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Estimates of the total wetted-area commercially fished for eels in the South Island (2020 to 2023), and the proportion of longfin habitat fished

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Contents

PLAIN LANGUAGE SUMMARY

The aim of this project was to estimate the extent of the spatial area that was commercially fished for longfin and shortfin eels in the South Island from 2020 to 2023. For longfin only, this was compared to the previous estimate of all habitat to provide an update of the proportion of longfin habitat that is fished commercially. This provides an indication of the spatial fishing pressure that both longfin and shortfin eel species have experienced and can be used as a tool to assess the status or health of eel stocks.

From 2020 to 2023 there were 1851 eel fishing events of approximately 15 fyke nets set per event, from 21 fishers. About half of the eel fishing events were from lakes and half from rivers. Most fishing on rivers was from the riverbank where the target species was longfin, and most lake fishing was vessel-based where shortfin were targeted. Nearly three-quarters of longfin fishing events and half of shortfin events were in Southland, Otago, and Westland, with most of the remaining shortfin effort focused on Te Waihora (Lake Ellesmere) and Lake Brunner.

A total of 3714 unique river reaches (totalling approximately 2700 km) were fished over the four years. Half the river reaches were fished only once in the four years, with a fifth of the reaches fished more than four times. The total area fished for longfin in the South Island from 2020 to 2023 was 55.4 km^2 and for shortfin this was 42.7 km^2. Of the total current longfin habitat in rivers, and in lakes accessible to longfin in the South Island, about 14% is currently fished. Compared to the previous estimate of the proportion of longfin habitat fished in 2016, the current estimate has declined by about 20% reflecting a substantial drop in fishing effort in recent years.

EXECUTIVE SUMMARY

Beentjes, M.P.; Shankar, U. (2025). Estimates of the total wetted-area commercially fished for eels in the South Island (2020 to 2023), and the proportion of longfin habitat fished

***New Zealand Fisheries Assessment Report 2025/26.* 26 p.**

The longfin eel spatial area commercially fished in the South Island over the four fishing years 2019–20 to 2022–23 (2020 to 2023) was estimated using fine scale reporting of effort (latitude and longitude) from the electronic reporting system (ERS). This was compared to the estimates of the total current longfin habitat from a previous study in 2016, to provide an update of the proportion of longfin habitat that is currently fished.

All recorded river eel fishing positions on the ERS in 2020 to 2023 were georeferenced to individual segments of the River Environment Classification (REC), version 2.5. Using information from the REC, the wetted area commercially fished in rivers was estimated for longfin and shortfin eels, separately (i.e., sum(river segment length × mean width of segment at mean annual low flow)). The wetted area fished in naturally formed lakes with areas over 0.9 km^2 that have unimpeded access to longfin eels, was estimated as the length of shoreline fished/lake perimeter × longfin habitat area.

In 2016 the total longfin habitat area estimate in South Island rivers was derived from ‘probability of capture’ models within REC segments, a relatively small number of which were above hydro dams. Similarly total longfin habitat in lakes was estimated for lakes with area over 0.9 km^2 that were naturally formed with unimpeded access to longfin eels, and included only the littoral zones or parts of the lake that longfin eels were thought to inhabit. Both river and lake habitat were expressed as wetted area. There are no current estimates for total shortfin habitat.

There were 1851 fishing events (average 15 fyke nets per event) from 21 fishers or permits in the data set and of these 45% were from lakes and 55% from rivers. Most river fishing was land-based targeting longfin, and most lake fishing was vessel-based targeting shortfin. Nearly three-quarters (73%) of valid-LFE fishing events (targeting or catching longfin) were in Eel Statistical Areas AW (Southland), AV (Otago), and AX (Westland). Similarly, over half (53%) of valid-SFE fishing events (targeting or catching shortfin) were in AS (Te Waihora) and most of the remaining effort was in coastal parts of AW, AV, and AX (mostly Lake Brunner).

A total of 3714 unique river segments were fished over the four years (2020 to 2023), that covered a distance of 2705 km. Nearly half (46%) of the unique fished segments were fished just once, but almost a fifth (19%) were fished more than four times. The total wetted area fished for longfin in the South Island from 2020 to 2023 was 55.4 km^2 (51.34 km^2 for rivers and 4.05 km^2 for lakes), and for shortfin this was 42.69 km^2 (39.17 km^2 from rivers and 3.52 km^2 from lakes). Total current longfin habitat in South Island rivers, and in lakes accessible to longfin (including Department of Conservation land, and areas closed to fishing by Fisheries New Zealand.) was estimated at 408.1 km^2 in 2016, and the current 55.4 km^2 fished equated to 13.6% of this.

Compared to the previous estimate of the wetted area fished for longfin (2010 to 2014), the number and length of unique segments fished in the recent period (2020 to 2023) has dropped by about 50%, the river wetted area fished by 59%, and the lake wetted area fished by 55%. The estimate of the proportion of longfin habitat fished, declined from 32.2% to 13.6%; virgin habitat fished dropped from 21.8% to 9.1%; and the maximum impacted abundance, taking into account all potential losses of habitat combined with fishing activity, dropped from 52.6% to 39.6%. The roughly 50% reduction in longfin habitat that was fished between 2010–2014 and 2020–2023 is consistent with the progressive decline in effort over the last fifteen years, due largely to the economics of fishing, an ageing fisher demographic, TACC cuts, market fluctuations, and recently the temporary loss of processing capability.

1. INTRODUCTION

The commercial freshwater eel fishery in New Zealand developed in the late 1960s and landings consist of both the endemic longfin eel (*Anguilla dieffenbachii*), and the shortfin eel (*Anguilla australis*) which is also found in southeast Australia. Longfin eels are considered to be more at risk of overfishing than shortfin because they are endemic to New Zealand and migrate and spawn at a considerably older age, for both sexes (Fisheries New Zealand 2024). Further, longfin females are considered to be more at risk of overfishing than males and sustainability depends on there being sufficient numbers of females surviving to migrate and spawn each year (Jellyman et al. 2000, Hoyle & Jellyman 2002, Fu et al. 2012). In the South Island, longfin eels are found further inland than shortfin eels, occupying high country lakes, some of which have had both longfin upstream and downstream passage blocked by hydro-electric dams, essentially removing this habitat from the total habitat available for longfins where they can contribute to spawning (Beentjes et al. 1997, Beentjes 2005). Graynoth et al. (2008) estimated that as much as 6000 t of longfin eels are contained in hydro reservoirs. There are, however, trap and transfer programmes for elvers at most of the major New Zealand hydro-electric dams (Crow et al. 2023).

For the successful management of any fishery, it is desirable to have some index of relative abundance for the fished portion of the population to monitor the effects of fishing on the population. Many conventional fisheries sampling and survey techniques for determining relative abundance indices cannot validly or practically be applied in the freshwater eel fishery, with the notable exception of catch-per-unit-effort (CPUE) analyses which are routinely carried out for the commercial eel fishery (Beentjes & McKenzie 2017, Beentjes 2021).

Before 2019–20 fishing year (1 October to 30 September) commercial eel catches were reported on catch effort landing returns (CELRs) and then on Eel Catch Effort Returns (ECER), and the finest spatial resolution of reporting was by Eel Statistical Area (ESA) which are broadly catchment-based, but include multiple major river systems (Figure 1). With the introduction of the electronic reporting system (ERS) in 2019–20, eel catch is recorded by start and finish coordinates of fishing events (latitude and longitude).

A Fisheries New Zealand project in 2015 (EEL2014-01) collected fine scale spatial data during face-to-face interviews with fishers throughout New Zealand (Beentjes et al. 2016). During interviews, 53 fishers were asked where they had caught longfin eels within the five-year period (2009–10 to 2013–14) and the extent of fishing was annotated on topographical maps which was analysed using GIS methods. This was compared with the extent of the modelled current total longfin habitat to provide a quantitative estimate of the proportion of the habitat that was fished at this time, and conversely the proportion that was unfished (Beentjes et al. 2016). The results gave longfin habitat fished estimates of 32.5% for the South Island, 22.5% for the North Island, and 27.2% for the whole of New Zealand.

The objective of the current project (EEL2023-02) was to update the longfin habitat fished estimates in the South Island only, this time using fine scale reporting of effort (latitude and longitude) from the ERS and compare that with the results of the 2015 study to see if there has been any change in spatial effort and intensity.

Specific objectives

1. To characterise South Island commercial eel fisheries.
2. To analyse CPUE trends in the South Island commercial eel fisheries (LFE and SFE 11, LFE and SFE 12, LFE and SFE 13, LFE and SFE 14, LFE and SFE 15, and LFE and SFE16) using data up to the end of the fishing year 2023–24.
3. To determine the proportion of longfin habitat fished commercially.
4. Broader Outcomes.

Objectives 1 and 2 are reported in Beentjes (2025).

2. METHODS

2.1 Fishing location data

The fishing effort data used in this report were extracted from the Fisheries New Zealand Enterprise Data Warehouse (EDW) and for each daily record (i.e., fishing event) from fishing years 2020 (2019–20) to 2023 (2022–23) (1 October to 30 September) for all South Island fishing events. All data were reported by fishers in the ERS with the following variables recorded:

- Event key
- Trip ID
- Client key
- Start date- date at start of nets lifted
- Start time – time at start of first net lift
- Start position – latitude and longitude of first net lift
- Finish date- date at finish of last net lift
- Finish time – time at finish of last net lift
- Finish position – latitude and longitude of last net lift
- Method (FN, fyke net; EFN, Ellesmere fyke net; EP, eel pot; FP, fish trap)
- Number of net lifts
- Estimated catch weight of shortfin (SFE)
- Estimated catch weight of longfin (LFE)
- Target species (SFE or LFE)
- Is vessel used – yes or no
- Are nets baited – yes or no
- Eel Statistical Area (derived from latitude and longitude)

Henceforth we refer to rivers as including rivers, streams and creeks. Commercial eel fishing can take place from a vessel or from land on the riverbank. A fishing event in the eel fishery is defined as when a series of fyke nets (usually about 10 to 30) are set a distance apart along a riverbank, or around a lake shore and left to fish for, typically, for one or two nights before retrieval. The ERS records the position of the first and last net lifted.

