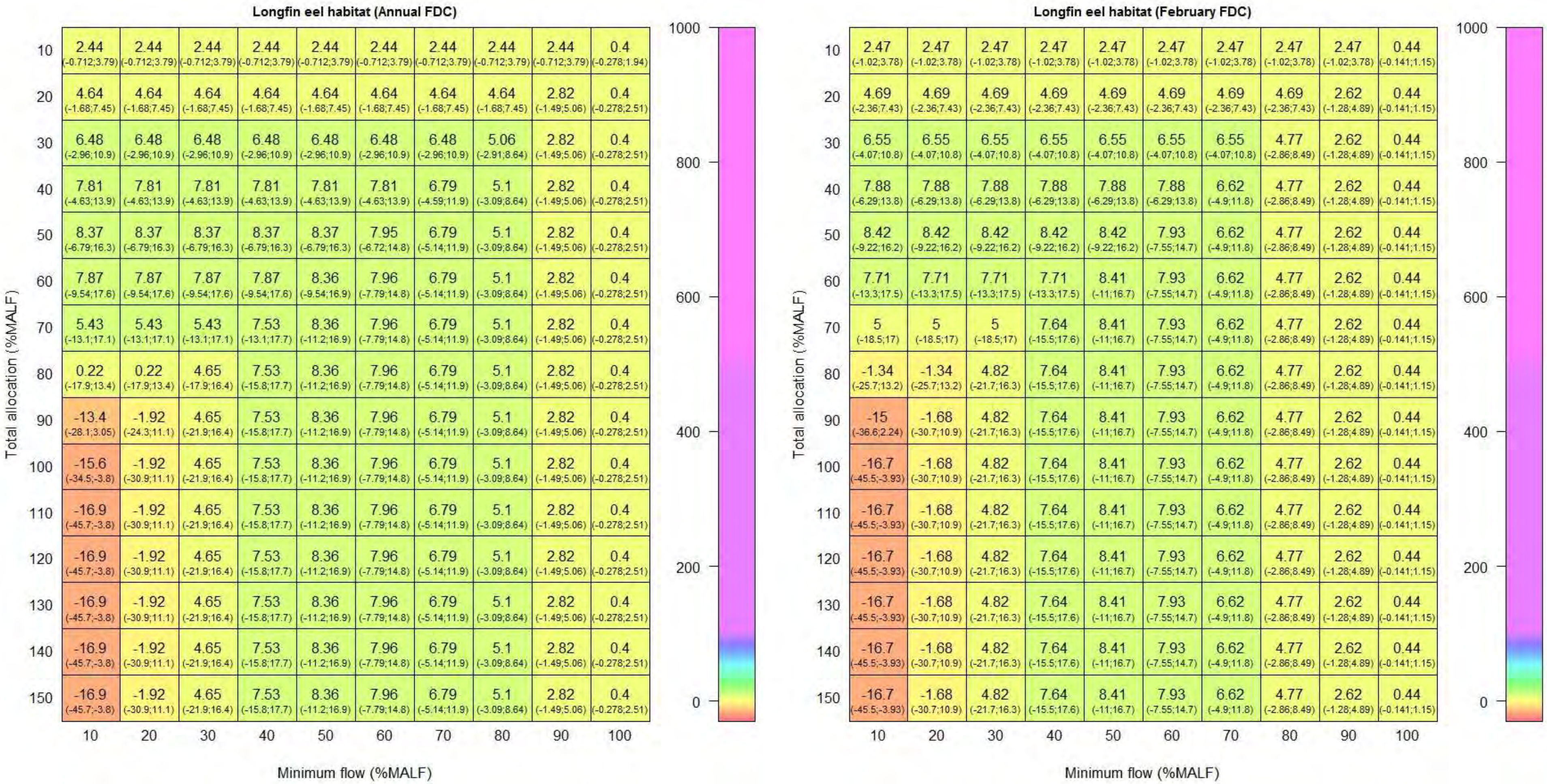
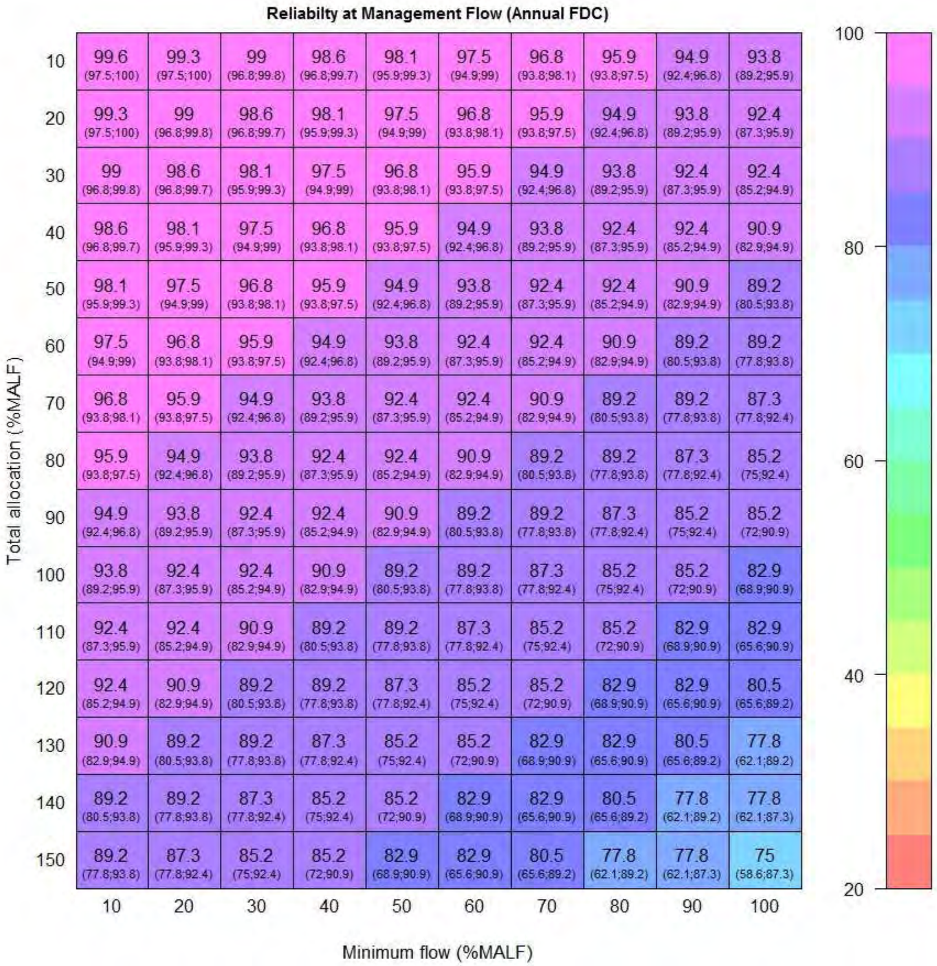


Figure 4-6: Large river (mean flow ≥ 20 m3 s-1) decision space diagrams for change in longfin eel habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

4.2 Small river management unit



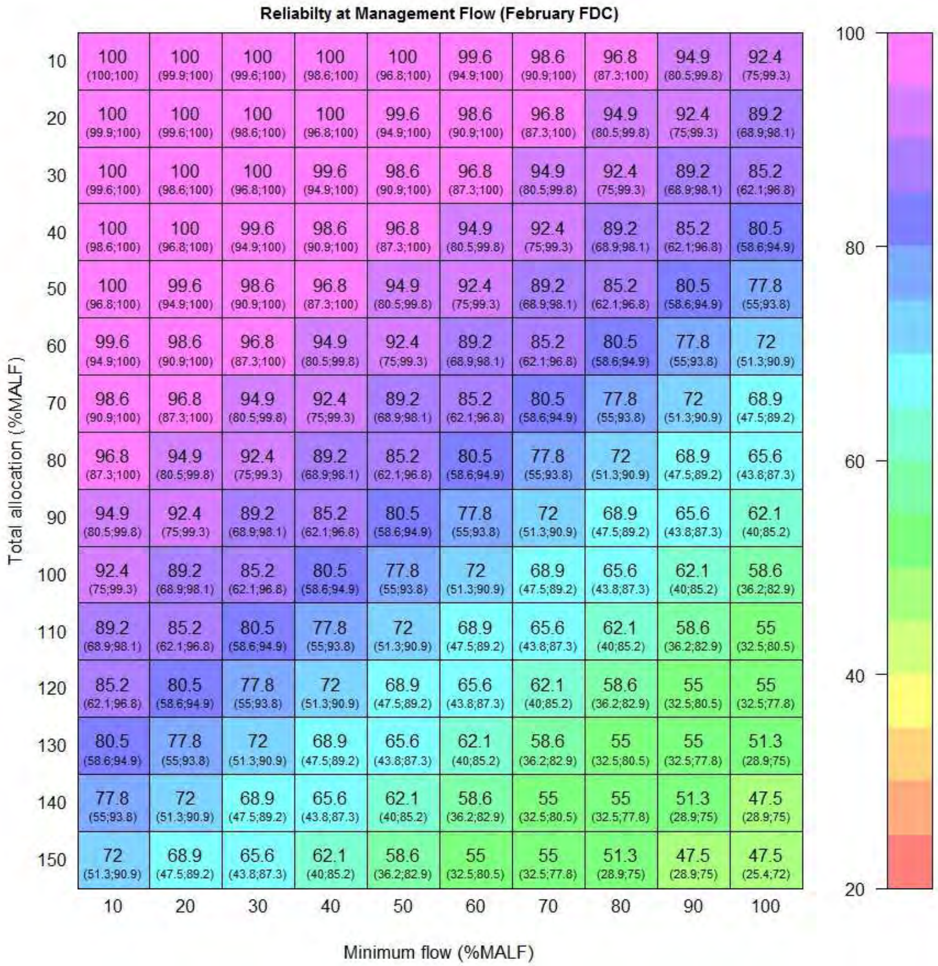


Figure 4-7: Small river (mean flow < 20 $m^3 s^{-1}$) decision space diagrams for reliability at management flow. The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

