A piece of the puzzle: analyses of recent strandings and historical records reveal new genetic and ecological insights on New Zealand sperm whales

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Text S1.

Packages used for visualization of genetic results

tidyverse 1.3.1 (Wickham et al. 2019); sf v1.4-5 (Pebesma et al. 2018); rnaturalearth v0.1.0 (South 2017a); rnaturalearthdata v0.1.0 (South 2017b); rnaturalearthhires v 0.2.0; rgeos v0.5-5 (Bivand & Rundel 2017); fs v1.5.0 (Hester & Wickham 2018); viridis v0.6.1 (Garnier et al. 2021) and ggmap v3.0.0 (Kahle & Wickham 2013).

Details on stable isotope analysis

Carbon isotope data were corrected via a 2-point normalisation process (Paul et al. 2007) using NIST 8573 (USGS40 L-glutamic acid; certified $\delta^{13}C$ = - 26.39 ± 0.09 ‰) and NIST 8542 (IAEA-CH-6 Sucrose; certified $\delta^{13}C$ = - 10.45 ± 0.07 ‰). A 2-point normalisation process using NIST 8573 (USGS40 L-glutamic acid; certified $\delta^{15}N$ = - 4.52 ± 0.12 ‰) and IAEA-N-2 (ammonium sulphate: certified $\delta^{15}N$ = + 20.41 ± 0.2 ‰) was applied to $\delta^{15}N$ data. DL-Leucine (DL-2-Amino-4-methylpentanoic acid, $C_6H_{13}NO_2$, Lot 127H1084, Sigma, Australia) was run every ten samples to check analytical precision and enable drift corrections to be made if necessary. NIST 8547 (IAEA-N1 ammonium sulphate; certified $\delta^{15}N$ = + 0.43 ± 0.04 ‰) and USGS65 Glycine (certified $\delta^{13}C$ = - 20.29 ± 0.04 ‰; certified $\delta^{15}N$ = 20.68 ± 0.06 ‰) were run daily to check isotopic accuracy with 2 laboratory standards L Proline and homogenized squid run as an additional check of precision.

Table S1. Details of the 2018 strandings of sperm whales (*Physeter macrocephalus*) in New Zealand. Sex was determined genetically (see main text).

	Date stranded	**Subgroup**	**GPS**	**Location**	**Sex**	**mtDNA haplotype**	**Total body length (mm)**	**$\delta^{15}N$ (‰)**	**$\delta^{13}C$ (‰)**
KS18-08Pm	25/5/18	1	-39.568131, 174.061645	Kaupokonui, Taranaki	male	B	1340	14.6	-17.4
KS18-09Pm	25/5/18				male	O	1400	14.6	-16.9
KS18-10Pm	25/5/18				male*	C	1260	14.5	-17.6
KS18-11Pm	25/5/18				male	New	1250	14.5	-17.5
KS18-12Pm	25/5/18				male	Z	1320	14.6	-17.3
KS18-13Pm	25/5/18				male	B	1250	14.7	-17.3
KS18-14Pm	25/5/18				male	A	1250	14.1	-17.3
KS18-15Pm	25/5/18				male	B	1175	14.2	-17.6
KS18-16Pm	25/5/18				male	M	1290	14.9	-16.5
KS18-17Pm	28/5/18	2			male	B	1290	14.7	-17.0
KS18-18Pm	28/5/18				male	B	1245	15.2	-16.8
KS18-19Pm	28/5/18				male	A	1105	14.0	-17.2
KS18-20Pm	9/6/18	3	-39.618133, 174.268383	Hawera, Taranaki	male	A	1300	-	-
KS18-21Pm	7/7/18	-	-41.717054, 174.188918	Marfells Beach, Clifford Bay	male	A	1613	16.3	-16.5

*this individual was anatomically misidentified as a female during the stranding event

Table S2. Mean group size of sperm whales (*Physeter macrocephalus*) involved in mass strandings between 1895 and 2021 in New Zealand, grouped by type, stranding location and season. Data shown as mean ± SD (n).

Type	Location	Austral Season			
		Spring	*Summer*	*Autumn*	*Winter*
Male-dominated	East coast	2 (1)	-	-	6 (1)
	West coast	6 ± 4.5 (4)	-	6 ± 5.8 (3)	9 ± 8.5 (2)
	Offshore Island	-	-	31 (1)	2 (1)
Female-dominated	East coast	-	-	59 (1)	-
	West coast	72 (1)	27 (1)	25 (1)	13 (1)
	Offshore Island	-	-	20 (1)	-
Unknown	East coast	2 (1)	-	-	-
	West coast	-	5 (1)	-	-
	Offshore Island	2 (1)	6.5 ± 6.4 (2)	-	-

Table S3. Number of individual sperm whale (*Physeter macrocephalus*) single strandings between 1873 and 2021 in New Zealand, grouped by sex, location and season.