2.2 Longfin and shortfin areas fished in rivers

The ERS data start and finish positions were imported into ArcGIS Pro (v3.3) where they were plotted and inspected for veracity. Where possible these were georeferenced and then assigned to River Environment Classification (REC) segments. They were subsequently checked for continuity from start to end point by using the ArcGIS Pro network analysis tracing tool. The most common errors were that the finish position was the same as the start position or that they were not in the river or lake. The REC was created by the Ministry for the Environment and the National Institute of Water and Atmospheric Research (NIWA) (Snelder et al. 2004) and has since been updated to version 2.5 (Crow et al. 2014). Unlike LINZ topographic maps, the REC system is a synthetic river network derived from a digital elevation model. There are 593 466 REC segments with mean length of 696 m (range 15 to 32 627 m) with additional information about physical characteristics such as stream order, mean flow, catchment areas, distance inland, altitude, topography, geology and land cover etc. Shortfin fishing locations were also included in the current analyses for 2020 to 2023 fishing events, unlike the previous analyses from 2010 to 2014 which only dealt with longfin.

The fishing event data for the four fishing years (2020 to 2023) were then processed in the following way:

1. A fishing event where longfin was caught or recorded as targeted, was labelled 'valid-LFE', and those where shortfin was caught or recorded as targeted was labelled 'valid-SFE'.
2. For each fishing event (N = 1851), 'sensible' positions were identified, i.e., those with both start and finish positions on the water <20 km apart for vessel-based fishing, and <6 km apart for land-based fishing (N = 264 from vessel-based, and N = 271 from land-based fishing). Where start and finish positions were greater than these distances apart, the finish position was on land, or the start and finish positions were at the same place, these were labelled 'non-sensible' (N = 1316). The criteria and rationale for assigning sensible and non-sensible labels to fishing events were informed by consulting five current South Island eel fishers.
3. For 'sensible' positions the river was traced from the start position REC segment to the finish position segment (tracing the river path), taking 50% of the start and finish segment, and 100% of segments in between. Tracing was accomplished using a bespoke program in Fortran that processed all valid start and end points.
4. The mean length of the river fished was estimated for the traced sensible start-finish vessel fishing and land-based fishing events (6.7 km for vessel fishing, se = 0.34; and 2.3 km for land-based fishing, se = 0.09).
5. For the remaining non-sensible fishing events (N = 1316), the mean length of river fished from sensible fishing events was used as a proxy and the river was traced downstream from the start position for 6.7 km (vessel fishing) or 2.3 km (land-based fishing).
6. For the full set of fishing events ('sensible' and corrected 'non-sensible', (N = 1851) the following metrics were then calculated for the traced sections of river for 'unique' river segments fished (N = 3714), regardless of the number of times fished:
    a. Mean stream order (Strahler system), in which source tributaries represent order one, and there can be as many as eight stream orders in some large catchments such as the Clutha River (where order eight represents the main stem Clutha River).
    b. Total length of rivers fished (m).
    c. Number of REC segments.
    d. Mean MALF (cumecs): Mean annual low flow in cubic metres per second.
    e. Mean MALFwidth (m): River width at MALF. The statistics for MALF and river width at MALF for each segment were modelled from actual data recorded at 485 gauging stations throughout New Zealand (Booker & Wood 2014). If MALFwidth was less than 1 m then it was converted to 1 m, because it is not realistic to be able to set nets in a creek less than 1 m wide.
    f. Wetted area fished (km^2): River habitat fished estimates were expressed as wetted area calculated from REC segment length (m) × mean segment width at MALF (m) /10^6. This was calculated for valid-LFE and valid-SFE fishing events separately and combined. This assumes that the entire area of rivers is available to either species.

Fishing intensity in rivers

Because waterways (i.e., REC segments) can be fished by one or more fishers, and multiple times a year by an individual fisher, an index of fishing intensity was calculated to distinguish among lightly and heavily fished areas. The number of times a unique segment (N = 3714) was fished over the four years (2020 to 2023) was summed and the proportion of these segments fished at frequencies of 0, 1, 2, 3, 4, and over 4 times was calculated. Values greater than one indicate that more than a single pass or fishing event has occurred over the four years. In this way it was possible to map the cumulative effort spatially on the REC. This was also carried out for individual years. Data were analysed for valid-SFE and valid-LFE fishing events separately.

2.3 Area fished in natural lakes

The REC is primarily a river system model and does not include lakes unless they were natural rivers that had been flooded for hydro power production or for other purposes. For these analyses, all lake fishing was considered outside the REC and hence treated differently. An exception to this were some small wetland areas less than 0.9 km^2 associated with rivers that were included in the REC in the current analyses for 2020 to 2023. Only lakes over 0.9 km^2 that were naturally formed and considered to currently have unimpeded access for longfin eels were included in the fished lake habitat estimates. For these, total longfin habitat (km^2) was estimated previously by Beentjes et al. (2016, appendix 1), based on the euphotic, or littoral zone, where aquatic macrophyte plants extend. For the shallow and or coastal lakes, which are overwhelmingly dominated by shortfin eels, the habitat was prorated to 10% of the total lake area to reflect the low longfin densities. The littoral area of lakes was not available in any New Zealand freshwater database but was estimated for 36 South Island lakes over 0.5 km^2 by Beentjes et al. (1997) based on the depth of the euphotic zone or the maximum depth to which macrophytes are found, and then estimated from bathymetric maps. Although longfin eels may reside in waters deeper than this, it was generally considered that most food exists in the littoral zone and this is where fishing tends to be concentrated. Littoral zone areas not available in Beentjes et al. (1997) were estimated using the same principle using data from the NIWA Aquatic Plants Database and NIWA unpublished data on lake bathymetry. In theory, if these natural lakes have unimpeded access to longfin, then they will have access to shortfin, although many of these more inland and higher altitude lakes are not suitable as shortfin habitat.

The main South Island lakes fished between 2020 and 2023 were Te Waihora and Lake Brunner which are primarily shortfin fisheries, but where longfin are still caught. Given this, in these analyses, the shortfin lake habitat fished was assumed to be the same as for longfin. Lake Brunner is a natural hydro lake above Arnold Dam (Westland) commissioned in 1932. This lake was categorised as a natural lake with unimpeded access to longfin eels because it has been intensively fished for decades, suggesting that recruitment is occurring to a large extent supplemented by elver trap and transfer (Crow et al. 2023) and spawning migrants are thought to escape when the dams overtops during flood events. Virtually all fishing in these natural lakes is by vessel along the lake shoreline. The 2020 to 2023 wetted area fished (i.e., habitat fished) in natural lakes was estimated as follows:

1. For Lake Brunner the sensible vessel mean river length fished (i.e., 6.7 km) was used as a proxy of lake shoreline fished because all start and finish net lift positions were the same, i.e., at the boat ramp.
2. For Te Waihora, where start and end positions were reasonable, (i.e. not <0.5 km or >20 km) the calculated distance between start and fishing positions was used, otherwise the sensible vessel mean river length fished (6.7 km) was used.
3. For all other natural lakes over 0.9 km^2 the mean distance fished by vessel (6.7 km) was used.
4. For all other natural water bodies under 0.9 km^2 the mean distance fished by vessel (6.7 km) was used. These were usually small wetland areas that feed into mainstem river segments and were identified by REC segments.
5. The wetted area for these fished natural lakes was then estimated by: length of shoreline fished (km)/lake perimeter (km) × longfin habitat (km^2).

For the previous analyses, natural lakes accessible to longfin that had been fished from 2010 to 2014 were identified, and for these the area of habitat fished was simply the wetted area (km^2) of the entire lake, the littoral zone, or a prorated proportion of these areas (Beentjes et al. 2016, appendix 1).

2.4 Estimates of total South Island longfin habitat

The total current longfin habitat in rivers and lakes throughout New Zealand was estimated as part of the 2010 to 2014 fishing data analyses by Beentjes et al. (2016). These estimates of total longfin river habitat have not been repeated in the current updated analyses for the South Island, and we assume that these have not changed to any meaningful extent. Detailed methods on how these estimates were made are provided in Appendix A of this report, and briefly described below.

The total longfin river habitat was derived from the 'probability of capture' model developed by Leathwick et al. (2008) who used statistical models to describe the probabilities of capture for longfins and other freshwater species in all rivers and stream segments throughout New Zealand, including Stewart Island. Although the model sometimes included habitat above hydro dams, the bulk of the habitat was below dams. The probability of capture' model also includes Department of Conservation land, and areas closed to fishing by Fisheries New Zealand. As described above for longfin river habitat fished, longfin total habitat was expressed in the same way: i.e., wetted area (km^2) = REC segment length (m) × mean segment width at MALF (m) /10^6.

Lake habitat was estimated for natural lakes over 0.9 km^2 accessible to longfin eels, or selected natural hydro lakes where longfin are known to be present, as the wetted area (km^2) of the entire lake, the littoral zone, or a prorated proportion of these areas (Appendix A).

2.5 Estimates of longfin habitat fished

2.5.1 Proportion of current longfin habitat fished

The formulae to estimate the proportions of total longfin habitat fished are the same as those for the previous analyses in 2010 to 2014 (Beentjes et al. 2016).

Rivers

The proportion of longfin habitat fished in rivers was determined from the empirical relationship between fished segments, and total segments where longfin are predicted to be present. Using wetted area (km^2) as a proxy for habitat, the proportion of current (2019–20 to 2022–23) river habitat fished (PC_{river_fished}) is given by:

$$PC_{river\_fished} = \frac{A_{river\_fished}}{A_{river\_pred}} \qquad (1)$$

where:

A_{river_fished} is the wetted area (km^2) of the REC fished.

