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GIS mapping of the longfin eel commercial fishery throughout New Zealand, and estimates of longfin habitat and proportion fished

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The objective of this project was to map, using GIS methods, longfin eel fishing effort throughout New Zealand providing the first detailed and high resolution representation of where and how often fishers set their nets in New Zealand rivers, lakes and harbours. From these data, estimates were made of the proportion of longfin habitat that is currently fished.

The data used in the study were commercial longfin eel fishing location data for the five year period 2009–10 to 2013–14 from face to face interviews with 53 individual commercial eel fishers from throughout New Zealand. This represented over 93% of the longfin catch in that period. Using ArcGIS, all recorded fishing location information was georeferenced to individual segments of the River Environment Classification (REC2).

The total current longfin habitat in rivers was derived from 'probability of capture' models within REC2 segments and expressed as wetted area (river segment length multiplied by the mean width of segment at mean annual low flow (MALF), whereas habitat in lakes was estimated from the proportions of lake areas that eels were thought to inhabit, which was usually the littoral zone (the shallower parts of a river or lake where aquatic plants are usually found). Fished habitat was expressed as the wetted area of fished river REC2 segments (or part thereof) and fished natural lakes to which longfins have unimpeded access. Habitat of lakes behind dams was excluded from current habitat available to longfins because of impeded access. Estimates of proportions of longfin habitat currently fished, virgin habitat fished, and the maximum impacted abundance are based on these estimates.

The mapped effort accounted for over 93% of the recent longfin catch, but given the significant overlap in fishing effort, most of the missing fishers' data is likely to be included in the data collected from the 53 interviewed fishers. Fishing was shown to occur throughout New Zealand predominantly in rivers, with smaller contributions from both natural and hydro lakes, and to lesser extent in harbours and estuaries. Fishing intensity over the five years ranged from an average of 0.2 to 5.5 fishing events per year in an REC2 segment with the North Island having more intensively fished areas than the South Island, particularly in Northland, Hauraki Plains, Waikato and the Manawatu River. Fishing intensity estimates are conservative because multiple annual fishing events in a segment by individuals were not considered.

Key findings

- About one third (35%) of New Zealand longfin river habitat (defined as locations with more than 0.5 probability of capture from the habitat model) was fished.
- For lakes currently accessible to longfin eels (i.e., natural entry into and egress to the sea), about five percent of habitat was fished. Just under half (44%) of natural lake longfin habitat has been lost as it has impeded access to longfin from the installation of hydro and reservoir dams.
- About one quarter (27.2%) of the New Zealand longfin river and lake habitat, currently accessible to longfin eels, was commercially fished. The proportion of this was 32.5% in the South Island, and 22.5% in the North Island.
- If hydro and reservoir dams that have been lost due to impeded access are considered part of the available habitat, then about one fifth (21.4%) of the total New Zealand habitat has been fished, with similar proportions for both islands.
- The proportion of habitat fished would be greater, by an unknown amount, if non-commercial (predominantly customary) fishing is taken into account.

- The maximum impacted abundance of longfin eels was estimated at 42% (i.e., the proportion of virgin/original longfin habitat affected by anthropogenic activity, particularly dams and fishing). This is based on the sum of habitat fished, habitat that has impeded access to longfin, and habitat lost through degradation, as a proportion of all virgin habitat. This assumes that fishing removes all eels in a fished area, that areas of impeded access contain no eels (with the exception of some nominal escapement), and that pre-exploitation density of eels was the same in all river segments that were in suitable habitat, defined as areas with a probability of capture of more than 0.5 from the habitat model.

Other findings

In the South Island 10.6% of the watershed area of fished segments (rivers and lakes) in the REC2 was within DOC reserves compared to 2.7% for the North Island. Note that commercial eel fishing is permitted in certain categories of DOC Public Conservation Land. Over half of the watershed area of fished segments in the South Island and nearly three-quarters in the North Island occurred in the land cover category 'High Producing Exotic Grasslands' (i.e., agricultural farmland).

Forty percent of the current available habitat in New Zealand is estimated to be within DOC Public Conservation Land, and just over half of this is in natural lakes. Of the available river habitat in New Zealand, one-quarter is in DOC Public Conservation Land and fishing takes place in nearly 8% of this habitat, mostly in the west coast of the South Island.

Six percent of the total current available habitat in New Zealand is estimated to be within MPI closed areas where commercial fishing is prohibited, and three quarters of this is from the North Island Rivers Motu, Mohaka and Whanganui Rivers.

Fishers interviewed indicated that their effort had declined in the last 5 to 10 years. This was described as being due to a range of factors including denied access to fishing grounds; an ageing demographic with fishers retiring or not prepared to fish marginal or difficult to access areas; a decline in the marketability and price of longfin eels compared to shortfin; and requirement to return large eels (over 4 kg). We note that the proportion of areas fished, therefore, would have been greater before this effort decline.

An electronic logbook currently being trialled by the commercial eel industry may allow automatic collection of these data in future.

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 (Ministry for Primary Industries 2015). 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, occupying high country lakes within which both upstream and downstream passage has been blocked by hydro-electric dams, essentially removing this habitat from the total habitat available for longfins that can contribute to spawning. Graynoth et al. (2008) estimated that as much as 6000 t of longfin eels are contained in hydro reservoirs.

For the successful management of any fishery it is desirable to have some index of relative abundance 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 CPUE analyses which are routinely carried out for the commercial eel fishery (Beentjes & Dunn 2014, 2015). Unlike virtually all other commercial fisheries in New Zealand, there is no fine scale reporting of eel catch using latitude and longitude coordinates and the finest spatial resolution of reporting is by Eel Statistical Area (ESA) on the Eel Catch Effort Return (ECER) which has been in use since 2001–02. ESAs are broadly catchment based, but include multiple major river systems (Figure 1). The key aim of this project was to gathering fine scale spatial data on where fishers have fished and caught longfin eels within the five year period (2009–10 to 2013–14). This was compared with the extent of the assumed current total longfin habitat to provide a quantitative estimate of the proportion of the habitat that is fished, and conversely the proportion that is unfished.

1.1 Previous studies

Graynoth et al. (2008) attempted to indirectly quantify or 'index' the longfin habitat in New Zealand based on field studies of the actual longfin biomass recorded from 212 sites from rivers and streams in Southland, Westland, Canterbury, Wellington, Wanganui and Waikato districts. They found that abundance was related to river flow and gradient and from these empirical relationships they estimated eel biomass throughout New Zealand using the River Environment Classification (REC) which contains information on flow and gradient for more than 500 000 numbered and linked reaches or segments. The resulting modelled biomass estimates were used as an index or proxy of the amount of habitat present for longfin eels and/or large female longfins. Graynoth then classified waterways in New Zealand into five classes:

1) Waters closed to fishing and having egress for spawning females, e.g., national parks
2) Waters protected in their upper reaches but where migrants can be fished further downstream
3) Water above dams or waterfalls where passage upstream and egress downstream is prevented
4) Waters open to commercial fishing.
5) Waters open to commercial fishing but not fished due to small size of waterway (less than 0.5 $m.s^{-1}$).

For each of these classes Graynoth et al. (2008) estimated the biomass, and by proxy the habitat contained within. In 2008, they estimated that about half of the current longfin biomass/habitat was in areas protected from fishing such as National Parks, reserves or in areas unlikely to be fished, and that the other half was open to commercial fishing. The study did not, however, attempt to look at the extent to which available areas were actually fished.

Whereas Graynoth et al. estimated habitat from predictions of biomass within classes of waterways, we have taken a more direct and empirical approach and mapped the areas fished by commercial fishers

throughout New Zealand using GIS methods. We did not, however, attempt to quantify customary or recreational effort or location in this project.

1.2 Commercial eel fishery

The commercial eel fishery targets both shortfin and longfins eels which are frequently caught in the same locations although longfin are more common further inland in faster flowing rivers and high country lakes, particularly in the South Island. Longfin preferred habitat is coarse gravel and boulders (Jellyman et al. 2003). The commercial freshwater eel fishery in New Zealand developed in the late 1960s with total eel catches peaking in 1972 at about 2100 t before fluctuating between 1972 and 1999 with an annual average catch of about 1300 t (Figure 2). Catches then progressively declined to a low of 520 t in 2009 (i.e. the fishing year 2008–09) before increasing to reach 712 t in 2012 and have been stable since then (Ministry for Primary Industries 2014). Over the last ten years the South Island has contributed 42%, on average, of the total New Zealand eel catch. The New Zealand longfin catch is only known with any confidence from 1984 onward, but it is likely that the proportion of longfin to shortfin would have been similar before this time at about 40% longfin. Trends in longfin catch are similar to total eel catch with the longfin catch evenly split between the North and South Islands (49% South Island).

The New Zealand eel fishery was introduced into the Quota Management System (QMS) in stages beginning with the South Island in 2001, with five Quota Management Areas (QMA) and Total Allowable Commercial Catches (TACC) set for shortfin and longfin species combined. The Chatham Island eel fishery was introduced into the QMS in 2004 with single QMAs for each species and lastly, the North Island eel fishery was introduced into the QMS in 2005 with four separate QMAs each for shortfin and longfin.

1.3 Current status of stocks

The status of New Zealand longfin eel (*Anguilla dieffenbachia*) stocks are unknown, but biomass has undoubtedly been 'fished down', and mean size reduced following more than forty years of commercial fishing (Beentjes et al. 2006, Beentjes 2008, Graynoth et al. 2008). Concerns have been raised about the sustainability of current harvest and whether spawning escapement and recruitment of glass eels are adequate (Jellyman et al. 2000, Hoyle & Jellyman 2002, Parliamentary Commissioner for the Environment 2013). The New Zealand longfin eel is particularly vulnerable to overfishing because it is endemic, long-lived, and spawning does not occur until 30 years or more for females. Indeed many female longfin eels in New Zealand waters pre-date the beginning of the commercial fishery in the 1960s.A length structured stock assessment model was developed for the New Zealand longfin eel and used to estimate New Zealand-wide pre-exploitation and current female spawning stock biomass, as well as that of eels above the minimum legal size (220 g) in the commercial fishery (Fu et al. 2012). The Ministry for Primary Industries Eel Working Group rejected the assessment because of the underlying assumptions on estimates of longfin commercial catches and recruitment to individual eel statistical areas. Non-fishing mortality, while unquantified, occurs from a range of factors such habitat destruction and modification, drain cleaning and weed removals, and downstream passage through hydroelectric turbines (Beentjes et al. 2005). Barriers to upstream migration have also reduced the potential habitat available to longfin as many productive high country lakes above hydro-electric dams are impassable to upstream migrating eels (Beentjes et al. 1997).

1.4 Objectives

Overall objective:

1. To determine the proportions of New Zealand longfin eel habitat that is not fished

Specific Objectives:

1. To calculate the proportion of current New Zealand longfin eel habitat that is not fished
2. To calculate the proportion of virgin New Zealand longfin eel habitat that is not fished

2. METHODS

2.1 Collection of fishing location data

Commercial fishing location data were captured through face to face interviews with individual commercial eel fishers by NIWA staff (Mike Beentjes and Julian Sykes), focusing on fishers that have landed the bulk of the longfin catch in recent years. Candidate fishers were initially identified by examining the landed longfin catch of all New Zealand eel fishers over the period 2011–12 to 2013–14 from data collected from the Ministry for Primary Industries research project 'Monitoring commercial eel fisheries' (EEL201202). Liaison, contact and interview arrangements with fishers were often facilitated by eel processing companies (Mossburn Enterprises Ltd, Levin Eel Trading Ltd, and New Zealand Eel Trading Ltd). Interviews were carried out from August 2014 through to September 2015 throughout New Zealand in processing factories, during the 2014 South Island Eel Industry Annual General Meeting in Invercargill, NIWA offices, MPI offices, as well as homes and workplaces of individual fishers. The main interview locations were Invercargill, Dunedin, Hokitika, Blenheim, Te Kauwhata, New Plymouth, Masterton, Whakatane, Helensville and Whangarei. In three cases, annotated topographic maps were provided by fishers in lieu of the interviews, and these fishers were nonetheless regarded as having been interviewed.

During the interviews, fishers were asked where they had caught longfins over the five fishing years 2009–10 to 2013–14. This period was chosen to include the most recent year (2013–14) as well as four earlier years to build a representative and current picture of spatial effort. Because longfin and shortfin are often caught together, particularly in the North Island, waterways were categorised as fished if some longfin had been caught and hence all fished areas have the same ranking, unrelated to catch. Fishers' areas were displayed on Land Information New Zealand (LINZ) electronic topographic maps (MapToasterTop v5.5.3 software by IntegratedMapping). The topographic maps have scales ranging from 1:2 million to 1:50 000 with the latter fine scale resolution map allowing small creeks and streams to be clearly located and fishing effort assigned. Waterways were annotated by marking lines on all lakes, rivers, streams, creeks, and other water ways (e.g. ponds and estuaries) where fishers indicated that they had caught longfin (Figure 3). To record the level of fishing intensity, for each line drawn, fishers were asked how often the discrete areas have been fished in the five year period (categories: frequent = 4 or 5 times, occasional = 2 to 3 times, and seldom =once). Interviews ranged in length from about 30 minutes to several hours depending on extent of their fishing activities and the nature of the waterways. Fishers frequently offered their views on the state of the longfin fishery and factors influencing catches and this information was noted.

2.2 Post-processing of fishing location data

2.2.1 Fished rivers

Henceforth we refer to rivers as including rivers, streams and creeks. The annotated lines on MapToaster were saved as polyline shapefiles and imported into ArcGIS 10.2.1 where they were converted to River Environment Classification (REC) segments with the network tracing tool within Utility Network Analyst. This process was time consuming and involved converting each drawn line representing a

waterway to one or more REC segments, or part thereof in some cases. 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 and referred to as REC2 (Crow et al. 2014). Unlike LINZ topographic maps, the REC system is a synthetic river network derived from a digital elevation model. For each of the 593 466 REC2 segments with mean length of 696 m (range 15 to 32 627 m) there is additional information about the physical characteristics such as stream order, mean flow, catchment areas, distance inland, altitude, topography, geology and land cover etc.

2.2.2 Fished lakes and estuaries-harbours

The REC2 is primarily a river system model, however it does include lakes, but as they are treated as river segments or polylines the geometry that describes lake area (polygon) is not represented. The REC2 however, does not include harbours/estuaries as segments and any fishing in harbours close to a river segment was captured by the nearest contiguous river segment as frequently nets were set in channels targeting longfins and shortfins that migrated tidally between freshwater and harbours, or in coastal lagoons at the entrance to rivers. Some fishing occurred well into harbours and for these records there was no way to link effort to the REC2. In this regard effort in harbours/estuaries is likely to be underestimated, particularly in the North Island where setting fyke nets in harbours such as the Manukau and Kaipara Harbours was common.

Fishing recorded in lakes was less precise than for rivers and was usually along the shoreline (or part thereof) in the euphotic or littoral zone where aquatic macrophyte plants extend. To include lakes in the area of habitat fished the fished lakes were assessed for 1) access to longfin eels and 2) status in terms of natural lake or man-made reservoir such hydro or water catchment impoundments (Appendices 1 and 2). Only lakes that were naturally formed and considered to currently have unimpeded access to longfin eels were included in the fished lake habitat. Of the 26 fished lakes, there were ten qualifying fished lakes for which the extent of habitat was estimated. Lake Brunner, above Arnold Dam (Westland) was commissioned in 1932, and is a natural hydro lake. Lake Brunner was included in the fished area because it has been intensively fished for decades, suggesting that recruitment is occurring to a large extent supplemented by elver trap and transfer (Martin et al. 2014), and spawning migrants are thought to escape when the dams overtops during flood events (pers. comm., Jacques Boubee).

2.3 Spatial fishing effort in rivers

2.3.1 Simple statistics

As a first exploratory step, all segments of fishing effort were joined to the entire REC2 Network (New Zealand Transverse Mercator (NZTM) coordinate system) to gauge the spatial extent of fishing effort throughout New Zealand. Statistics for fished segments included: number of segments, length of segments, mean of mean annual low flow (MALF); mean of river width at MALF (modelled statistics); mean of stream order (Strahler system), in which source tributaries are 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). The statistics for MALF and river width at MALF for each segment are modelled from actual data recorded at 485 gauging stations throughout New Zealand (Booker & Wood 2014).

REC2 segments, have mean annual flows ranging from less than 0.5 m^3/s for small creeks to over 500 m^3/s for the large river systems such as the Buller, Clutha and the Waikato Rivers. Eel biomass has been shown to be positively correlated with the mean annual low flow of rivers (Graynoth et al. 2008) and therefore it was considered important to categorise segments based on flow class, or some proxy, and compare fishing effort relative to flow. Rather than using mean flow within a segment, which is a modelled statistic, cumulative catchment area (km^2), a non-varying measure of the catchment area above the segment was considered to be more suitable. Each fished segment was grouped into one of the following cumulative catchment categories: under 1, 1–10, 10–100, 100–1000, over 1000–10000 km^2.

The extent of the REC2 fished was expressed as the proportion of all REC2 segments fished by number and length and most importantly by wetted area (km^2). Wetted area (km^2) is used throughout as a proxy for longfin river habitat and calculated from segment length (m) × mean segment width at MALF (m) / 10^6.

2.3.2 Fishing intensity

Because waterways (i.e. REC2 segments) can be fished by one or more fishers, and an individual can vary how often an area is fished, an index of fishing intensity was calculated to distinguish among lightly and heavily fished areas. For each fisher, segments recorded in the categories 'frequent', 'occasional' and 'seldom' were assigned nominal fishing intensity values of 1, 0.5, and 0.2 respectively. The overall fishing intensity in a segment is then the sum of fishing intensity from all fishers. Overall fishing intensity was then grouped into five nominal categories; low (<1), annually (1), medium (1.1 to 2), high (2.1 to 3), very high (>3). Values greater than one indicate that more than a single pass or fishing event has occurred in a year. In this way it was possible to map the cumulative effort spatially on the REC2. In some cases fishing intensity is conservative, because our categories did not take into account that some areas have multiple passes in a year by individual fishers. Further, about 7 % of longfin catch and hence effort was not captured in the interview process.

2.4 Estimates of longfin habitat

2.4.1 River habitat estimated from probability of capture model

The total current longfin habitat/distribution in 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/distribution 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 REC2 with the addition of new environmental variables and with new statistical analyses (Random Forest Analysis). The revised model and probability of longfin capture in REC2 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.

Probability of capture model used in this study

For the purpose of this study, 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 and a probability threshold of Cohen's Kappa of 0.69 for electric fishing resulted in slightly more than one-third (37%) of our fished segments being categorised as longfins absent, which seems intuitively too high and casts doubt on the efficacy of the model as a predictor of longfin habitat. The updated probability model still appears 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 showing up as longfins 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 1).

While 0.2 may be too lax to define longfin habitat adequately, 0.6 may be too restrictive and so we have provided probability of capture outputs for four probability thresholds. 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 is 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 is fished would be overestimated, particularly for the higher thresholds (Table 1). 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 MPI Eel Working Group (EELWG 2015/07b) recommended that the over 0.5 probability model is the most suitable and likely to be the best representation of longfin distributions within rivers (Figures 4 and 5). However, by using the 0.5 model, we assume that there are no eels in segments of probabilities below 0.5.

As described above, river habitat for longfin eels is expressed as the wetted area (km^2) calculated from REC2 segment length (m) × mean segment width at MALF (m) /10^6. This assumes that the entire area of rivers is available to longfin eels as habitat.

2.4.2 Habitat in lakes

Fished natural lakes

For ten fished lakes accessible to longfin, 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 (Appendix 1). 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 is 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 eels may reside in waters deeper than this, it is 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.

All Natural lakes

The total wetted area (km^2) of habitat available 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 (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. There were 95 candidate natural lakes of which

67 were considered to be accessible to longfin and for which habitat area was estimated (Appendix 1). As described for fished natural lakes 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 (Appendix 1). 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.

