Variation in mahinga kai growth rates and catch from Te Waihora

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Executive summary

Examining variation in tuna (shortfin and longfin eels) and pātiki (yellowbelly, sand and black flounder) population structure between different areas in Te Waihora is Objective 2 of the Whakaora Te Waihora “D5” project called ‘Fish restocking/recruitment’. Specifically, this involves examining the differences in catch-per-unit effort, length, condition and growth rates. Data will then be used to identify specific areas that are likely to be of higher fishery value.

Tuna populations were sampled at six sites around Te Waihora as well as in two of its major tributaries between 24 March 2014 and 1 April 2014. Five unbaited coarse mesh fyke nets were used to sample eels at each of the eight sites. Pātiki were sampled using set-nets (gill nets) at 10 sites around Te Waihora between 8 August 2014 and 18 August 2014. Five nets were set at each site, with site selection based on guidance by Ngāi Tahu. Ages were estimated from 90 shortfins, 21 black flounder, 84 sand flounder and 142 yellowbelly flounder captured across all sites.

A total of 518 eels were caught across all sites, excluding the catch from Fishermans Point which was dominated by migrant eels (n = 246). Catch abundance was dominated by shortfins, with a total of 482 (93 per cent) shortfins and 36 longfins captured over all sites. All of the longfin eels were caught in the two tributaries and none were captured at the six sites within the lake. Across the sites (excluding Fishermans Point), 201 kg of eels were caught with shortfins comprising 88 per cent (177 kg) and longfins 12 per cent (24 kg) of the total catch weight. For each net/night, a mean weight of 5.8 kg of eels was caught.

There were 513 pātiki caught from all 10 sites. Catch abundance was dominated by yellowbelly flounder, with a total of 393 (77 per cent) yellowbelly flounder, 98 (19 per cent) sand flounder and 22 (4 per cent) black flounder captured across all sites. Of the 186 kg of pātiki caught, yellowbelly flounder comprised 79 per cent (147.8 kg) of the total weight, sand flounder 14 per cent (25.8 kg) and black flounder 7 per cent (12.4 kg). On average, 10 pātiki were captured from each net/night, which was composed of eight yellowbelly flounder, two sand flounder and less than one black flounder (only captured intermittently). A mean weight of 3.7 kg of pātiki was caught for each net/night, which was composed of 2.9 kg of yellowbelly flounder, 0.5 kg of sand flounder and 0.3 kg of black flounder.

Shortfin eels taken for aging, varied in total length from 255–941 mm. The age of these fish ranged from 7 to 25 years (n = 90). Based on relationships derived from these data it would take 13.4 years to reach the minimum customary harvest size of 500 mm and 19.7 years to reach the optimum customary harvest size of 1,000 mm. Minimum national commercial size is 220 g and it would take 12.9 years to reach this weight. Te Waihora has a commercial fishery that targets small migrant male shortfins that had a mean weight of 124 g in the present study, which would be approximately 11.2 years old.

Growth rates of pātiki averaged (±s.e.) 100.4 (±0.8) mm/year for yellowbelly flounder, 119.2 (±2.5) mm/year for black flounder, and 84.8 (±2.2) mm/year for sand flounder. The minimum commercial size of pātiki is 250 mm and based on the growth rates observed in the present study a black, yellowbelly and sand flounder will reach this size within 2.1, 2.5 and 3.0 years respectively.

Mean length of shortfins observed in the present study was 512 mm (excluding Fishermans Point), which is larger than historical catches from Te Waihora. In a collation of existing length data from 40,179 shortfins caught in Te Waihora and its tributaries, Crow & Bonnett (2013) reported that shortfin catches were dominated by fish that were roughly 100 mm smaller than the present study.

Shortfin eels showed differences in population structure around Te Waihora. Kaitorete Spit West had the highest catch-per-unit effort (CPUE) values and sizes of shortfins along with the highest condition. This site is likely to be highly-valued because it appears to be have the most productive catches of large well-conditioned eels. Timberyard Point also had high catch-per-unit-effort (CPUE), but these catches contained smaller eels. Greenpark Sands West and Kaitorete Spit East had the lowest CPUE values and small eel sizes, which was also observed at Coes Ford. The low catch rates and small eels present around Greenpark Sands may be associated with the type of habitat present. Greenpark Sands has a large amount of firm sand that may be avoided by eels and it has previously been suggested that this is a cause of low shortfin numbers around Greenpark Sands. Shortfin eel growth appears to be ubiquitous throughout the Te Waihora Catchment, despite observing localised differences in shortfin sizes (both length and weight).

Pātiki population structure differed between sites within Te Waihora. Taumutu and the Halswell River Mouth are likely to be the most highly valued yellowbelly sites. Taumutu had the highest catches of large well-conditioned fish and is likely to be the most productive area in the lake for catching pātiki. Kaitorete Spit East also had high catches of large fish, but their condition was lower than Taumutu and the Halswell River mouth.

There were no consistent differences in the eel or pātiki population between the sites inside and outside of the Horomaka kōhanga. This is consistent with the findings of Jellyman et al. (in press) who found that although average CPUE abundance and weight was higher inside the Horomaka kōhanga, the differences in CPUE between inside and outside the kōhanga were not statistically significant. They also found that 17 per cent of the eels in the Horomaka kōhanga moved outside the reserve within four months; this level of movement will mean that any impacts of commercial fishing outside the Horomaka kōhanga will be difficult to detect a short time after the harvest is completed.

When considering how the lake should be managed in the future for tuna and pātiki, the role of lake level is likely to be critical. Low lake levels may restrict fish access to areas around the edge of the lake where the highest chironomid densities are located. Whilst this reduced access to chironomids will only directly impact bullies and small tuna (<400 mm) that predate on these invertebrates, it may indirectly impact larger tuna and pātiki that predate on bullies. Any reduction in the availability of this key prey species, that supports several trophic levels in Te Waihora, suggests that managers need to be mindful of complex problems that may occur during the summer when low lake levels occur. The influence of low lake levels on mahinga kai in Te Waihora is poorly understood, which should be an area of future research in the lake. The installation of a weir at the outlet of Te Waihora (to control lake levels) is being investigated in the Whakaora Te Waihora Programme, making it particularly important to understand the associations between lake level and ecosystem health before designing any structures.

1 Introduction

Mahinga kai (food gathering areas) is at the heart of Ngāi Tahu culture and identity. It remains the cornerstone of Ngāi Tahu spiritual, social, and economic wellbeing and is a symbol of the continuing relationship of Ngāi Tahu with the traditions and history of place. Mahinga kai was, and still is, the currency of Ngāi Tahu. Manaakitanga (ability of hosts to care for their visitors) remains a fundamental cultural value. The quality and quantity of food whānau (family) are able to provide guests is one of the factors underpinning manaakitanga and is a reflection of mana (standing). In fact, until a couple of centuries ago, mahinga kai provided Ngāi Tahu with almost everything they needed, including food, medicine, and raw materials for making clothing, tools, and shelter (Tau, Goodall et al. 1990).

The ability of Te Waihora mahinga kai to sustain whānau, is upheld in the whakataukī (tribal proverb) from Taumutu: *Ko ngā hau ki ētahi wāhi, ko ngā kai ki Orariki – No matter which way the wind blows, you will always eat at the pā of Orariki, Taumutu*. No matter what the season, you will always be able to find food in the Te Waihora environment (see Whakaora Te Waihora website)[1].

The food and other resources of Te Waihora were not simply exploited on an *ad hoc* basis (Tau et al. 1990). Natural resource management was practiced, which involved a set of beliefs about the relationship of humans to the natural world, knowledge of the natural environment and application of that knowledge and beliefs through tikanga and kawa (the correct laws and customs) to control the relationship with the environment. Ensuring the continuity of the application, generation and transmission of knowledge remains a priority for Ngāi Tahu whānui (extended, wider whakapapa connections).

Although the relative importance of the mahinga kai economy has declined since the advent of agriculture and urban migration, socio-cultural practices based around the harvest of mahinga kai have not disappeared. Wild kai gathering continues to take place and continues to be a fundamental element of some Ngāi Tahu livelihoods. Although less important for daily subsistence, the gathering of wild kai is often a highly appreciated recreational activity and part of cultural habits even in industrialised and urbanised areas (e.g., Tipa & Associates 2013). Te Waihora is considered nationally significant for both customary and commercial fisheries, contributing about a quarter of New Zealand's commercial eel catch and supporting a significant flatfish (pātiki) fishery.

Efficiently managing the tuna (shortfin and longfin freshwater eels) and pātiki fisheries in Te Waihora requires information on the spatial variation in catch and growth rates. Understanding the variability in catch and growth rates can be used to identify areas of the lake that have higher levels of fish productivity, helping guide management of the resources and restoration efforts. Targeting resources in high productivity areas would help maximise the fishery benefits, for example, when either time and/or resources are limited. Data on variation in catch rates can also be used to monitor any fishery development of assist with any future Kōhanga development, and identify factors influencing population structure of mahinga kai species. Unfortunately, there is limited information available that compares tuna and pātiki (yellowbelly, sand and black flounder) population structures between different areas of Te Waihora.

[1] http://tewaihora.org/

NIWA is managing the Whakaora Te Waihora (WTW) "D5" project called 'Fish restocking/recruitment including a review of fisheries management'. The D5 project brief has four key research-based objectives:

1. Identify the factors limiting mahinga kai recruitment. Specifically, the recruitment of yellowbelly flounder, shortfin eels and longfin eels will be monitored around lake openings using seine and fyke nets. Data will be used to generate relationships between mahinga kai recruitment and season, lake opening regime and species abundance. Identification of recruitment periods for these species will assist in the development of lake opening regimes.

2. Monitor the growth, sizes and relative abundance of key mahinga kai species. Specifically catch rates, condition, growth rates and length and weight distributions of shortfin eels will be monitored throughout the lake by fyke netting. The results will be used to compare the productivity of the shortfin eel fishery in different areas of the lake, evaluate the effectiveness of the establishment of the Horomaka kōhanga area and identify factors that may influence survival, growth and maturation of mahinga kai species.

3. Identify and evaluate the effectiveness of in-lake and wider catchment interventions aimed at providing protected or enhanced environments for mahinga kai species and their prey. Specifically, the effectiveness of enhancing in-lake spawning habitat for non-diadromous populations of prey species (bullies and īnanga) will be determined through assessing īnanga spawning habitat availability and quantifying the extent of non-diadromous populations of these species. In addition, the effects of macrophyte re-establishment on mahinga kai habitat and prey availability will be assessed by monitoring colonisation of re-established macrophyte beds by mahinga kai species and fish and invertebrate prey. Enclosure experiments will also be used to determine the effects of macrophyte re-establishment on fish biomass, size and survival.

4. Determine the effectiveness of the establishment and enhancement of kōhanga areas in protecting mahinga kai species. Specifically population estimates of shortfin eels in the Horomaka kōhanga reserve will be developed through mark-recapture and used as a baseline to monitor future changes in abundance resulting from the establishment of the reserve. Additionally, the movements of individual eels in and out of the reserve will be monitored through radio-telemetry. Telemetry data and population estimates will be used to calculate the number of eels within the Horomaka kōhanga reserve whose daily movements out of the protected area put them at risk of capture by commercial fishery operations.

The present study aims to assess Objective 2 of the D5 project by examining variation in tuna and pātiki population structure between different areas in Te Waihora. Specifically, this involves examining the differences in CPUE, length, condition and growth rates, and identify specific areas that are likely to be of higher fishery value. We also aim to compare tuna population differences inside and outside of the Horomaka kōhanga, but this has been examined more thoroughly in Objective 4 above (Jellyman et al. in press).

2 Methods

2.1 Tuna

2.1.1 Sampling sites

Tuna (shortfin and longfin) populations were sampled at eight sites within Te Waihora and two of its major tributaries (Harts Creek and Selwyn River) between the 24 March 2014 and the 1 April 2014 using a powered boat. The sites were selected based on guidance from the Te Waihora Management Board and Ngai Tahu customary fisherman, which focussed the work on the areas of highest customary significance (Figure 2-1).

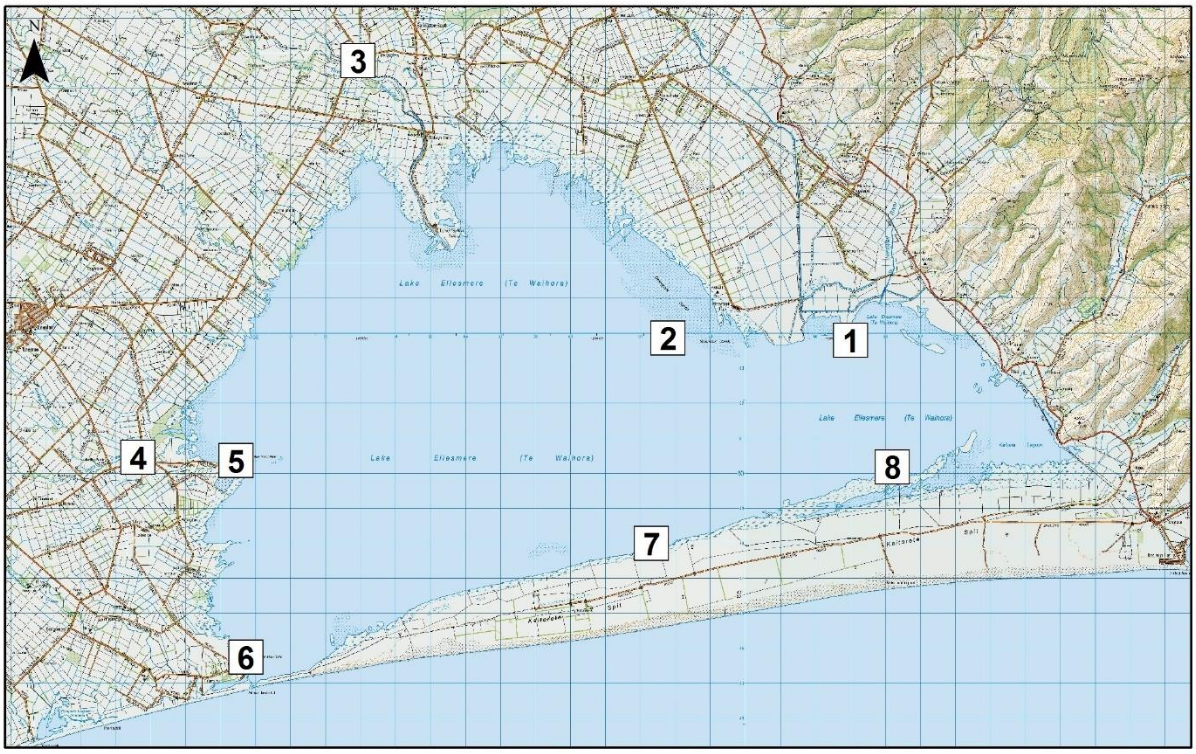


Figure 2-1: Tuna sampling sites in Te Waihora. Site numbers correspond to: (1) Greenpark Sands East (inside the Horomaka kōhanga), (2) Greenpark Sands West (outside the Horomaka kōhanga), (3) Selwyn River at Coes Ford, (4) Harts Creek at Harts Creek Wildlife Reserve, (5) Timberyard Point, (6) Fishermans Point, (7) Kaitorete Spit (Te Waiomākua) West (outside the Horomaka kōhanga), (8) Kaitorete Spit (Te Waiomākua) East (inside the Horomaka kōhanga). Sites 1 and 8 are within the Horomaka kōhanga while the remaining sites are outside of the reserve.

2.1.2 Sampling methods

Five unbaited coarse mesh fyke nets (12 mm stretched mesh, with a 6 m single leader and no escapement tubes) were used to sample eels at each of the sites. At each lake site, five fyke nets were spaced 50 m apart (in at least 30 cm of water) and set perpendicular (with the opening of the net facing the shore) to the shore, with both ends of the net staked into the lake bed so they did not move in the wind. For the tributary sites, the five unbaited nets were set facing downstream and spaced at least 50 m apart (in at least 30 cm of water). All fyke nets were left to fish overnight at each site.

2.1.3 Catch processing

Catch processing of the eels was completed in two steps. Firstly, the total number, species composition, and total weight of eels was recorded from each fyke net. Secondly, up to 100 shortfin eels (depending on numbers caught) were randomly selected from the five fyke nets at a site and anaesthetised with a natural clove-oil based fish anaesthetic (AQUI-S)[2]. The anesthetised eels were then measured for total length (mm) and weight (g). The catch data for each net was then converted into two indices of catch-per-unit effort (CPUE): kg/net/night (CPUE weight hereafter) and numbers/net/night (CPUE abundance hereafter).

Otoliths (ear bones) were extracted from 15 shortfin eels at each site and used for growth rate analysis. Longfins were not taken for aging because Ngāi Tahu requested that no longfins be killed during the present study. The 15 shortfins were selected using a size-stratified sampling protocol, which ensured eels were collected from a variety of size classes. The size-stratified sampling protocol included: five fish between 300-400 mm, five fish between 500-600 mm, and five fish larger than 600 mm. Shortfins were not taken for aging if they displayed any morphological features indicative of sexual maturity (Todd 1981a). All shortfins were humanely euthanized with an overdose of AQUI-S. The shortfins bodies were then provided to Ngāi Tahu for eating. Otoliths were prepared for aging using a modified crack and burn technique (Graynoth 1999). Growth rates were then calculated for each fish as mean annual length (mm) increase [i.e., total length (mm)/age of fish (years)] and mean annual weight (g) increase [i.e., total weight (g)/age of fish (years)]. No shortfins were taken for aging from Coes Ford (Selwyn River) because there were insufficient numbers to allow reliable relationships to be calculated for growth rates. Condition (K) for all eels was calculated using the following formula (Ricker 1971): $K = \text{Weight (g)} \times 10^6 / \text{Length (mm)}^3$

2.1.4 Habitat measurements

Water depth was measured at the mouth of each fyke net. Temperature (°C), dissolved oxygen (ppt and mg/L), pH, water clarity (cm^{-1}), conductivity ($\mu S\ cm^{-1}$) and salinity (ppt) were measured at each site. Water velocity and substrate composition were also measured at tributary sites. Wind direction and strength were obtained from the Environment Canterbury (ECan) weather station at Taumutu. Substrate and invertebrate data for the lake sites were obtained from Marc Schallenberg (University of Otago).

2.1.5 Data analysis

One-way analysis of variance (ANOVA) was used to compare: eel weights, eel lengths, eel condition, CPUE abundance and CPUE weight between all sites. Tukey's honestly significant difference (HSD) post-hoc tests were used to identify differences between pair-wise combinations of sites. Attempts were made to use regression analyses to explore relationships between CPUE abundance and CPUE weight and habitat measurements, but unfortunately there were insufficient data to allow robust relationships to be generated.

Data from Fisherman's Point (Site 6) were not included in any of the inter-site comparisons because it contained an unusually high number of migrant eels. These catch data were not considered to be representative of the lake and would have generated misleading results; data on lengths and weights

[2] AQUI-S © was the anaesthetic used for all catch processing because it is the only fish anaesthetic registered under the Agricultural Compounds and Veterinary Medicine (ACVM) Act 1997. It also contains biodegradable ingredients. This anaesthetic was chosen to ensure that any tuna and pātiki taken for eating by Ngāi Tahu were safe for consumption and that fish returned to the water would also be unsafe for future consumption should they be captured during any customary harvests.

of eels from this site were analysed separately. Eels at Fisherman's Point were classified as migrants based on external morpholgical features mentioned in Todd (1981a).

Age and growth rates

Least-squares linear regression was used to examine relationships between age and size (length and weight) and to estimate the average age of shortfins when they reach minimum customary, optimum customary and minimum commercial harvest size. The minimum customary harvest size of 500 mm was used based on conversations with Ngāi Tahu representatives (Mandy Home, pers. comm.), while the optimum customary size of 1,000 mm (Don Brown, pers. comm). The national minimum size is set at 220 g but we also used a secondary minimum commercial harvest size of 124 g for the lake. This minimum size of 124 g was selected because Te Waihora has a specific commercial fishery that targets undersized migrant male shortfins, which have a mean weight of 124 g (see Section 3.1.5). Regression results for eel length and weight were both presented in this report, which will provide Ngāi Tahu fisheries managers with the ability estimate shortfin age for any specific length or weight in the future.

Annual freshwater length increase was estimated for each eel by subtracting the mean length at entry to fresh water for shortfins [60 mm taken from Jellyman (1977)] from the recorded lengths, and then dividing by their age (years). Annual freshwater weight increase was also determined by dividing weight by their age (years). Weight at entry into fresh water was not subtracted before dividing by age as this was negligible (~0.2 g) relative to the weight of the fish (c. 200 g).

2.2 Pātiki

2.2.1 Sampling sites

Pātiki (yellowbelly, sand and black flounder) were sampled at ten sites from around Te Waihora (Figure 2-2) between the 8 August 2014 and the 18 August 2014. The sites were selected based on guidance by Te Waihora Management Board and Ngai Tahu customary fisherman, which focussed the work on the areas of highest customary significance.

2.2.2 Sampling methods

Set-nets (also known as gill nets) were used to sample larger pātiki from each of the sites. Set-nets were 40 m long with 5 ½" mesh, nine mesh deep. Five set-nets were deployed at each site, at intervals of approximately 40–50 m apart, or as close to this spacing as was possible depending on the availability of adequate water depth. All nets were set perpendicular to the lake shore and each end of the net was secured using sinkers. All nets were marked with floats and left to fish overnight.

2.2.3 Catch processing

Catch processing of pātiki was completed using two steps. Firstly, the total number, species composition, and total weight of pātiki was recorded from each net. The catch data for each net were then converted into two indices of catch-per-unit effort (CPUE): kg/net/night (CPUE weight) and numbers/net/night (CPUE abundance). Secondly, up to 50 pātiki of each species were randomly selected from each site and anaesthetised using a natural clove-oil based fish anaesthetic (AQUI-S). The anaesthetised fish were then measured for total length (mm) and weight (g).

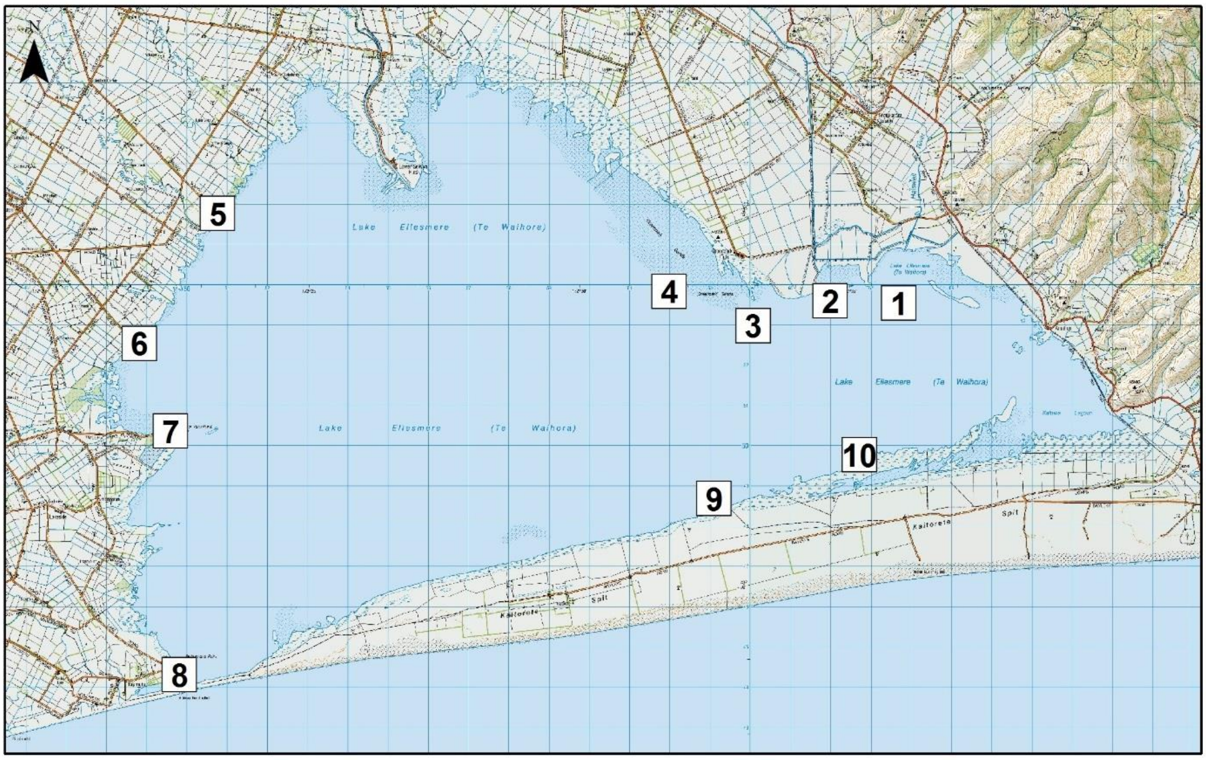


Figure 2-2: Pātiki sampling sites in Te Waihora. Site numbers correspond to: (1) Nutts Drain mouth, (2) Halswell River mouth, (3) Greenpark Sands East (inside of the Horomaka kōhanga boundary), (4) Greenpark Sands West (outside of the Horomaka kōhanga boundary), (5) Irwell River mouth, (6) Doyleston Drain mouth, (7) Timberyard Point, (8) Taumutu, (9) Kaitorete Spit (Te Waiomākua) West (outside of the Horomaka kōhanga boundary), (10) Kaitorete Spit (Te Waiomākua) East (inside of the Horomaka kōhanga boundary).

Otoliths were extracted from up to 15 pātiki of each species, at each site. Pātiki were selected using a size-stratified sampling protocol, which ensured fish were collected from a variety of size classes. The size-stratified sampling protocol included: five fish between 130-200 mm, five fish between 200-270 mm, and five fish larger than 270 mm. Pātiki were humanely euthanized by prolonged exposure to AQUI-S and the bodies were provided to Ngāi Tahu for eating. Condition (K) for all pātiki was calculated using the following formula (Ricker 1971): K = Weight (g) x 10^6/ Length $(mm)^3$. For simplicity, the same condition calculation was used for eels and pātiki. Otoliths were prepared and aged following the methodology used in Jellyman (2011). Growth rates were calculated for each fish as mean annual length (mm) increase [i.e., total length (mm)/age of fish (years)] and mean annual weight (g) increase [i.e., total weight (g)/ age of fish (years)].

2.2.4 Habitat measurements

Water depth, temperature (°C), dissolved oxygen (ppt and mg/L), pH, water clarity (cm^{-1}), conductivity (µS cm^{-1}) and salinity (ppt) were measured at each site. Wind direction and strength were obtained from the ECan weather station at Taumutu. Substrate and invertebrate data for lake sites were obtained from Marc Schallenberg (University of Otago).

2.2.5 Data analysis

Statistical comparisons between sites were carried out using yellowbelly and sand flounder, but there were insufficient data gathered on black flounder to complete statistical tests. One-way ANOVA was used to compare weight of individual pātiki, length of individual pātiki, condition of individual pātiki, CPUE abundance and CPUE weight between all sites. Between-site differences were investigated using a Tukey's HSD post-hoc test. One-way ANOVA comparisons could not be completed using all species combined, because each species displayed differences in weight, length and condition ($P < 0.001$), which would have confounded any between-site comparisons.

Attempts were made to use regression analyses to explore relationships between CPUE abundance and CPUE weight and habitat measurements, but unfortunately there were insufficient data to allow robust relationships to be calculated. Data either did not display enough variation between sites or were compromised by equipment issues (i.e., net theft or damage).

3 Results

3.1 Tuna

3.1.1 Species composition

A total of 518 eels were caught during this survey, excluding the catch from Fishermans Point[3] (Table 3-1). Catch abundance was dominated by shortfins, with a total of 482 (93 per cent) shortfins and 36 longfins captured across all sites. All of the longfin eels were caught in the two tributary sites. Across the sites (excluding Fishermans Point), of the 201 kg of eels caught in the present study, shortfins comprised 88 per cent (177 kg) while longfins comprised 12 per cent of the total catch weight (24 kg).

Shortfin eel CPUE abundance differed significantly among the sampling sites (One-way ANOVA: $F_{5,24}$ = 5.17, P = 0.002). No shortfin eels were recorded from Harts Creek, so this site was excluded from post-hoc comparisons. Coes Ford (Selwyn River) was the only other tributary site sampled, which had significantly lower shortfin abundance (0.4 eels/net/night) than the five lake sites (Figure 3-1a). The lake site with the lowest CPUE abundance was Greenpark Sands West (4 eels/net/night). Kaitorete Spit East (6.4 eels/net/night) also had similarly low CPUE abundance as Greenpark Sands West, but the other three lake sites all had a CPUE abundance of ≥20 eels/net/night (Figure 3-1a). The highest CPUE abundance was recorded at Timberyard Point (38 eels/net/night), but catches at this site were also the most variable and did not significantly differ from the other three high abundance sites (Figure 3-1a).

Shortfin eel CPUE weight also differed significantly among the sampling sites (One-way ANOVA: $F_{5,24}$ = 10.18, P = <0.001), and in general, patterns in CPUE weight were similar to those in CPUE abundance (Figure 3-1b). The biggest difference between CPUE abundance and CPUE weight comparisons was observed at Kaitorete Spit West. Kaitorete Spit West had the highest CPUE weight even though Timberyard Point had the highest CPUE abundance (Figure 3-1a, b). Similar to the CPUE abundance patterns, the three sites with the highest CPUE weight (i.e., Greenpark Sands East, Kaitorete Spit West and Timberyard Point) were not significantly different from each other because of high variability (Figure 3-1b). In contrast to CPUE abundance, CPUE weight at Coes Ford was not significantly different from all other sites, it was only different from the three sites with the highest CPUE weight (Figure 3-1b).

[3] The data from Fishermans Point are excluded because of a high proportion of migrant eels in the catch. These data are presented separately in Section 3.1.6

Table 3-1: Catch-per-unit-effort (CPUE) for numbers and weight of eels captured from all sites. CPUE units for abundance are numbers/net/night and CPUE units for weight are in kg/net/night. Overall values are summed for abundance and weights, but averaged for CPUE indices across the sites.

	Abundance (numbers)						Weight (kg)					
	Longfin		Shortfin		All eels		Longfin		Shortfin		All eels	
Site	Total No.	CPUE	Total No.	CPUE	Total No.	CPUE	Total weight	CPUE	Total weight	CPUE	Total weight	CPUE
Coes Ford	14	2.8	2	0.4	16	3.2	9.33	1.87	0.99	0.20	10.32	2.06
Greenpark Sands East	0	0	138	27.6	138	27.6	0	0	38.84	7.77	38.84	7.77
Greenpark Sands West	0	0	20	4	20	4	0	0	4.49	0.90	4.49	0.90
Harts Creek	22	4.4	0	0	22	4.4	14.71	2.94	0	0	14.71	2.94
Kaitorete Spit East	0	0	32	6.4	32	6.4	0	0	12.07	2.414	12.07	2.41
Kaitorete Spit West	0	0	100	20	100	20	0	0	68.26	13.65	68.26	13.65
Timberyard Point	0	0	190	38	190	38	0	0	52.55	10.51	52.55	10.51
Overall	36	1.03	482	13.77	518	14.80	24.04	0.69	177.20	5.06	201.24	5.75

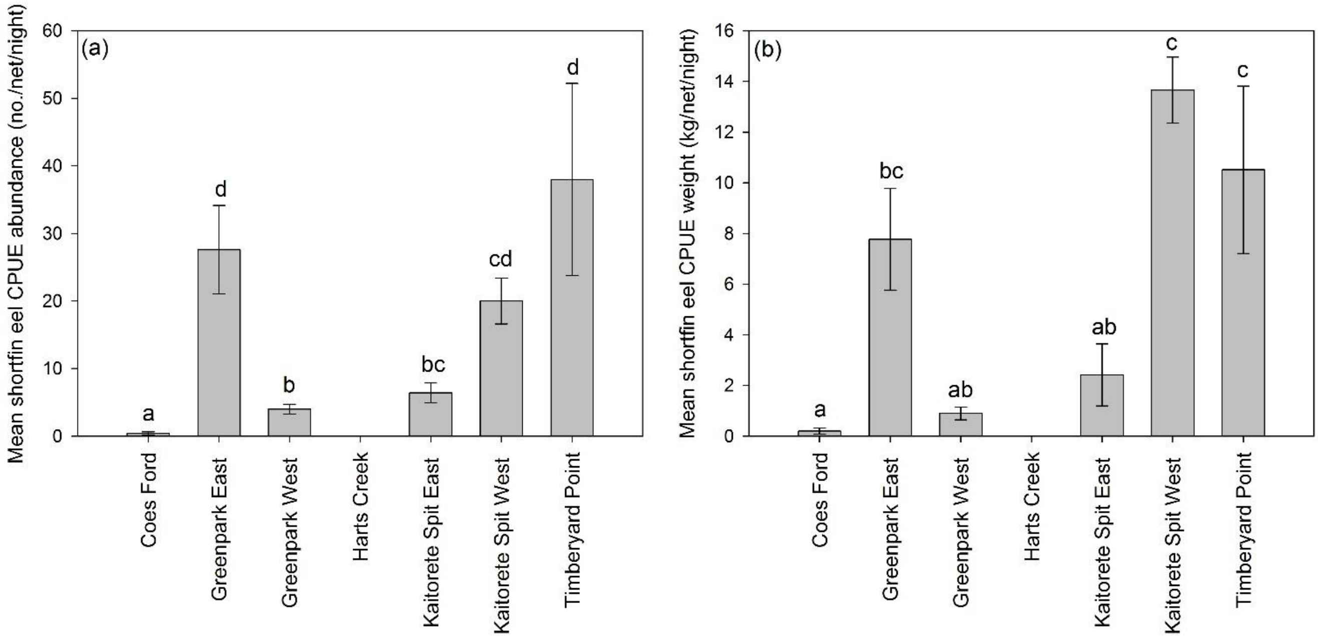


Figure 3-1: Mean (±SE) CPUE abundance (a) and CPUE weight (b) of shortfin eels at the different sites sampled around the lake and tributaries. Significant differences ($P < 0.05$) between sites were calculated by Tukey's HSD tests. Sites that do not share a letter are significantly different from each other.

Longfin eels were only caught at two sites, and both were tributary sites (Harts Creek and Coes Ford) (Figure 3-2). Compared to shortfin eels, longfin eels had higher CPUE abundance and CPUE weight measures at these two sites (Figure 3-1, Figure 3-2). Mean CPUE abundance at Coes Ford (2.8 eels/net/night) was lower than at Harts Creek (4.4 eels/net/night) (Figure 3-2a). Mean CPUE weight followed the same pattern as CPUE abundance with mean CPUE weight higher in Harts Creek than at Coes Ford (Figure 3-2b). Because of high variability in net catches at each site, between-site differences (i.e., Coes Ford vs. Harts Creek) were not statistically significant for either CPUE abundance (One-way ANOVA: $F_{1,8}$= 0.91, P = 0.37) or CPUE weight (One-way ANOVA: $F_{1,8}$= 0.66, P = 0.44) (Figure 3-2).

