Habitat for female longfinned eels in the West Coast and Southland, New Zealand

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A B S T R A C T

Longfinned eels (*Anguilla dieffenbachii*) are endemic and widely distributed throughout New Zealand. They used to support significant Maori fisheries and were present in very high numbers in most waters. In recent times, land use changes, dams, and commercial fishing have reduced the stocks of large female longfinned eels and, as a consequence, the level of recruitment of juvenile eels to New Zealand may be declining. The objectives of this study were to estimate the amount of habitat present for adult and large female eels in lakes and rivers; and the amount of habitat in waters exposed to and protected from commercial fishing in the Southland and West Coast Conservancies of the Department of Conservation (DOC). There are about 84 000 km of rivers and streams in the West Coast and Southland, and over 10 000 lakes, ponds and tarns. The amount of potential habitat for adult and large female longfinned eels was estimated by calculating the tonnage of all sizes of longfinned eels in these waters. A regression equation, based on mean annual flows and river gradients, was developed using field data on the biomass of eels collected from a wide variety of rivers and streams in the West Coast and Southland and from other areas of New Zealand. The equation explained 64% of the variation in eel biomass (n = 130) and was a superior measure of habitat to suitability-of-use curves and other indices. Estimates of eel biomass per ha in the littoral zones of lakes were used to assess the total tonnage of eels and amount of potential habitat in these waters. About 7% of riverine habitat and 26% of lake habitat is totally protected in DOC reserves. However, because reserves tend to be concentrated in high-country and inland regions which support low densities of eels, the amount of longfinned eel habitat in New Zealand that is protected within DOC reserves is probably less than 10%. Therefore previous concerns about the adequacy of reserves for longfinned eels are still justified and additional measures may be required to ensure the stock is managed on a sustainable basis.

Keywords: longfinned eels, *Anguilla dieffenbachii*, eel habitat, eel escapement, West Coast, Southland.

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1. Introduction

Longfinned eels (*Anguilla dieffenbachii*) are endemic and widely distributed throughout New Zealand. They were present in very high numbers in most waters and supported significant Maori fisheries prior to European colonisation. Land use changes, dams, and commercial fishing have reduced stocks in many waters and raised concerns about the long-term sustainability of this species. In particular, large female longfinned eels are highly vulnerable to the cumulative effects of commercial fishing and are now found mainly in remote, unfished locations and small streams (Beentjes & Chisnall 1998; Jellyman et al. 2000, pers. obs.).

It has been suggested that the stocks of large female eels can be best sustained by the prohibition of commercial fishing, either in reserves or selected catchments (Jellyman et al. 2000). However, eel fishers have claimed that there is sufficient habitat in National Parks and reserves within the Department of Conservation (DOC) estate to sustain adequate stocks for reproduction and thereby maintain the recruitment of juvenile eels.

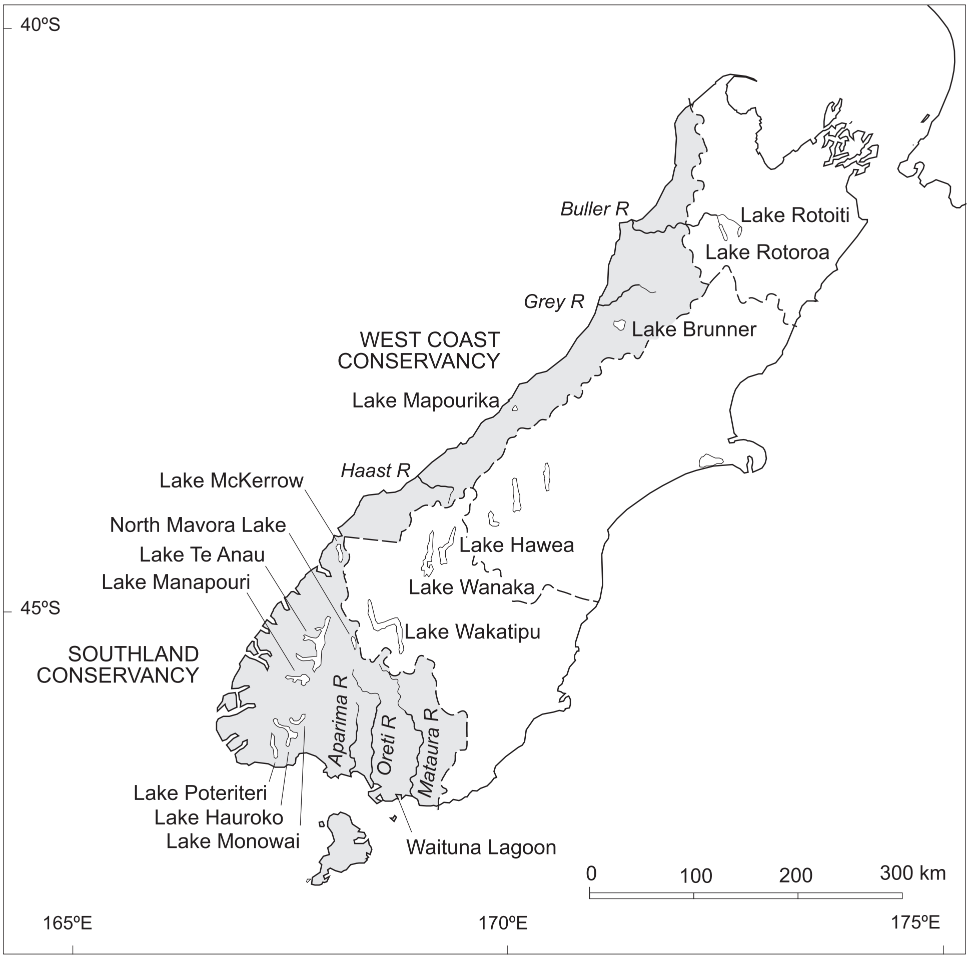
Previous estimates of the extent of areas closed to fishing in New Zealand were only approximate and were based on the length of rivers and areas of the main lakes (Jellyman 1993). However, in recent years a GIS-based, River Environment Classification (REC) database has been developed by NIWA for the Ministry for the Environment and Regional Councils (Snelder et al. 1999; Snelder et al. 2000; Snelder & Biggs 2002). The REC contains thousands of numbered and linked reaches, together with detailed information on climate, geology, land use, mean flows, gradients and other features. This presented a new opportunity to assess more accurately the extent of waters that were open and closed to fishing and the amount of protected eel habitat.

The objectives of this study were to:

- Develop suitability-of-use curves that could be used, in conjunction with GIS databases, to estimate the amount of habitat present for adult and large female eels in lakes and rivers;
- Estimate the amount of habitat in waters exposed to and protected from commercial fishing in the Southland and West Coast Conservancies.

The West Coast and Southland regions (Fig. 1) were selected for study because rivers in these regions were some of the first to be mapped using GIS techniques by NIWA and because they include diverse habitats and extensive DOC reserves.

Figure 1. Map showing West Coast and Southland Conservancies, Department of Conservation, as well as the rivers and lakes listed in Tables 8 and 11.



2. River habitats

2.1 ESTIMATION OF HABITAT FOR FEMALE LONGFINNED EELS

2.1.1 Habitat preferences

Longfinned eels are the largest freshwater fish present in New Zealand, and mature females range from about 750 mm to 1500 mm in length and up to 20 kg in weight. Large eels prefer deep (> 1 m), slow-flowing water (< 0.2 m/s) in rivers and have different habitat requirements from small juveniles (Jellyman et al. in press). During the day they usually seek cover under banks and tree roots (Glova et al. 1998) while at night they forage in slow-flowing water, feeding on fish and large invertebrates. Burnet (1952a) concluded that the highest biomass of large longfinned eels was found in ‘stable streams with good cover in the form of heavy weed growth, overhung banks, or deep, turbid water’. Moderate stocks were found in ‘streams of moderate stability, with some good cover’ whilst low stocks were found in ‘moderately stable to unstable streams, open shingle beds, and little cover other than a few pools’.

2.1.2 Biomass as an index of habitat for large female eels

The total biomass of eels was used as an index of the potential amount of habitat available for large female eels (> 700 mm) in both rivers and lakes. This index was chosen because the numbers of large eels were more closely related to total biomass than to total density. For example, Fig. 2 shows the good relationship ($R^2 = 0.77$) between the density of large eels (> 400 mm) and total biomass of all sizes of eels in the Aparima River, in Southland. The relationship with total density was less significant ($R^2 = 0.53$) because densities were strongly influenced by the numbers of small juvenile eels present.