Hydro lakes, impoundments and reservoirs

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. 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 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

2.5 Proportion of current longfin habitat fished

The proportion of longfin habitat fished in rivers is 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 river habitat fished (PC_{river_fished}) is given by

$$PC_{river\_fished} = A_{river\_fished} / A_{river\_pred}$$

Where current refers to the five year period covered by the fisher survey (2009–10 to 2013–14), A_{river_fished} is the wetted area (km^2) of the REC fished, and A_{river_pred} is the wetted area (km^2) of the REC at some probability threshold value of longfin capture (over 0.2, over 0.4, over 0.5 and over 0.6). Proportions are provided for the North and South Islands separately, and for New Zealand as a whole. South Island proportions include Stewart Island habitat.

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

$$PC_{river\_lakes\_fished} = (A_{river\_fished} + A_{nat\_lake\_fished}) / (A_{river\_pred} + A_{nat\_lake})$$

Where $A_{nat\_lake\_fished}$ is the wetted area (km^2) of accessible natural lakes fished, and A_{nat_lake} is the wetted area (km^2) of suitable habitat in all accessible natural lakes. Accessible lakes are herein defined as those over 0.9 km^2 in which longfin have unimpeded access to the sea. Proportions are provided for the North and South Islands separately, New Zealand as a whole, Eel Statistical Areas and Quota Management Areas. South Island proportions include Stewart Island habitat.

2.6 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

$$PV_{river\_lakes\_fished} = (A_{river\_fished} + A_{nat\_lake\_fished}) / (A_{river\_pred} + A_{nat\_lake} + A1_{hydro\_lake\_nat} + A1_{river\_res} + A_{degrad})$$

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. We have no data on habitat degradation loss from farms drains, farm pumping stations, culverts, drainage, river modification and channelling, willow clearing, and water quality etc. Nominally, 5% of current river habitat was assumed to be lost through degradation. Proportions are provided for the North and South Islands separately, New Zealand as a whole, Eel Statistical Areas and Quota Management Areas. South Island proportions include Stewart Island habitat.

2.7 Maximum impacted 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 ($AI_{anthropogenic}$) is expressed by the relationship between all habitat losses, including fished habitat (= numerator), and all virgin habitat unaffected by anthropogenic activities (=denominator) and is given by

$$AI_{anthropogenic} = (A_{river\_fished} + A_{nat\_lake\_fished} + A2_{hydro\_lake\_nat} + A2_{river\_res} + A_{degrad}) / (A_{river\_pred} + A_{nat\_lake} + A1_{hydro\_lake\_nat} + A1_{river\_res})$$

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, 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 are provided for the North and South Islands separately, New Zealand as a whole, Eel Statistical Areas and Quota Management Areas.

Relative abundance of longfin is assumed to be the same in all segments with probability of capture >0.5. No assumptions are made about fishing mortality.

2.8 Fishing in DOC Public Conservation Land and land use categories

To estimate the extent of commercial fishing that takes place in Department of Conservation (DOC) Public Conservation Land, the all fishing dataset was intersected with DOC Public Conservation Land

watersheds. Watersheds are the catchment area for each segment within the REC2 rivers and lakes. If a fished segment overlapped with a DOC Public Conservation Land, the watershed area, or part thereof, was calculated and conversely for any area that did not overlap with DOC Public Conservation Land, the watershed area was also calculated. Note that commercial eel fishing is permitted in certain categories of DOC Public Conservation Land.

Similarly watershed areas corresponding to land cover categories were calculated for all fished segments. Land cover is available from NIWA's Land Cover Database.

2.9 Habitat within DOC Public Conservation Land and MPI closed areas

To estimate the extent of the total current habitat available to longfin in New Zealand that is within DOC Public Conservation Land, the shapefile was intersected with the probability of capture habitat shapefile (Probability of capture > 0.5), clipping the REC2 segments that are common to both. If a segment overlapped with DOC Public Conservation Land the wetted area of the segment was calculated as described in Section 2.4.1. Habitat wetted area was then summed for natural lakes, accessible to longfin, that are within DOC Public Conservation Land (see Appendix 1). The fished wetted area within the DOC Public Conservation Land was also calculated.

The same approach was used to estimate total current habitat available to longfin in New Zealand that is within MPI closed areas, i.e., areas where commercial fishing is prohibited. Wetted area of natural lakes, accessible to longfin, that are within the MPI closed areas were estimated from the habitat adjusted area of these lakes stored in the attribute table of the closed areas shapefile. Lake habitat areas (km^2) were as follows: North Island: Taharoa lakes, 3; Lake Poukawa, 1; Pencarrow Lakes, 2.5. South Island: Rangitata Lagoon, 0.5; Lake Forsyth, 0.6; Wainono Lagoon, 5.

Finally the proportions of the total New Zealand current habitat available to longfin that are within the DOC Public Conservation Land and within MPI closed areas were calculated from the habitat wetted areas above.

3. RESULTS

3.1 Data from fisher interviews

3.1.1 Descriptive analyses

As a rule, fishers were supportive, forthcoming and seemingly honest in conveying information on locations fished where they had caught longfins over the five year period 2009–10 to 2013–14. Only two of the roughly 60 fishers approached refused to participate in the interviews, while several fishers had left the industry, and a few could not be contacted. The remaining fishers' catch of longfin was too small to be informative and no attempt was made to contact these individuals.

Information on locations of fishing events where they had caught longfin over the five year period 2009–10 to 2013–14 were provided by 53 fishers (26 south Island and 27 North Island) between August 2014 and September 2015 (Table 2). New Zealand wide, over 93% of the longfin catch has been accounted for in the shapefile representing spatial effort.

There were 24 658 REC2 segments comprising rivers and lakes fished by 53 fishers interviewed, some of which were fished by more than one individual (Table 3, Figures 6 and 7). The proportion of lakes fished is about 4% of all fishing with the remainder occurring in rivers, with 103 fishing events in estuaries and harbours unconnected with inflow REC segments. These 103 events are not covered by the REC and are not included in the analyses. Harbours fished included mainly Manukau Harbour,

Kaipara Harbour, Hokianga Harbour, Whangarei Harbour, Mangawhai Harbour, and Mahurangi Harbour, all in the upper north Island. Fished lakes included the following: South Island lakes: Brunner, Waitaki, Waipori, Dunstan, Coleridge, Sumner, Loch Katrine, Mason, Taylor, Shephard, and North Island lakes: Rotorangi, Mangamahoe, Ratapehu, Ratapiko, Ohakuri, Atiamuri, Whakamaru, Maraetai, Waipapa, Arapuni, Karapiro, Matahina, Aniwhenua, Waahi, Waikare, Rotokawau, and Manuwai (Appendix 1).

The number of unique segments (i.e, counted only once regardless if fished by more than one fisher) was 17 344 of which about 4% were lakes (Table 3). There were 7314 or 29.7% of segments fished by more than one fisher.

Using the all fishing unique data set that includes lakes, 2.9% of all New Zealand REC segments were fished, with 2.4% of South Island segments fished and 3.5% of North Island segments fished (Table 4). Similarly 4.6 %, 3.7%, and 5.7% of REC segments respectively were fished by waterway length. Overall nearly 19 000 km of rivers and lakes were fished throughout New Zealand. These statistics are simply a measure of the extent of New Zealand waterways fished and do not relate to whether or not there are longfin present in the waterways.

Cumulative catchment area increases from the top to the bottom of the catchment, and for both North and South Island most fishing takes place in the mid catchment reaches where area is between 10 and 10 000 km^2 (Table 5, Figure 8).

Metrics related to fishing in rivers are shown in Table 6. Fishing in the South Island tends to be lower in the catchments, in larger streams and rivers with greater flow, width and stream order compared to the North Island (Table 6, Figures 9 and 10). The wetted area of fished rivers for all New Zealand was 222 km^2 (Table 6).

3.1.2 Fishing intensity

Fishing intensity is the sum of effort of all fishers in a given segment. Hence for an intensity value of 1 the segment could have been fished once by one fisher every year, or every second year by two fishers. Overall for New Zealand just under half of unique segments were fished less often than once a year and 44% were fished once or twice a year, and less than 10% were fished more than twice a year (Table 7, Figure 11). The North Island tended to have higher fishing intensities overall compared to the South Island with over 10% of segments fished more than twice a year compared to less than 5% for the South Island. This is also reflected in the mean fishing intensities (Table 7, Figure 11).

Areas with the most intense fishing (fished more than twice per year) in the South Island were: Wairau River catchment, particularly near the coast; Opihi and Orari River catchments; Waitaki River; Tokomairiro River, Clutha River, Pomahaka River, Mataura River; large sections of the Oreti catchment and especially the tributary Makarewa River; lower Aparima River; sections of the Waiau River; Lake Brunner (Figures 12 to 15). The most intense fishing (fished more than twice per year) in the North Island were: Wairoa catchment including tributaries Wairua and Manganui Rivers, lower Waikato River and tributaries Whangamarino River Maramarua River, Opuatia Stream, Mangawara Stream and Waipa River; all Waikato River hydro lakes above Karapiro Dam, particularly Lake Ohakuri; Piako River and tributaries; Waihou River and tributaries; lower Kaituna River; Lower Tarawera River, Tukituki River; small section of Tutaekuri River; virtually all of the Manawatu River, except the Manawatu Gorge (Figures 16 to 19).

3.2 Longfin habitat

3.2.1 Fished longfin habitat in rivers

The total current longfin habitat (i.e., wetted area, km^2) in New Zealand rivers was derived from the 'predicted probability of capture' models. The metrics generated for unique fishing records in rivers (N = 16 686) are shown together with those for the four probability of capture predictive models (Table 8). Total river habitat for the >0.5 probability model is estimated at 628.5 km^2 for New Zealand with 44% of this in the South Island. River flow, river width and stream order were all greater for fished segments than the predicted probability of capture modelled data indicating that fishing is occurring in the lower catchments where eels are predicted to be present. For example, the mean stream order for all New Zealand fished segments is 4.9 compared with 2.1 for the >0.5 probability model (Table 8). The wetted area of fished rivers for all New Zealand was 222 km^2, with 55% of this occurring in the South Island (Table 8, Figure 20). The proportion of the predicted segments fished by number and length is relatively small compared to the predicted habitat fished, which is 35% for all New Zealand at >0.5 probability of capture (Figure 21). Similarly the proportion of the predicted river segments fished by wetted area (=river habitat) were 44% for the South Island and 28% for the North Island (Figure 21).

3.2.2 Fished longfin habitat in lakes

Implicit in the habitat estimates from lakes are assumptions about access to longfin, extent of the habitat, proportions of longfin to shortfin, and contribution to spawning from selected dammed lakes etc. (Appendices 1 and 2). The habitat currently available to longfin eels in New Zealand lakes accessible to longfins eels (i.e., with natural entry into and egress to sea) is estimated at 239 km^2, split evenly between North and South Islands, and of this, 13 km^2 are fished from ten lakes (Table 9). Before hydro dams and other barriers to eel migration there was an additional 190 km^2 (44%) of longfin habitat in natural lakes that is now effectively unavailable to longfin (notwithstanding elver transfer programmes), the bulk of which is in the South Island. In addition, the man-made lakes are also unavailable to longfin, but the historic habitat occupied by these lakes is estimated from the original river bed habitat, not that of the lake. There is about 16 km^2 of flooded river habitat now unavailable to longfins, again mostly from the South Island (Table 9). A further breakdown of these lake area categories by Eel Statistical Area (ESA) is given in Appendix 3.

Because of the loss of lake habitat through hydro-electric dams and water reservoir dams the proportions of the total river and lake habitat available to longfin has changed. Historically the proportion of lake to river habitat in the South Island was about the same, whereas current lake habitat has been reduced to 30% of the available habitat (Figure 22). For the North Island the proportions have changed very little, reflecting the high incidence of man-made lakes which were historically river habitat.

3.2.3 Fished current and virgin longfin habitat, and maximum impacted abundance

Using all habitat estimated for lakes, and habitat for rivers at the >0.5 probability of capture model, the proportion of current longfin habitat fished in New Zealand is estimated at 27.2% (Table 10, Figure 23). The South Island proportion of current habitat fished is 10% greater than that of the North Island. Estimates of the proportion of virgin habitat fished, at recent fishing levels (2009–10 to 2013–14), are 21% for all of New Zealand, with similar estimates for each Island. Taking into account all potential losses of habitat combined with fishing activity, the maximum impacted abundance of longfin in New Zealand (i.e., the proportion of virgin/original longfin habitat affected by anthropogenic activity) is estimated at 42%, and this is much higher in the South Island (Table 10, Figure 23). A further breakdown of current habitat fished, virgin habitat fished, and maximum impacted abundance by Eel Statistical Area (ESA) is given in Appendix 4, and by Quota Management Area (QMA) in Appendix 5.

3.3 Fishing in DOC Public Conservation Land and by land cover categories

In the South Island 10.6% of the watershed area of fished segments (rivers and lakes) in the REC2 were within DOC Public Conservation Land. By far, most fishing occurred in Stewardship Areas, followed by Scenic Reserves, National Parks and Marginal Strips (Figure 24). Most of the South Island DOC areas fished are on the west coast. By contrast, in the North Island only 2.7% of the watershed area of fished segments were within DOC Public Conservation Land. Most fishing occurred in Scenic Reserves, Government Purpose Reserves, Fixed Marginal Strips and Stewardship Areas, and was spread throughout the North Island (Figure 25).

In the South Island over half of the watershed area of fished segments occurred in High Producing Exotic Grassland, with the next top five accounting for about 25% of fishing (Indigenous Forest, Gravel Rock, River, and Low producing Grassland) (Figure 26). In the North Island nearly three quarters of fishing occurs in High Producing Exotic Grassland, with the next top five accounting for a further 18% (Indigenous Forest, River, Exotic Forest, Manuka and/or Kanuka, Short Rotation cropland) (Figure 27).

3.4 Habitat within DOC Public Conservation Land and MPI closed areas

The total current habitat from lakes and rivers (prob > 0.5 model) available to longfin in New Zealand is shown together with that within the DOC Public Conservation Land and MPI closed areas in Table 11. Nearly 8% of the habitat in DOC Public Conservation Land is currently fished with most of this occurring in the west coast of the South Island. Forty percent of the total current available habitat in New Zealand is within DOC Public Conservation Land, and just over half of this is in natural lakes (Table 11, Figure 28). Twenty six percent of the total New Zealand river habitat and 78% of the total lake habitat is in DOC Public Conservation Land. Similarly 51% of the total current available habitat in the South Island is in DOC Public Conservation Land, evenly split between rivers and natural lakes, whereas 31% of North Island habitat is in DOC Public Conservation Land with nearly two thirds of this in natural lakes (Table 11, Figure 28). Thirty nine percent of the total South Island river habitat and 78% of the total lake habitat is in DOC Public Conservation Land, whereas 15% of the North Island total river habitat and 78% of total lake habitat is in DOC Public Conservation Land.

Similarly, 6% of the total current available habitat in New Zealand is within MPI closed areas, with corresponding estimates of 2% for the South Island and 10% for the North Island (Table 11, Figure 28). The bulk of the closed area habitat is from the Whanganui, Motu and Mohaka Rivers in the North Island.

4. DISCUSSION

4.1 Capture of fishing location data

This is the first attempt, using GIS methods, to map commercial fishing effort for longfin eels nationally at the level of individual rivers, streams, creeks, and parts thereof, as well as from lakes (see Figures 6 and 7). Further, the intensity or frequency of fishing within these discrete areas has also been investigated, revealing those areas which are the most heavily and lightly fished. Hitherto, the highest level of resolution on where longfin eels are being caught has been from the MPI research programme 'Monitoring commercial eel fisheries' which collects commercial catch data at the spatial resolution of catchment and sub-catchments. For example for the Mataura River in Southland, catch is provided for four reaches (sub-areas) and all contributing tributaries therein (Beentjes 2013). The South Island Eel Industry is currently trialling an electronic logbook utilising a purpose built 'app' that runs on Android based devices that records catch of eels including GPS latitude and longitude location information. Assuming national coverage and full uptake by fishers, this will not only provide similar data on catch location, but also data on catch and effort by discrete location.

The mapped effort in this programme is considered to be accurate and comprehensive accounting for over 93% of the longfin catch (see Table 2). Given the significant overlap in fishing effort, the missing fishers' data is likely to be partially included in the data collected from the 53 interviewed fishers. Any underestimates or inaccuracies of effort mapping are considered to be relatively small, and likely to be due to fishers not accurately recalling where and when they had fished over the five-year period. Fishing occurs throughout New Zealand, predominantly in rivers, with smaller contributions from both natural and hydro lakes, and to lesser extent in harbours and estuaries (see Table 3). Fishing intensity analyses show a wide range of fishing intensities ranging from 0.2 to 5.5 fishing events per year in an REC2 segment (see Table 7). The North Island has more intensively fished areas than the South Island, particularly in Northland, Hauraki Plains, Waikato and the Manawatu River (see Figures 12 to 19). In some segments, fishing intensity is conservative, because multiple passes in a year by individual fishers were not taken into account. Although there were no data collected on the magnitude of the catch taken at fished segments, it is a reasonable assumption that those areas most intensively fished are likely to have the most longfin eels.

4.2 Longfin habitat fished

Estimates of total longfin habitat and fished longfin habitat were based on the wetted area of rivers (segment length × MALF width) and the proportions of lake areas that eels were thought to inhabit. This assumes that the entire wetted area of rivers is available to eels as habitat, which may not be the case for very large rivers where eels are more likely to be found closer to river banks. Similarly, 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 that longfins were absent (see Table 1). Similarly, there is no way of knowing where eels are absent, despite the model predicting that eels are present. Further, by using the 0.5 model as the default, we assume that there are no eels in segments of probabilities below 0.5, which is likely to be untrue in all cases.

Thirty five percent of all New Zealand longfin river habitat (>0.5 probability of capture habitat model) is estimated to be fished, based on estimated river habitat fished of 222.8 km^2 and total habitat of 628.5 km^2 (see Table 8). For lakes currently accessible to longfin eels only 13 km^2 of the total 239 km is fished (5%) (see Table 9), many of which are difficult to access by fishers or are within DOC reserves. Just under half (44%) of the original natural lake longfin habitat has been lost through impeded access to longfin by installation of hydro and reservoirs dams (see Table 9).

About one-quarter (27.2%) of the current total available habitat (>0.5 probability of capture habitat model) in all New Zealand lakes and rivers is commercially fished and this is 10% greater for the South than the North Island (see Table 10, Figure 23). We did not, however, attempt to quantify non-commercial effort or location in this project and for the North Island and Northland particularly, the proportion of habitat fished will be greater since customary fishing often occurs in areas where commercial fishing is unwelcome. If the current levels of fishing were occurring before the loss of habitat through dams and degradation, about one-fifth (21%) of the New Zealand wide habitat would be fished, with similar proportions for both islands (see Table 10). During interviews fishers commonly remarked that effort has dropped dramatically in the last five years due to a number of factors including: denied access to previous fishing grounds by land owners and DOC; an ageing demographic with fishers retiring or not prepared to fish marginal or difficult to access areas as they did historically; a decline in the marketability and port price of longfin eels compared to shortfin; and increasing size of longfin eels being caught, many of which are over 4 kg and are required to be returned to the water. Hence, had we conducted the interviews five years earlier we could have expected that the proportion of habitat that was fished would have been much greater.

4.3 Maximum impacted abundance

The maximum impacted abundance, which is simply a measure of all potential losses of habitat combined with habitat fished, compared to the virgin habitat, is estimated at 42% (see Table 10, Figure 23), or

alternatively 58% of abundance is not impacted. This assumes that all eels in fished segments are removed which is unlikely to be correct, particularly given the increasing numbers of large females over the maximum legal size of 4 kg that are being reported as being returned. Hence the impacted abundance is likely to be less than 42%. Further, a number of assumptions were made including a nominal escapement of 50% from lakes Te Anau and Manapouri, 5% from other dammed lakes, and 5% loss of habitat from habitat degradation. The other key assumption is that all segments with probability of capture over 0.5 have equal abundance.

4.4 Habitat in DOC Public Conservation Land and MPI closed areas

Just over 10% of the South Island river and lake habitat commercially fished is in DOC reserves with most fishing within DOC Public Conservation Land occurring in the west coast. In contrast, only 3% of the North Island river and lake habitat fished is in DOC Public Conservation Land. Hence, based on recent current fishing practices, restricting fishing access within DOC Public Conservation Land is only likely to impact the fishery in the South Island. Note that commercial eel fishing is permitted in certain categories of DOC Public Conservation Land.