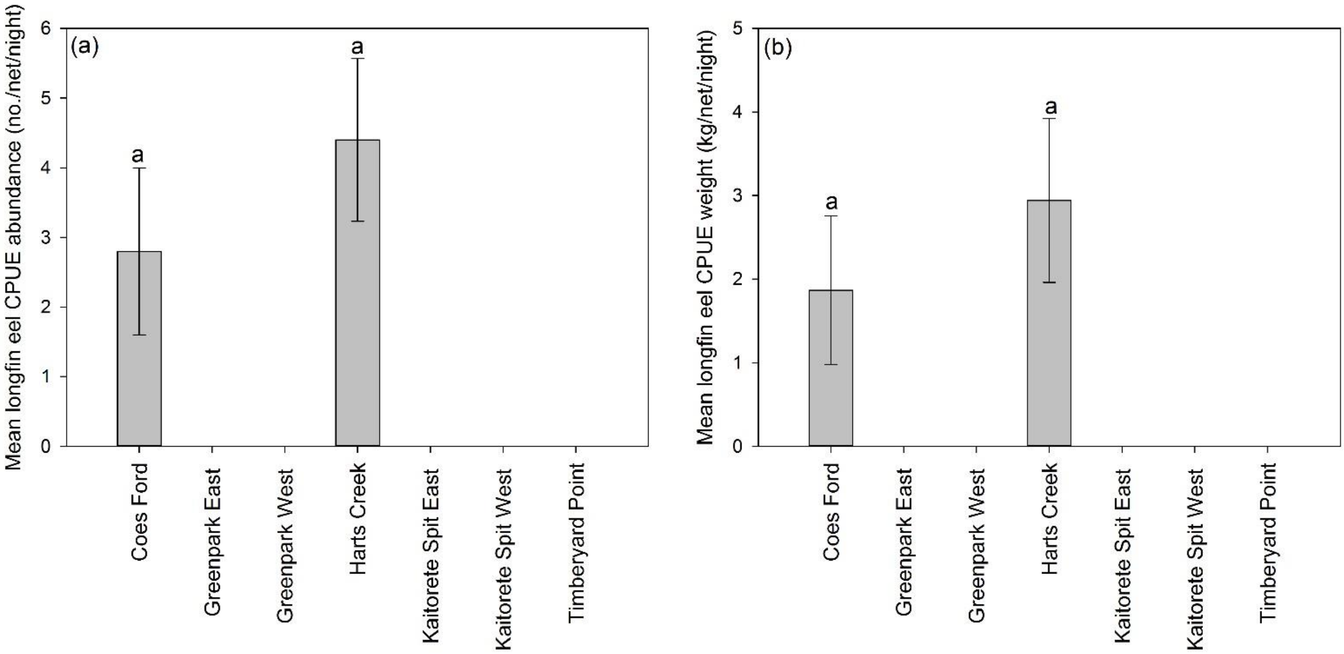


Figure 3-2: Mean (±SE) CPUE abundance (a) and CPUE weight (b) of longfin eels at the different sites sampled around the lake and tributaries. Significant differences ($P < 0.05$) between sites were calculated by Tukey's HSD tests. Sites that share the same letter are not significantly different from each other.

3.1.2 Length and weight characteristics

Shortfin eels

Of the 482 shortfin eels caught during sampling, 401 were measured for total length; eels were counted at two sites after 100 individuals had been measured. The length of these 401 shortfins ranged between 219–1,038 mm with a mean size of 512 mm (Figure 3-3). There was a strong peak around 350–450 mm with almost 40 per cent of the total catch in this size range (Figure 3-3). The percentage of shortfin eels in each size class declined steadily from this peak to their maximum recorded size (Figure 3-3).

There were significant differences in the mean length of shortfin eels between sampling sites (One-way ANOVA: $F_{5,395} = 14.07$, $P < 0.001$). Mean length was lowest at the Greenpark Sands West site (442 mm) and was highest at Kaitorete Spit West (619 mm) (Figure 3-4a, Figure 3-5). Shortfin eels at Kaitorete Spit West were significantly longer than eels at all other sites except Coes Ford (mean length = 586 mm) (Figure 3-4a, Figure 3-5). However, only two shortfin eels were caught at Coes Ford and it was the only site that did not have shortfin eels greater than 850 mm (Figure 3-5).

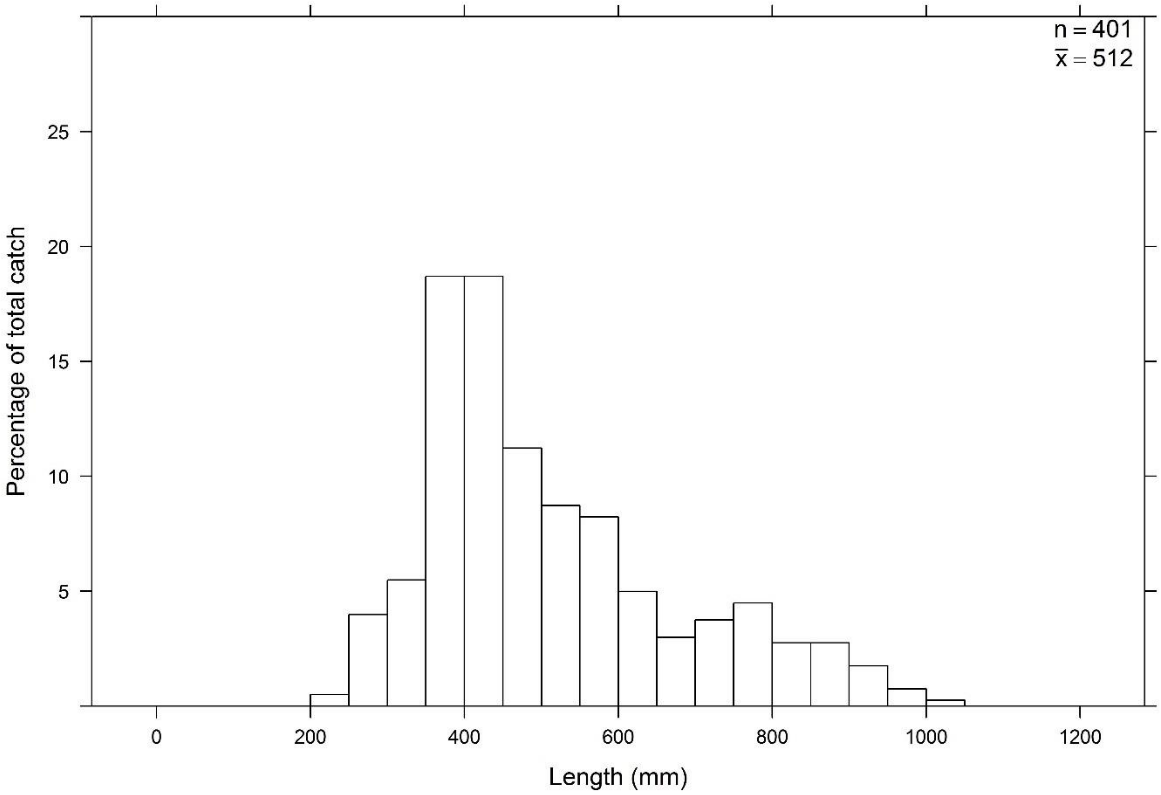


Figure 3-3: Length-frequency distribution for all measured shortfin eels caught during sampling. Both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown on the plot. Size class bins were 50 mm.

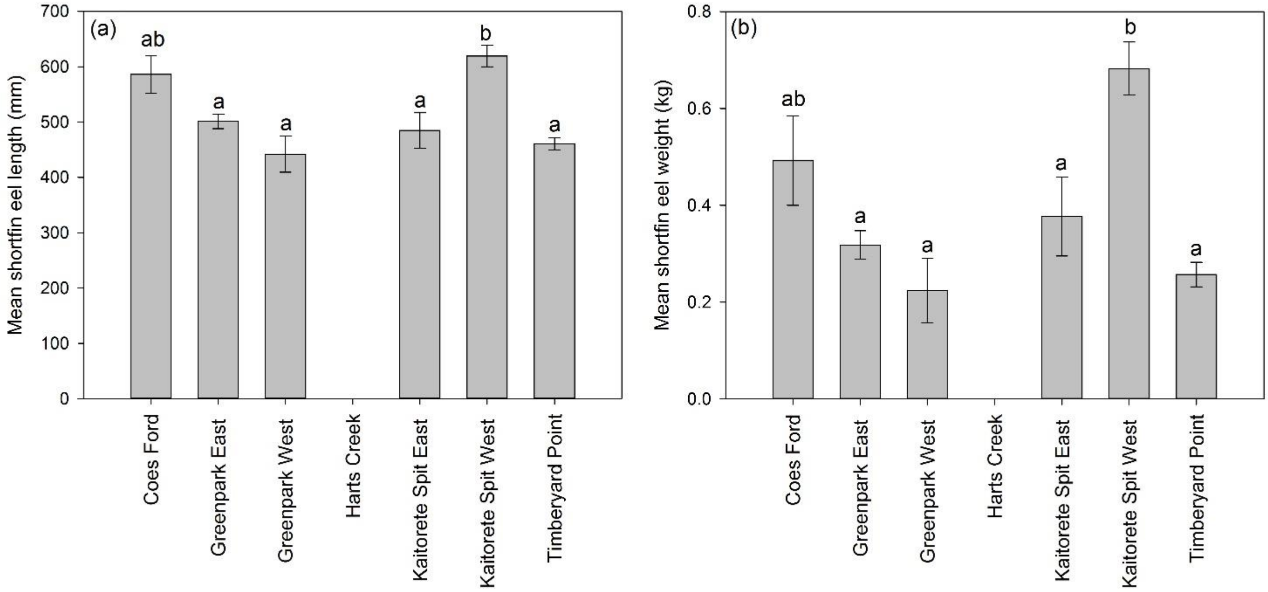


Figure 3-4: Mean (±SE) length (a) and weight (b) of shortfin eels at the different sites sampled around the lake and tributaries. Significant differences (P < 0.05) between sites were calculated by Tukey's HSD tests. Sites that do not share a letter are significantly different from each other.

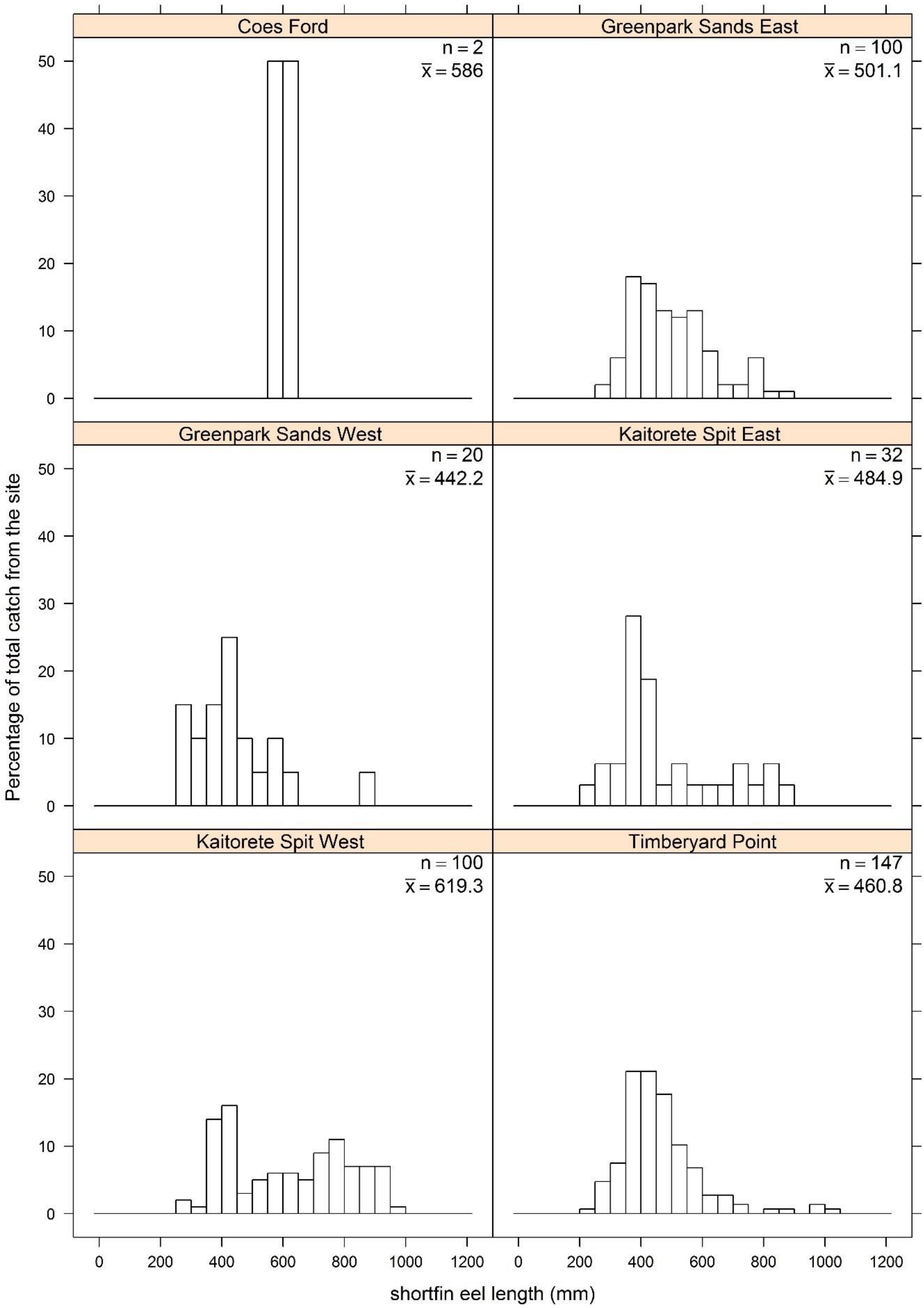


Figure 3-5: Length-frequency distributions for sites where shortfin eels were caught. For each site, both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown. Size class bins were 50 mm.

The weight of the 401 shortfin eels varied between 28–2,260 g with a mean weight of 388 g (Figure 3-6). The weight-frequency plot for shortfin eels peaked at 100–150 g and more than 50per cent of the eels caught were ≤200 g (Figure 3-6). There were significant differences in the mean weight of shortfin eels between sampling sites (One-way ANOVA: $F_{5,395}$ = 16.14, P < 0.001). Similar to mean length, mean weight was lowest at the Greenpark Sands West site (224 g) and was highest at Kaitorete Spit West (683 g) (Figure 3-4b, Figure 3-7). Shortfin eels at Kaitorete Spit West where significantly heavier than eels at all other sites except Coes Ford (Figure 3-4b, Figure 3-7). However, Coes Ford had a very low sample size and was the only site that did not have any shortfin eels greater than 1,300 g (Figure 3-7).

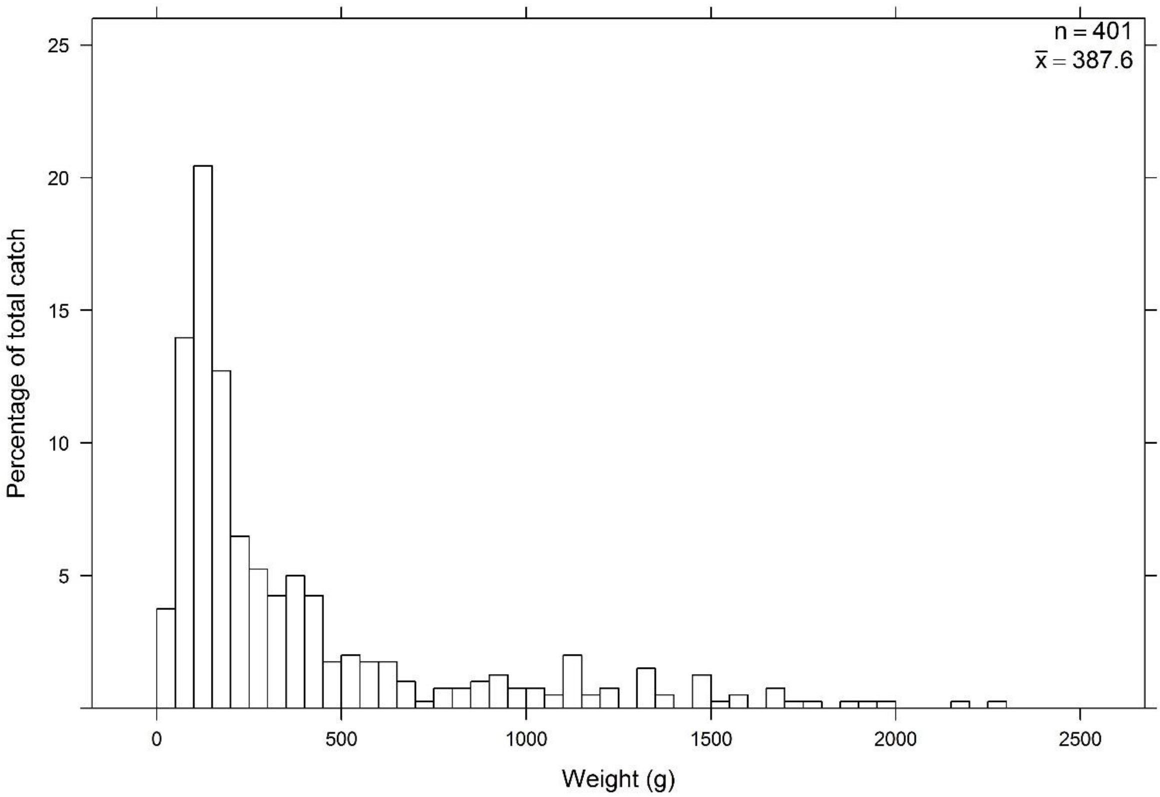


Figure 3-6: Weight-frequency distribution for all shortfin eels measured during sampling. Both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown on the plot. Weight class bins were 50 g.

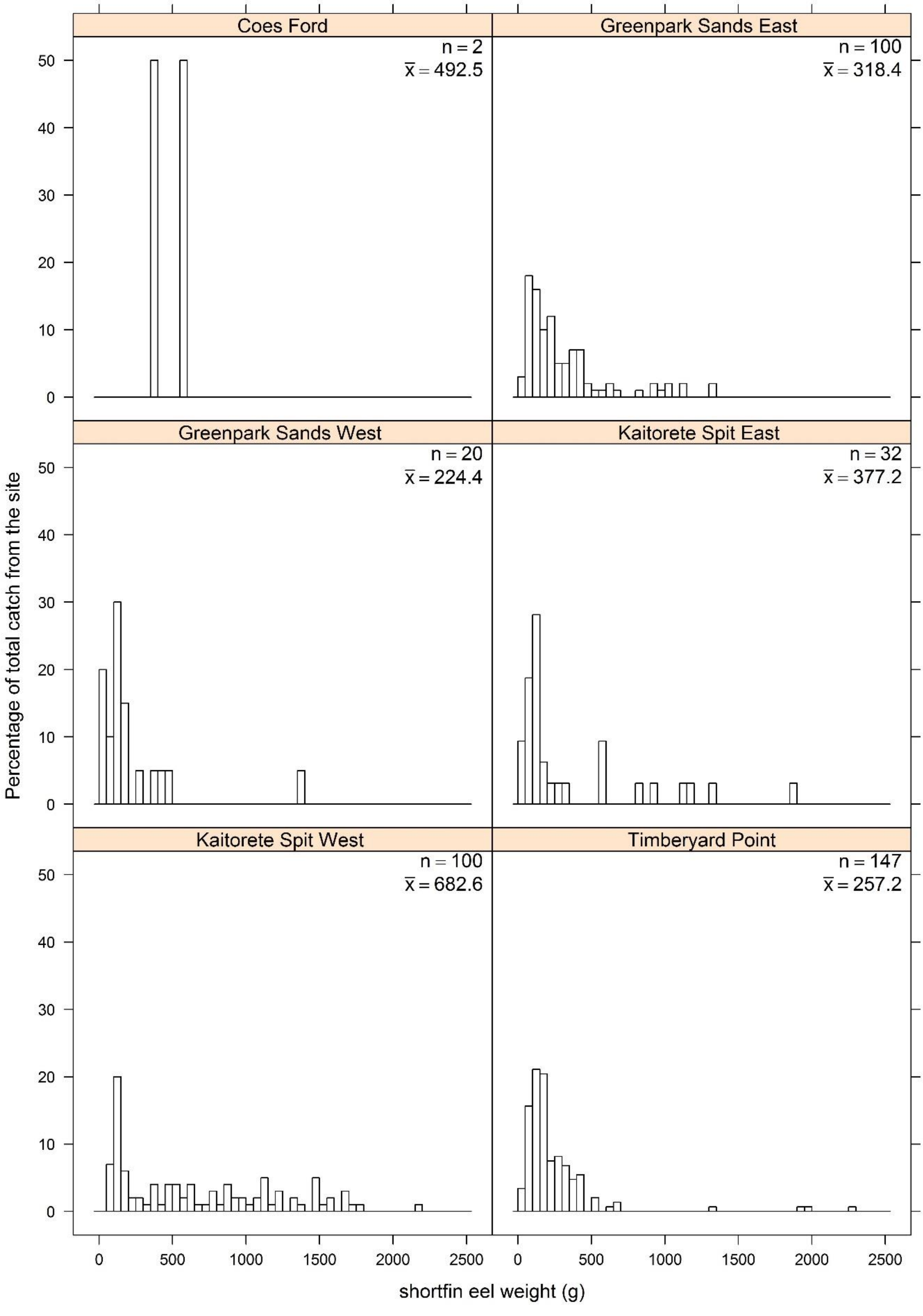


Figure 3-7: Weight-frequency distributions for sites where shortfin eels were caught. For each site, both the number of eels measured (n) and mean eel size ($\bar{x}$) are shown. Weight class bins were 50 g.

Longfin eels

There were 36 longfin eels captured among all sites, which were all measured for total length. These eels varied in total length from between 274 and 930 mm, with a mean size of 595 mm (Figure 3-8). There was a strong peak around 550–600 mm with almost 40per cent of the total catch measuring between 500 and 600 mm (Figure 3-8). Beyond a size of 700 mm, the same number of longfin eels were present in each size class (Figure 3-8).

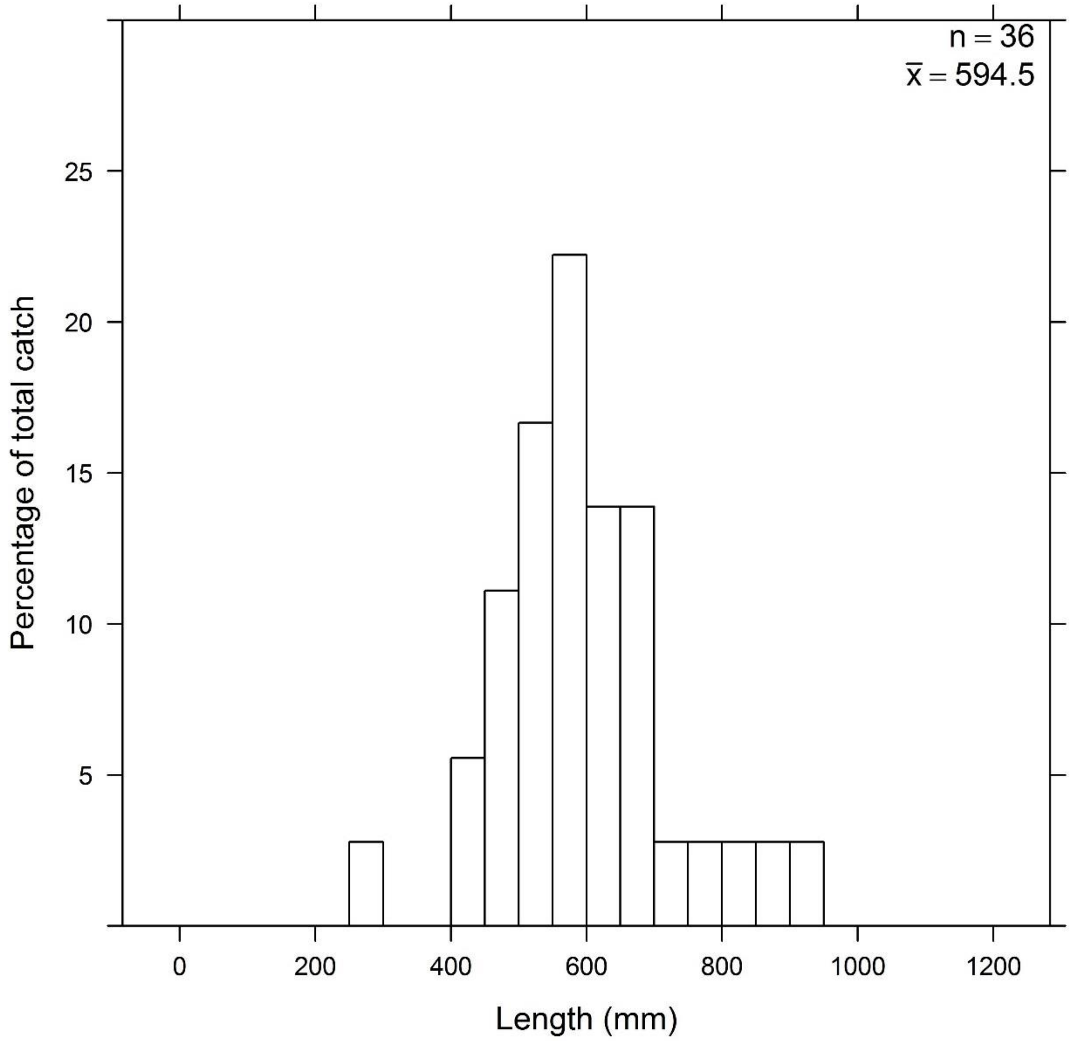


Figure 3-8: Length-frequency distribution for all longfin eels caught during sampling. Both the number of eels measured (n) and mean eel size ($\bar{x}$) are shown on the plot. Size class bins were 50 mm.

There were no significant differences in the lengths of longfin eels between Harts Creek and Coes Ford (One-way ANOVA: $F_{1, 34} = 0.001$, $P = 0.978$). The mean length of longfins was nearly identical between sites: measuring 595 mm at Coes Ford and 594 mm at Harts Creek (Figure 3-9). At Coes Ford, a peak in longfin eel length was observed in the 600–650 mm size classes, whereas Harts Creek showed a lower size class peak of 500–550 mm (Figure 3-10). A number of small longfin eels (<300 mm) were caught at Coes Ford but at Harts Creek the smallest recorded longfin was 445 mm (Figure 3-10).

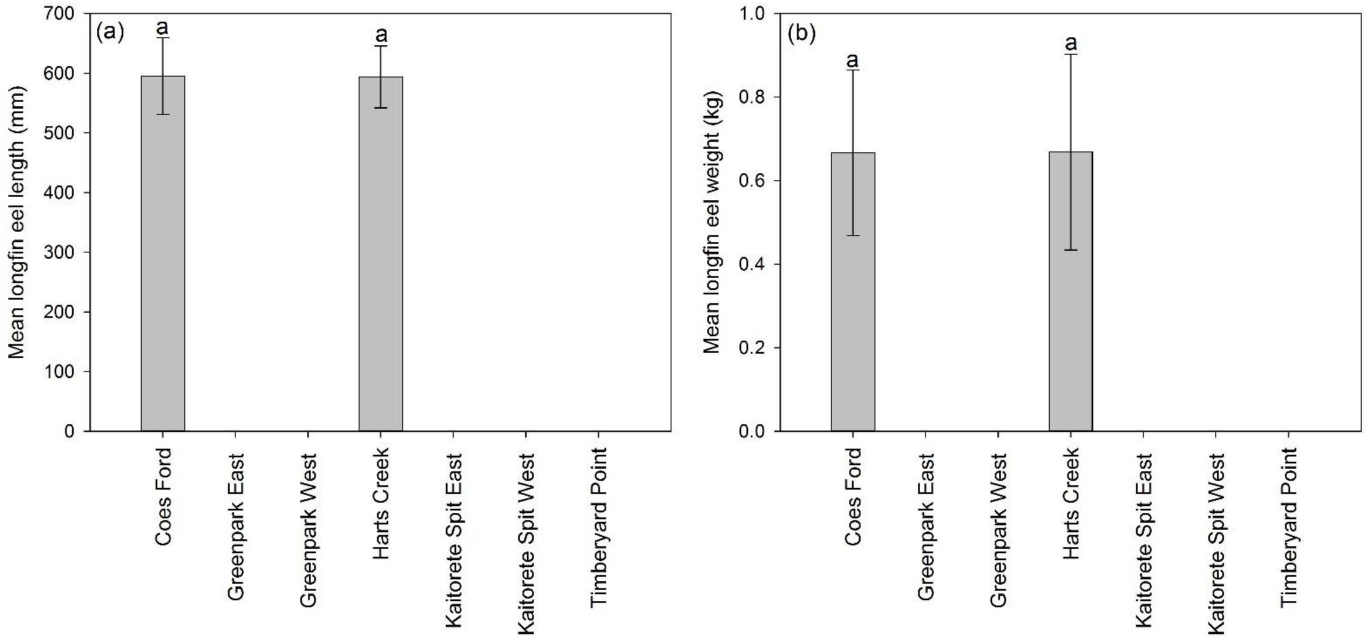


Figure 3-9: Mean (±SE) length (a) and weight (b) of longfin eels in the two lake tributaries where they were caught. Significant differences ($P < 0.05$) between sites were calculated by Tukey's HSD tests. Sites that share a letter are not significantly different from each other.

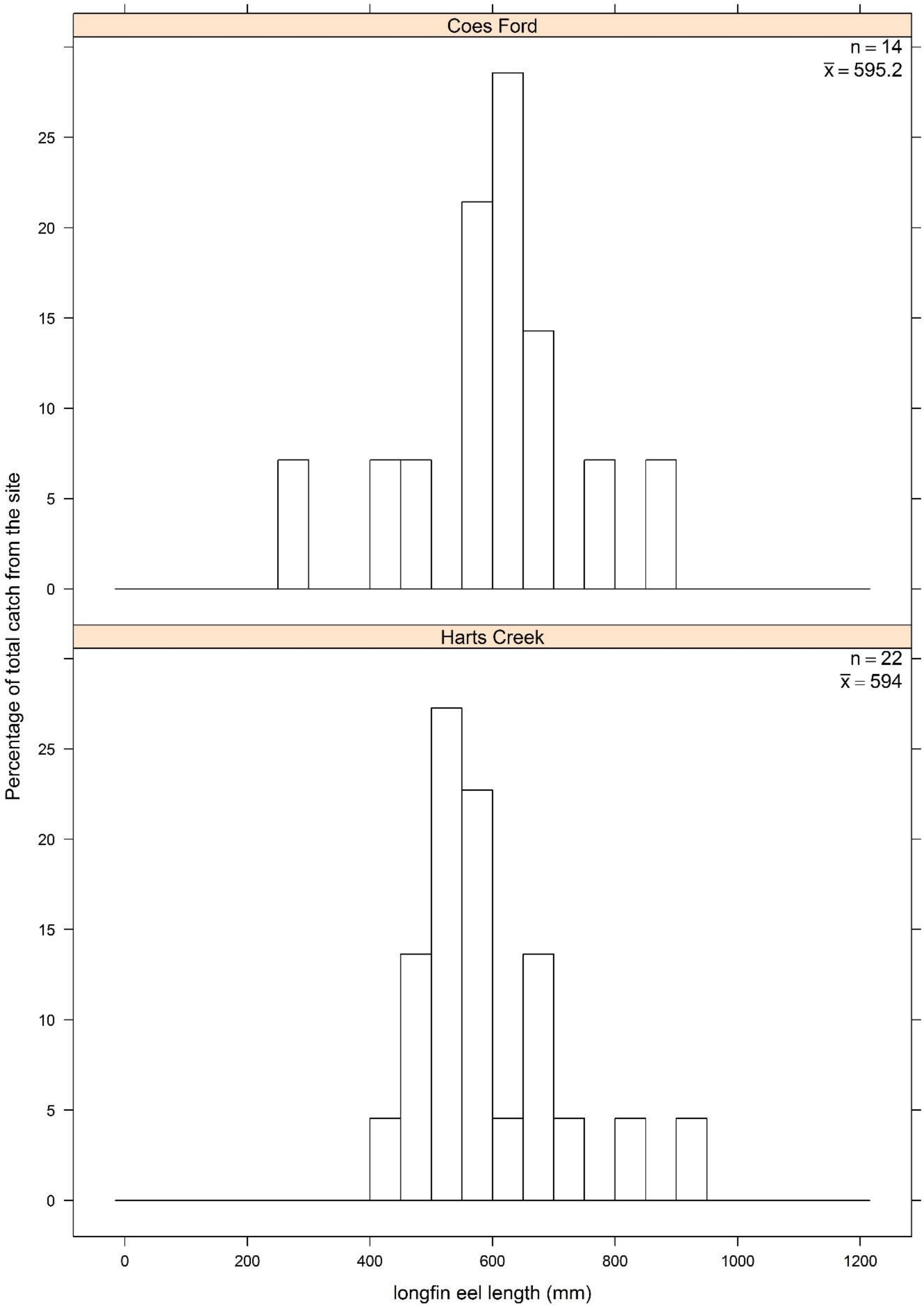


Figure 3-10: Length-frequency distributions for sites where longfin eels were caught. For each site, both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown. Size class bins were 50 mm.

The weight of longfin eels ranged between 70 and 2,400 g with a mean weight of 668 g (Figure 3-11). This mean weight was 280 g heavier than the shortfin eels captured in the present study. The weight-frequency plot for longfin eels peaked at 500–550 g compared to the much smaller peak for shortfin eels of 100–150 g (Figure 3-11). Similar to longfin mean length, there was no significant difference in the mean weight of longfin eels between sites (One-way ANOVA: $F_{1,34} < 0.001$, $P = 0.99$). The mean weight of longfins at Coes Ford and Harts Creek was very similar, measuring at 666 g and 669 g respectively (Figure 3-12). Similar to site differences observed for mean length, the mean weight peak was higher at Coes Ford (500–700 g) than at Harts Creek (300–550 g) (Figure 3-12).

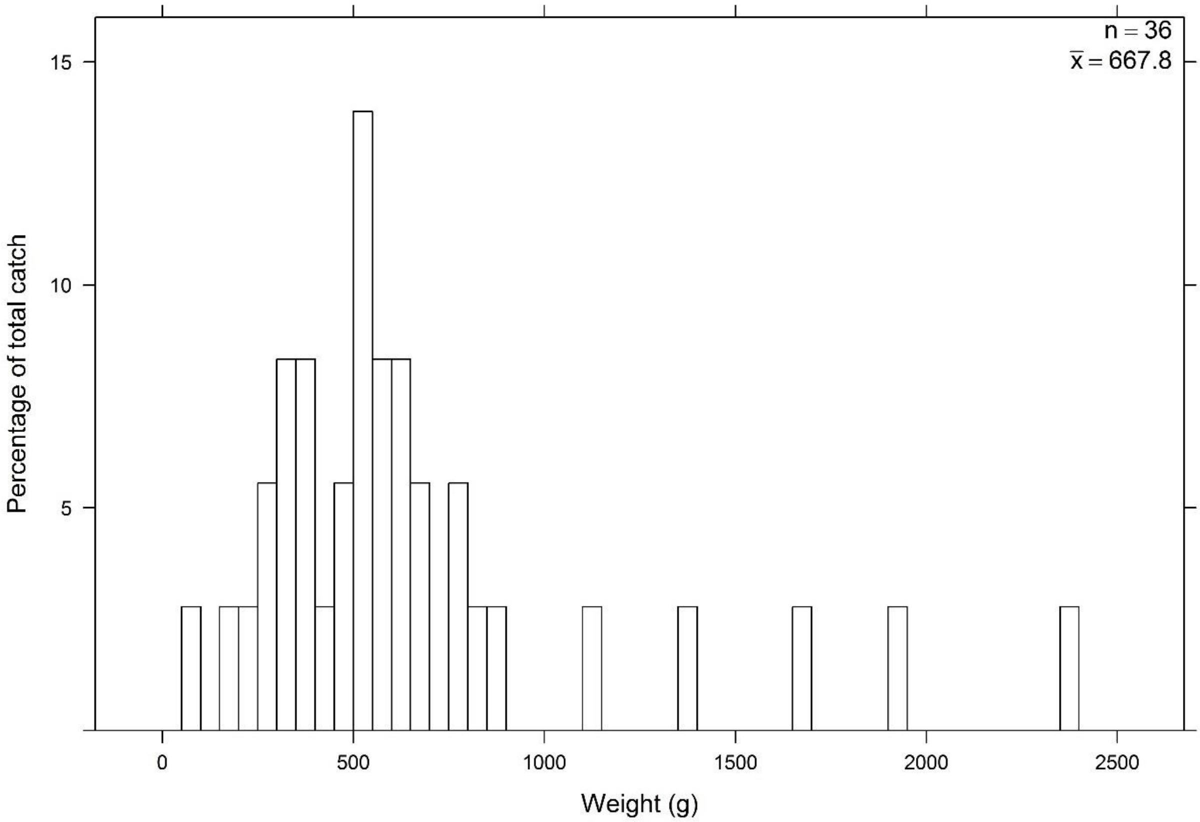


Figure 3-11: Weight-frequency distributions for sites where longfin eels were caught. For each site, both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown. Weight class bins were 50 g.