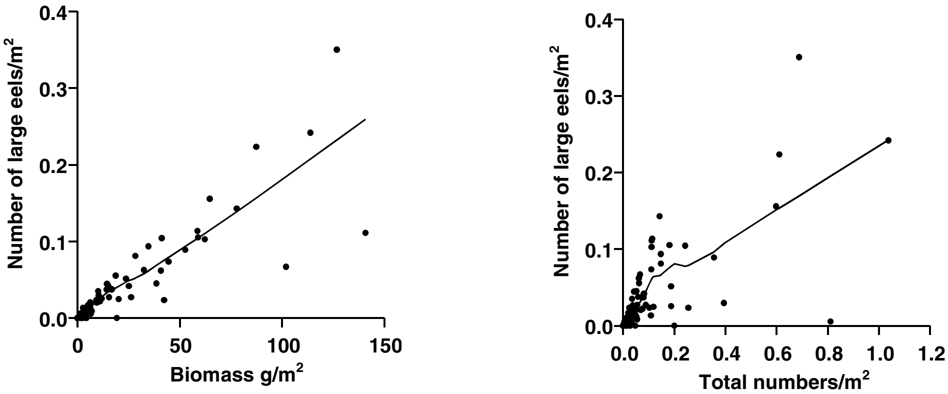


Figure 2. Relationship between the density of large eels (> 700 mm) and the total biomass and total density of eels present in sites within the Aparima River catchment, 2000/01 ($n = 83$)

Other potential indices of the amount of habitat present, such as counts of the numbers of females present and suitability-of-use curves, were considered but were rejected for various reasons.

The amount of female longfinned eel habitat could not be measured using information on the number of large females present (> 700 mm) because these eels are highly vulnerable to the cumulative effects of commercial fishing and are now scarce in heavily fished waters (Beentjes & Chisnall 1998; Jellyman et al. 2000). For example, large female eels (> 700 mm) constituted 27% of the biomass of eels present in small lightly fished tributaries of the Aparima River (< 0.5 m^3/s, $n = 56$) but only 0.7% of the biomass in larger, heavily fished, waters (> 0.5 m^3/s, $n = 32$). However, there is some evidence that the biomass of smaller eels may increase and compensate for the loss of large eels, due to improved density-dependant survival and growth rates. For example, some heavily fished waters contain a high biomass of small eels just under the size limit. Biomass is a measure of the productive capacity and is considered to be a better index of potential habitat than counts of the numbers of large females present.

Conventional suitability-of-use curves (Jowett & Richardson 1995) and habitat quality indices based on microhabitat features used in the Instream Flow Incremental Methodology (IFIM), such as water depths, velocities and substrates, cannot be used in the REC because this detailed information is not available. Indices based on the probability of longfinned eels being present (McDowall & Taylor 2000; Broad et al. 2001) were not used because longfinned eels are ubiquitous throughout the West Coast and Southland. It would also be impractical to estimate habitat from the numbers and biomass of migrating female eels within particular catchments (Burnet 1969) as this would involve the construction and maintenance of weirs.

Biomass statistics have other advantages over habitat indices and density estimates. GIS databases, such as the REC, contain accurate measurements of the length of each river reach and the area and perimeter of lakes. Biomass can be expressed as kg/km and kg/ha and used to calculate the total tonnage of eels present. Comparisons can then be made between rivers and lakes, and with commercial fishing yields. Therefore it was concluded that biomass was the best index of the potential amount of habitat available for adult and female longfinned eels.

Information on the biomass of eels in rivers was derived from historical records, collected prior to the development of commercial fishing, and from more recent surveys. Both sets of data were combined and used in the development of predictive models. The New Zealand Freshwater Fish Database (NZFFDB) was also inspected and used in preliminary attempts to develop new suitability-of-use models of the amount of adult eel habitat present (see Section 4).

2.1.3 Historical data on eel biomass

In 1937/38, over 10 000 longfinned eels averaging 711 mm and 1626 g were removed from 24.1 km of the Hedgehope River in Southland (Hobbs & Cairns 1938; Cairns 1941, 1942). A post-trapping survey showed the great bulk (> 90%) of the eels had been removed. The river supported 685 kg/km and at least 300 females/km, based on the proportion of large females (> 700 mm) in other rivers in Southland (Table 1) (Burnet 1952a).

Eel stocks in tributaries of the Waiau River, Southland, in 1947/48 were calculated from Burnet 1952a (Table 1). Stocks ranged from 19 kg/km and 8 females/km in the Upper Whitestone, an unstable shingle bed stream with shallow pools and no other cover, to 659 kg/km and 320 females/km in the Kakapo Stream, a deep, stable, stream with flax and other cover (Hobbs 1948; Burnet 1952a).

Sites in the Horokiwi and Wainuiomata streams in the Wellington region were electric-fished in the early 1950s (Burnet 1952b). The biomass of longfinned eels averaged 166 and 173 kg/km in these two streams, respectively.

TABLE 1. EEL STOCKS AND OTHER FEATURES OF WAIAU RIVER TRIBUTARIES IN SOUTHLAND. DATA FROM BURNET 1952a.

STREAM	DISTANCE FROM SEA (km)	ALT. (m)	WIDTH* (m)	EELS (km^{-1})*	MEAN WEIGHT (kg)	STOCKS (kg/km)	TRAPPED FISH, % (> 700 mm)	FEMALES (km^{-1})
Kakapo	120	255	5	387	1.71	659	82.8	320
Flaxy	115	250	2–22?	144	1.59	231	69.3*	99
Lillburn	32	70	22	145	1.45	211	59.4	86
Whitestone (lower)	118	250	22	102	1.51	154	54.7	56
Whitestone (upper)	130	340	22	15	1.24	19	54.7	8

* Estimates

Streams in the upper Whanganui system in the North Island were surveyed by electric-fishing in 1961 and 1962 (Woods 1964). Eels, mainly longfinned, were scarce and densities averaged 0.039/m^2. Few elvers reached these high-altitude streams (500–900 m elevation and 200–300 km from the sea), mean weights averaged 129.4 g and few large female longfins were present (3.6%). The biomass of eels present ranged from 5 kg/km for a 1 m wide stream to 50 kg/km for a 10 m wide stream.

2.1.4 Recent surveys

Quantitative electric-fishing surveys in three small coastal streams from 1996 to 1998 (Glova et al. 1998) showed stocks ranged from 6 to 25 large (> 700 mm) longfinned eels per km. The biomass of all sizes of eels ranged from 109 to 235 kg/km.

In February 2001 and 2002, 89 sites in tributaries and the mainstem of the Aparima River in Southland were electric-fished and data were collected on the size and abundance of longfinned eels present (Graynoth & Jellyman unpubl. data). The objective was to determine the numbers and biomass of eels per km and therefore techniques differed from normal surveys that normally aim to assess densities (n/m^2) (Richardson & Jowett 1996). All water types were fished for relatively long distances and sub-sampling techniques, using habitat measurements from aerial surveys, were used to estimate stocks in the braided mainstem. Also, special surveys were undertaken in very small streams to ensure all types of waters were adequately surveyed. The population of eels in three reaches of the Aparima mainstem and two tributaries was also assessed with fyke nets. Ten baited nets per site were fished at 40 m intervals for two to three consecutive nights and the total population was assessed by calculating the rate of depletion (Burnet 1952a).

Hans Eikaas (University of Canterbury) and Philippe Gerbeaux (DOC Hokitika) also made available data on the numbers and size of eels caught by electric-fishing at 31 sites in the Buller and Grey River catchments in January and February 2002. A 50 m long reach was stop-netted and the entire width of the stream was fished twice. Catches were converted to biomass of eels per km of river using data on stream widths, eel densities and mean weights.

2.1.5 Models of the biomass of eels

River Environment Classification variables

Regression equations were developed to predict eel biomass in the West Coast and Southland regions using variables listed in the REC (Table 2) and historical and recent data from the rivers listed above. The Whanganui River was excluded because there was insufficient information on the precise locations surveyed.

The rivers surveyed contained examples of most of the river types present in the West Coast and Southland. The sample contained a higher than expected proportion of lowland rivers draining pastoral catchments, and a lower than expected proportion of small streams draining high-altitude, indigenous forest and tussock catchments (unpubl. data). Nevertheless, the sample focused on waters where eels are most abundant and was of similar composition to NZFFDB electric-fishing records from these districts.