A_{river_pred} is the wetted area (km^2) of the REC at probability of longfin capture of 0.5 or higher. Relative abundance of longfin is assumed to be the same in all river segments

Lakes and rivers

The proportion of current combined river and lake habitat fished ($PC_{river\_lake\_fished}$) is given by:

$$PC_{river\_lake\_fished} = \frac{A_{river\_fished}+A_{nat\_lake\_fished}}{A_{river\_pred}+A_{nat\_lake}} \qquad (2)$$

Where:

$A_{nat\_lake\_fished}$ is the wetted area (km^2) of accessible natural lakes fished.

A_{nat_lake} is the wetted area (km^2) of suitable longfin habitat in all accessible natural lakes., i.e., those over 0.9 km^2 in which longfin have unimpeded access to the sea.

Proportions of current longfin habitat fished (lakes and rivers combined) are provided for South Island as a whole, and also by Eel Statistical Area and Quota Management Area.

2.5.2 Proportion of virgin longfin habitat fished

The proportion of virgin unmodified habitat fished is determined in the same way as the proportion of current combined river and lake habitat fished ($PC_{river\_lake\_fished}$) except that habitat where longfin are present also includes natural hydro lakes where access is now impeded, river habitat lost by the creation of artificial and inaccessible impoundments or reservoirs, and habitat lost through degradation. The proportion of virgin habitat fished ($PV_{river\_lakes\_fished}$) is given by:

$$PV_{river\_lake\_fis} = \frac{A_{river\_fished}+A_{nat\_lake\_fish}}{A_{river\_pred}+A_{nat\_lake} + A1_{hydro\_lake\_nat}+A1_{river\_res} + A_{degrad}} \quad (3)$$

Where:

$A1_{hydro\_lake\_nat}$ is the wetted area (km^2) of all natural lakes where hydro or other dams have resulted in 100% impeded access in and out the lakes.

$A1_{river\_res}$ is the wetted area (km^2) of the original river habitat replaced by artificial impoundments or reservoirs,

and A_{degrad} is the wetted area (km^2) of habitat lost to non-specific habitat degradation, i.e., farms drains, farm pumping stations, culverts, drainage, river modification and channelling, willow clearing, and water quality etc. There are no quantitative data on habitat degradation but nominally, 5% of current river habitat was assumed to be lost through degradation.

Proportions of virgin longfin habitat fished are provided for South Island as a whole, and by Eel Statistical Area and Quota Management Area.

2.5.3 Proportion maximum impacted longfin abundance

To estimate the maximum anthropogenic impact on relative longfin abundance from commercial fishing and habitat loss we also need to consider the habitat loss in 1) natural hydro lakes where access is impeded, 2) the loss of previous river habitat by the creation of artificial and inaccessible hydro reservoirs or impoundments, and 3) any other losses due to habitat degradation. Hence, the impacted abundance ($A1_{anthropogenic}$) is expressed by the relationship between all habitat losses plus fished habitat (numerator), and all virgin habitat unaffected by anthropogenic activities (denominator), and is given by:

$$A1_{anthropogenic} = \frac{A_{river\_fished}+A_{nat\_lake\_fish} + A2_{hydro\_lake\_nat} + A2_{river\_res} + A_{degrad}}{A_{river\_pred}+A_{nat\_lake} + A1_{hydro\_lake\_nat}+A1_{river\_res}} \quad (4)$$

Where:

$A2_{hydro\_lake\_nat}$ is the wetted area (km^2) of all natural lakes where hydro or other dams have resulted in impeded access in and out the lakes, less any allowance for elver transfer and catch and transfer of migrating eels, i.e., 50% of the littoral wetted area for Lakes Te Anau and Manapouri and a nominal 5% for all other New Zealand natural hydro lakes combined.

$A2_{river\_res}$ is the wetted area (km^2) of the original river habitat replaced by artificial impoundments or reservoirs with impeded access, less any allowance for spawning contribution due to elver transfer and passive escapement of spawning eels over spillways and overtopping dams in periods of floods, combined with sporadic programmes of migrant catch and transfer, i.e., nominally, 5% of habitat from artificial impoundments or reservoirs throughout New Zealand.

Proportions of maximum impacted longfin abundance are provided for South Island as a whole and also by Eel Statistical Area and Quota Management Area.

No assumptions are made about fishing mortality.

2.6 Spatial distribution of effort

ERS 2020 to 2023 position data that shows the start and finish location of the sets plotted on a South Island map at high resolution (0.04-degree squares) were presented to the Eel Working Group on 17 December 2024. However, Fisheries New Zealand data confidentiality rules only allowed publication of these data in the following summarised form:

- *Latitudes and longitudes (maps or any other means of display) are truncated to a 1 degree level of resolution if they refer in any way to the magnitude of catches;*
- *Latitudes and longitudes (maps or any other means of display) are truncated to a 0.2 degree level of resolution if they do not refer in any way to the magnitude of catches;*
- *Information that identifies specific vessels or people is removed including any unique system identifiers of vessels or people (includes companies);*
- *Vessel attributes (e.g. length, breadth, tonnage, nationality etc.) are removed;*
- *Data is grouped such that no group contains data less than 3 vessels or 3 persons (includes companies) unless:*

Plotting the catch location at the 0.2-degree level of resolution and restricting to 3 persons, results in little of the data being shown, and in some areas all data are lost. Plotting the catch location data adhering to data confidentiality guidelines is of no value in understanding the spatial nature of the eel fishery, hence these maps are not presented. The spatial distribution is, however, broadly described in the results.

3. RESULTS

3.1 Fishing event metrics

There were 1851 South Island fishing events (average of 15 fyke nets per fishing event), from 21 fishers or permits between 2020 and 2023 in the ERS analyses data set, all with position data (latitude and longitude). Of these 1851 fishing events, 45% were from lakes and 55% from rivers (Table 1). Most lake fishing (89%) was in Te Waihora (Lake Ellesmere) followed by Lake Brunner. Vessels were used in over half of the fishing events (55%) and of these more than three quarters were in lakes (78%). Of the 45% of fishing events that were land-based, nearly all (95%) were from rivers (Table 1). Shortfin eels were the main target species (61%) and of this, nearly three quarters (72%) of shortfin fishing events were in lakes. Baiting of nets was much more common in rivers than lakes, and when targeting longfin where nearly all nets were baited (Table 1). The total wetted area fished for all fishing events over the four years (including areas that may have been fished multiple times) was 754.6 km^2 of which 94% was in lakes.

3.2 Metrics for unique river segments fished

The total number of REC river segments in the South Island is 324 589 with total length of 231 195 km (Table 2), although a very small number of these may be small lakes. The numbers of fished unique river segments from 2020 to 2023, where a unique segment is defined as one which is counted only once, regardless of whether it was fished by more than one fisher or multiple times, are shown in Table 2. For valid-LFE fishing events, there were 3555 unique segments fished (1.1% of all South Island REC segments) and 2567 km of river fished (1.1% of the length of all South Island REC segments), Similarly, for valid-SFE fishing events, there were 2038 unique segments fished and 1483 km of river fished, equating to 0.62% and 0.64% of the REC segments respectively (Table 2).

For all fishing events in 2020 to 2023, regardless of target species or if eels were caught, 3714 unique South Island river segments were fished that covered a distance of 2705 km (Table 3). Other metrics included are mean stream order, MALF statistics, and river wetted area fished.

3.3 Fishing intensity and spatial distribution of effort in rivers

Fishing intensity is the sum of effort of all fishers in unique segments over the four fishing years (2020 to 2023). Nearly half (46%) of the unique fished segments (N = 3714) were fished just once, but almost a fifth (19%) were fished more than four times (Table 4), with a maximum fishing intensity of 36 times for 3 segments. Valid-LFE fishing events had higher unique segment fishing intensity than valid-SFE fishing events (Table 4, Figures 2 and 3). The total number of unique segments fished progressively declined from 2020 to 2023 (i.e., 2179, 1961, 830, 766) with a corresponding decline in fishing intensity to the extent that in 2023 there were negligible segments fished more than twice (Figures 2 and 3).

Although spatial maps of fishing positions and fishing intensity cannot be provided for confidentiality reasons, the bulk of the South Island river-fishing effort between 2020 and 2023 was in the largest Southland and Otago rivers and tributaries, with highest fishing intensity in the coastal sections. Key rivers were Mataura River, Oreti River, Aparima River, Waiau River (Southland), Clutha River, and Taieri River (Otago). There was relatively little fishing in rivers outside of Southland and Otago except for Haswell River, Waimakariri River (Canterbury), Buller River, Grey River, Hokitika River, and Karamea River (Westland). Te Waihora and Lake Brunner were also intensively fished over this period, targeting shortfin.

The proportions of valid-LFE and valid-SFE fishing events within the Eel Statistical Areas (ESA) are shown in Table 5. Nearly three-quarters (73%) of valid LFE fishing events were in ESAs AW (Southland), AV (Otago), and AX (Westland). Similarly, over half (53%) of valid SFE fishing events were in AS (Te Waihora) and most of the remaining effort was in coastal parts of AW, AV, and AX (mostly Lake Brunner) (Table 5).

3.4 Wetted area fished

The total wetted area fished for longfin in the South Island from 2020 to 2023 was 55.4 km^2 (51.34 km^2 for rivers and 4.05 km^2 for lakes), and for shortfin this was 42.69 km^2 (39.17 km^2 from rivers and 3.52 km^2 from lakes) (Table 3, Figure 4). The wetted area fished was larger for longfin than shortfin in all ESAs except AS (Te Waihora) and AU (Waitaki), and overall, 91% of longfin and 87% of shortfin area fished was in just three ESAs (AV, AW and AX) (Figure 4).

3.5 Longfin habitat fished

Estimates of total current longfin habitat (wetted area), along with longfin habitat fished (wetted area fished) in the South Island for fishing years 2020 to 2023 are shown in Table 6. As mentioned in the methods, the longfin habitat was not estimated as part of this study and was taken from the previous analyses (Beentjes et al 2016). Total current longfin habitat in rivers, and in lakes over 0.9 km^2 accessible to longfin in the South Island was estimated at 408.1 km^2, and of this 55.4 km^2 was fished from 2020 to 2023, i.e., 13.6% (equation 2) (Table 6). Of the 55.4 km^2 longfin habitat that was fished, most was in rivers with only 7% in lakes.