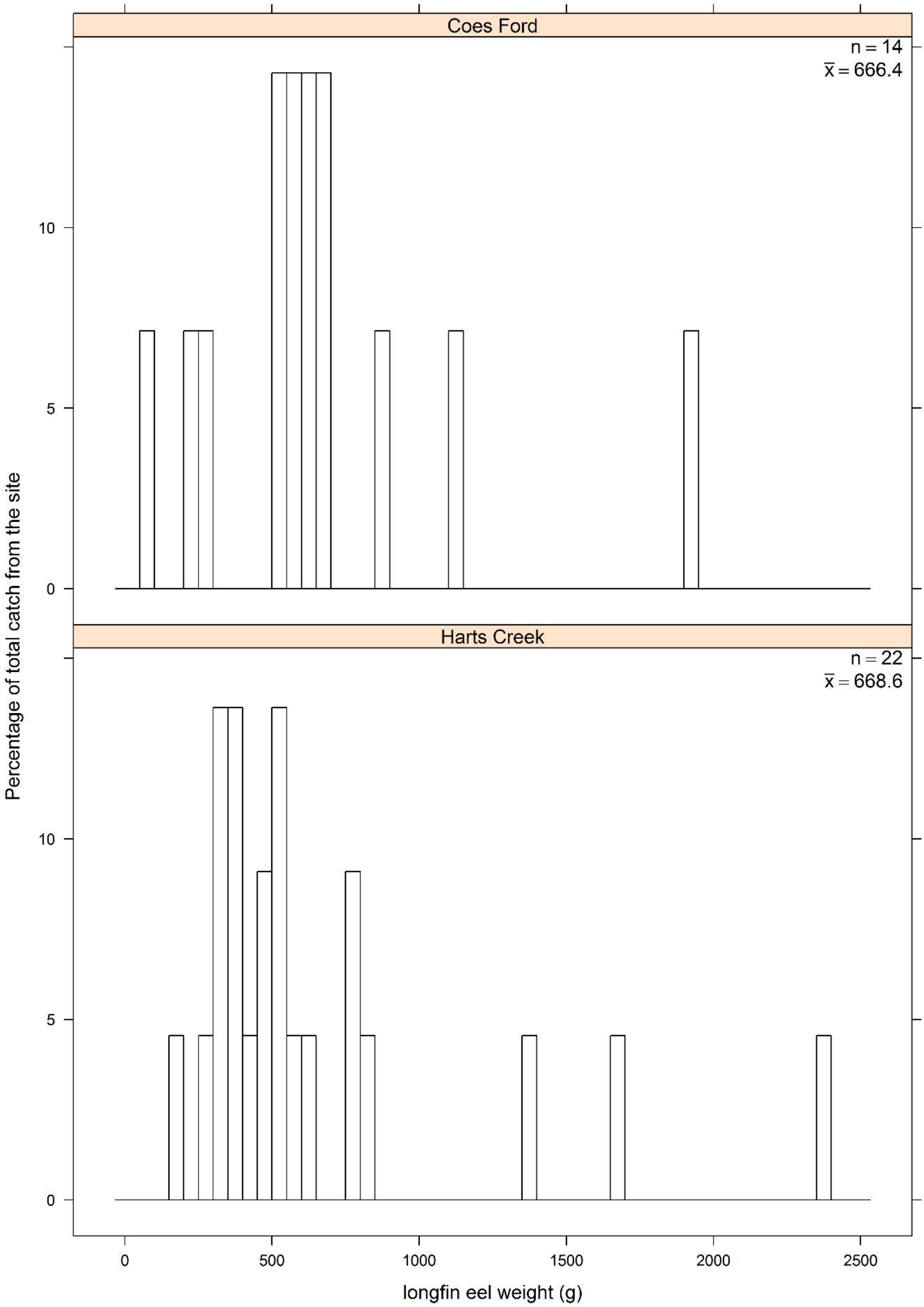


Figure 3-12: Weight-frequency distributions for sites where longfin eels were caught. For each site, both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown. Weight class bins were 50 g.

3.1.3 Condition

Shortfin eels

Shortfin eel condition (K) showed marked variability across the 401 individuals that were measured. Condition values for shortfin eels ranged between 0.81 and 8.07 K (Figure 3-13). There was a strong peak in condition between 2–2.5 K, with over 50per cent of the total catch occurring in this range of condition values (Figure 3-13). Condition values greater than three were rare, but there were some extremely well-conditioned eels caught. The shortfin (migrant female) eel that had a condition value of 8.07 was 595 mm in length and weighed 1.7 kg; usually a shortfin of this weight from Te Waihora would be nearly 300 mm longer (890 mm). This data point was inspected to check for any errors in the data recording, but it was correctly written. This observation, however, may have been made in error because this condition factor is extraordinarily large.

There were significant differences in the mean condition of shortfin eels between sampling sites (One-way ANOVA: $F_{5,395} = 4.22$, $P < 0.001$). The mean condition of shortfin eels at both Greenpark Sands sites were significantly lower than the condition of eels at Kaitorete Spit West (2.4 K) (Figure 3-14). Mean shortfin condition was lowest at the Greenpark Sands West site (1.84 K), but highest in the lake tributary site, Coes Ford (2.4 K); eel condition at Coes Ford was not significantly different from other sites because only two eels were caught (Figure 3-15). Shortfin eels with very high condition values (>3 K) were only recorded at Kaitorete Spit West and Timberyard Point (Figure 3-15).

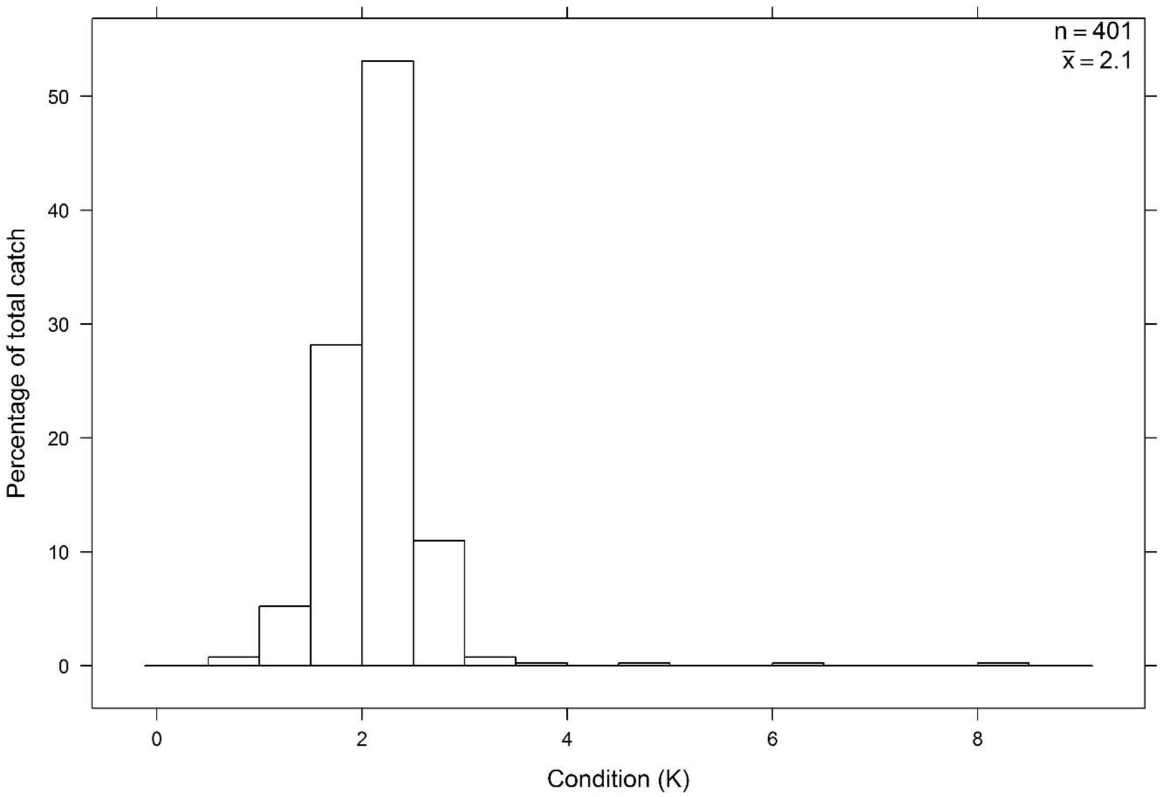


Figure 3-13: Condition-frequency distribution for all shortfin eels measured during sampling. Both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown on the plot. Condition bins were 0.5 K.

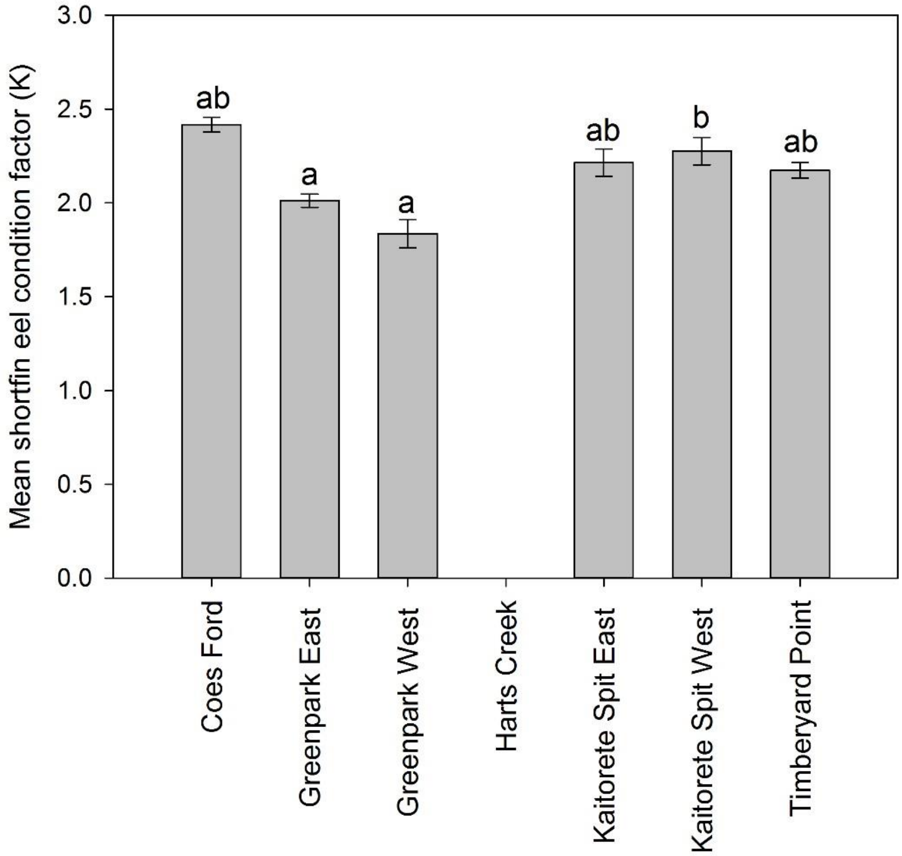


Figure 3-14: Mean (±SE) condition of shortfin eels at the different sites sampled around the lake and tributaries. Significant differences ($P < 0.05$) between sites were calculated by Tukey's HSD tests. Sites that do not share a letter are significantly different from each other.

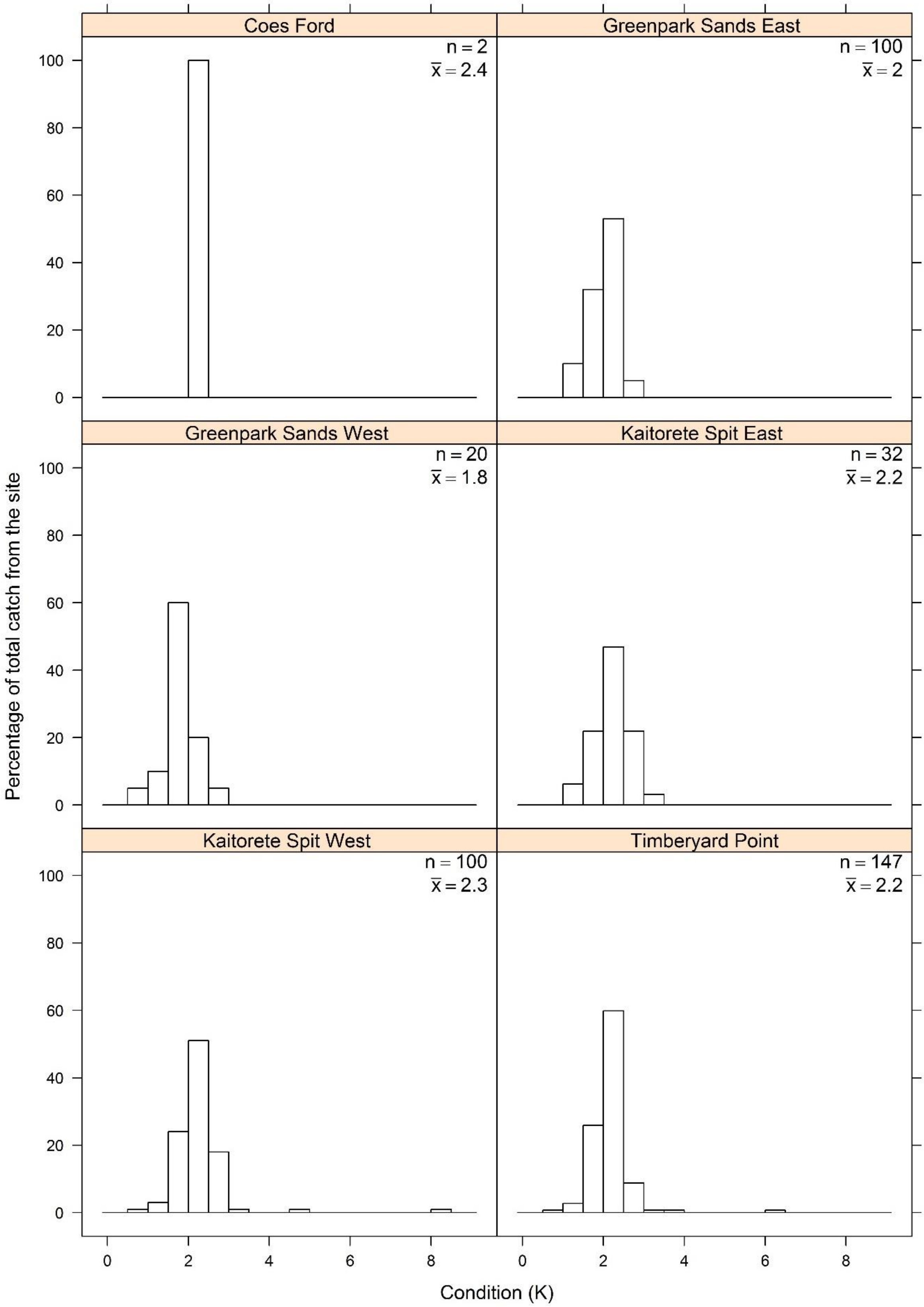


Figure 3-15: Condition-frequency distributions for sites where shortfin eels were caught. For each site, both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown. Size class bins were 0.5 K.

Longfin eels

Compared to shortfin eels, there was much less variability in the range of longfin eel condition (2.2–3.4 K) (Figure 3-16). The peak in condition values was higher for longfin eels than for shortfin eels and was between 2.5 to 3.0 K (Figure 3-16). Similar to shortfin eels, over 50 per cent of the total catch was within the peak range of condition values. Eels with very high condition values greater than three were relatively rare for shortfin eels and comprised only approximately 2per cent of the total catch, however, for longfin eels almost 20 per cent of the total catch exceeded this level of condition.

There was no significant difference in the mean condition of longfin eels between the two lake tributary sites (One-way ANOVA: $F_{1, 34} = 0.114$, $P = 0.738$). The mean condition values of longfins was nearly identical between sites since mean condition was 2.80 K at Coes Ford and 2.76 K at Harts Creek (Figure 3-17). At both sites, the peak in longfin eel condition was between 2.5 to 3.0 K (Figure 3-18). This peak was more prominent at Harts Creek as over 60 per cent of eels had condition values within this range.

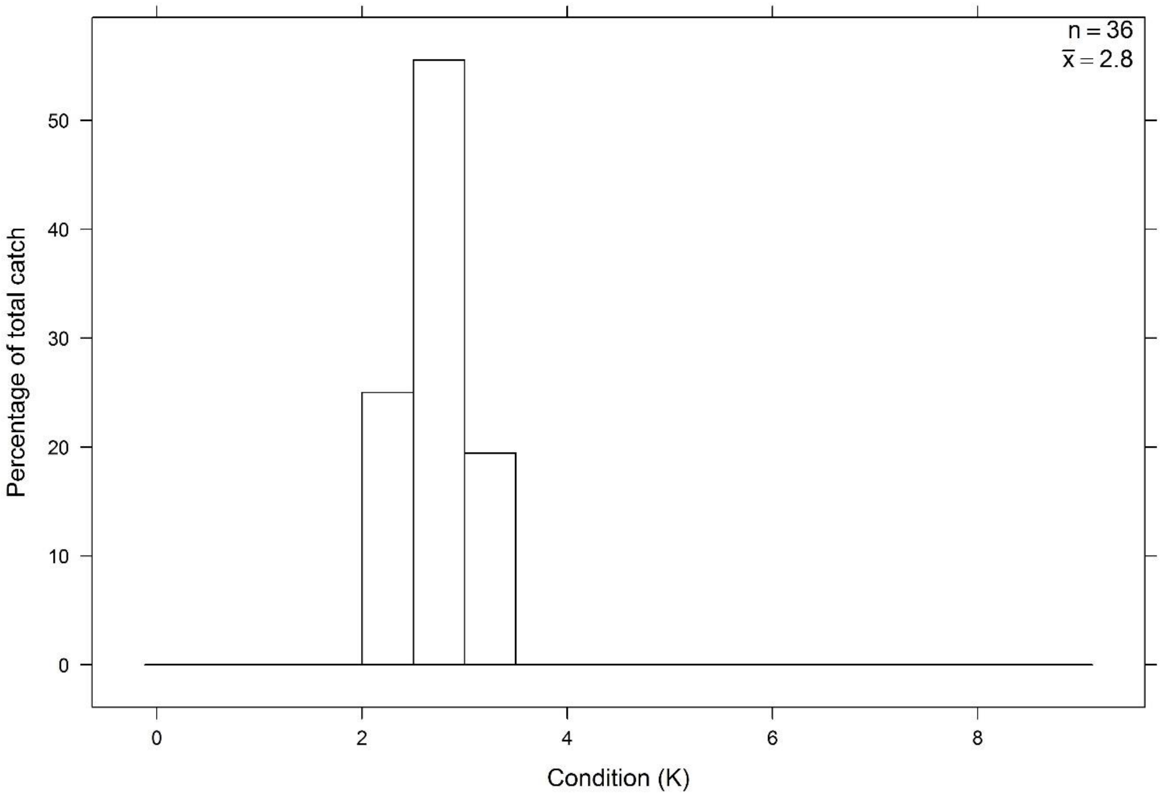


Figure 3-16: Condition-frequency distribution for all longfin eels measured during sampling. Both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown on the plot. Condition bins were 0.5 K.

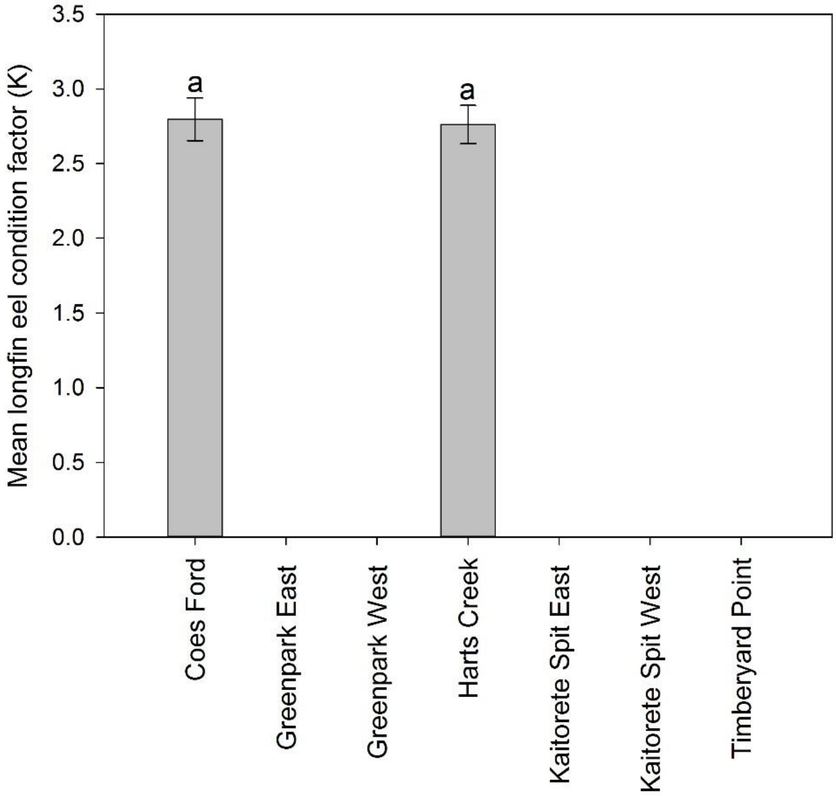


Figure 3-17: Mean (±SE) condition of longfin eels in the two lake tributaries where they were caught. Significant differences (*P* < 0.05) between sites were calculated by Tukey's HSD tests. Sites that share a letter are not significantly different from each other.

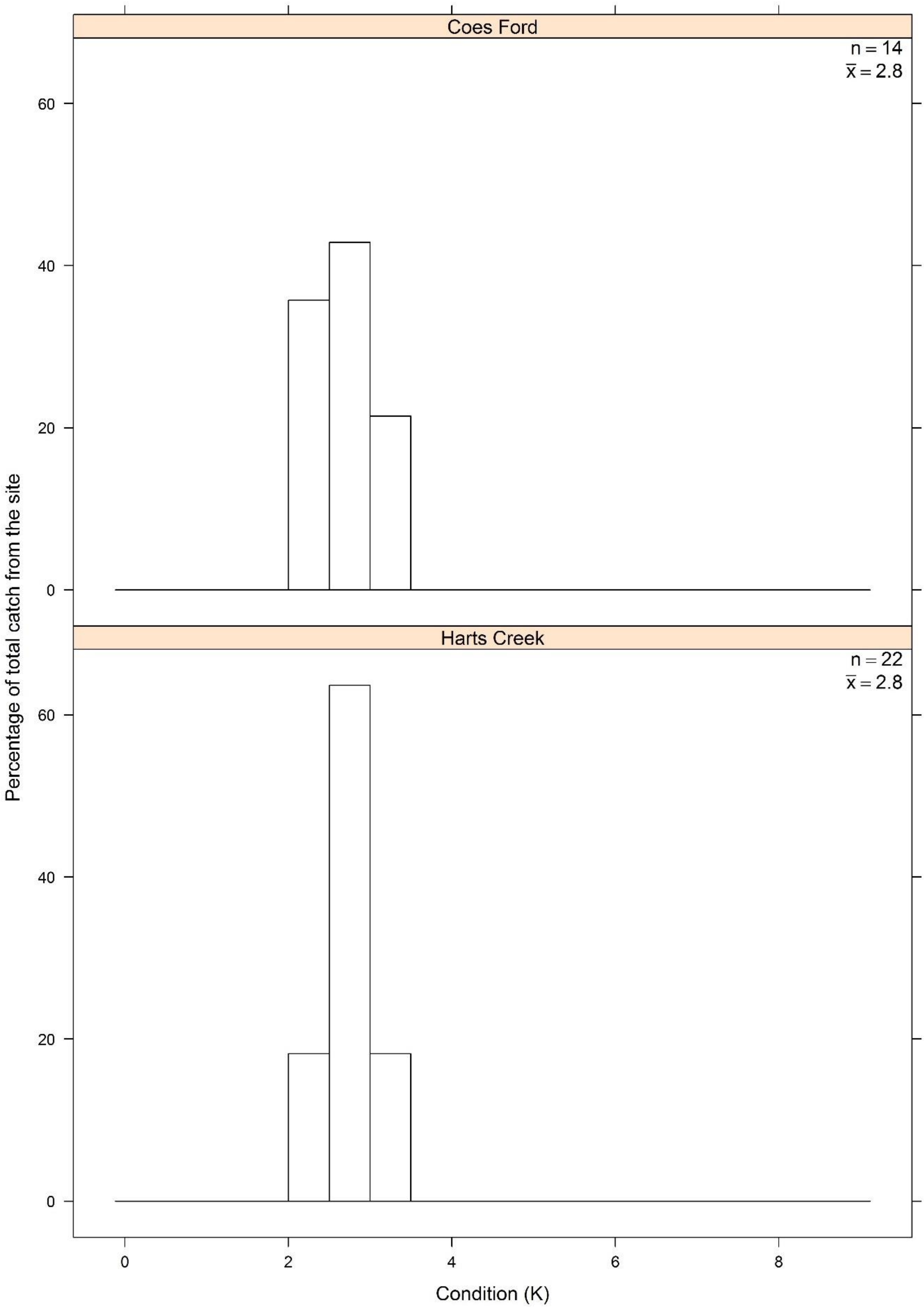


Figure 3-18: Condition-frequency distributions for sites where longfin eels were caught. For each site, both the number of eels measured (n) and mean eel size ($\overline{x}$) are shown. Size class bins were 0.5 K.

3.1.4 Growth rates

Shortfin eels were taken from the six lake sites for aging (this included Fishermans Point). These eels varied in total length from 255–941 mm and the age of these fish ranged from 7 to 25 years (n = 90). There was no difference in either the mean length (One-way ANOVA: $F_{5,84} = 0.71$, $P = 0.62$) or mean weight (One-way ANOVA: $F_{5,84} = 0.89$, $P = 0.49$) of shortfin eels taken for aging between the different sites, but there was a significant difference in the age of these eels between sites (One-way ANOVA: $F_{5,84} = 2.99$, $P = 0.02$). The mean age of shortfin eels at Fishermans Point and Kaitorete Spit East were significantly older than eels from Greenpark Sands West (Figure 3-19).

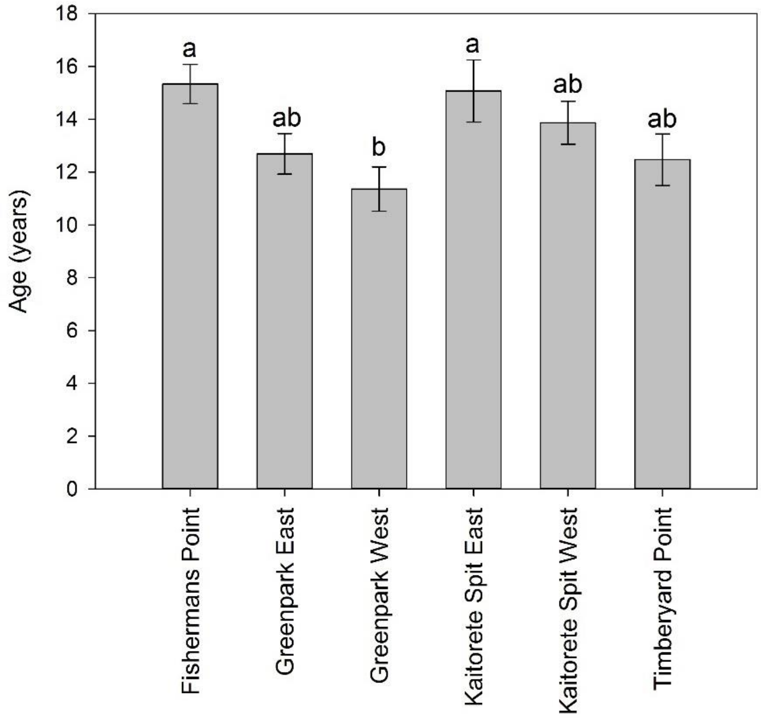


Figure 3-19: Mean (±SE) age of shortfin eels at the different sites sampled around the lake. Significant differences ($P < 0.05$) between sites were calculated by Tukey's HSD tests. Sites that do not share a letter are significantly different from each other.

Across all sites, mean growth (±SE) was 35 (±2) mm/yr and 25 (±5) g/yr. There were no significant differences in the mean growth rates of shortfins between sites regardless of whether growth rate was calculated using annual length (One-way ANOVA: $F_{5,84} = 0.92$, $P = 0.47$) or annual weight increments (One-way ANOVA: $F_{5,84} = 0.73$, $P = 0.60$) (Figure 3-20). Mean growth rates for length varied between 31.2 and 36.7 mm/yr across sites (Figure 3-20a). There was much greater between-site variability for weight-based growth rates compared to length growth rates. The slowest mean weight-based growth rate was at Greenpark Sands West (18.6 g/yr) and the fastest growth rate was at Fishermans Point (34.9 g/yr) (Figure 3-20b).

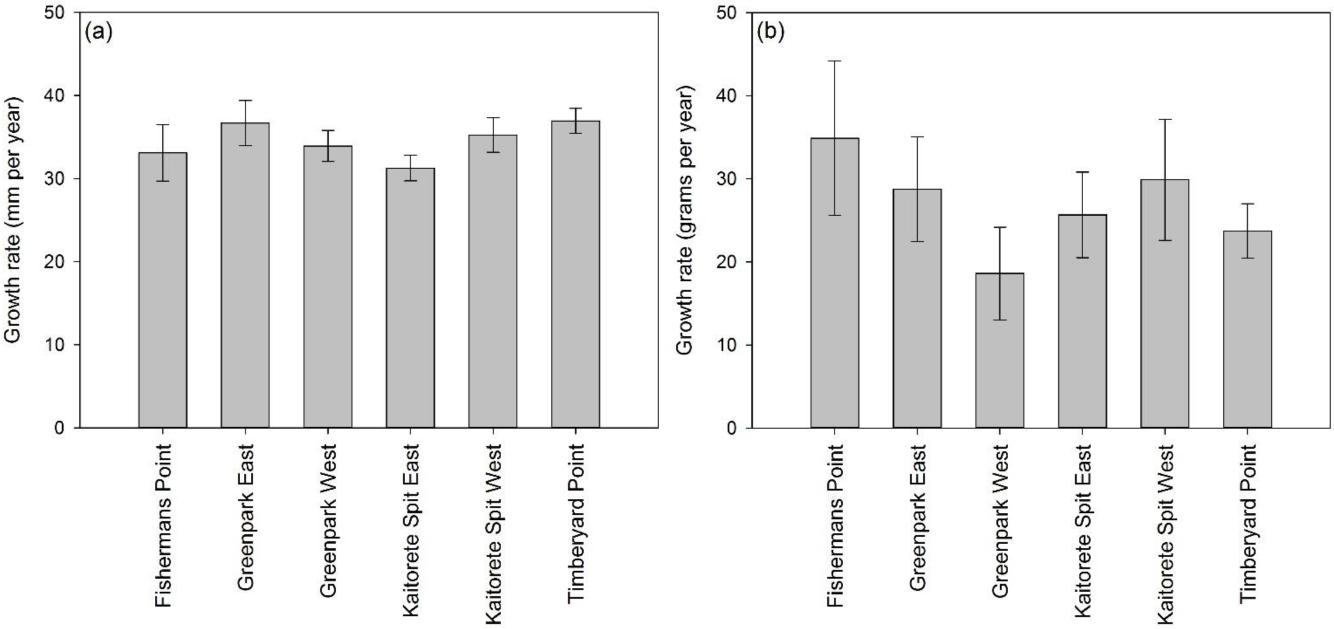


Figure 3-20: Mean (±SE) growth rate of shortfin eels at the different sites sampled around the lake based on changes in length (a) and weight (b) as a function of age. No results for Tukey's HSD tests are shown because there were no significant differences between sites for annual length (One-way ANOVA: $F_{5,84} = 0.92$, $P = 0.47$) or annual weight increments (One-way ANOVA: $F_{5,84} = 0.73$, $P = 0.60$).

Weights and lengths both formed significant ($P < 0.001$) relationships with age (Figure 3-21, Figure 3-22). All aging data were combined from all sites given that growth rate and size did not differ between sites. Based on conversations with Ngāi Tahu representatives, a minimum size of shortfins that are suitable for customary harvest is around 500 mm (Mandy Home, pers. comm.) while the optimum size is around 1000 mm (Don Brown, pers. comm.). This minimum customary size will weigh roughly 260 grams and it will take 13.4 years to reach this size, based on the equations for the linear relationships in Figure 3-24 and Figure 3-25. Minimum national commercial size is 220 g and it will take, on average, 12.9 years to reach this weight in the lake. Te Waihora has a commercial fishery that targets small migrant male shortfins, and commercial fishers are permitted to take fish smaller than the minimum commercial size. Based on a mean weight of 124 g observed for migrant male shortfins at Fishermans Point (see section 3.1.5), these migrant males are likely to be 11.2 years old. The optimum customary sized eels of 1000 mm was calculated to be 19.7 years of age, although the age of larger eels tended to be more variable (Figure 3-21).

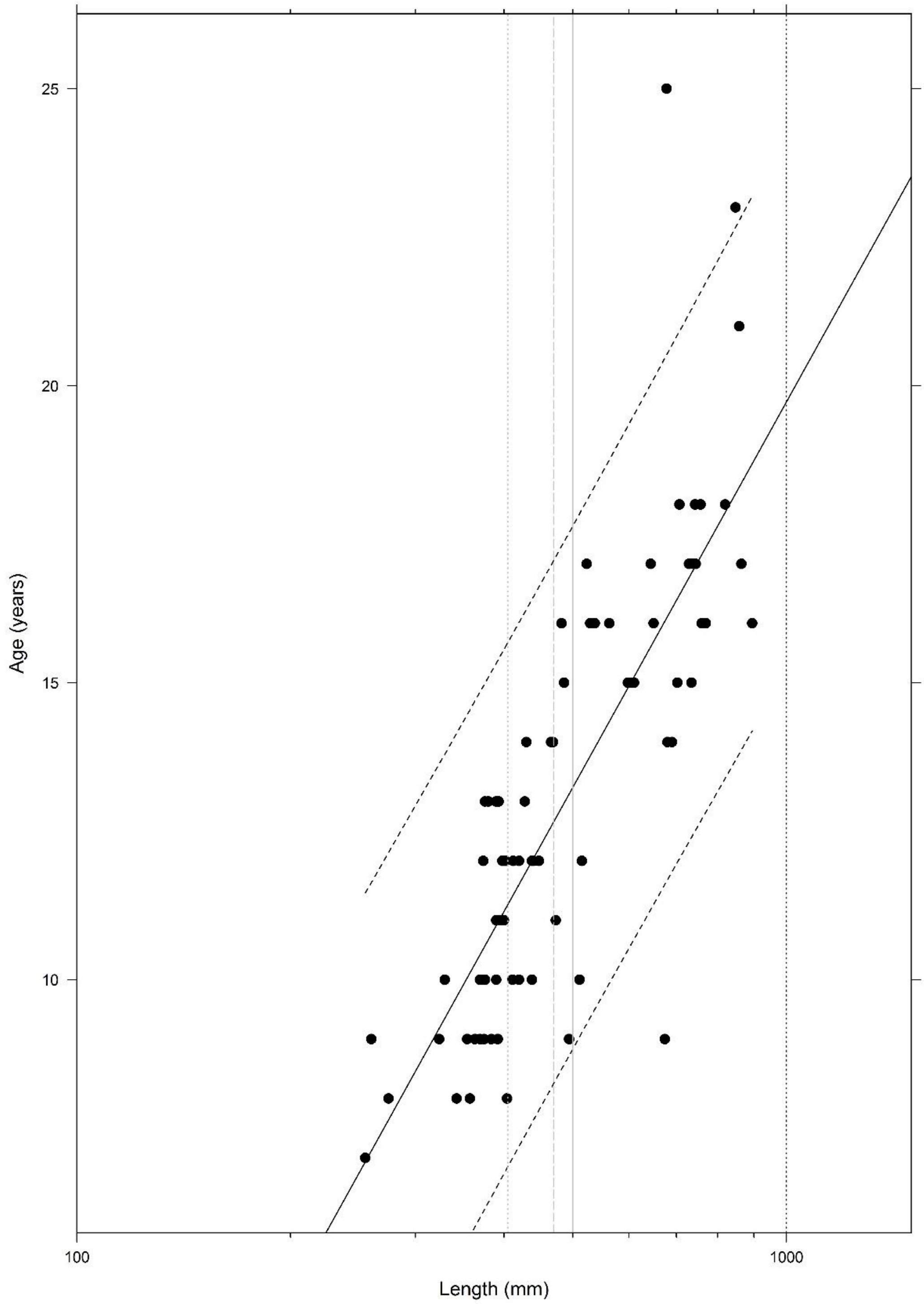


Figure 3-21: Age-length relationship for shortfin eels caught at sites around Te Waihora. The dotted grey line (bottom) indicates the minimum commercial migrant male harvesting size (c. 405 mm), the dashed grey line indicates the minimum commercial size harvesting limit (excluding male migrants) for the lake (c. 470 mm), the solid grey line is the minimum size for customary harvest (500 mm), the dotted black line is the optimum customary harvest size. Relationship for the linear regression is Age (years) = 21.55*$\mathrm{Log_{10}}$Length(mm)-44.93280 ($F_{1,73}$ = 137.9, P < 0.001, R^2 = 0.65).