TABLE 2. RIVER ENVIRONMENT CLASSIFICATION (REC) VARIABLES CONSIDERED FOR USE IN REGRESSION EQUATIONS OF EEL BIOMASS. SEE SNELDER & BIGGS (2002) FOR DEFINITIONS OF VARIABLES

SCALE	VARIABLE NAME	TYPE	USED	COMMENT
Regional	Climatic zone	6 categories	No	West Coast and Southland are both cool humid climates
Topographic	Source of flow	8 categories	No	Data mainly from Hill and Lowland SOF
	Geology	> 14 categories	No	No relationship found to eel density and biomass
	Land use (cover)	> 8 categories	No	No relationship found to eel density or biomass
	River management units	> 32 categories	No	No relationship found to eel density or biomass
	Valley landform	3 categories	No	Valley slope categories. Reach gradient used instead
Reach				
Length	Length (m)	Continuous	Yes	Used to calculate stocks. Varies from 30 m to 9 km
Discharge	Catchment area (km^2)	Continuous	No	Used mean annual flow instead
	Stream order	6 categories	No	Also divided into 3 Network position classes
	Mean annual flow (m^3/s)	Continuous	Yes	Derived from area, rainfall and evaporation
	Mean annual low flow (m^3/s)	Continuous	No	Only available for Aparima catchment at present
Gradient	Reach slope (%)	Continuous	Yes	Some errors in GIS database. Arbitrary bounds of 0.1 and 50% applied
	Topographic wetness index	Continuous	No	log (km^2/slope) Can be used to identify ephemeral streams
Position	Mean altitude (m)	Continuous	No	Can substitute for gradient in models
	Distance from sea (km)	Continuous	No	Only important for eels < 300mm
Morphology	Channel morphology	10 categories	No	Difficult to determine from current GIS layers
	Width, depth and velocity	Continuous	No	Can be estimated from mean annual flow and gradient

Eel biomass equation

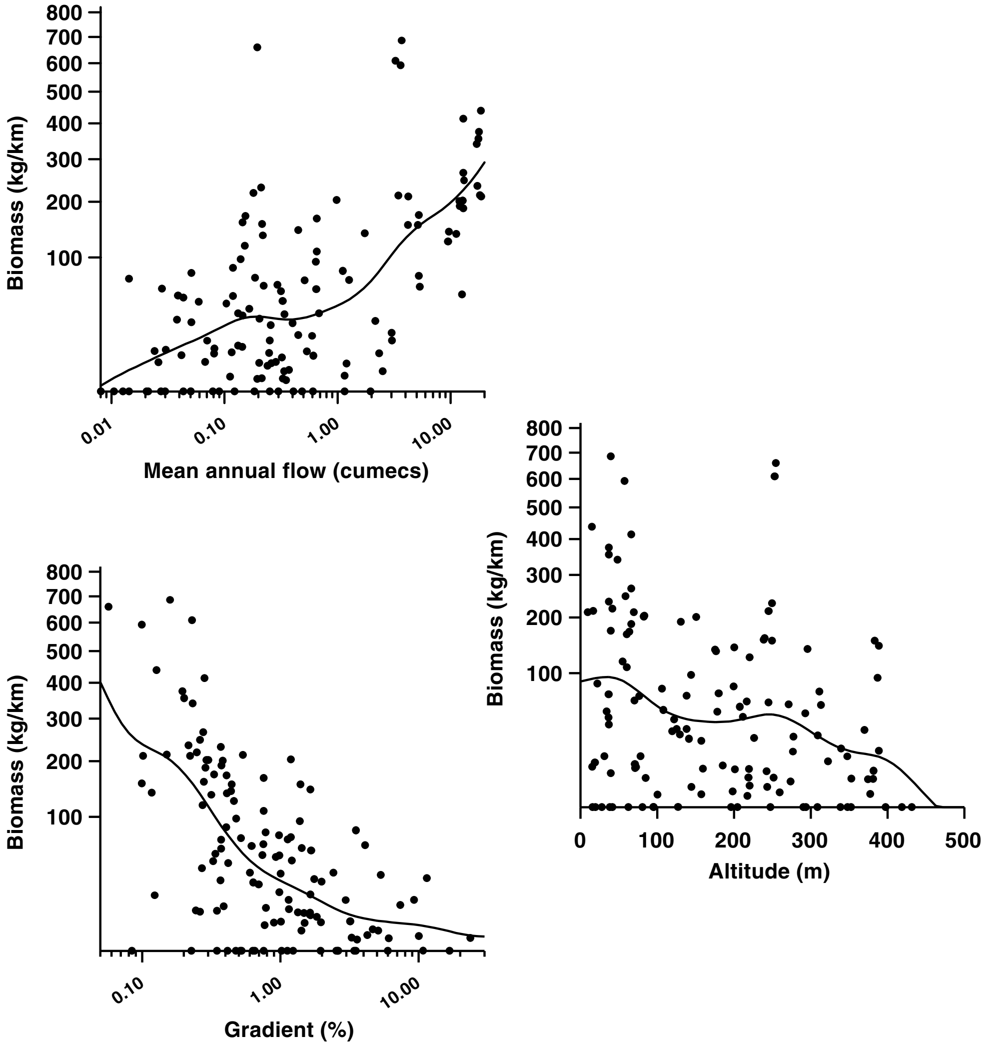
After a detailed consideration of various modelling options and the predictor variables available (Table 2) it was decided to focus on flow and gradient because of their over riding influence on river morphology and instream habitats (Rosgen 1994) and because of their strong correlations with eel biomass. The biomass of eels $(kg/km)^{0.5}$ was significantly correlated with mean annual flow ($r = 0.613$), reach gradient ($r = -0.605$), and to a lesser extent to altitude ($r = -0.29$), and several other variables (Fig. 3 and unpubl. data). Large rivers of gentle gradient contained a higher biomass of eels per km than small, steep, mountain streams.

Plots showed that the arithmetic biomass of eels per km of river increased in a linear fashion with the logarithm of mean annual flow F (L_n m^3/s) for rivers of similar gradient (Fig. 4). The minimum flow for eels to be present was about 10 l/s (mean annual flow). The equation was therefore formulated as a linear regression starting from a fixed origin. The gradient of this regression equation was negatively related to stream gradient G (L_n % slope).ie:

$$\text{Biomass} = \exp(a + b{*}G){*}\ (F + c)$$

An exponential relationship was used with constants a and b to ensure that the gradient of the regression equation, and hence biomass, did not become negative. The constant c adjusts flows to the fixed origin. Negative estimates of biomass at extreme low flows (< c) were corrected to nil.

Figure 3. Relationship between biomass of eels (kg/km) and mean annual flow (m^3/s, cumecs), reach gradient (% slope), and altitude (m). DWLS smoother, tension = 1 (Wilkinson 1999).



Parameters were estimated using the non-linear module in SYSTAT (Wilkinson 1999) (Table 3). The sites fished were not a random sample of the population of reaches in the REC and contained a higher than expected proportion of large low gradient streams and rivers. Also the variability in biomass was not constant and increased in reaches where eels were more abundant (Fig. 4). It was

Figure 4. Influence of reach gradient (% slope) on the relationship between the biomass of all sizes of eels (kg/km) and mean annual flow (cumecs). Biomass calculated at the means of four gradient categories.

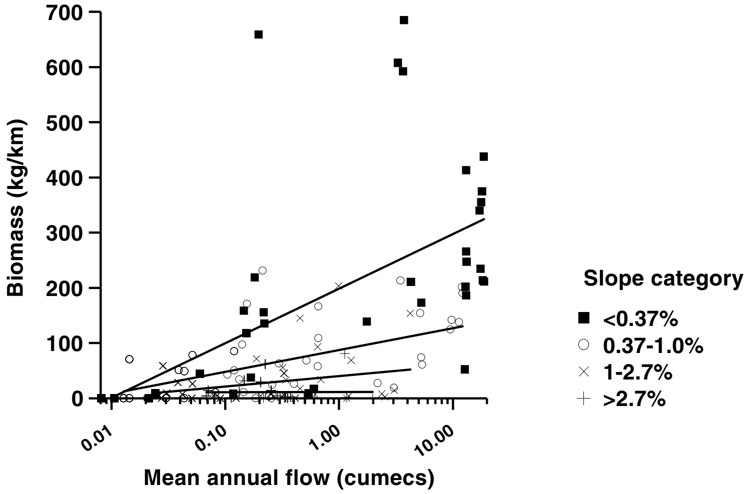


TABLE 3. PARAMETER ESTIMATES, ASYMPTOTIC STANDARD ERRORS (ASE) AND WALD 95% CONFIDENCE INTERVALS FOR EEL BIOMASS EQUATION.