The proportion of current longfin habitat fished by ESA ranged from 0% in AN (Nelson) to 48% in AV (Otago), and only three ESAs had more than 10% fished (AU, Waitaki; AV; AW) (Table 7a, Figure 5). Similarly, only one QMA (QMA 15) had more than 10% of longfin habitat fished (Table 8a). The corresponding estimates for virgin habitat fished (equation 3) and maximum impacted abundance (equation 4) were 9.1% and 39.6%, respectively and are shown by ESAs and Quota Management Areas (QMA) (Tables 7a and 8a, respectively, Figure 6).

4. DISCUSSION

4.1 Fishing practice and area fished

ERS fishing position data were analysed to estimate the wetted area in rivers and lakes that was fished in the South Island for longfin and shortfin, individually, over the period 2020 to 2023 (see Table 3, Figure 4). This follows on from a similar project before the introduction of the ERS, where for longfin only, wetted area fished was estimated for the period 2010 to 2014 based on information provided from face-to-face interviews with longfin eel fishers throughout New Zealand (Beentjes et al. 2016). The current study is the first to estimate the area fished for shortfin eels. In both studies, the intensity or frequency of fishing within these discrete areas was also quantified, revealing those areas which were the most heavily and lightly fished.

The effort data collected in the ERS has highlighted the differences between fishing practices used for the two eel species. The South Island eel fishery is a mixed fishery in many places, such as the lower reaches of rivers, where both species are often present and vulnerable to capture by fyke net.

In the four-year period from 2020 to 2023, shortfin were targeted more often than longfin overall and in lakes (Table 1). Vessels were used more often targeting shortfin than longfin and baiting of nets was less common (Table 1).

The number and length of unique REC river segments fished for shortfin were about one half of those for longfin (see Table 3) and these segments tended to be more concentrated near the coast than those segments fished for longfin (not shown due to Fisheries New Zealand data confidentiality rules). This was consistent with the fishing intensity results where nearly half of the unique river segments (N = 3714) were not fished at all for shortfin, compared to only a few percent unfished for longfin, i.e., not targeted or caught in the fishing event (see Table 4, see Figures 2 and 3). Further, a much higher proportion of the unique segments were fished more than once for longfin (60%) compared to shortfin (21%).

The total wetted area fished for longfin in rivers and lakes was 51.3 km^2 and 4.04 km^2 for longfin, respectively, and for shortfin this was substantially less in rivers at 39.2 km^2, but similar in lakes at 3.5 km^2 (see Table 3).

4.2 Spatial and temporal fishing effort

Although spatial data cannot be presented in this report for data confidentiality reasons, the breakdown of fishing events by ESAs shows clearly that half of the valid shortfin events were in Te Waihora (AS1), 8% were in Otago (AV) mainly from Lake Waihola and lower Clutha River, 16% from Southland (AW) in the lower coastal reaches, and 13% from Westland (AX) mainly in Lake Brunner (see Table 5). Longfin distribution of fishing events was more concentrated in the main Otago and Southland rivers. The comparative lack of fishing events in the northeast coast of the South Island (AN, AP, AQ, AR, AT and AU), for either species, is related to the introduction in 2017 of nominal 1 tonne longfin TACCs in the QMAs that include these ESAs, which results in unwanted bycatch of longfin, when targeting shortfin. In addition, over 4 kg (maximum legal-size limit) longfin eel captures in these areas are increasing as effort has declined, and consequently fishers tend to avoid fishing in these areas.

The progressive decline in fishing effort from 2020 to 2023 is evident in the fishing intensity plotted by year (Figures 2 and 3). This decline stems from the permanent closure of the only South Island eel processor in 2022, international market fluctuations, and to a short term lack of processing infrastructure, rather than to a decline in abundance (Beentjes 2025).

4.3 Longfin habitat fished

Using previously estimated habitat within lakes over 0.9 km^2 accessible to longfin, and rivers at the >0.5 probability of capture model (Beentjes et al. 2016), the proportion of longfin habitat fished in the South Island for the period 2020 to 2023 was estimated at 13.6% (equation 2) (see Table 6), however, this may be slightly underestimated, as it includes river habitat above hydro dams that is not accessible to longfin. Similarly, the 2020 to 2023 estimate of the proportion of virgin longfin habitat fished (equation 3) was 9.1%. The maximum impacted abundance of longfin (equation 4), accounting for all potential losses of habitat and fishing activity, was 39.6% (see Table 7a, Figure 6).

The total longfin habitat in the South Island is an estimate only, based on the wetted area of rivers (i.e., segment length × MALF width) and the proportions of lake areas for which longfin eels were thought to inhabit and have unimpeded access and egress. This assumes that the entire wetted area of rivers is available to longfin eels as habitat, which is not the case for habitat above hydro dams, for very large rivers where eels are more likely to be found closer to river banks, or in particular segments of rivers with more optimal habitat. In addition, the estimates of total longfin habitat from the probability of capture models should be regarded with caution given that there were many segments where eels were caught yet the model predicted longfins were absent (Beentjes et al. 2016). Similarly, there is no way of knowing where eels are absent, despite the model predicting that eels are present.

There are currently no estimates of total shortfin habitat in New Zealand, and hence it is not possible to estimate the proportion of shortfin habitat that is fished. Regardless, the shortfin habitat would certainly exclude the upper reaches of South Island rivers and high-country lakes preferred by longfin, and would include more of the lakes such as Te Waihora, Lake Brunner, and Waihola, as well as coastal wetlands. In other words, the same areas that shortfin was caught in 2020 to 2023, plus other similar areas that were not fished.

4.4 Comparison between 2010 to 2014 and 2020 to 2023 fishing years

Different methods were used to estimate the area fished in the two studies (2010 to 2014, and 2020 to 2023), and hence the proportion of longfin habitat fished. Further, as mentioned, the latter study also provided estimates of the area fished for shortfin, absent from the 2010 to 2014 study which focused exclusively on the spatial distribution of longfin target effort. Despite the different methods, fundamentally the same outcomes were achieved and are broadly comparable. One key difference between methods is that the current study defined a longfin or shortfin fishing event by whether that species was targeted or caught, and on some occasions a single event could be categorised as both a shortfin and a longfin fishing event. The earlier study disregarded shortfin, and fishers provided spatial effort data primarily on areas where they predominantly caught longfin. In this regard, the latter study may have overestimated the area of longfin fished, compared to the original estimate.

Fishing intensity is not directly comparable because of the different ways that it was estimated and compiled, but in broad terms the practice of fishing the same areas multiple times in a year, or over a number of years, has continued. The most productive areas, and those that are most accessible and economic to fish are likely to be fished most often. These areas may, however, change depending on whether shortfin or longfin are the preferred catch and on the marketable sizes required by processors.

The most significant change to the spatial location of areas fished has been in the northeast of the South Island (see Figure 5) where the longfin habitat fished has declined dramatically between the two periods. As explained above, this is a result of the setting of 1 tonne nominal longfin TACCs which has in effect closed the fishery in this region.

Compared to the first period (2010 to 2014), the number and length of unique segments fished in the recent period (2020 to 2023) has dropped by about 50%, the river wetted area fished has dropped by 59%, and the lake wetted area fished declined by 55% (see Table 3). The corresponding estimate of the proportion of longfin habitat fished, declined by more than one-half from 32.2% to 13.6% (Table 6,

Figure 6). Similarly, the virgin habitat fished dropped by a similar degree from 21.8% to 9.1%. The maximum impacted abundance also dropped, but not to the same extent, from 52.6% to 39.6% (Table 6, Figure 6).

The roughly 50% reduction in longfin habitat that was fished between 2010 to 2014 and 2020 and 2023 is not surprising given the progressive decline in effort over the last fifteen years due largely to economics of fishing, an ageing fisher demographic, TACC cuts, market fluctuations, and recently the temporary loss of processing capability. Fishers have not always been able to sell their entire legal catch, and over the last two years they have been requested to supply eels of particular sizes and or species (e.g.., shortfin eels over 700 g). By way of comparison the number of longfin fishers in the early study numbered 26, compared with 21 longfin and shortfin fishers, in the recent study, of which only 6 permits were fished in 2023. The proportion of longfin and shortfin habitat fished is likely to increase if markets and processing capability improves.

5. FULFILMENT OF BROADER OUTCOMES

The following broader outcomes were delivered:

- A commitment to contributing positively to the social, economic, cultural, and environmental wellbeing of New Zealand.
- An innovative GIS project on the extent of longfin eel habitat that is fished which is largely unique from an international perspective and will benefit a range of stakeholders, including the general public, Māori, the commercial fishing industry, environmental NGOs, and the international eel research community.

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8. TABLES

Table 1: Metric variables for all South Island eel fishing events between 2020 to 2023 fishing years from ERS data. Cumecs, cubic metres per second; MALF, mean annual low flow; wetted area = length fished × mean stream width at MALF (rivers); and length of shoreline fished /lake perimeter × longfin habitat (km^2) (lakes). Baited refers to the baiting of fyke nets. LFE, longfin eel; SFE, shortfin eel.