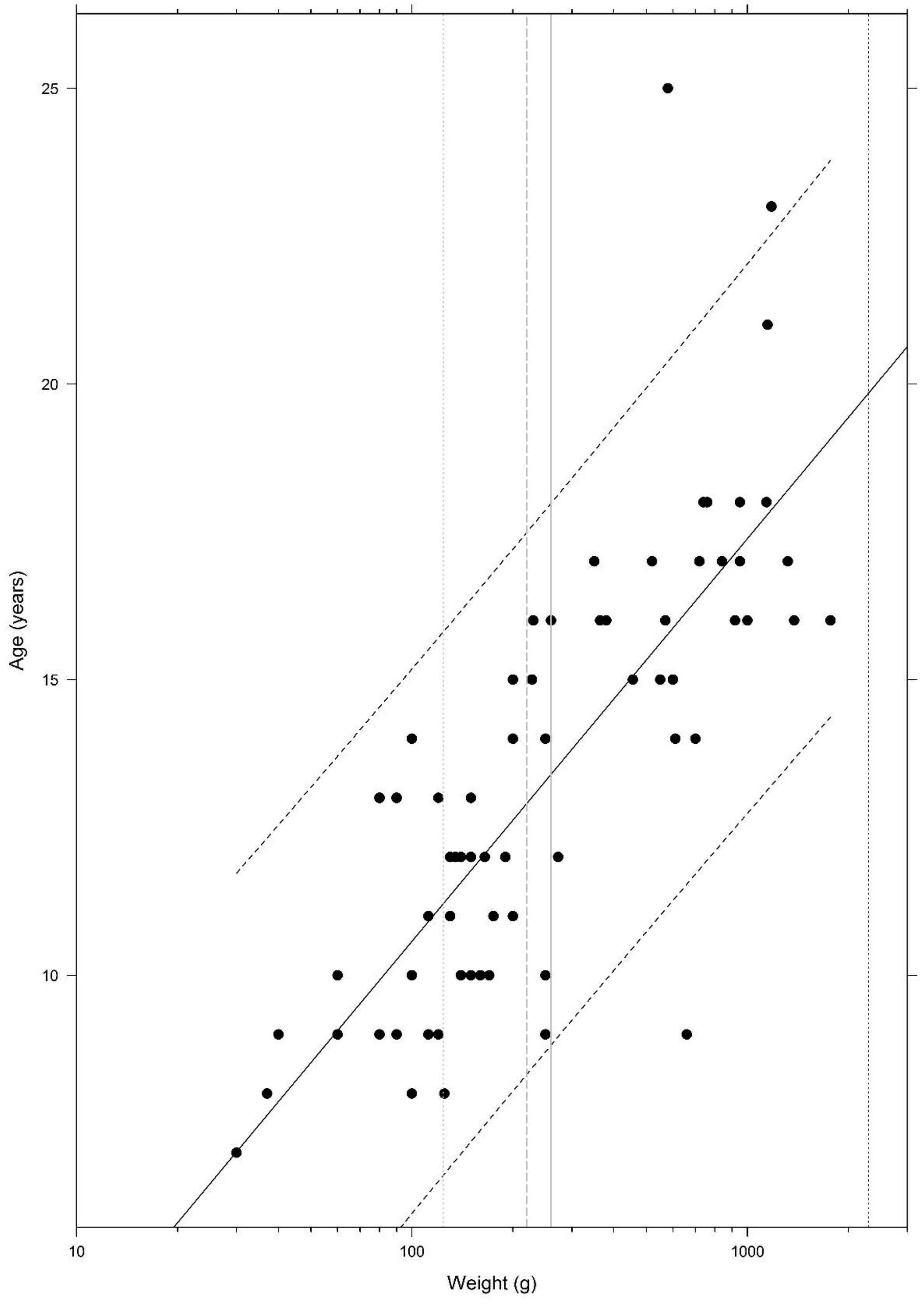


Figure 3-22: Age-weight relationship for shortfin eels caught at all sites around Te Waihora. The dotted grey line (bottom) indicates the minimum commercial migrant male size (124 g), the dashed grey line indicates the minimum commercial size harvesting limit (excluding male migrants) for the lake (c. 220 g), the solid grey line is the minimum size for customary harvest (c. 260 g), the dotted black line is the optimum customary harvest size (c 2300 g). Relationship for the linear regression is Age (years) = 6.81*Log_{10}Weight(g)-3.04 ($F_{1,73}$ = 121.6, P < 0.001, R^2 = 0.62).

3.1.5 Fishermans Point

A total of 246 eels were caught from Fishermans Point (Table 3-2). Because of time constraints, lengths and weights were measured for 137 of these fish and a further 109 fish were bulk weighed and counted. Weight of each species from the 109 bulk weighed/counted fish were estimated based on the species composition observed for the 137 measured eels. Of the 137 eels measured, the catch abundance and weight was dominated by shortfins. Shortfins comprised 91 per cent of the abundance (n = 125) while longfins only made up 9 per cent (n = 12). Similarly, shortfins comprised 86 per cent (79.5 kg) of the total weight while longfins only made up 14 per cent (13.2 kg). Averaged across all fish caught (i.e., processed and bulk weighed fish), 62 eels were captured from each net/night, which was composed of six longfins and 56 shortfins. A mean weight of 41.3 kg of eels was caught for each net/night, which was composed 5.8 kg of longfins and 35.5 kg of shortfins.

Of the 137 processed fish, 70 per cent of the catch were migrant eels (n = 97). Of the 97 migrant eels, 96 were migrant shortfins and one was a migrant longfin. Of the 96 migrant shortfins, 67 were males and 29 were females. Male shortfin migrants were small with a mean size of 399 mm (Figure 3-23), with c. 95 per cent of the male fish being between 350–450 mm long. The size ranges of males was very limited and all fish were between 343-497 mm. Female migrants were much larger than males, ranging between 721–987 mm in length with a mean size of 829 mm. Most of the female migrants were between 750–900 mm. Males only weighed between 80–190 g while females were heavier, weighing between 720–2,000 g (Figure 3-24). Males weighed 124 g on average and 70 per cent of the catch were between 100–150 grams. Females weighed 10x more than males on average, with a mean weight of 1.27 kg. The condition factor of males averaged 2.0 K (range: 0.8–2.5), while females had slightly higher condition of 2.2 K (range: 1.5–3.2) (Figure 3-25). There were two migrant males in very poor condition that only had condition factors of around 1, but the majority of both males and females was between 1.8 and 2.3 K.

Table 3-2: Catch-per-unit-effort (CPUE) for numbers and weight of the 137 eels processed at Fishermans Point. CPUE units for abundance in eels/net/night and CPUE units for weight are shown in kg/net/night. Species composition and species weight of the 109 bulk weighed/counted fish were estimated based on the relative species composition in the 137 processed eels.

	Abundance						Weight					
	Longfin		Shortfin		All eels		Longfin		Shortfin		All eels	
	Total No.	CPUE	Total No.	CPUE	Total No.	CPUE	Total weight	CPUE	Total weight	CPUE	Total weight	CPUE
Processed eels	12	3.0	125	31.3	137	34.3	13.2	3.3	79.5	19.9	92.8	23.2
All eels	22	5.5	224	56.0	246	61.5	23.1	5.8	142.0	35.5	165.1	41.3

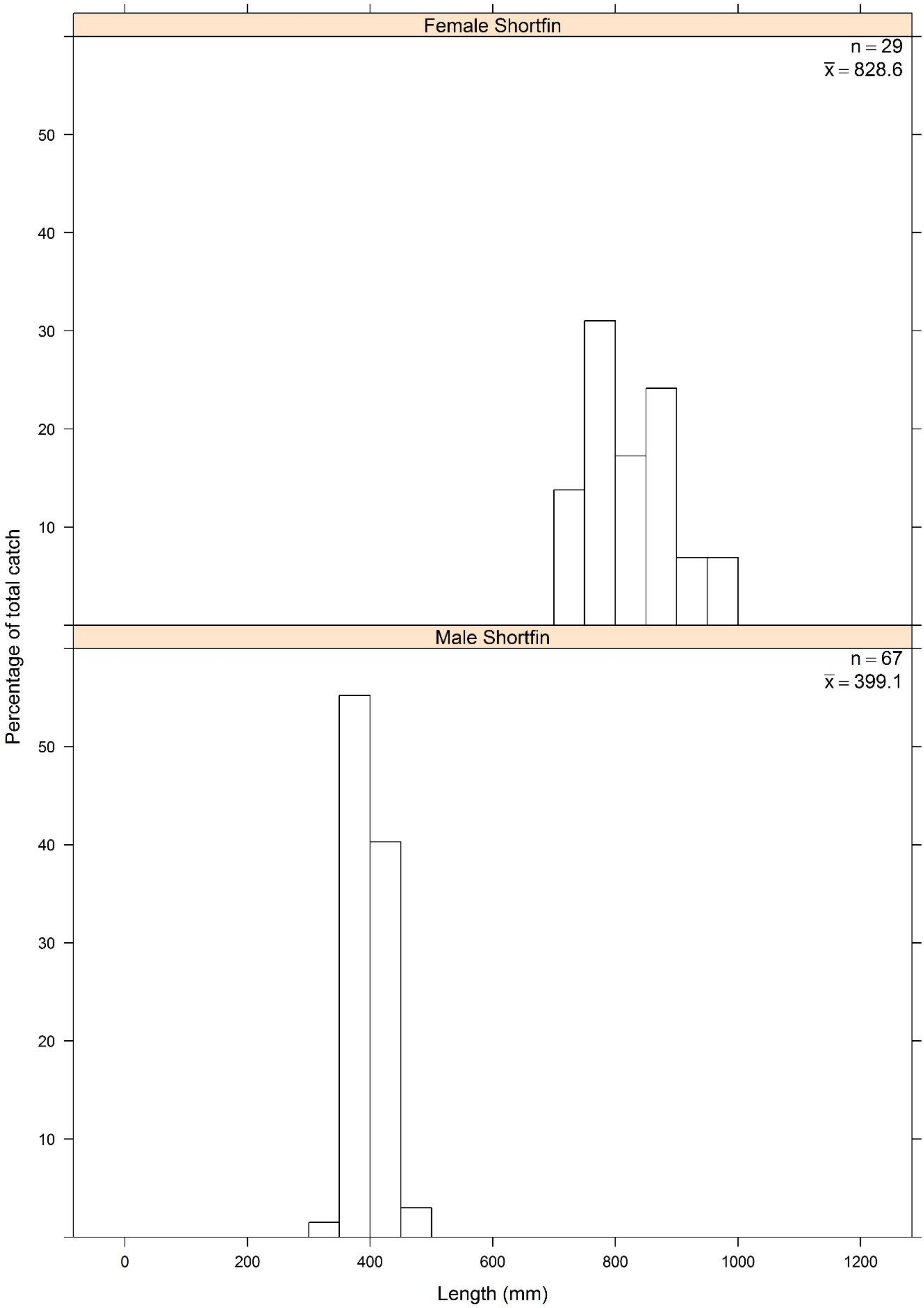


Figure 3-23: Length-frequency distributions for shortfin migrant females and males captured at Fishermans Point. The number of eels measured (n) and mean eel size ($\bar{x}$) are shown. Size class bins were 50 mm.

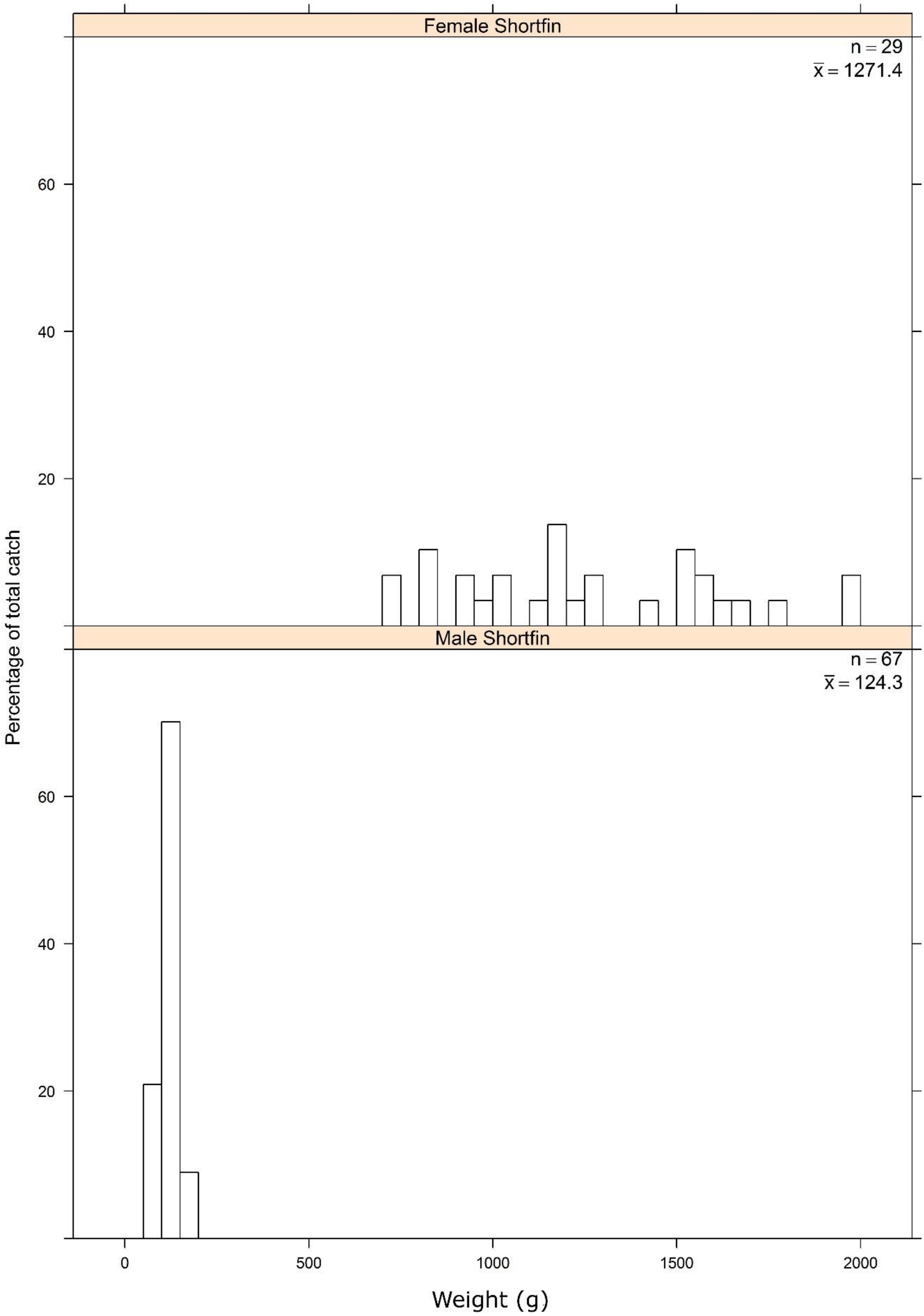


Figure 3-24: Weight-frequency distributions for shortfin migrant females and males captured at Fishermans Point. The number of eels measured (n) and mean eel size ($\overline{x}$) are shown. Size class bins were 50 g.

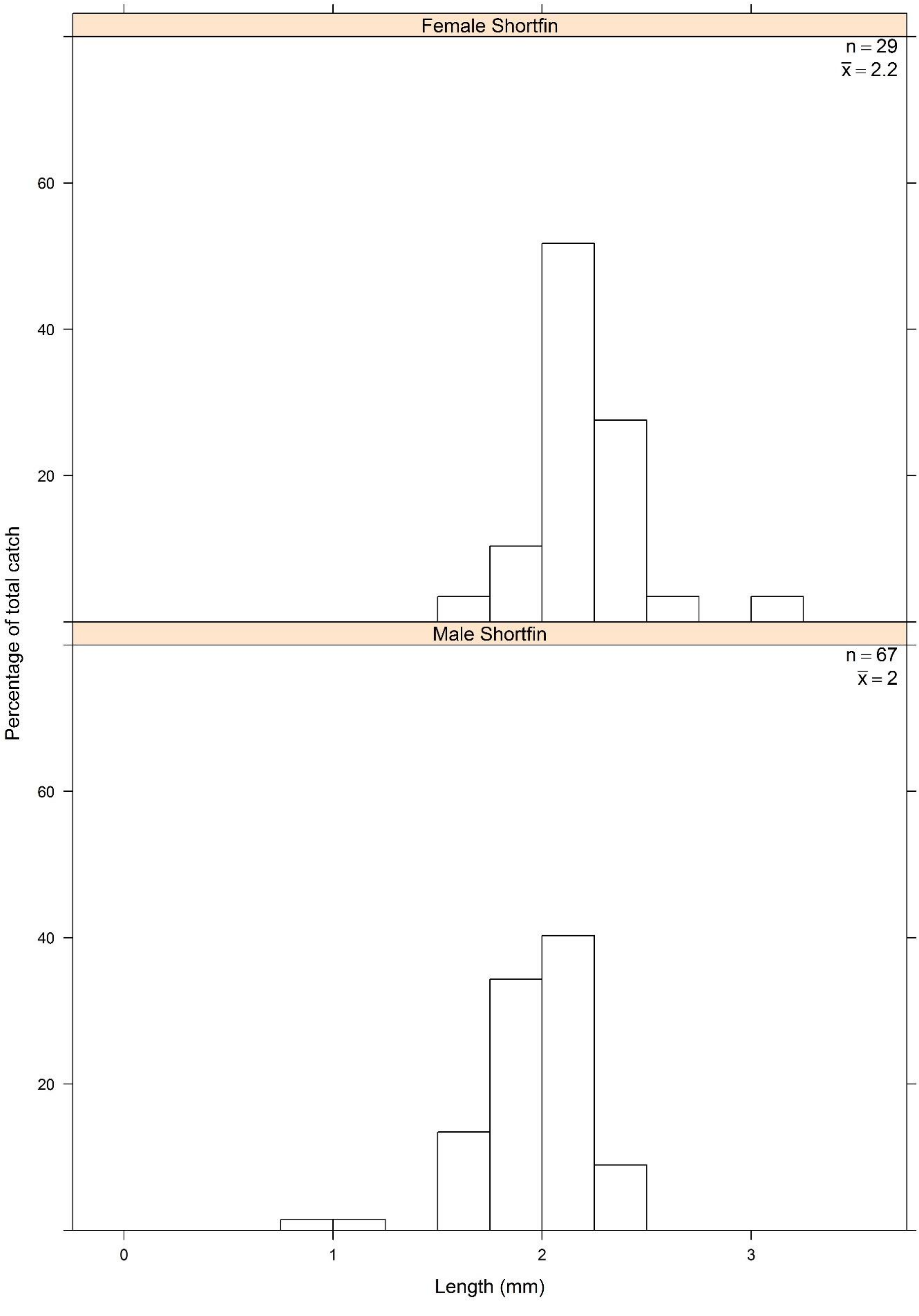


Figure 3-25: Condition-frequency distributions for shortfin migrant females and males captured at Fishermans Point. The number of eels measured (n) and mean eel condition ($\overline{x}$) are shown. Size class bins were 0.25 K.

3.1.6 Summary table of differences between sites

The following table summarises the differences in shortfin population between sites so that it can be quickly accessed. The results outlined below are a summary of the comparisons between sites (post-hoc Tukey test), where sites that share letters are not statistically different. Based on the post-hoc tests, the sites with the highest values for each variable are shown in green, while the sites with the lowest values are shown in red. For simplicity, sites that were not significantly different from all other sites (i.e., had two letters) are shown in white[4]. If the lowest or highest values were observed from two sites (e.g., CPUE abundance comparison between Greenpark Sands East and Timberyard point) shared the same letter; a "+" symbol was used to show which site had the highest value, while a "-" symbol shown was used to show which site had the highest value.

Kaitorete Spit West had the highest CPUE weight, length, weight and condition of eels (Table 3-3). These results suggest that Kaitorete Spit West has the largest and best conditioned fish, but at a slightly reduced abundance relative to some of the other sites. Kaitorete Spit West may therefore be an important area if Ngāi Tahu fishers wish to capture a moderate number of large, well-conditioned eels. Greenpark Sands East and Timberyard Point both displayed the highest CPUE abundance, but these scored lower for length, weight and condition. These abundance and size results suggest that Greenpark Sands East and Timberyard Point are supporting higher numbers of smaller fish, which may be an important area for Ngāi Tahu fishermen wishing to target smaller shortfins. Coes Ford, Greenpark Sands West and Kaitorete Spit East generally had low toaverage catch rates of smaller fish.

Table 3-3: Summary of post-hoc test comparisons between sites. Individual pairwise comparisons and values for each site can be found in sections 3.1.2-3.1.6.

Site	CPUE abundance (no./net/night)	CPUE weight (kg/net/night)	Length (mm)	Weight (g)	Condition (K)	Age (years)	Growth rate (mm/year)	Growth rate (g/year)
Coes Ford	a-	a-	ab	ab	ab		a	a
Greenpark Sands East	d	bc	a	a	a	ab	a	a
Greenpark Sands West	b	ab	a-	a-	a	b-	a	a-
Kaitorete Spit East	bc	ab	a	a	ab	a+	a-	a
Kaitorete Spit West	cd	c	b+	b+	b	ab	a	a+
Timberyard Point	d+	c+	a	a	ab	ab	a+	a
Fishermans Point						a		

[4] It should be noted that sites with two letters may not differ significantly from the highest or lowest sites, which means the results section should be consulted when making detailed conclusions or statements about differences between sites for each of the variables. This is table was designed to be a simplification of the post-hoc ANOVA comparisons to help identify which sites had the highest and lowest fishery values, not as a substitute for all the detailed ANOVA results outlined in the results section.

3.1.7 Shortfin population inside and outside of the Horomaka kōhanga

There were no consistent differences in shortfin eel size, CPUE or condition between sites inside and outside of the Horomaka kōhanga (Figure 3-26). There were differences between individual sites, but no results suggested that there were consistent differences in sizes or catch rates between the Horomaka and the area outside of the boundary that is open to commercial fishing. Note, that Jellyman et al. (in press) have done additional comparisons inside and outside the Horomaka kōhanga for shortfin eels on both a larger sample size and sampling area.

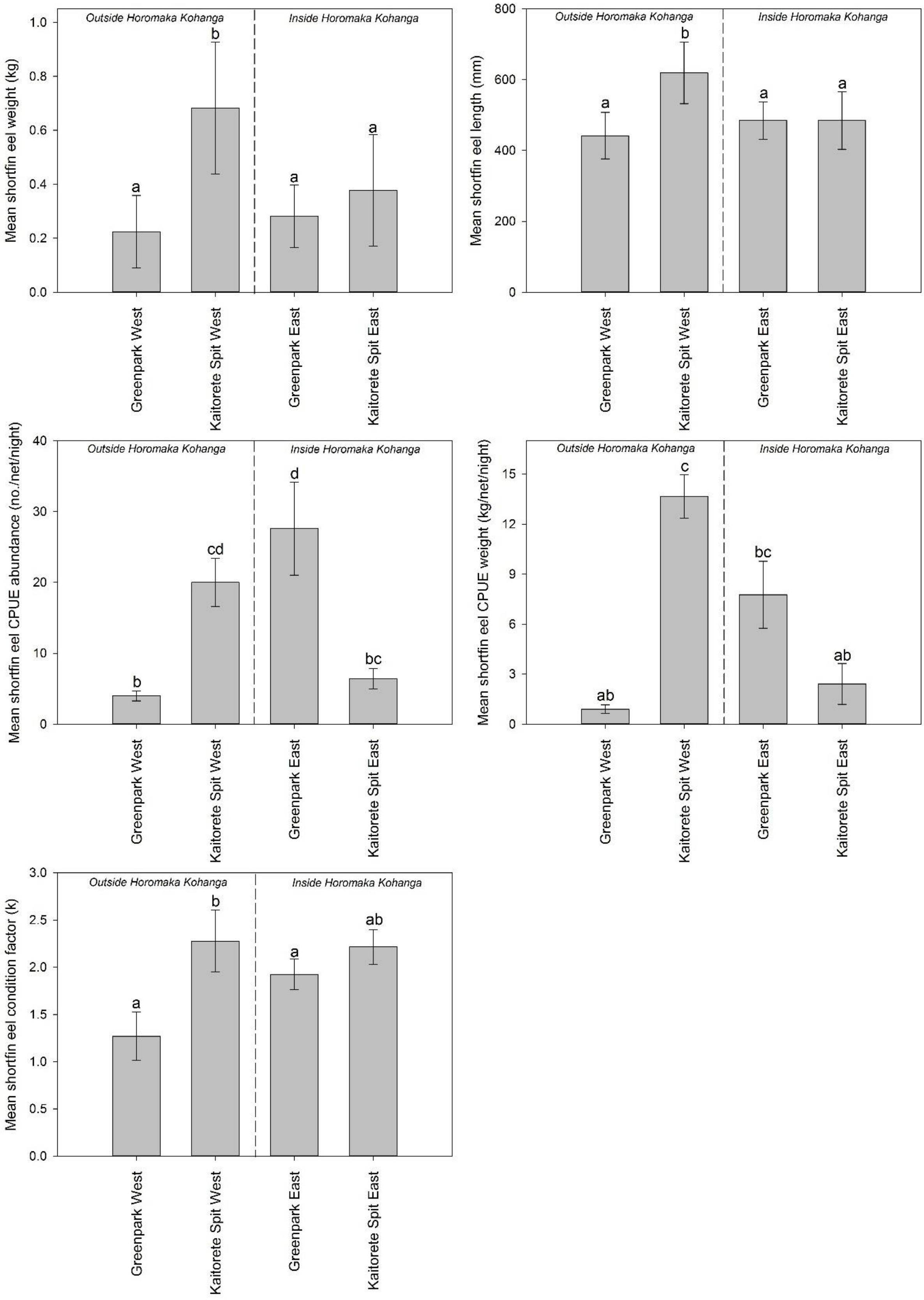


Figure 3-26: Mean (±SE) shortfin length, weight, CPUE and condition at sites adjacent to the Horomaka kōhanga boundary. Significant differences ($P < 0.05$) between sites were calculated by Tukey's HSD tests outlined in the previous sections. Sites that do not share a letter are significantly different from each other.

3.2 Pātiki

3.2.1 Species composition

A total of 513 pātiki comprising three species were caught from all 10 sites (Table 3-1, Table 3-4). The three species captured were yellowbelly flounder (*Rhombosolea leporina*), sand flounder (*Rhombosolea plebeia;* also called “dab”, “white”, “diamond” or “square” flounder) and black flounder (*Rhombosolea retiaria*). Catch abundance was dominated by yellowbelly flounder, with a total of 393 (77 per cent), 98 (19 per cent) sand flounder and 22 (4 per cent) black flounder captured across all sites. Of the 186 kg of pātiki caught in the present study, yellowbelly flounder comprised 79 per cent (147.8 kg) of the total catch weight, sand flounder 14 per cent (25.8 kg) and black flounder 7 per cent (12.4 kg). On average, 10 pātiki were captured from each net/night, which was composed of eight yellowbelly flounder, two sand flounder and 0-1 black flounder (only captured intermittently). A mean weight of 3.7 kg of pātiki was caught for each net/night, which was composed of 2.9 kg of yellowbelly flounder, 0.5 kg of sand flounder and 0.3 kg of black flounder.

Table 3-4: Catch-per-unit-effort (CPUE) for numbers (top) and weight (bottom) of pātiki captured from all sites. CPUE units for abundance in numbers/net/night and CPUE units for weight are shown in kg/net/night. Overall values are summed for abundance and weights, but averaged for CPUE indices across the sites.

	Abundance (numbers)							
	Yellowbelly		Black flounder		Sand flounder		All flounder	
Site	Total No.	CPUE	Total No.	CPUE	Total No.	CPUE	Total No.	CPUE
Drain Road	8	1.6	4	0.8	0	0	12	2.4
Greenpark East	36	7.20	1	0.20	21	4.20	58	11.60
Greenpark West	31	6.20	0	0	13	2.60	44	8.80
Halswell River mouth	57	11.40	3	0.60	16	3.20	76	15.20
Irwell River	47	9.40	7	1.40	0	0	54	10.80
Kaitorete East	57	11.40	2	0.40	12	2.40	71	14.20
Kaitorete West	14	2.80	0	0	9	1.80	23	4.60
Nutts Drain	43	8.60	3	0.60	20	4.00	66	13.20
Taumutu	82	16.40	1	0.20	7	1.40	90	18.00
Timberyard Point	18	3.60	1	0.20	0	0	19	3.80
Overall	393	7.90	22	0.44	98	1.96	513	10.26

	Weight (kg)							
	Yellowbelly		Black flounder		Sand flounder		All flounder	
Site	Total Weight	CPUE	Total Weight	CPUE	Total Weight	CPUE	Total Weight	CPUE
Drain Road	2.85	0.57	1.82	0.36	0	0	4.67	0.93
Greenpark East	12.32	2.46	0.72	0.14	5.30	1.06	18.34	3.67
Greenpark West	11.11	2.22	0	0	3.25	0.65	14.35	2.87
Halswell River mouth	22.77	4.55	2.08	0.42	4.32	0.86	29.17	5.83
Irwell River	18.52	3.70	3.54	0.71	0	0	22.06	4.41
Kaitorete East	21.32	4.26	1.27	0.25	3.13	0.63	25.71	5.14
Kaitorete West	4.61	0.92	0	0	2.08	0.42	6.70	1.34
Nutts Drain	14.95	2.99	2.30	0.46	5.70	1.14	22.95	4.59
Taumutu	32.34	6.47	0.32	0.06	2.02	0.40	34.67	6.93
Timberyard Point	7.02	1.40	0.37	0.07	0	0	7.39	1.48
Overall	147.80	2.96	12.42	0.28	25.79	0.52	186.01	3.72

3.2.2 Relative abundance

Yellowbelly flounder

For yellowbelly flounder, CPUE weight differed between sites (DF = 9, F = 15.48, $P < 0.001$), as did CPUE abundance (DF = 9, F = 13.64, $P < 0.001$). Taumutu, Kaitorete Spit East and the Halswell River mouth had the highest CPUE abundance and CPUE weight. The lowest CPUE abundance and CPUE weight was observed at Drain Road, Greenpark East, Greenpark West, Kaitorete Spit West and Timberyard Point.

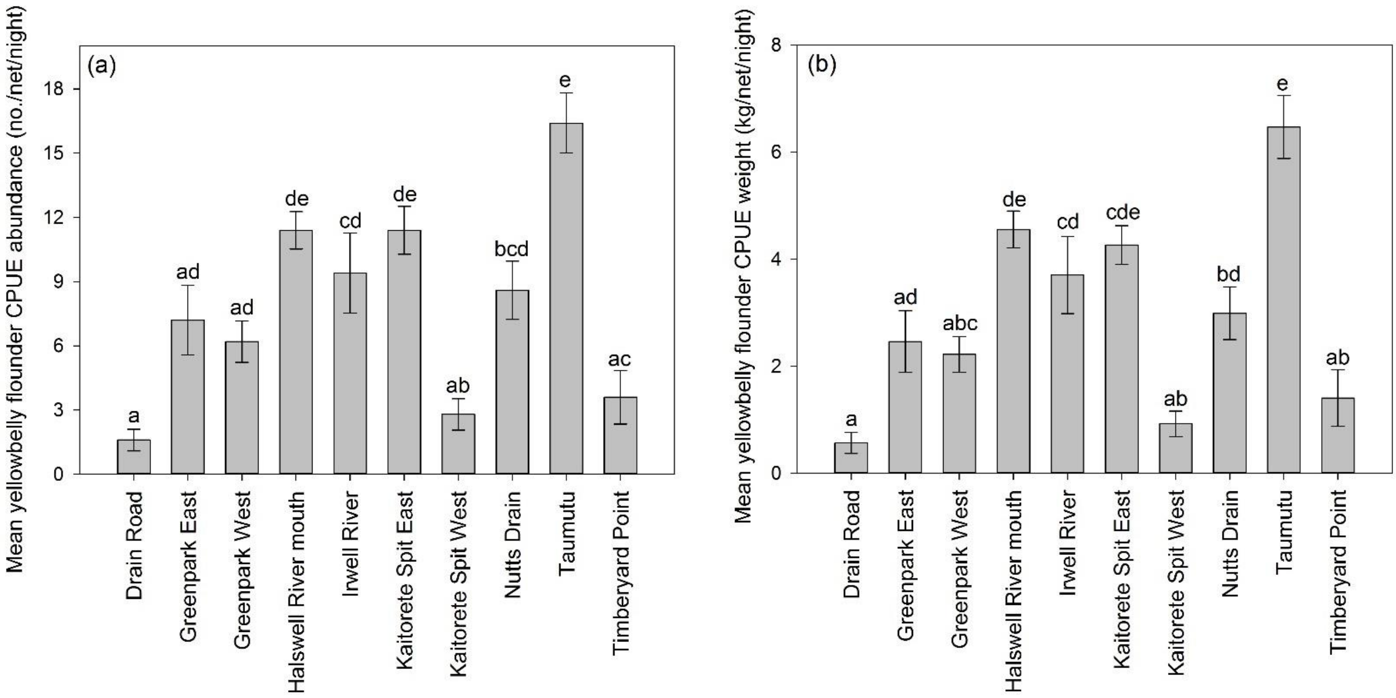


Figure 3-27: Mean (±SE) CPUE abundance (a) and CPUE weight (b) of yellowbelly flounder at the different sites sampled around the lake. Significant differences ($P < 0.05$) between sites were calculated by Tukey's HSD tests. Sites that do not share a letter are significantly different from each other.

Sand flounder

For sand flounder, neither CPUE weight (DF = 6, F= 1.6, $P = 0.18$) nor CPUE abundance (DF = 6, F = 1.4, $P = 0.25$) differed between sites (Figure 3-28). Sand flounder were absent from Drain Road, Irwell River and Timberyard Point.

Black flounder

No analysis could be completed for black flounder because of insuficient data. CPUE abundance and CPUE weight was very low around the lake and no black flounder were found from Greenpark West or Kaitorete Spit West (Figure 3-29).

