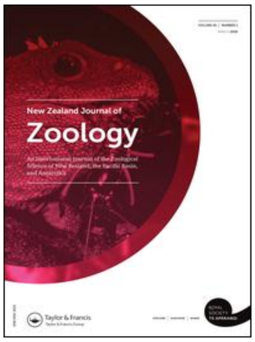

New Zealand Journal of Zoology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tnzz20

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To cite this article: Cohen Stewart , Erin Garrick , Matthew McDougall & Zane Moss (2021): Waterfowl hunting wetlands as habitat for two New Zealand eel species, New Zealand Journal of Zoology, DOI: 10.1080/03014223.2021.1885454

To link to this article: https://doi.org/10.1080/03014223.2021.1885454

NEW ZEALAND JOURNAL OF ZOOLOGY
https://doi.org/10.1080/03014223.2021.1885454

SHORT COMMUNICATION

Waterfowl hunting wetlands as habitat for two New Zealand eel species

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ABSTRACT

New Zealand's native shortfin eel (*Anguilla australis*) and endemic longfin eel (*Anguilla dieffenbachii*) have been negatively affected by wetland habitat loss. However, in Southland, open water wetland habitat has been created by hunters in the form of waterfowl hunting wetlands (duck ponds), habitat which can be utilised by eels. The aim of this study was to estimate the number and biomass of eels supported by Southland duck ponds to highlight the value of hunter-created wetlands as eel habitat. Eel population surveys were conducted in 56 duck ponds located on private agricultural land across Southland. Shortfin eels were found in 28 ponds with an average population size of 22 and biomass of 9.3 kg. Longfin eels were found in 26 ponds with an average population size of nine and biomass of 7.6 kg. Estimates indicate there are 7,013 ± (1761) duck ponds in Southland and they collectively support 36,000 shortfin eels weighing 15,500 kg and 60,000 longfin eels weighing 53,000 kg. Results from this study show that duck hunting ponds are utilised by shortfin and longfin eels.

ARTICLE HISTORY
Received 6 August 2020
Accepted 30 January 2021

HANDLING EDITOR
Cor Vink

KEYWORDS
Gamebird; conservation; hunting; waterfowl; longfin eel; shortfin eel; native; introduced; mallard

Introduction

Wetlands support high levels of biodiversity globally and are important habitat for a wide range of plants and animals (Cronk and Fennessy 2001; Keddy 2010; Ma et al. 2010; Batzer and Boix 2016). Since 1900, global wetland coverage has declined by at least 50% (Davidson 2014) and in New Zealand there has been a 90% reduction in wetland habitat since European colonisation (Aussiel et al. 2011). Wetland habitat loss in New Zealand has been implicated in the decline of several native animal species (Hayes and Williams 1982; Jellyman 2007; O'Brien and Dunn 2007; O'Donnell and Robertson 2016) and is of concern for conservation managers (Sage 2018).

In Southland, New Zealand, wetland habitat loss has been substantial (Robertson et al. 2019). However, the loss of some natural open water wetland habitat has to a small degree been offset with the construction of man-made wetlands (duck ponds), built to hunt mallard ducks (*Anas platyrhynchos*), a highly valued introduced gamebird (Stewart and Garrick 2017). These ponds are located on private land throughout Southland, are often shallow (<2 m deep), and are usually <1 ha in size.

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Supplemental data for this article can be accessed at https://doi.org/10.1080/03014223.2021.1885454.

Duck ponds in Southland also provide habitat for a variety of native fish, including shortfin (*Anguilla australis*) and longfin (*Anguilla dieffenbachii*) eels. These species are harvested commercially (Beentjes 2019), are taonga for Māori (McDowall 2011) and are important predators in aquatic communities (Ryan 1986; Jellyman 1996). The IUCN (International Union for Conservation of Nature) classifies shortfin eel as 'near threatened' (Pike et al. 2019a) and longfin eel as 'endangered' (Pike et al. 2019b). Declines in eel populations may be related to overexploitation (Hoyle and Jellyman 2002), hydropower dams (Boubée and Williams 2006) and habitat loss from wetland drainage and stream channelisation (Beentjes et al. 2005).