PARAMETER	ESTIMATE	ASE	PARAM./ ASE	WALD CONF. INT. LOWER	WALD CONF. INT. UPPER
a	2.440	0.164	14.866	2.115	2.765
b	–0.805	0.086	–9.343	–0.975	–0.634
c	4.721	0.240	19.703	4.247	5.195

therefore decided to negatively weight data points according to mean flow and hence eel biomass. Weights were allocated to individual data points based on their sampling frequency and ranged from 1 for large rivers (>10 m^3/s) to 7 or more for small streams (c. 50 litres/s).

Confidence limits and residuals

The equation was a good fit to the data (R^2= 0.64, n = 130, Fig. 5). Residuals increased in proportion to the estimated mean with a coefficient of variation of 1.37. Therefore biomass and tonnage estimates have 95% confidence limits of about ±24%.

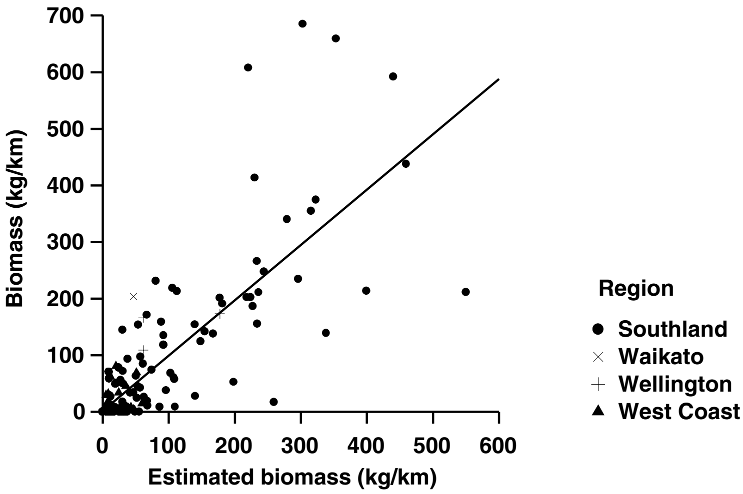


Figure 5. Comparison of observed biomass and expected biomass, by Regional Council district.

Residuals were not significantly related to REC variables such as altitude, distance inland, source of flow, geology or land use and therefore these factors were not included in the model. There was no information in the REC on factors such as instream habitats, minimum flows and flow variability that could be expected to influence eel biomass.

2.2 CLASSIFICATION OF REACHES IN THE REC

The West Coast, Nelson, Otago and Southland Conservancies supplied GIS shape files describing conservation land units within the DOC estate. Several different files (Table 4) were used because conservancy boundaries (Fig. 1) did not coincide with REC, catchment and Regional Council boundaries. After

TABLE 4. SHAPE FILES (POLYGONS) DESCRIBING THE STATUS OF DEPARTMENT OF CONSERVATION LAND.

CONSERVANCY	FILE NAME	SIZE (kb)	DATE
Nelson	Doc_nm_buller1	1590	29 Jan 02
	st_creek_ea_wc_accord	1	29 Jan 02
	Taswild	256	01 Sep 98
	vic_fp_wc_accord	39	29 Jan 02
West Coast	Consunitoverlying	1440	19 Nov 01
	cu_u	18600	17 Jan 02
Southland	Alldoc	14471	19 Feb 02
	Special areas	321	05 Apr 01
	Eco_areas	100	07 May 01

discussions with DOC staff, units were classified as legally closed or open to commercial eel fishing (Table 5).

DOC landuse files were processed and overlaid on the REC shape files for each Regional Council area (Appendix). A placeholder class also had to be created to account for significant gaps in the DOC database. The landuse polygons did not always match the REC reach polylines, possibly because of differences in the scale of data capture and for other reasons. For example, riparian reserves usually followed the course of the river but were sometimes up to 125 m distant possibly because the river had migrated across its floodplain. Therefore each reach was cut up into smaller sections (using the polygon boundaries) each of which was classified as 'open' or 'closed' to eel fishing. The total length of each type of section was then summed and the reach classified into 'open' or 'closed' by the predominant type (≥ 50%).

Waters were grouped into 4 classes:

Class 1: Waters that should not have been commercially fished (e.g. National Parks) and have safe egress for migrating female eels.

Class 2: Waters that are protected in their upper reaches but where migrants could be fished further downstream.

Class 3: Waters that are protected in their upper reaches but where migration either into or out of these areas is constrained by dams and other barriers.

Class 4: Waters that are commercially fished.

An ArcView programme was written to classify each reach by tracing the entire path downstream to the sea and analysing the classes of reaches encountered (Table 6). For example, if water flowed from a closed area into a reach where fishing was permitted, the upstream reach was classified as Class 2. This was a slow process and it took up to a month of continuous computer time to complete the classification of large catchments.

TABLE 5. LEGAL STATUS OF DOC LAND IN WEST COAST AND SOUTHLAND REGIONAL COUNCIL DISTRICTS AND CLASSIFICATION INTO OPEN AND CLOSED AREAS.

ACT AND LAND USE	CODE	EEL FISHING	NUMBER OF LAND UNITS	
			WEST COAST	SOUTHLAND
Conservation Act				
Amenity area	CAAA	Open	15	0
Conservation covenant	CACC	Open	8	5
Conservation Park	CACP	Open	4	96
Ecological area	CAEA	Closed	43	1
Marginal strip	CAMS	Open	252	782
State Forest	CAST	Open	604	953
Wilderness	CAWL	Closed	1	0
Wildlife management	CAWM	Closed	7	0
Conservation covenant	CFCC	Open	12	0
National Parks Act				
National Park	NPNP	Closed	7	945
Reserves Act				
Conservation covenant	RACC	Closed	21	22
Wildlife management reserve	RAGP	Closed	57	92
Historic reserve	RAHR	Closed	16	5
Cemetery and Gravel	RALP	Closed	353	616
Nature Reserve	RANT	Closed	3	99
Recreational Reserve	RARR	Closed	106	811
Scientific Reserve	RASI	Closed	1	37
Scientific Reserve	RASR	Closed	2	0
Scenic Reserve	RASRA	Closed	126	359
Scenic Reserve	RAPPL	Closed	0	8
Wildlife Act				
Wildlife Reserve	WARF	Closed	2	1
Islands	WAWS	Closed	1	0
			1641	4832

TABLE 6. CLASSIFICATION OF RIVER REACHES FOR EEL FISHING.

CLASS	DESCRIPTION	STATUS OF REACH TO EEL FISHING	DOWN-STREAM REACHES	UPSTREAM ACCESS
1	Reserve	Closed	Closed	Open
2	Migrants vulnerable	Closed	Open	Open
3	Access problems	Either*	Either*	Dam
4	Fished	Open	Either*	Open

* Includes closed and open reaches

2.2.1 Class 3 rivers and lakes above dams and waterfalls

A GIS map of the distribution and height of dams was derived from the New Zealand Dam Inventory (Anon. 1997) to assess whether either juvenile recruitment or adult out-migration was compromised. Dams less than 3 m in height were not listed and it was assumed they did not stop eel passage. It should be noted that eels can surmount some dams, such as the Arnold Dam, and a fish pass has been constructed in recent years on the Mararoa Dam below Lake Manapouri.

Recruitment into lakes and rivers can also be hampered by waterfalls, and possibly by subterranean outlets, such as at Lake Christabel (Johnson et al. 1976). Although the explorer Charles Douglas 'found eels in Alpine Lakes where the outlet stream went over falls sheer down for hundreds of feet' (McDowall 1980), eel recruitment and hence stocks will be reduced in these circumstances. Small eels (< 120 mm) can climb vertical surfaces (Jellyman 1977) and probably surmount waterfalls of 20 to 40 m in height (McDowall 1990) but will be blocked by very swift rapids and gorges (Cairns 1941; Hobbs 1948; McDowall 1990).

No attempts were made to identify the location of waterfalls or rapids using GIS data on discharge and gradient. Firstly, the ArcView programme that identifies the character of all downstream reaches would have to be re-run for all waters. This would be a slow procedure. Secondly, false measurements of high gradients are often recorded in the GIS database and these errors would have to be identified and filtered out. Finally there was insufficient information on the extent to which eels can surmount rapids and waterfalls of different height and character.