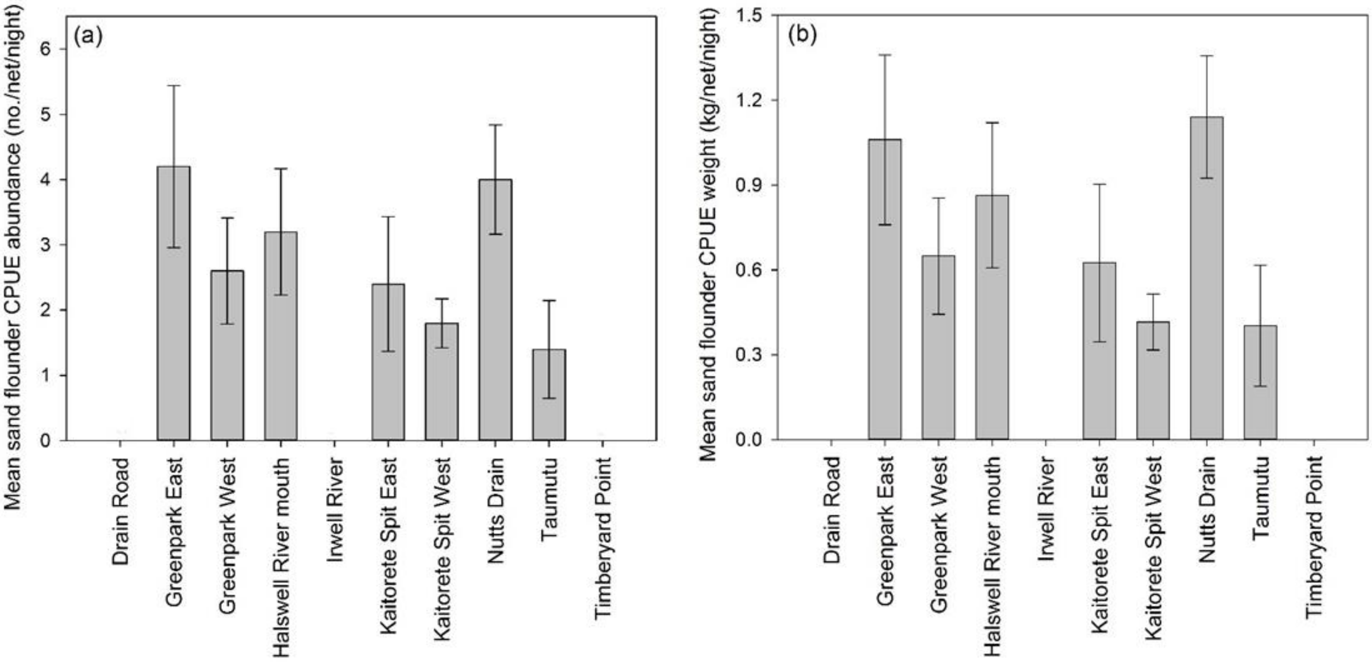


Figure 3-28: Mean (±SE) CPUE abundance (a) and CPUE weight (b) of sand flounder at the different sites sampled around the lake. No results for Tukey's HSD tests are shown because there were no significant differences between sites for either CPUE weight (DF = 6, F= 1.6, *P* = 0.18) nor CPUE abundance (DF = 6, F = 1.4, *P* = 0.25) differed between sites.

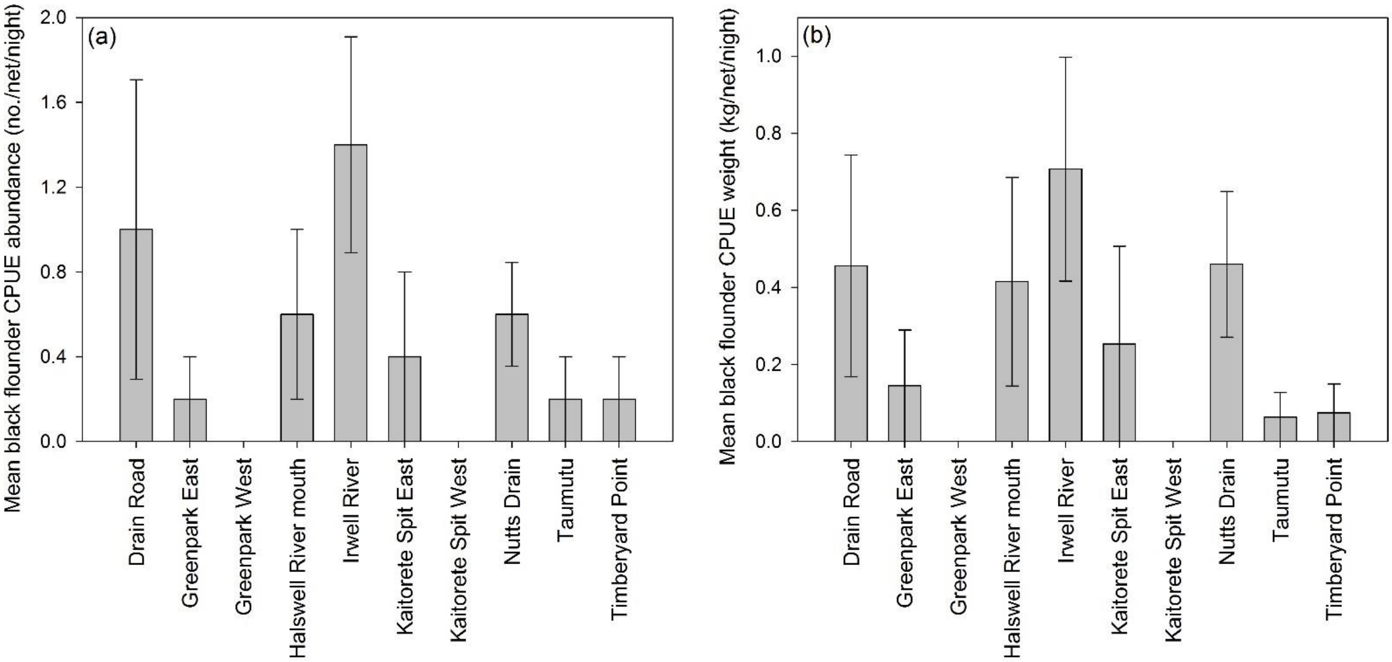


Figure 3-29: Mean (±SE) CPUE abundance (a) and CPUE weight (b) of black flounder at the different sites sampled around the lake. No post-hoc comparisons were completed on black flounder CPUE data because there was insufficient data available for statistical comparisons.

3.2.3 Length and weight characteristics

Length and weight characteristics of pātiki from around the lake are presented in the following sections for all three species. Statistical tests were only carried out on yellowbelly and sand flounder because there was insufficient data available for black flounder.

Yellowbelly flounder

The length of the 393 yellowbelly flounder ranged between 249 and 353 mm with a mean size of 302 mm (Figure 3-30). There was a strong peak from 290–310 mm, with c. 50 per cent of the catch falling into this size range. The percentage of yellowbelly flounder in each size class declined steadily from this peak to their maximum recorded size. There were significant differences in the mean length of yellowbelly flounder between sampling sites (One-way ANOVA: $F_{9,383}$= 4.67, P<0.001). The mean length was lowest at the Greenpark East site (291 mm) and was highest at Taumutu (306 mm) (Figure 3-31, Figure 3-32). Yellowbelly flounder at Greenpark East were significantly smaller than eels at Taumutu, Timberyard Point, Halswell River mouth, Irwell River and Kaitorete Spit East (Figure 3-31). Nutts Drain also had smaller fish present than Taumutu and the Halswell River mouth. The remaining sites all had very similar lengths of yellowbelly flounder present (Figure 3-31, Figure 3-32).

The weight range of the 393 yellowbelly flounder was between 192 and 596 g with a mean weight of 376 g (Figure 3-33). The weight-frequency plot for pātiki peaked at 360–400 g and more than 50 per cent of the pātiki weighed between 320–420 g (Figure 3-33). There were significant differences in the mean weight of yellowbelly flounder between sampling sites (One-way ANOVA: $F_{9,383}$= 5.92, P < 0.001). Weight displayed more between site variability than length (Figure 3-31, Figure 3-34). Greenpark East, Kaitorete Spit West and Nutts Drain all had weights significantly smaller than the Halswell River mouth, Irwell River and Taumutu (Figure 3-31). The lightest average weight was 330 g found at Kaitorete Spit West, while the heaviest average weight of 400 g was found at the Halswell River mouth (Figure 3-34).

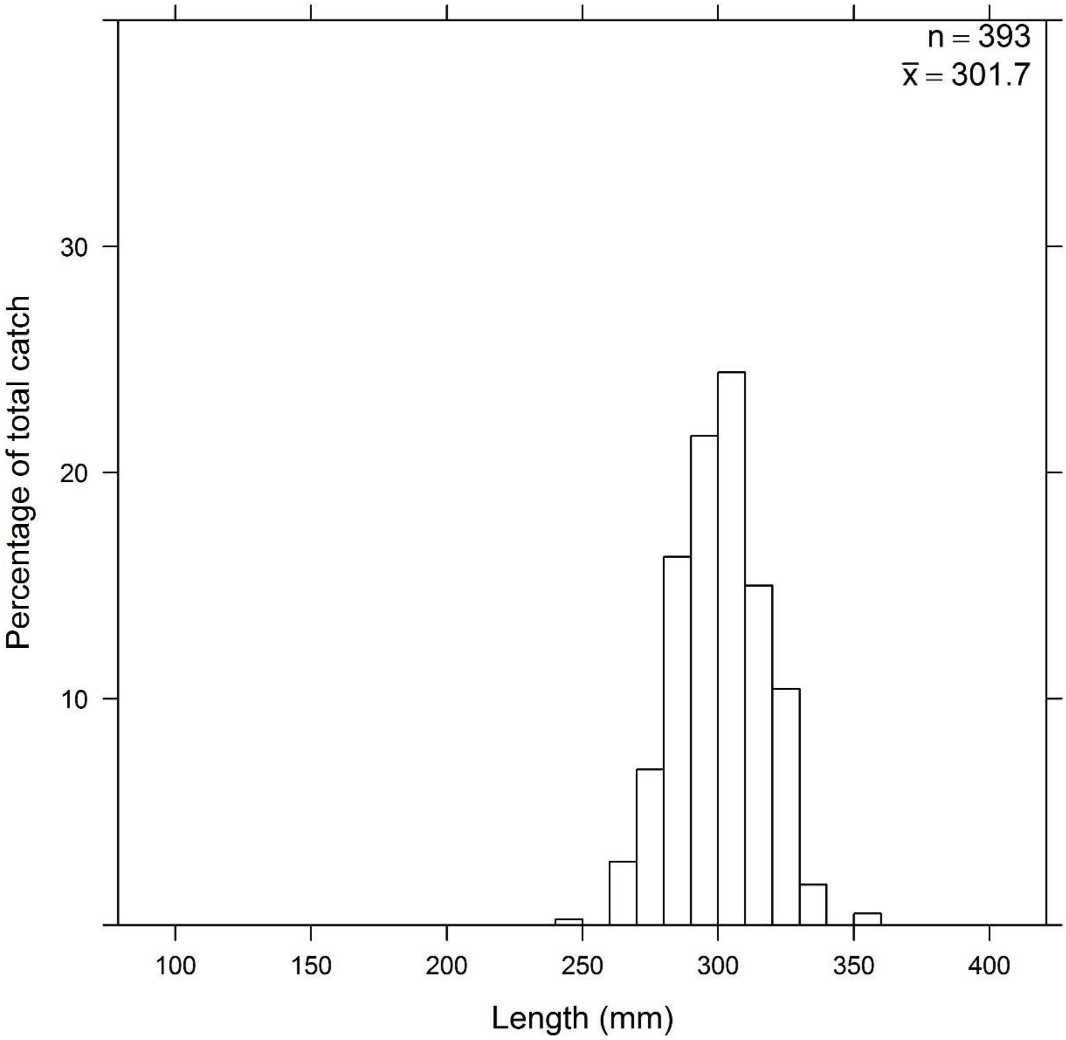


Figure 3-30: Length-frequency distribution for all yellowbelly caught during sampling. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Size class bins were 10 mm.

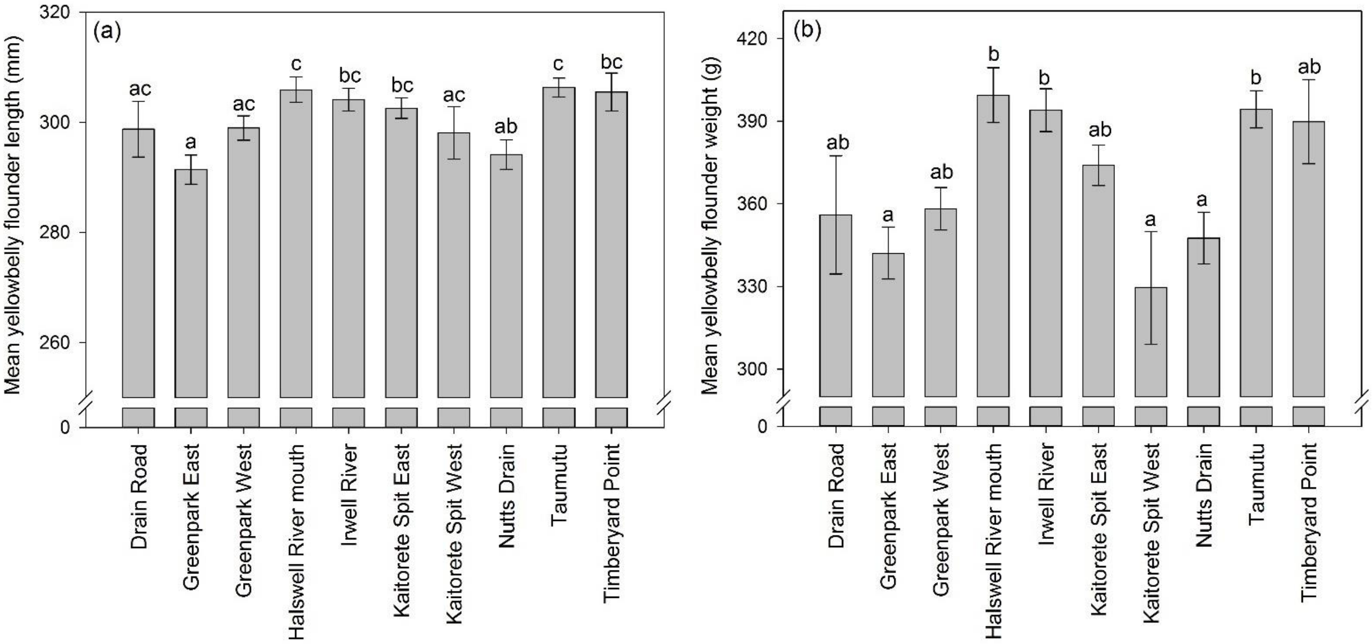


Figure 3-31: Mean (±SE) length (a) and weight (b) of yellowbelly flounder at the different sites sampled around the lake. Significant differences (*P* < 0.05) between sites were calculated by Tukey's HSD tests. Sites that do not share a letter are significantly different from each other.

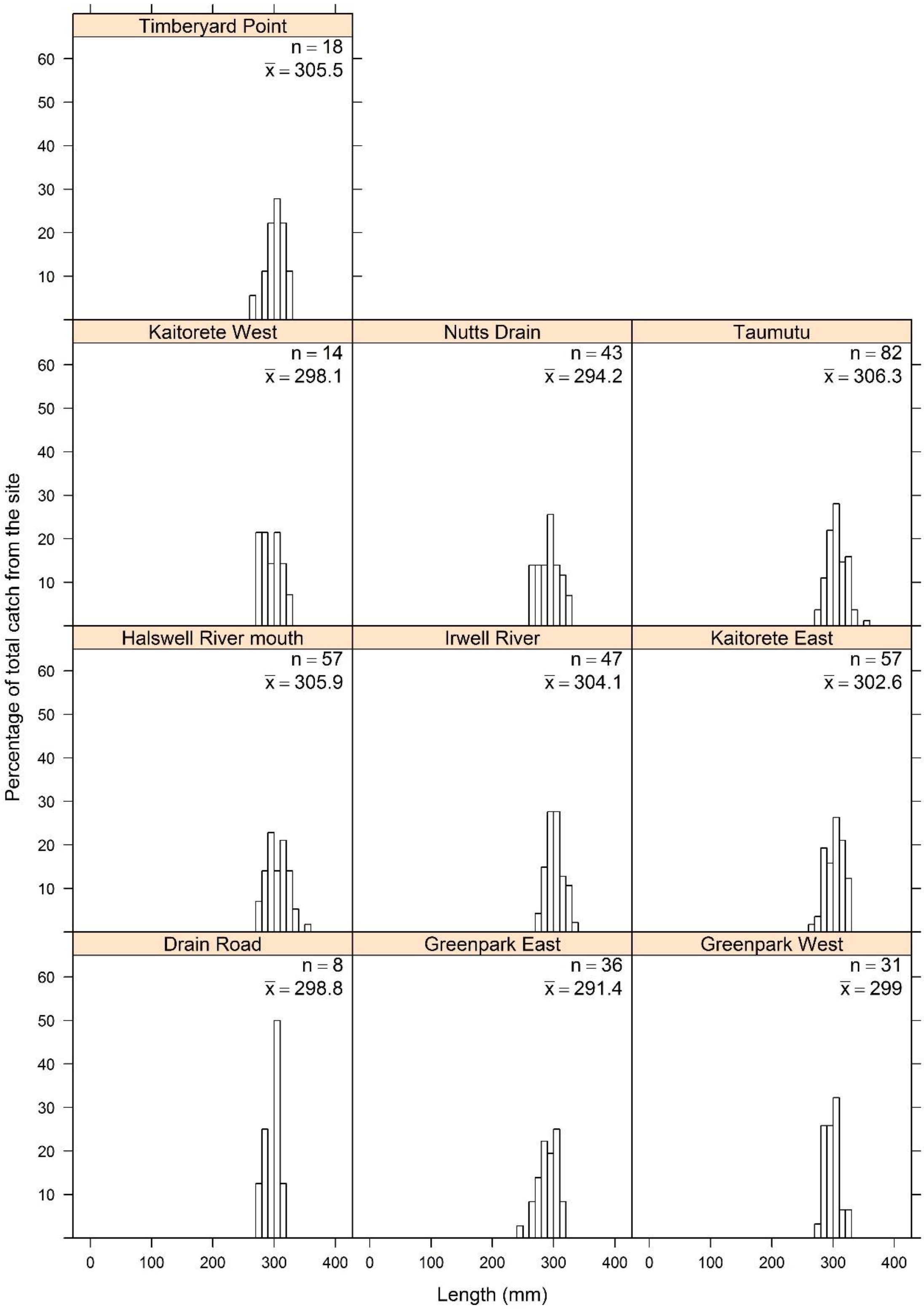


Figure 3-32: Length-frequency distributions of yellowbelly flounder from each site. For each site, both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Size class bins were 10 mm.

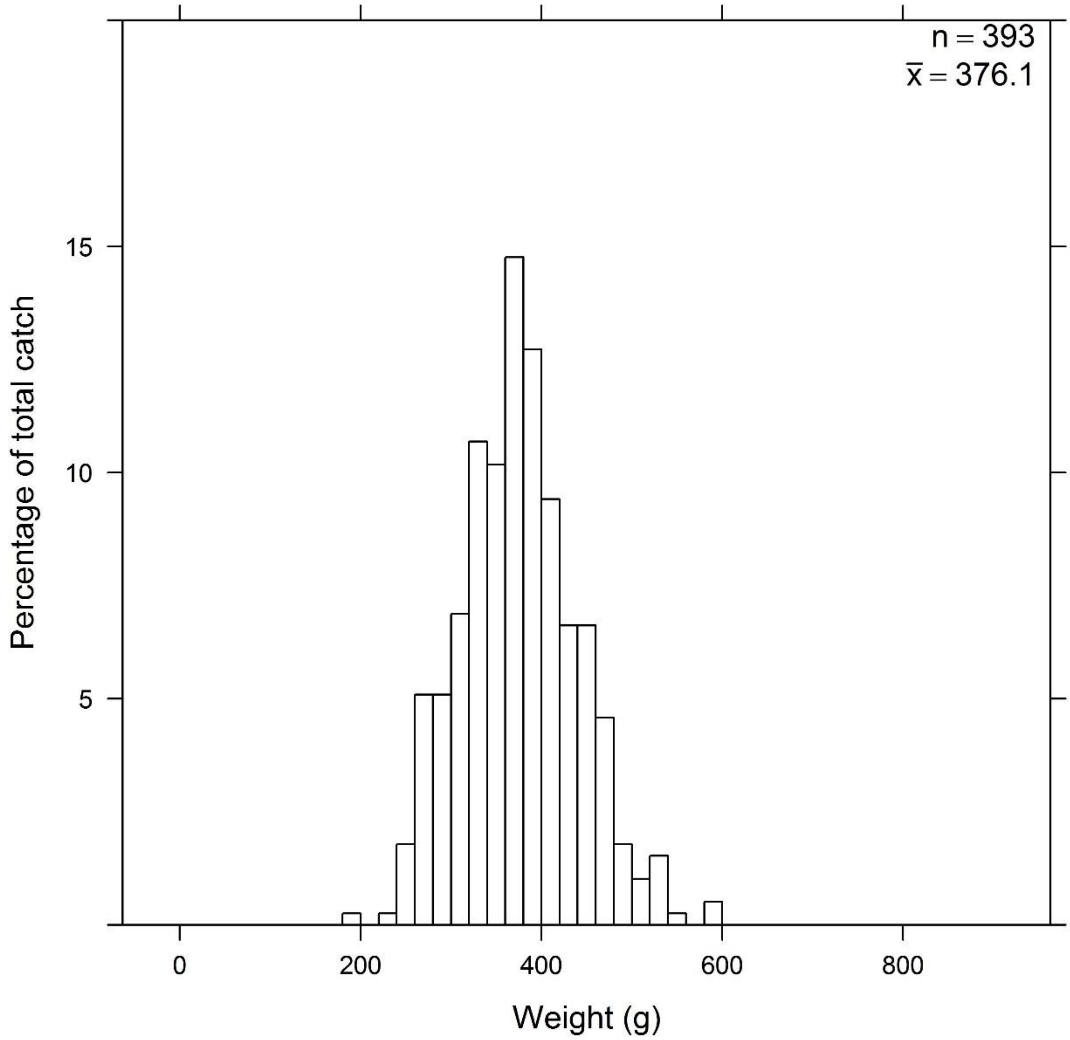


Figure 3-33: Weight-frequency distribution for all yellowbelly flounder measured during sampling. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Weight class bins were 20 g.

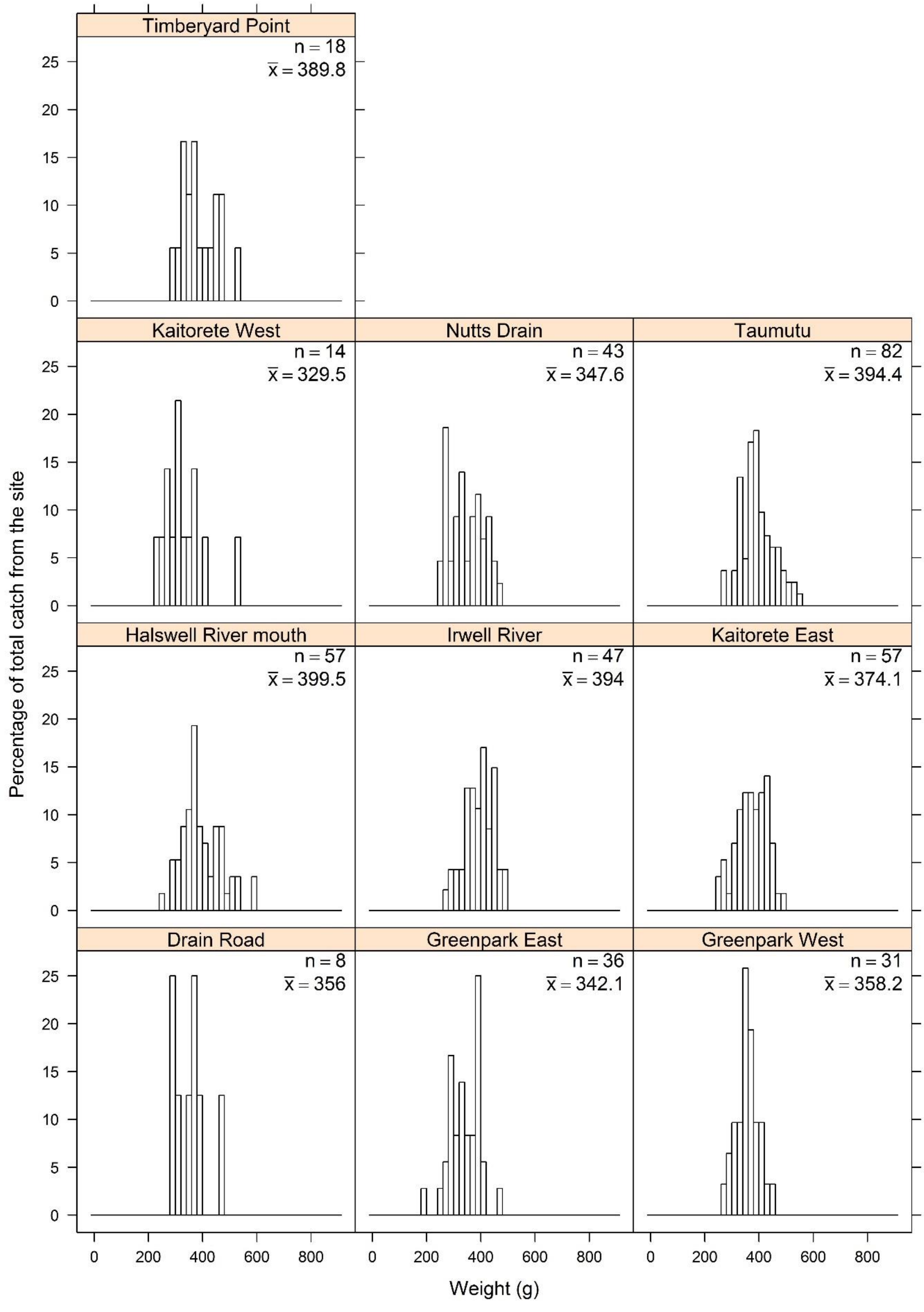


Figure 3-34: Weight-frequency distributions of yellowbelly flounder for each site. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Weight class bins were 20 g.

Sand flounder

The length of the 98 sand flounder ranged between 202 and 346 mm with a mean size of 250 mm (Figure 3-35). There was a strong peak from 240–260 mm, with more than 50 per cent of the catch falling into this size range. The percentage of sand flounder in each size class declined steadily from this peak to their maximum recorded size. Interestingly, the 346 mm sand flounder was at least 50 mm larger than the rest of the fish (note, this record was re-checked to make sure it was not an identification error and is correct). There were no significant differences in length between sampling sites (One-way ANOVA: $F_{6,91} = 1.1$, $P = 0.34$) (Figure 3-36). Mean length varied from 245–258 mm between sites, with the largest fish captured from Nutts Drain (Figure 3-37).

The weight range of sand flounder was between 98 and 389 g with a mean weight of 263 g (Figure 3-38). The weight-frequency plot for sand flounder peaked at 260–280 g, with most of the pātiki weighing between 200–340 g. There were no significant differences in the mean weight of sand flounder between sampling sites (One-way ANOVA: $F_{6,91} = 1.40$, $P = 0.22$) (Figure 3-36). Mean weight ranged from 231–288 g between sites with the heaviest fish being found at Taumutu (Figure 3-39).

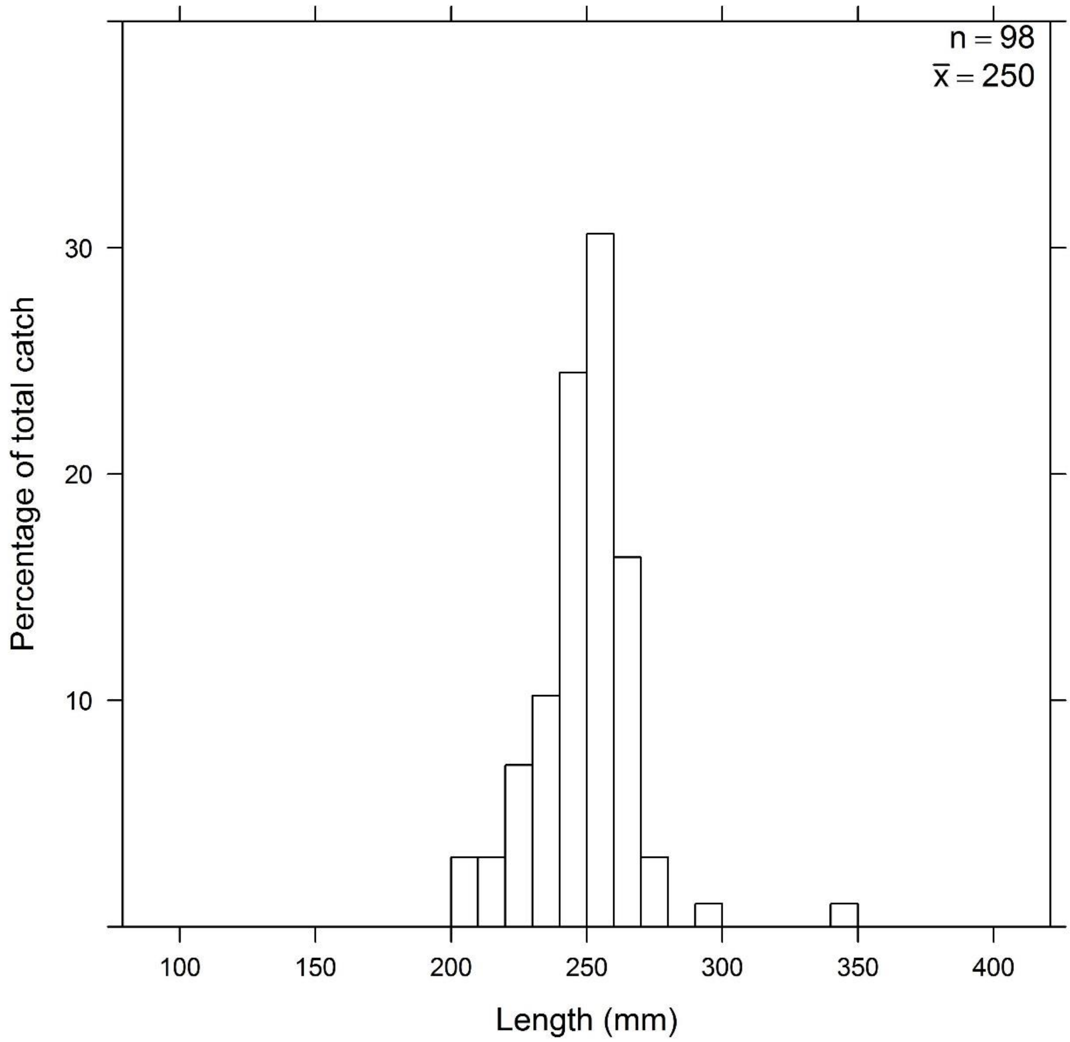


Figure 3-35: Length-frequency distribution for all sand flounder caught during sampling. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Size class bins were 10 mm.

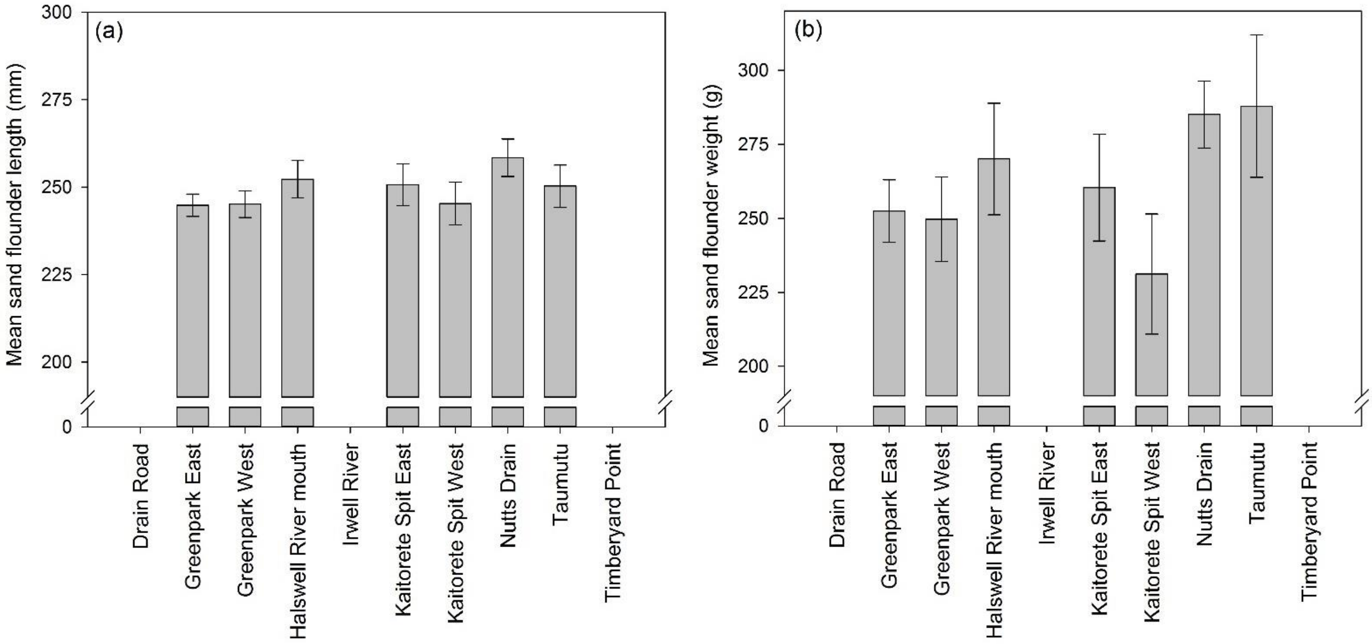


Figure 3-36: Mean (±SE) length (a) and weight (b) of sand flounder at the different sites sampled around the lake. No post-hoc comparisons are shown between sites because there was no differences in sand flounder length or weight between sites.

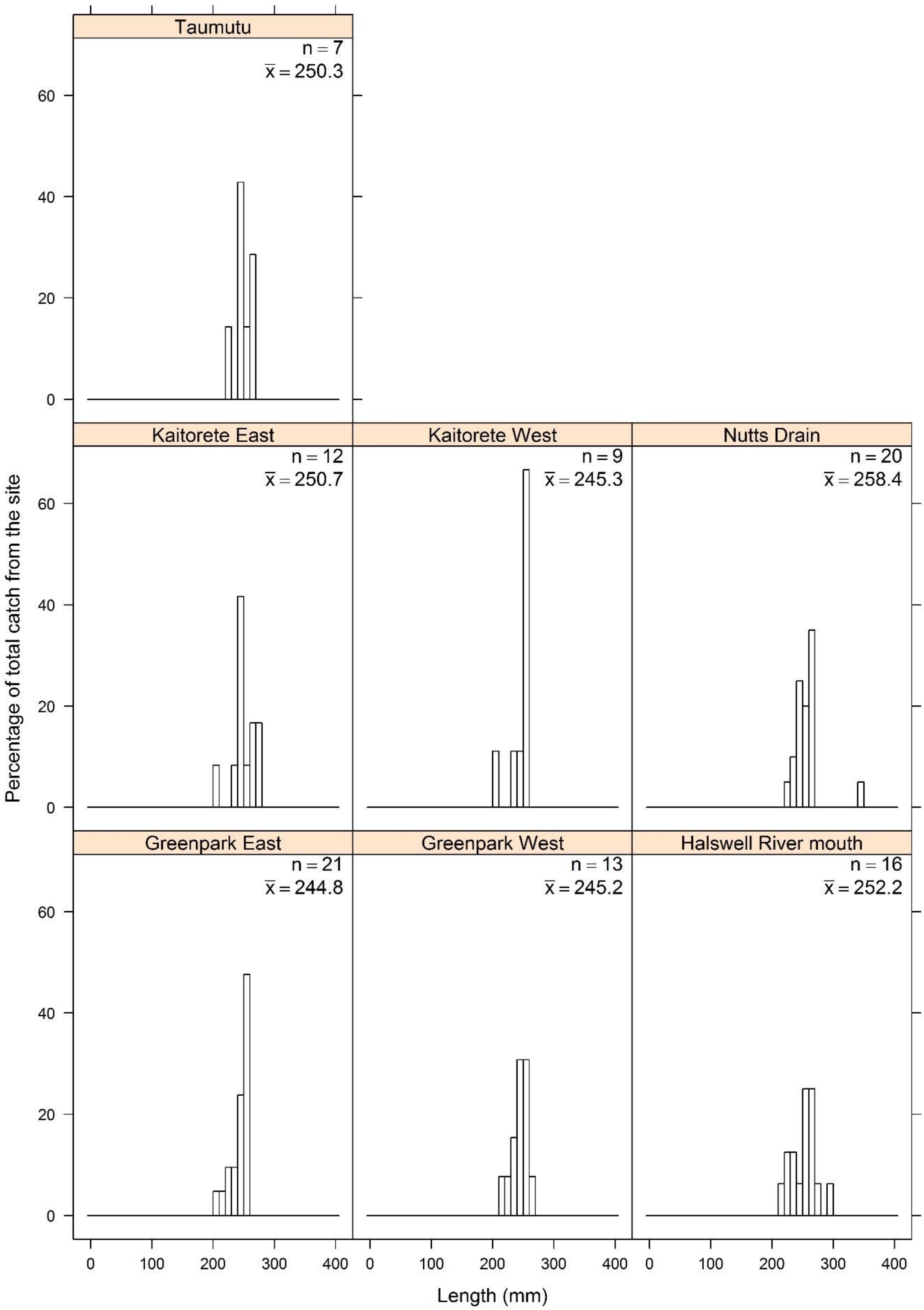


Figure 3-37: Length-frequency distributions of sand flounder from each site. For each site, both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Size class bins were 10 mm.