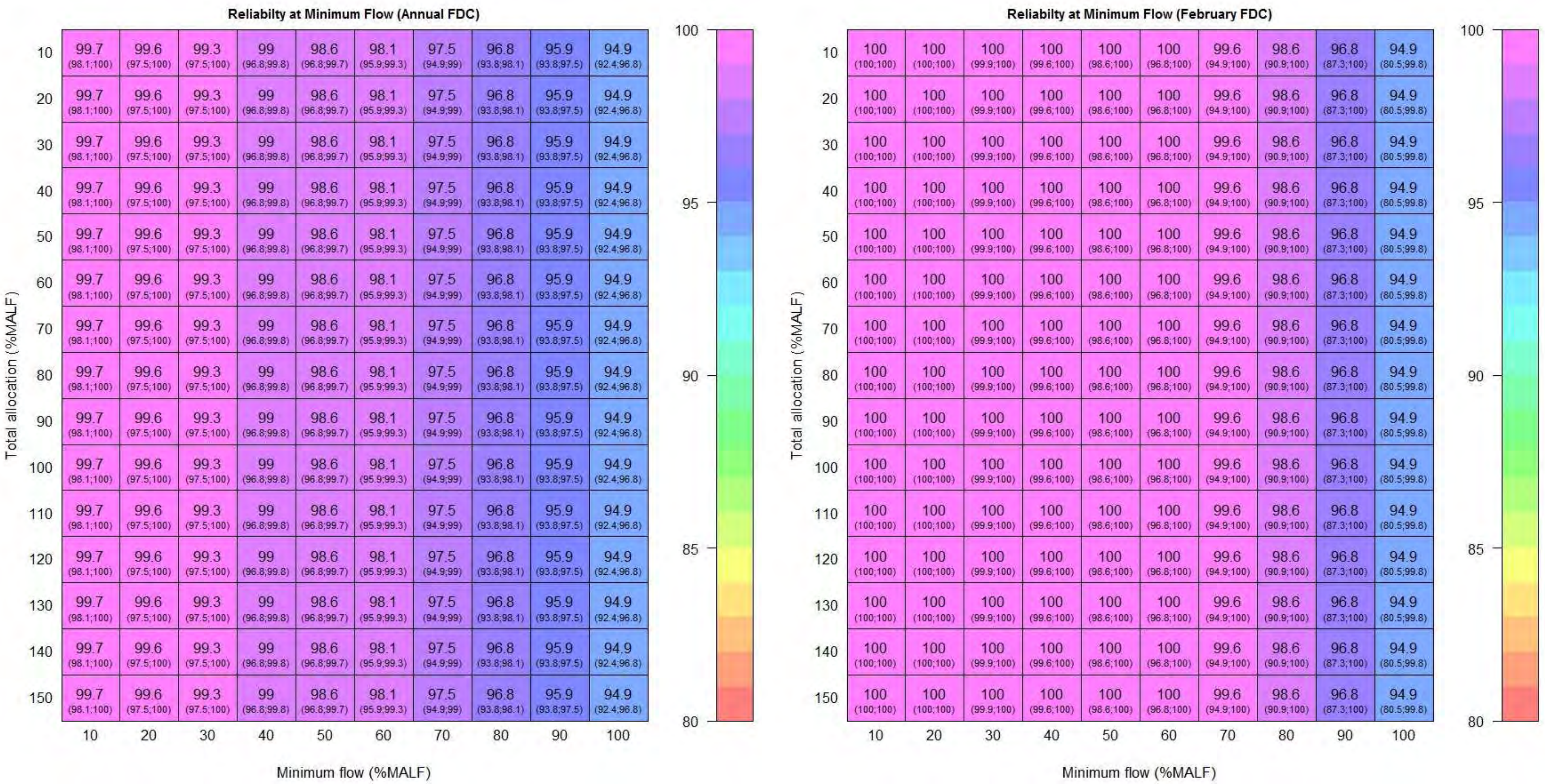
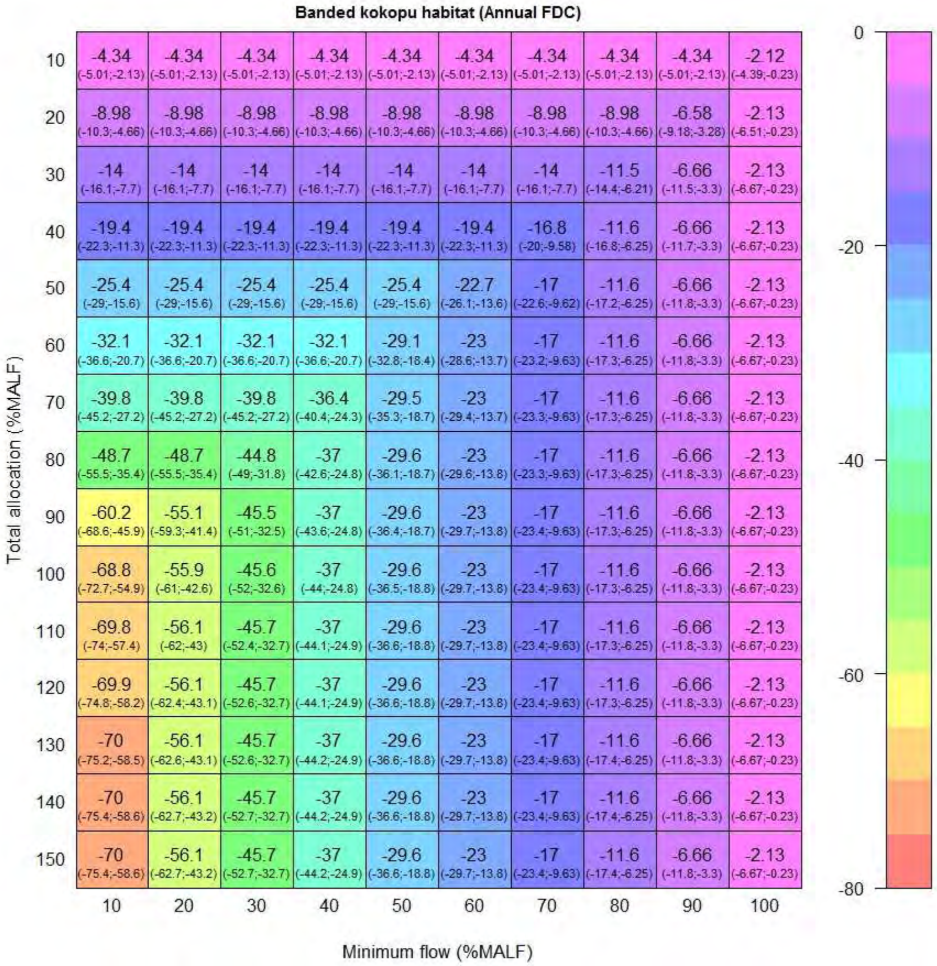


Figure 4-8: Small river (mean flow < 20 $m^3 s^{-1}$) decision space diagrams for reliability at minimum flow. The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.



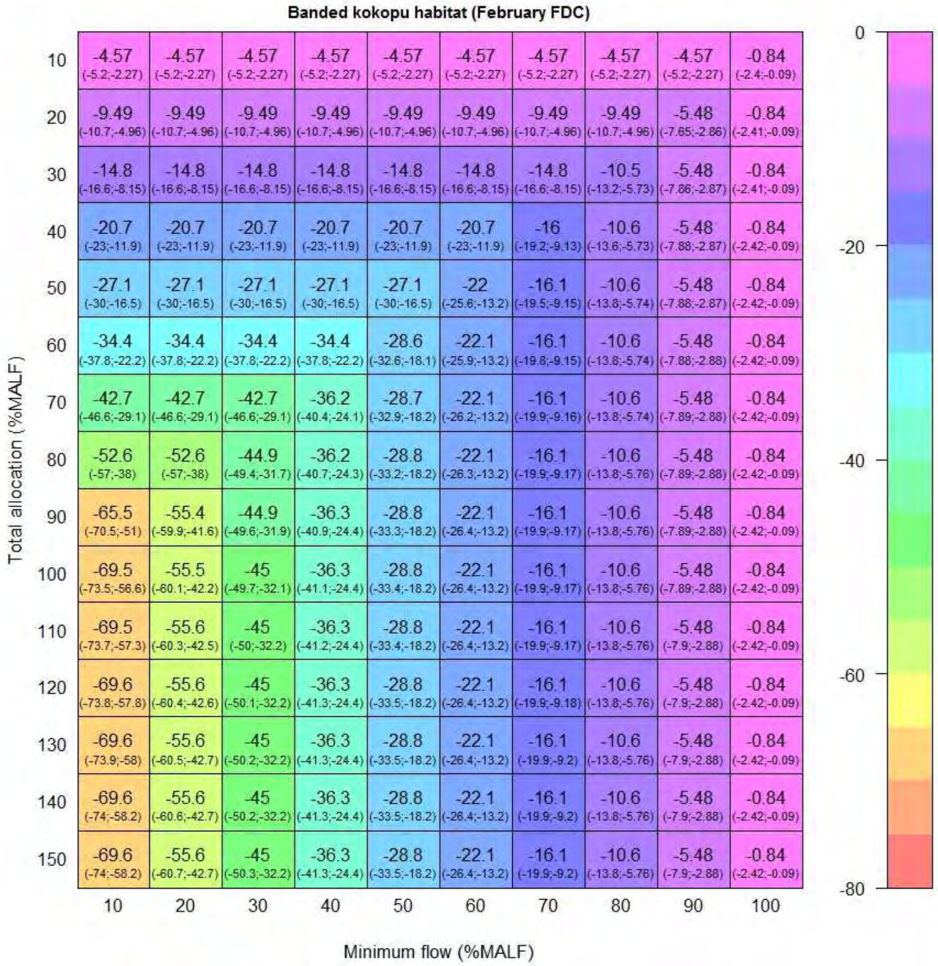


Figure 4-9: Small river (mean flow < 20 m^3 s^{-1}) decision space diagrams for change in banded kokopu habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