In terms of where habitat is distributed, 40% of the total current available habitat in New Zealand is estimated to be within DOC Public Conservation Land, and just over half of this is in natural lakes (see Table 11, Figure 28). However, without knowing the quality of the habitat, this may not represent 40% of the longfin eel biomass. Very few of these natural lakes in DOC Public Conservation Land are currently fished, so restricting access to fishers would have negligible effect on the commercial longfin fishery, with the exception of Lake Brunner in Westland, where fishers have operated until recently under DOC concessions. Of the available river habitat in New Zealand, one-quarter is in DOC Public Conservation Land and fishing takes place in nearly 8% of this, mostly on the west coast of the South Island.

In contrast, only 6% of the total current available habitat in New Zealand is estimated to be within MPI closed areas where commercial fishing is prohibited, and three quarters of this is from North Island Rivers Motu, Mohaka and Whanganui Rivers (see Table 11, Figure 28).

4.5 Other studies

Graynoth et al. (2008) estimated longfin habitat from predictions of biomass within classes of waterways and, excluding habitat in lakes that are dammed or above waterfalls, their estimate of habitat fished for New Zealand was 67% (see table 3a in Graynoth et al. 2008) and habitat within the excluded lakes accounted for 36% of habitat. In the current study the equivalent values are 27% and 22%. The differences are in part due to the approaches used to estimate longfin habitat and assumptions made. Graynoth et al. assumed that all waters open to commercial fishing and in rivers with MALFs of above 0.5 m^3/s were fished, whereas our interviews showed that fishers are only applying effort to the accessible and most productive areas. Hence, Graynoth et al. estimates of the fished habitat are likely to be too high.

4.6 Concluding remarks

This initiative to map current fishing effort throughout New Zealand has provided the first detailed and high resolution representation of where and how often fishers set their nets in New Zealand rivers, lakes and harbours where longfin are caught. It will hopefully provide a useful baseline against which future fishing location data can be compared. While there has been overlap with the shortfin fishery, given that many catches contain both species, a shortfin specific effort map would be expected to show considerably more effort near the coast and little contribution from inland lakes, particularly in the South Island. Consequently, the mapped shortfin fishing effort is likely to be skewed towards the lower reaches of the rivers and catchments where shortfin are more abundant.

4.7 Future Research Considerations

As the areas fished commercially are expected to change over time, MPI intends updating this work on a regular basis. The model used to predict longfin habitat was based on data recorded on the New Zealand Freshwater Fish Database (NZFFD). As most of the data used to develop the model were based on electric fishing, and mostly limited to wadeable waterways, the ability of the models to predict the presence of longfins in larger water bodies may have been limited. The net effect of this would have been to underestimate the amount of longfin habitat, thereby over-estimating proportions fished. This was offset to some extent by adding, *post hoc*, all river segments commercially fished for longfins which were not predicted to contain longfins, to the total area of predicted longfin habitat. As the NZFFD is growing rapidly, with increasing amounts of data from fyke net surveys of larger water bodies, the Eel Fishery Assessment Working Group (EELWG 2016-10b) recommended the derivation of a new predictive model sometime in the future to estimate the proportion of longfin habitat fished. For the project update the working group also recommended 1) investigating methods to capture areas fished by customary and recreational fishers, and 2) investigating available information on loss of wetlands and river area (e.g., through straightening) to come up with a realistic estimate of habitat loss. A nominal figure of 5% was used for the current study.

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Table 1: Probability model predictions for the 17 344 fished segments. Of the fished segments, 98.1% overlap with those where longfin are predicted to occur for a predictive threshold of 0.2 and over, and 52.4% for a threshold of 0.6 and over.

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

Table 2: Number of fishers interviewed, total longfin catch landed in 2011–12 to 2013–14 by all New Zealand fishers, and the amount and proportion of this catch accounted for in the information gathered on location of commercial fishing from interviewed fishers.

			Longfin accounted for in interviews	
Area covered	Fishers (N)	Total longfin catch (kg)	Catch (kg)	%
South Island	26	431 127	407 049	94.4
North Island	27	230749	210 921	91.4
New Zealand	53	661 876	617 970	93.4

Table 3: Total number of REC2 segments by lake and river, and fisher interview data as it overlaps with the REC2. Percent segments in lakes is shown as are records of fishing in estuaries or harbours that cannot be associated with the REC2. The all fishing data includes all fisher records with some segments fished by one or more fishers, while all fishing unique segments are counted only once, regardless of how many fishers have fished the segment. incl., including; excl., excluding; REC2, River Environment Classification version 2.

	REC2 segments				Estuary/harbour
Data sources	Total	Rivers	Lakes	% lakes	records
REC2	593 466	578 366	15 100	2.5	–
All fishing incl. lakes	24 658	23 692	966	3.9	103
All fishing unique incl. lakes	17 344	16 686	658	3.8	103
All fishing unique excl. lakes	16 686	16 686	–	–	103

Table 4: Number and length of REC2 segments and the number and proportion fished for all of New Zealand by North and South Island for all fishing unique data including lakes (N = 17 344).

	Segment number			**Segment length (km)**		
Area	**REC2**	**Fished**	**% fished**	**REC2**	**Fished**	**% fished**
South Island	324 589	7 859	2.4	231 195	8 552	3.7
North Island	268 877	9 485	3.5	181 934	10 311	5.7
New Zealand	593 466	17 344	2.9	413 129	18 863	4.6

Table 5: Proportion of REC2 all fishing unique river segments, including lakes, fished by cumulative catchment area. N= 17 344 New Zealand, N = 7859 South Island, N =9485 North Island.

	Percent fished		
Cumulative catchment area (km^2)	**South Island**	**North Island**	**New Zealand**
< 10	11	14.1	12.8
10–100	24	31.0	27.9
100–1000	35	34.9	35.1
1000–10000	24	18.8	21.3
> 10000	5	1.3	3.0
Total	100	100	100

Table 6: Metric variables for all fishing unique river REC2 segments. Cumecs, cubic metres per second; MALF, mean annual low flow; Total wetted area = length × mean stream width at MALF.

Variable	New Zealand	South Island	North Island
Segments (N)	16 686	7 542	9 144
Length (km)	12 393	5 647	6 746
Total wetted area (km^2)	222.8	123.6	99.2
Mean of MALF (cumecs)	10.3	16.0	5.7
Mean catchment area (km^2)	1185	1616	830
Mean of stream width at MALF (m)	18.8	24.0	14.4
Mean stream order	4.9	5.0	4.7

Table 7: Proportion of all fishing unique REC2 segments, including lakes, fished at different levels of fishing intensity. Mean, minimum and maximum fishing intensities are also shown. N= 17 344 New Zealand, N = 7859 South Island, N =9485 North Island.

	Percent fished		
Fishing intensity (times fished per year)	**South Island**	**North Island**	**New Zealand**
< 1	45.6	50.1	48
1	26.7	29.4	28
1.1–2	23.3	10.2	16
2.1–3	4.1	7.1	6
> 3	0.3	3.2	2
Mean	0.92	0.97	0.95
Min	0.2	0.2	0.2
Max	3.5	5.5	5.5

Table 8: Metric variables associated with all REC2 segments for four levels of probability of capture and for unique fished river segments. Cumecs, cubic metres per second; MALF, mean annual low flow; Total wetted area = length × mean stream width at MALF.

	All New Zealand				
	Probability of capture				
Variable	>0.2	>0.4	>0.5	>0.6	Fished
Segments (N)	488 010	366 732	292 167	215 002	16 686
Length (km)	335 728	249 950	198 120	147 433	12 393
Total wetted area (km^2)	915.1	735.7	628.5	518.3	222.8
Mean of MALF (cumecs)	0.7	0.8	0.8	1.0	10.3
Mean catchment area (km^2)	69.8	85.6	97.3	116.0	1185.0
Mean of stream width at MALF (m)	2.8	2.9	3.1	3.4	18.8
Mean stream order	2.0	2.1	2.1	2.2	4.9

	South Island				
	Probability of capture				
Variable	>0.2	>0.4	>0.5	>0.6	Fished
Segments (N)	229 447	133 012	92 675	62 241	7 542
Length (km)	162 277	93 656	65 005	44 087	5 647
Total wetted area (km^2)	509.4	350.7	278.9	222.2	123.6
Mean of MALF (cumecs)	1.0	1.4	1.7	2.2	16.0
Mean catchment area (km^2)	87.1	131.6	166.8	219.8	1616.2
Mean of stream width at MALF (m)	3.4	4.0	4.4	5.2	24.0
Mean stream order	2.0	2.1	2.2	2.3	5.0

	North Island				
	Probability of capture				
Variable	>0.2	>0.4	>0.5	>0.6	Fished
Segments (N)	258 563	233 720	199 492	152 761	9 144
Length (km)	173 452	156 294	133 114	103 346	6 746
Total wetted area (km^2)	405.9	385.0	349.5	296.2	99.2
Mean of MALF (cumecs)	0.4	0.4	0.5	0.5	5.7
Mean catchment area (km^2)	54.5	59.5	65.1	73.7	829.6
Mean of stream width at MALF (m)	2.2	2.3	2.5	2.7	14.4
Mean stream order	2.0	2.0	2.1	2.2	4.7

Table 9: Wetted area habitat (km^2) estimated from New Zealand natural lakes currently accessible to longfin, and the amount of this fished. Habitat from dammed natural lakes and man-made lakes is also shown, where the habitat from the latter is estimated from the original river bed using the REC2.

	Habitat (wetted area, km^2)			
	Lakes accessible to longfin		Dammed lakes inaccessible to longfin	
	Fished	All	Natural lakes	Man-made lakes (REC2)
North Island	4.04	109	14.3	4.4
South Island	8.99	129	175.9	11.3
New Zealand	13.03	239	190.1	15.7

Table 10: Estimates of total current longfin habitat fished, virgin habitat fished, and maximum impacted abundance from all rivers and lakes for North Island, South Island and New Zealand. River habitat used is that predicted by the >0.5 probability of capture model. Max, maximum.

	Percent (%)		
Location	Current habitat fished	Virgin habitat fished	Max. impacted abundance
North Island	22.5	20.9	29.0
South Island	32.5	21.8	52.6
New Zealand	27.2	21.4	42.1

Table 11: Estimates of total current habitat (wetted area) available to longfin in New Zealand (a), and within DOC Public Conservation Land (b) and MPI closed areas (c). The habitat fished within these areas is also shown. River habitat is predicted by the >0.5 probability of capture model.

	Habitat in New Zealand				
a)	Available habitat (km^2)			Fished habitat	
	Rivers	Natural lakes	Total	km^2	%
All NZ	628	239	867.0	235.8	27.2
South Island	278.9	129.2	408.1	132.6	32.5
North Island	349.5	109.3	458.8	103.2	22.5

	Habitat in DOC Public Conservation Land				
b)	Available habitat (km^2)			Fished habitat	
	Rivers	Natural lakes	Total	km^2	%
All NZ	162.5	186.0	348.5	27.1	7.8
South Island	108.3	92.6	200.9	21.3	10.6
North Island	54.2	94.2	148.4	5.8	3.9

	Habitat in MPI closed areas				
c)	Available habitat (km^2)			Fished habitat	
	Rivers	Natural lakes	Total	km^2	%
All NZ	40.4	12.6	53.0	0	0
South Island	0.3	6.1	6.4	0	0
North Island	40.1	6.5	46.6	0	0

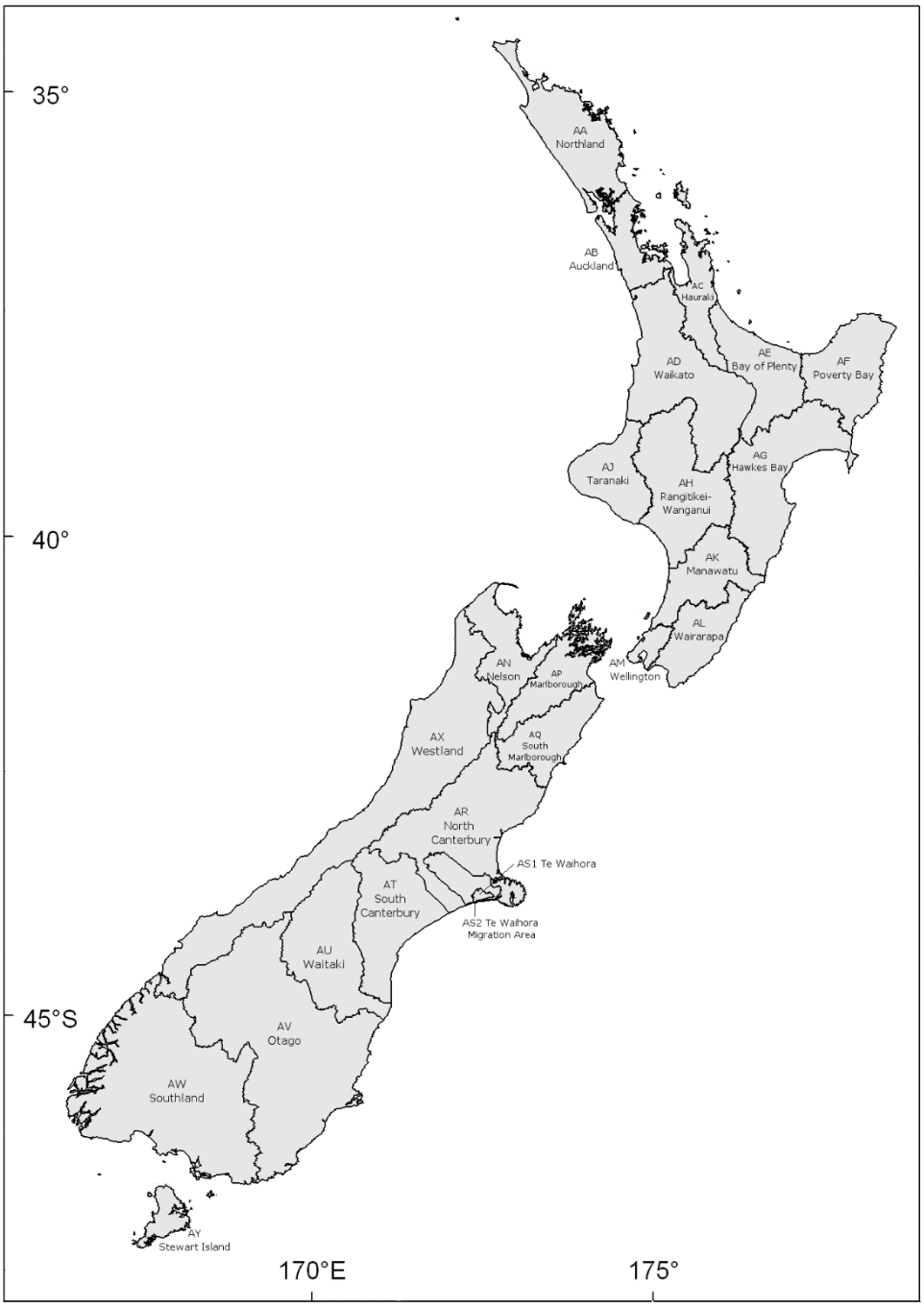


Figure 1: Eel Statistical Areas for reporting catch from the commercial freshwater eel fishery.

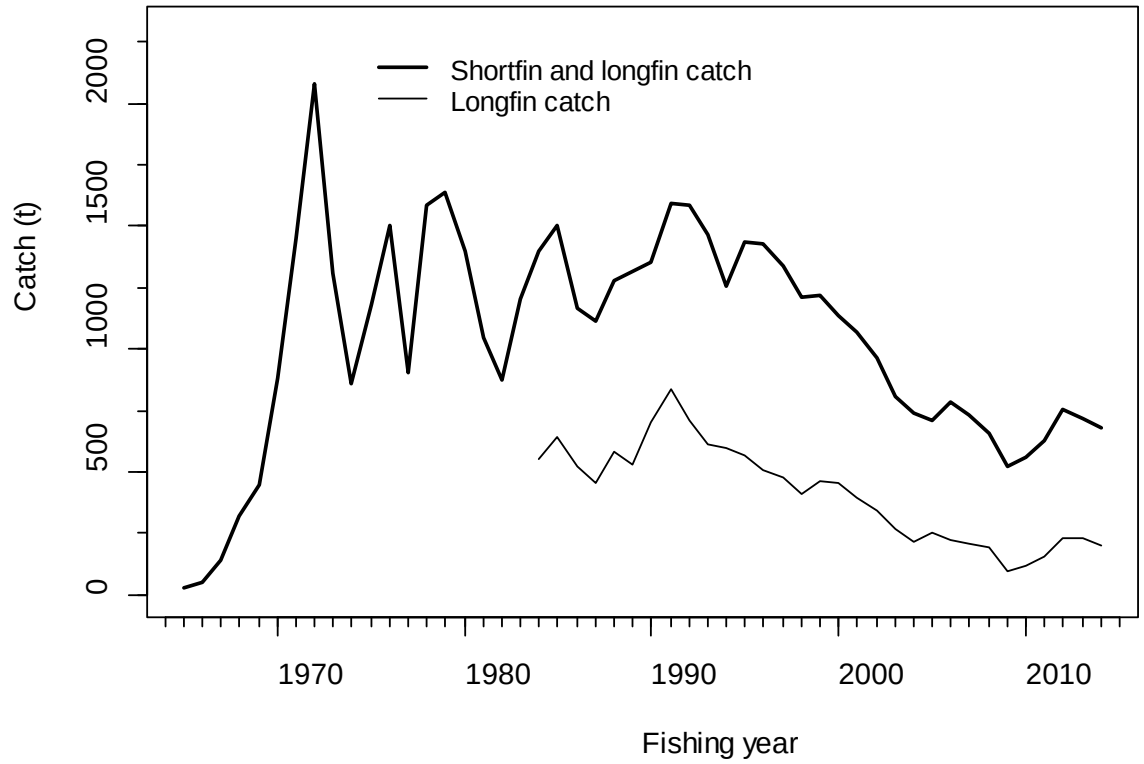


Figure 2: New Zealand commercial fishery landings of all eels (shortfin and longfin combined) from 1965 to 2014 and of longfin eels from 1984 onward (Before 1984 there are no data on individual species catch) (Data from Ministry for Primary Industries, 2014). Data are shown by calendar year up to 1988 and thereafter by fishing year where 2010 represents 2009–2010 fishing year (1 October to 30 September).

