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## EXECUTIVE SUMMARY

**Graynoth, E.; Booker, D.J. (2009). Biomass of longfin eels in medium to large rivers**

***New Zealand Fisheries Assessment Report 2009/44. 24 p.***

In previous reports the total tonnage of longfin eels present in New Zealand (12 200 tonnes) was estimated from empirical relationships between eel biomass and habitat in rivers and lakes. Tonnage estimates were also employed as an index of the amount of habitat present for large female longfin eels. Eel biomass was strongly related to the gradient and mean annual low flow of rivers. Generalised Additive Models (GAMs) were developed to predict both the current biomass of eels and the original biomass that existed before the start of commercial fishing. However, it was difficult to measure the abundance and biomass of eels in medium and large rivers using conventional techniques, such as mark recapture and depletion fyke netting, and there was uncertainty about the predicted biomass of eels in these waters.

This report describes an attempt to calculate eel stocks in medium and large rivers using measurements of the amount of daytime resting and nocturnal feeding habitat present (Ministry of Fisheries contract EEL2007/05). It was shown that large eels frequent deep slow-flowing water during the day and move into shallow water at night to feed. The amount of daytime and nocturnal habitat present was measured as weighted useable area (WUA), using water depths and velocities, and was shown to increase in larger wider rivers. However, the biomass of eels in 212 surveyed sites was weakly related to the WUA. Other factors such as the amount of instream and bank cover and fishing pressure are likely to be more important than WUA, especially in large rivers.

New GAMs were developed to predict the likely biomass of eels in a representative sample of large rivers and in all rivers throughout New Zealand. Bootstrap techniques were used to estimate the 95% confidence limits for tonnage estimates in rivers ( $\pm 18\%$ ) and the proportion in reserves and small streams ( $\pm 11\%$ ). The revised national stock estimates is 11 900 tonnes, of which 49% are in reserves or in small streams that are unlikely to be fished. These estimates are not significantly different from previous estimates. Therefore the detailed tables presented in the previous report on the tonnage of eels in different rivers and regions are still valid and can be used for management.

## 1. INTRODUCTION

Estimates of the biomass and spawning escapement of female longfin eels (*Anguilla dieffenbachii*) in fresh waters throughout New Zealand have been presented in previous reports (Graynoth & Niven 2004, Graynoth et al. 2008b) (MFish Projects EEL2002/03 and EEL2006/03). The tonnage of longfin eels was estimated from empirical relationships between eel biomass and habitat in rivers and lakes, and was employed as an index of the amount of habitat present for large female longfin eels. Generalised Additive Models (GAMs) were developed using data on the biomass per kilometre of longfin eels from 212 sites in rivers and streams in Southland, West Coast (South Island), Canterbury, Wellington, and Wanganui districts. Eel biomass was strongly related to the mean annual low flow and gradient of the reach studied. Models were developed to predict both the current biomass of eels and the original biomass that existed before the start of commercial fishing.

There was some uncertainty about biomass estimates in medium and large rivers (mean annual low flow over 5 m<sup>3</sup>/s) because it is very difficult to measure eel abundance and biomass in large rivers using conventional techniques such as mark recapture and depletion fyke netting. Graynoth et al. (2008b) indicated that about 37% of the total biomass of eels in South Island rivers used to be supported in large rivers. Stocks have been reduced in recent years by commercial fishing and these large rivers probably support about 18% of the current biomass of eels.

The specific objectives of the work reported here (MFish Contract EEL2007/05) were to estimate the biomass of longfin eels in medium to large rivers in order to refine the biomass and spawning escapement estimates of female longfin eels. The habitat preferences of large eels and the amount of habitat present in rivers of different sizes were determined. Generalised instream habitat models (Lamouroux & Jowett 2005) were developed for adult longfin eel feeding and resting habitat and applied to a selection of large rivers. The aim was to determine whether eel habitat and biomass increase with river size or stabilise in large rivers. The results from this study were then used to update national estimates of eel biomass and tonnage in rivers.

## 2. METHODS

### 2.1. Habitat suitability curves for longfin eels in rivers

The amount of instream habitat for eels, and other fish, is usually determined from field studies of the relative density of fish in different habitats. Features of these habitats, such as water depths, velocities, and substrate composition, are measured and habitat suitability curves developed showing trends in habitat quality with each of these features (Bovee 1982). These curves are then applied to field measurements to determine the amount of physical habitat present at different flows. The amount of physical habitat is quantified as the mean habitat suitability index (HSI) for the reach (range 0–1) or as the total weighted useable area (WUA) per linear metre of river (river width multiplied by HSI).

Large eels generally hide under instream and bank cover during the day and emerge at night to feed in slow flowing shallow water. Therefore two series of habitat suitability curves were developed to account for differences in daytime and nocturnal behaviour. Day time habitat suitability curves were developed for the density (n/m<sup>2</sup>) of longfin eels (over 400 mm), and for the total biomass (g/m<sup>2</sup>) of all sizes of longfin eels present. Field data on eel abundance, biomass, water depths, velocity, and substrate composition was collected from 812 sites in 6 streams and rivers (Ashburton River, Ashley River, Firewood Creek, Horokiwi Stream, Pigeon Bay Stream, and Te Maari Stream (Glova et al. 1998, Jellyman et al. 2003, Graynoth et al. 2008a). Nocturnal

habitat suitability curves for medium sized shortfin and longfin eels (300 to 700 mm) were also calculated from surveys in Company Creek (Westland) and the Waipara and Selwyn Rivers in Canterbury (Graynoth 2006). These curves were based on observations of the locations of 164 eels together with additional measurements of 700 depths, velocities, and substrates. Visual observations indicated there were no major differences in habitat preferences between the two species at night, and therefore data for both species was combined.

Daytime and nocturnal habitat suitability curves were developed using GAMs (Jowett & Davey 2007) with a quasipoisson family and a logarithmic link for density and biomass data and with a binomial family and a logit link for the nocturnal presence/habitat availability data.

## **2.2. Field data on eel biomass and instream habitats**

The amount of daytime and nocturnal eel habitat at mean annual low flows (MALF) was calculated for three sets of field data.

- (a) A sample of 10 single channel and braided rivers where detailed Instream Flow Incremental Methodology (IFIM) surveys (Bovee 1982) have been undertaken (NIWA file data). Information was available on the depth, water velocity, and substrate composition across a number of transects (9–47) together with stage heights at different flows. Mean annual low flows at these sites ranged from 0.1 to 100 m<sup>3</sup>/s (Jowett 1998).
- (b) Field data on eel species composition, size, and biomass (Graynoth & Niven 2004, Graynoth et al. 2008b). A total of 212 sites throughout New Zealand were surveyed in summer when flows were close to their annual minimum (MALF). Data were collected from 7 South Island catchments (Aparima, Buller, Ellesmere, Grey, Pigeon Bay, Oreti, and Waiau (Southland)) and 5 North Island catchments (Horokiwi, Ruamahanga, Wanganui, Wanuiomata, and Te Maari). Measurements were made of mean stream width, depth, flow, and substrate composition. A subset of 121 sites was studied in more detail and 91 sites that were either dry or had inadequate substrate data were excluded from some analyses. A matrix (1000 points) of depth velocity measurements was calculated from mean reach depths and velocities using equations described by Schweizer et al. (2007). They showed the variation in individual depths and velocities could be accurately simulated using field data on mean reach velocity, depth, Froude number, flow, and a roughness index based on substrate composition.