Sex	**Location**	**Austral Season**				
		Spring	*Summer*	*Autumn*	*Winter*	*Unknown*
Female	East coast	6	10	1	2	-
	West coast	7	6	3	4	-
	Offshore Islands	-	1	-	-	-
	Unknown	-	-	1	-	-
Male	East coast	16	9	11	10	-
	West coast	10	19	3	7	-
	Offshore Islands	1	3	2	2	-
	South coast	2	1	1	1	-
	Unknown	-	-	1	1	-
Unknown	East coast	6	8	11	3	1
	West coast	12	18	5	7	-
	Offshore Islands	4	4	1	3	-
	South coast	1	1	1	2	-
	Unknown	1	4	1	-	-

Table S4. Results of generalised linear models (GLMs) examining the relationship between latitude and the predictor variables type (female-dominated and male-dominated group, for mass strandings) or sex (for single strandings) and season (austral spring, summer, autumn and winter). Model evaluation using AICc ranked the null model (shaded in grey) highest for mass strandings and the model retaining sex as a significant predictor variable for single strandings. Significant variables are indicated in bold.

Model	**Δ AICc**	**% deviance explained**	**df**
Mass strandings (latitude ~)			
null model	0	0	2
~ type	1.57	6.50	3
~ season	8.24	8.18	5
~ type + season	12.11	10.67	6
~ type * season	19.91	26.09	8
Single strandings (latitude ~)			
~ **sex**	0	12.04	3
~ **sex** + season	2.95	14.23	6
~ **sex** * season	5.88	16.56	9
null model	15.74	0	2
~ season	17.28	0.34	5