Given the extent of duck ponds throughout Southland, the aim of this study was to (1) quantify the extent (numbers and biomass) to which shortfin and longfin eel utilise Southland duck ponds (2) obtain a coarse estimate for the number and biomass of eels collectively supported by Southland duck ponds and (3) identify variables which influence eel abundance in Southland duck ponds.

Materials and methods

Pond location and selection

Before conducting any eel surveys, pond owners were contacted to obtain access. Google Earth satellite imagery was then used to ensure selected ponds were of various sizes, elevations and distances from the coast because these variables may affect eel abundance and species composition (McDowall 1990; McDowall and Taylor 2000). Ponds were not randomly selected because all ponds were located on private property and access required landowner permission.

Survey procedure

Eel population surveys were conducted in 56 ponds across the Southland region, 35 of those ponds were <100 m in elevation. Eels were captured using fyke nets that were baited with tinned cat food and set overnight. Fyke nets had a flat-bottomed mouth with a circumference of 2.8 m. Nets had three traps, were 3.3 m long with a screen length and depth of 5.5 and 0.7 m respectively. Stretched mesh size was 22 mm. Where possible, fyke nets were set perpendicular to the shoreline but on occasion were set parallel with the shoreline because of water or sediment depth.

Eels were captured between 20 November 2019 and 20 March 2020 and in November 2020 (late austral spring, summer and early autumn). Following capture, eels were anaesthetised with clove oil (when required) and identified as either shortfin or longfin eels according to features outlined in McDowall (1990). Eels were separated by species, counted, bulk weighed, and an average weight was determined. Two ephemeral ponds were not fished.

Eels were captured using a single overnight set of the fyke net/s or consecutive three-night fyke net sets where the catch was retained each night for depletion sampling (Jellyman and Crow 2016). For those ponds in which consecutive depletion sampling was conducted ($n = 10$), a population estimate (±95% Confidence Interval (CI)) for the number of shortfin eel and longfin eel was generated with Microfish 3.0 (Van Deventer and Platts 1989) which uses the maximum-likelihood method (Platts et al. 1983).

To generate a population estimate for the number of eels in ponds which were only sampled with one overnight set, the population size was approximated using the combined (shortfin and longfin) average first night proportional catch rate obtained from ponds that were depletion sampled over three nights. Once a population estimate was established for a pond, a shortfin and/or longfin eel biomass estimate for the pond was also established by multiplying the estimated population size by the average shortfin/longfin eel size in the corresponding pond.

To keep sampling effort similar amongst ponds and ensure comparable catching efficiency, the number of nets set in each pond was standardised per unit of pond area for all ponds except for one particularly large pond. Approximately one net was added to each pond for every 600 m^2 of pond area i.e. a pond with a surface area of 1,800 m^2 would have three fyke nets set in the pond. In one large (24,000 m^2) pond which had thirteen nets set, three nights of depletion capture was conducted to obtain an individual population and biomass estimate for that pond.

Pond variables

Recorded pond variables included area, perimeter, age (< or > 10 years), depth (> or < 1 m) fishing status (whether the pond had been commercially/recreationally fished), elevation, euclidean distance to the coast (Foveaux Strait) and fish passage rated as either good or poor based on visual assessment. Pond age and fishing status was provided by the pond owners and pond elevation, area, perimeter and euclidean distances from the coast were determined using Google Earth Pro.

Statistical analysis

To assess which variable or group of variables best explain eel abundance in Southland duck ponds, ten models were produced *a priori* (Table 1). The model set was developed after consideration of the relevant literature and knowledge of shortfin and longfin eel biology. Justification for the candidate models is included in Table 1.