	Lake	River (*N*)	Lake (%)	River (%)	*N* (%)
All events	835	1 016	45.1%	54.9%	1 851
Vessel events	798	226	77.9%	22.1%	1 024 (55%)
Non-vessel events	37	790	4.5%	95.5%	827 (45%)
Vessel events (target LFE)	6	120	4.8%	95.2%	126
Vessel event (target SFE)	792	106	88.2%	11.8%	898
Target LFE events	24	704	3.3%	96.7%	728 (39%)
Target SFE events	811	312	72.2%	27.8%	1 123 (61%)
Baited net events	27	593	4.3%	95.6%	620 (34%)
Unbaited net events	807	406	66.6%	33.3%	1 213 (66%)
Baited net events (LFE target)	14	489	2.8%	97.2%	503
Baited net events (SFE target)	13	104	11.1%	88.9%	117
Mean stream order	–	3.79	–	–	–
Mean MALF (cumecs)	–	11.32	–	–	–
Sum length fished (km)	5 594	3 115	64%	36%	8 710
Sum wetted area (km^2)	713.4	41.3	94.5%	5.5%	754.6

Table 2: Number and length of all unique REC segments in the South Island; and the number, length and proportion of these unique river segments fished. Data are shown for fishing periods 2010 to 2014 for longfin fishing only as identified by fishers; and 2020 to 2023 from ERS data by valid-SFE and valid-LFE longfin fishing events (i.e., where either longfin or shortfin were caught or targeted) for the latter period. LFE, longfin eel, SFE, shortfin eel. NA, not determined for shortfin

	REC segments			REC segment length		
Period	REC (*N*)	Fished (*N*) LFE /SFE	Fished (%) LFE /SFE	REC (km)	Fished (km) LFE/SFE	Fished (%) LFE/SFE
2010 to 2014	324 589	7 542/NA	2.3/NA	231 195	5 647/NA	2.4/NA
2020 to 2023	324 589	3 555/2 038	1.1/0.62	231 195	2 567/1 483	1.1/0.64

Table 3: Metric variables for unique river REC segments fished from 2010 to 2014, and 2020 to 2023 fishing periods in the South Island. The 2010 to 2014 data include unique river segments identified by fishers where longfin was caught; the 2020 to 2023 data include unique river segments from valid shortfin or valid longfin fishing events (i.e., where either longfin or shortfin were caught or targeted) recorded in the ERS. Totals in 2020 to 2023 includes unique river segments fished, regardless of target species or whether eels were caught. Lake area fished is also shown. Cumecs, cubic metres per second; MALF, mean annual low flow; Total wetted area = length × mean stream width at MALF. The 2010 to 2014 results are from Beentjes et al. (2016).

	2010 to 2014	2020 to 2023		
	Longfin	Longfin	Shortfin	Total
Segments (*N*)	7 542	3 555	2 038	3 714
Length (km)	5 647	2 567	1 483	2 705
Mean of MALF (cumecs)	16	33.8	56	32.7
Mean of stream width at MALF (m)	24	22.5	30.3	21.8
Mean stream order	5	4.9	5.3	4.9
River wetted area fished (km^2)	123.6	51.34	39.17	52.59
Lake wetted area fished (km^2)	8.99	4.05	3.52	5.80

Table 4: Number and percent of fishing intensity of unique South Island REC segments (*N* = 3714) fished for all fishing events, 'valid longfin' fishing events, and 'valid shortfin' fishing events for 2020 to 2023 fishing years combined. Fishing intensity ranges from no fishing (zero) to being fished more than four times (Over 4). 'Valid longfin' is where longfin was caught or targeted on a fishing event. 'Valid shortfin' is where shortfin was caught or targeted on a fishing event. LFE, longfin eel; SFE, shortfin eel.

	Unique segments		Unique segments		Unique segments	
Fishing intensity	All (*N*)	All (%)	LFE (*N*)	LFE (%)	SFE (*N*)	SFE (%)
0	1	0.03	160	4.31	1 676	45.13
1	1 717	46.23	1 675	45.10	1 285	34.60
2	629	16.94	594	15.99	256	6.89
3	381	10.26	387	10.42	116	3.12
4	294	7.92	280	7.54	93	2.50
Over 4	692	18.63	618	16.64	288	7.75
Totals	3 714	100	3 714	100	3 714	100

Table 5: Number and percent of 'valid longfin' fishing events, and 'valid shortfin' fishing events for 2020 to 2023 fishing years combined for each South Island Eel Statistical Area (ESA). 'Valid-LFE is where longfin was caught or targeted on a fishing event. 'Valid-SFE' is where shortfin was caught or targeted on a fishing event. LFE, longfin eel; SFE, shortfin eel.

ESA	Valid-LFE		Valid-SFE	
	(*N*)	%	(*N*)	%
AP	54	4.8	57	4.3
AQ	3	0.3	7	0.5
AR	9	0.8	12	0.9
AS1	191	17.1	666	50.0
AS2	10	0.9	37	2.8
AT	10	0.9	21	1.6
AU	21	1.9	29	2.2
AV	167	15.0	110	8.3
AW	474	42.5	218	16.4
AX	177	15.9	175	13.1
Totals	1 116	100	1 332	100

Table 6: Estimates of total current longfin habitat (wetted area) from rivers, and in lakes accessible to longfin, together with longfin habitat fished, for fishing years 2010 to 2014 and 2020 to 2023 in the South Island. The longfin habitat estimates, and 2010 to 2014 fished habitat results are from Beentjes et al. (2016). Note that a small proportion of longfin river habitat is above hydro dams and not accessible to longfin.

	Longfin habitat (km^2)			Fished longfin habitat (km^2)			
	Rivers	Natural lakes	Total	Rivers	Natural lakes	Total	% fished
2010–14	278.9	129.2	408.1	123.6	8.99	132.6	32.5
2020–23	278.9	129.2	408.1	51.34	4.05	55.39	13.6

Table 7: Estimates of total current longfin habitat fished, virgin habitat fished, and maximum impacted abundance from all rivers and lakes by Eel Statistical Area, and overall for the South Island, for fishing years 2010 to 2014 (a); and 2020 to 2023 (b). See Figure 1 for Eel Statistical Area locations. The 2010 to 2014 results (a) are from Beentjes et al. (2016). LFE, longfin; Max, maximum.

a) 2020 to 2023

				2020 to 2023
				Percent (%)
Island	Eel Statistical Area	Current habitat fished	Virgin habitat fished	Max. impacted abundance
South Island	AN	0.0	0.0	4.0
South Island	AP	9.4	8.9	14.4
South Island	AQ	0.6	0.6	5.1
South Island	AR	0.8	0.8	4.7
South Island	AS	4.4	4.4	4.9
South Island	AT	1.0	1.0	4.5
South Island	AU	20.4	4.9	78.2
South Island	AV	48.2	13.1	83.3
South Island	AW	19.7	14.8	31.1
South Island	AX	6.3	6.0	10.2
South Island	All	13.6	9.1	39.6

b) 2010 to 2014

				2010 to 2014
				Percent (%)
Island	Eel Statistical Area	Current habitat fished	Virgin habitat fished	Max. impacted abundance
South Island	AN	11.5	11.1	15.5
South Island	AP	42.1	40.1	47.1
South Island	AQ	7.9	7.6	12.4
South Island	AR	58.1	55.9	61.7
South Island	AS	0.0	0.0	0.4
South Island	AT	38.6	37.3	42.1
South Island	AU	52.2	12.4	85.9
South Island	AV	46.2	12.5	82.8
South Island	AW	32.2	24.2	40.7
South Island	AX	30.2	29.0	34.0
South Island	All	32.5	21.8	52.6

Table 8: Estimates of total current longfin habitat fished, virgin habitat fished, and maximum impacted abundance from all rivers and lakes by Quota Management Area/Eel Statistical Area, and overall for the South Island, for fishing years 2010 to 2014 (a); and 2020 to 2023 (b). See Figure 1 for Eel Statistical Area locations. The 2010 to 2014 results (a) are from Beentjes et al. (2016). QMA, Quota Management Area; LFE, longfin; ANG, Anguilla; Max, maximum

a) 2020 to 2023

					2020 to 2023
					Percent (%)
Island	QMA	Eel Statistical Area	Current habitat fished	Virgin habitat fished	Max. impacted abundance
South Island	LFE 11	AN-AP	2.9	2.8	7.3
South Island	LFE 12	AQ-AR	0.8	0.7	4.8
South Island	LFE 13	AS	4.4	4.4	4.9
South Island	LFE 14	AT-AU	9.7	4.0	61.3
South Island	LFE 15	AV-AW	28.5	13.8	62.4
South Island	LFE 16	AX	6.3	6.0	10.2
South Island	All	All	13.60	9.1	39.6

b) 2010 to 2014

					2010 to 2014
					Percent (%)
Island	QMA	Eel Statistical Area	Current habitat fished	Virgin habitat fished	Max. impacted abundance
South Island	ANG 11	AN-AP	21.1	20.3	25.4
South Island	ANG 12	AQ-AR	50.1	48.2	53.9
South Island	ANG 13	AS	0.0	0.0	0.4
South Island	ANG 14	AT-AU	44.7	18.2	75.8
South Island	ANG 15	AV-AW	36.5	17.8	66.4
South Island	ANG 16	AX	30.1	29.0	34.0
South Island	All	All	32.5	21.8	52.6