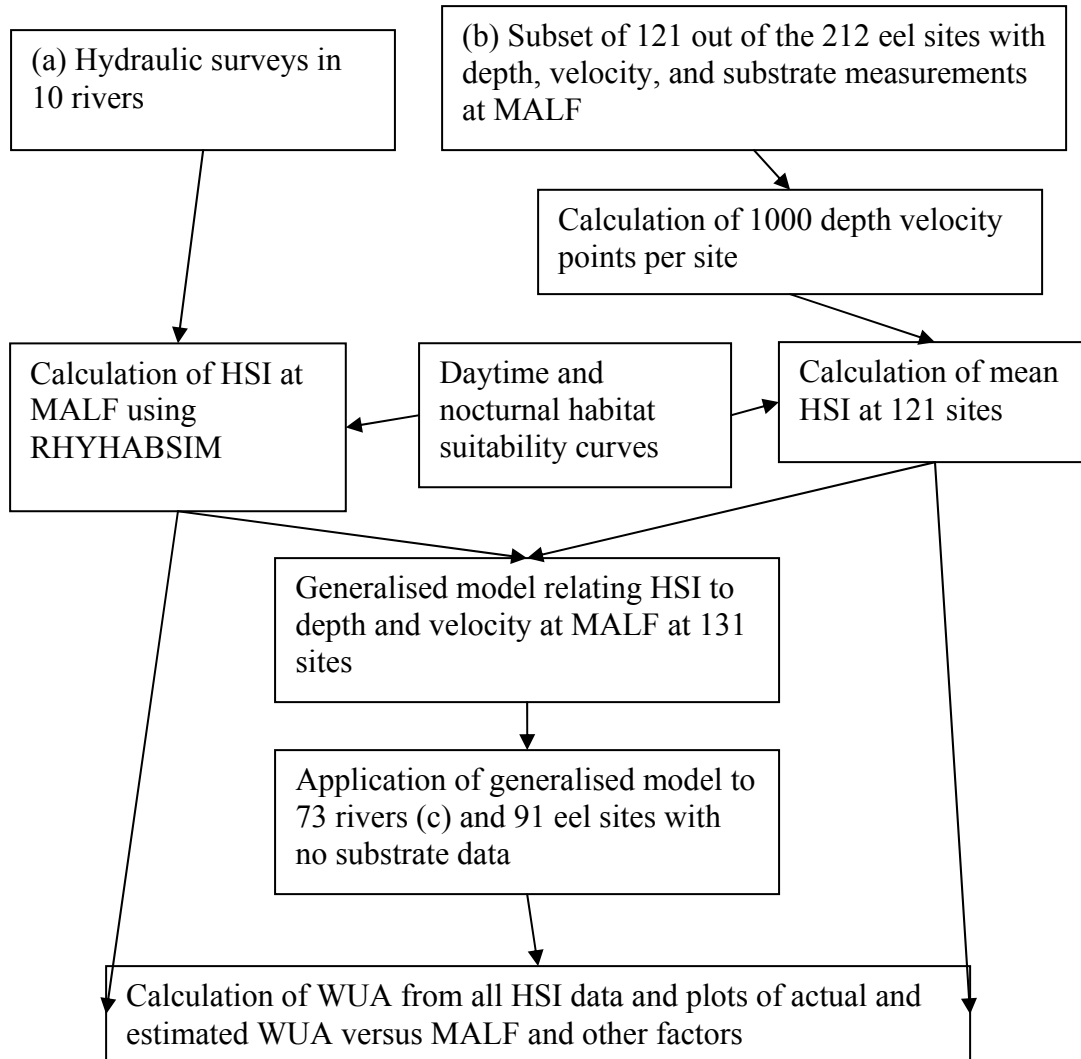
The biomass of longfin eels was expressed as g/m<sup>2</sup> and kg/km and two biomass estimates were calculated for each of the 212 study sites. The “current” biomass was derived from the field surveys while the “original” biomass is the best estimate of biomass present before commercial fishing (see Graynoth (2008b) for techniques used).

- (c) A sample of 73 sites from single channel rivers in New Zealand (Jowett 1998). This paper contains information on the mean width, depth, and velocity at mean annual flow and MALF in these rivers.

## **2.3. Generalised instream habitat models and WUA**

Mean HSI based on water depths and velocities in study (a) were calculated at MALF using the River Hydraulics and Habitat Simulation programme (RHYHABSIM) (Jowett 1989) while mean

HSI at 121 of the sites in study (b) was calculated by applying daytime and nocturnal habitat suitability curves to matrices of depth velocity measurements using equations of Schweizer et al. 2007 (Figure 1). Generalised instream habitat models (Lamouroux & Capra 2002, Lamouroux & Jowett 2005) were then developed to predict mean HSI values from mean reach depths and velocities at MALF. These generalised models were applied to the remaining 91 sites in study (b) and to the 73 rivers in study (c) and used to calculate WUA. Changes in WUA in the Waipara and Waitaki Rivers at different flows were also calculated using RHYHABSIM .



**Figure 1: Flow chart of the data and calculations used to estimate WUA in datasets (a), (b) and (c).**

#### **2.4. Relationship between eel biomass and habitat suitability indices**

Relationships between estimates of the current and original biomass of longfin eels in the 212 surveyed sites (Graynoth et al. 2008b) and river flow (MALF), gradient, and the amount of daytime and nocturnal habitat present were examined. GAMs, with an error distribution based on

the quasipoisson family with logarithmic links, were used to model biomass, as in previous studies (Graynoth et al. 2008b). Slightly more conservative spline curves with 2 degrees of freedom (dof) were used in all models in contrast with the spline curves with 3 dof used previously.

## 2.5. Prediction of eel biomass in large rivers and New Zealand wide

GAMs based on MALF, gradient and width, and dataset (b) were used to predict eel biomass at MALF in data sets (a) and (c). These new eel biomass estimates were then combined with the original data set of 212 sites (b) making a combined database of 288 sites (excluding duplicate rivers) (Figure 2). This procedure was used to add more large rivers to the database and to compensate for the selection of relatively wide shallow rivers during the field surveys.

The combined database was then used to develop GIS-based GAMs following procedures described by Graynoth et al. (2008b). These used flow and gradient with 3 dof and were employed to update previous estimates of eel biomass (kg/km) and tonnage (t) in different classes of rivers around New Zealand (Graynoth et al. 2008b). River width could not be used because the River Environment Classification (REC) (Snelder & Biggs 2002) has no data on river widths. The total tonnage in various classes of rivers in the North and South Islands was then summed, combined with tonnage estimates in lakes, and used to calculate the proportion of eels in reserves and small streams (see Graynoth et al. (2008b) for details).

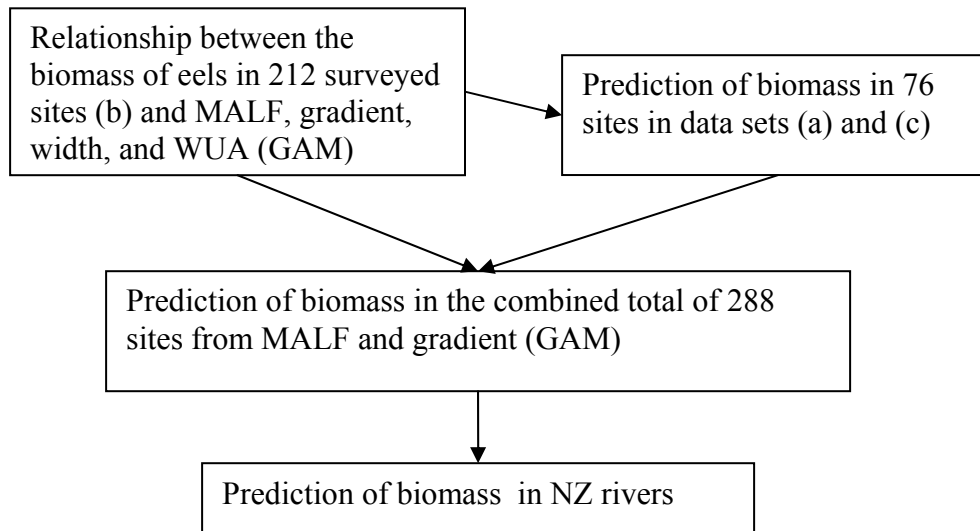


Figure 2: Flow chart describing equations used to predict eel biomass in New Zealand rivers.