Categorical variables were converted to dummy variables (0, 1) where 1 represented the larger variable (for example pond depth >1 m = 1, <1 m = 0) and similarly, fished = 1, not fished = 0, and for fish passage, yes = 1, and no = 0. The independent variables were scaled using function scale in Program R (R Development Core Team 2018). Models were compiled using generalised linear models (GLM, family = Gaussian, link = Identity) in RStudio (RStudio Team 2016) package Rcmdr (Fox et al. 2009). Models were ranked on their AIC adjusted for small sample size (AICc) (Anderson et al. 2001) where the lowest AICc has the greatest support. Models with delta AICc < 2 are considered to have some support (Burnham and Anderson 2002). Models within 2 AICc units of the top model were examined to ensure the parameters were informative (i.e. made biological sense, and that the 85% confidence interval did not span zero (Arnold 2010)).

An early evaluation of the shortfin data showed a single outlier (311 shortfin eel, pond 23, supplementary material S1) was dominating the data. As the sample size (number of ponds) was relatively small, this pond was removed from the analysis.

Table 1. Structure of models used to investigate the variables or combinations of variables influencing the number of eels in Southland duck ponds.

Model	Variables	Reasoning	Supporting references
Area	Area	Large areas of habitat should be able to support more eels.	
Perimeter	Perimeter	Edge habitat provides more habitat heterogeneity. Longfin eel will utilise undercut banks.	Jellyman et al. (2003)
Depth	Depth[a]	Water depth preference can vary by eel species and size class.	Jellyman et al. (2003)
Physical characteristics	Pond area, pond perimeter, area*perimeter, depth[a]	These combinations of physical pond characteristics may influence habitat suitability and complexity.	
Elevation	Pond elevation	Longfin eels are typically found at higher elevations relative to shortfin.	McDowall (1990)
Distance from coast	Euclidean distance to the coast	Longfin eels generally penetrate further inland relative to shortfin eels.	McDowall (1990)
Fishing status	Commercially fished[a]	Fyke nets are effective at capturing eels. Longfin eels are slow to mature so may be particularly vulnerable to commercial fishing.	McDowall (1990); Jellyman and Graynoth (2005); Jellyman and Crow (2016)
Fish passage	Fish passage[a]	Small eels are good climbers, but fish passage barriers may influence large eel recruitment.	McDowall (1990); Boubée et al. (1999); pers. obs.
Fish passage + Fishing status	Fish passage[a], fishing status[a]	If a pond has been fished and passage is poor there may be a synergistic effect. i.e. the fishing removes eels and poor passage limits recruitment post-fishing.	
Competition	Density of heterospecific eels	Shortfin and longfin eel can co-exist but competition may occur because some foraging habits are similar i.e. both are nocturnal.	Glova and Jellyman (2000)

[a]Denotes categorical variable.

Estimating the number of duck ponds in Southland

To estimate the number of duck ponds in Southland and across low-lying Southland, 10 km × 10 km gridlines were superimposed across satellite imagery of the Southland province in Google Earth. Twenty 100 km^2 quadrats were randomly selected across Southland and across the area below 100 m in elevation (low-lying Southland). The number of duck ponds in each quadrat was then manually counted. An average (±95% CI) number of duck ponds per 100 km^2 was obtained and extrapolated across the Southland area (20,004 km^2) (excluding Fiordland and Stewart Island) and low-lying Southland (4,315 km^2) to generate estimates for the number of duck ponds.

Estimating the number and biomass of eels supported by Southland duck ponds

To generate an estimate for the number and biomass of shortfin and longfin eels supported by Southland duck ponds, the average (±95% CI) number and biomass of shortfin ($n = 35$) and longfin eels ($n = 56$) per pond was estimated. The 95% confidence interval for the average number and biomass of shortfin and longfin eels was a log-normal based confidence interval (Formula 1), which is used when count data are skewed (Williams et al. 2002).

Log-normal based confidence intervals for the quantity x can be constructed as:

$$C = \exp\left(t_{\alpha/2,\,df} \times \text{ sqrt }\left(\ln\left(1 + \left(\frac{SE(x)}{x}\right)^2\right)\right)\right)$$
$$\text{Lower Limit } = \frac{x}{C} \tag{1}$$
$$\text{Upper Limit } = x \times \text{C}$$

where $t_{\alpha}/_{2,df}$ is the critical value from the t-distribution with df degrees of freedom for a $(1-\alpha)\%$ confidence interval (for a mean count, $df = n - 1$) and $SE(x)$ is the standard error for the estimated quantity x. Note that $SE(x)/x$ is the coefficient of variation (CV) for x.