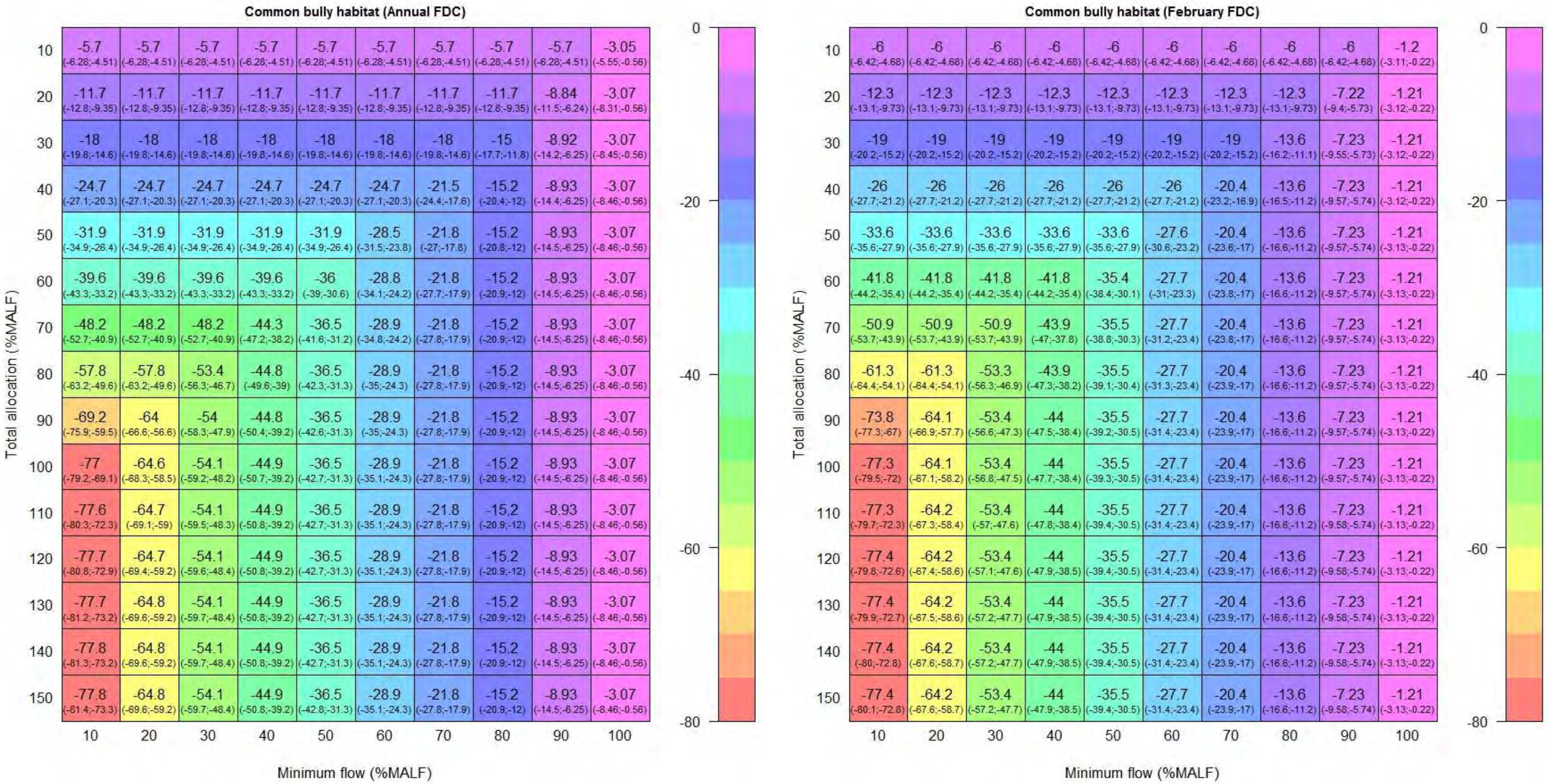


Figure 4-10: Small river (mean flow < 20 m³ s⁻¹) decision space diagrams for change in common bully habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

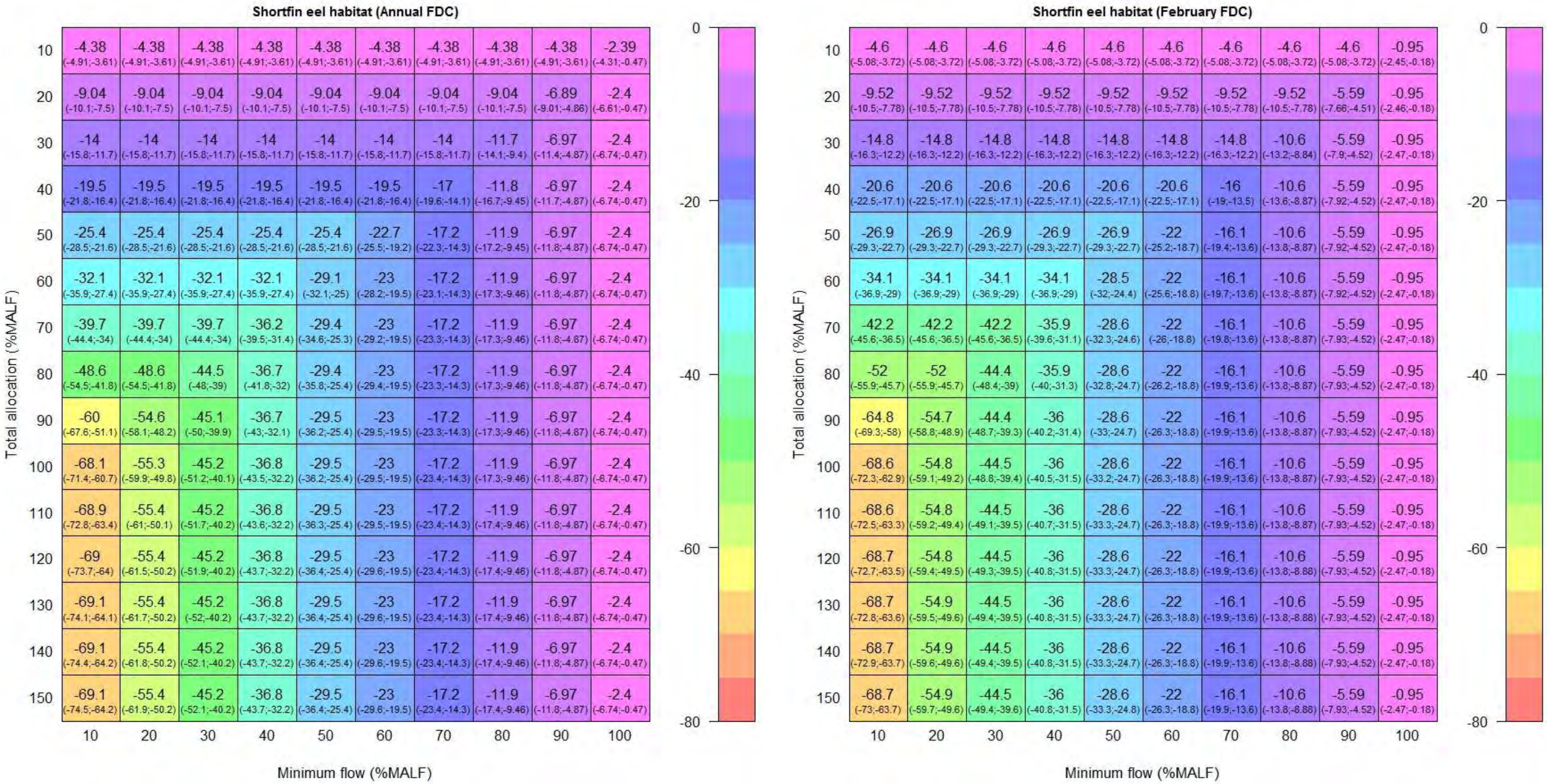


Figure 4-11: Small river (mean flow < 20 $m^3 s^{-1}$) decision space diagrams for change in shortfin eel habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