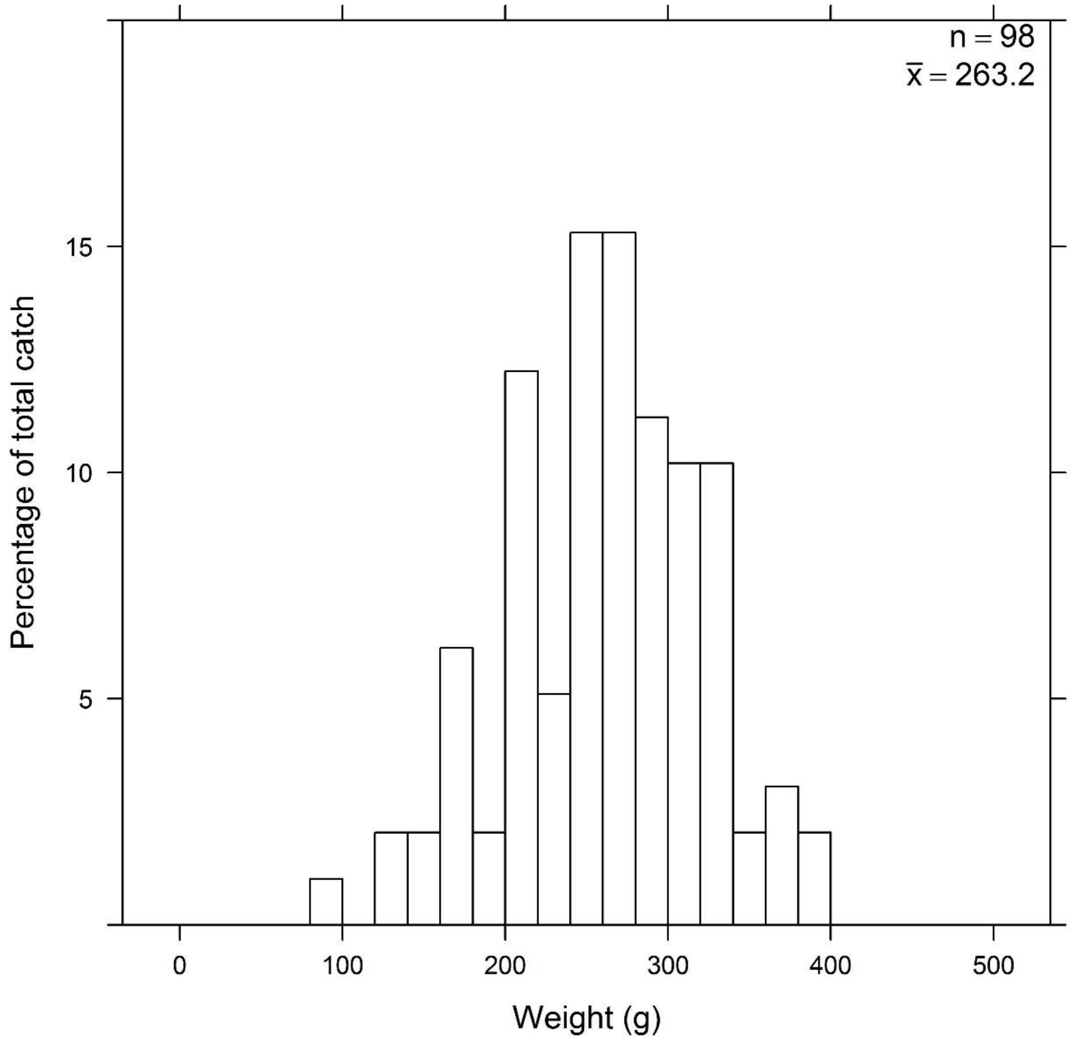


Figure 3-38: Weight-frequency distributions of sand flounder measured from all sites. Both the number of pātiki measured (n) and mean pātiki size ($\bar{x}$) are shown on the plot. Weight class bins were 20 g.

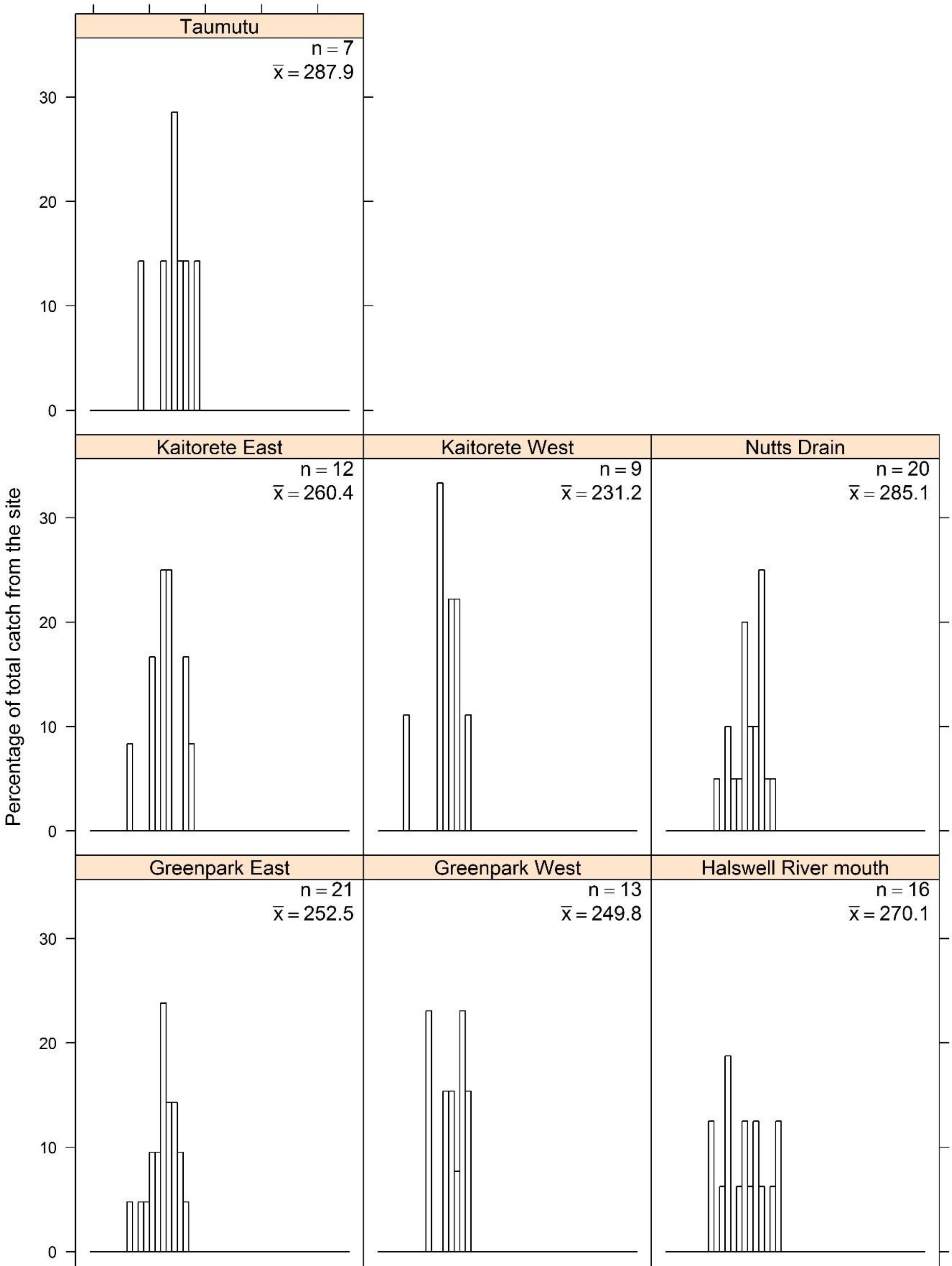


Figure 3-39: Weight-frequency distributions of sand flounder for each site. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Weight class bins were 20 g.

Black flounder

Only 22 black flounder were captured among all sites which averaged 317 mm in total length (Figure 3-40) and around 564 g (Figure 3-43). There appeared to be two size classes, one group of fish around 240–270 mm and one group around 320–350 mm. The mean length and weight was highly variable between sites because of the low sample sizes (Figure 3-41), but Nutts Drain appeared to have the largest fish (both length and weight) (Figure 3-42, Figure 3-44). Mean weight of the black flounder was 522 g and mean length was highly variable between sites because of the low sample sizes (Figure 3-41, Figure 3-44).

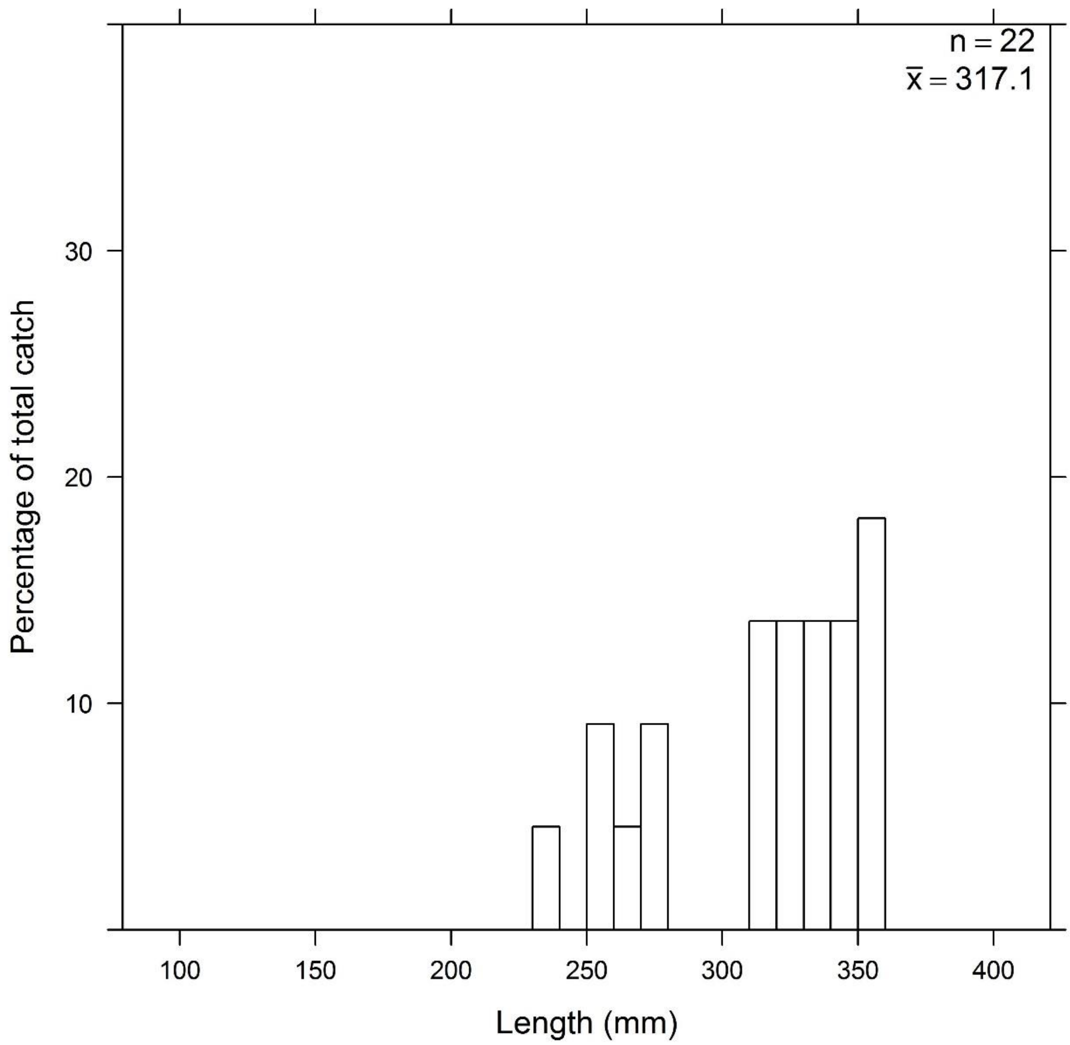


Figure 3-40: Length-frequency distribution for all black flounder caught during sampling. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Size class bins were 10 mm.

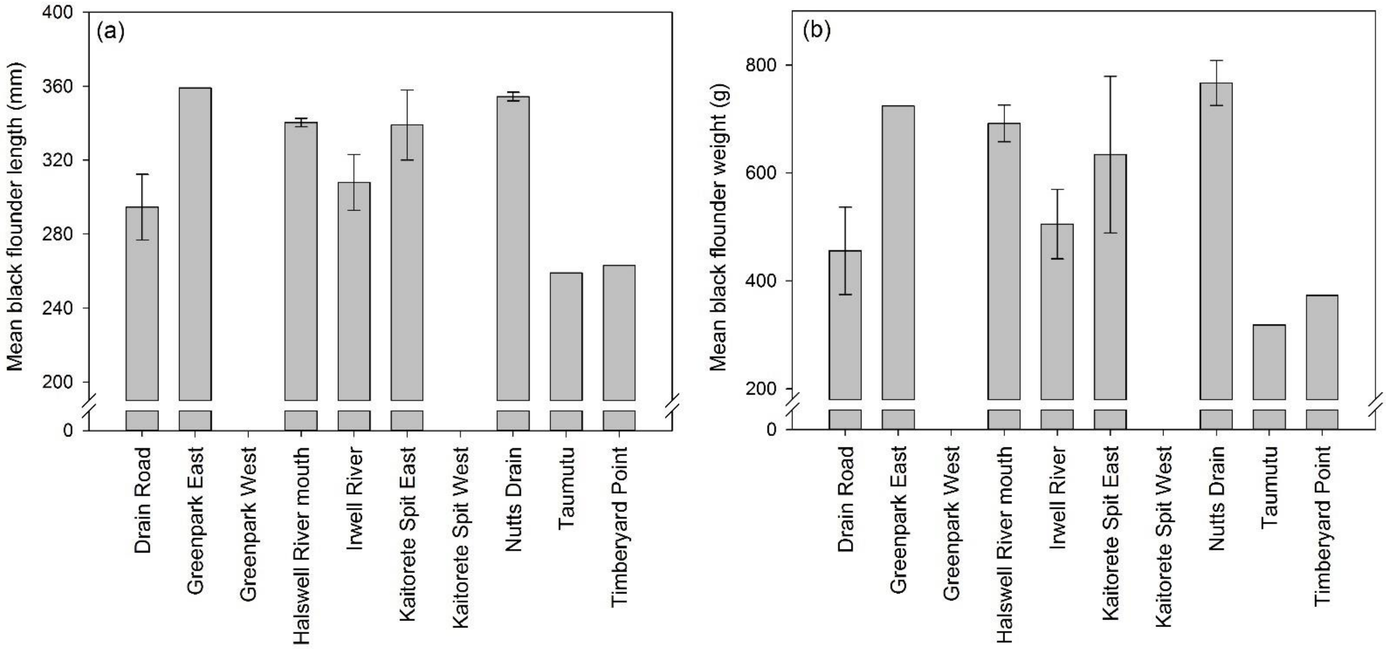


Figure 3-41: Mean (±SE) length (a) and weight (b) of black flounder at the different sites sampled around the lake and tributaries. No statistical comparisons were completed between sites because of insufficient data.

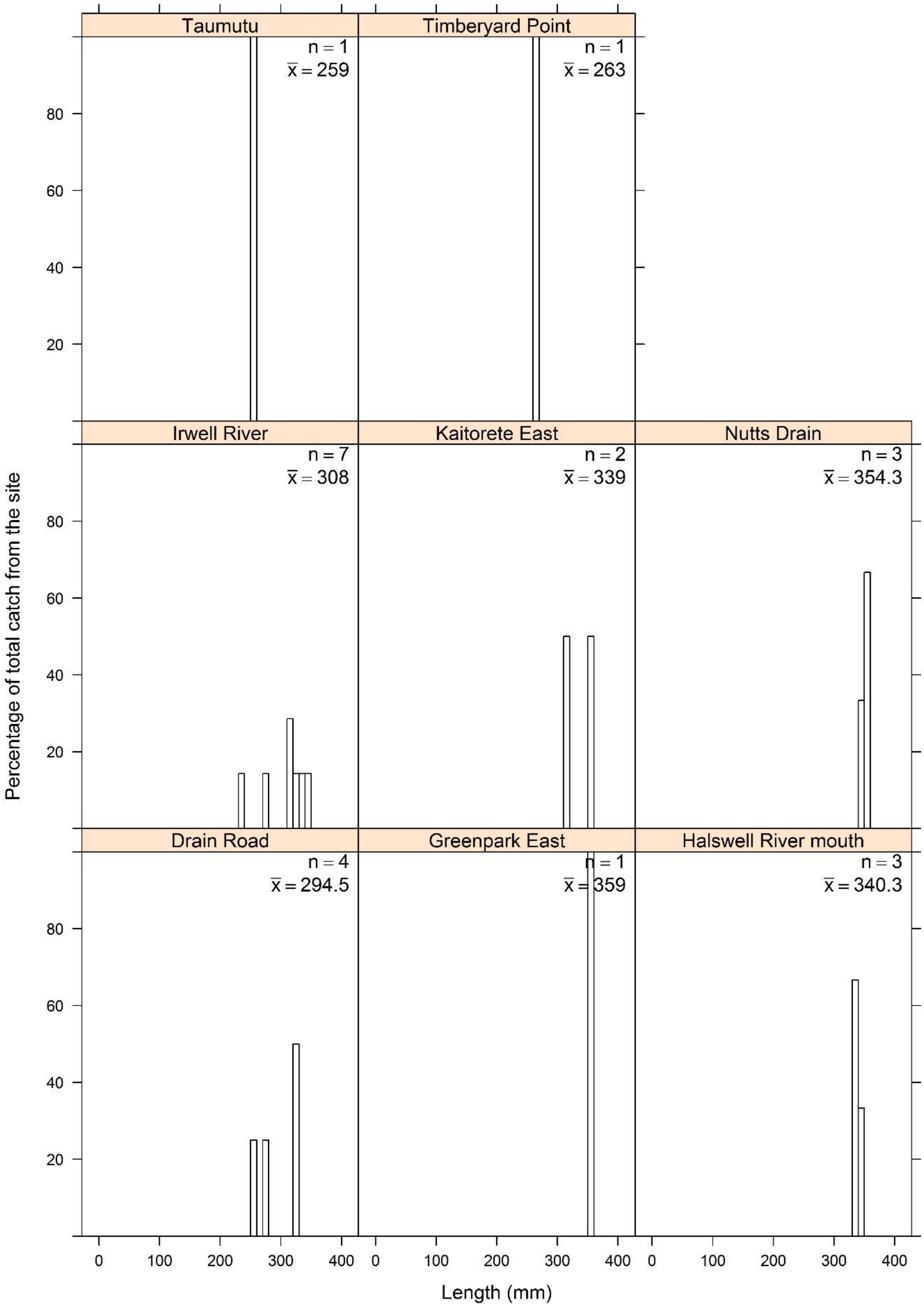


Figure 3-42: Length-frequency distributions of black flounder from each site. For each site, both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Size class bins were 10 mm.

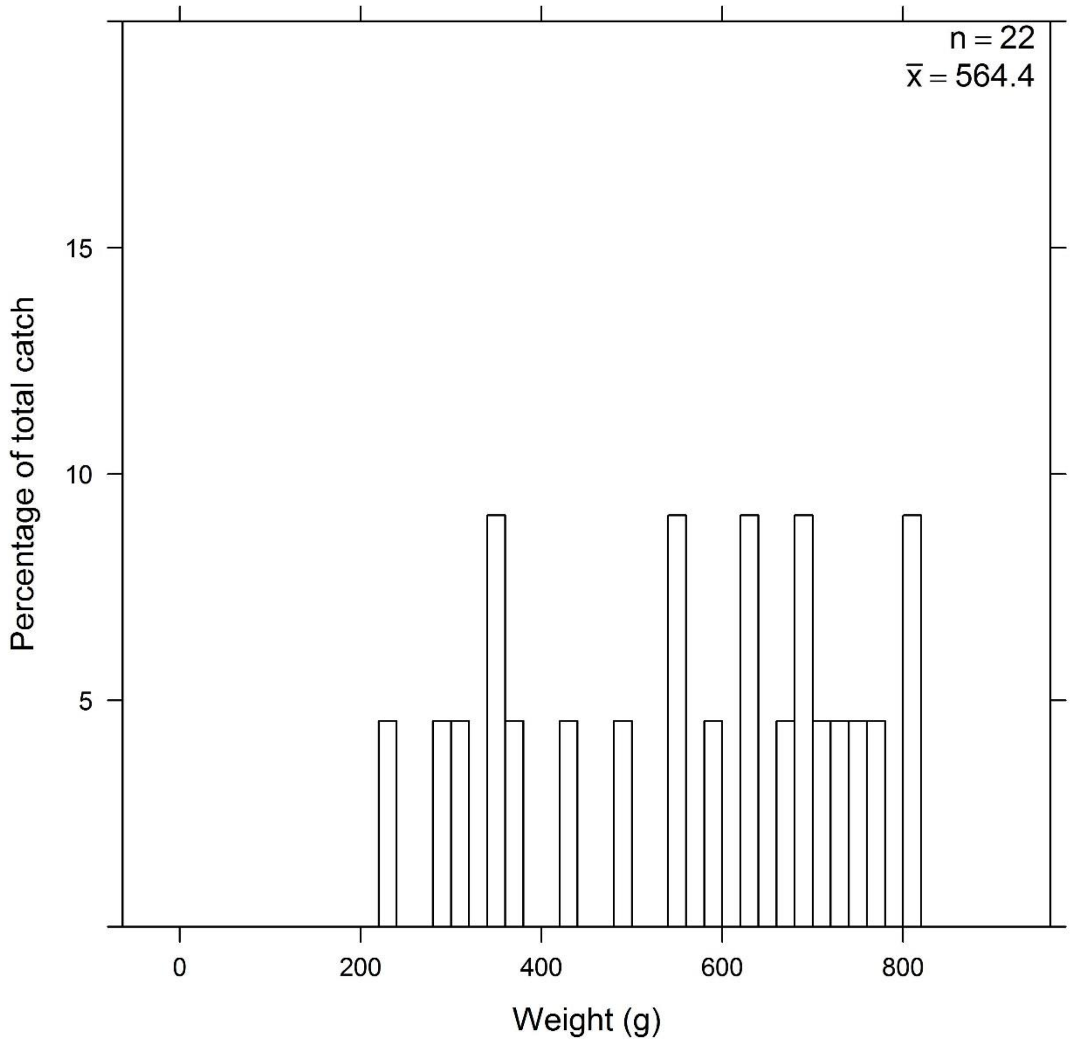


Figure 3-43: Weight-frequency distributions of black flounder measured from all sites. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Weight class bins were 20 g.

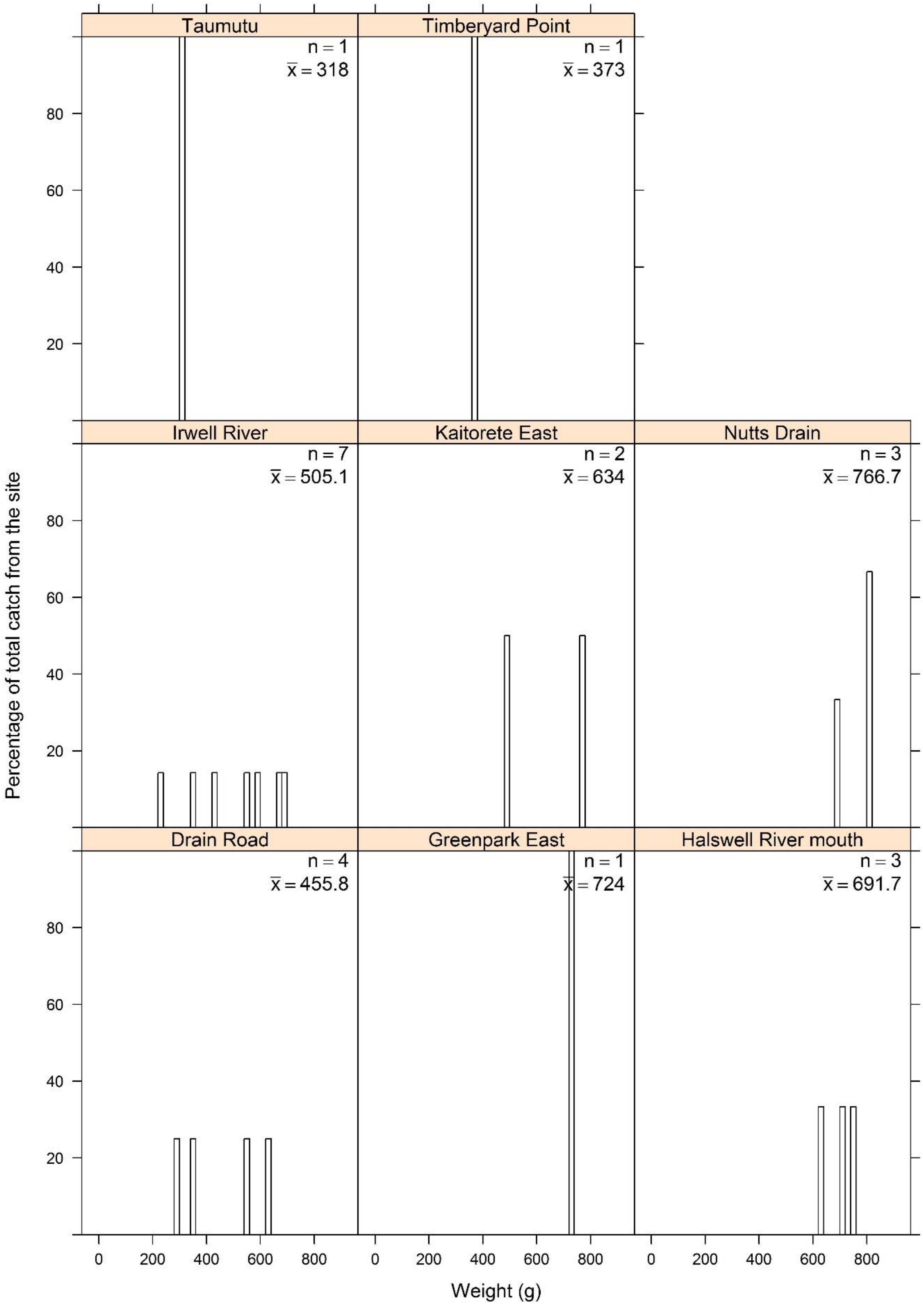


Figure 3-44: Weight-frequency distributions of black flounder for each site. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Weight class bins were 20 g.

3.2.4 Condition

Yellowbelly flounder

The condition factor (K) of the 393 yellowbelly flounder was very consistent and only ranged from 10–16 K with a mean value of 13.6 K (Figure 3-45). Nearly 40 per cent of the catch had a condition factor of 14 K, with the percentage of the catch in other categories declining steeply above and below this value. There were significant differences in condition factor of yellowbelly flounder between sampling sites (One-way ANOVA: $F_{5,383} = 4.85$ $P < 0.001$). Mean condition at Kaitorete Spit West (12.3 K) was significantly lower than all other sites except Drain Road (Figure 3-46). These differences can also be seen in the condition-frequency plots for each site where most sites peak around 13–14 K, but Kaitorete Spit West and Drain Road have peak frequencies around 11–12 K (Figure 3-47).

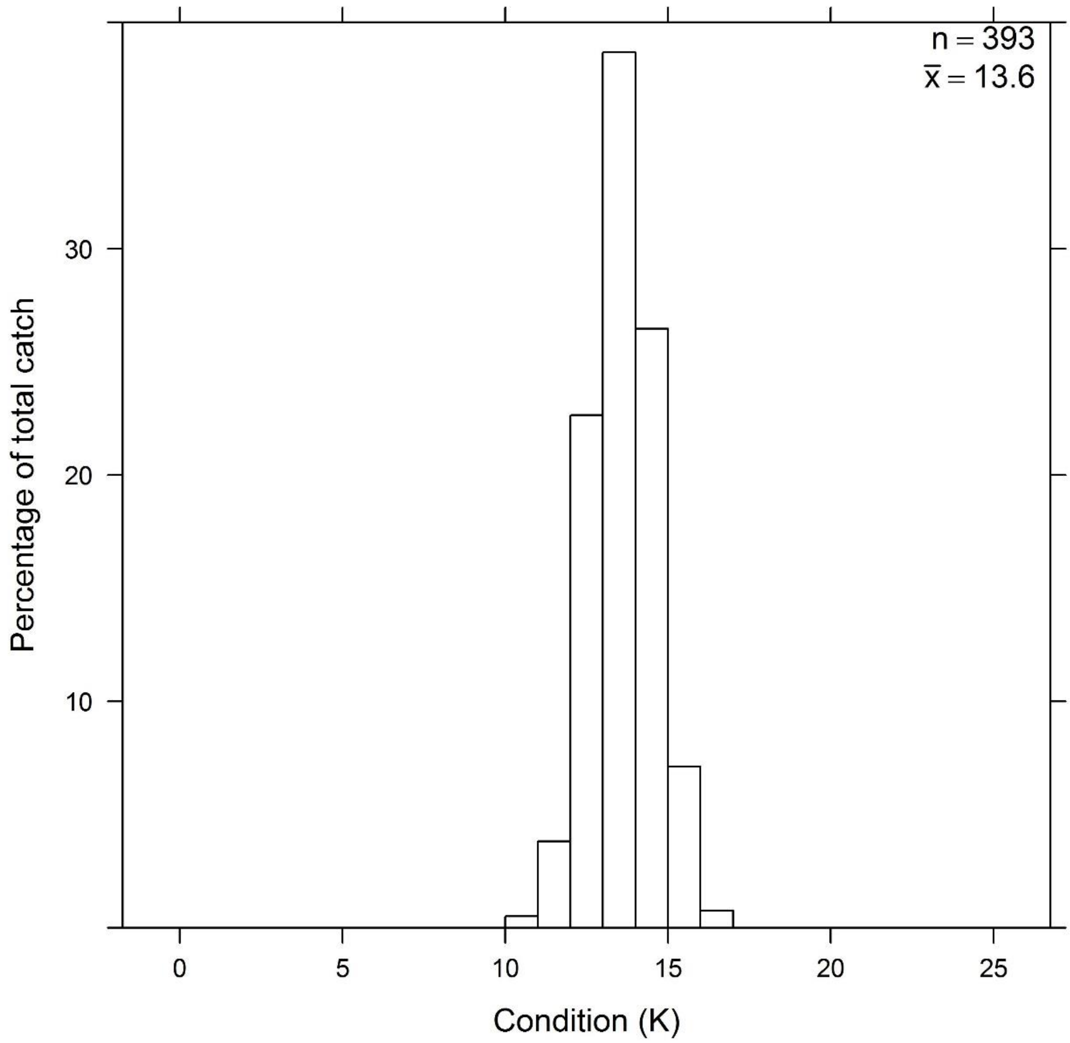


Figure 3-45: Condition-frequency distribution for all yellowbelly flounder measured during sampling. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Condition bins were 1.0 K.

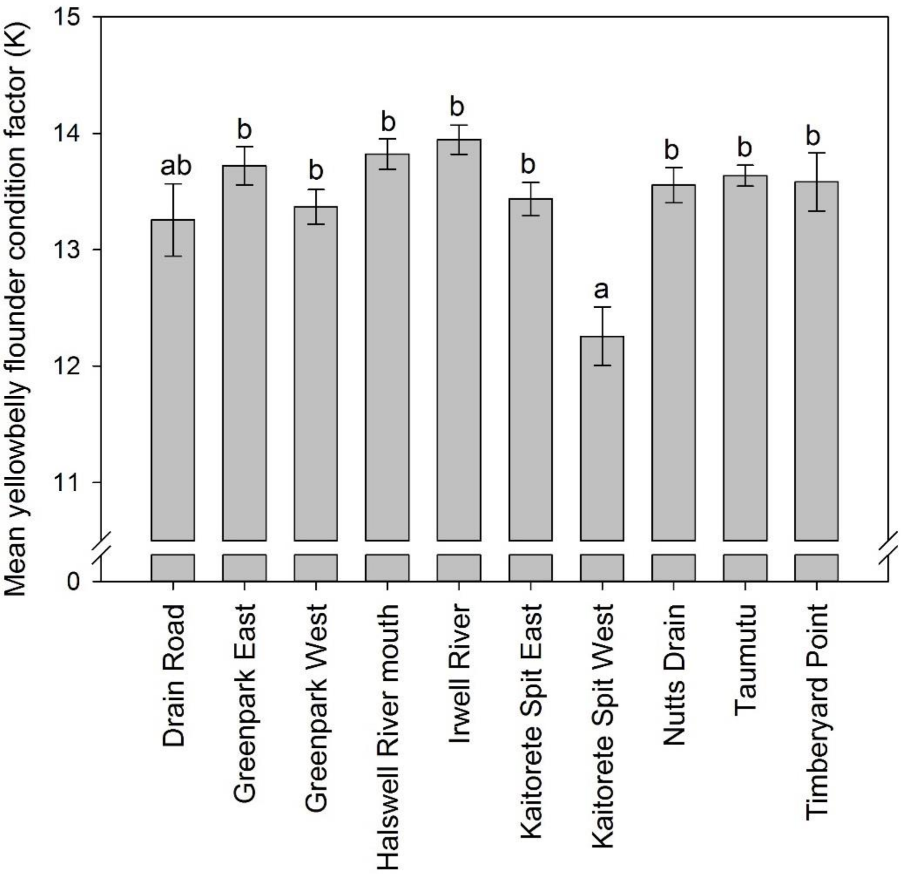


Figure 3-46: Mean (±SE) condition of yellowbelly flounder at the different sites sampled around the lake. Significant differences (*P* < 0.05) between sites were calculated by Tukey's HSD tests. Sites that do not share a letter are significantly different from each other.