9. FIGURES

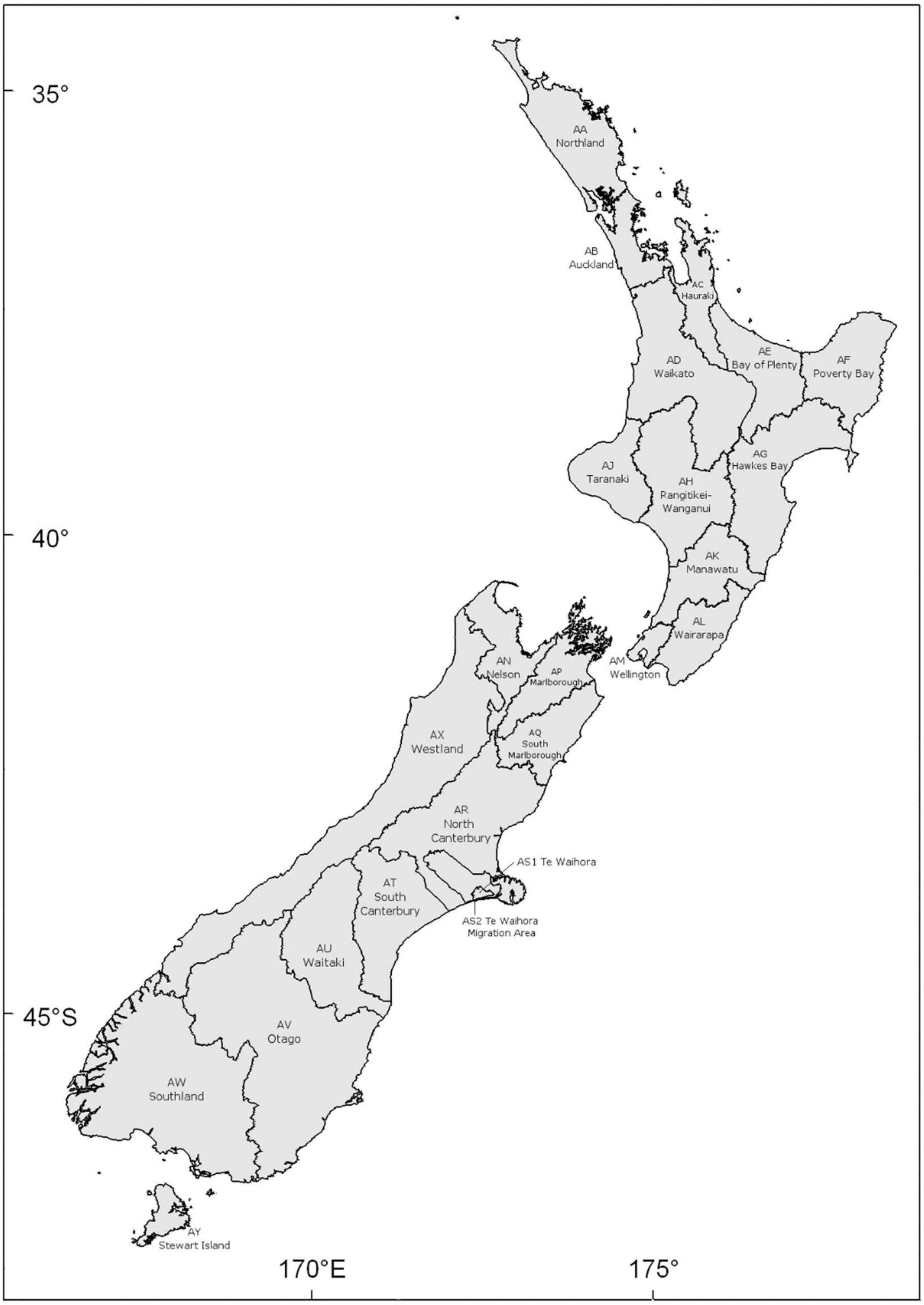
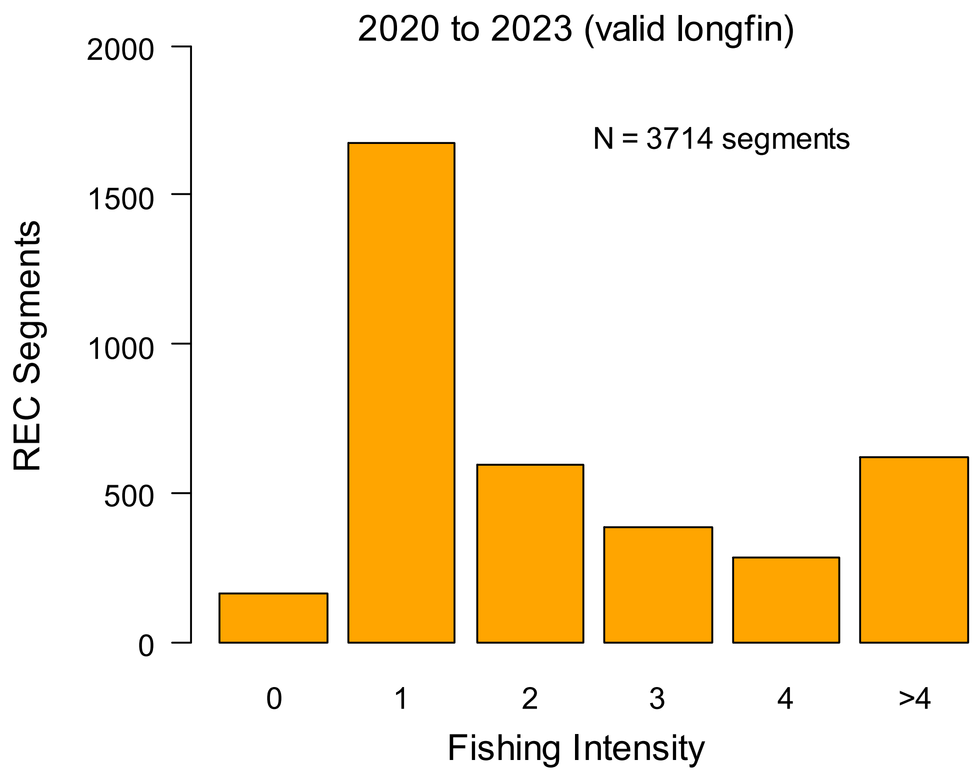


Figure 1: Eel Statistical Areas used for reporting location of catch from the commercial freshwater eel fishery before 2019–20, after which fishing events were reported by latitude and longitude.



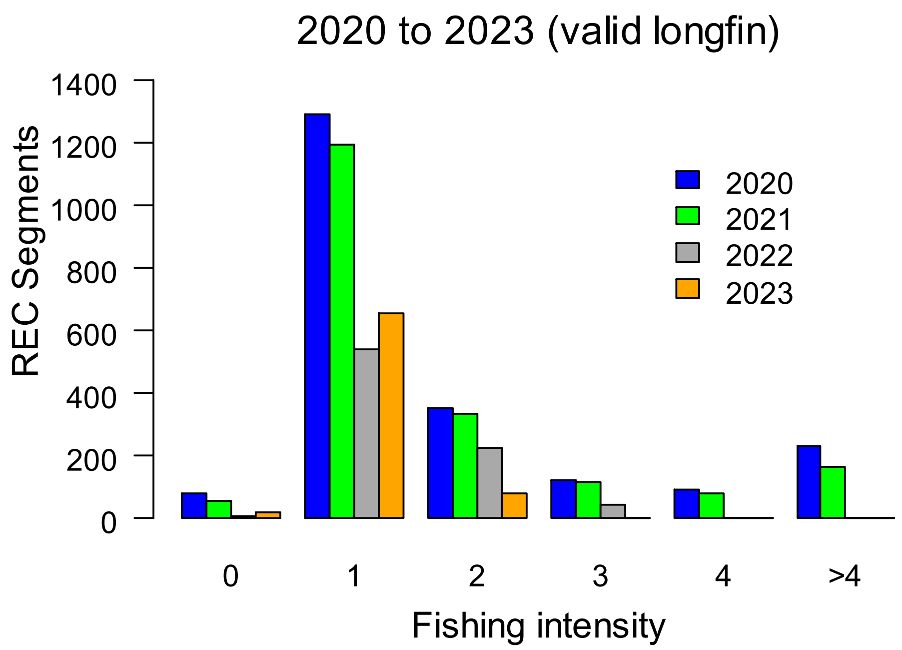


Figure 2: Histogram of the total number of unique South Island REC segments fished (*N* = 3 714) for 'valid longfin' fishing events, and where no longfin were caught or targeted (= zero intensity) for 2020 to 2023 fishing years combined (top panel), and by fishing year (bottom panel). Intensity ranges from zero to more than four times. Valid longfin is where longfin was caught or targeted on a fishing event.