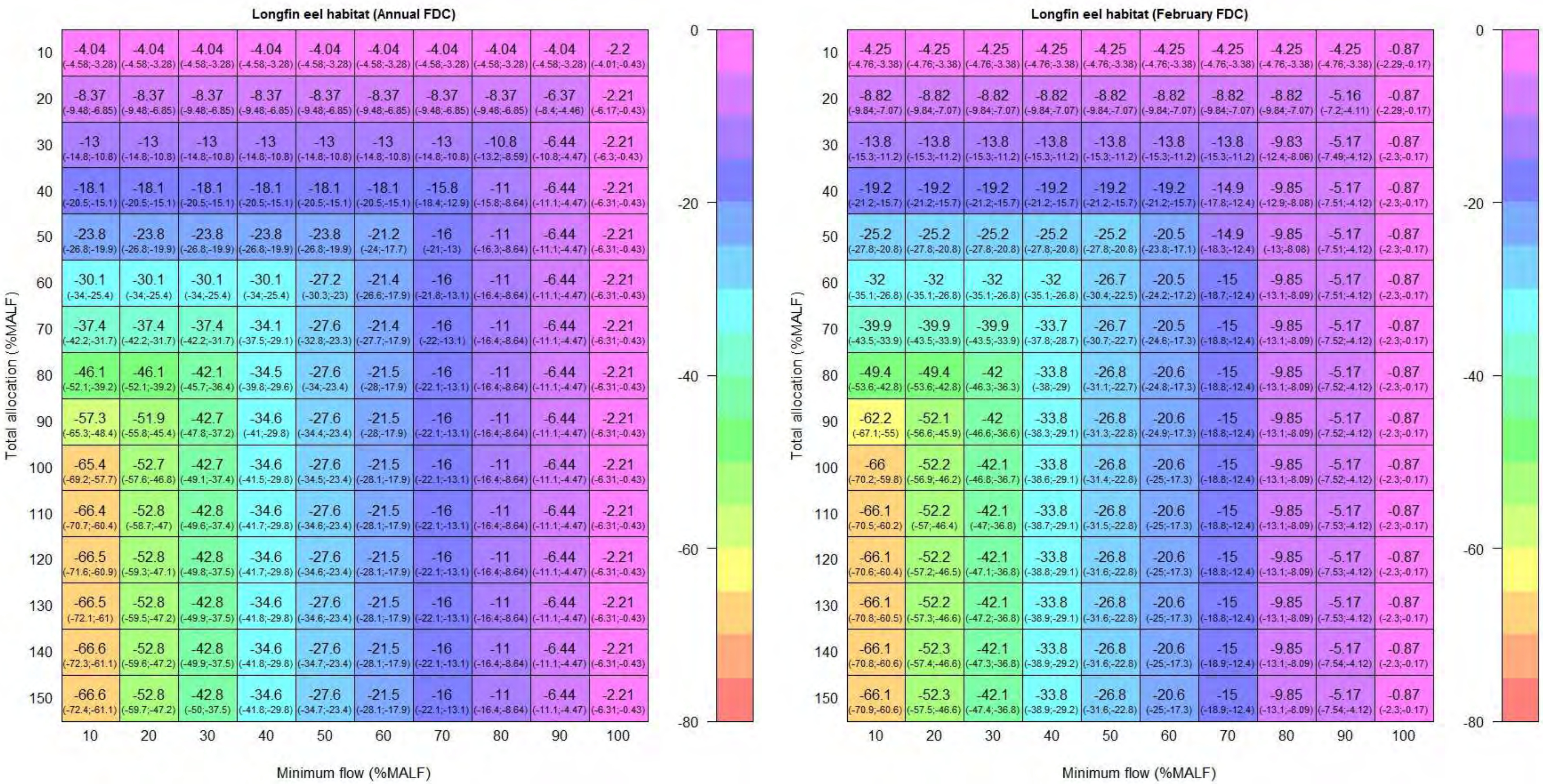
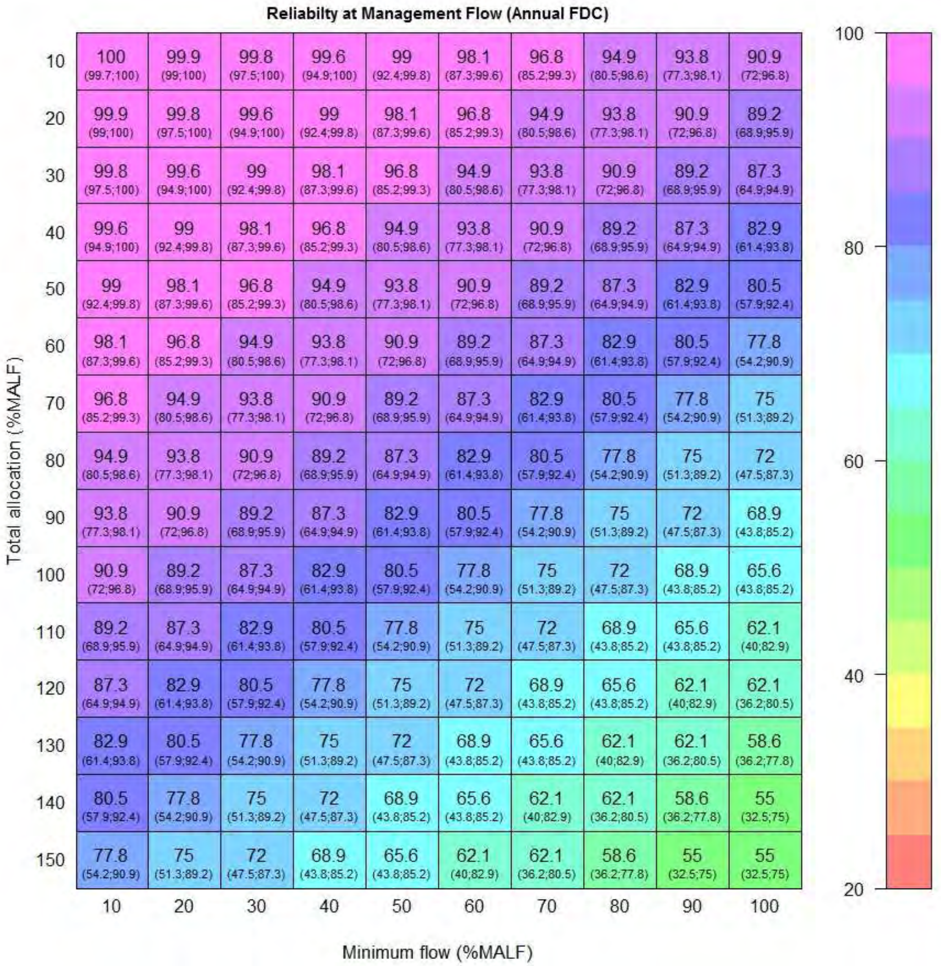


Figure 4-12: Small river (mean flow < 20 $m^3 s^{-1}$) decision space diagrams for change in longfin eel habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

4.3 Warm extremely wet climate management unit



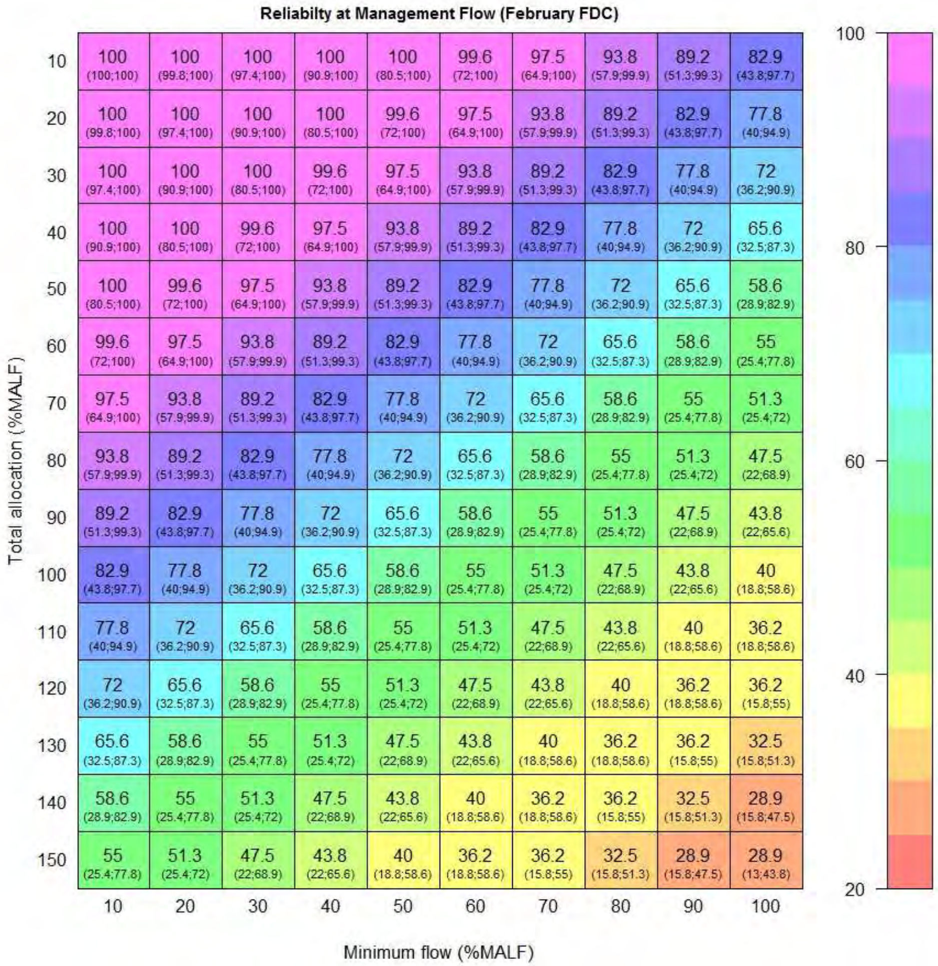
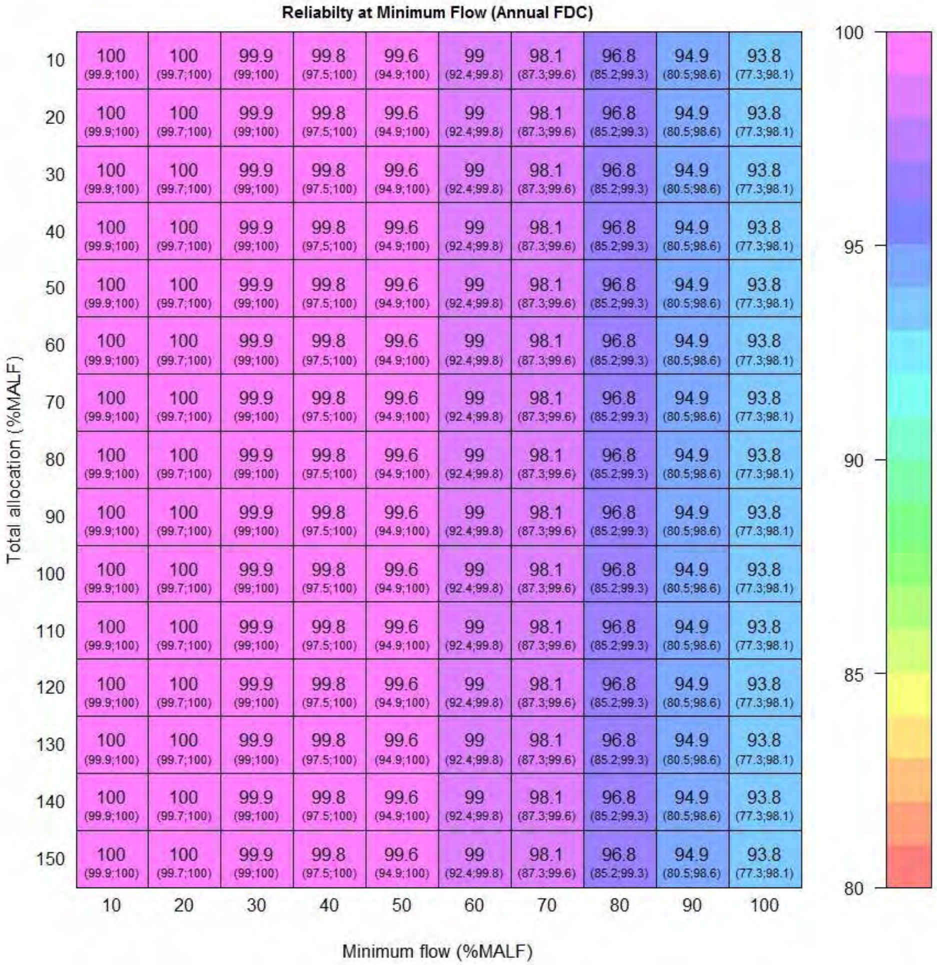


Figure 4-13: Warm extremely wet (REC WX climate class) decision space diagrams for reliability at management flow. The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.