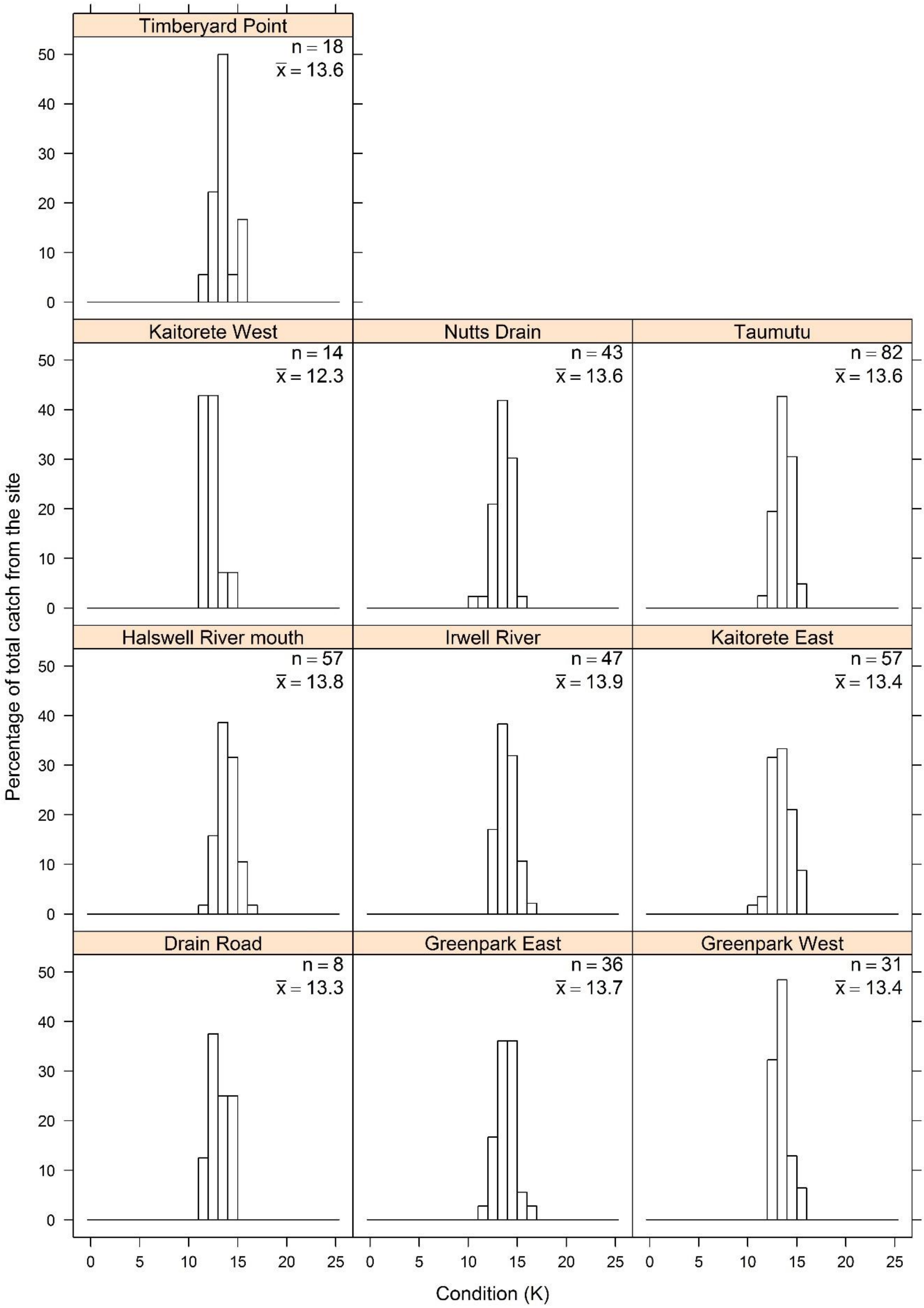


Figure 3-47: Condition-frequency distributions of yellowbelly flounder for each site. For each site, both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown. Size class bins were 1.0 K.

Sand flounder

The condition factor (K) of the 98 sand flounder was higher and more variable than yellowbelly flounder, ranging from 8.7–21.3 K with a mean value of 16.6 K (Figure 3-48). Approximately 32 per cent of the catch had a condition factor of around 16 K, with a decreasing percentage of fish in condition categories above and below this value. There were no significant differences in condition factor of sand flounder between sampling sites (One-way ANOVA: $F_{6,91} = 2.04$, $P = 0.07$) (Figure 3-49). Upon closer inspection of the condition data, the fish with the lowest condition factor of 8.7 K, found at Nutts Drain (Figure 3-50), turned out to be the longest sand flounder captured. Reasons for the poor condition of this fish are further explored in Section 4.

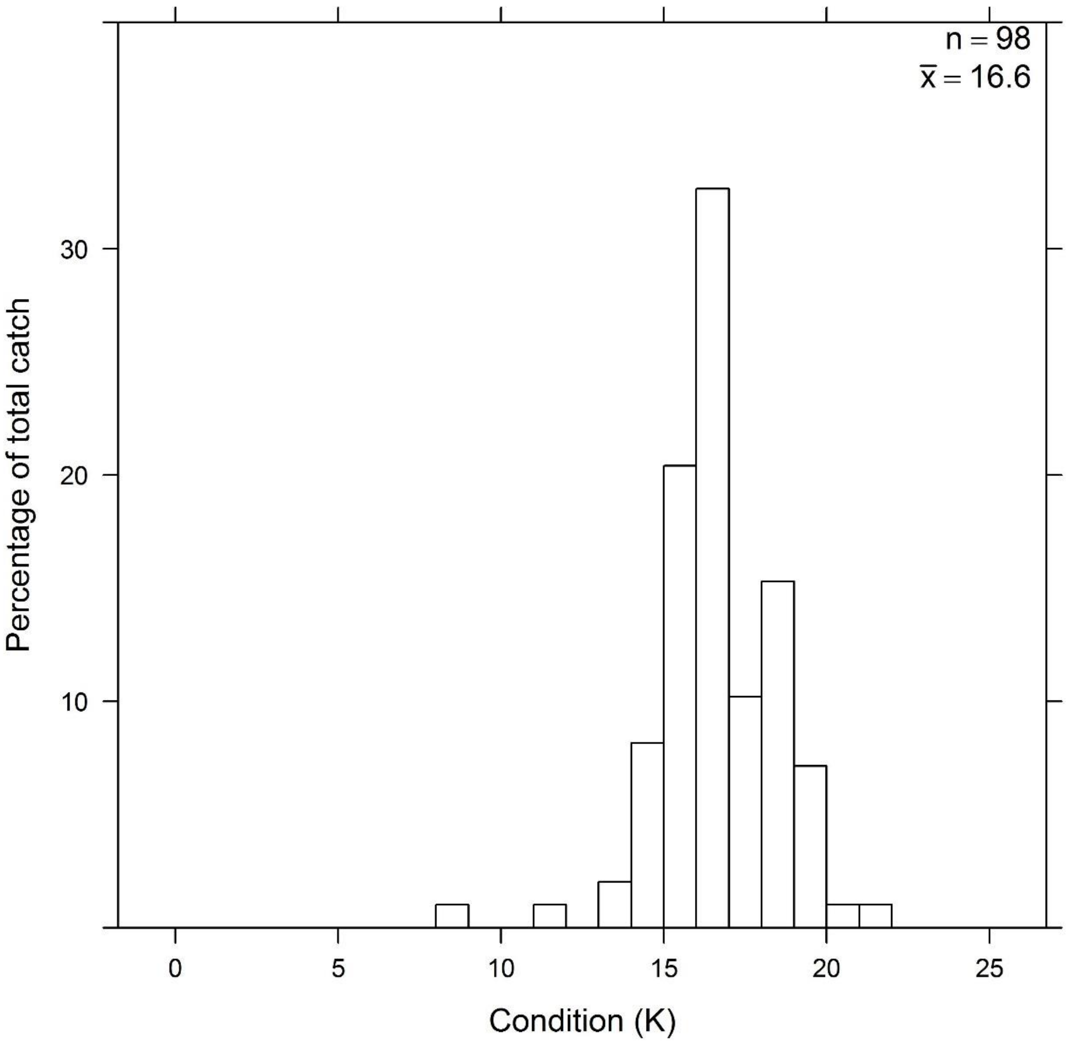


Figure 3-48: Condition-frequency distribution for all sand flounder measured during sampling. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Condition bins were 1.0 K.

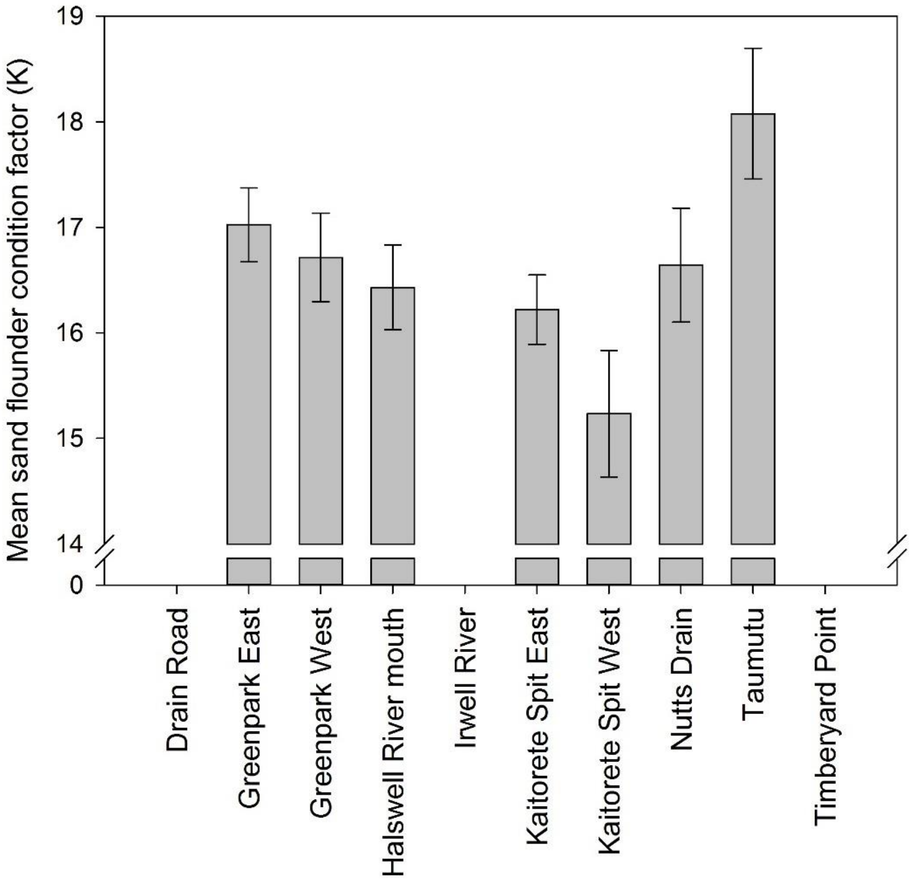


Figure 3-49: Mean (±SE) condition of sand flounder at the different sites sampled around the lake. No statistical differences were observed between sites.

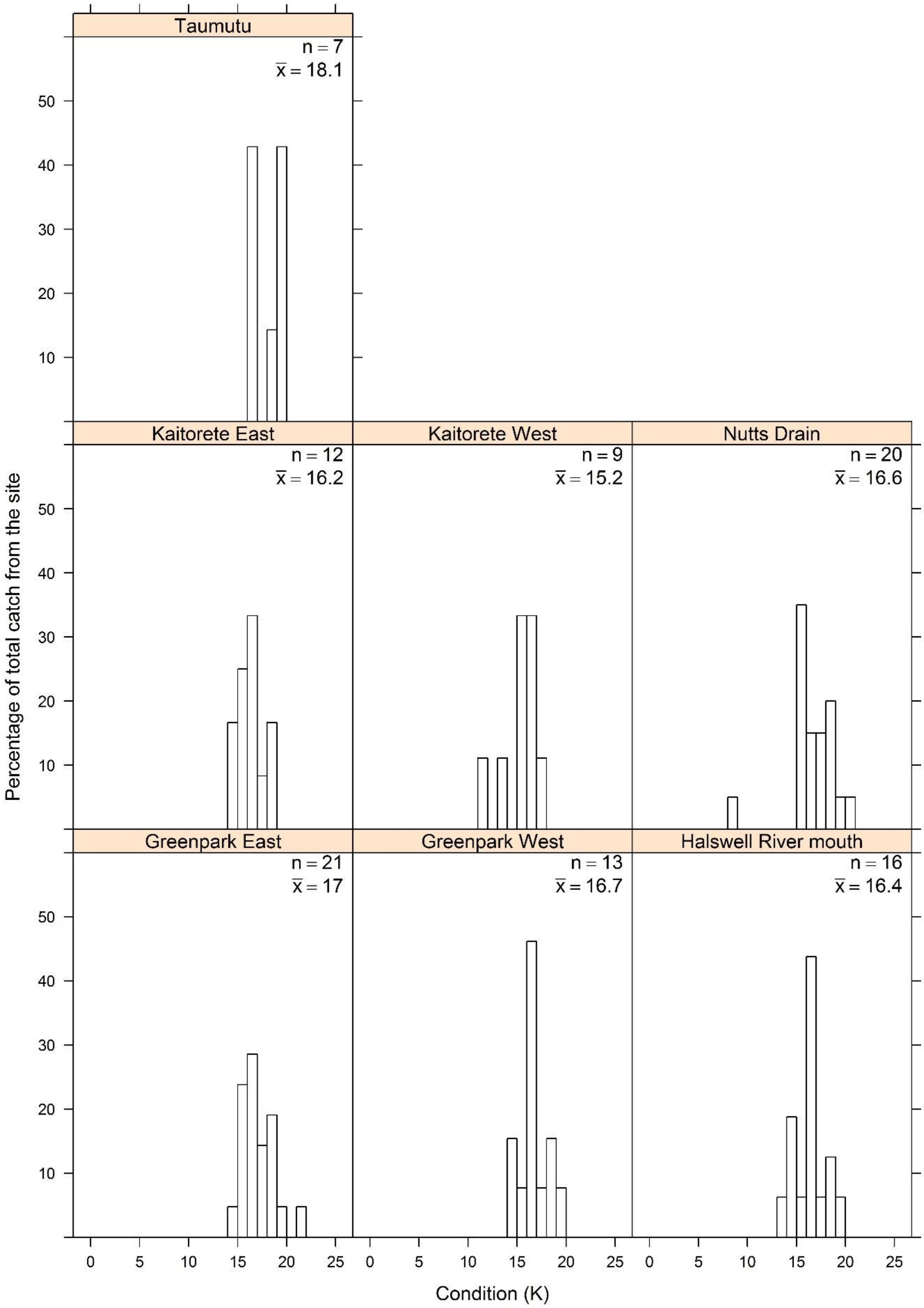


Figure 3-50: Condition-frequency distributions of sand flounder for each site. For each site, both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown. Size class bins were 1.0 K.

Black flounder

The condition factor (K) of the 22 black flounder was generally similar to sand flounder, ranging from 12.4–20.5 K with a mean value of 17.2 K (Figure 3-51). Approximately 32 per cent of the catch had a condition factor of 18 K, with a sharp decrease in the percentage of fish in condition categories above this value. There was insufficient data to compare condition between sites (Figure 3-52), but generally condition was similar between sites (Figure 3-53).

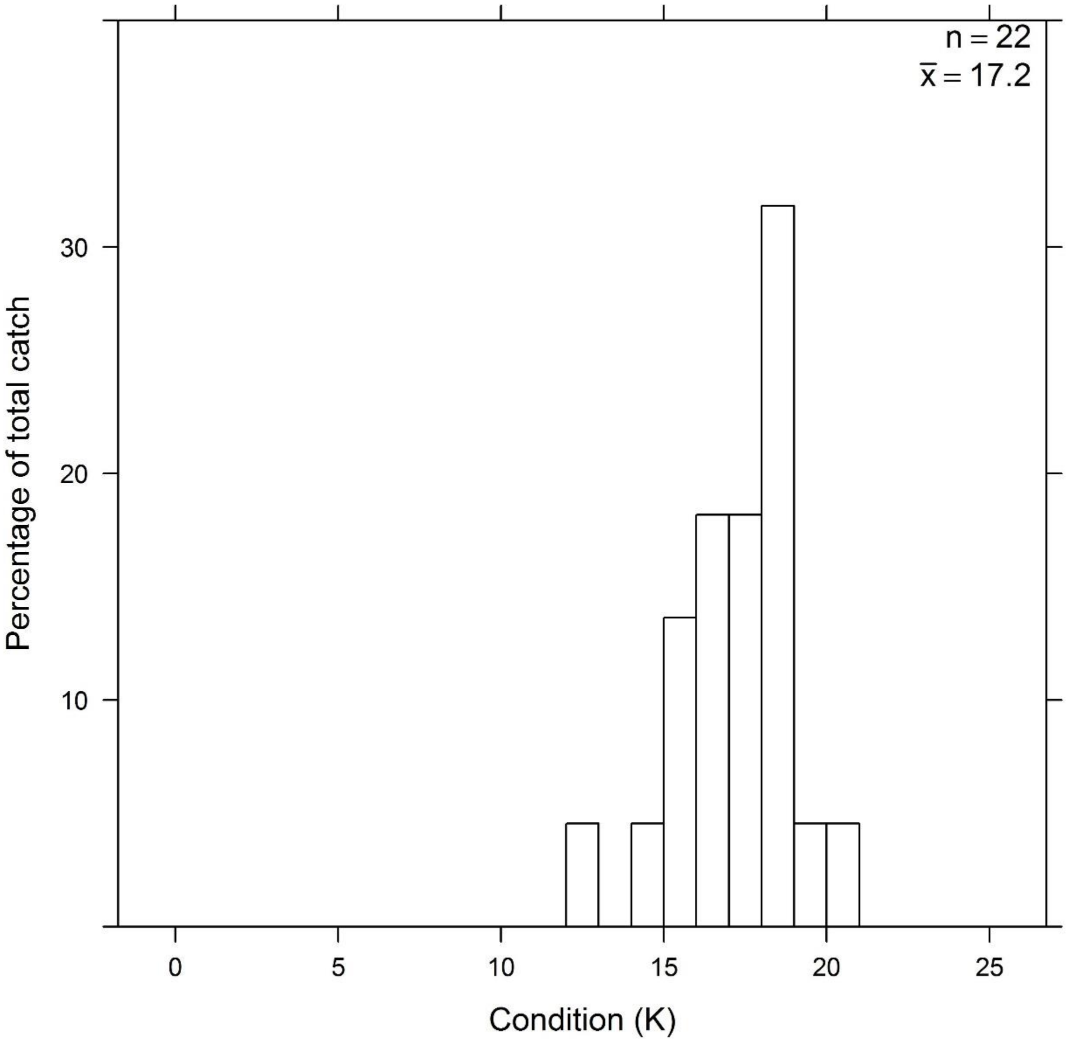


Figure 3-51: Condition-frequency distribution for all black flounder measured during sampling. Both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown on the plot. Condition bins were 1.0 K.

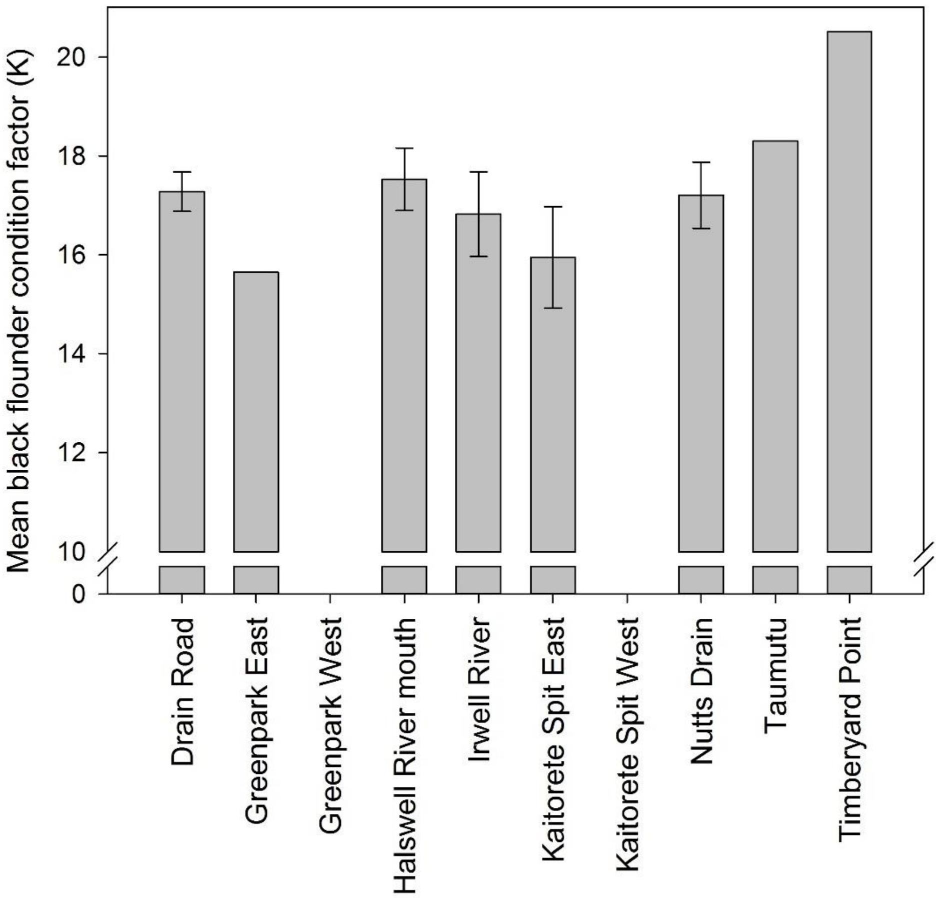


Figure 3-52: Mean (±SE) condition of black flounder at the different sites sampled around the lake. No statistical comparisons were completed between sites because of insufficient data.

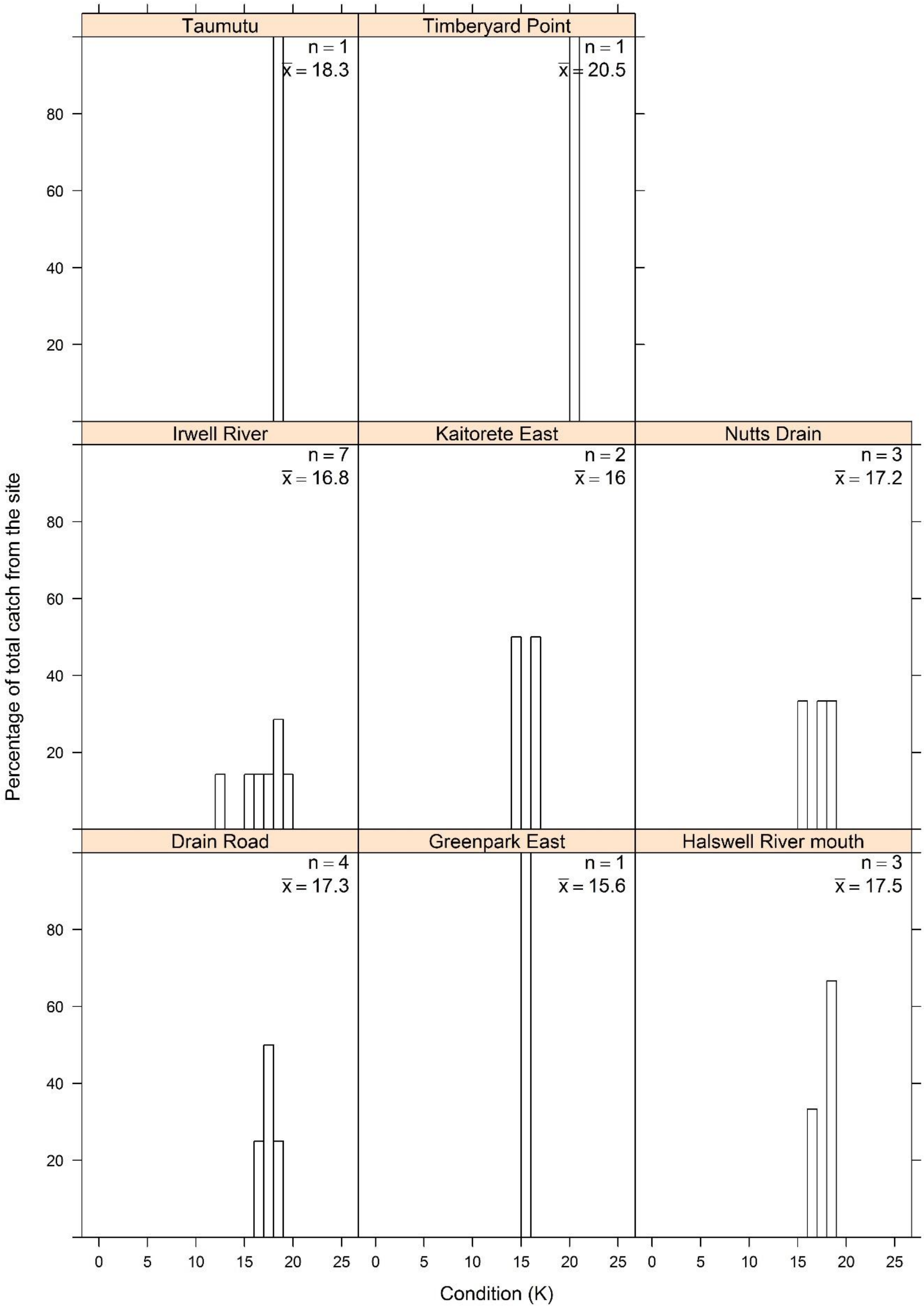
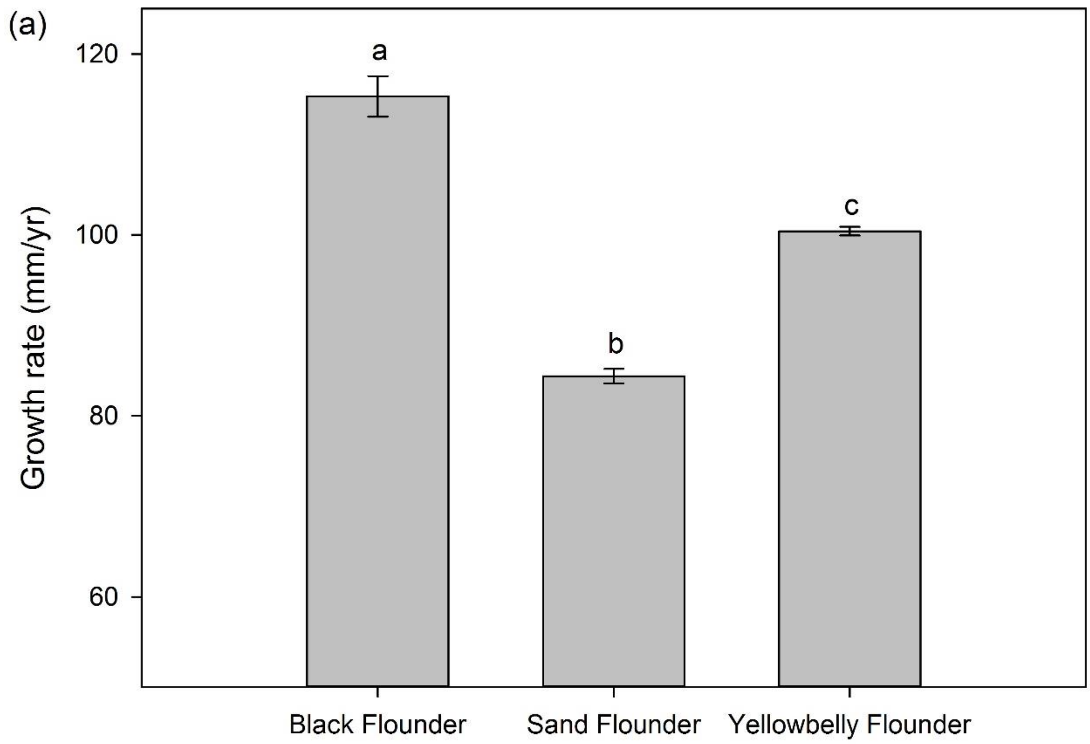


Figure 3-53: Condition-frequency distributions of black flounder for each site. For each site, both the number of pātiki measured (n) and mean pātiki size ($\overline{x}$) are shown. Size class bins were 1.0 K.

3.2.5 Growth rates

Ages were estimated from 142 yellowbelly flounder, 84 sand flounder and 21 black flounder. Annual length increase and annual weight increase differed significantly between species (*length* - One-way ANOVA: $F_{2,240}$ = 243.5, P < 0.001; *weight* - One-way ANOVA: $F_{2,240}$ = 182.9, P < 0.001) (Figure 3-54). Black flounder was the fastest growing flounder species, followed by yellowbelly and then sand flounder. Because the fish caught in the present study had limited variation in age, we were unable to generate reliable length-growth and length-age relationships for flounder.

Growth rates of yellowbelly flounder in mm/year did not differ between sites (One -way ANOVA: $F_{9,132}$=1.85, P = 0.07), but growth rates in g/year did significantly differ between sites (One -way ANOVA: $F_{9,132}$=2.54, P = 0.01). Post-hoc comparisons show that the difference among sites was generated by the Kaitorete West fish site having a significantly lower annual weight increase than flounder caught at the Halswell River mouth (Figure 3-55). The growth rate of sand flounder in mm/year did not differ between sites (One -way ANOVA: $F_{6,73}$=1.74, P = 0.13). Similarly, growth rates of sand flounder in g/year did not differ between sites (One -way ANOVA: $F_{6,73}$=1.24, P = 0.30). No statistical comparisons were completed between sites for black flounder because of insufficient data.



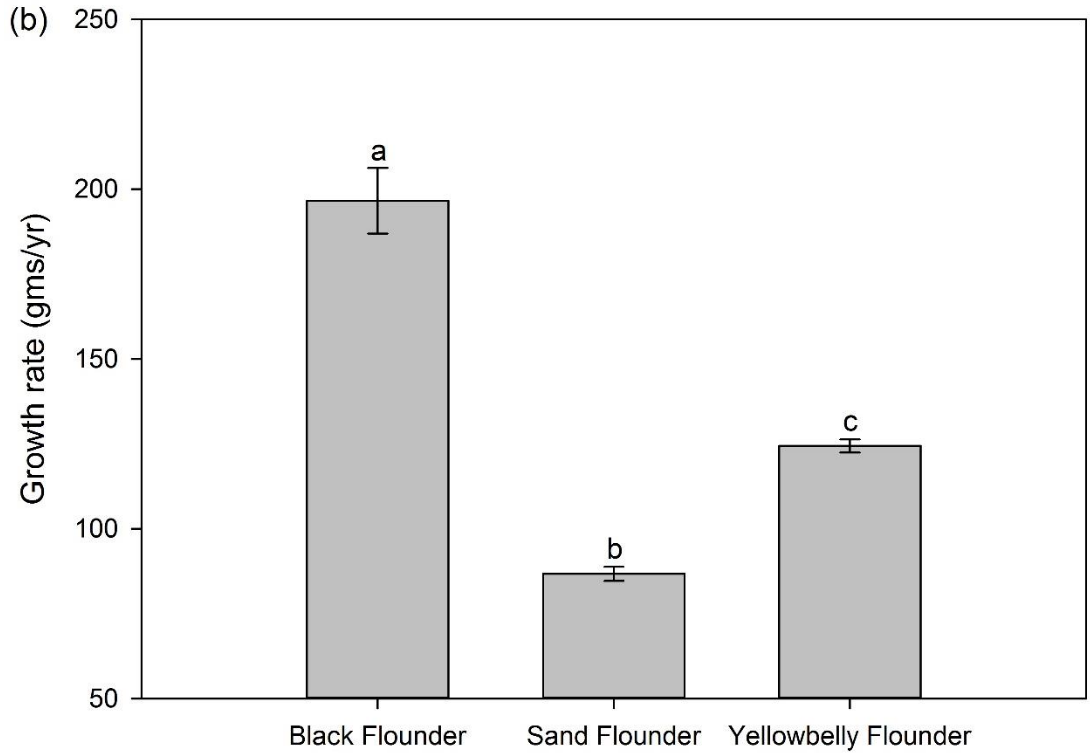


Figure 3-54: Mean (±SE) growth rate of the three flounder species in length (a) and weight (b). Significant differences ($P < 0.05$) between species were calculated by Tukey's HSD tests. Sites that do not share a letter are significantly different from each other.

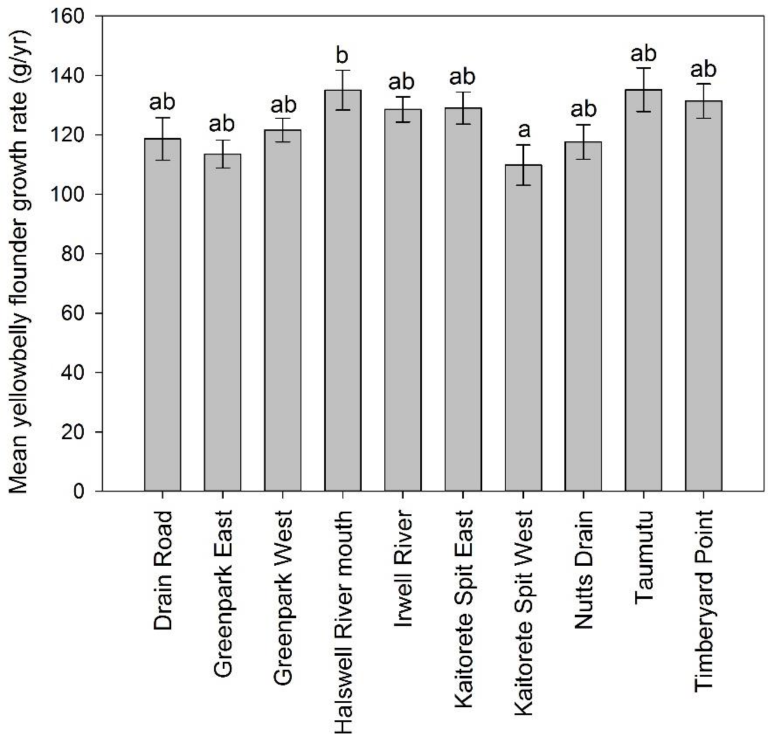


Figure 3-55: Mean (±SE) annual weight increase of yellowbelly flounder at the different sites sampled around the lake. Significant differences ($P < 0.05$) between sites were calculated by Tukey's HSD tests. Sites that do not share a letter are significantly different from each other.

3.2.6 Summary table of differences in yellowbelly population structure between sites

To quickly access the results on pātiki abundance and sizes, the following section summarises all of the pair-wise site comparisons between sites (post-hoc statistical comparisons) for yellowbelly flounder outlined in Section 3.2. The sites with the highest values for each variable are shown in green and the sites with the lowest values are shown in red. For simplicity, sites that were not significantly different from the sites with either the highest or lowest values are shown in white[5]. If the lowest or highest values were observed from two sites, a "+" symbol was used to show which site had the highest value, while a "-" symbol was used to show which site had the lowest value.

Taumutu, Kaitorete Spit East and the Halswell River Mouth had the highest CPUE abundance and CPUE weight of all the sites for yellowbelly flounder (Table 3-5). The lowest CPUE values were observed at Drain Road for both abundance and weight. The highest mean length was observed at Taumutu, but this was not statistically different to seven of the other sites. The highest mean weight was observed at the Halswell River Mouth but this was not statistically different to the weights observed at six of the other sites.

Considering results across all post-hoc comparisons (Table 3-5), Taumutu and the Halswell River Mouth are likely to be the most productive sites for yellowbelly flounder. Taumutu has the highest

[5] It should be noted that sites with two letters may not differ significantly from the highest or lowest sites, which means the results section should be consulted when making detailed conclusions or statements about differences between sites for each of the variables. This is table was designed to be a simplification of the post-hoc ANOVA comparisons to help identify which sites had the highest and lowest fishery values, not as a substitute for all the detailed ANOVA results outlined in the results section.

CPUE abundance, CPUE weight and length of yellowbelly flounder. The Halswell River Mouth is also likely to be a productive area for yellowbelly catches because it was not statistically different to Taumutu in any of the post-hoc comparisons. The Halswell River Mouth also had the highest mean weight of yellowbelly flounder.

Drain Road and Kaitorete Spit West are likely to be the lowest pātiki catches (Table 3-5). Drain Road had the lowest CPUE abundance and CPUE weight, while Kaitorete Spit West had the lowest mean weight and condition values. Kaitorete Spit West also had significantly lower values than other sites for most post-hoc comparisons.

Table 3-5: Summary of post-hoc ANOVA comparisons between sites for yellowbelly flounder. Sites that share letters are not statistically different and the site with the highest and lowest mean value are shown with a "+" and "–" respectively. Individual ANOVA comparisons and values for each site can be found in Section 3.2.