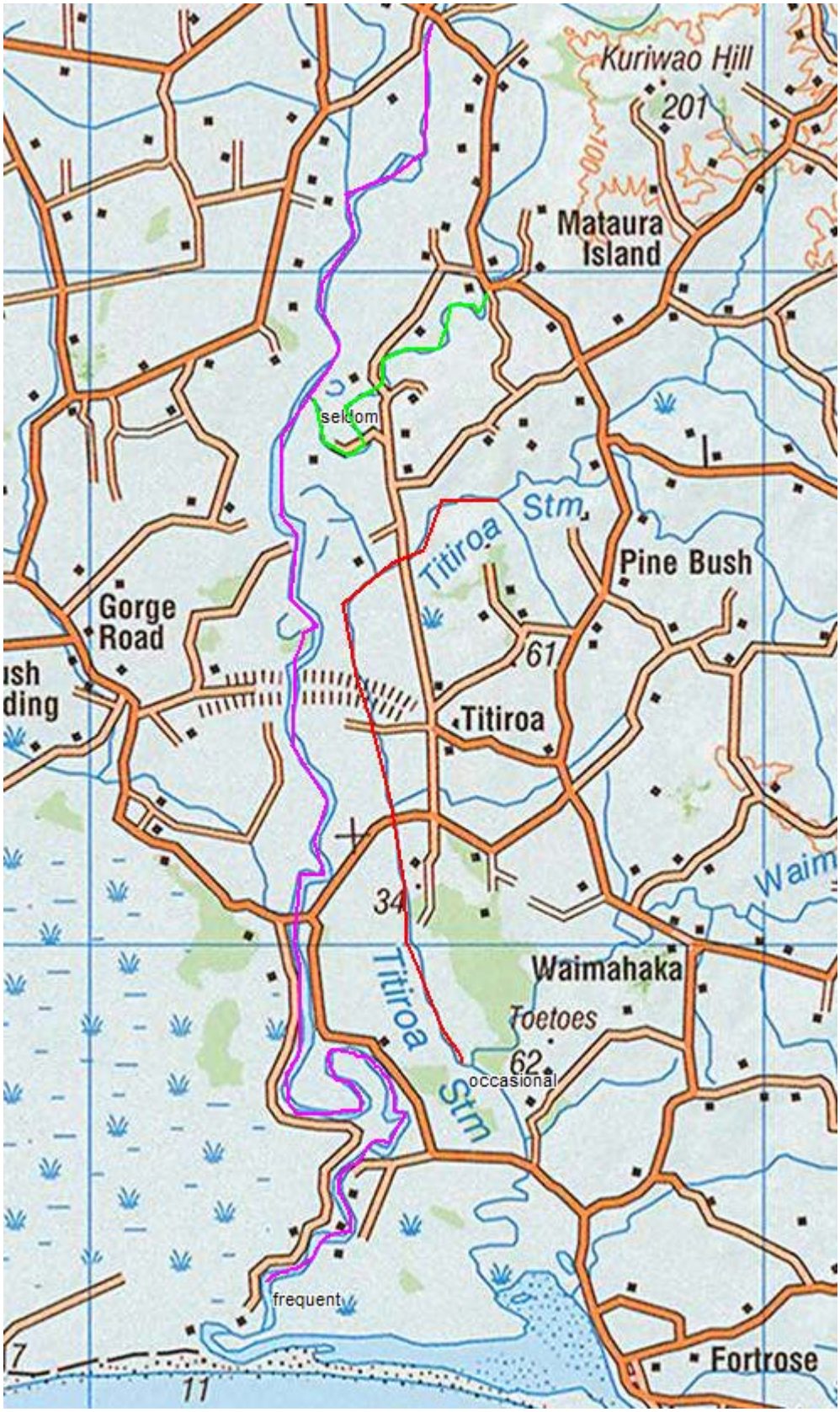


Figure 3: Theoretical example of a fisher's effort on the Lower Mataura River catchment in southland annotated on MapToaster topographic map (1:250 000). Three annotated lines are shown here indicating where and how often these rivers have been fished in the last five years. Frequent (purple), Occasional (red), and seldom (green).

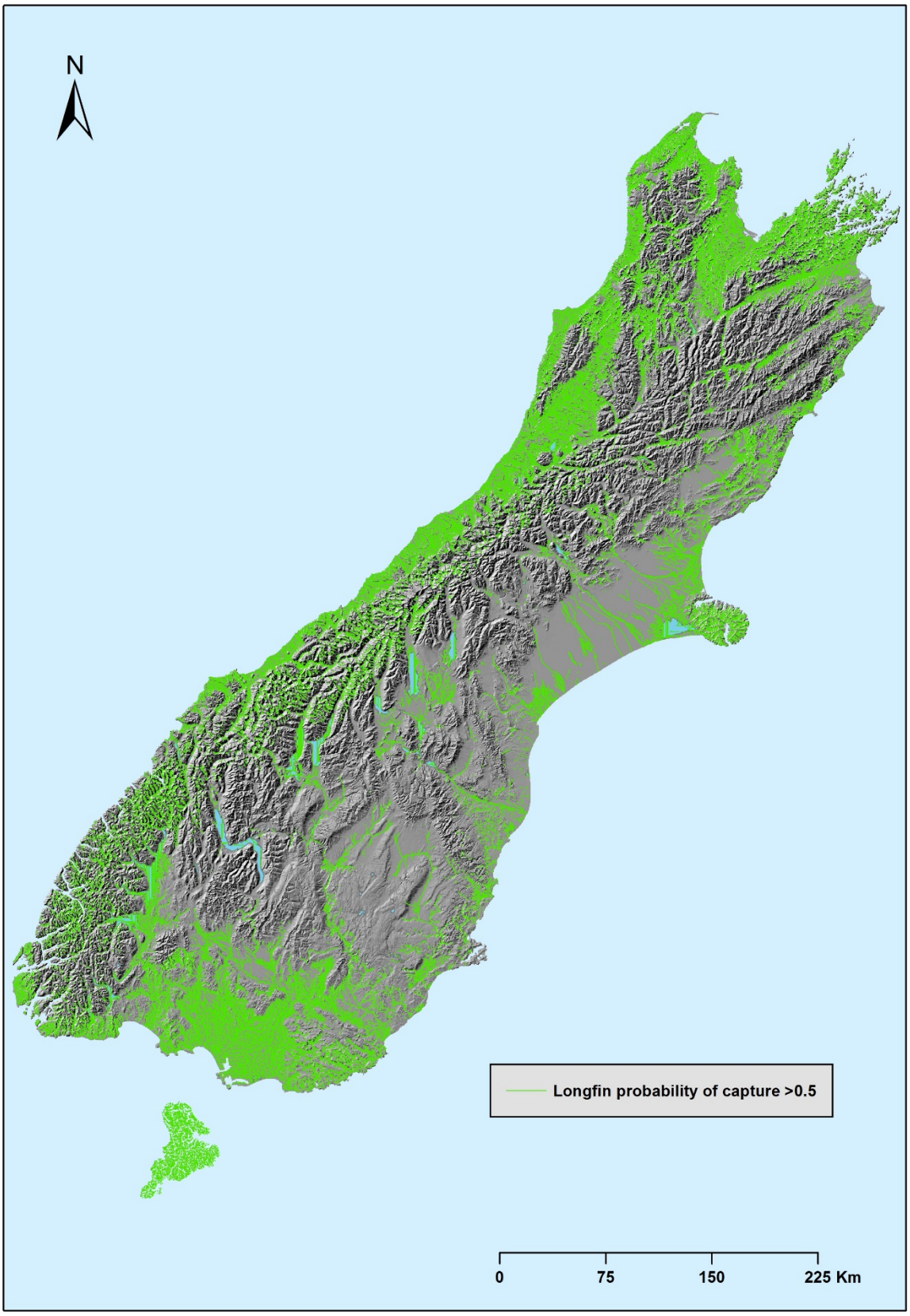
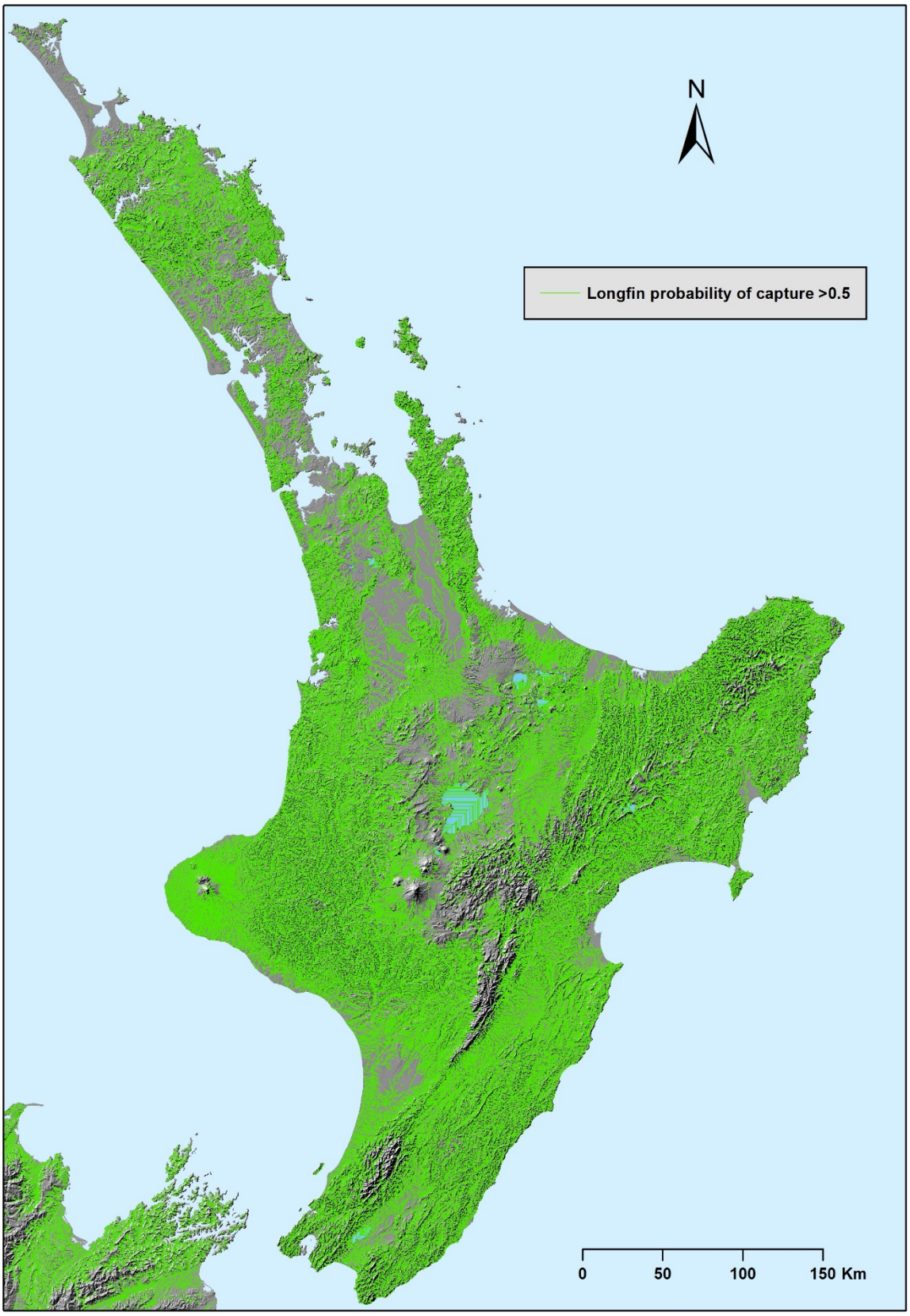


Figure 4: South Island probability of capture of over 0.5 for longfin eels, adjusted by fishing data where eels were caught. Based on Crow et al. (2014). Green represents REC2 segments where longfin are predicted to be present.



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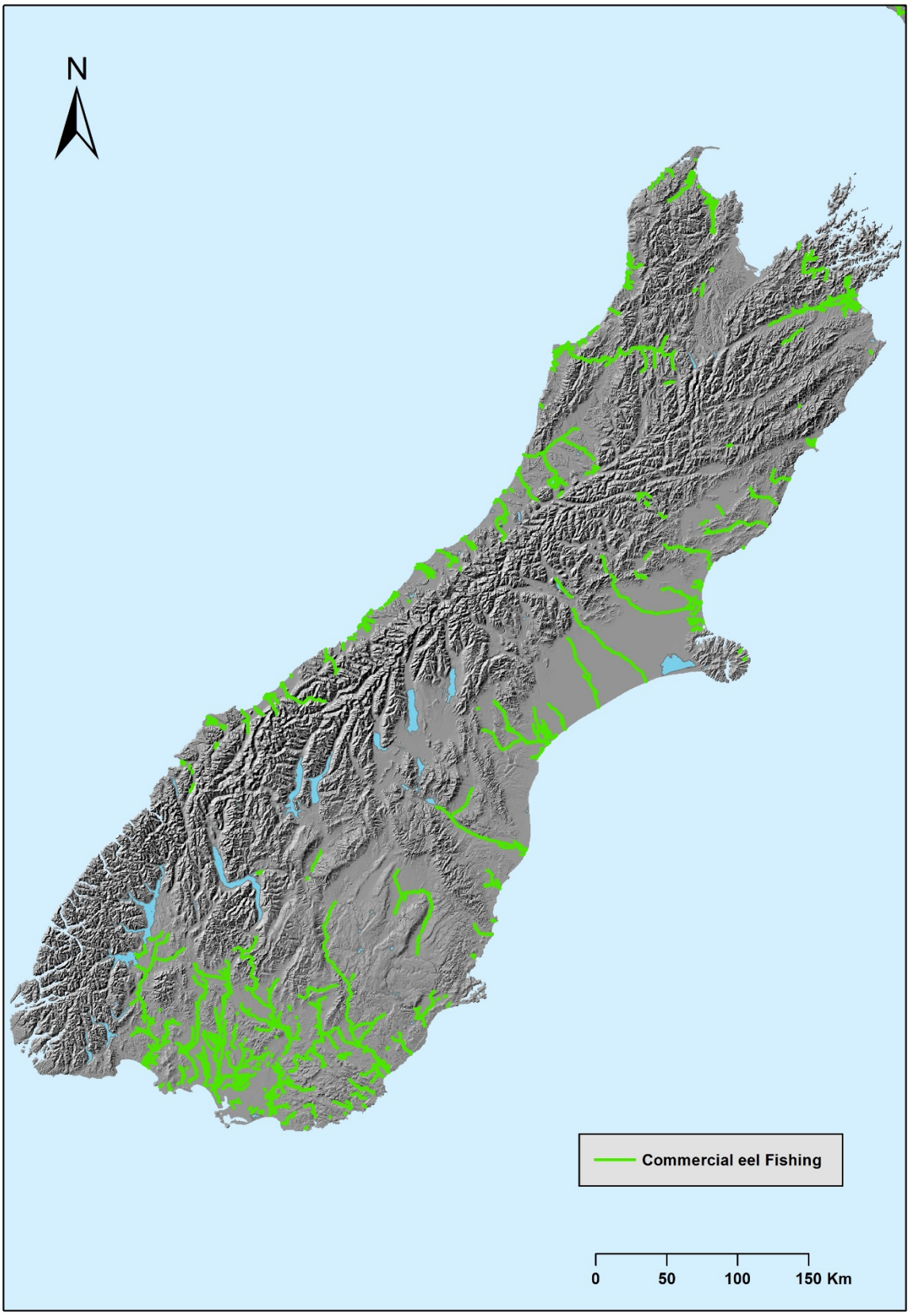

Figure 6: South Island commercial fishing effort overlaid on the REC2 where longfin eels have been caught over the period 2009–10 to 2013–14.

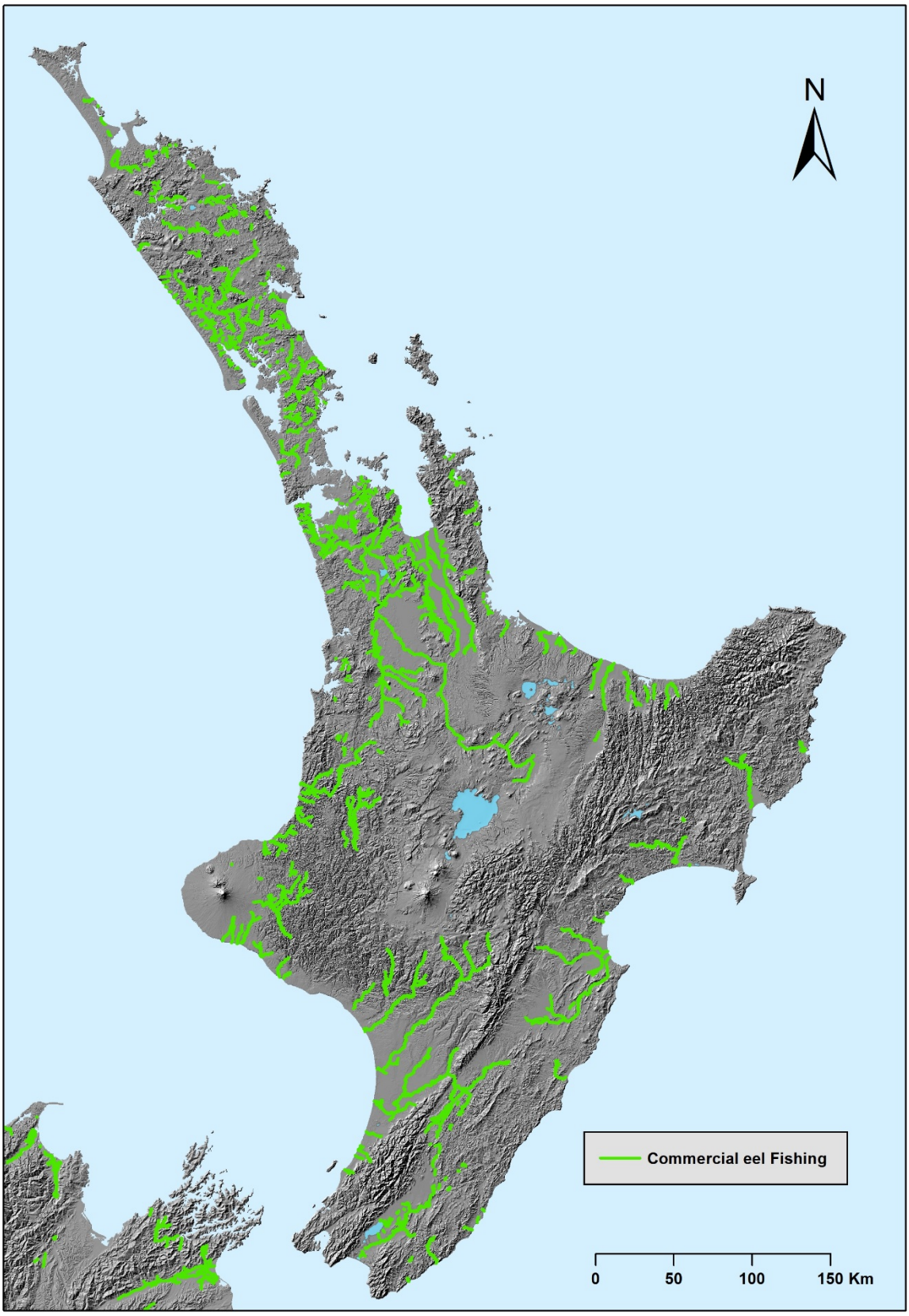

Figure 7: North Island commercial fishing effort overlaid on the REC2 where longfin eels have been caught over the period 2009–10 to 2013–14.

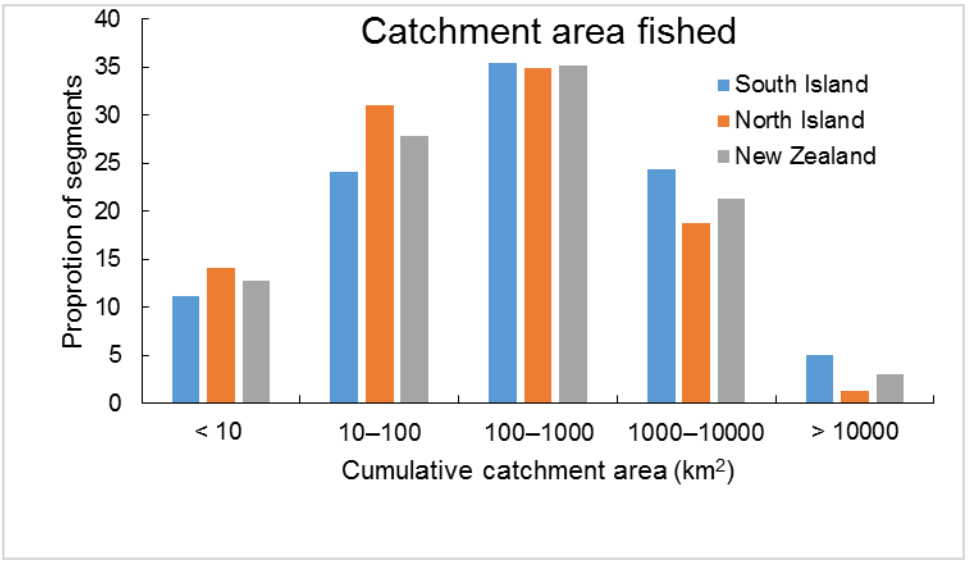

Figure 8: Histogram of the proportion of all fishing unique REC2 segments, including lakes, fished by cumulative catchment area. N= 17 344 New Zealand, N = 7859 South Island, N =9485 North Island.