2.2.2 Results of the classification of rivers

The total area closed to fishing is about 16% of the 5.5 million ha of land in the West Coast and Southland regions. Rivers that are fully protected in the West Coast and Southland (Class 1) are:

- Small coastal streams south of Kahurangi Point and south of the Heaphy River.
- Five Mile Creek and Company Creek.
- Small streams south of the Waikukupu River.
- Lower reaches of the Ohinetamatea Creek.
- Most rivers and streams in Fiordland National Park from the Kaipo River south to the Waitutu River.
- Most rivers and streams in Stewart Island.

Many rivers had their headwaters classified in Class 2. Some of these rivers (such as the Heaphy, Hollyford and Wairaurahiri) might be fully protected and put into Class 1 if there was little or no fishing for migrant eels in the lower reaches. Rivers above dams (Class 3) include the Arnold, upper Waiau and Monowai Rivers, while fished areas (Class 4) includes much of the Buller, Grey and other large West Coast Rivers, together with most of Southland to the east of Fiordland National Park.

2.3 EEL BIOMASS AND POTENTIAL HABITAT AVAILABLE IN RIVERS

The biomass and tonnage of eels was estimated for over 117 000 reaches totalling 84 000 km in length in the West Coast and Southland (Table 7). For the West Coast and Southland, the mean biomass was 47 and 37 kg/km, respectively.

TABLE 7. TOTAL RIVER LENGTH (km) AND ESTIMATED TONNES OF ALL SIZES OF EELS IN WEST COAST AND SOUTHLAND RIVERS BY FISHING CLASS (SEE TEXT FOR DEFINITIONS)

FISHING	WEST COAST		SOUTHLAND		TOTAL	PERCENTAGE
CLASS	LENGTH	TONNES	LENGTH	TONNES	TONNES	TONNES
1	410	15	9822	220	235	7
2	13645	312	3048	85	397	11
3	986	71	7844	242	313	9
4	25327	1487	23338	1105	2592	73
Totals	40368	1885	44052	1652	3537	100

The highest biomass of eels was found in coastal rivers and streams, and lower numbers were found in inland waters at high altitudes. The average biomass of eels and numbers of reaches present declined with altitude (Fig. 6). If it is accepted that biomass is a reasonable estimate of the amount and quality of female longfinned eel habitat present, then about 7% of the eel habitat in rivers and streams in the West Coast and Southland is fully protected (Class 1, Table 7). If it is assumed migrating eels in Class 2 are not caught, this rises to 18%, and if some migrating eels manage to bypass the Arnold Dam below Lake Brunner and the Mararoa Weir (Jellyman 1993), perhaps 20% of river dwelling female migrants might be protected against fishing. However, the majority of habitat is found in the lowland areas and about 73% of the total habitat in rivers is open to commercial fishing.

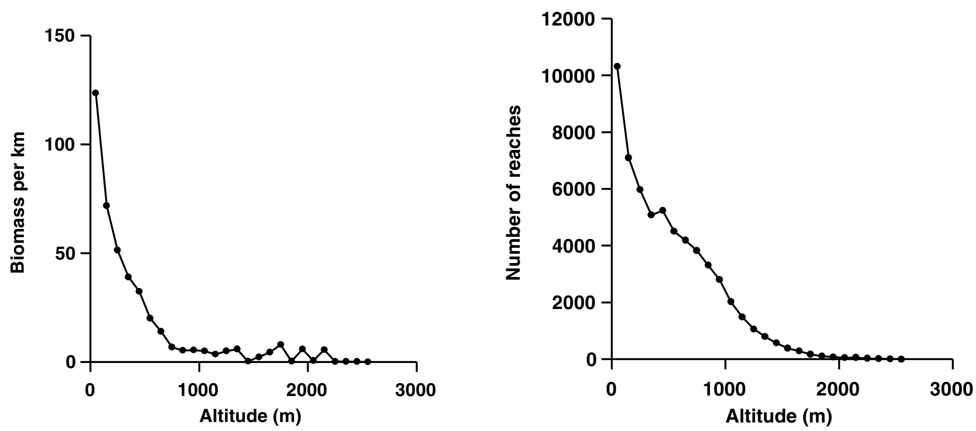


Figure 6. Reduction in the number of reaches and mean biomass per km of river with increasing altitude in the West Coast region.

No specific analysis was undertaken to determine the proportion of unfished habitat in Class 3 waters. Examination of the shape files suggests that less than 10% of the habitat in the West Coast is protected. In Southland about 40% is protected, mainly in the western tributaries of Lakes Te Anau, Manapouri, and Monowai. However, the Maroroa River, Upukeroroa River, and southern tributaries of the Eglington River are open to eel fishing and these probably hold a higher biomass of eels than tributaries in the Fiordland National Park.

3. Lake habitats

3.1 ESTIMATION OF HABITAT IN LAKES

3.1.1 Methods

The West Coast and Southland regions contain some of the largest and deepest lakes in New Zealand (Irwin 1975). There are 22 large lakes exceeding 1 km^2 in the West Coast, 33 in Southland, and over 10 000 lakes, ponds and tarns in total.

Although eels can be caught using eel pots in deep water, most eels live in the shallow and productive littoral zone of lakes (Jellyman 1989, 1996). Information on the biomass of eels in the littoral zone was derived from statistics on commercial harvests of eels and from estimates of the biomass of eels in lakes and large rivers. Tonnages were calculated by multiplying biomass by the area of the littoral zone.

3.1.2 Commercial harvests of eels

There are no official statistics of eel harvests from New Zealand lakes, with the exception of Lake Ellesmere. However, this is an atypical shallow, brackish lake and it is difficult to estimate the extent of the productive littoral zone. Assuming a littoral zone of 15 800 ha, then yields in recent years average about 6 kg/ha/yr (Jellyman et al. 1995). This is considerably lower than the yields of 13 to 25 kg/ha/yr from coastal lagoons in Italy (Rossi et al. 1988).

Victor Thompson, an eel processor in Southland, and Dave Richardson, a commercial fisher (Beentjes 1998), provided estimates of the total harvest of eels over the past 30 years from three large South Island lakes (Table 8). Lake Wanaka appears to produce more eels per ha of littoral habitat (18 kg/ha/yr) than lakes Wakatipu (3 kg/ha/yr) and Hawea (1.4 to 2 kg/ha/yr).

TABLE 8. EEL HARVEST (TONNES) ESTIMATED BY COMMERCIAL FISHERS OVER 30 YEARS IN THREE SOUTH ISLAND GLACIAL LAKES.

LAKE	EST. TOTAL HARVEST (tonnes)*	LITTORAL AREA (ha)**	TOTAL HARVEST (kg/ha)	ANNUAL YIELD (kg/ha)
Wakatipu	500	5464	91	3
Wanaka	800	1507	531	18
Hawea	200**–300	4654	43–64	1.4–2

* Victor Thompson pers. comm. ** Beentjes et al. (1997, 1998)

Annual yields in these lakes appear to be similar to those from inland lakes in Europe and North America where yields range from 3 to 10 kg/ha (Tesch 1977). Based on these overseas studies, oligotrophic lakes in New Zealand should yield about 5 kg/ha/yr provided they are adequately stocking with juvenile eels (Beentjes et al. 1997).

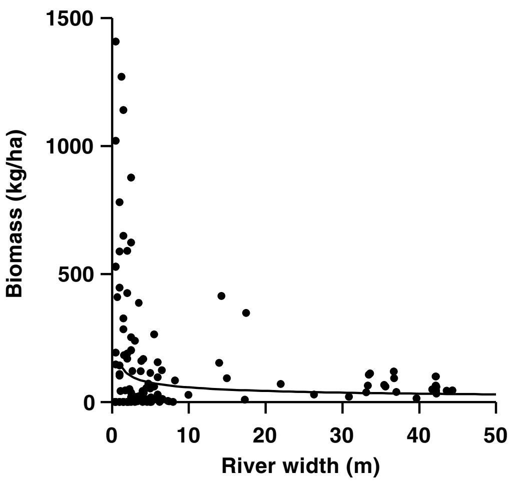
3.1.3 Biomass of fish in lakes

Although many New Zealand lakes supported high numbers of large longfinned eels (Hobbs 1947; Hobbs 1948; McDowall 1980, 1990; Parsons & Hammond 1989), stocks have probably declined because of commercial fishing but also as a result of dam construction and environmental changes (Jellyman et al. 1995; Beentjes et al. 1997). However, there are few statistics available on the biomass of eels in New Zealand lakes. Eel stocks in Lake Pounui in the Wairarapa could not be estimated using mark–recapture techniques because tagged fish did not randomly redistribute through the population (D.J. Jellyman pers. comm.) and although similar methods were also used to estimate eel stocks in Pukepuke Lagoon (Castle 1972) details of the results were never published. Some biomass data are available for other fish. Upland bullies were present at 220 kg/ha in a small tarn in Canterbury (Staples 1975; Downing & Plante 1993) and the littoral zone of Lake Coleridge supports about 7 kg/ha of salmonids (Graynoth 1999).