## 2.6 Calculation of confidence limits

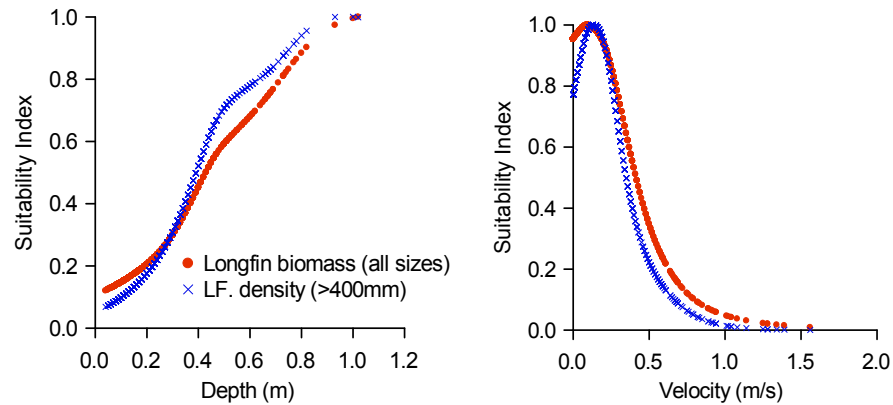
Confidence limits for the tonnage of eels in different river classes in the North and South Islands and the proportion of eels in reserves were calculated using bootstrap techniques in R (Venables & Ripley 2002, Crawley 2005). The GAMs were calculated 1000 times, each using a resampled and replaced dataset of 288 sites. Each of these 1000 models was then applied to the North and South Island REC databases to calculate biomass and tonnage present.



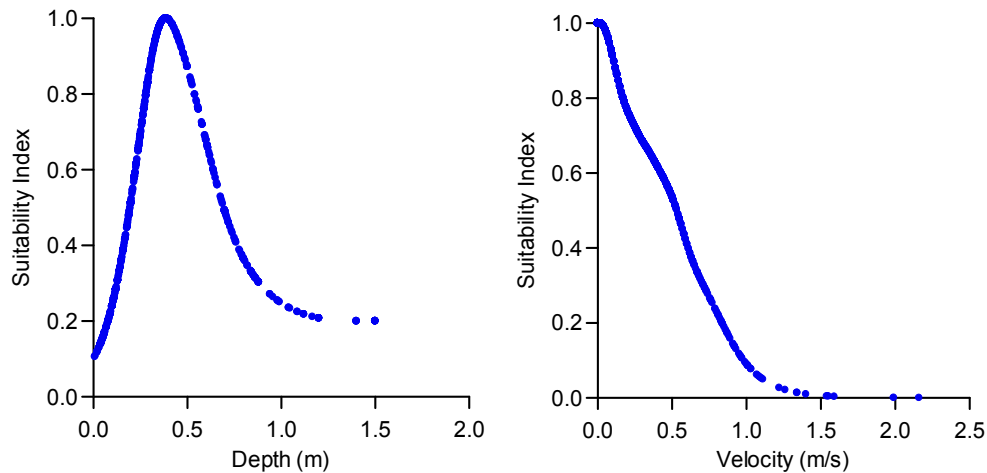
### 3. RESULTS

#### 3.1. Habitat suitability curves for longfin eels in rivers

Daytime habitat suitability curves (Figure 3) explained 28.5% of the deviance in the density ( $n/m^2$ ) of large longfin eels and 26.4% of the deviance in biomass ( $g/m^2$ ). Eels preferred slow flowing water both during the day and night (Figure 4), but moved from deep water during the day into shallower water at night.



**Figure 3: Daytime depth and velocity habitat suitability curves for longfin (LF) eels (>400 mm) and longfin eel biomass.**



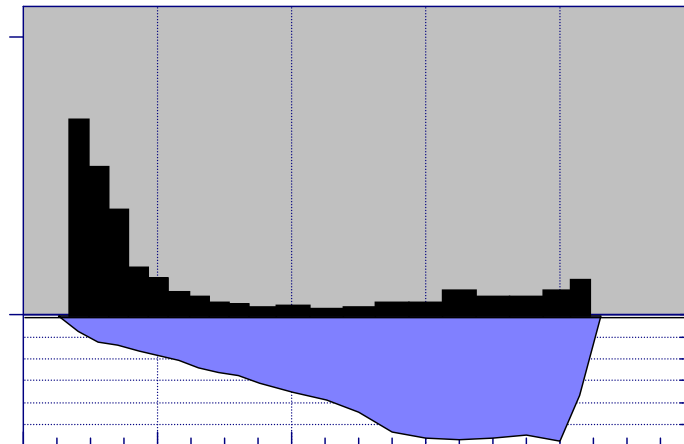
**Figure 4: Nocturnal depth and velocity habitat suitability curves for longfin and shortfin eels (300 to 700 mm).**

#### 3.2. Habitat suitability indices and generalised instream habitat models

Mean daytime habitat suitability indices (HSI) for eel biomass in a sample of large rivers at MALF (Study a) ranged from 0.08 to 0.21 (Table 1). Nocturnal indices were generally higher and ranged from 0.09 to 0.32. Examination of transects across rivers showed that eel habitat in large rivers is generally confined to the slow flowing margins (Figure 5).

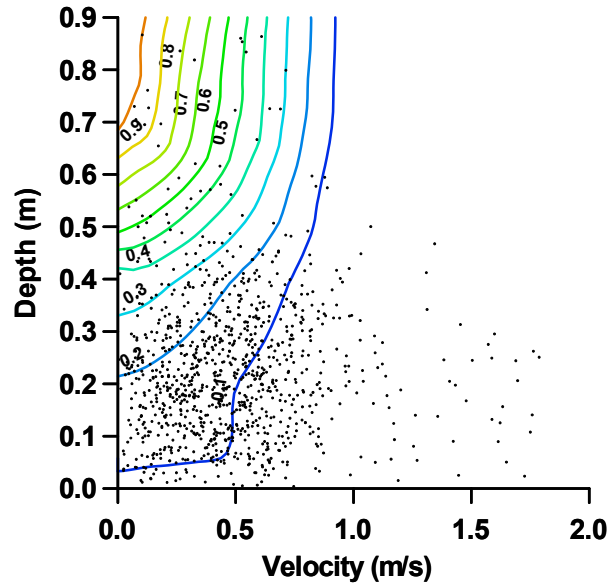
**Table 1: Daytime biomass and nocturnal habitat suitability indices in the Waipara River and 9 large rivers at MALF. Mean depths and velocities taken from Rhyabsim and used in the generalised models (see text).\*, approximate.**

River	MALF (m <sup>3</sup> /s)	Mean depth	Mean velocity	Daytime HSIndex	Nocturnal HSIndex	Predict. Day index	Predict. Night index
Waipara	0.1	0.135	0.171	0.191	0.323	0.159	0.306
Oreti	5.0	0.263	0.554	0.082	0.211	0.115	0.212
Mataura	5.3	0.512	0.505	0.209	0.294	0.213	0.326
Ahuriri	8.5	0.41	0.669	0.095	0.251	0.106	0.194
Motueka	9.3	0.417	0.485	0.173	0.318	0.200	0.323
Arnold	22.5	0.785	0.715	0.181	0.218	0.144	0.252
Lower Tongariro	27	0.73	0.90	0.089	0.127	0.092	0.261
Clutha at Wanaka	74	1.336	0.701	0.191	0.145	0.167	0.140
Clutha at Balclutha	100*	1.622	0.715	0.151	0.091	0.168	0.046
Lower Waitaki Priests Road	100*	0.642	0.556	0.161	0.263	0.204	0.294



**Figure 5: Cross sectional distribution of nocturnal habitat (HSI) in the lower Clutha River (Balclutha) at MALF (100 m<sup>3</sup>/s).**

Habitat suitability was also calculated for the 121 sites selected in dataset (b). Figure 6 illustrates the wide scatter of depth velocity pairs derived using equations of Schweizer et al. 2007.