The average (±95% CI) number and biomass of shortfin eel was extrapolated across the estimate for the total number of duck ponds in low-lying Southland. Extrapolating the average shortfin eel count/biomass across the number of low-lying ponds only is important because shortfin eel do not tend to penetrate far inland (McDowall 1990). Because longfin eel do penetrate inland, the average longfin eel population and biomass estimate was extrapolated across the total number of ponds in Southland.

Results

Eel surveys

Of the 56 surveyed ponds, shortfin eels were found in 28 ponds (50%) and longfin eels were found in 26 ponds (46%) (supplementary material, S1). Both species of eel were found coexisting in eleven ponds (20%). Overall, at least one eel species was found in 44 (79%) of the surveyed ponds (supplementary material, S1). Three other endemic/native fish species were captured in the fyke nets and included giant kokopu (*Galaxias argenteus*), inanga (*Galaxias maculatus*) and common bully (*Gobiomorphus cotidianus*). Juvenile *Galaxias* sp. and *Gobiomorphus* sp. were also observed in the margins of some ponds.

Three night depletion surveys on ten ponds revealed that the proportion of the eel catch caught on the first, second and third night of trapping varied by pond (Table 2). On average, 52.1%, 24.6% and 12.2% of the estimated population of eels were captured on the first, second and third night of trapping respectively (Table 2).

Eel population estimates for each pond were variable (supplementary material, S1), ranging from zero to 311 shortfin eel and zero to 81 longfin eel. Eel biomass estimates ranged from 0 kg to 169 kg of shortfin and 0 kg to 60 kg of longfin. On average, Southland duck ponds supported 21.6 (10.8–43.4, 95% CI) shortfin eels, weighing 9.3 kg kg (3.8 kg–22.8 kg, 95% CI) and 8.5 (5.2–14.1, 95% CI) longfin eel weighing 7.6 kg (4.8–11.9 kg, 95% CI).

Table 2. Catches, estimated population size and proportional catch rates of shortfin and longfin eel captured over three nights in ten Southland duck ponds.

Pond	Night 1 catch	Night 2 catch	Night 3 catch	Total catch	Estimated population size ± 95%CI	P_1	P_2	P_3	P*
A	5	1	0	6	6 ± 0	0. 83	0.17	0.0	100
B	2	4	1	7	8 ± 7	0.25	0.50	0.13	0.88
C	2	0	0	2	2 ± 0	100	0	0	100
D	3	4	1	8	9 ± 6	0.33	0.44	0.11	0.89
E	3	7	2	12	19 ± 28	0.16	0.37	0.11	0.63
F	17	32	6	55	84 ± 48	0.20	0.38	0.07	0.65
G	8	2	2	12	12 ± 2	0.67	0.17	0.17	100
H	20	6	9	35	42 ± 16	0.48	0.14	0.21	0.83
I	5	0	2	7	7 ± 2	0.71	0.0	0.29	100
J	8	4	2	14	14 ± 3	0.57	0.29	0.14	100
					Average proportional catch rates ± 95%CI	0.52 ± 0.17	0.25 ± 0.10	0.12 ± 0.05	

For more information on the characteristics of these ponds, see supplementary material S1.
P_1, P_2, P_3, the proportion of the estimated eel population caught on nights one, two and three, respectively. P* The proportion of the total catch relative to the estimated population size. Ponds 1–6 are catches for shortfin eel, ponds 7–10 are catches for longfin eel. The average proportional catch rate is for shortfin and longfin eel combined.

Variables influencing eel abundance

In most cases, shortfin eels dominated the catch in ponds at lower elevations (<100 m), whilst longfin eels dominated the catch in ponds further inland and at higher elevation (>100 m) (supplementary material, S1). Of the candidate models, the elevation model ($w_i = 0.403$, $\beta_{Elevation} = -6.501$, 85% CI -11.745–−1.258) and distance from the coast model ($w_i = 0.294$, $\beta_{Distance\_Coast} = -6.176$, 85% CI -10.064–−2.288) had the most support and explained the abundance of shortfin eel better than the other models (Table 3). For longfin eels, the pond area model ($w_i = 0.93$, $\beta_{Area} = 8.24$, 85% CI 5.56–10.93) explained abundance better than any other model in the set (Table 4).