The biomass of American eels in lakes varies from 0.2 to 79 kg/ha, with the exception of the shallow and productive Lake Champlain in Vermont (161–421 kg/ha) (La Bar & Facey 1983). Carss et al. (1999) recorded that European eels ranged from 14 to 40 kg/ha in shallow lochs (< 1.5 m) near Aberdeen in Scotland.

Most West Coast and Southland lakes are either oligotrophic or dystrophic (Jolly & Brown 1975; Viner 1987) with low concentrations of total phosphorus (McColl 1972; Downing & Plante 1993). Total phosphorus concentrations in four lakes ranged from 4.1 µg per litre in Lake Rotoiti to 9.9 µg per litre in Lady Lake (Burns & Rutherford 1998). Based on these total phosphorus levels and equations in (Downing et al. 1990; Randall et al. 1995), West Coast and Southland lakes may support about 16 kg/ha (range 7 to 29) for all fish species combined.

Figure 7. Biomass of longfinned eels (kg/ha) in relation to river width, Aparima River and tributaries.



Large eels tend to be found near the banks of large rivers, a similar pattern to that found in lakes. Therefore large rivers provide a useful insight, in the absence of other data, on eel biomass in lakes. The biomass of longfinned eels per unit area (kg/ha) is highest in small streams and declines in large rivers (Fig. 7). The average biomass is about 60 kg/ha for rivers more than 20 m wide (n = 22, SD 30).

3.1.4 Biomass values used

We used the 60 kg/ha biomass estimate derived from studies in large rivers because this is similar to cumulative harvests in Lakes Wakatipu and Hawea and would support the long-term annual yields of about 3 to 10 kg/ha observed in New Zealand and Northern Hemisphere lakes. The biomass estimates of 16 kg/ha from total phosphorus levels and 7 kg/ha from salmonids in Lake Coleridge are insufficient to support commercial eel harvests. This is an approximate estimate and could be subject to an error of ± 50%.

3.1.5 Littoral zones and the biomass of eels per km of shoreline

The width of the littoral zone in lakes depends upon water clarity and bathymetry. Examination of 28 South Island lakes listed in Beentjes et al. (1997) indicates that the average littoral zone is about 150 m wide (SD 100, range 30 to 380 m). This excludes turbid lakes such as Pukaki and exceptionally shallow lakes such as Ellesmere. The tonnage of eels was calculated using a value of 900 kg/km of shoreline, derived from a biomass of 60 kg/ha and a littoral width of 150 m. For lakes with an area/shoreline ratio (km^2/km) of less than 0.15, the littoral zone was assumed to include the entire lakebed. These were generally tarns and small lakes with an area less than 0.6 km^2 and shoreline less than 4 km in length.

3.1.6 Decline in biomass at high altitudes

Eel production and biomass in lakes may decline with altitude because of low water temperatures (Woods 1964) and access problems. Some high-altitude tarns are both inaccessible and colder than 10°C for much of the year, the temperature at which growth ceases (Graynoth & Taylor 2000). However, most large lakes are situated at low altitudes. About 88% of the total lake area in Southland is below 250 m and most lakes in the West Coast are also situated at low altitudes, with the exception of Lakes Rotoiti and Rotorua and Christabel (620, 459, and 660 m, respectively). Therefore biomass estimates were not adjusted to compensate for the effects of altitude.

3.2 CLASSIFICATION OF LAKES

Information on lake area and perimeter was derived from the 1:50 000 NZMS 260 Map Series (New Zealand Vector Topographic Database, Alllake.shp, 6 Dec 2001, digitised and distributed by Eagle Technology). Okarito Lagoon and some other saline coastal lagoons are not included in this database but probably support relatively few longfinned eels (Jellyman 1993). Lakes were allocated to the four classes described earlier by overlaying REC polylines over lake polygons (Table 9). Lakes were classified according to the predominant class of tributaries entering the lake and from lists of waters 'open' and 'closed' to fishing (Tai Poutini Tuna 1999). Lake Mahinapua was classed as 'open' to commercial fishing although ownership will be transferred to Ngai Tahu under the Crown Deed of Settlement.

This method excluded many small alpine tarns, farm ponds and goldmining dredge holes that had no significant outlet streams. These waters comprised

TABLE 9. TOTAL AREA, PERIMETER AND MEAN ALTITUDE OF LAKES IN THE WEST COAST AND SOUTHLAND BY FISHING CLASS (SEE TEXT FOR DEFINITIONS).

REGION	CLASS	NUMBER	TOTAL AREA (km^2)	TOTAL PERIMETER (km)	MEAN ALTITUDE (m)
West Coast	1	11	1	17	255
	2	240	82	328	787
	3	20	49	98	202
	4	508	35	417	284
	Total	779*	168	861	436
Southland	1	2016	137	1120	436
	2	307	110	307	613
	3	894	575	1198	624
	4	3639	14	702	204
	Total	6856	836	3327	391

* Excludes small ponds and tarns in the West Coast with no tributaries or outlet streams

less than 10% of the surface area of lakes in these regions and many may have contained no eels because of access problems. For Southland, we classified these waters according to the class of rivers nearby (Table 9). This was a laborious task and we did not consider it worthwhile doing this for the West Coast.

The extent of littoral areas could not be estimated either from bathymetric maps or maximum depths (Irwin 1975) and there were inadequate data to classify lakes by trophic status.

3.3 HABITAT IN DIFFERENT CLASSES

Lakes that are closed to commercial fishing in the West Coast include (in order of decreasing area) Rotoroa, Kaniere, Rotoiti, Mapourika, Ianthe, Wahapo, Moeraki, Haupiri, Poerua and Rotokino. In Southland, closed lakes include Te Anau, Manapouri, Hauroko, Poteriteri, Monowai, McKerrow, Waituna Lagoon, and Lakes Hakapoua and Alabaster. However, Maori are able to harvest eels for customary purposes from many of these lakes, and for others, either migrant eels can be potentially harvested (Class 2) or access is compromised (Class 3).

Southland supports the greatest amount of Class 1 habitat, where eels are protected from source to sea. The total biomass of eels in protected lakes may exceed 500 tonnes (Table 10) and this includes about 100 tonnes of eels in Lake Poteriteri and the Waituna Lagoon (Table 11). Other protected lakes include Hakapoua (17 t), Ada (14 t), Cadman (9 t), Marchant (8 t), Alice (8 t) and Monk (8 t) and over a thousand small lakes and tarns (Table 9). In the West Coast, less than 20 tonnes is fully protected (Mueller 3 t, Lake Gault 3 t). For both districts combined, about 26% of the potential eel habitat in lakes, tarns and ponds is

TABLE 10. BIOMASS (TONNES) OF EELS IN LAKES AND TOTALS FOR BOTH RIVERS AND LAKES IN THE WEST COAST AND SOUTHLAND.

CLASSES	LAKES				RIVERS,	LAKES PLUS RIVERS	
	SOUTHLAND	WEST COAST	TOTAL	PERCENT	TOTAL	TOTAL	PERCENT
1	515	9	524	26	235	759	14
2	192	214	406	20	397	803	14
3	799	84	883	44	313	1196	22
4	76	127	203	10	2592	2795	50
Total	1582	434	2016	100	3537	5553	100

TABLE 11. TONNES OF LONGFINNED EELS IN MAJOR RIVER CATCHMENTS AND LAKES IN THE WEST COAST AND SOUTHLAND.