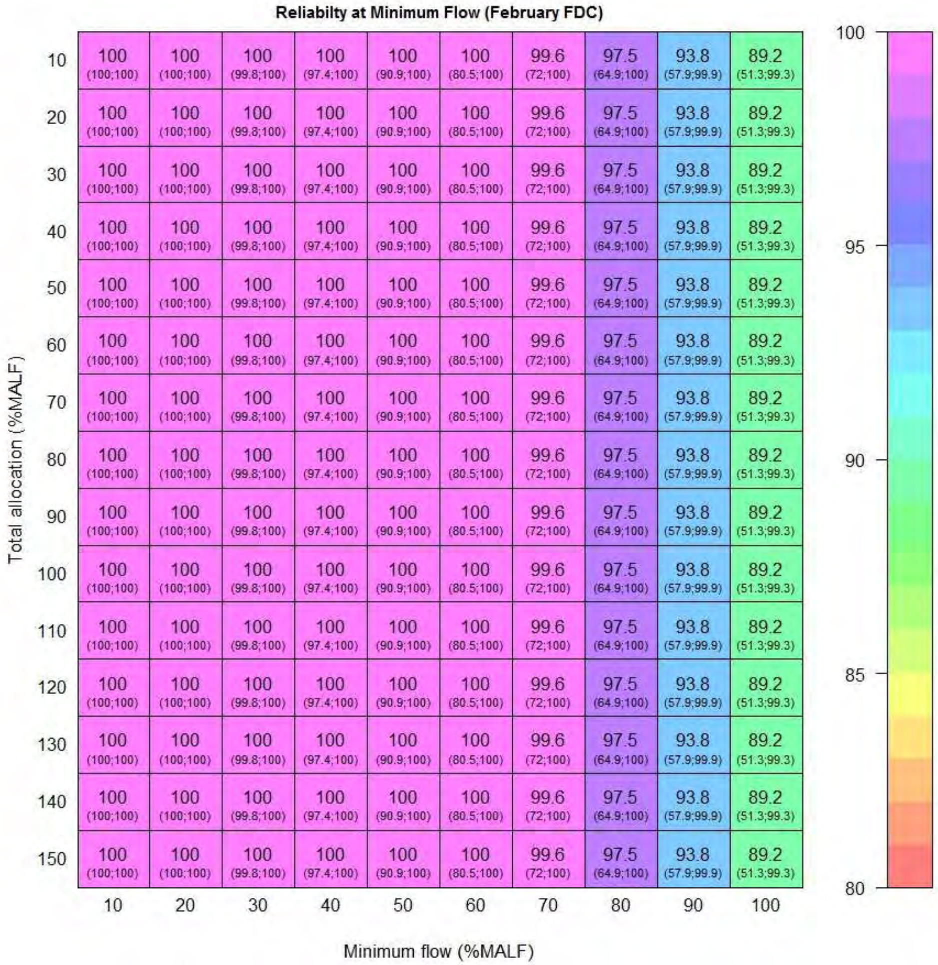


Figure 4-14: Warm extremely wet (REC WX climate class) decision space diagrams for reliability at minimum flow. The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

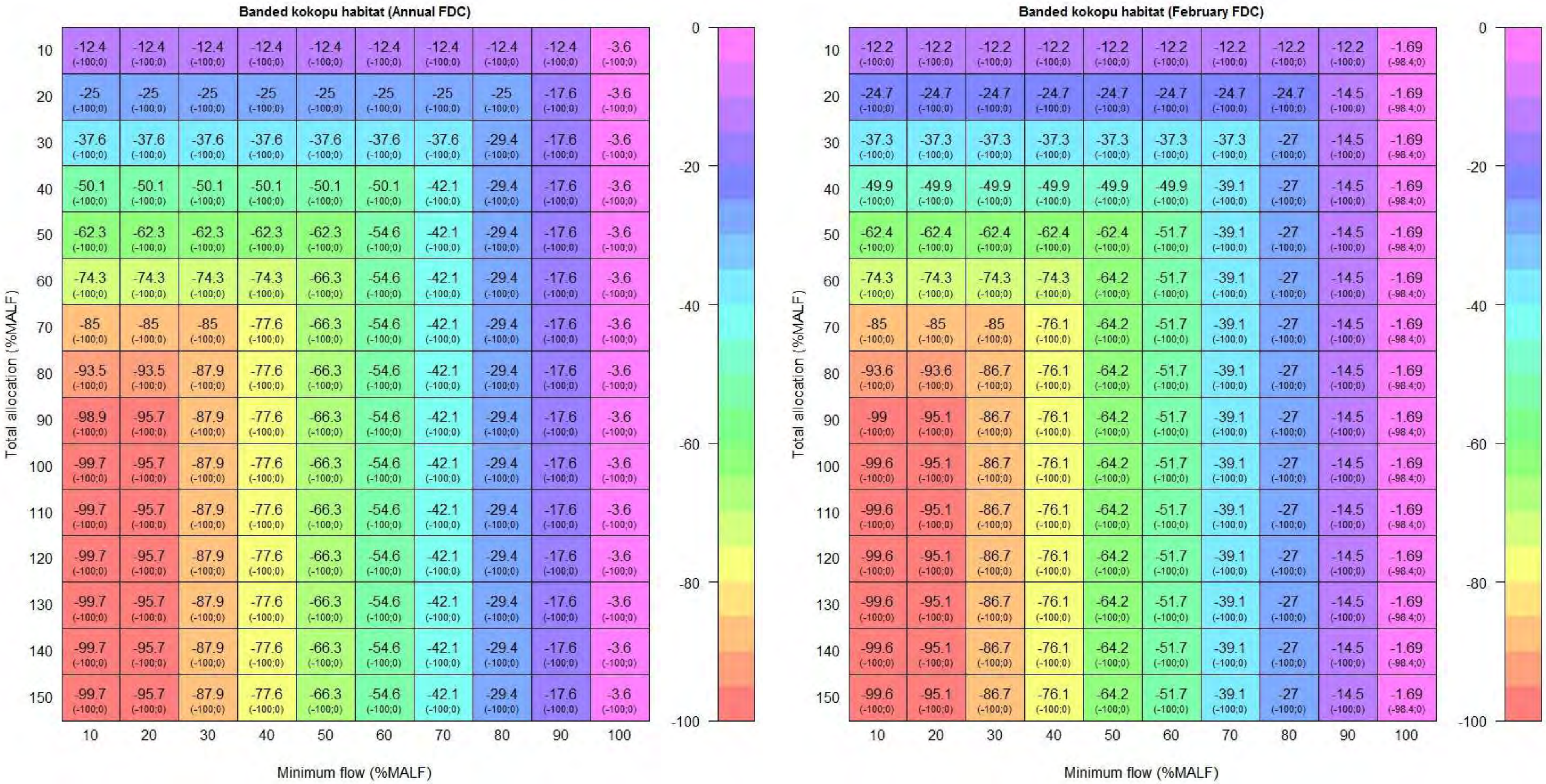


Figure 4-15: Warm extremely wet (REC WX climate class) decision space diagrams for change in banded kokopu habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

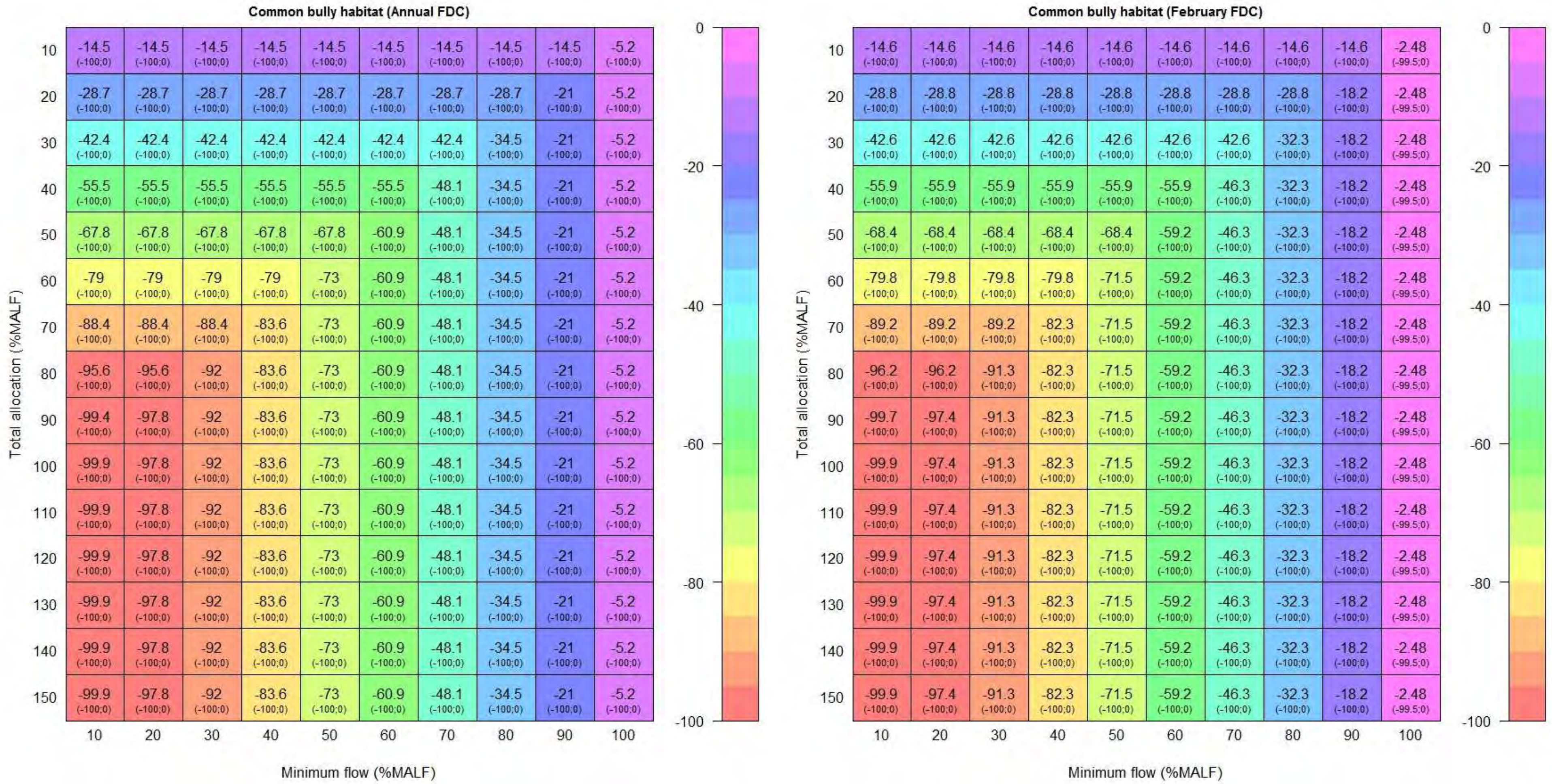
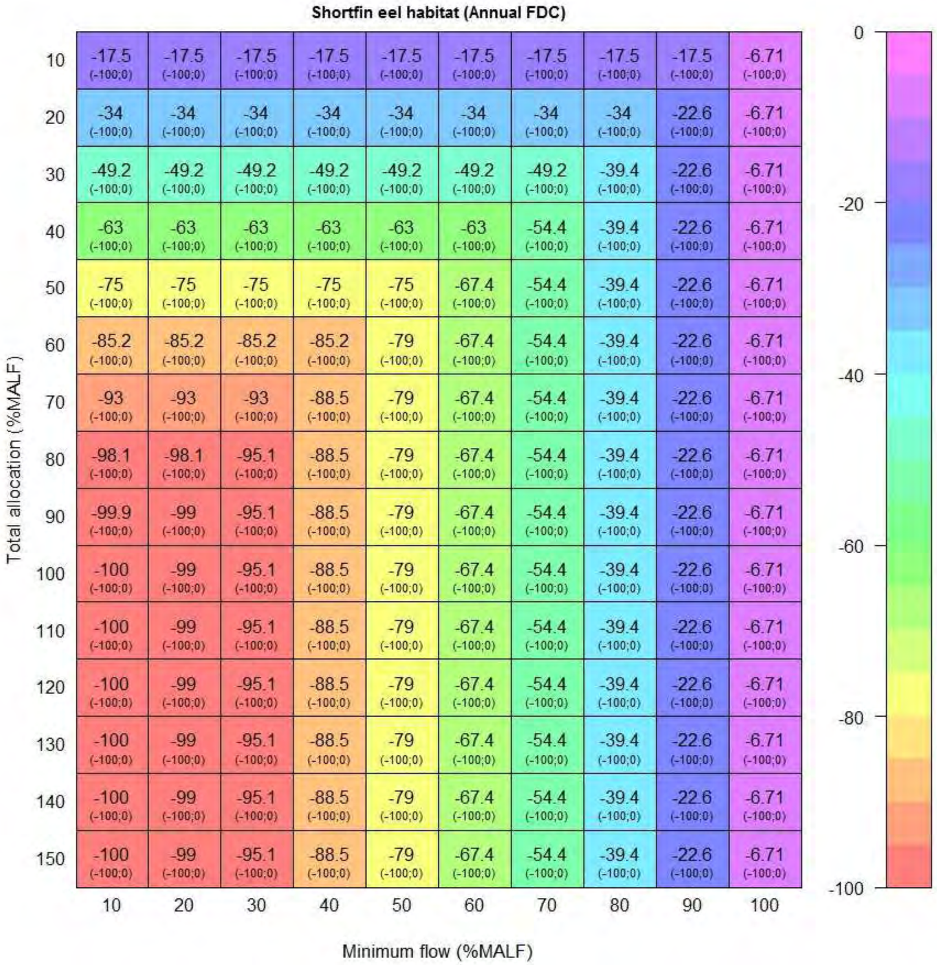