Site	Highest CPUE abundance (no./net/night)	Highest CPUE weight (kg/net/night)	Highest mean length (mm)	Highest mean weight (g)	Condition (K)	Growth Rate (mm/year)	Growth Rate (g/year)
Drain Road	a-	a-	ac	ab	ab	a	ab
Greenpark East	ad	ad	a-	a	b	a-	ab
Greenpark West	ad	abc	ac	ab	b	a	ab
Halswell River Mouth	de	de	c	b+	b	a	a+
Irwell River	cd	cd	bc	b	b+	a	ab
Kaitorete Spit East	de	cde	bc	ab	a	a	ab
Kaitorete Spit West	ab	abc	ac	a-	a-	a	ab
Nutts Drain	bcd	bd	ab	a	b	a	b-
Taumutu	e+	e+	c+	b	b	a+	ab
Timberyard Point	ac	ab	bc	ab	b	a	ab

3.2.7 Pātiki population inside and outside of the Horomaka Boundary

There were no consistent differences in yellowbelly size, CPUE or condition for sites inside compared to outside of the Horomaka kōhanga (Figure 3-56). There were differences between individual sites (e.g., Kaitorete Spit West did have significantly lower yellowbelly condition than the other sites inside or outside of the Horomaka), but no results suggested that there were consistent differences in sizes or catch rates inside the Horomaka kōhanga compared to the area outside of the boundary that is open to commercial fishing.

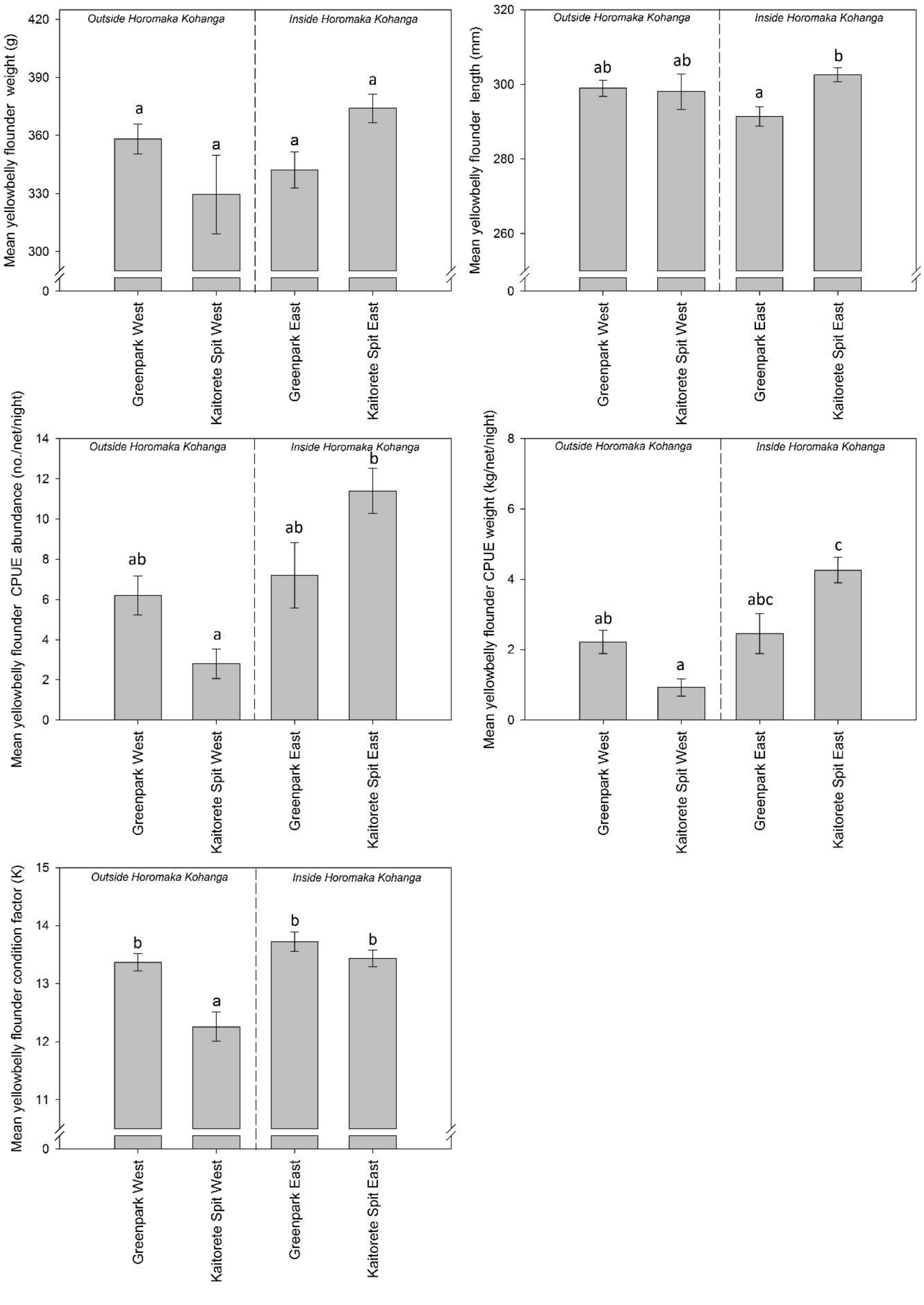


Figure 3-56: Mean (±SE) yellowbelly length, weight, CPUE and condition at sites adjacent to the Horomaka kōhanga boundary. Significant differences (P < 0.05) between sites were calculated by Tukey's HSD tests outlined in the previous sections. Sites that do not share a letter are significantly different from each other.

4 Discussion

4.1 Tuna

4.1.1 Overview of tuna population structure

Species composition

Catches in Te Waihora were dominated by shortfin eels, with 93 per cent of the catch being composed of this species (by numbers). The dominance of shortfins in the lake is also reflected by the nil catches of longfins recorded in the commercial eel catch from Te Waihora (Beentjes & Dunn 2014). These nil catches (numbers landed) of longfins, however, may partially be influenced by the voluntary returns of any longfins captured by commercial fisherman – which are not currently recorded (Don Jellyman pers. comm.) In a collation of 41,377 eel catches from research studies in Te Waihora (Crow & Bonnett 2013), shortfins comprised 97 per cent (n = 40,179) which is consistent with the present study. Fyke net catches from tributaries of Te Waihora are also dominated by shortfins (66 per cent of total numbers) (Jellyman & Graynoth 2010). Although the proportion of longfins was higher in the tributaries compared to the lake in the present study, combined results from Jellyman & Graynoth (2010) and the present study suggests that the wider Te Waihora catchment is generally dominated by shortfins. Te Waihora – the lake itself, not the wider catchment – previously contained higher numbers of longfins, but these appear to have largely disappeared (Jellyman & Todd 1982). The loss of longfins from Te Waihora has been suggested to be associated with their exposure to commercial fishing over their relatively long life time in freshwaters (Jellyman & Todd 1982); and the degradation of longfin habitat within the lake caused by the extensive loss of macrophyte beds in the 1960's (Jellyman et al. 1995).

The higher abundance and biomass of shortfins compared to longfins in Te Waihora is likely to be associated with habitat preferences of the two species. Shortfins typically prefer slow flowing water bodies and lowland lakes with high turbidity (McDowall 1990; Jellyman et al. 2003). This type of habitat is readily available within Te Waihora. Longfin eels do, however, live in lakes and can dominate lake catches, e.g., Crow & Jellyman (2010), but lowland turbid lakes like Te Waihora are usually dominated by shortfins. For example, lowland turbid lakes in the South Island contain much higher proportions of shortfins (over 75 per cent) than longfins (Beentjes & Bull 2002). The dominance of shortfins is also seen in the nearby Te Roto o Wairewa (Lake Forsyth), which had catches composed of 75 per cent shortfins in a fyke net survey (Jellyman & Cranwell 2007). Catches from other Northland lakes and lowland lakes in the Waikato have also been shown to be dominated by shortfins (Chisnall 1998; Williams et al. 2011). Catches from seven lowland turbid lakes around the Pouto peninsula in Northland also contained 94 per cent shortfin eels. As a result of their habitat preferences, the spatial distribution of shortfin eels throughout New Zealand means it is primarily associated with lowland coastal areas (Leathwick et al. 2008; Crow et al. 2014)

The habitat available in the upper reaches of streams is preferred by longfin eels (McDowall 2010), which is seen with regards to catches from the Te Waihora tributaries. Longfins prefer faster-flowing, stony streams and rivers with low levels of turbidity (McDowall 1990). While the Te Waihora catchment as a whole is dominated by shortfins, the upper reaches of the Halswell River, Harts Creek, and LII River are dominated by longfins (Jellyman & Graynoth 2010). All of these tributaries are spring fed with predominately stony bed substrates and have clear, faster flowing water that is preferred by longfins. Jellyman & Graynoth (2010) also found that there was a weak, but significant relationship between the percentages of longfins caught and distance inland (distance to lake edge).

This increasing relative abundance of longfins with distance inland is observed throughout New Zealand (McDowall 2010).

Sizes of eels

The mean length of shortfin eels observed in the present study was 512 mm (excluding Fishermans Point), which is larger than historical catches (1975-2005) from Te Waihora (Crow & Bonnett 2013) (Table 4-1). In a collation of existing length data from 40,179 shortfins caught in Te Waihora and its tributaries, Crow & Bonnett (2013) reported that shortfin catches were dominated by fish between 400–420 mm with an associated mean length of 391 mm. This mean was calculated with a variety of fishing methods that are capable of catching smaller fish than the present study, but the mean size of fyke net caught fish was still only 431 (±0.5) mm (Crow & Bonnett 2013); roughly 80 mm smaller than the present study. Even in a site-by-site comparison where mean size ranged from 461–619 mm, fyke-net catches in the present study were still larger than the historical mean fyke-net catch size of 391 mm. Shortfins in the present study were, however, 100 mm smaller than the mean shortfin size captured from the Te Waihora tributaries by Jellyman & Graynoth (2010) (Table 4-1). The tributaries are not commercially fished, possibly allowing shortfin eels to reach larger sizes compared to the commercially fished lake areas sampled in the present study. Similarly, the nearby Te Roto o Wairewa (Lake Forsyth) has an average shortfin length 200 mm larger (mean length = 718 mm) than the present study. The large sizes of shortfins in Te Roto o Wairewa was attributed to only customary harvests occurring that target migrant eels, allowing the adult population to reach exceptional sizes (Jellyman & Cranwell 2007). Although the present study has a larger mean size than historical data from Te Waihora, the mean sizes of shortfins are generally similar to other areas around the South Island (Table 4-1).

There appears to be a slightly higher proportion of larger shortfins captured in the present study compared to historical data from Te Waihora. The most abundant size classes in the present study are consistent with historical data in Crow & Bonnett (2013), which suggests that the larger mean size in the present study was caused by a greater relative proportion of large shortfins in the catch. Length-frequency data from Crow & Bonnett (2013) showed an extreme peak around 400 mm size classes and steep declines in the relative abundance of sizes above and below this peak. Length-frequency data in the present study had greater relative proportions of large shortfins around 500–1,000 mm, which resulted in an increase in the overall mean shortfin eel size.

Table 4-1: Mean lengths of fyke netted shortfin eels from South Island waterways, lakes and lagoons. * = regularly commercially fished reach; ** = seldom commercially fished reach; *** = unfished commercially; 1= National park. Modified from Jellyman (2012).

Location	Number	Mean length (mm)	SE (mm)	Reference
Orari Lagoon	218	508	6	Jellyman (2012)
Orari River	119	518	8	Jellyman (2012)
Temuka River	33	561	14	Jellyman (2012)
Orakipaoa Stream	48	550	7	Jellyman (2012)
Opihi Lagoon	795	522	4	Jellyman (2012)
Opihi River	139	568	7	Jellyman (2012)
Dead Arm	121	555	8	Jellyman (2012)
Hook River	3	715	10	Jellyman (2012)
Hook Drain	81	580	14	Jellyman (2012)
Waihao Lower	22	564	16	Jellyman (2012)
Waihao Upper	209	620	5	Jellyman (2012)
Company Creek***	122	637	14	NIWA (unpubl. data)
Lake Rotoiti 1***	8	732	-	Jellyman (1995)
Grey River*	219	592	51	Beentjes (1999)
Kakanui River - estuary	532	507	6	Jellyman et al. (1997)
Waitaki River - lower	29	607	15	Beentjes & Chisnall (1997)
Waiataki River - near dam	114	747	15	Beentjes & Chisnall (1997)
Clutha River - lower	80	668	13	Beentjes & Chisnall (1997)
Clutha River – Balclutha	163	616	9	Beentjes & Chisnall (1997)
Taieri River*	441	625	40	Beentjes (1998)
Mataura River	117	635	94	Beentjes (1998)
Oreti River	55	669	148	Beentjes (1998)
Wainono lagoon East	338	461	-	Jellyman & Sykes (1998)
Wainono lagoon West	241	489	-	Jellyman & Sykes (1998)
Harts Creek – lower reaches	209	597	10	Jellyman & Graynoth (2010)
LII	13	654	37	Jellyman & Graynoth (2010)
Selwyn River	178	617	10	Jellyman & Graynoth (2010)
Te Waihora Catchment	40,179	431	0.5	Crow & Bonnett (2013)
Wairewa (Lake Forsyth)	945	718	3	Jellyman & Cranwell (2007)
Mean		595	22	

Migrant shortfins from Fishermans Point

The lower abundance of migrants at the other sites relative to Fishermans Point suggests that most migrants had congregated towards the outlet area by this time of year (March). This timing is consistent with Todd (1981b) who found that the proportions of migrant eels around the outlet of Te Waihora peaked during late February-early March.

The ratio of males:females for migrant shortfins captured from Fishermans Point was broadly consistent with the findings of Todd (1981b). Of the migrant shortfins measured in the present study, 67 (70 per cent) were males and 29 (30 per cent) were females. Todd (1981b) found that during early March (i.e., a similar time of year to the present study), the migrant shortfin eel catch was *c*. 90 per cent males, which is slightly higher than the proportion of males captured in the present study. Differences in the percentage of males captured in Todd (1981b) and the present study, could be associated with differnces in the timing of sampling or current commercial harvests that often target migrant male shortfins. Results of the two studies do support the dominance of males in the catch during early March. Jellyman and Todd (1998) stated that the sex ratio in the lake was previously dominated by females, but has shifted to a male dominated population (by numbers) over the last 50 years. Female shortfin numbers increase relative to males through to the beginning of May, but the sex ratio of migrants can vary with lake opening timings (Todd 1981b). Lake openings were unlikley to have influenced the catches in the present study because the lake had been closed for three months prior to sampling (Jellyman & Crow 2015).

Length, weight and condition of migrant male shortfins appears to have remained constant in Te Waihora over the last 20 years despite historical declines being recorded previously. Mean (±SE) length, weight and condition of male shortfin migrants captured in the present study was 399 ± 13 mm, 124 ± 3 g and 2.0 ± 0.05 K respectively. A survey of male migrants from 1993–1995 (Jellyman & Todd 1998) reported mean length (390 mm) weight (140 g) and condition (2.0) values that were almost identical to the values observed in the present study. The consistency between the values observed between the mid 1990's and the present study suggests that the population structure of males has remained reasonably consistent. This is somewhat surprising, given that the length and weight of male migrants decreased by 20 per cent in Te Waihora from 1940–1980 (Jellyman & Todd 1998).

CPUE

Mean CPUE of the present study was 5.8 kg/net/night, which is similar to other studies in the Canterbury area. South Canterbury rivers have shown a consistent mean CPUE of 4.7 from 1983–1999, which is slightly lower than the present study. CPUE is broadly consistent with Te Waihora from Wainono Lagoon where a CPUE of 5.19 and 7.99 has previously been recorded. Further south in Otago (Mataura, Aparima River), catches are generally higher than the present study. Similarly, rivers around Kaikōura also show a slightly higher CPUE than in Te Waihora. The highest recorded CPUE was from Wairewa, but this was because of the exceptional numbers of large eels caused by the customary harvesting practice that targets outgoing migrants and does not target fish living in the lake itself (Jellyman & Cranwell 2007).

Table 4-2: Mean CPUE of shortfins from various South Island studies. *Wairewa CPUE was not included in the mean calculation because this was an exceptionally high value. ANG14 refers to the MPI reporting area for commercial fishing that covers South Canterbury.

Location	Mean CPUE (kg/net/night)	Reference
Wairewa (Lake Forsyth)*	54.1	Jellyman & Cranwell (2007)
ANG14 rivers	13.7	Jellyman (2012)
ANG14 rivers excluding Dead Arm	11.9	Jellyman (2012)
Aparima	7.5	Jellyman & Graynoth (2005)
Mataura – reserve	6.4	Jellyman et al. (2009)
Mataura – commercially fished	2	Jellyman et al. (2009)
Kaikōura rivers	10.6	Crow & Jellyman (2009)
South Canterbury Rivers 1983–1989	4.7	Jellyman (1993)
South Canterbury, Waitaki, 1990–1999	4.7	Beentjes & Bull (2002)
Wainono Lagoon East	5.19	Jellyman & Sykes (1998)
Wainono Lagoon West	7.99	Jellyman & Sykes (1998)
Mean ± SE	7.5 ± 4	All studies [excluding Jellyman & Cranwell (2007)]

Catch rates in the Horomaka kōhanga are now higher than they were 20 years ago (Jellyman et al. in press), which is consistent with the catch-rate trends observed in commercial catches from outside the Horomaka kōhanga. Comparisons with Glova & Sagar (2000) and Jellyman et al. (in press) suggest that CPUE has more than doubled in the Horomaka kōhanga over the last 20 years. A similar increase in abundance has been reported from commercial catches, where there appears to have been a three-fold increase in catch between 2000–2012 (Beentjes & Dunn 2014). The consistent increases in catches suggest that the entire lake (Horomaka kōhanga and commercially fished areas) has been experiencing increased catch rates. Beentjes & Dunn (2014) suggested CPUE increases had been consistent with perceptions of commercial fishers who suggest that fishing in Te Waihora is "as good as it has ever been". Beentjes & Dunn (2014) suggested that the increase in CPUE was associated with an increase in the size of the fish being captured by the commercial fishers. The size of commercially caught eels has substantially increased over time (Beentjes & Dunn 2014), which is also consistent with findings in the present study compared to Glova & Sagar (2000).

4.1.2 Relative abundance of tuna around Te Waihora and the Horomaka kōhanga

Shortfin eels showed differences in population structure around Te Waihora. Kaitorete Spit West had the highest CPUE values and sizes of shortfins along with condition. This site has the most productive catches of large well-conditioned eels. Timberyard Point also had high CPUE, but these catches contained smaller eels. Greenpark Sands West and Kaitorete Spit East had the lowest CPUE values and small eels, which was also observed at Coes Ford. The low catch rates and small eels present around Greenpark Sands may be associated with the habitat present. Greenpark Sands has a large amount of firm sand present that is likely to be avoided by eels (Jellyman & Chisnall 1999) and this has previously been suggested as a reason for low shortfin eel numbers around this area of the lake (Glova & Sagar 2000).

There were no consistent differences in the eel population between the sites inside and outside of the Horomaka kōhanga. This is consistent with the findings of Jellyman et al. (in press) who found that 17 per cent of the eels in the Horomaka kōhanga moved outside the reserve within four months.

4.1.3 Growth rates of tuna in Te Waihora

Across all sites, mean growth (±SE) of shortfins was 35 (± 2) mm/year and 25 (± 5) g/year, which is consistent with other studies completed. The most recent study on shortfin growth rates in Te Waihora was completed seven years ago by Jellyman & Graynoth (2010) who reported a growth rate of 34 mm. Of the previous six growth studies carried out in Te Waihora (see Jellyman 2012), mean annual increments varied from 24–39 mm/year (Table 4-3), which again is consistent with the growth rate reported in the present study. The highest recorded growth rate in Te Waihora was from a study in 2007, where shortfin average annual growth increments were 39 mm/year. Growth rate in the nearby Wairewa (Lake Forsyth) were also similar to those observed in Te Waihora, with shortfin annual length increases averaging 31 mm/year (Jellyman & Cranwell 2007).

Growth rates of shortfins in Te Waihora are high compared to the national average of 20 mm/year reported by Jellyman (2009). An aging study of commercially harvested shortfins from the South Island found that the average time for shortfins to reach 240 g was 15.6 years (Beentjes 1998). Based on the average weight increases found in the present study, shortfins in Te Waihora would reach this weight in only 9.6 years, which is six years faster that other areas in the South Island, on average. There has been a broad trend of increases in mean growth rates of feeding (i.e., pre-migrant) shortfins recorded from studies in Te Waihora published between the 1970's and 2000's (Jellyman & Smith 2008) (Table 4-3). Mean (±SE) annual growth increments appear to have increased from 24 mm/year in 1974 to 39 mm/year in 2007 (a 63 per cent increase) and recently 35 mm/year has been observed twice (in 2010 and in the present study). Generally, lowland shallow coastal lakes similar to Te Waihora have high growth rates of shortfins. Crow & Jellyman (2014) reported an average growth rate of 42 mm/year from shallow coastal lakes around the Kaipara Harbour in Northland. Higher growth rates in these shallow coastal lakes are likely to be caused by higher temperatures, as temperature is an important factor influencing growth rates (Kearney et al. 2008).

Shortfin growth appears to be ubiquitous throughout the Te Waihora catchment, despite observing localised differences in shortfin sizes (both length and weight). The present study found no differences in growth rates between sites within the lake, which is also supported by results from Jellyman & Graynoth (2010). Jellyman and Graynoth (2010) calculated growth rates of shortfins from the major tributaries of Te Waihora (Harts Creek, Irwell River, Selwyn River, LII and Halswell River) and found that the average growth rate of shortfins in the tributaries was 34 mm/year, which was almost identical to the 35 mm/year observed from the lake in the present study. The lack of any localised growth rate differences was surprising because we expected to observe differences in growth rates given that food resources have been shown to vary dramatically throughout the lake (Glova & Sagar 2000). The lack of localised growth differences suggests that sites containing larger fish were not more productive, but simply contained older fish. This can be seen in the above results where the three sites with the highest age (Fishermans Point, Kaitorete Spit East, Kaitorete Spit West) also had the highest mean length and mean weight. Similarly, the site with the lowest mean age (Greenpark West) also had the lowest length and weight. The areas with older and larger fish may have received lower fishing pressure, allowing the fish to reach an older age. Unfortunately, no localised information on harvest rates are available to examine the relationship between fishing pressure and eel size or ages within Te Waihora. The influence of commercial fishing on ages of shortfins is perhaps reflected in the nearby Wairewa. This lake has no commercial fishing pressure and has a similar average growth rate to Te Waihora (Jellyman & Cranwell 2007), but the fish are much larger, presumably because they are able to reach a greater age.

Table 4-3: Mean annual growth increment (mm/year) for feeding and migrating shortfins from Te Waihora for various years (From Jellyman 2012). * = Beentjes and Chisnall 1998; ** = sample from tributaries, Jellyman and Graynoth (2010).

Year	Number aged	Growth (mm/year)	SE
1974	230	24.0	0.3
1975	1,208	25.6	0.2
1994	265	31.2	0.6
1996/97*	116	35.3	0.5
2007	65	38.9	1.0
2010**	20	34.2	1.3

Table 4-4: Growth rates of shortfins from various New Zealand studies.

Location	Number aged	Mean growth (mm/year)	Reference
Wairewa (Lake Forsyth)	123	31	Jellyman & Cranwell (2007)
Waihao River	43	26.8	Jellyman (2012)
Temuka River	40	21.7	Jellyman (2012)
Waiau River	11	27.5	Beentjes & Chisnall (1998)
Aparima River	76	33.8	Beentjes & Chisnall (1998)
Oreti River	19	36.1	Beentjes & Chisnall (1998)
Mataura River	75	41	Beentjes & Chisnall (1998)
Clutha River (lower)	26	38.2	Beentjes & Chisnall (1998)
Waitaki River (lower)	70	39.5	Beentjes & Chisnall (1998)
Waitaki River (middle)	42	34.7	Beentjes & Chisnall (1998)
Te Waihora	116	35.3	Beentjes & Chisnall (1998)
Hurunui River	46	23.3	Beentjes & Chisnall (1998)
Grey River	65	18.4	Beentjes & Chisnall (1998)
Mean ± SE		31 ± 2	

4.2 Pātiki

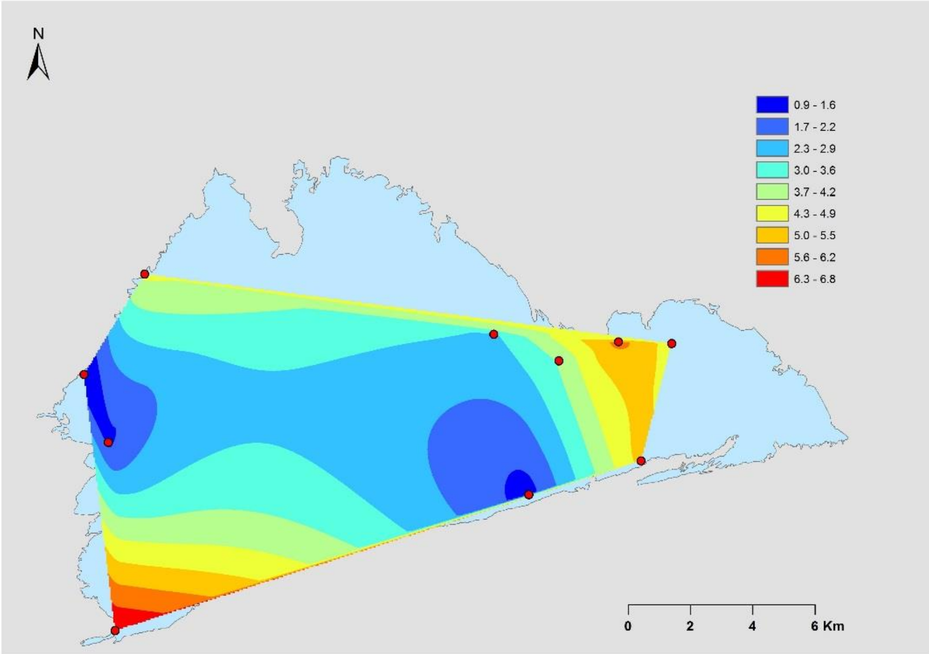
4.2.1 Overview of Pātiki population structure

The pātiki population was dominated by yellowbelly flounder, which is consistent with recent studies. Jellyman (2011) found that yellowbelly flounder made up 64 per cent and 80 per cent of seine and trawl catches respectively over a three-year period, which is consistent with the present study that found yellowbelly flounder made up 77 per cent of the total pātiki abundance. The catches in the present study were also consistent with the recruitment catches of pātiki from Te Waihora observed from 2013–2015. Jellyman & Crow (2015) conducted a series of seine and super-fyke (fine-meshed fyke net) sampling trips targeting freshly recruited flounder from 2013–2015, and found that yellowbelly flounder made up 86 per cent of pātiki abundance. This high proportion of yellowbelly flounder recorded in the present study differs from historical commercial catches. Although yellowbelly flounder have dominated commercial catches from individual years, black flounder have been the dominant species. Historically, black flounder make up 58 per cent of the total catch weight followed by sand flounder (22 per cent) and yellowbelly flounder (20 per cent) (Jellyman & Smith 2008). These commercial catches, however, are reported for an MPI statistical area that covers the marine and freshwater environment between Banks Peninsula and the Waitaki River (SA022), but most (if not all) of the black flounder catch is from Te Waihora (Marc Griffiths, MPI, pers. comm.). The dominance of black flounder in the commercial catch may be associated with their higher growth rates compared to the other two species (Jellyman 2011, present study), enabling the fishery to attain a higher biomass in Te Waihora.

Variability in commercial catch rates and species composition between years is likely to be associated with the duration and timing of lake openings. Taylor (1996) found that there is a correlation between the commercial flounder landings (total weight) and the duration of lake openings three years prior. This correlation suggested that during years when there was a long period of the lake being open to the sea during spring, the commercial catches three years later would generally be larger (Taylor 1996). The spring opening is consistent with findings from Jellyman & Crow (2015) which found that the dominant pātiki recruitment occurred between August-November, but the entry timing of individual species differed. The variation in species recruitment may indicate that if long lake openings occur during early spring then commercial catches three years later may be dominated by yellowbelly flounder, but if a long lake opening occurs later in the spring/early summer then the commercial catches three years later are more likely to be dominated by black flounder (Jellyman & Crow 2015).

4.2.2 Relative abundance of pātiki around Te Waihora

Pātiki population structure differed between sites within Te Waihora. Taumutu and the Halswell River mouth are likely to be the most productive sites for capturing yellowbelly flounder. Taumutu had the highest catches of large well-conditioned fish and is likely to be the most productive area in the lake for catching pātiki. Kaitorete Spit East also had high catches of large fish, but their condition was lower than Taumutu and the Halswell River mouth. The general patterns in productivity of the pātiki fishery can be visualised for the lake using CPUE indices to generate gradient maps (Figure 4-1). These gradient maps both show similar trends to those outlined above, where the most productive areas are located at Taumutu and around the Halswell River mouth.



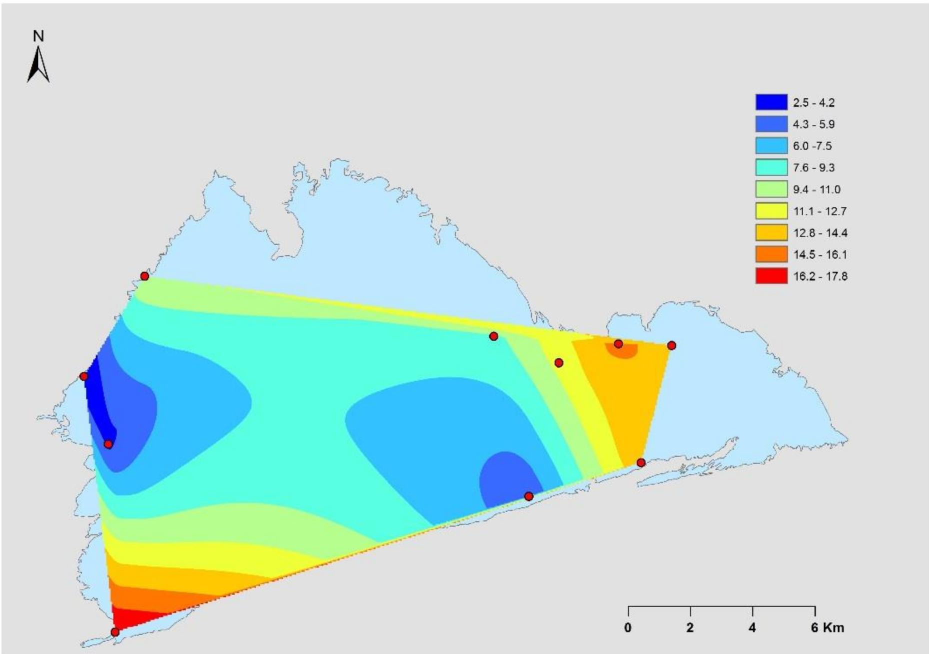


Figure 4-1: Gradient maps of pātiki CPUE weight (kg/net/night) (top) and abundance (no./net/night) (bottom) for all pātiki species combined. Areas of the lake that are light blue fall outside the boundary of the extrapolation.

4.2.3 Growth rates of pātiki

Growth rates observed in the present study were similar to those observed by Jellyman (2011). Yellowbelly flounder in the present study had a mean (±s.e.) growth rate of 100.4 (±0.8) mm/year which is slightly higher than the 91 mm/year reported by Jellyman (2011). The minimum commercial size of pātiki is 250 mm and based on the growth rates observed in the present study a black, yellowbelly and sand flounder will reach this size within 2.1, 2.5 and 3.0 years, respectively. These observed times are slightly slower than the 1.6, 2.2 and 2.3 years required to reach 250 mm for black, yellowbelly and sand flounder, respectively, that were reported by Jellyman (2011). However, Jellyman (2011) and the present study both found the same between-species growth rate pattern which was that black flounder are the fastest growing species, followed by yellowbelly flounder and then sand flounder.

4.3 Influence of low lake levels on shortfin and pātiki food resources

Low lake levels may restrict access to chironomids for fish during the summer months. Chironomid coverage is generally lowest in the centre of the lake and higher around the lake margins (Figure 4-2). During the summer when the lake level is typically low, fish will therefore have reduced access to high densities of chironomids. While this reduced chironomid access will only directly impact on bullies and small tuna <400 mm that directly predate on these invertebrates (Kelly & Jellyman 2007), it may indirectly impact on larger tuna that predate on bullies. In addition to the restricted chironomid access for common bullies, recent research also suggests that low lake levels also limit access to spawning areas for common bullies (Jellyman et al. in press), compounding the population pressures placed on common bullies during low lake levels. The reduced availability of the chironomid food supply, that supports several trophic levels in Te Waihora, suggests that managers need to be mindful of complex problems that may occur during the summer when lake levels are low. Jellyman & Crow (2015) also discussed the other aspects of low lake levels that should be considered, which includes: high water temperatures that can result in decreased water quality and increased likelihood of algal blooms (which can potentially be toxic); reduced access to potential spawning habitat around lake margins as well as reduced water depth for pelagic feeding fishes. Jellyman (2012) noted that "one issue that has not been researched is the assertion by commercial and customary fishers that a low lake is preferred in summer to a partially-low lake – the reason being that a partially low lake can be high enough to just cover Greenpark Sands, and this acts as a "heat trap" during warm summer days, and elevates water temperature appreciably"; the approximate lake levels considered to be low versus partially-low were not stated. The influence of low lake levels on mahinga kai in Te Waihora is poorly understood, which should be an area of future research in the lake. The installation of a weir at the outlet of Te Waihora (to control lake levels) is being investigated in the Whakaora Te Waihora Programme, making it particularly important to understand the associations between lake level and ecosystem health before constructing any such structure.

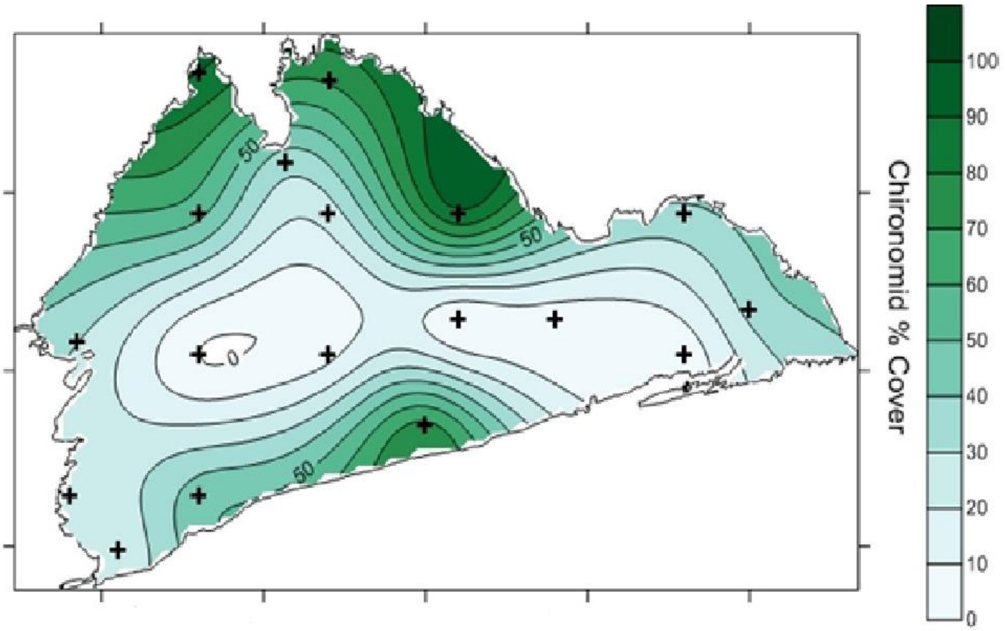


Figure 4-2: Chironomid coverage in Te Waihora. Figure provided by Marc Schallenberg with permission from the Whakaora Te Waihora Partners.

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6 Glossary of abbreviations and terms

WTW	Whakaora Te Waihora
CPUE	Catch-Per-Unit-Effort

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