RIVERS	TONNES	LAKES	CLASS	TONNES
Buller	384	Rotoiti	2	22
Grey	333	Rotoroa	2	30
Haast	102	Brunner	3	42
Aparima	118	Mapourika	2	16
Oreti	300	McKerrow	2	33
Mataura	354	Poteriteri	1	61
		Hauroko	2	88
		Monowai	3	55
		Manapouri	3	148
		Te Anau	3	333
		North Mavora	3	24
		Waituna Lagoon	1	38

totally protected in Class 1 (Table 10). Another 20% of the habitat is classified as 2 and 43% as Class 3.

The total biomass of eels present in rivers and lakes is estimated at about 5600 tonnes of which about 14% is totally protected in Class 1 waters (Table 10). Another 14% is in Class 2, 22% in Class 3, and 50 % in waters open to fishing.

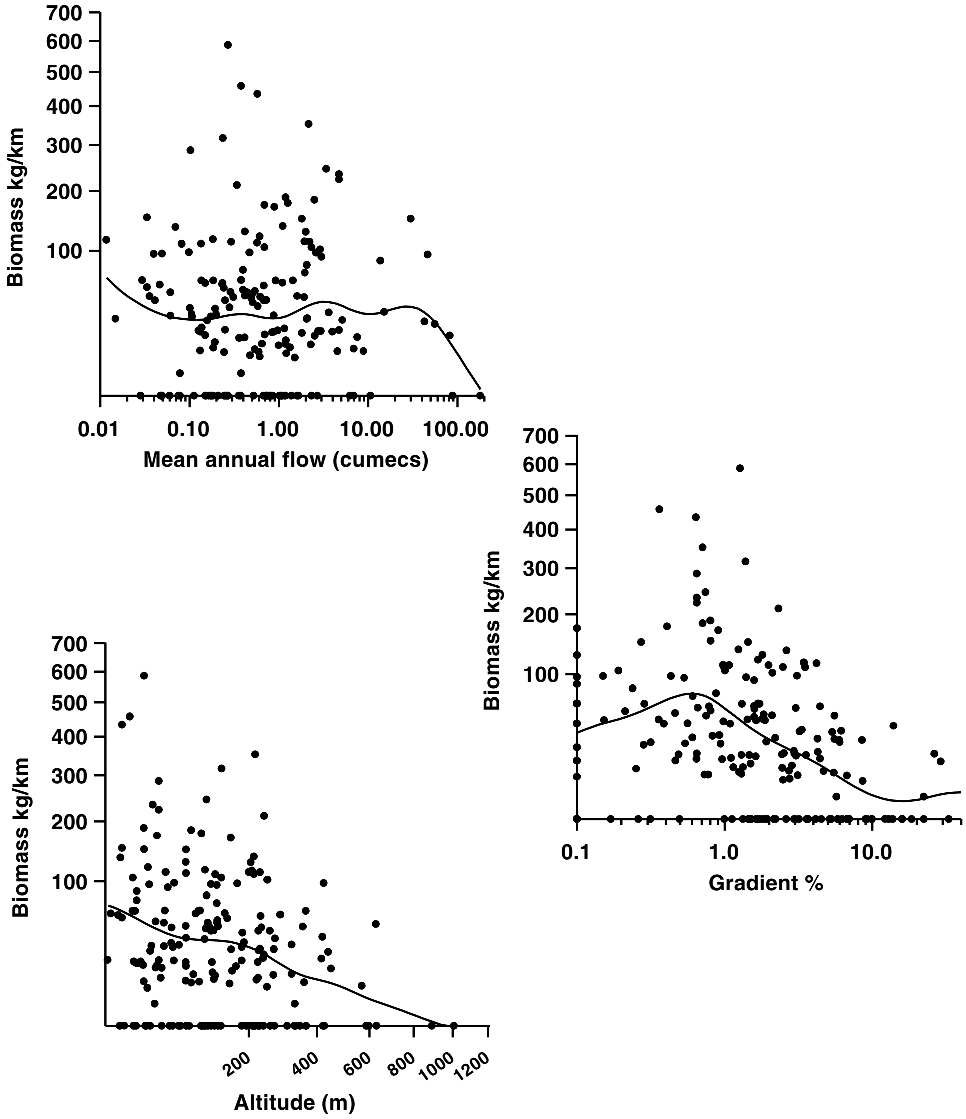
4. Models derived from the New Zealand Freshwater Fish Database

The New Zealand Freshwater Fish Database (NZFFDB) contains a large amount of information on the distribution and relative abundance of fish throughout New Zealand. Because of its extensive geographical coverage the database was inspected and used in preliminary attempts to develop new suitability-of-use models of the amount of adult eel habitat present in rivers.

On 20 July 2001, the database contained information from 1627 sites electric-fished throughout the West Coast and Southland. Longfinned eels were found at 1203 of these sites, and 436 contained measurements of the area fished and numbers of eels caught. Despite the large amount of material available, it proved impossible to develop accurate suitability-of-use models of the amount of adult eel habitat present. There was often insufficient information on the area and types of water electric-fished, the intensity and efficiency of electric-fishing, and the numbers, size distribution, and weight of longfinned eels caught. There was a bias towards shallow water, because of electric-fishing, and a high proportion of sites had to be excluded because of inadequate fishing effort. Also, exact linkages between NZFFDB sites and REC reaches were difficult to determine.

Attempts to accurately predict eel biomass per km using a subset of the best data were also unsuccessful. Densities were calculated for 187 sites in the West Coast where the precise REC reach had been identified and where more than 50 m^2 had been electric-fished. Mean weights of eels were estimated from mean weight and flow relationships developed in the Aparima River, and river widths were calculated from flows and hydraulic equations (Jowett 1998). Biomass declined with increasing gradient (r = – 0.61) and altitude (r = – 0.29) (Fig. 8), as in the previous studies. However, the relationships were less significant and there was no increase in biomass with flow (r = 0), possibly because of the techniques used to electric fish large rivers. The results were unrealistic as they indicated small streams were of equal value to large rivers as eel habitat. Also there was no relationship between NZFFDB results and biomass calculated using the equation described earlier in this report. It was therefore concluded that accurate, GIS based, models of the amount of adult longfinned eel habitat in the West Coast and Southland could not be developed at present using the NZFFDB.

Figure 8. Relationship between the NZFFDB estimates of the biomass of eels (kg/km) and mean annual flow (cumecs), gradient (slope %), and altitude (m) in the West Coast region.



5. Discussion

5.1 DATA USED

The data used were carefully selected in order to meet the objectives of this study. Good samples were collected from rivers in both the Southland and West Coast Districts and new electric-fishing and fyke netting techniques were employed to estimate eel stocks in large rivers. In tributaries, all water types present, including pools, were fished. Historical data were also used to indicate the potential value of rivers that had not been commercially fished and to balance out some sites that might have been fished just prior to our field surveys.

Commercial fishing will almost certainly have had some impact of the biomass of eels present. The calculated tonnages are not precise estimates and should not be used for fisheries management without further studies to validate them. At present they should be regarded as a relative index of the potential value of these waters for the rearing of adult and large female eels.

5.2 STATISTICAL MODELS

To predict biomass in rivers, various statistical models were tested using combinations of categorical and continuous data (unpubl. results). Analysis of variance, covariance and other models that used categorical variables, such as source of flow, geology, and land use, were of little value because accurate information on eel stocks was not available for uncommon combinations of different categories. Also, rivers can be regarded as ecological continuums with diffuse boundaries and it is difficult to classify them into discrete communities using biological features (Biggs et al. 1990). The regression equation used was more versatile than some other models and can be used to estimate eel stocks at both small and large spatial scales and in habitats that are impossible to survey, such as deep rivers.

5.3 REC VARIABLES USED

Eel biomass in rivers was predicted using mean annual flow and gradient, two factors that have an overriding influence on hydraulic features (stream width, depth and velocity) and morphological features (water types and substrates) (Rosgen 1994) that control the amount of instream habitat and food supplies available for eels and other fish.

Although eel biomass declined with increased altitude (Figs 3 and 6), altitude was not used because residuals from the final equation were unrelated to altitude. Rivers were smaller and steeper in their headwaters than in their lower reaches. However, although rivers at high altitudes (> 500 m) may contain less eels than comparable rivers at low altitude (because they are colder and further from the sea, Broad et al. 2001), until more information is available it is not possible to take this into account. Fortunately there are relatively few high-altitude rivers and streams (> 500 m) present in the regions studied and tests showed that the equation used might overestimate total stocks by an insignificant percentage (< 2%).