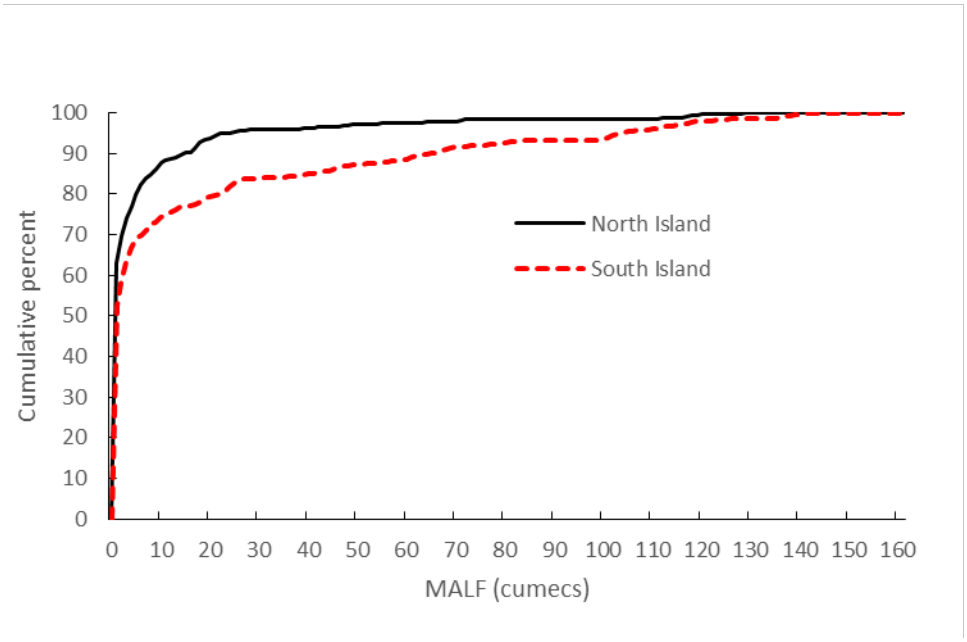

Figure 9: Cumulative frequency plot of river flow (MALF) for North and South Islands for unique fished REC2 segments (N = 9143 North Island, N =7542 South Island). MALF, mean annual low flow; cumecs, cubic metres per second. South Island mean = 16 cumecs, North Island mean = 5.7 cumecs.

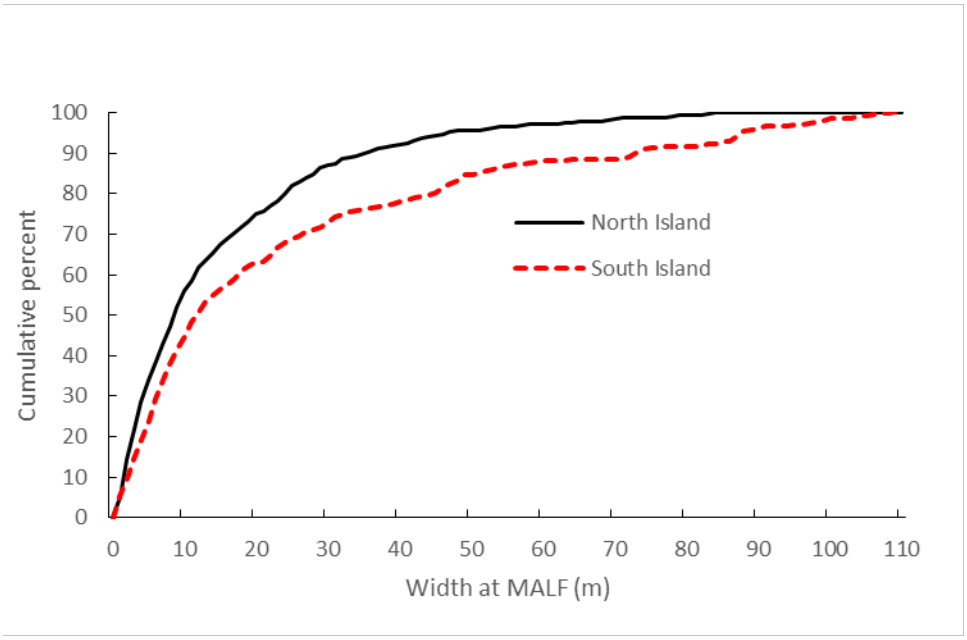

Figure 10: Cumulative frequency plot of river width at MALF for North and South Islands for unique fished REC2 segments (N = 9143 North Island, N =7542 South Island). MALF, mean annual low flow. South Island mean = 24.0 m, North Island mean = 14.4 m.

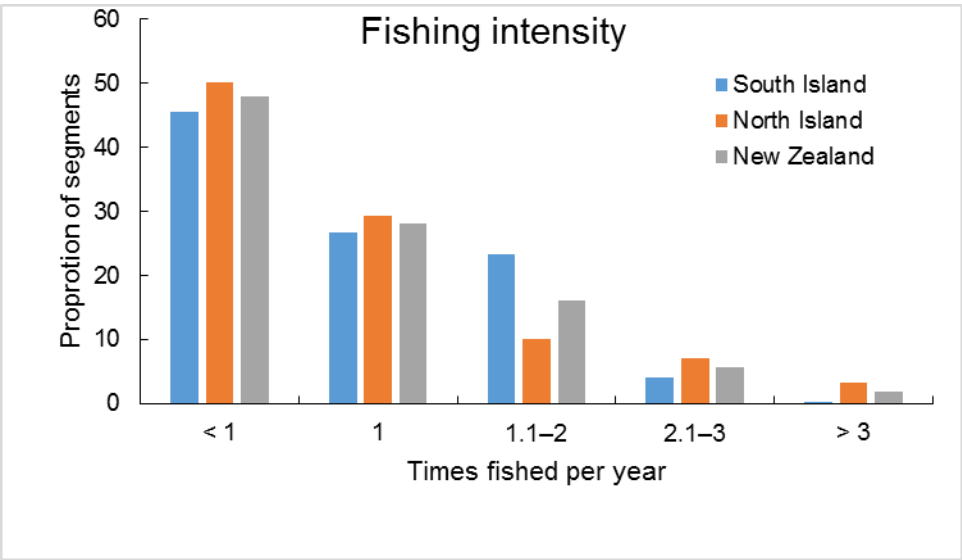

Figure 11: Histogram of the proportion of all fishing unique REC2 segments, including lakes, fished at different levels of fishing intensity. N= 17 344 New Zealand, N = 7859 South Island, N =9485 North Island.

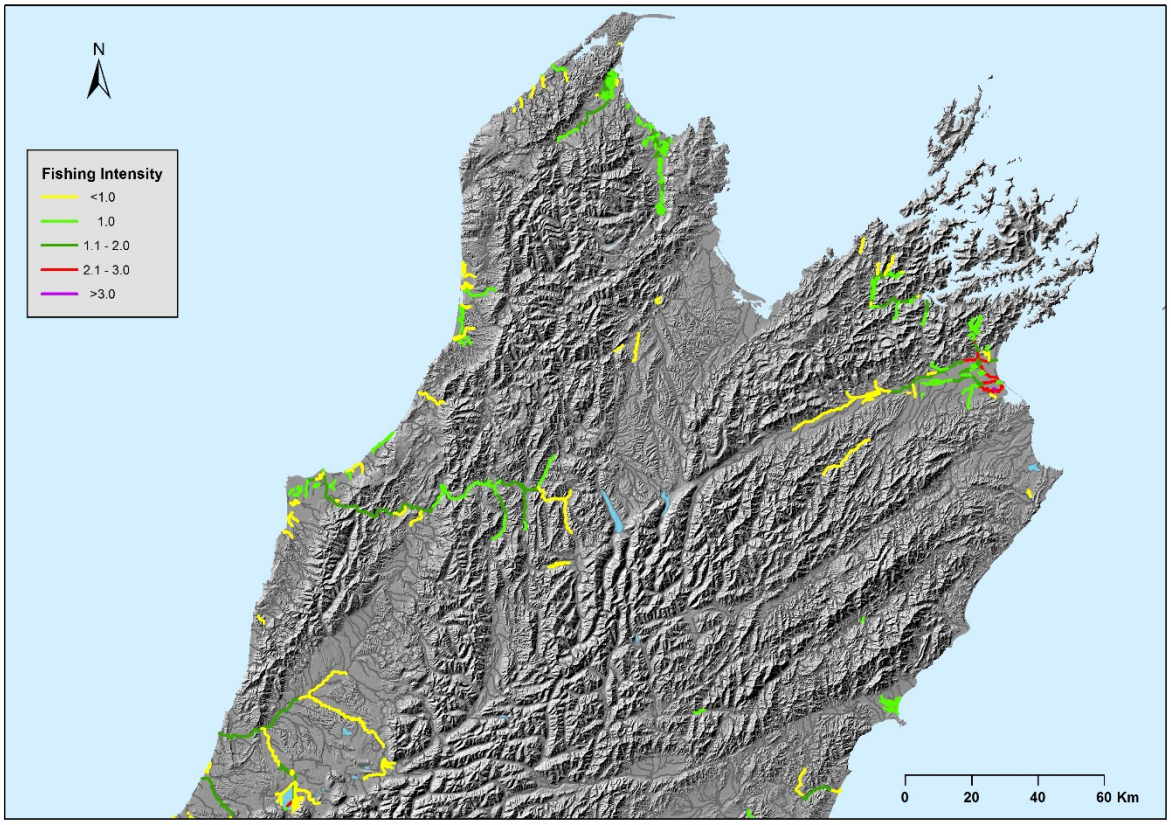

Figure 12: Northern South Island commercial fishing effort where longfin eels have been caught over the period 2009–10 to 2013–14. Fishing intensity is overlaid on the REC2.

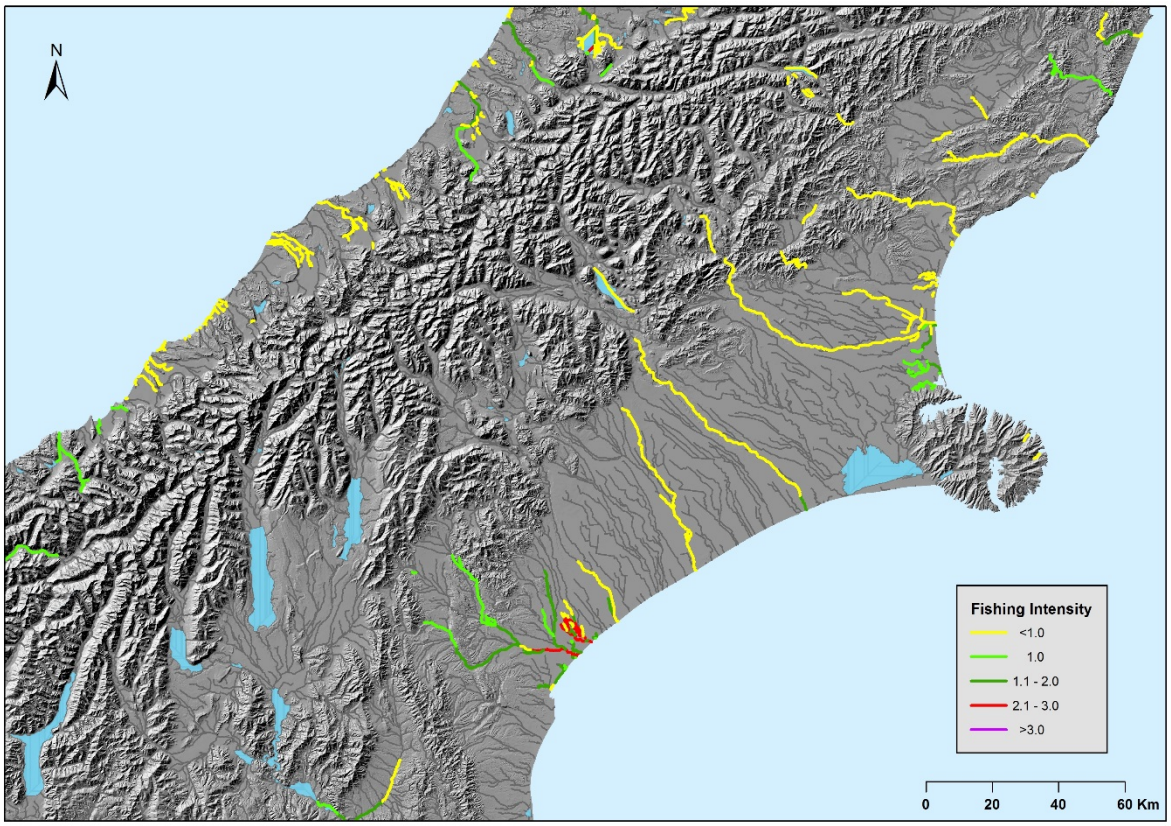

Figure 13: Central South Island commercial fishing effort where longfin eels have been caught over the period 2009–10 to 2013–14. Fishing intensity is overlaid on the REC2.

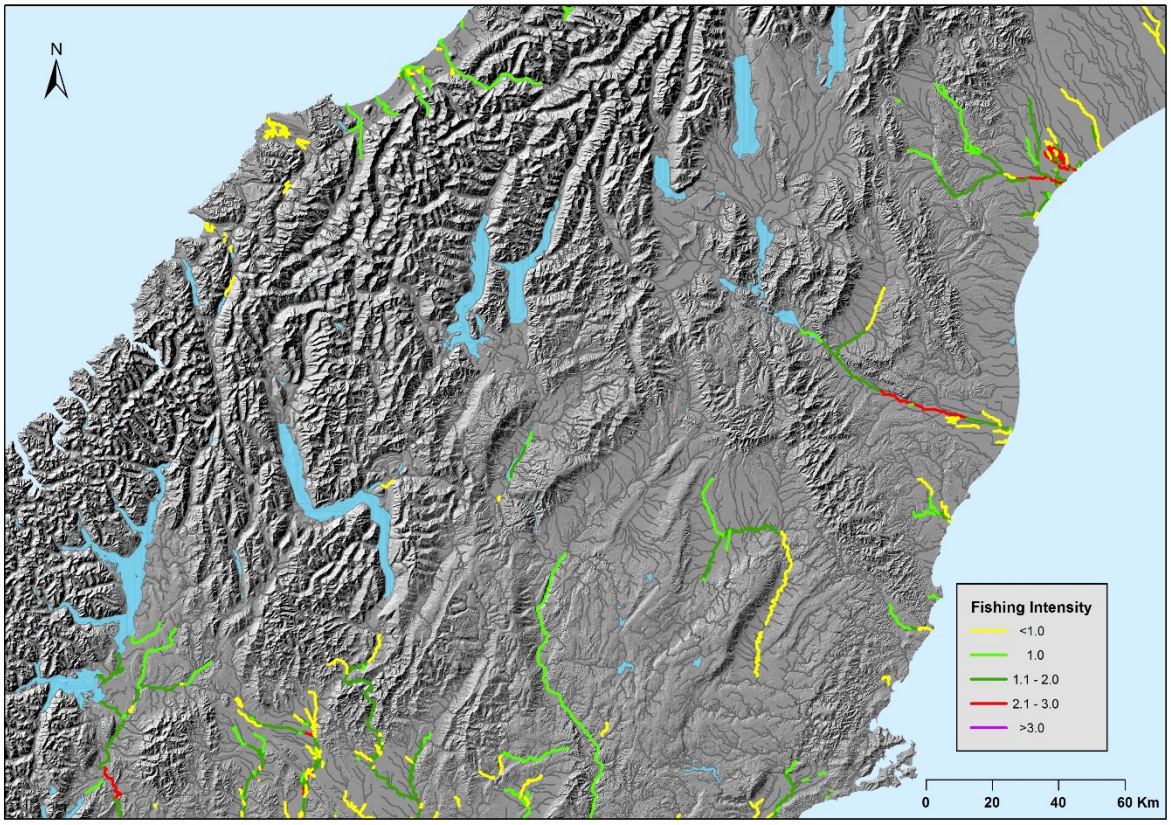

Figure 14: Southern South Island commercial fishing effort where longfin eels have been caught over the period 2009–10 to 2013–14. Fishing intensity is overlaid on the REC2.

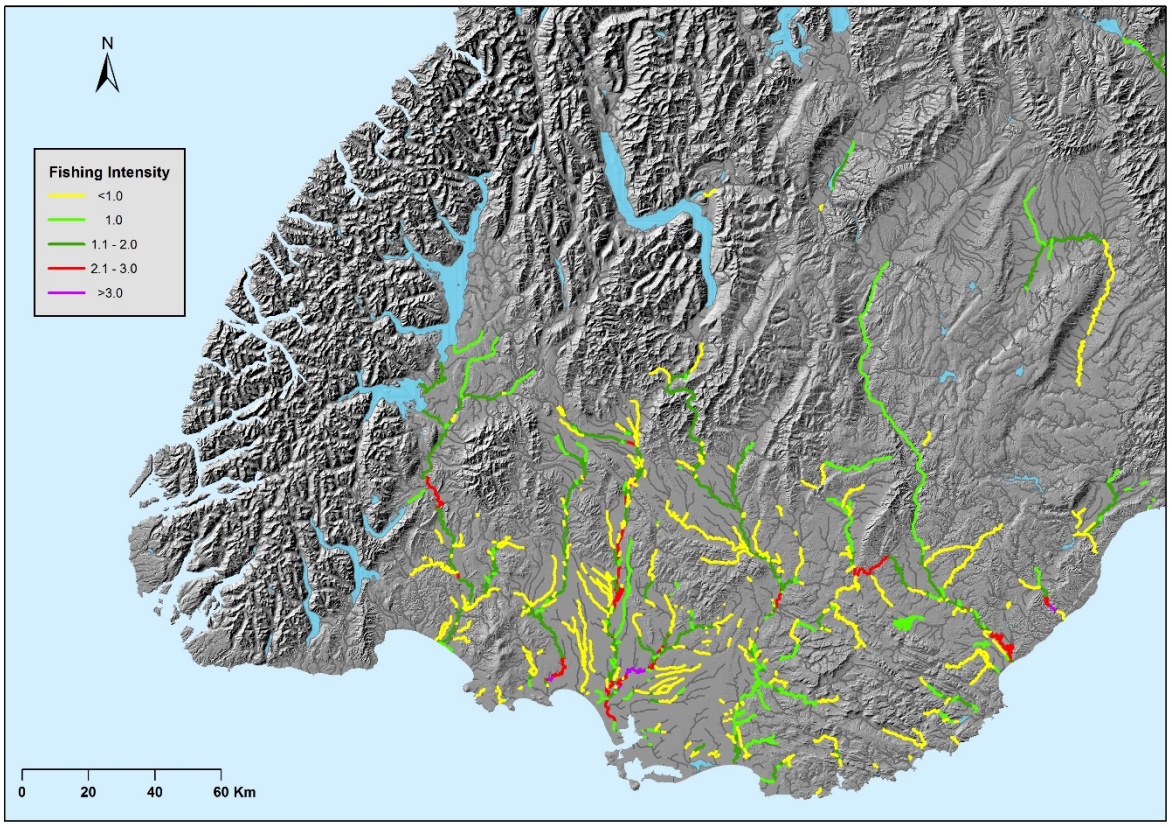

Figure 15: Southland South Island commercial fishing effort where longfin eels have been caught over the period 2009–10 to 2013–14. Fishing intensity is overlaid on the REC2.