**Figure 6: Depth velocity matrix calculated for site 2 (Aparima River mainstem, lower reaches) based on mean depth of 0.22 m and velocity of 0.45 m/s with  $smix1$  of -0.403 and  $smix$  of 0.401 (Schweizer et al. 2007). The contour plot was derived from daytime biomass habitat preference curves (Figure 3) and shows the strong preference for deep slow water during the day.**

The generalised linear models used to predict mean daytime and nocturnal habitat suitability indices from measurements of mean depth and velocity at MALF are shown in Table 2. These were derived from both sets of data (a +b) combined ( $n = 131$ ) and are a good fit to the data (Tables 1 and 2).

**Table 2: Generalised models used to predict habitat suitability indices (HSI) and weighted useable area (WUA). All coefficients significant at  $P < 0.01$ .  $N = 131$ . NA, not applicable.**

Coefficients	Daytime	Std. error	Nocturnal	Std. error
Intercept	0.019	0.004	0.118	0.010
Depth	1.469	0.030	1.958	0.088
Depth <sup>2</sup>	-0.704	0.044	-1.544	0.157
Velocity	-0.046	0.016	NA	NA
Velocity <sup>2</sup>	NA	NA	-0.358	0.120
DepthVelocity	-1.654	0.068	-1.733	0.238
DepthVelocity <sup>2</sup>	1.168	0.096	2.236	0.276
HSI Adj. $R^2$	0.982		0.872	
WUA Adj. $R^2$	0.975		0.979	

### 3.3. Changes in WUA with flow in selected rivers

Trends in WUA with flow in a small single channel river (Waipara) were compared with those in a large braided river (Waitaki) (Figure 7). The amount of habitat remains fairly constant at all flows in the Waitaki ( $> \text{MALF}$ ) but declines sharply at extremely low flows in the Waipara River. In most rivers there was more nocturnal than daytime habitat present (Figure 7, Tables 1 & 3).

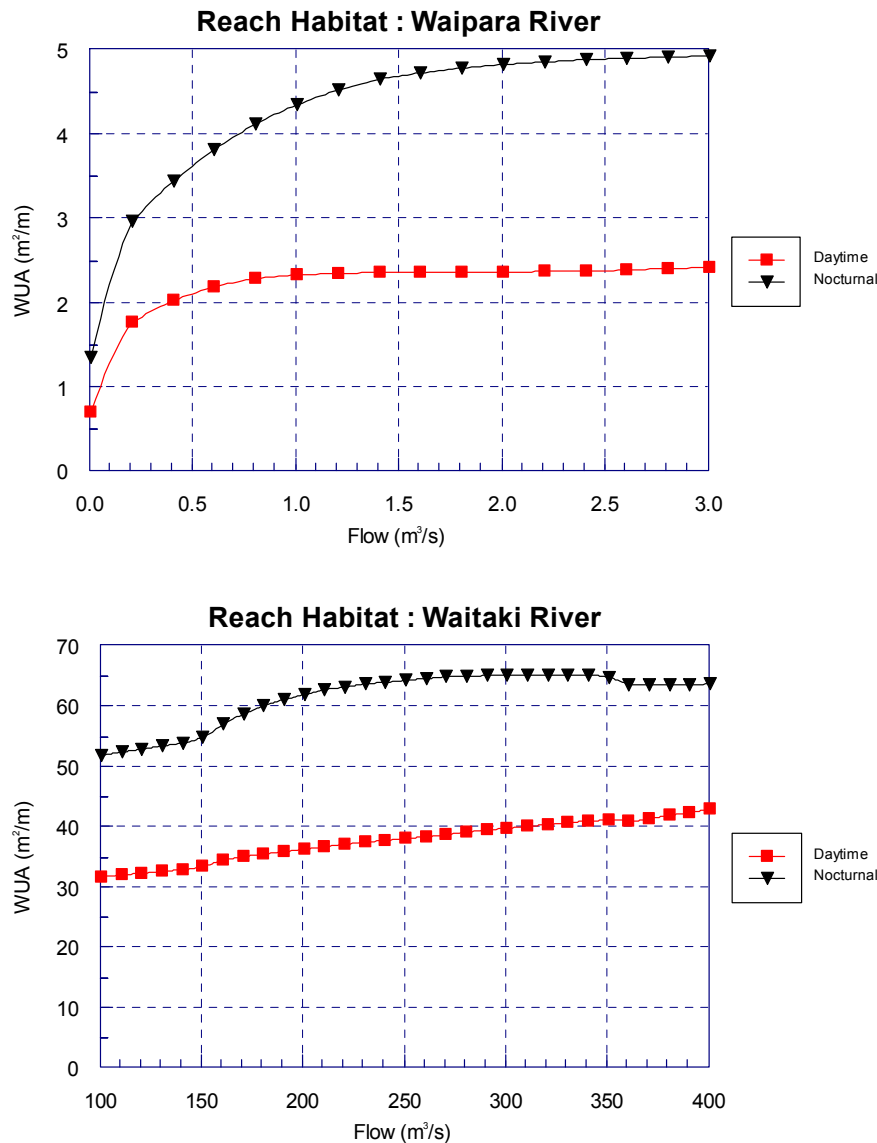


Figure 7: Trends in weighted useable area (WUA) with flow in a small river (Waipara) and a large river (Waitaki). MALF for the Waipara was  $0.1 \text{ m}^3/\text{s}$  compared with  $100 \text{ m}^3/\text{s}$  in the Waitaki.

### 3.4. Differences in WUA between rivers of different sizes

The amount of daytime and nocturnal habitat present (WUA) in different rivers was closely correlated ( $r = 0.94$ ,  $n = 204$ ) and increased with river width ( $r = 0.88$  for types of habitat) (Figure 8, Table 3). There was no evidence that the amount of habitat levelled off and stabilised in large rivers. Differences between the data sets in the WUA present can be explained by the selection of

wide (shallow) rivers for electric fishing compared with the relatively narrow (deep) rivers surveyed by Jowett 1998 (Figure 9).

**Table 3: Daytime and nocturnal weighted useable area (WUA) in selected rivers at mean annual low flow (MALF) arranged in order of increasing MALF. MAF, mean annual flow, \* approximate flows.**

River	MAF (m <sup>3</sup> /s)	MALF (m <sup>3</sup> /s)	MALF Width (m)	Daytime WUA (m)	Nocturnal WUA (m)
Waipara	2.7	0.1	8.1	1.54	2.61
Oreti	30.3	5.0	32	2.59	6.66
Mataura	18.8	5.3	25	5.20	7.30
Ahuriri	23.7	8.5	31	2.93	7.71
Motueka	61	9.3	42	7.33	13.48
Arnold	58	22.5	43	7.81	9.39
Lower Tongariro	32.2	27	38	3.43	4.86
Clutha at Wanaka	203.6	74	75	14.43	10.95
Clutha at Balclutha	400*	100*	80	12.12	7.36
Lower Waitaki	350*	100*	196	31.55	51.55