Figure 4-16: Warm extremely wet (REC WX climate class) decision space diagrams for change in common bully habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.



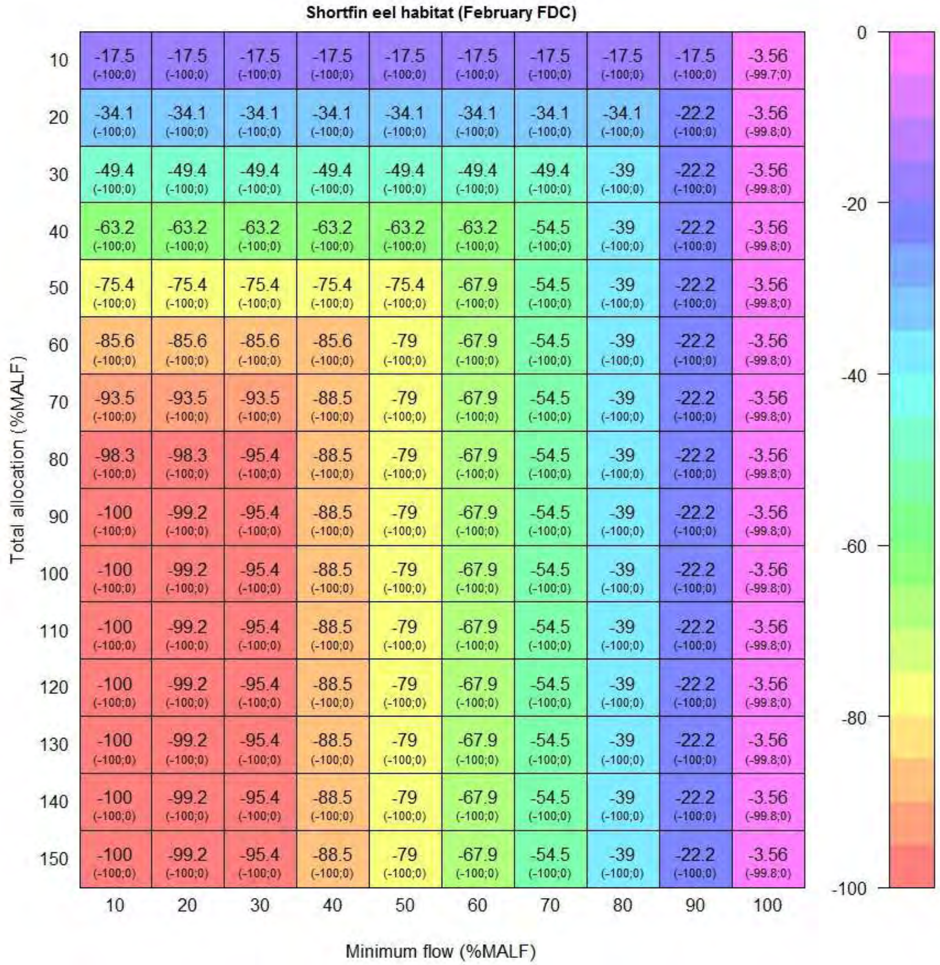
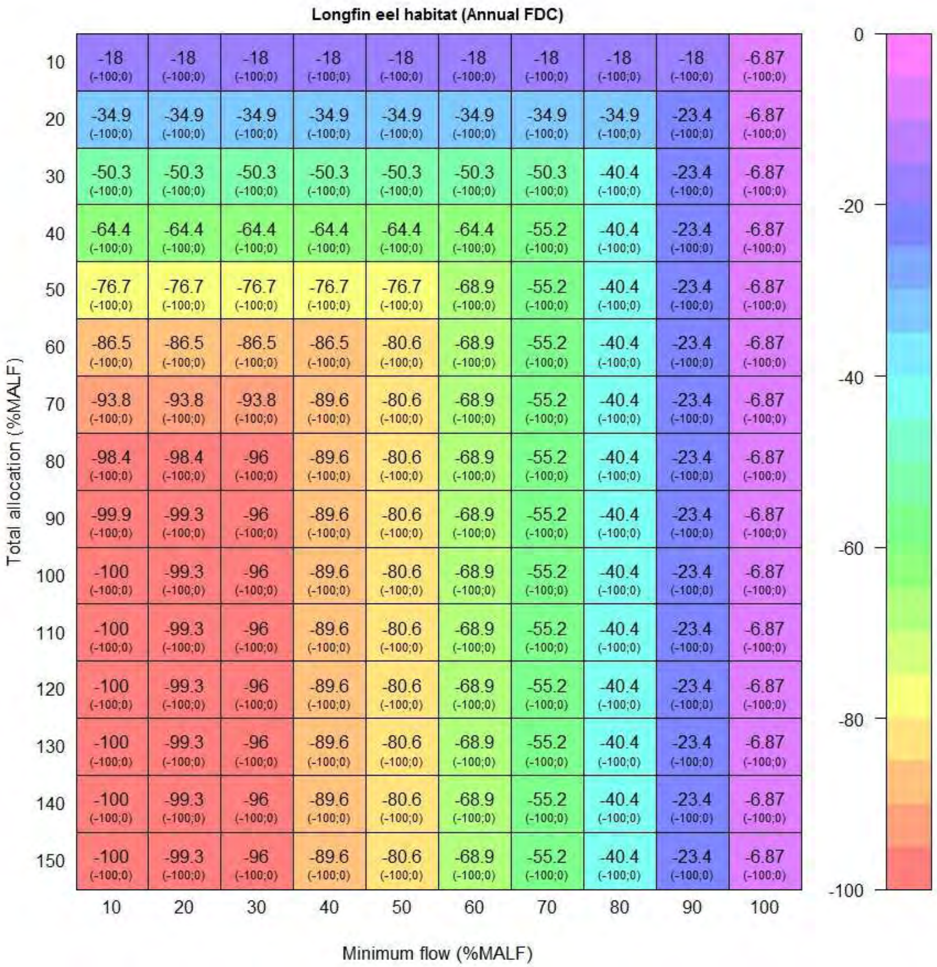


Figure 4-17: Warm extremely wet (REC WX climate class) decision space diagrams for change in shortfin eel habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.