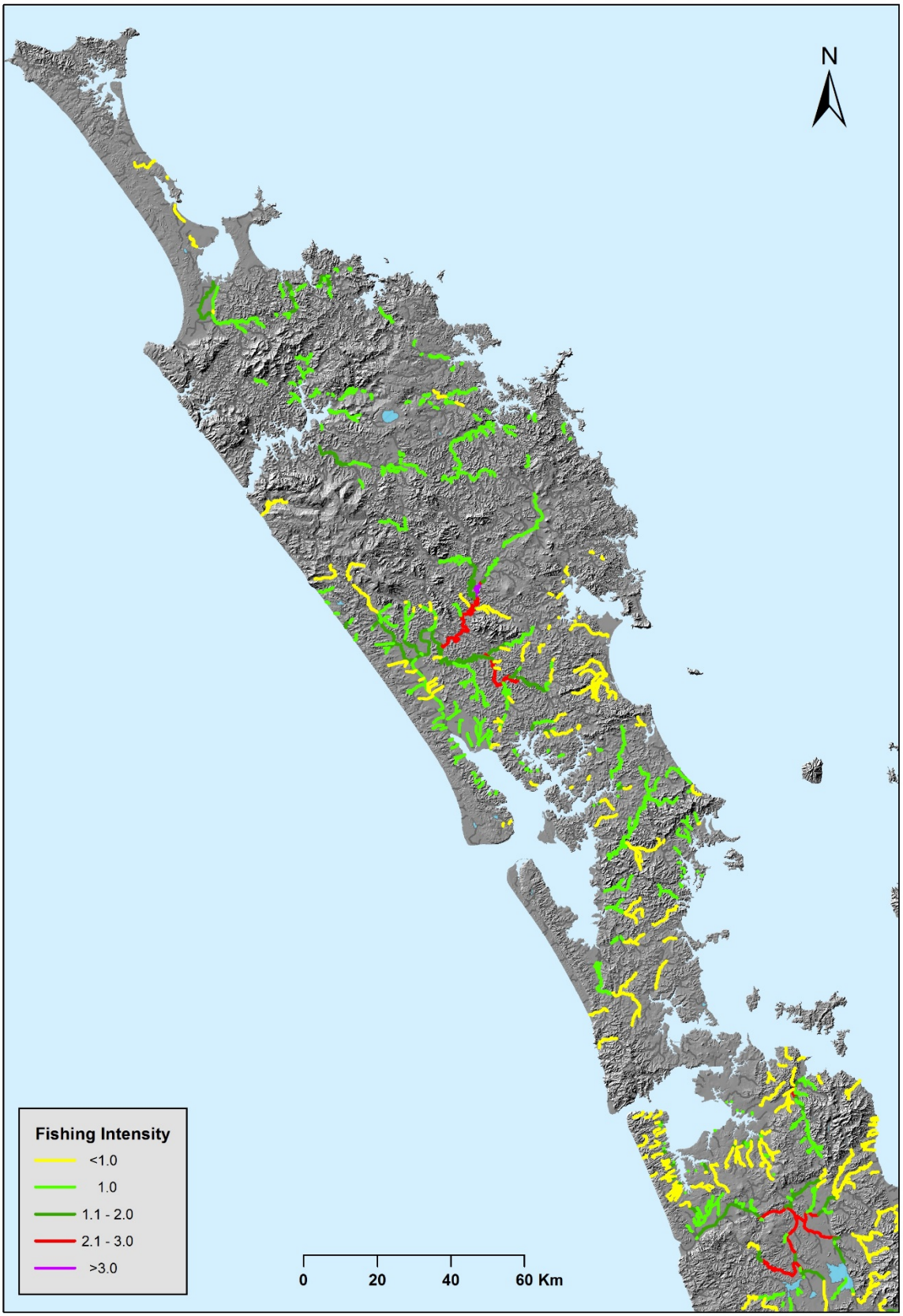

Figure 16: Northland North Island commercial fishing effort where longfin eels have been caught over the period 2009–10 to 2013–14. Fishing intensity is overlaid on the REC2.

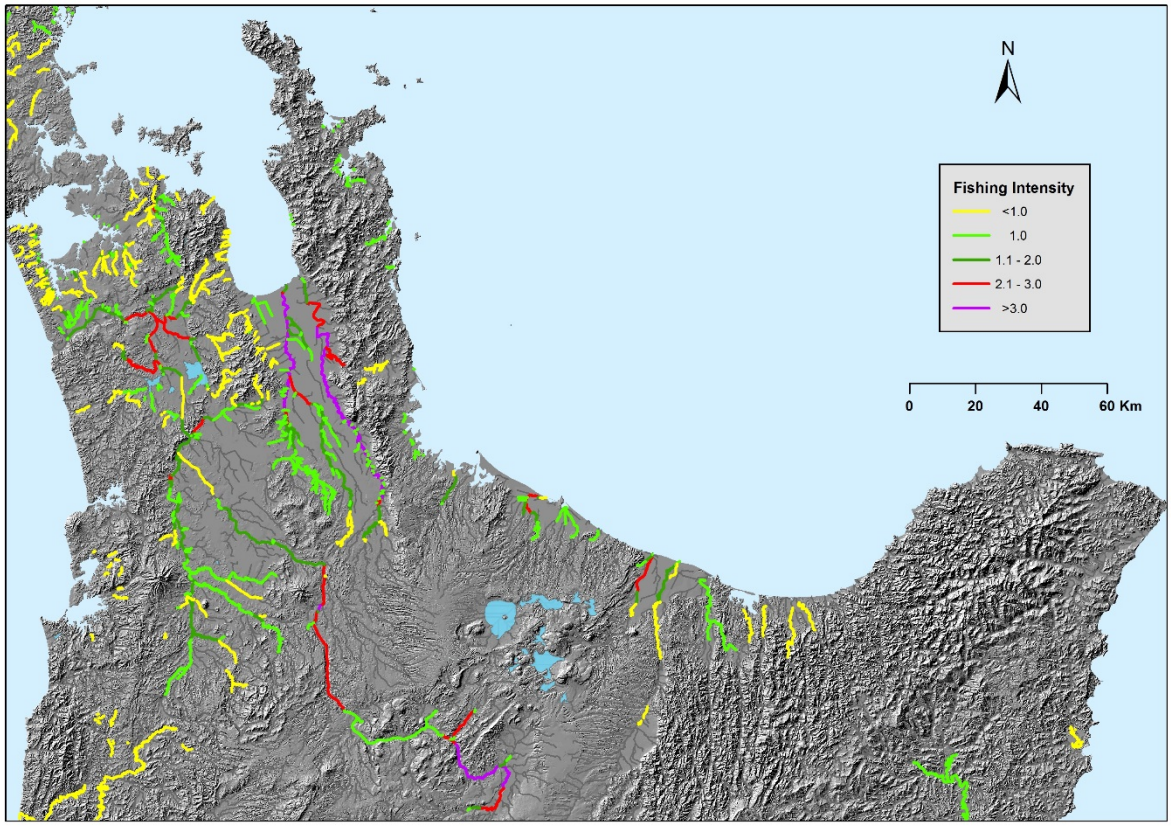

Figure 17: North central North Island commercial fishing effort where longfin eels have been caught over the period 2009–10 to 2013–14. Fishing intensity is overlaid on the REC2.

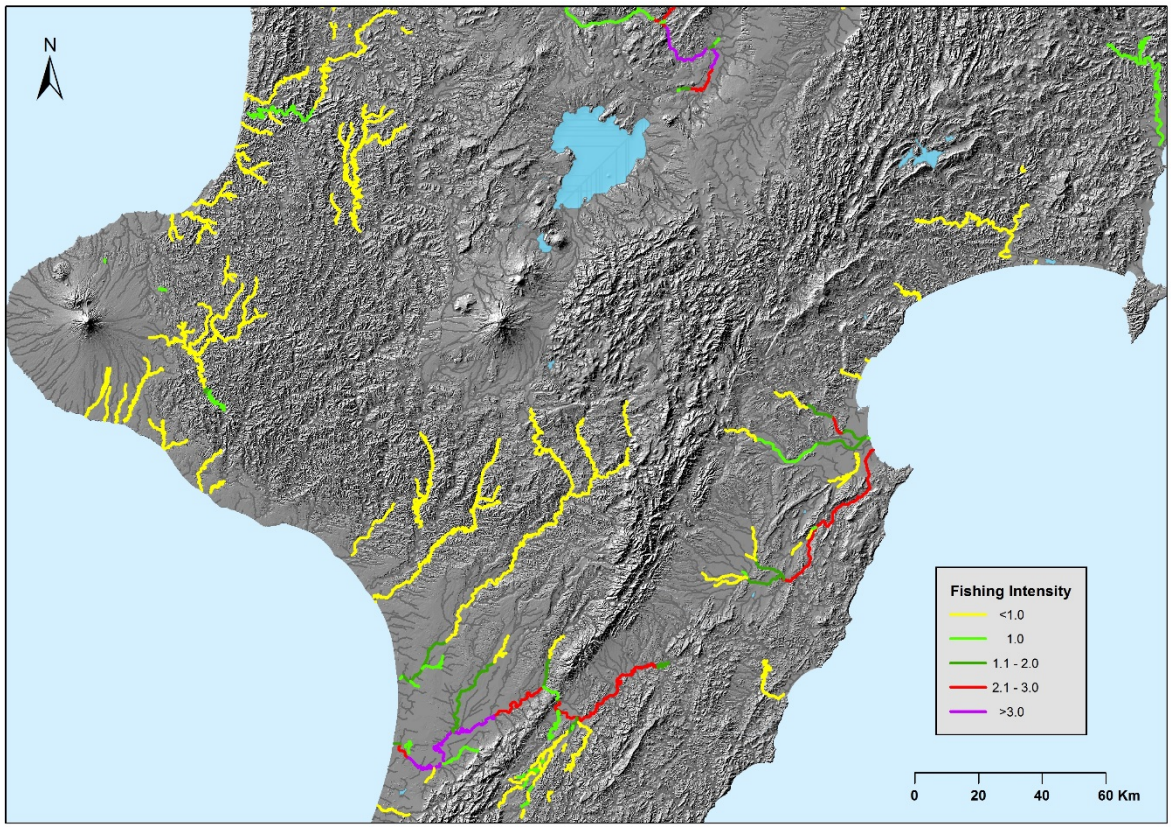

Figure 18: South central North Island commercial fishing effort where longfin eels have been caught over the period 2009–10 to 2013–14. Fishing intensity is overlaid on the REC2.

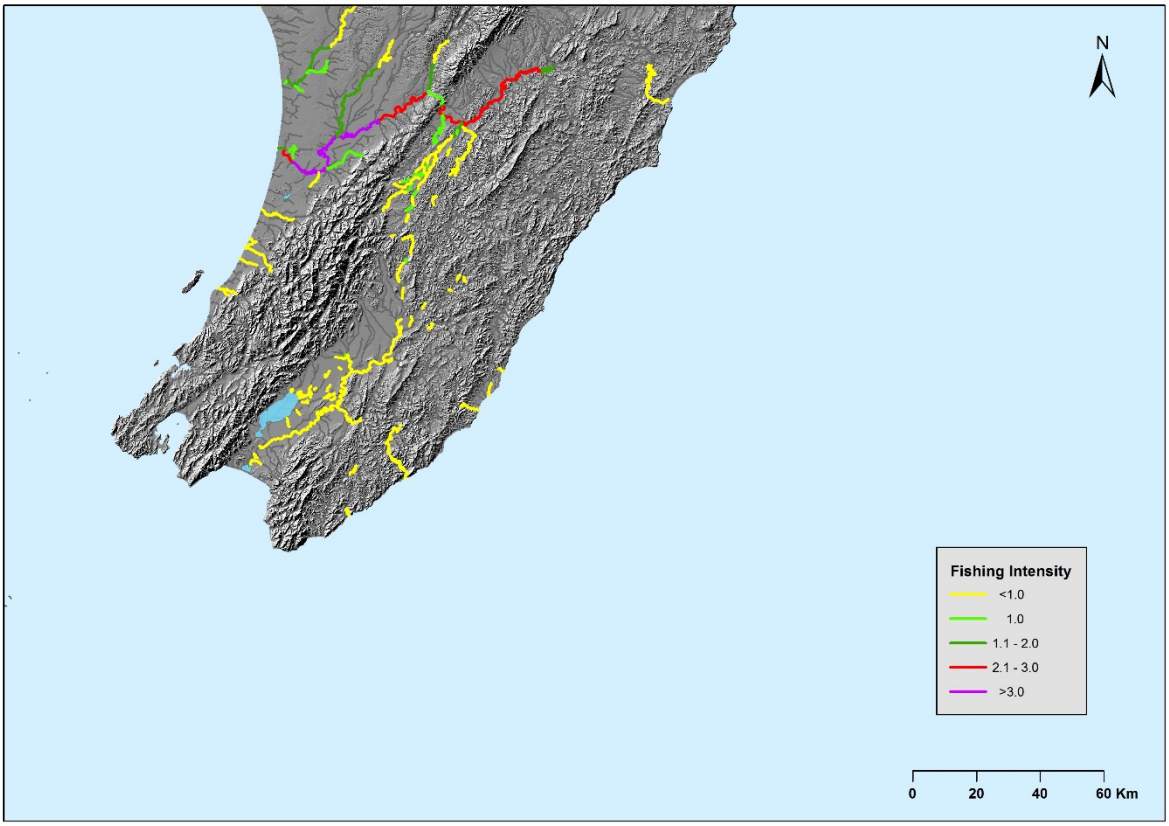

Figure 19: South North Island commercial fishing effort where longfin eels have been caught over the period 2009–10 to 2013–14. Fishing intensity is overlaid on the REC2.

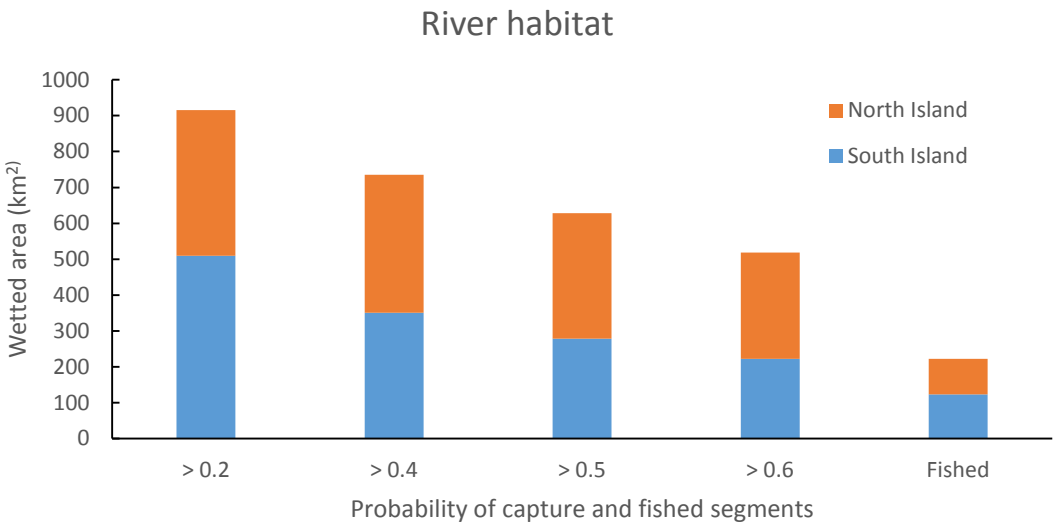

Figure 20: River habitat (wetted area, km^2) for the South and North Islands for four levels of probability of capture and for unique fished river segments (data from Table 8).

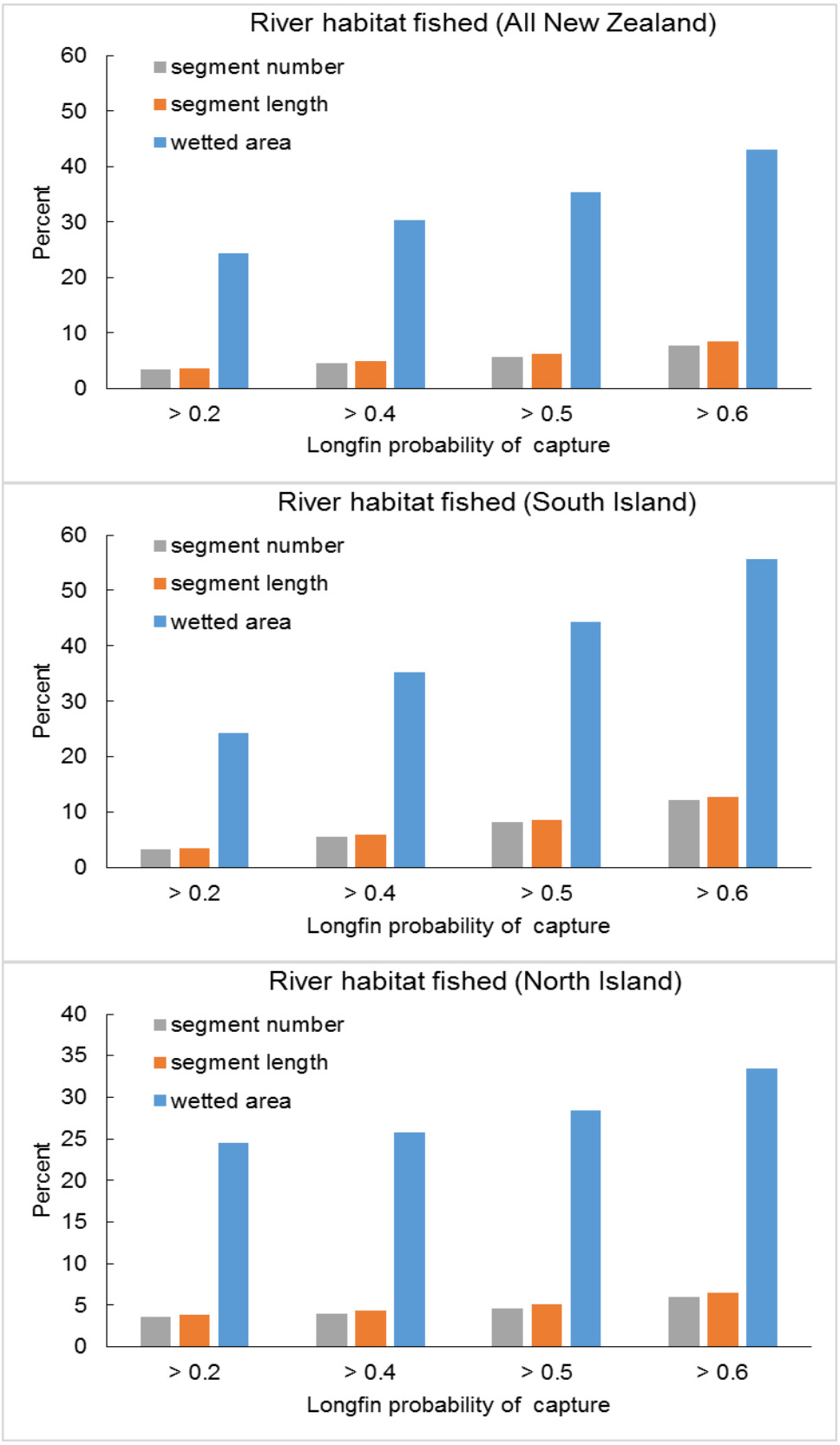

Figure 21: All fishing unique REC2 segments in rivers, expressed as proportion of segment number, length and wetted area (= habitat) for four levels of probability of capture for all New Zealand and separately for the South and North Islands (data from Table 8).