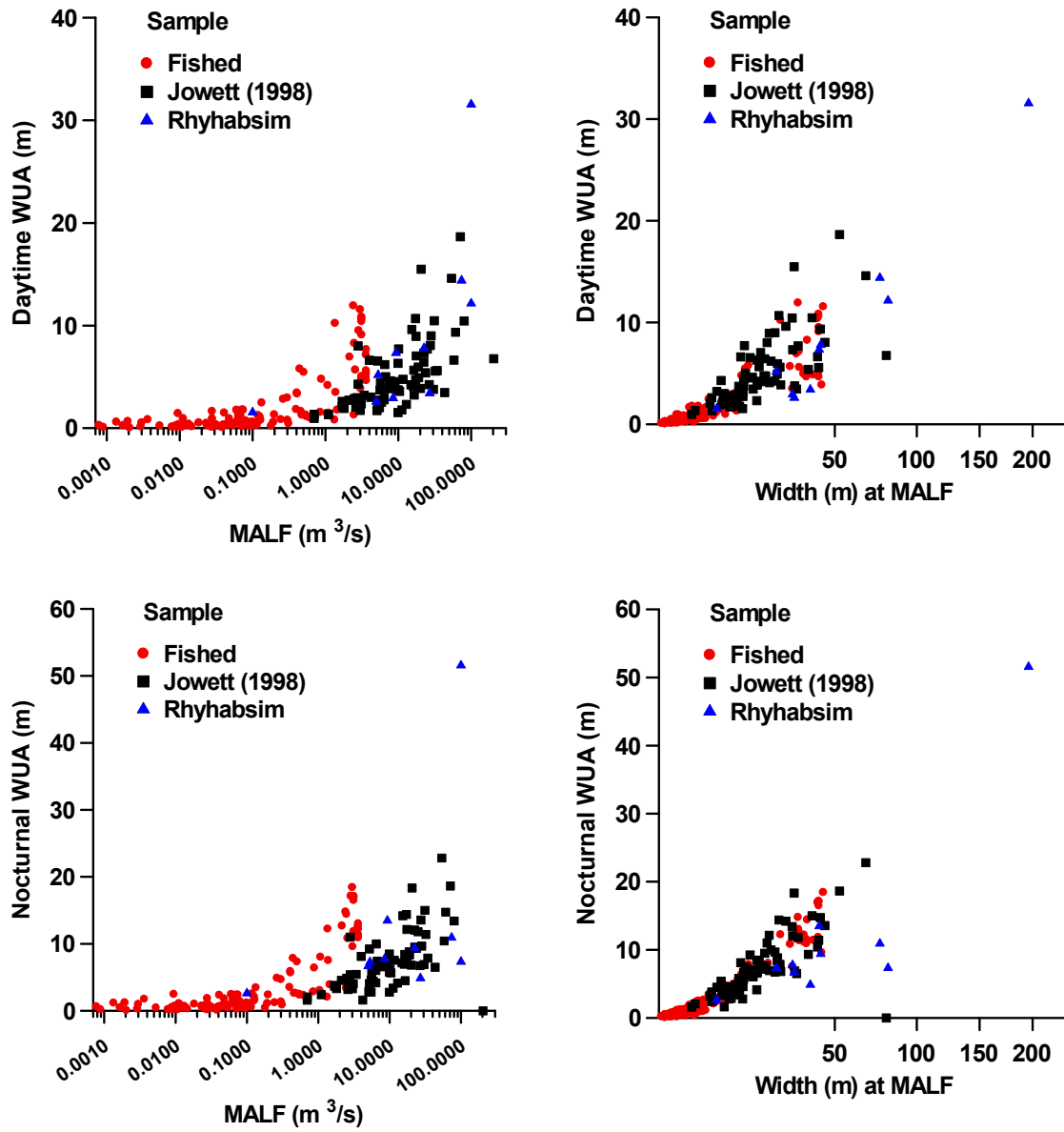


Figure 8: Increase in eel habitat area with river flow (log) and width in datasets (a) Rhyhabsim, (b) electric fished, and (c) Jowett (1998).

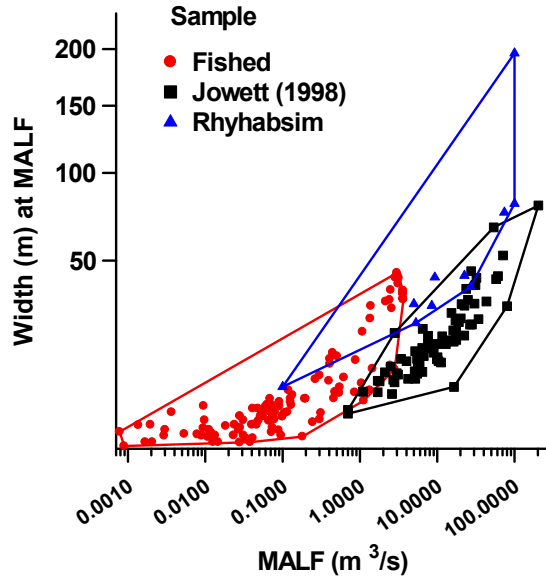


Figure 9: Width (square root) and flow (log) at MALF in datasets (a) Rhyhabsim, (b) electric fished, and (c) Jowett (1998).

### 3.5. Relationships between eel biomass and habitat suitability indices.

There were weak relationships between field measurements of current longfin eel biomass ( $\text{g/m}^2$ ) and mean daytime and nocturnal habitat suitability indices ( $r = 0.25$  and  $0.29$  respectively) (Figure 10). There was a stronger relationship between the biomass of eels per km ( $\text{kg/km}$ ) and the total amount of physical habitat present (WUA) because this took the size (width) of the river into account (Figure 11). Correlation coefficients for daytime and nocturnal WUA were  $0.55$  and  $0.60$  respectively. However, there was a considerable scatter in the relationship and increases in WUA beyond  $5 \text{ m}^2/\text{m}$  had no apparent influence on eel biomass.

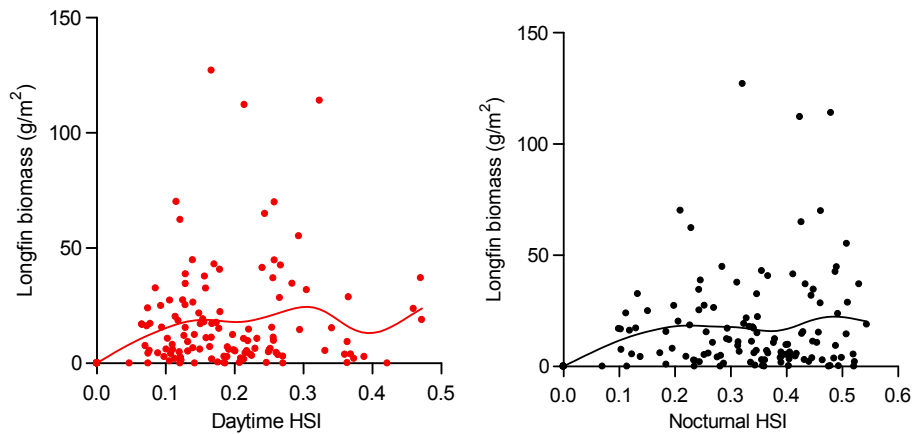
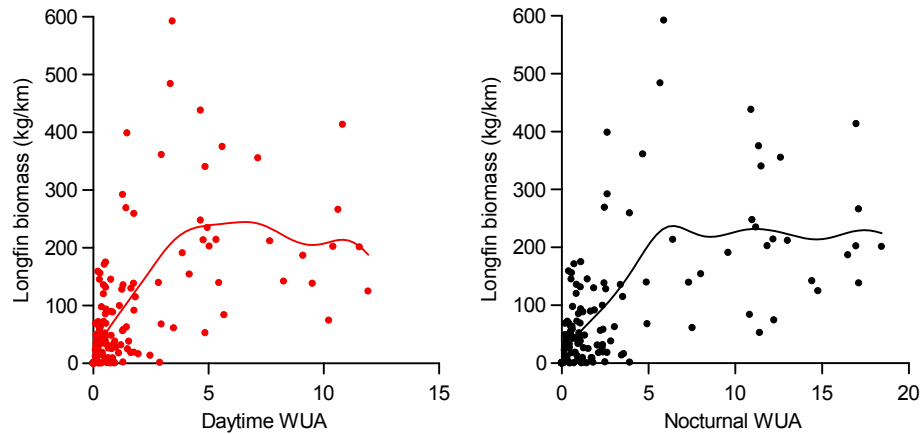


Figure 10: Relationships between the biomass of eels ( $\text{g/m}^2$ ) and mean daytime and nocturnal habitat suitability indices. Line is a distance weighted smoother. ( $n = 144$  sites – this includes 23 streams that dried up in summer and contained no habitat and no eels).