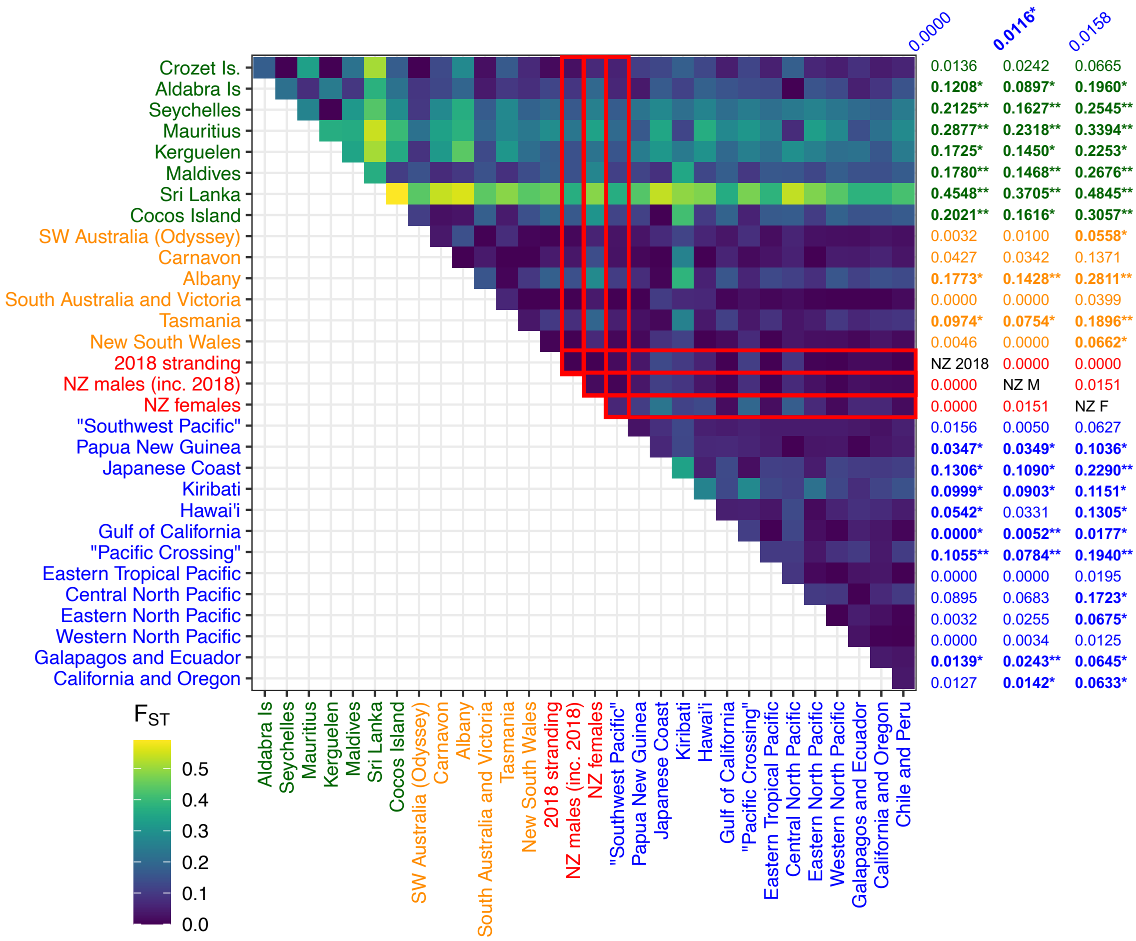
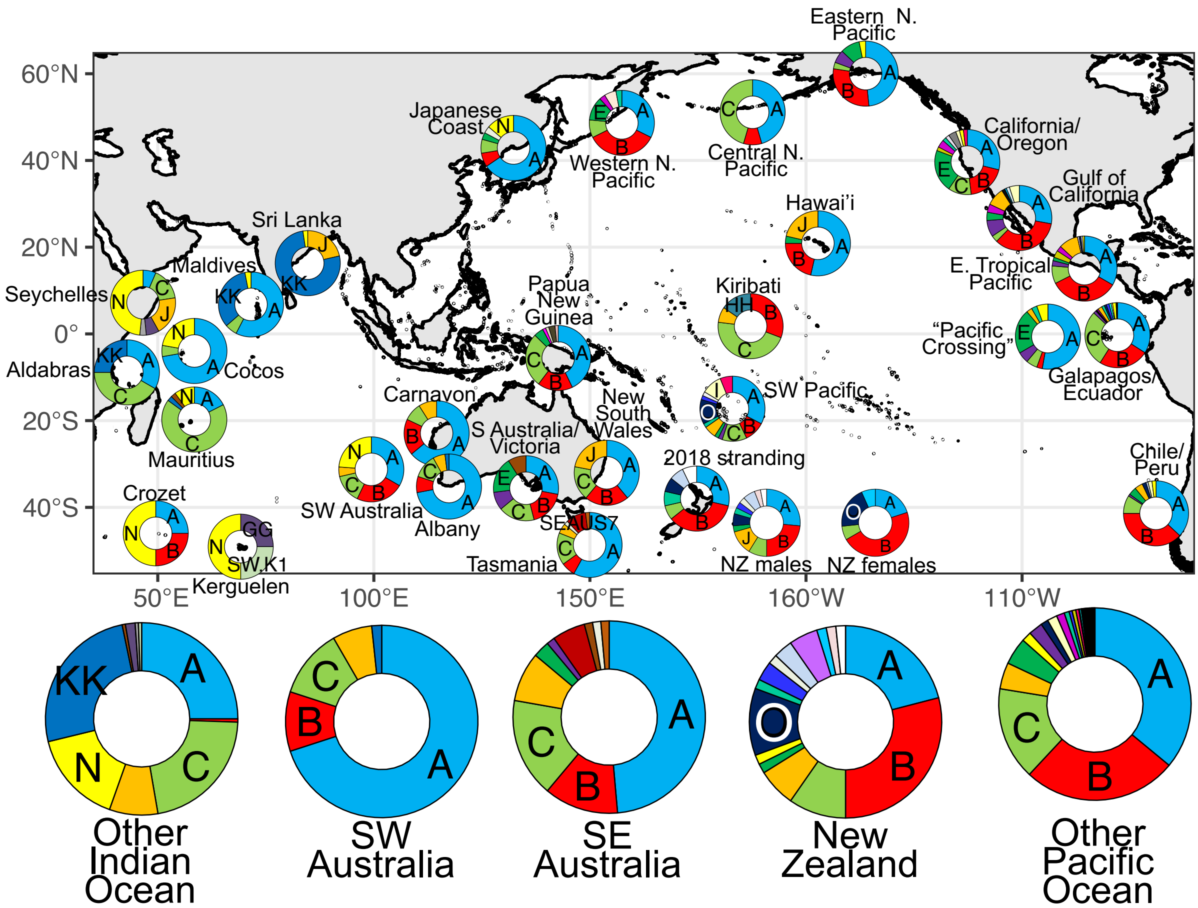


Figure S1. Pairwise F_{ST} between New Zealand strandings (in red) and regions within Australia (location names in orange), and the Pacific (location names in blue) and Indian Oceans (location names in green) summarising haplotype frequency information from Supplement Figure S2 (locations ordered from West to East). Specific F_{ST} values in comparison to 2018 males are given in the left column on the right edge of the plot, in comparison to the total NZ male sample (incl. the 2018 males) in the middle column, and to the total New Zealand female sample in the right column. Values for comparison against Chile/Peru given above plot. Heatmap values corresponding to New Zealand samples indicated by the red outlines. Significant differentiation between strata has been tested using a Fisher's exact test with bold font and * denoting significance at 0.05 and ** at 0.001. Note, in some cases, sample size corrections (Weir and Cockerham, 1984) have resulted in an F_{ST} of 0, while the Fisher's exact test still detects significant differentiation in allele frequencies. See Supplement Figure S2 for sample sizes.