Catchment geology, land use, and source of flow had no significant influence on eel biomass in this study. Other investigations have shown that eel densities and growth rates are higher in warm, productive, pastoral streams than in cold, forested headwaters (Hicks & McCaughan 1997; Broad et al. 2001). Also, source of flow and geology were identified as important factors influencing invertebrate density and community structure in Canterbury and Waikato streams (Suren et al. 2000) and water quality in Canterbury (Snelder & Guest 2000; Snelder et al. 2000). More detailed studies on streams of comparable size and gradient would be needed to measure the influence of these factors on eel biomass.

6. Implications for management

6.1 ESCAPEMENT OF FEMALE LONGFINNED EELS FROM CLASS 1 HABITAT

This study shows that about 14% of the total biomass of longfinned eels in the West Coast and Southland is totally protected within DOC reserves. It was assumed that a similar proportion of potential habitat for female longfinned eels is protected. Most of this habitat is situated in a few large lakes such as Lake Poteriteri and the Waituna Lagoon.

It is extremely difficult to determine the total escapement of mature female longfinned eels from these areas without a large and expensive field programme. Computer simulation models (unpubl.), based on data from the Aparima River, indicate that a population of 7500 female eels (> 700 mm) produces about 240 migrants each year. This equates to about 5.7% of the biomass of female eels and about 1% of the biomass of all sizes of eels. In unfished populations, the proportion of the total biomass may be a little higher, depending upon growth rates and the size distribution of eels present (Downing & Plante 1993). Therefore, perhaps 2200 migrant female eels, averaging 3.4 kg, are produced each year from the 759 tonnes of eels protected in Class 1 habitat (Table 10).

6.2 ESCAPEMENT OF FEMALES FROM CLASS 2 HABITAT

About 14% of the biomass and potential habitat for female longfinned eels is protected in Class 2 waters. This includes many large lakes such as Rotoiti and Rotoroa and the headwaters of rivers such as the Karamea, Buller, Gowan, Matiri, Hollyford, Wairarurahiri, and Lords Rivers. Many waters such as Lakes McKerrow and Hauroko were classified as Class 2 because of a narrow (100 to 500 m wide) strip of non-DOC land adjacent to the coast.

Adult eels are believed to be territorial and non-migratory (Chisnall & Kalish 1993), and therefore eels living in the headwaters of these rivers should be unaffected by commercial fishing in the lower reaches. It also seems unlikely that many mature eels will be caught during their downstream migration to the sea. This normally occurs in autumn after rainfall (Todd 1981) and migrants are rarely caught in fyke nets, being most vulnerable to specially constructed weirs that are not used nowadays (Buck 1950; Moriarty 1972).

It seems reasonable to assume that most of the migrant female eels in Class 2 waters in the West Coast and Southland will be protected from the impacts of current commercial and customary fishing practices. Nevertheless, in order to maximise the escapement of mature female longfinned eels from Class 2 waters, fisheries managers might need to consider prohibiting the catching and killing of migrant female longfinned eels in the mainstem and lower reaches of selected Class 2 catchments.

6.3 ESCAPEMENT OF FEMALES FROM CLASS 3 HABITAT

Access to approximately 22% of longfinned eel habitat has been modified by the construction of hydro and other dams. This includes Lakes Te Anau and Manapouri that may support about 500 tonnes of eels and about 9% of the total habitat. Most of the eels migrating from Lakes Manapouri and Te Anau will probably be killed while passing through the turbines at Deep Cove. However, about 500 adult eels are netted each year and transferred downstream to the Waiau River (Caroline Spooner-Kenyon pers. comm.) and an unknown number pass downstream either over the Mararoa Weir or through the fish pass (Jellyman 1993).

6.4 ESCAPEMENT OF FEMALES FROM CLASS 4 HABITAT

About 50% of the eel biomass and hence female longfinned habitat is legally open to commercial fishing (Table 10). This is mainly in large rivers in such as the Buller, Grey, Mataura, and Oreti (Table 11). Studies in the Aparima River catchment indicate that small tributaries, with mean flows less than 0.5 m^3/s, are unlikely to be fished (Fig. 9) and may contain reasonable numbers of large female eels. Also, some streams and rivers in State Forests are inaccessible and will not be fished. If it assumed that streams with mean annual flows of less than 1 m^3/s are not fished, this totals about 660 tonnes of eels or about 14% of the habitat in both districts. Provided that mature eels can escape to sea, these small streams may be of equivalent value to all Class 1 waters protected in DOC reserves.

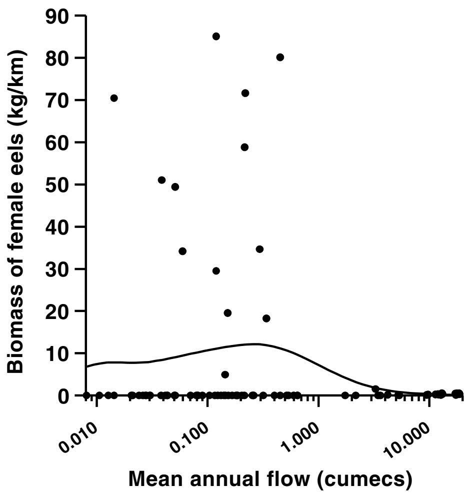


Figure 9. Biomass of large female eels (kg/km) in the Aparima River and tributaries. DWLS smoother (Wilkinson 1999).

6.5 EEL HABITAT IN RESERVES

The main conclusion of this study is that about 14% to 28% of the eel biomass and potential female longfinned eel habitat in Southland and the West Coast is protected within Class 1 and 2 waters in DOC reserves. If small streams in Class 4 waters are added, about 42% of the total habitat is unlikely to be fished.

New Zealand supports a single stock of longfinned eels that is managed on a national and local basis. The nationwide importance to eel conservation of DOC reserves in the West Coast and Southland cannot be properly assessed until a national survey has been completed. Nevertheless, we suspect the total area of habitat protected in New Zealand is probably less than 10% and could be as low as 5%. This is because most of the DOC reserves are situated in the central high country (East Cape, Hawke's Bay, Canterbury, and Otago), and therefore will support low densities and tonnages of eels (Fig. 3), or are located upstream of the Waikato and other hydro dams (Jellyman 1993). With the possible exception of the Abel Tasman National Park, there are few coastal reserves where eels are fully protected.

Provision of closed areas is seen as the single most effective method of protecting eels (Jellyman 1993). If only a small amount of habitat is protected from commercial fishing, previous concerns about the adequacy of reserves for longfinned eels are still justified (Jellyman et al. 2000; Hoyle & Jellyman 2002) and additional measures may be required to ensure the stock is managed on a sustainable basis. These could include a variety of fisheries management practices, including changes to size limits and total allowable catches (TAC), the selective harvesting of either yellow or silver eels, and various types of reserves (Hoyle & Jellyman 2002). The issues are complex and involve a variety of other organisations and interests. Ideally, information should be available on the extent of reserves, and on a range of other subjects such as eel stocks, recruitment, growth rates, harvests, and economic and cultural issues. In the absence of these data and given the long generation time of female longfinned eels (approximately 40 years), conservative management is advocated. The adequacy of present closed areas needs to be reviewed after the completion of a national study, and to make specific recommendations on the basis of the present report would be premature. Given that there is likely to be considerable discussion about the desirable extent of closed areas, and little biological justification for specific percentages, fishery managers should give some consideration to appropriate national levels of closed areas.

6.6 FUTURE STUDIES

This is the first attempt to estimate eel stocks and habitats in New Zealand using the REC. Additional information on several topics would help improve the accuracy and value of future studies. These include:

- Data on the size structure and biomass of eels in lakes. There are plans to re-examine data collected many years ago in Lake Pounui and it may also be possible to estimate stocks in some lakes by examining the effects of fishing pressure on length frequency distributions. However, the best solution is to survey a selection of fished and unfished lakes.
- Stock estimates in rivers could be improved by the use of electric-fishing boats, fyke net depletion, and mark–recapture techniques. Estimates could also be validated by surveys in fished and unfished rivers.
- Improvements to the REC and lakes database are needed. These include better estimates of reach gradient, width, and morphology. Data on mean annual low flows and ephemeral streams would be useful, as the current equation overestimates eel stocks in regions such as Canterbury where streams dry up in summer. Additional data on the extent of littoral areas and on lake trophic status would also be helpful.
- Improved software is needed. In particular, a Fortran programme should be written to classify closed and open reaches.

7. Acknowledgements

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Appendix 1

Simplified flow chart of data analysis procedures