**Figure 11: Relationships between the biomass of eels (kg/km) and the amount of daytime and nocturnal weighted useable area (WUA m<sup>2</sup>/m) present. Line is a distance weighted smoother. (n = 144 sites).**

The biomass (kg/km) of eels in dataset (b) (n= 212) was modelled using GAMs with MALF, gradient, river width, and habitat width (Tables 4 and 5, Figure 12). Most of the variation in biomass was explained using MALF, gradient, and river width. Width was preferred to WUA as a predictive variable because it is easier to measure and is closely correlated with WUA. The addition of either daytime or nocturnal WUA to models containing width (Model 3) had no statistically significant effect.

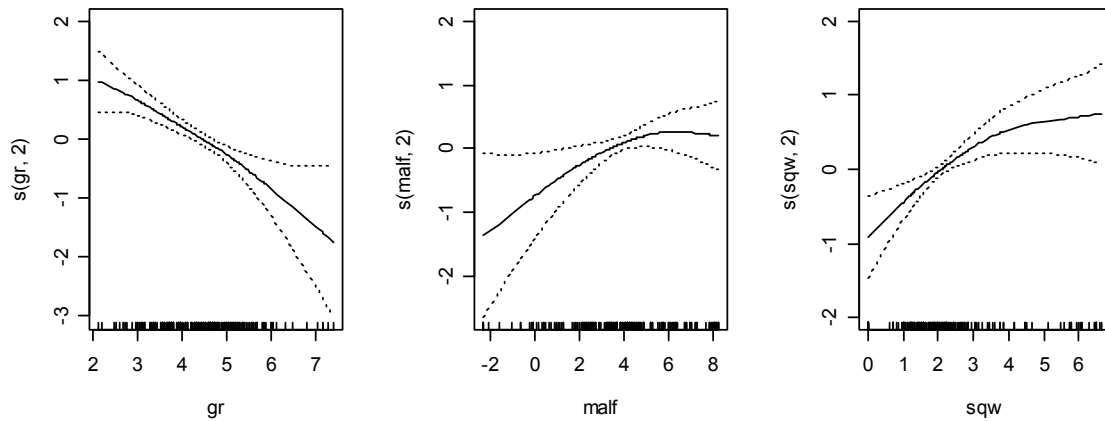
**Table 4: Prediction of the current biomass (kg/km) of longfin eels using GAMs (n = 212). MALF, ln (ls). Gradient, ln (%\*100). WUA, square root transformed. The F test measures the significance of differences between this and the previous model, except that model 5 is compared with model 3.**

No	Model	dof	% deviation explained	F	P value
1	MALF	209	36.9		
2	MALF+gradient	207	47.0	16.94	<0.001
3	MALF+gradient+width	205	50.3	6.11	0.003
4	MALF+gradient+width+daytime WUA	203	51.7	2.55	0.081
5	MALF+gradient+width+nocturnal WUA	203	51.6	2.42	0.091



**Table 5: Prediction of the original biomass of longfin eels using GAMs (n = 212). MALF, ln (ls). Gradient, ln (%\*100). WUA, square root transformed. The F test measures the significance of differences between this and the previous model, except that model 5 is compared with model 3.**

No	Model	dof	% deviation explained	F	P value
1	MALF	209	51.0		
2	MALF+gradient	207	62.6	30.16	<0.001
3	MALF+gradient+width	205	65.9	9.26	<0.001
4	MALF+gradient+width+daytime WUA	203	66.2	0.83	0.44
5	MALF+gradient+width+nocturnal WUA	203	66.1	0.64	0.53



**Figure 12: Smoothed preference values (terms) with  $\pm 1$  standard error in a gam (Model 3 in Table 4) predicting current biomass (kg/km) using gradient (gr = ln gradient (%\*100), mean annual low flow (malf = ln (l/s) and width (sqw = square root width (m)).**

### 3.6. Prediction of eel biomass in large rivers using MALF, gradient, and width

GAMs based on MALF, gradient, and river width (Model 3, Tables 4 and 5) were then used to predict the biomass of eels in large rivers (samples b and c). These rivers were substantially larger than the 212 rivers sampled and were of medium to low gradient (Figure 13). A contour plot of observed and predicted current biomass (using Model 3 in Tables 4 and 5) illustrates the influence of gradient and MALF on biomass in these large rivers (Figure 14).

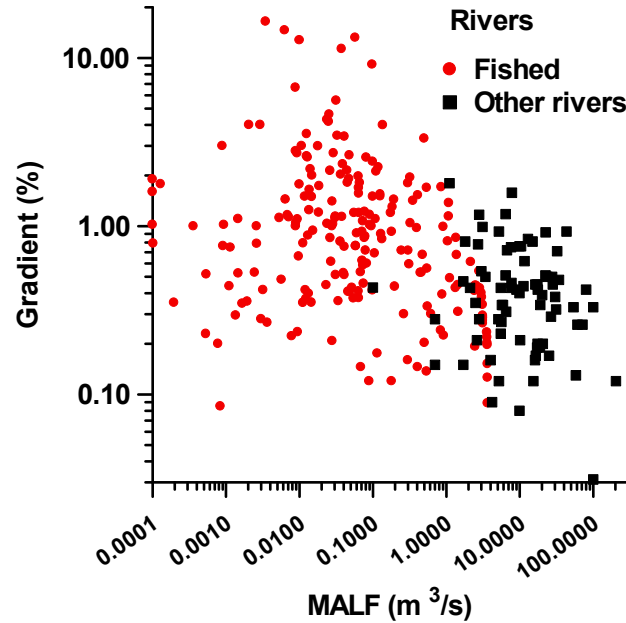


Figure 13: River gradient and MALF in sampled and other rivers.

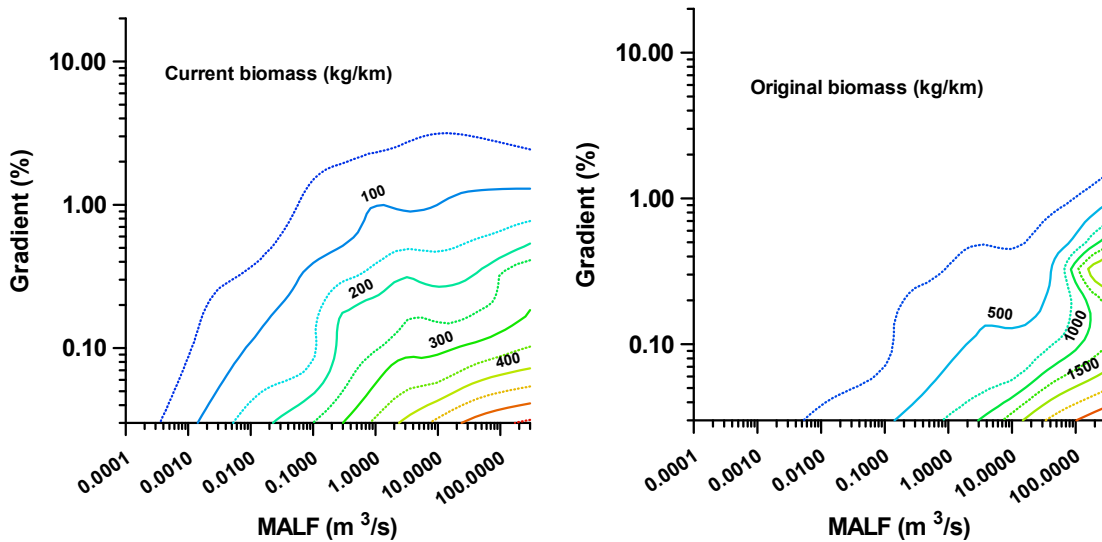


Figure 14: Predicted biomass of longfin eels (Model 3 in Tables 4 and 5). Erratic variations in curves are caused by variations in river width.

### 3.7. Comparison of revised GAMs with GAMs used in previous studies

The new revised GAMs (Model 3 in Tables 4 and 5) use measurements of river width as well as flow and gradient. The addition of width into these revised GAMs indicates that biomass estimates for eels in the large rivers surveyed by Jowett (1998) are likely to be overestimated by about 25% to 50% (Figure 15). This is because the only large rivers that could be sampled were generally shallow and braided (see Figure 9). These had a relatively high proportion of resting and feeding habitat (see Figure 8) compared with the narrow single channel rivers surveyed by Jowett (1998). The exception was the braided lower Waitaki river which is exceptionally wide (196 m) and relatively shallow (0.64 m) at its minimum flow of 100 m³/s. The original biomass of

eels in the Waitaki River was estimated with the new revised models at 1826 kg/km compared with previous estimates of 978 kg/km based on flow and gradient alone.