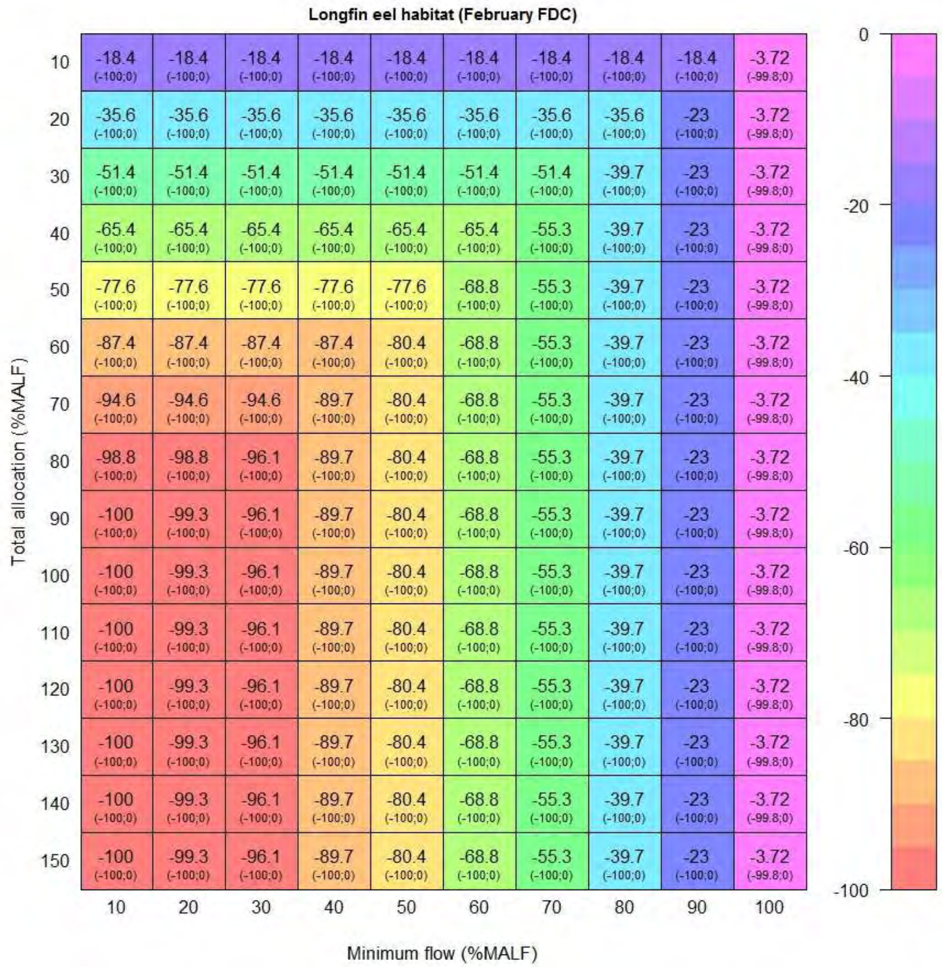


Figure 4-18: Warm extremely wet (REC WX climate class) decision space diagrams for change in longfin eel habitat (% of habitat available at MALF). The median value for all locations in the management unit is presented, with the 10th and 90th percentiles included in brackets. Left: Annual flow duration curves; Right: February flow duration curves.

5 Discussion

5.1 Consequences of the proposed NES default limits

The consequences of applying the proposed NES default allocation limits to each of the management units are presented in Table 5-1 and have been taken directly from the decision space diagrams for each value for each management unit. The proposed NES large river rules (minimum flow of 80% of MALF and total allocation of 50% of MALF) were used for the large river management unit, while the proposed NES small river rules (minimum flow of 90% of MALF and total allocation of 30% of MALF) were used for the other two management units.

These results demonstrate the variability in consequences for each of the values between the management units and over different time periods using the uniform rules proposed in the NES. The medians for both measures of the reliability of supply are similar between all three management units for the annual FDC under the proposed NES rules (Table 5-1). However, the variability within management units is quite different, with much higher variability between stream reaches within the warm extremely wet climate management unit.

The predicted consequences for WUA for fish are considerably different between the management units (Table 5-1). This is expected because the management units were largely defined based on the spatial variations in consequences for WUA. In the large river management unit, for both the annual and February FDCs the proposed NES rules would result in increase in median WUA for all four species. The change in habitat for banded kokopu WUA is significantly higher (median increase of 83.5%) than WUA for the other species (24.4%, 5.3% and 5.1% respectively for common bully, shortfin eel and longfin eel). However, this probably reflects a relatively low quantity of suitable habitat for banded kokopu under natural conditions, meaning that a small absolute change in suitable habitat can lead to large percentage changes.

Table 5-1: Summary of the consequences of applying the proposed NES default limits to each of the three management units. The median and the 10th and 90th percentile values (in parentheses) are shown for each consequence for all locations in each management unit. Negative values indicate a decrease in habitat from that available at MALF.

Management unit		Reliability at management flow	Reliability at minimum flow	Banded kokopu habitat	Common bully habitat	Shortfin eel habitat	Longfin eel habitat
Large River	Annual FDC	89.2 (85.2; 90.9)	94.9 (92.4; 94.9)	83.5 (37.1; 131)	24.4 (1.9; 38.2)	5.3 (-3.7; 9.1)	5.1 (-3.1; 8.6)
	February FDC	77.8 (51.3; 80.5)	90.9 (87.3; 98.1)	79.5 (23.4; 128)	23.2 (0.6; 37.4)	4.9 (-3.4; 9.0)	4.8 (-2.9; 8.5)
Small River	Annual FDC	92.4 (87.3; 95.9)	95.9 (93.8; 97.5)	-6.7 (-11.5; -3.3)	-8.9 (-14.2; -6.3)	-7.0 (-11.4; -4.9)	-6.4 (-10.8; -4.5)
	February FDC	89.2 (68.9; 96.1)	96.8 (87.3; 100)	-5.5 (-7.9; -2.9)	-7.3 (-9.6; -5.7)	-5.6 (-7.9; -4.5)	-5.2 (-7.5; -4.1)
Warm extremely wet climate	Annual FDC	89.2 (68.9; 95.9)	94.9 (80.5; 98.6)	-17.6 (-100; 0)	-21.0 (-100; 0)	-22.6 (-100; 0)	-23.4 (-100; 0)
	February FDC	77.8 (40; 94.9)	93.8 (57.9; 99.9)	-14.5 (-100; 0)	-18.2 (-100; 0)	-22.2 (-100; 0)	-23.0 (-100; 0)

In both the small river and warm extremely wet management units, the median change in habitat for all four species is negative (Table 5-1). In the small river management unit, the median reduction in habitat under the proposed NES rules is relatively small for all species (-6.4% for longfin eels to -8.9% for common bullies). However, for the warm extremely wet management unit, the median changes in physical habitat for all species is around -20%. The spatial variability within this management unit is also extremely large (ranging from no change to complete loss of habitat). It is likely that many of the sites displaying such significant percentage changes in habitat are small streams where the absolute change in habitat is very small.

The proposed NES default minimum flow and allocation rules may provide sufficiently equitable median consequences for each of the assessed values in Northland, i.e., on average most places have quite similar outcomes. However, the EFSAP results demonstrate that the proposed NES rules will result in variable consequences in different areas of the region, and thus potentially inequitable outcomes for different values if adopted. The proposed NES default limits are only one example of a range of options available to planners for managing water resource use. The challenge for water resource managers is to evaluate the relative advantages and disadvantages of different allocation scenarios so that an informed decision can be made on the most appropriate limit combinations. The EFSAP decision space diagrams can facilitate this process by summarising the regional scale consequences of particular water resource use limit combinations. The consequences of choosing alternative combinations of limits to those in the proposed NES vary both between values and between management units. Broadly, the large river and warm wet climate management units are more sensitive to changes in limits than in the small river management unit. The following section describes how the EFSAP decision space diagrams describe these differences and can be used to support the decision making process.

5.2 Use of decision space figures for limit setting

Definition of water resource use limits involves a trade-off between different instream and out-of-channel uses of water. EFSAP is used to evaluate the consequences of a range of scenarios for water allocation limits, thereby enabling water resource managers to make a more informed and transparent choice. The following guidance is provided to explain how to use the EFSAP modelling outputs presented in this report for choosing limits from amongst the different scenarios.

The scenarios assessed using EFSAP, and their associated consequences for reliability and instream habitat, are presented as 'decision space' diagrams (e.g., Figure 4-1 to Figure 4-18). The decision space summarises the consequences for each scenario, i.e., combination of minimum flow and allocation limit. For each scenario, the median, 10th and 90th percentiles of the consequences for the values (i.e., the reliability or change in habitat) are presented (e.g., Figure 5-1). These percentiles summarise the consequences of that combination of limits for all locations in a management unit. The median is used to represent the "central" consequence for that value across all locations in a management unit. In some locations the consequence will be worse, and in some locations better. The difference between the 10th and 90th percentiles gives an indication of how variable the consequences for a value are across all locations within the management unit. The greater the difference between these figures, the larger the variation in consequences between locations, the smaller the difference between the figures, the more uniform and thus equitable the consequences are between locations in the management unit. Ninety percent of locations in the management unit will have a consequence which is at least as good as the 10th percentile.

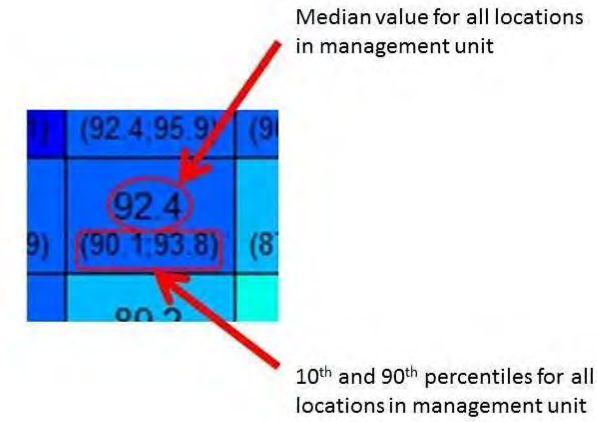


Figure 5-1: Interpreting the decision space diagram summary statistics.

The first task in determining appropriate water resource use limits should be the determination of freshwater objectives for each value (MfE 2011). Ideally freshwater objectives should be clear (i.e., defined levels of protection for environmental values and availability and reliability of water for out-of-channel uses), transparent (i.e., stakeholders can understand why they have been selected as objectives) and measureable (i.e., it is possible to measure whether the objectives are being met) (Snelder et al. 2013). Once freshwater objectives have been set, the decision space diagrams can be used to determine which combination of limits satisfies the objectives (e.g., Figure 5-2).

For illustrative purposes, we arbitrarily set freshwater objectives of a median reliability at management flow of ≥90%, median reliability at minimum flow of ≥95% and a median loss of habitat ≤15%. Having defined these objectives, the combinations of minimum flow and total allocation which satisfy the objective for each value can be determined from the decision space diagrams. In Figure 5-2, this is represented by the areas enclosed by thick black lines on the decision space for each of the three values (top panels and bottom-left panel). For this example, the black lines are defined by whether the median value in each square meets the objective threshold, but potentially other percentiles could be used. Once the subset of limits that satisfy the objectives for each individual value have been defined, they are combined to find the set of limits which meet all objectives. This is illustrated in the bottom-right panel of Figure 5-2, where the grey shaded area represents the intersection of the three objectives and therefore the combinations of minimum flow and total allocation that satisfy all three objectives. Further decision space diagrams for different values, or the same values at different times of the year, can be added to the analysis, and their associated objectives used to further constrain the possible range of suitable limits.