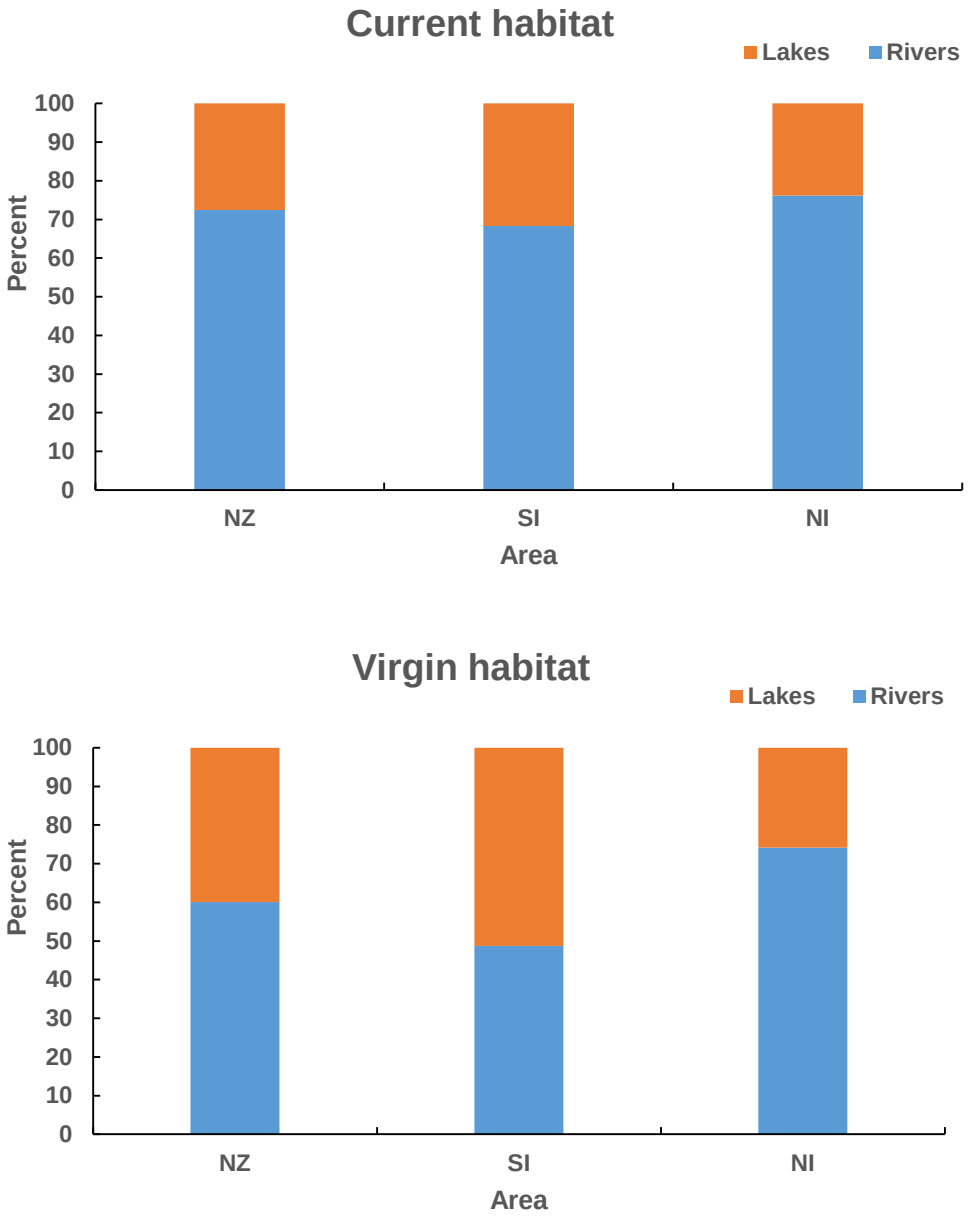

Figure 22: The percent of habitat in rivers and lakes currently (top panel) and historically (bottom panel) available to longfin eels. River habitat is estimated from the >0.5 probability of capture model. NZ, New Zealand; SI, South Island; NI, North Island.

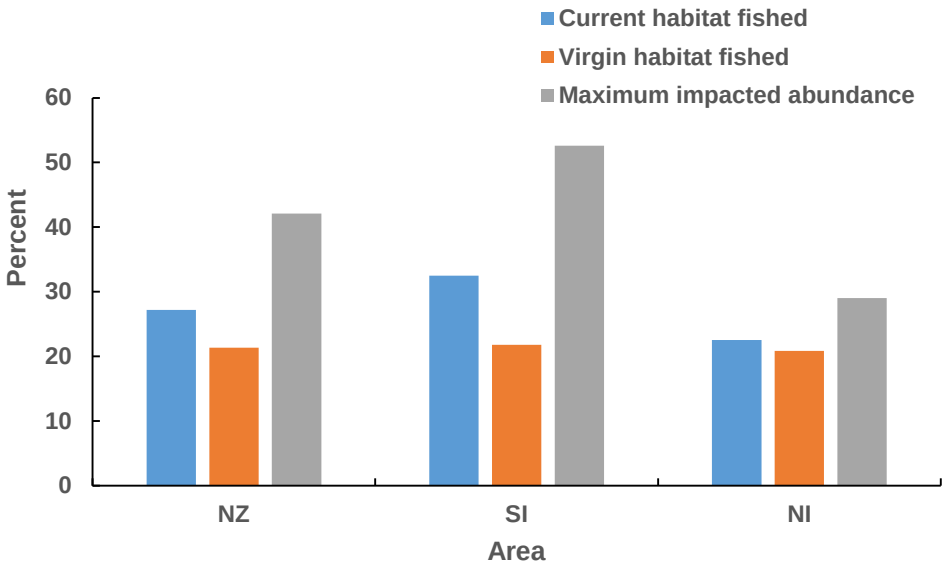

Figure 23: Percent current longfin habitat fished, virgin habitat fished, and maximum impacted abundance from all river and lake longfin habitat estimates. River habitat used is that predicted by the >0.5 probability of capture model. NZ, New Zealand; SI, South Island; NI, North Island (data from Table 10).

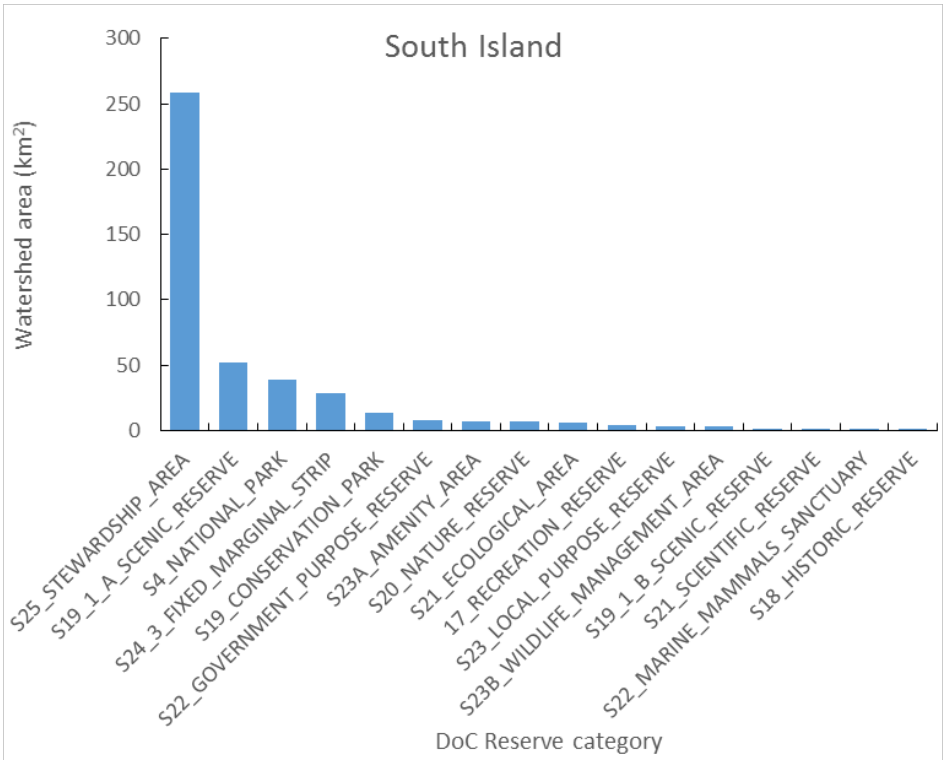

Figure 24: All fishing (rivers and lakes) within DOC Public Conservation Land in the South Island expressed as watershed area. 10.6% of fished watershed area is within reserves. DOC, Department of Conservation.

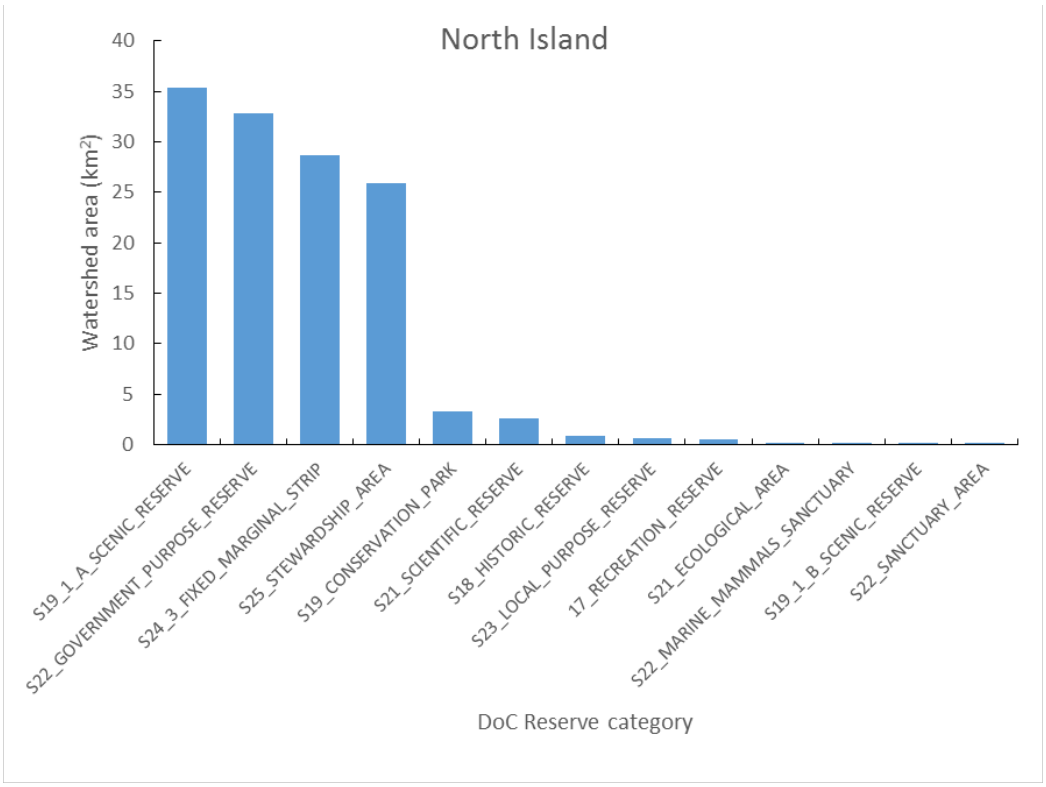

Figure 25: All fishing (rivers and lakes) within DOC Public Conservation Land in the North Island expressed as watershed area. 2.7% of fished watershed area were within reserves. DOC, Department of Conservation.

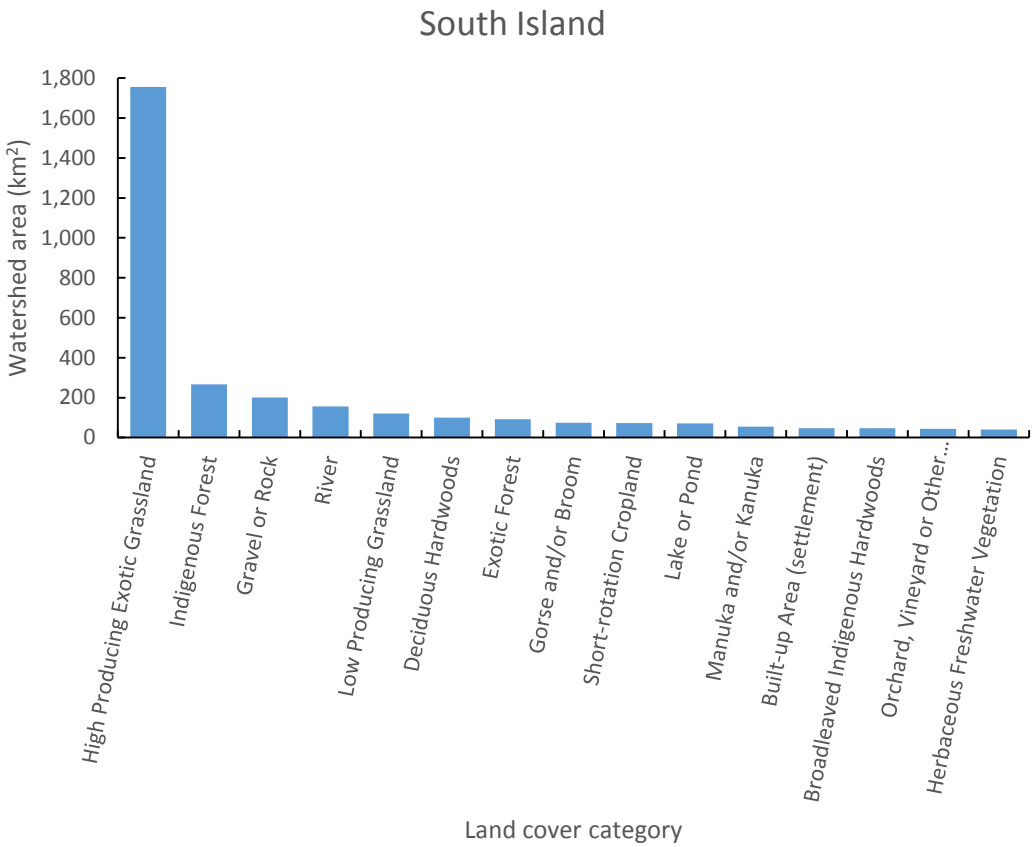

Figure 26: Fishing (rivers and lakes) within land cover categories in the South Island expressed as watershed area. (98% of fished events are shown).

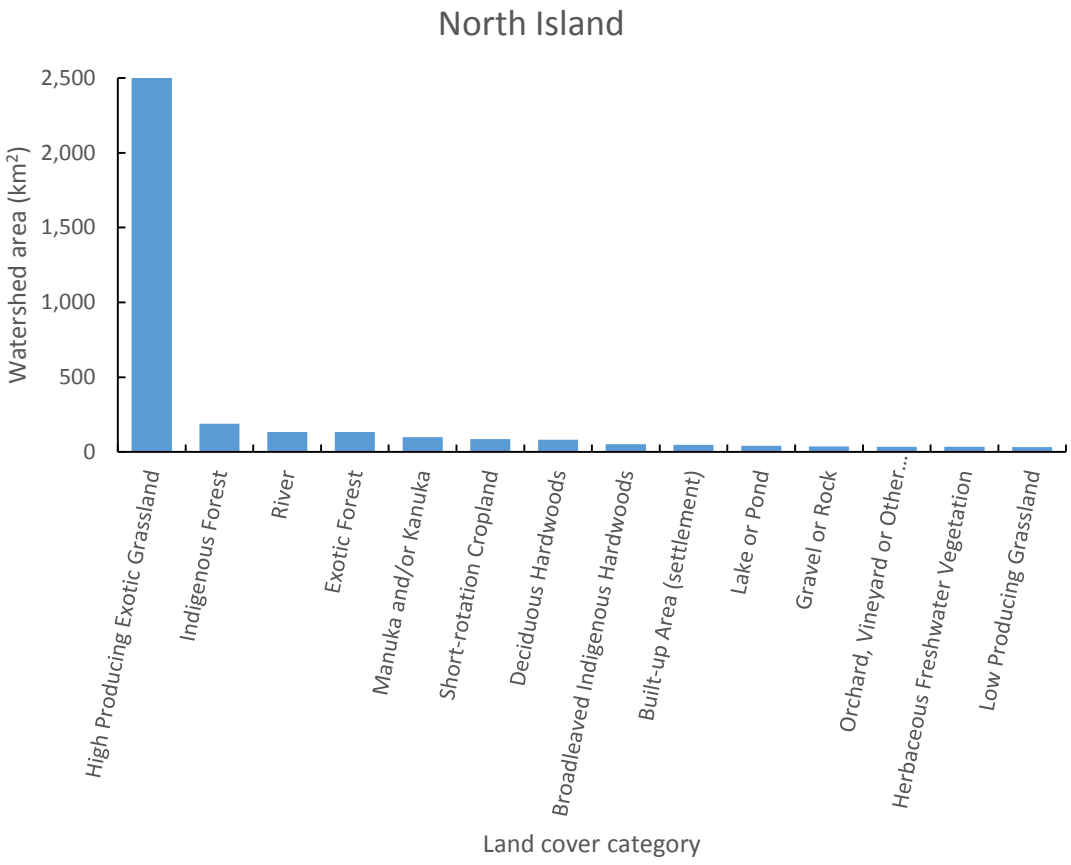

Figure 27: Fishing (rivers and lakes) within land cover categories in the South Island expressed as watershed area. (98% of fished events are shown).

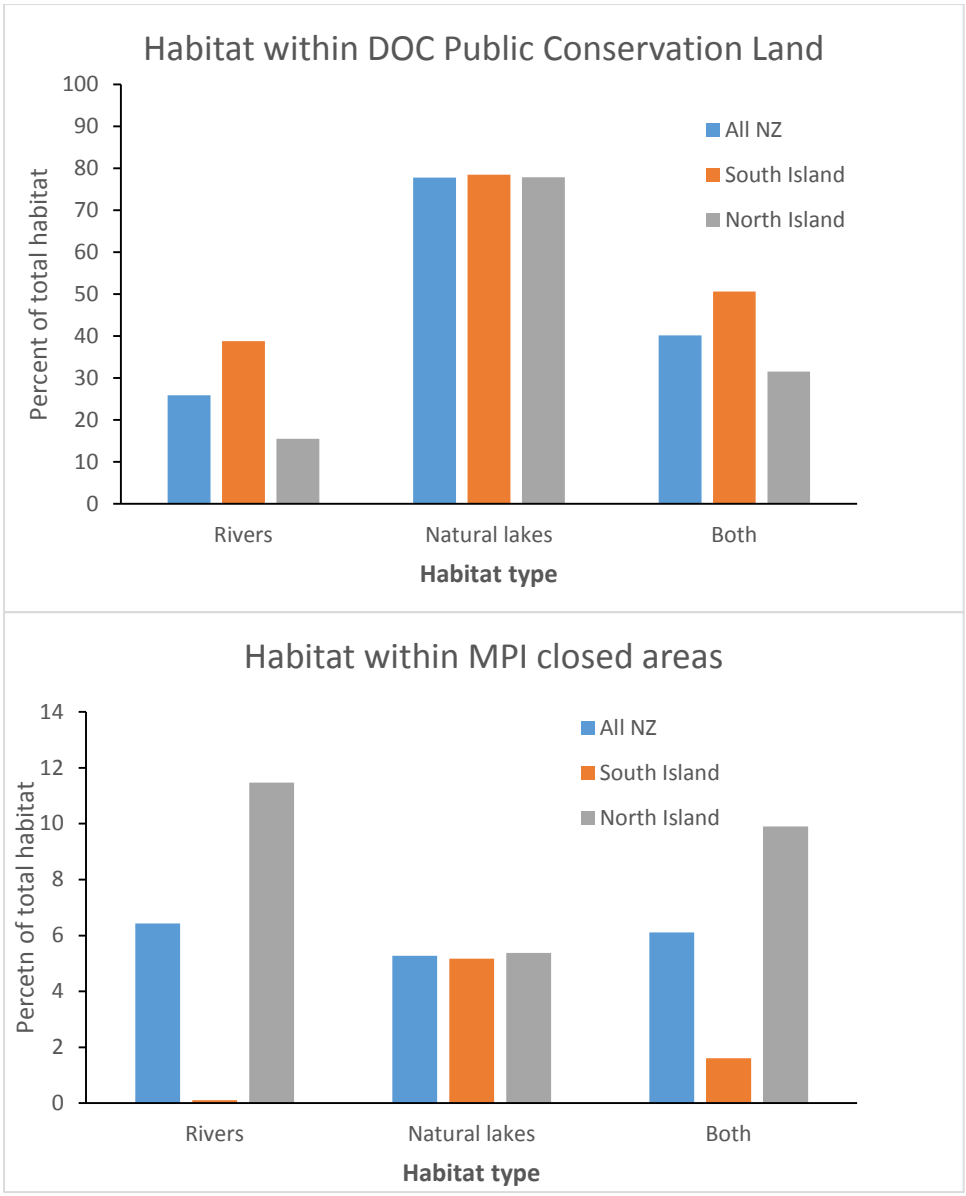

Figure 28: Proportions of total current habitat (wetted area) available to longfin in New Zealand within DOC Public Conservation Land (top panel) and MPI closed areas (bottom panel). River habitat is predicted by the >0.5 probability of capture model. DOC, Department of Conservation; MPI, Ministry for Primary Industries.

Appendix 1: Natural lakes over 0.9 km^2 in New Zealand. Habitat is estimated for lakes thought to be accessible to longfin eels. * Hydro lakes Brunner, Te Anau and Manapouri are also included in the natural lakes because of trap and transfer of elvers and migrants, and limited passive migrant passage downstream. SFE, shortfin. NA, not applicable; ESA, Eel Statistical Area; DOC, Department of Conservation.