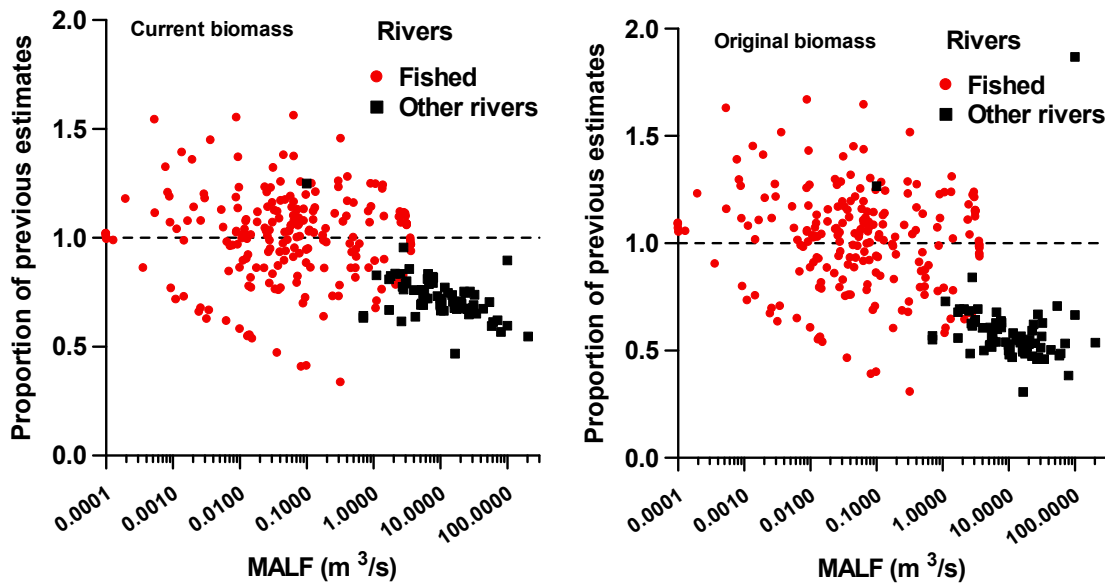


Figure 15: Relative change in biomass estimates between the previous GAMS and these new revised models (Models 3, Tables 4 and 5). Note the Waitaki River outlier in top right hand corner of the original biomass plot.

### 3.8. Revised biomass estimates for New Zealand rivers

River width cannot currently be used to predict eel biomass on a national basis in the REC and therefore GAMS based on MALF and gradient (Figures 16 and 17) were then used to revise New Zealand wide estimates of longfin biomass. These GAMS used biomass values measured in 212 surveyed sites plus values predicted in 76 large rivers using model 3 in Tables 4 and 5. These models were less biased towards wide shallow rivers than those used in the original study (Graynoth et al. (2008), i.e., Model 2 in Tables 4 and 5). However, the deviance values of 57% for the current biomass and 72% for the original biomass are inflated because of the incorporation of predicted values and the deviance values of Model 3 in Tables 4 and 5 (50% and 66% respectively) are considered to be more accurate.

The revised New Zealand wide biomass estimates (Table 6) are not significantly different from previous estimates (Graynoth et al. 2008). The percentage of the total biomass of longfin eels in reserves and lightly fished small streams is the same (49%), and the total tonnage of eels declines only 3% from 12 202 tonnes to 11 883 tonnes.

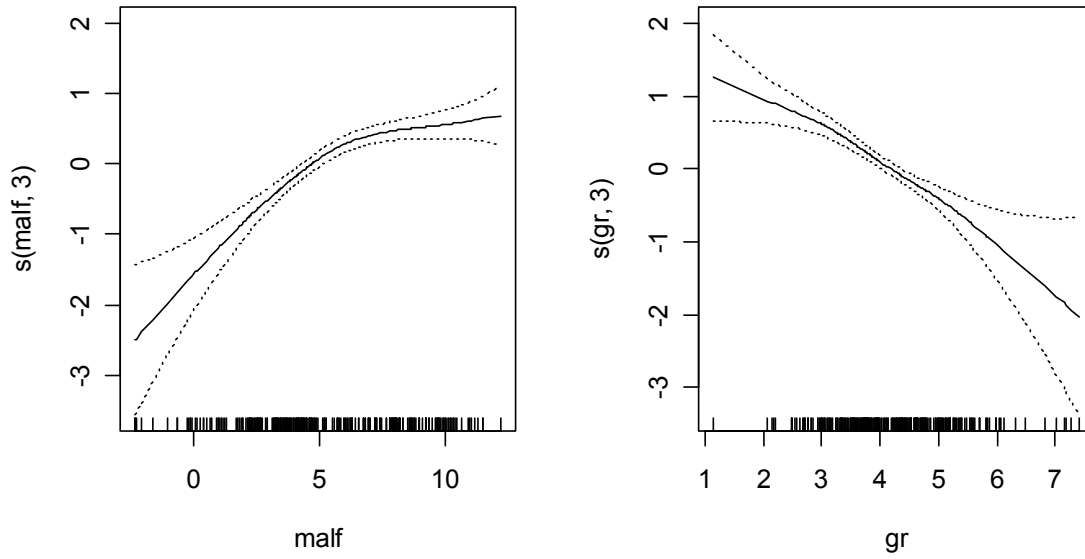


Figure 16: Smoothed preference values (terms) with  $\pm 1$  standard error in a GAM predicting current biomass (kg/km) using mean annual low flow ( $\text{MALF} = \ln(\text{l/s})$  and gradient ( $\text{gr} = \ln(\text{gradient} (\% \cdot 100))$ ).