Potential fish migration barriers were observed at some ponds (perched culverts, steep overflows) and some ponds had no noticeable connectivity to creeks or drains. However, for both shortfin and longfin eel, there was no support for the fish passage model (AICc > 2) (Tables 3 and 4). There was also no support for the fishing model (AICc > 2) (Tables 3

Table 3. Ranking of fitted candidate models explaining the abundance of shortfin eels in Southland (New Zealand) duck hunting ponds.

Model	AICc	Delta AICc	AICc weight	Model likelihood	*K*
Elevation	488.514	0.000	0.403	1.000	3
Distance from coast	489.149	0.635	0.294	0.728	3
Null	492.084	3.570	0.068	0.168	2
Fish passage	492.148	3.634	0.066	0.163	3
Fish passage + Fishing status	493.552	5.038	0.032	0.081	4
Depth	493.585	5.071	0.032	0.079	3
Fishing status	493.704	5.191	0.030	0.075	3
Area	493.904	5.390	0.027	0.068	3
Competition	494.191	5.677	0.024	0.059	3
Perimeter	494.242	5.728	0.023	0.057	3
Physical characteristics	500.330	11.816	0.001	0.003	6

AICc = Akaike's information criterion adjusted for small sample size, delta AICc = difference in AICc between the model and the top model, AICc weight = relative (to the set of models) model weight, *K* = number of parameters.

Table 4. Ranking of fitted candidate models explaining the abundance of longfin eels in Southland (New Zealand) duck hunting ponds.

Model	AICc	Delta AICc	AICc weights	Model likelihood	*K*
Area	457.572	0.000	0.928	1.000	3
Physical characteristics	462.984	5.413	0.062	0.067	6
Perimeter	467.292	9.720	0.007	0.008	3
Depth	472.612	15.040	0.001	0.001	3
Fishing status	472.612	15.040	0.001	0.001	3
Null	472.626	15.055	0.000	0.001	2
Fish passage	473.152	15.580	0.000	0.000	3
Fish passage + Fishing status	473.544	15.973	0.000	0.000	4
Elevation	474.312	16.740	0.000	0.000	3
Competition	474.862	17.290	0.000	0.000	3
Distance from coast	587.562	129.990	0.000	0.000	3

AICc = Akaike's information criterion adjusted for small sample size, delta AICc = difference in AICc between the model and the top model, AICc weight = relative (to the set of models) model weight, *K* = number of parameters.

and 4) which suggests the occurrence of eel fishing in the ponds recent history is not an important predictor of eel abundance.

Estimate for the number of Southland duck ponds and eels supported by duck ponds

On average there are c. 35 (±8.8) duck ponds per 100 km^2 in Southland and c. 39 (±10.3) duck ponds per 100 km^2 in low-lying Southland. By extrapolating the estimate for the number of ponds per 100 km^2 in Southland across the Southland area, it is estimated that there are 7,013 ± 1716 duck ponds in Southland and for low-lying Southland (4,315 km^2), it is estimated there are 1,776 ± 446 duck ponds.

The average numbers and biomass of shortfin eel in ponds below 100 m in elevation was extrapolated across the estimate for the number of duck ponds in low-lying Southland. It is estimated there are 36,059 (17,960–77,133) shortfin eels collectively weighing 15,453 kg (6,285–37,998 kg). For longfin eel it is estimated that Southland duck ponds support a population of 59,747 (36,140–98,774), collectively weighing 53,045 kg (33,702–83,491 kg).