Lake name	Lake ID	Island	ESA	Area_km^2	Longfin access	Habitat area (km^2)	Area type	Within DOC Public Conservation Land	Comment
Falls Dam	11 614	South	AV	1.40	No	NA	NA	NA	No eels
Greenland Reservoir	7 657	South	AV	4.48	No	NA	NA	NA	No eels
Lake Adelaide	54 060	South	AX	1.28	No	NA	NA	NA	No eels
Lake Alice	52 722	South	AW	1.77	No	NA	NA	NA	No eels
Lake Cadman	26 051	South	AW	2.12	No	NA	NA	NA	No eels
Lake Christabel	39 837	South	AX	2.58	No	NA	NA	NA	No eels
Lake Kaniere	38 502	South	AX	14.74	No	NA	NA	NA	No eels
Lake Manuwai	24 304	North	AA	1.27	No	NA	NA	NA	No eels
Lake Okareka	15 325	North	AE	3.34	No	NA	NA	NA	No eels
Lake Okataina	54 731	North	AE	10.73	No	NA	NA	NA	No eels
Lake Owhareiti	24 039	North	AA	1.02	No	NA	NA	NA	No eels
Lake Rakatu	30 380	South	AW	1.30	No	NA	NA	NA	No eels
Lake Rotoehu	40 188	North	AE	7.90	No	NA	NA	NA	No eels
Lake Rotoiti (NI)	54 730	North	AE	33.69	No	NA	NA	NA	No eels
Lake Rotokakahi	15 621	North	AE	4.33	No	NA	NA	NA	No eels
Lake Rotoma	40 102	North	AE	11.12	No	NA	NA	NA	No eels
Lake Rotorua	11 133	North	AE	80.48	No	NA	NA	NA	No eels
Lake Tarawera	54 732	North	AE	41.15	No	NA	NA	NA	No eels
Lake Tennyson	26 477	South	AQ	2.33	No	NA	NA	NA	No eels
Lake Tikitapu	15 312	North	AE	1.44	No	NA	NA	NA	No eels
Lake Tutira	36 981	North	AG	1.70	No	NA	NA	NA	No eels
Lake Waiparera	13 467	North	AA	1.09	No	NA	NA	NA	No eels
no_name1	5 264	South	AV	6.23	No	NA	NA	NA	No eels

Lake name	Lake ID	Island	ESA	Area_km^2	Longfin access	Habitat area (km^2)	Area type	Within DOC Public Conservation Land	Comment
no_name2	41 757	South	AX	1.03	No	NA	NA	NA	No eels
no_name3	47 399	South	AU	1.25	No	NA	NA	NA	No eels
no_name4	47 404	South	AU	1.16	No	NA	NA	NA	No eels
no_name5	47 406	South	AU	1.15	No	NA	NA	NA	No eels
no_name6	53 963	South	AX	1.07	No	NA	NA	NA	No eels
Catlins Lake	36 046	South	AV	4.32	Yes	4.32	All	no	Shallow
Hatuma Lake	32 805	North	AG	1.53	Yes	1.53	All	no	Shallow
Kangaroo Lake	38 664	South	AX	1.25	Yes	0.31	25% of lake	yes	Estimate
Lady Lake	38 665	South	AX	1.41	Yes	0.35	25% of lake	yes	Estimate
Lake Ada	53 062	South	AX	2.39	Yes	2.39	All	yes	Shallow
Lake Ahaura	39 226	South	AX	1.98	Yes	0.50	25% of lake	yes	Estimate
Lake Alabaster	47 067	South	AX	5.29	Yes	1.32	25% of lake	yes	Estimate
Lake Beattie	51 625	South	AW	1.79	Yes	1.79	All	yes	
Lake Brunner*	38 974	South	AX	40.61	Yes	3.60	50% of littoral	yes	Some escapement of migrants likely
Lake Clearwater	41 305	South	AT	1.97	Yes	1.97	All	no	
Lake Ellery	46 140	South	AX	3.88	Yes	3.88	All	yes	
Lake Ellesmere (Te Waihora)	48 177	South	AS	197.81	Yes	19.78	10% of lake	no	Mostly SFE habitat
Lake Emma	41 299	South	AT	1.67	Yes	1.67	All	yes	
Lake Forsyth (Wairewa)	47 579	South	AR	5.59	Yes	0.55	10% of lake	yes	Mostly SFE habitat
Lake Fraser	28 401	South	AW	1.91	Yes	1.91	All	yes	
Lake George	28 543	South	AW	0.91	Yes	0.91	All	yes	
Lake Grassmere	28 066	South	AQ	6.99	Yes	0.69	10% of lake	no	Mostly SFE habitat
Lake Grave	52 884	South	AW	2.20	Yes	2.20	All	yes	
Lake Hakapoua	28 624	South	AW	5.30	Yes	5.30	All	yes	
Lake Haupiri	39 225	South	AX	2.24	Yes	0.56	25% of lake	yes	Estimate
Lake Hauroko	26 111	South	AW	71.85	Yes	8.00	littoral	yes	Plant depth

Lake name	Lake ID	Island	ESA	Area_km^2	Longfin access	Habitat area (km^2)	Area type	Within DOC Public Conservation Land	Comment
Lake Heron	47 892	South	AR	6.95	Yes	4.90	littoral	yes	Plant depth
Lake Hochstetter	39 621	South	AX	5.00	Yes	1.25	littoral	yes	Plant depth
Lake Horowhenua	4 345	North	AK	3.04	Yes	3.04	All	no	Shallow
Lake Humuhumu	50 401	North	AA	1.40	Yes	1.40	All	no	Shalllow
Lake Ianthe	47 491	South	AX	4.71	Yes	4.00	littoral	yes	Plant depth
Lake Mahinapua	38 421	South	AX	3.94	Yes	3.94	All	no	Shallow
Lake Mapourika	46 959	South	AX	8.90	Yes	1.30	littoral	yes	Plant depth
Lake Marchant	52 243	South	AW	2.65	Yes	2.65	All	yes	
Lake Mckerrow	54 356	South	AX	22.84	Yes	3.70	littoral	yes	Plant depth
Lake Moeraki	46 723	South	AX	2.42	Yes	2.42	All	yes	Shallow
Lake Mokeno	50 314	North	AA	1.59	Yes	1.59	All	yes	Shallow
Lake Monk	28 708	South	AW	2.04	Yes	2.04	All	yes	Shallows
Lake Ngaroto	14 406	North	AD	0.92	Yes	0.92	All	yes	Shallow
Lake Onoke	1	North	AL	6.22	Yes	6.22	All	yes	Shallow
Lake Ototoa	50 270	North	AB	1.07	Yes	1.07	All	yes	Shallow
Lake Paringa	46 725	South	AX	4.75	Yes	1.87	littoral	yes	Plant depth
Lake Pearson	48 660	South	AR	2.02	Yes	1.18	littoral	yes	Plant depth
Lake Poerua	38 955	South	AX	2.13	Yes	0.53	25% of lake	yes	Estimate
Lake Poteriteri	26 036	South	AW	44.20	Yes	5.30	littoral	yes	Based on Hauroko
Lake Poukawa	35 662	North	AG	1.04	Yes	1.04	All	no	Shallow
Lake Pupuke	50 151	North	AB	1.04	Yes	1.04	All	no	Shallow
Lake Ronald	53 025	South	AW	1.16	Yes	1.16	All	yes	Shallow
Lake Rotoiti	27 762	South	AN	9.64	Yes	2.50	littoral	yes	Plant depth
Lake Rotokino	47 095	South	AX	1.43	Yes	1.43	All	yes	Shallow
Lake Rotongaro	49 186	North	AD	2.84	Yes	2.84	All	yes	Shallow
Lake Rotoroa	26 887	South	AN	23.61	Yes	4.60	littoral	yes	Plant depth
Lake Sheppard	39 357	South	AR	1.09	Yes	0.40	littoral	no	Plant depth

Lake name	Lake ID	Island	ESA	Area_km^2	Longfin access	Habitat area (km^2)	Area type	Within DOC Public Conservation Land	Comment
Lake Sumner	54 738	South	AR	13.73	Yes	2.24	littoral	no	Plant depth
Lake Taharoa	21 917	North	AA	2.04	Yes	2.04	All	no	Shallow
Lake Taharoa	12 876	North	AD	2.16	Yes	2.16	All	yes	Shallow
Lake Taylor	39 356	South	AR	2.07	Yes	0.77	littoral	no	Plant depth
Lake Tuakitoto	44 599	South	AV	1.32	Yes	1.32	All	no	Shallow
Lake Waahi	41 314	North	AD	4.45	Yes	0.40	10% of Lake	yes	Mostly SFE habitat
Lake Waihola	44 391	South	AV	6.08	Yes	0.60	10% of Lake	no	Mostly SFE habitat
Lake Waikare	50 782	North	AD	34.37	Yes	3.40	10% of Lake	no	Mostly SFE habitat
Lake Waipori	44 694	South	AV	1.84	Yes	0.18	10% of Lake	no	Mostly SFE habitat
Lake Wairarapa	1 708	North	AL	77.37	Yes	77.37	All	yes	Shallow
Lake Whangape	49 180	North	AD	10.79	Yes	1.70	16% of lake	yes	Shallow
Lake Widgeon	28 835	South	AW	1.73	Yes	1.73	All	yes	Shallow
Lake Wilmot	54 435	South	AX	2.32	Yes	2.32	All	yes	Shallow
Runanga Lake	36 215	North	AG	1.11	Yes	1.11	All	no	shallow
Wainono Lagoon	12 469	South	AT	3.99	Yes	0.39	10% of lake	no	Mostly SFE habitat
Waituna Lagoon	54 742	South	AW	13.59	Yes	1.30	10% of lake	yes	Mostly SFE habitat
Whakaki Lagoon	34 665	North	AG	4.75	Yes	0.47	10% of lake	no	Mostly SFE habitat
Manapouri*	54 735	South	AW	141.78	Yes	2.21	50% of littoral	yes	Migrant trap and release
Te Anau*	52 566	South	AW	342.97	Yes	9.00	50% of littoral	yes	Migrant trap and release
Total				1443.1		238.5			

Appendix 2: All New Zealand hydro lakes. Habitat is estimated for natural hydro lakes where longfin eels are thought to be present, from the littoral area based on the depth to which macrophyte plants are known to grow, or from total lake area for shallow lakes, or prorated total area. For man-made lakes where longfin eels are thought to have been present in relic rivers, the habitat was estimated from the original river bed using the REC2. ESA, Eel Statistical Area.

Lake name	Lake_ID	Island	ESA	Area (km^2)	Status	Area type	Habitat area (km^2)	Comment
Cobb Reservoir	24 969.00	South	AN	2.37	Man-made	River-REC	0.10	
Kapitea Reservoir	38 638.00	South	AX	3.40	Man-made	River-REC	0.02	
Lake Aniwhenua	39 876.00	North	AE	1.99	Man-made	River-REC	0.27	
Lake Arapuni	14 546.00	North	AD	8.27	Man-made	River-REC	1.25	
Lake Atiamuri	13 957.00	North	AD	2.03	Man-made	River-REC	0.00	No eels
Lake Aviemore	7 408.00	South	AU	28.34	Man-made	River-REC	1.41	
Lake Benmore	7 409.00	South	AU	75.85	Man-made	River-REC	1.86	
Lake Coleridge	48 451.00	South	AR	36.88	Man-made	River-REC	0.14	
Lake Dunstan	54 737.00	South	AV	26.73	Man-made	River-REC	3.68	
Lake Karapiro	14 680.00	North	AD	7.70	Man-made	River-REC	1.73	
Lake Mahinerangi	45 151.00	South	AV	18.17	Man-made	River-REC	0.17	
Lake Maraetai	13 876.00	North	AD	4.00	Man-made	River-REC	0.00	No eels
Lake Matahina	40 124.00	North	AE	2.18	Man-made	River-REC	0.36	
Lake Moawhango	18 610.00	North	AH	4.86	Man-made	River-REC	0.12	
Lake Monowai	29 244.00	South	AW	31.92	Man-made	River-REC	0.43	
Lake Ohakuri	13 970.00	North	AD	9.39	Man-made	NA	0.00	No eels
Lake Otamangakau	21 383.00	North	AH	1.56	Man-made	River-REC	0.02	
Lake Rotorangi	7 506.00	North	AJ	6.26	Man-made	River-REC	0.70	
Lake Roxburgh	7 633.00	South	AV	5.21	Man-made	River-REC	2.64	
Lake Ruataniwha	45 525.00	South	AU	3.49	Man-made	River-REC	0.25	
Lake Waipapa	13 857.00	North	AD	1.16	Man-made	River-REC	0.00	No eels
Lake Waitaki	12 307.00	South	AU	5.67	Man-made	River-REC	0.57	
Lake Whakamaru	13 873.00	North	AD	5.39	Man-made	NA	0.00	No eels
Diamond Lake	54 132.00	South	AV	1.77	Natural	NA	0.00	No eels
Green Lake	29 254.00	North	AW	4.83	Natural	Littoral	1.20	Estimate
Lake Alexandrina	47 193.00	South	AU	6.46	Natural	Littoral	3.00	Plant depth

Lake name	Lake_ID	Island	ESA	Area (km^2)	Status	Area type	Habitat area (km^2)	Comment
Lake Erskine	52 998.00	South	AW	1.05	Natural	NA	0.00	No eels
Lake Gunn	53 851.00	South	AW	2.71	Natural	Littoral	0.86	Plant depth
Lake Hankinson	52 666.00	South	AW	3.39	Natural	Littoral	0.09	Estimate
Lake Hawea	54 736.00	South	AV	151.77	Natural	Littoral	46.00	Plant depth
Lake Herries	51 985.00	South	AW	1.10	Natural	Littoral	0.50	Estimate
Lake Hilda	52 393.00	South	AW	1.00	Natural	Littoral	0.50	Estimate
Lake Kuratau	13 148.00	North	AD	1.03	Natural	NA	0.00	No eels
Lake Manapouri	54 735.00	South	AW	141.78	Natural	Littoral	4.50	Plant depth
Lake Mcivor	52 613.00	South	AW	1.67	Natural	NA	0.00	No eels
Lake Ohau	45 514.00	South	AU	59.27	Natural	Littoral	7.50	Plant depth
Lake Pukaki	46 564.00	South	AU	172.74	Natural	Littoral	3.50	Plant depth
Lake Rotoaira	21 367.00	North	AD	15.66	Natural	Littoral	12.30	Plant depth
Lake Taupo	54 734.00	North	AD	612.64	Natural	NA	0.00	No eels
Lake Te Anau	52 566.00	South	AW	342.97	Natural	Littoral	18.20	Plant depth
Lake Te Au	52 397.00	South	AW	1.56	Natural	Littoral	0.50	Estimate
Lake Tekapo	47 228.00	South	AU	96.59	Natural	Littoral	15.30	Plant depth
Lake Unknown	45 924.00	South	AV	1.08	Natural	NA	0.00	No eels
Lake Wahapo	46 964.00	South	AX	2.45	Natural	Littoral	0.45	Plant depth
Lake Waikareiti	40 396.00	North	AG	4.07	Natural	Littoral	0.47	Plant depth
Lake Waikaremoana	40 050.00	North	AG	49.86	Natural	Littoral	1.50	Plant depth
Lake Wakatipu	53 532.00	South	AV	298.25	Natural	Littoral	54.00	Plant depth
Lake Wanaka	54 672.00	South	AV	204.00	Natural	Littoral	15.00	Plant depth
Lochnagar	54 177.00	South	AV	3.04	Natural	NA	0.00	No eels
North Mavora Lake	53 353.00	South	AW	10.18	Natural	Littoral	4.20	Plant depth
South Mavora Lake	53 338.00	South	AW	1.63	Natural	Littoral	0.58	Plant depth
Total							205.9	

Appendix 3: Wetted area habitat (km^2) estimated from New Zealand natural lakes currently accessible to longfin, and the amount of this fished by Eel Statistical Area and Quota Management Area (QMA). Habitat from dammed natural lakes and man-made lakes is also shown, where the habitat from the latter is estimated from the original river bed using the REC2.

			Habitat (wetted area, km^2)			
			Lakes accessible to longfin		Dammed lakes inaccessible to longfin	
Island	QMA	ESA	Fished	All	Natural lakes	Man-made lakes (REC2)
North Island	LFE 20	AA	0.2	5.03	0	0
North Island	LFE 20	AB	0	2	0	0
North Island	LFE 21	AC	0	0	0	0
North Island	LFE 21	AD	3.84	11	12.30	2.98
North Island	LFE 21	AE	0	0	0	0.63
North Island	LFE 21	AF	0	0	0	0
North Island	LFE 22	AG	0	4	1.97	0
North Island	LFE 23	AH	0	0	0	0.14
North Island	LFE 23	AJ	0	0	0	0.7
North Island	LFE 22	AK	0	3	0	0
North Island	LFE 22	AL	0	84	0	0
North Island	LFE 22	AM	0	0	0	0
South Island	ANG 11	AN	0	7	0	0.1
South Island	ANG 11	AP	0	0	0	0
South Island	ANG 12	AQ	0	1	0	0
South Island	ANG 12	AR	5.21	10.1	0	0.14
South Island	ANG 13	AS	0	19.8	0	0
South Island	ANG 14	AT	0	4	0	0
South Island	ANG 14	AU	0	0	29.3	4.09
South Island	ANG 15	AV	0.18	6.4	115	6.49
South Island	ANG 15	AW	0	45.5	31.1	0.43
South Island	ANG 16	AX	3.6	35.6	0.45	0.018
North Island			4.04	109	14.3	4.4
South Island			8.99	129	175.9	11.3
New Zealand			13.03	239	190.1	15.7

Appendix 4: 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 South Island, North Island and New Zealand. River habitat used is that predicted by the >0.5 probability of capture model. Max, maximum. QMA, Quota Management Area.

			Percent (%)		
Island	QMA	Eel Statistical Area	Current habitat fished	Virgin habitat fished	Max. impacted abundance
North Island	LFE 20	AA	36.1	34.7	40.2
North Island	LFE 20	AB	34.9	33.8	38.2
North Island	LFE 21	AC	50.0	47.6	55.0
North Island	LFE 21	AD	43.2	34.4	55.7
North Island	LFE 21	AE	17.4	16.2	23.9
North Island	LFE 21	AF	8.6	8.2	13.6
North Island	LFE 22	AG	17.3	16.0	24.7
North Island	LFE 23	AH	24.8	23.6	29.9
North Island	LFE 23	AJ	17.0	15.9	23.6
North Island	LFE 22	AK	36.0	34.5	40.6
North Island	LFE 22	AL	4.2	4.1	5.0
North Island	LFE 22	AM	2.4	2.2	7.4
South Island	ANG 11	AN	11.5	11.1	15.5
South Island	ANG 11	AP	42.1	40.1	47.1
South Island	ANG 12	AQ	7.9	7.6	12.4
South Island	ANG 12	AR	58.1	55.9	61.7
South Island	ANG 13	AS	0.0	0.0	0.4
South Island	ANG 14	AT	38.6	37.3	42.1
South Island	ANG 14	AU	52.2	12.4	85.9
South Island	ANG 15	AV	46.2	12.5	82.8
South Island	ANG 15	AW	32.2	24.2	40.7
South Island	ANG 16	AX	30.2	29.0	34.0
North Island	All	All	22.5	20.9	29.0
South Island	All	All	32.5	21.8	52.6
New Zealand	All	All	27.2	21.4	42.1

Appendix 5: Estimates of total current longfin habitat fished, virgin habitat fished, and maximum impacted abundance from all rivers and lakes by Quota Management Area (QMA), and overall for South island, North Island and New Zealand. River habitat used is that predicted by the >0.5 probability of capture model. Max, maximum.

		Percent (%)		
Island	QMA	Current habitat fished	Virgin habitat fished	Max. impacted abundance
North Island	LFE 20	35.8	34.4	39.7
North Island	LFE 21	31.4	27.3	41.7
North Island	LFE 22	13.2	12.7	16.5
North Island	LFE 23	22.0	20.8	27.7
South Island	ANG 11	21.1	20.3	25.4
South Island	ANG 12	50.1	48.2	53.9
South Island	ANG 13	0.0	0.0	0.4
South Island	ANG 14	44.7	18.2	75.8
South Island	ANG 15	36.5	17.8	66.4
South Island	ANG 16	30.1	29.0	34.0
North Island	All	22.5	20.9	29.0
South Island	All	32.5	21.8	52.6
New Zealand	All	27.2	21.4	42.1