In this example, the defined objectives for all three values result in a combination of limit options that overlap (Figure 5-2). Water resource managers therefore have the choice of defining limits that satisfy all objectives for the values that have been assessed. However, even within this more constrained set of options for limits, value judgments are required to define the final choice of limits. For example, options could include maximising environmental protection (minimum flow of 80% of MALF and total allocation of 10% of MALF), maximising reliability (minimum flow of 10% of MALF and total allocation of 10% of MALF), or maximising total allocation (minimum flow of 80% of MALF and total allocation of 50% of MALF). The decision will vary based on the relative importance of the different instream and out-of-stream values assessed, and may vary between management units (MfE 2013). In making the decision on the most appropriate combination of limits, it should also be remembered that values additional to those evaluated by EFSAP may be important and may therefore help to guide the decision making process (MfE 2011, 2013). For example, a minimum flow of 10% of MALF (which satisfies all three of the objectives here), combined with a modest allocation (e.g., 20% of MALF) may not be considered acceptable due to the excessive departure from the natural range of variability that may typify natural character.

It is possible that under alternative objectives a situation may arise whereby no combination of limits would satisfy all objectives. In this situation, a compromise has to be found between the different values until an acceptable combination of limits can be agreed upon (Land and Water Forum 2012, MfE 2013). The decision space diagrams can assist in this trade-off process by illustrating to stakeholders and resource managers how limits interact with each other and the relative consequences of alternative management decisions. This makes the process of limit setting more transparent and accountable.

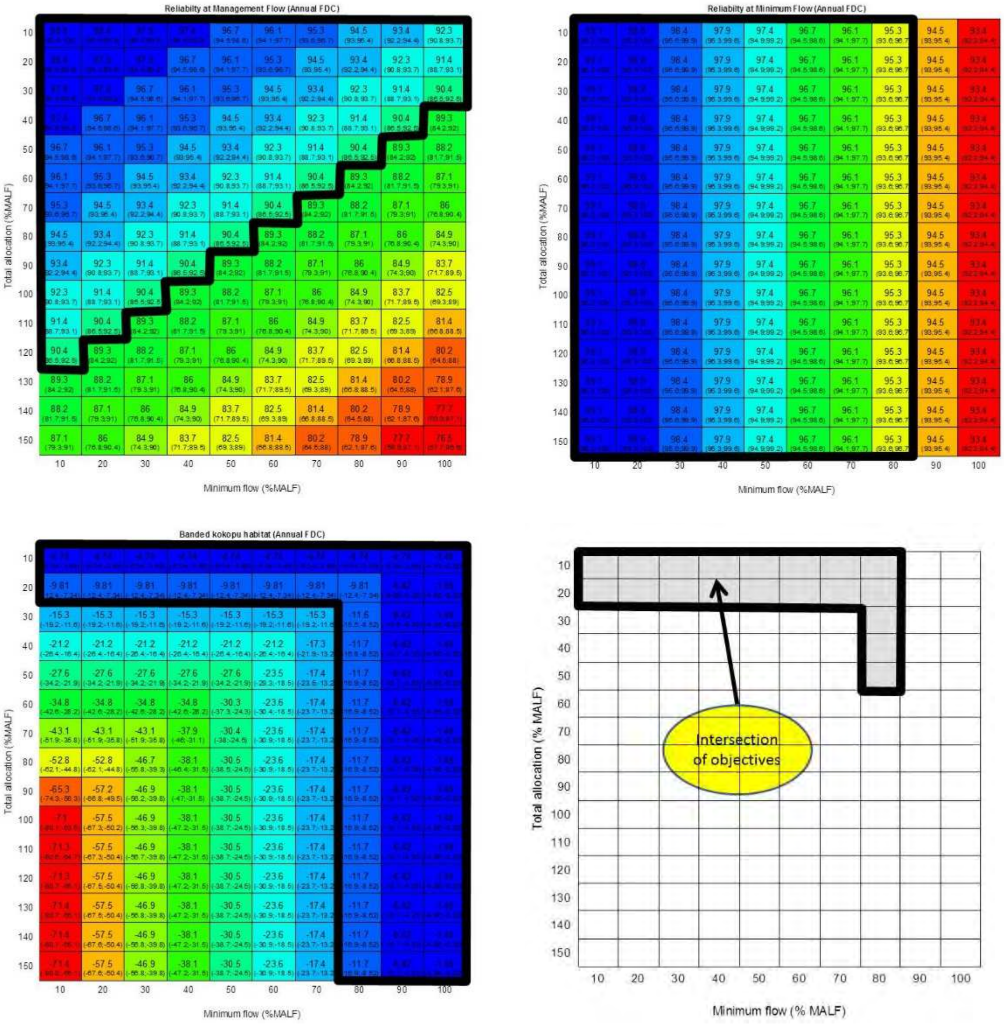


Figure 5-2: Example of evaluating objectives for multiple values and determining range of limits that satisfy all objectives, as described in the text above.

5.3 Limitations

Snelder et al. (2011) identified six limitations associated with the methodology that has been used for this study, which should be acknowledged and taken into consideration when interpreting and applying the results presented above. First, the concept of flow variability was not explicitly considered in the analysis. Flow variability is increasingly acknowledged as being critical for ecosystem health and therefore should be considered in setting environmental flows (Poff et al. 1997, Poff et al. 2010). The EFSAP methodology is primarily designed to evaluate the effects of run-of-river abstractions, where total allocation is low relative to the mean flow. This type of water use primarily affects the flow regime in terms of the magnitude and duration of low flows, but tends to have relatively little effect on medium to high flows. Where more intensive water resource development that significantly alters the flow regime has occurred, or is expected to occur (e.g., damming, flood harvesting or water diversion), a more detailed, site specific assessment would be required that explicitly considered the effects on flow variability.

A second limitation is that FDCs provide no information regarding the temporal sequencing of flows. It is therefore not possible to determine whether periods of restriction or time at minimum flows occur consecutively or scattered through time. This is partially alleviated by providing results based on monthly FDCs. In this study, for example, we have reported results for the February FDC as being representative of the most resource restrictive period. Analysis of natural flow time series would be required if more detail on the timing and temporal sequencing of restrictions was needed. This is also necessary if the effects of extreme events such as droughts are required.

Another limitation of this study was that the uncertainties associated with any estimate were not evaluated. The analysis was dependent on estimates of MALF and FDCs. Uncertainties around the estimation of these parameters at individual locations can be large, especially around the low flows that this analysis focussed on (Booker et al. 2012). In addition, the at-station hydraulic geometry and generalized physical habitat model uncertainties were propagated through the various analyses. This means that the observed patterns are probably indicative of the relative differences at a regional scale, but that the uncertainties for individual segments could be large. Future work will aim to quantify the total uncertainty of the predictions, as well as decrease the uncertainties associated with individual models.

A fourth limitation to our approach is that the complexity of flow management was simplified. We treated each stream segment as independent and made an assessment of the consequences on physical habitat and reliability as though the minimum flow was observed at that segment and that allocation, and therefore total abstraction, occurred in its upstream catchment. In reality, abstractions are distributed unevenly in space and the consequences accumulate down the river network in a non-uniform manner. This means that consequences for physical habitat retention and reliability across the network can be more variable than shown in our analysis. In addition, it was assumed that all water abstractions were taken directly from rivers and did not include groundwater abstractions that may affect river flows in a different and less direct way.

A fifth limitation concerns the assumption that the quantity of physical habitat is an appropriate indicator of ecosystem protection during low flow periods. We used a measure of the proportional change in the availability of physical habitat at a reference low flow to compare the consequences for instream values. This assumes that ecosystems are naturally stressed at low flows, but this may not always be the case. Alternative indices of the impact on habitat could also be used, which may give different outcomes. This could include the total change in habitat, for example, which better integrates the affects across the whole flow regime, but may not be representative of the main constraints on fish community dynamics. In some locations, for some species, factors other than physical habitat, such as water quality, temperature, and migration pathways may be more important controls. Other flow dependent values such as recreation or cultural values may also be more significant. Despite these limitations, the use of changes in physical habitat to evaluate the consequences of flow change is well established in New Zealand and worldwide (Beca 2008, MfE 1998).

A final limitation is that this analysis was restricted to only selected indicator taxa. These taxa were selected based on known and predicted distributions (i.e., NZFFD; Leathwick et al. 2008) and their conservation status (Allibone et al. 2010) to maximise their relevance, but the choice of taxa was still restricted to those for which generalised habitat models are available (Table A-1). A full analysis for environmental flow setting would include multiple species and life stages, and an acknowledgement of the interdependence between taxa and life stages. An advantage of the EFSAP methodology over other habitat modelling approaches is that it facilitates better integration of multiple taxa into the limit setting process through the option to overlap multiple decision spaces. Ideally, however, water resource use limits would also be based on linking physical habitat availability and quality to population dynamics (e.g., Capra et al. 2003).

6 Conclusions

The NPSFM (MfE 2011) requires that Regional Councils define environmental flow limits that include both minimum flows and total allocation limits. Where demand for water resources is high, detailed, site specific assessments will be required to define limits. However, there is also a need to define limits for less intensively developed catchments in a cost effective and transparent way.

The EFSAP methodology provides an approach for water resource managers to evaluate the consequences of setting different water resource use limits across all parts of a catchment or region including those for which detailed information is not available. The integrated use of scientific tools allows concurrent evaluation of consequences for both instream habitat and reliability of supply for out-of-channel water uses. It also accounts for the interaction between minimum flow and total allocation limits. By modelling a range of scenarios it also allows resource managers to more effectively communicate to stakeholders the varying consequences of different water resource limits.

In combination with clearly defined and measurable objectives, the EFSAP outputs facilitate definition of transparent and justifiable water resource use limits. However, water resource managers will still be required to make value judgements in collaboration with stakeholders to balance the needs of competing values. They will also need to consider values that are not evaluated by EFSAP such as cultural, natural character and recreational values. Consequently, decision making will remain an iterative process involving multiple stakeholders with competing demands and values.

The results of this project can be used by NRC to see how different values are affected by different water quantity management options and how this varies across the region. Three potential water management units were identified based on river size and climate. Defining limits based on these management units will help NRC in establishing more equitable limits at a regional scale. The EFSAP results can also be used to show communities the trade-offs between protecting river ecosystems and making water available for use. They also demonstrate the sensitivity of the different management units to changes in limits, with the large river and warm wet climate units more sensitive than the small river class. The EFSAP results can therefore be used to help NRC and communities decide, in a more transparent way, which limits best satisfy their objectives for managing freshwater values. They may also be valuable to NRC during public consultation by assisting to communicate results to the public.

7 Acknowledgements

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