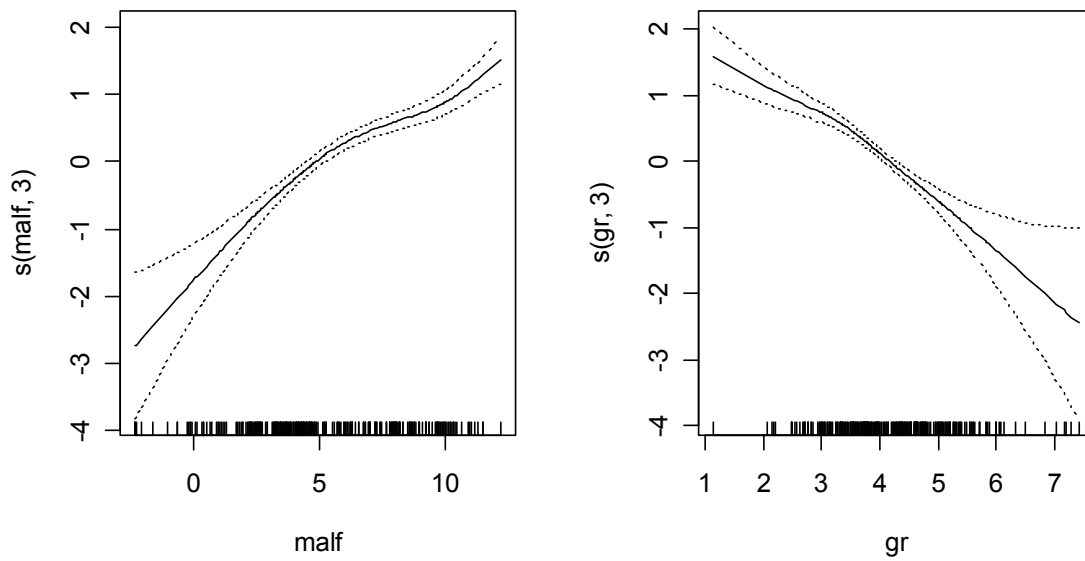


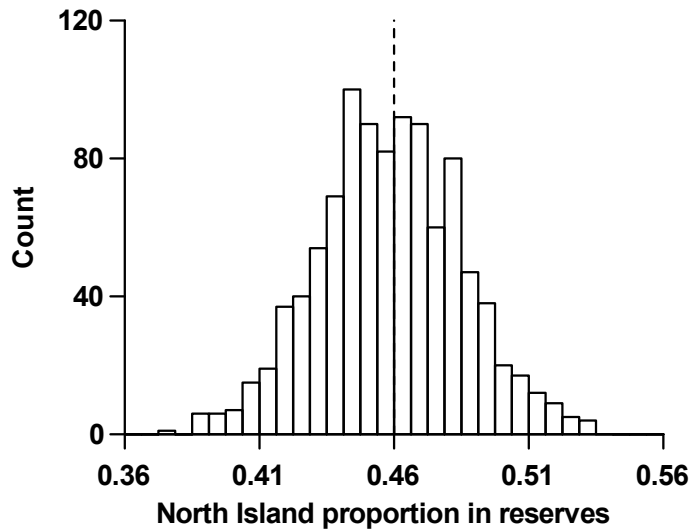
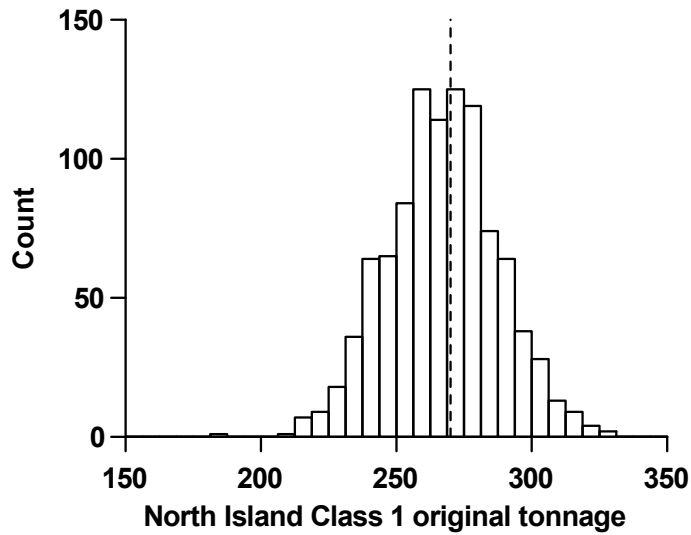
Figure 17: Smoothed preference values (terms) with  $\pm 1$  standard error in a GAM predicting original biomass (kg/km) using mean annual low flow ( $\text{MALF} = \ln(\text{l/s})$  and gradient ( $\text{gr} = \ln(\text{gradient} (\% \cdot 100))$ ).

**Table 6: Updated summary of longfin eel tonnage estimates in rivers and lakes. % not fished refers to the estimated biomass of eels that is either in reserves or is unlikely to be fished. Numbers in parentheses are previous estimates based on Graynoth (2008). Lakes remain unchanged. Class 1, not commercially fished; Class 2, waters protected in their upper reaches; Class 5, small streams (Mean annual flow <0.5 m<sup>3</sup>/s); Class 4, open for commercial fishing.**

Present estimates	Island	Class 1	Class 2	Class 5	Sub total	Class 4	Total	% not fished
Biomass model		Original	Original	Original	Original	Current		
Rivers	NI	270 (340)	483 (702)	1975 (1759)	2728 (2800)	3196 (3279)	5924 (6079)	46 (46)
	SI	344 (363)	817 (1091)	1550 (1265)	2711 (2719)	2626 (2782)	5337 (5501)	51 (49)
Lakes	NI	0	9	0	10	65	75	13
	SI	167	233	0	400	147	547	73
Total		781 (870)	1542 (2035)	3525 (3024)	5849 (5930)	6034 (6273)	11883 (12 202)	49 (49)
Percentage of total		7 (7)	13 (17)	30 (25)	49 (49)	51 (51)	100 (100)	

### 3.9 Confidence limits

Confidence limits (95%) for the tonnage of eels in different classes of North and South Island rivers (Table 6) were remarkably consistent, and averaged  $\pm 18\%$  (range 13% to 27%). Typical bootstrap distributions of tonnage estimates and the proportion in reserves are shown in Figure 18. The minimum and maximum estimates of the percentage in reserves ranged from 40.8% to 51.2% in North Island rivers (mean 46%) and from 46.4% to 55.0% in South Island rivers (mean 51%).



**Figure 18: Examples of bootstrap estimates (1000 replications). North Island rivers, tonnage of eels in Class 1 and proportion in reserves and small streams (Classes 1, 2, and 5). Actual means (Table 6) are shown as vertical dotted lines.**

#### 4. DISCUSSION

The habitat suitability curves developed in this study are in agreement with observations from other studies (Burnet 1952, Glova & Jellyman 2000). These show that large eels move from their daytime hiding places into shallow runs and riffles at night where they feed on benthic invertebrates (Cairns 1942). Although the models explained a relatively low percentage of the deviance present (26 to 28%), the relationships were highly significant statistically and the curves are considered to be a moderate to good index of the amount of daytime resting habitat and nocturnal feeding habitat present in rivers.

There were insufficient field data available to develop definitive habitat suitability curves for female longfin eels (over 700 mm) in rivers. These fish eat benthic invertebrates and fish (Cairns 1942), mostly at night, but are occasionally seen during the day, generally in deep, slow flowing pools and runs. Therefore the habitat curves developed for smaller longfins should be appropriate for these large females.

Habitat suitability indices were calculated using depth and water velocity suitability curves. Curves based on substrate, instream, and other habitat features could not be used because there is no information on these features in the River Environmental Classification (REC) database and therefore they cannot be used to predict eel stocks in unsurveyed rivers.

It was found that the amount of habitat present at MALF could be predicted very accurately from measurements of mean width, depth, and velocity and that complex, mixed effects, models (Lamouroux & Capra 2002, Lamouroux & Jowett 2005) were not needed to quantify the habitat available for eels.

In this study it was assumed that eel populations were more likely to be limited by the amount of nocturnal feeding and daytime resting habitat available at MALF than at higher flows. Although there were insufficient hydrological and hydraulic data available to test this hypothesis, the total amount of habitat present (WUA) appears to be fairly constant at most flows (Figure 7) and therefore it seems likely that the actual flows used to measure habitat will have a minor influence on the results.

The weak relationships found between eel biomass ( $\text{g m}^{-2}$ ) and HSI was not unexpected because other studies (Burnet 1952, Glova & Jellyman 2000; Jellyman et al. 2003) have shown that factors such as the presence of instream and bank cover have a greater influence on the density and biomass of large eels than water depths and velocities alone. Also other factors such as differences in water quality, temperature, food supplies, and recruitment contribute to the variability in eel biomass and may conceal relationships with physical habitat.

The revised biomass estimates and percentage of eels in reserves are not significantly different from previous estimates. Therefore the tables presented in the previous report (Graynoth et al. 2008) are still generally valid and can be used for management.

Previous studies (Graynoth et al. 2008b) used stratified sampling techniques to calculate confidence limits and showed that biomass estimates for rivers similar in character to the Aparima River in Southland should have potential errors of about  $\pm 18\%$ . Virtually identical confidence limits for entire classes of rivers were calculated in this study using a totally different bootstrap technique. However, the same caveats apply as in previous studies. The margin of error for national and regional tonnage estimates will be greater than  $\pm 18\%$  because of the difficulty of estimating eel stocks in large rivers and lakes. More accurate estimates of eel biomass in large rivers are dependent upon improvements to the River Environment Classification database. In particular, it should be possible to estimate river widths and substrates using data from the new Freshwater Fish Database and other sources (Leathwick et al. 2008). It would also be worthwhile developing new techniques to measure eel populations in large rivers and lakes using a combination of radio/acoustic tracking methods (Jellyman & Sykes 2003) and conventional mark recapture techniques (Seber 1973).

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