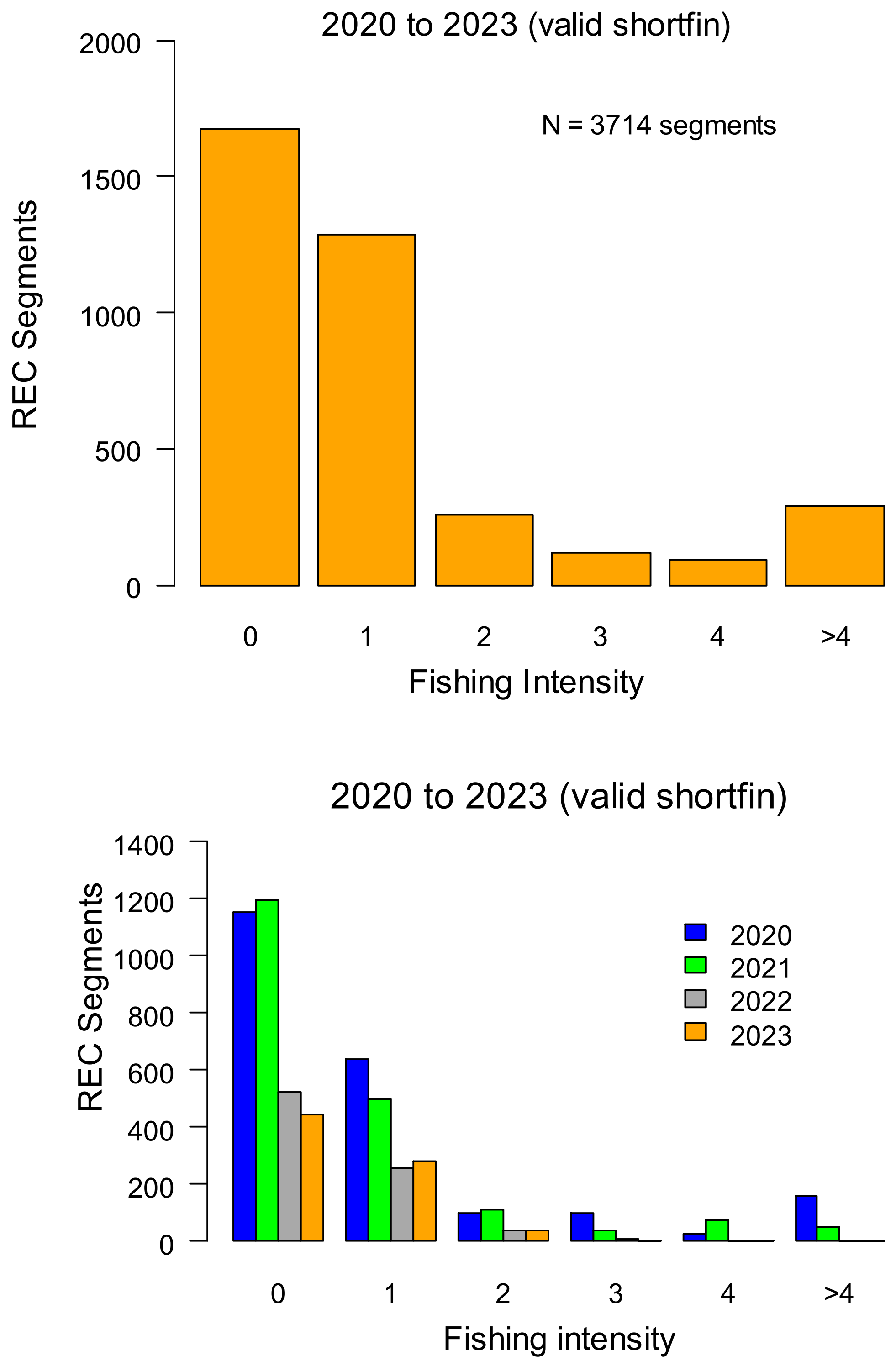


Figure 3: Histogram of the total number of unique South Island REC segments fished (*N* = 3 714) for 'valid shortfin' fishing events, and where no shortfin were caught or targeted (= zero intensity) for 2020 to 2023 fishing years combined (top panel), and by fishing year (bottom panel). Intensity ranges from zero to more than four times. Valid shortfin is where shortfin was caught or targeted on a fishing event.

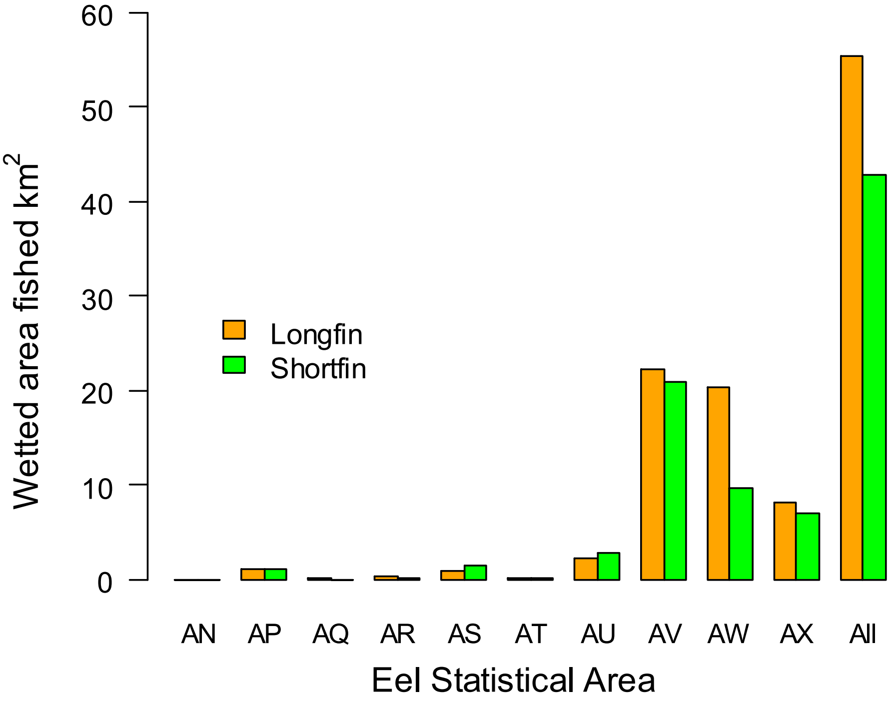


Figure 4: Total wetted area fished (km^2) for combined unique river segments and lake unique areas, by Eel Statistical Area, and all areas combined, over the period 2020 to 2023. Results are shown for valid-LFE and valid-SFE fishing events, i.e., where these species were caught or targeted. See Figure 1 for location of Eel Statistical Areas.

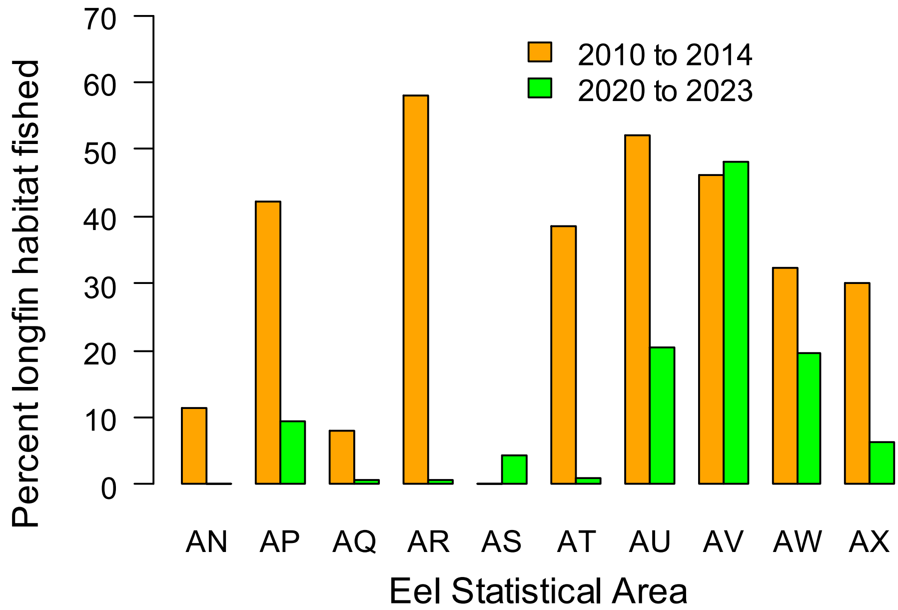


Figure 5: Percent longfin habitat fished (rivers and lakes combined, km^2) by Eel Statistical Area for the periods 2010 to 2014 and 2020 to 2023. Results are shown for valid-LFE, i.e., longfin was caught or targeted. See Figure 1 for location of Eel Statistical Areas.

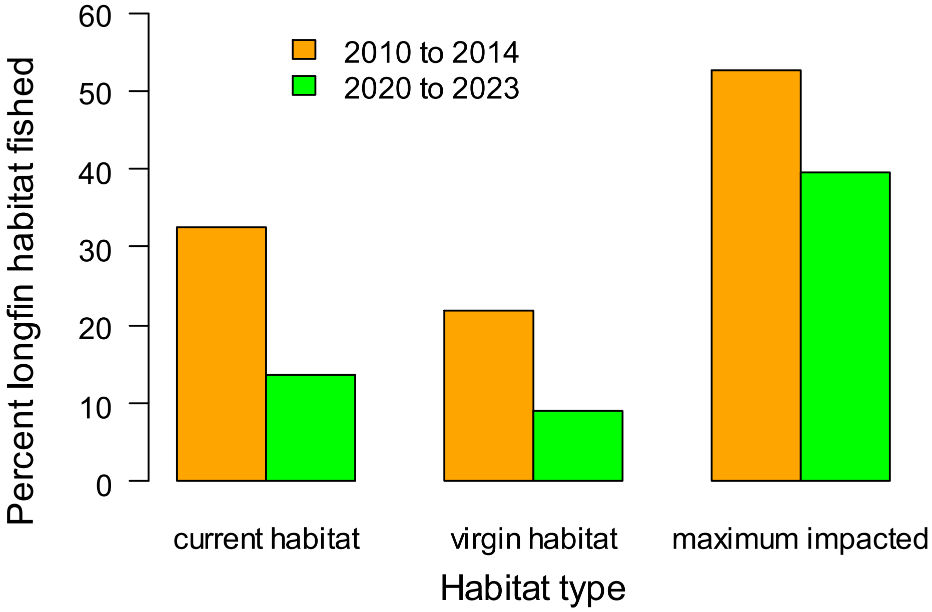


Figure 6: Estimates of percent total current longfin habitat fished, virgin habitat fished, and maximum impacted abundance, from all rivers and lakes for the South Island, for fishing years 2010 to 2014, and 2020 to 2023. The 2010 to 2014 results are from Beentjes et al. (2016). Virgin habitat is all habitat where longfin were historically present including natural hydro lakes where access is now impeded, river habitat lost by the creation of artificial and inaccessible impoundments or reservoirs, and habitat lost through degradation (see Section 2.5.2). Maximum impacted abundance includes all habitat losses plus fished habitat (see Section 2.5.3).

10. APPENDIX

Appendix A. Methods used to estimate longfin habitat in rivers and lakes (from Beentjes et al. 2016)

River longfin habitat

The total current longfin habitat/distribution in New Zealand rivers was initially derived from the 'probability of capture' model developed by Leathwick et al. (2008) who used statistical models to describe the probabilities of capture for longfins and other freshwater species in all rivers and stream segments throughout New Zealand, including Stewart Island, but excluding the Chathams Islands. Their model was based on 22 500 fished sites recorded on the NIWA New Zealand Freshwater Fish Database (NZFFD), of which longfins were present in 6650 sites, and on the physical environment of discrete stream segments as recorded on the REC and elsewhere. Boosted regression trees (BRT) were used to model the relationships between fish occurrence and the physical environment.

The probability of longfin capture model is, in essence, a *defacto* longfin habitat suitability map, with the suitability of habitat related to probability of capture. Marginal habitat tends to be the high-altitude streams which may also be inaccessible due to waterfalls and the most suitable habitat is in moderately coastal locations extending considerable distances inland in lower gradient rivers. The model is to some extent controlled by sites that have recorded longfins in the NZFFD. For example, in some locations where longfin are known to be present, they are not always accurately represented by Leathwick's probability values.