Discussion

This study has shown that Southland duck hunting ponds are utilised by shortfin and longfin eels and collectively they support substantial populations and biomass of eels. To put the eel biomass estimates (15.5 t of shortfin, 53 t of longfin) into perspective, the 2018 commercial harvest of shortfin and longfin eels in Southland was approximately 10 and 38 tonnes respectively (Beentjes 2019). Of that harvest, approximately 10%–15% are captured from duck hunting ponds (V. Thompson, Mossburn Enterprises, pers. comm.). Clearly, not only do Southland duck ponds support significant populations of eels, but they are also important to the local commercial eel fishery.

Eel catch rates varied widely with some ponds supporting no eels and others supporting more than 100 eels. For shortfin eels, elevation and distance from the coast were the best predictors of abundance. In general, shortfin eel dominated the catch in ponds that were of lower elevation (<100 m) and closer to the coast whereas longfin eel dominated the catch in ponds that were further inland and at higher elevation (>100 m). These distribution patterns are typical of New Zealand eel species (McDowall 1990; McDowall and Taylor 2000) and likely reflect their different life history strategies. Further, in most cases, where longfin and shortfin eels co-occurred, shortfins outnumbered longfins. However, the density of heterospecific eels was not an important predictor of eel abundance. Interspecific differences in eel diet have been observed (Jellyman 1989) which may allow for co-existence despite some similar foraging habits (Glova and Jellyman 2000).

Pond area was the most important predictor of longfin eel abundance. This result is intuitive; larger areas of wetland habitat should provide more available habitat to support eels. When constructing wetlands for waterfowl hunting, managers should advocate for larger wetlands because they can support greater numbers of waterfowl (McDougall et al. 2009), which is in the interest of hunters, and provides more habitat for longfin eels.

Fish passage was not an important predictor of eel abundance in Southland duck ponds. This result was unexpected because some ponds possessed potential fish migration barriers like perched culverts, steep waterfall-like overflows, or had no obvious connectivity to creeks or drains. There are two likely reasons fish passage was not an important predictor of eel abundance. Firstly, some ponds may have been misclassified as having poor fish passage because passage was not obvious. When classifying ponds, those without obvious above ground passage were classified as having poor fish passage. This may not have been the case. It is likely that some ponds were fed by tile drains rather than creeks/open drains and eels are highly adept at moving through tile drains (pers. obs.). Secondly, eels, especially young eels, are known to be good climbers and can navigate substantial structures (McDowall 1990; Boubée et al. 1999, pers. obs.). Eels from ponds in this study may have been able to navigate their way into ponds despite the presence of potential migration barriers and this could explain why fish passage was not an important predictor of eel abundance.

Fyke nets, which are commonly used by eel fishers, are very effective at catching eels and can remove a substantial proportion of the eel population in three or four nights of fishing (Jellyman and Graynoth 2005; Jellyman and Crow 2016, this study). Despite this, the occurrence of eel fishing in a ponds recent history was not an important predictor of eel abundance. This result was unexpected but suggests that post-commercial eel fishing, new eel recruits can suitably locate and recolonise duck hunting ponds.

International literature has clearly demonstrated the benefit that hunting can provide to other species of interest (Oldfield et al. 2003; Lewis and Jackson 2005; Loveridge et al. 2006). Hunters will often put significant effort and resources into enhancing and/or protecting the habitat of their quarry, with corresponding benefits for species that share that habitat (Oldfield et al. 2003; Loveridge et al. 2006). This study demonstrates that Southland gamebird hunters have put significant effort into establishing duck hunting ponds and both shortfin and longfin eels benefit from such habitat. It can therefore be argued that without the introduced mallard duck, there would be less motivation for hunters to create open water wetland habitat and consequently, the amount of habitat available for eels would be reduced. As such, conservation and biodiversity managers should acknowledge the potential habitat value of duck hunting ponds.

Acknowledgements

The authors thank all the Southland landowners and duck hunters who kindly provided access to their duck ponds for the eel surveys. The authors also thank David MacGregor, Craig Horrell, Len Prentice, Bill Jarvie, Joshua Tabak and Blake Harper for their assistance with the eel surveys. Vic Thompson provided information on commercial eel harvest in Southland and two anonymous reviewers provided helpful comments on an earlier draft of this paper. This work was funded by the Southland Fish and Game Council.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was funded by my employer, the Southland Fish and Game Council.

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