Crow et al. (2014) subsequently updated the probability of capture model for the REC with the addition of new environmental variables and with new statistical analyses (Random Forest Analysis). The revised model and probability of longfin capture in REC segments has been used in the current analyses. Unlike Leathwick et al. (2008), Crow et al. estimated probability of capture separately for methods electric fishing, fyke net, and visual observations. Cohen's Kappa (Cohen 1960), a classification which maximises the agreement between two correct classification rates (i.e., true presence and true false) was used to estimate the optimal probability of capture. The threshold chosen was where 90% of observations were correctly assigned, and the estimated probability thresholds of capture were 0.65 for electric fishing, 0.69 for fyke net fishing, and 0.3 for visual methods.

All three methods (electric fishing, fyke net, and visual) were combined by assuming that for each segment, if the probability of capture of one or more of the three methods indicated that longfin were present, then they were actually present and assigned a value of 'present'. Exploratory analyses of fishing effort (2010 to 2014 fishing data) and a probability threshold of Cohen's Kappa of 0.65 for electric fishing resulted in slightly more than one-third (37%) of fished segments being categorised as longfins absent, which seems intuitively too high and cast doubt on the efficacy of the model as a predictor of longfin habitat. The updated probability model still appeared to be influenced to some extent by the number and proximity of observations in river systems, with those with few observations in the NZFFD often indicated that longfins were absent despite being abundant and fished intensively. Hence, the combined three method probability model, with probabilities of capture of values 0.2 and over, 0.4 and over, 0.5 and over, and 0.6 and over were compared with fished segments from our fisher interviews, as a 'ground truthing' test (Table A1).

Table A1: Probability model predictions for the 17 344 fished segments in 2010 to 2014. Of the fished segments, 98.1% overlapped with those where longfin were predicted to occur for a predictive threshold of 0.2 and over, and 52.4% for a threshold of 0.6 and over. (From Beentjes et al. 2016).

Probability threshold model	Longfin present (%)
>0.2	98.1
>0.4	84.6
>0.5	71.0
>0.6	52.4

While 0.2 appeared too lax to define longfin habitat adequately, 0.6 seemed too restrictive and so probability of capture outputs for four probability thresholds were estimated. The information on spatial fishing effort obtained from commercial eel fishers should be representative of longfin habitat, although some habitat may be optimal and some marginal, but this was difficult to know without catch information associated with effort. Hence for segments where fishing was recorded (N= 17 344), the probability threshold models were 'tuned' by converting all values listed as 'absent' to 'present'. Without this procedure the habitat would be underestimated and the proportion of habitat that was fished would be overestimated, particularly for the higher thresholds. However, the 'tuning' process eliminates known under-counts, but there is no way of identifying the over-counts, i.e., segments for which the model indicates eels are present when they are not. The Fisheries New Zealand Eel Working Group (EELWG 2015/07b) recommended that the over 0.5 probability model was the most suitable and likely to be the best representation of longfin distributions within rivers (Figures A1).

River habitat for longfin eels was expressed as the wetted area (km^2) calculated from REC segment length (m) × mean segment width at mean annual low flow (MALF) (m) $/10^6$. This assumes that the entire area of rivers is available to longfin eels as habitat. A relatively small number of REC segments above hydro dams were included by the 0.5 probability model, and these were used in the total longfin habitat estimate.

Natural lakes longfin habitat

The total wetted area (km^2) of habitat available (=accessible) to longfins in natural lakes was estimated from the complete list of New Zealand lakes that were naturally formed, over 0.9 km^2, and considered to currently have unimpeded access to and egress to the sea for longfin eels (Beentjes et al 2016, appendix 1). This list includes all ten natural fished lakes accessible to longfin except Loch Katrine and Lake Mason in Canterbury, and Lake Rotokawau north of Kaipara Harbour which are all less than 0.9 km^2 – for these three lakes habitat was assumed to be the area of the entire lake. For New Zealand there were 95 candidate natural lakes of which 67 were considered to be accessible to longfin and for which habitat area was estimated (Beentjes et al 2016, appendix 1). The area of habitat was taken as the wetted area (km^2) of the entire lake, the littoral zone, or a prorated proportion of these areas. For some lakes, with little or no information on bathymetry or macrophytes, it was necessary to make a judgement call on the extent of the habitat and suitability of the habitat and this was often based on information for similar or nearby lakes (Beentjes et al 2016, appendix 1). South Island hydro-electric Lakes Manapouri and Te Anau were included in the natural lakes list at the recommendation of the Eel Working Group (EELWG-2015/07b) because there is an active elver transfer and migrant trap and release programme that has been running in these lakes since 2002 with nearly 7000 migrant eels transferred in 2014–15, of which about half were female (Unpublished data, Meridian Power Scheme, Mark James). For these two lakes, habitat was taken as 50% of the littoral area. Similarly, Lake Brunner was also included in the natural lakes because of the substantial fishery that exists in this lake, suggesting that elvers have access to the lake naturally and spawning migrants are thought to escape when the dam overtops during flood events. Lake Brunner habitat was taken as 50% of the littoral area to account for the dominance of shortfin in the lake and the compromised access. Te Waihora habitat was taken as 10% of the lake as it is dominated by shortfin.

Hydro lakes, impoundments and reservoir longfin habitat

All New Zealand lakes for which there is a hydro-electric dam or a barrier to upstream and downstream migration of longfins were extracted from the NIWA lakes database (Beentjes et al 2016, appendix 2). Although currently unavailable to longfin eels, the total wetted area (km^2) of dammed natural lakes such as Lakes Wanaka, Hawea and Wakatipu provided historic habitat for longfins. Man-made reservoirs or impoundment such as Lakes Dunstan, Waitaki, Karapiro and Matahina sit over relic reaches of rivers such as the Clutha, Waitaki, Waikato and Rangitaiki Rivers, respectively. A total of 51 hydro lakes were examined and of these 12 were deemed to have no eels because of features such as waterfalls or high altitude, leaving 39 lakes where habitat was estimated. Habitat was estimated for dammed natural lakes in the same way as described above for accessible natural lakes. Man-made impoundments and reservoirs, however, were first converted back to the original river segments and then within these the wetted area (km^2) was estimated as previously described, i.e., segment length (m) × mean segment width at MALF (m) / 10^6.

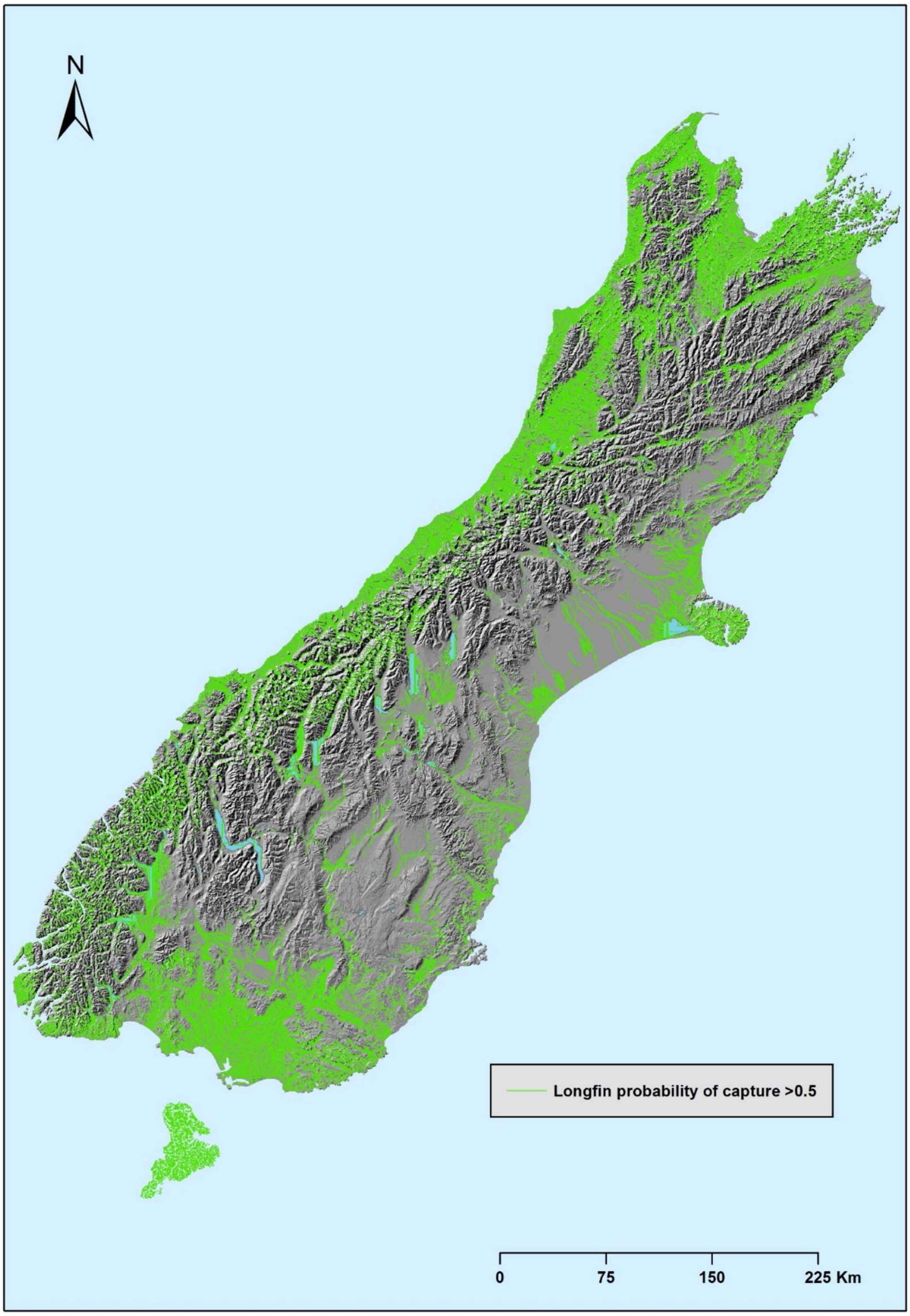


Figure A1: South Island probability of capture of over 0.5 for longfin eels, adjusted by fishing data where eels were caught. Based on Crow et al. (2014). Green represents REC segments where longfin were predicted to be present. From Beentjes et al. (2016).