(a)


Eastern N. Pacific
Japanese Coast
Western N. Pacific
Central N. Pacific
California/ Oregon
Gulf of California
Hawai'i
Sri Lanka
Maldives
Seychelles
E. Tropical Pacific
Papua New Guinea
Kiribati
"Pacific Crossing"
Galapagos/ Ecuador
Aldabras
Cocos
Carnavon
New South Wales
SW Pacific
S Australia/ Victoria
Mauritius
2018 stranding
Chile/ Peru
Crozet
SW Australia
Albany
SEAUS7
SW.K1
Kerguelen
Tasmania
NZ males
NZ females
60°N
40°N
20°N
0°
20°S
40°S
50°E
100°E
150°E
160°W
110°W
Other Indian Ocean
SW Australia
SE Australia
New Zealand
Other Pacific Ocean

(b)

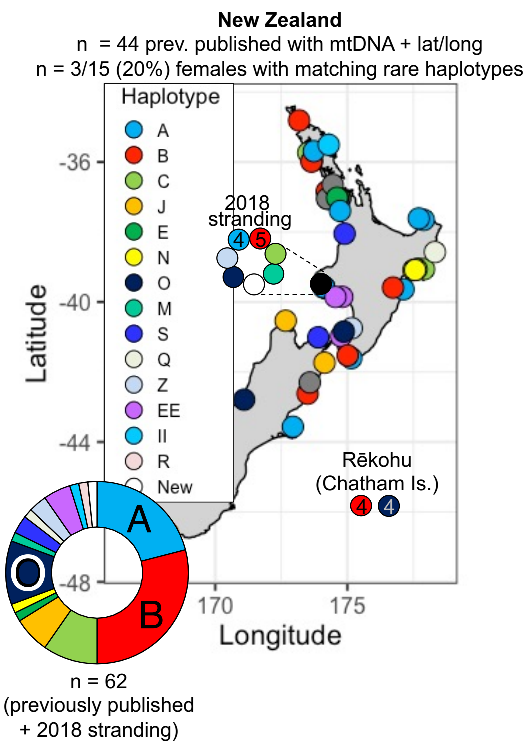

New Zealand
n = 44 prev. published with mtDNA + lat/long
n = 3/15 (20%) females with matching rare haplotypes
Haplotype
A
B
C
J
E
N
O
M
S
Q
Z
EE
II
R
New
2018 stranding
Rēkohu (Chatham Is.)
Latitude
Longitude
-36
-40
-44
-48
170
175
n = 62
(previously published + 2018 stranding)

Figure S2. (a) Haplotype frequencies for regional populations and broad groupings of these populations from the Pacific and Indian Ocean obtained from this current study, Day et al. (2021), Girardet et al. (2021), and Alexander et al. (2016) (and references therein). Haplotype names correspond to Figure 1. Sample sizes: Crozet Is. n = 4, Aldabras n = 12, Seychelles n = 31, Mauritius n = 40, Kerguelen n = 4, Maldives n = 33, Sri Lankan = 42, Cocos Island n = 18, SW Australia (Odyssey) n = 21, Carnavon n = 11, Albany n = 49, South Australia and Victoria n = 11, Tasmania n = 43, New South Wales n = 18, 2018 male strandings n = 14, NZ males (inc. 2018) n = 34, NZ females n = 15, “Southwest Pacific” n = 49, Papua New Guinea n = 63, Japanese Coast n = 29, Kiribati n = 13, Hawai'i n = 28, Gulf of California n = 122, “Pacific Crossing” n = 36, Eastern Tropical Pacific n = 114, Central North Pacific n = 11, Eastern North Pacific n = 31, Western North Pacific n = 34, Galapagos and Ecuador n = 285, California and Oregon n = 52, Chile and Peru n = 100. Aggregate regions: Other Indian Ocean (excl. Australia) n = 184, SW Australia n = 60, SE Australia n = 72, New Zealand total (incl. 2018 stranding and individuals of unknown sex) n = 62, Other Pacific Ocean (excl. Australia and New Zealand) n = 967. (b) Location of previously haplotyped New Zealand individuals. Of the female individuals, 3/15 (20%) shared the rare haplotypes found in New Zealand males ‘M’, ‘O’, ‘Q’, ‘R’, ‘S’ or ‘Z’ (also see Figure 4). Bottom left: the total haplotype frequencies for all New Zealand samples, including the 2018 males and previous New Zealand samples without explicit lat/long coordinates.

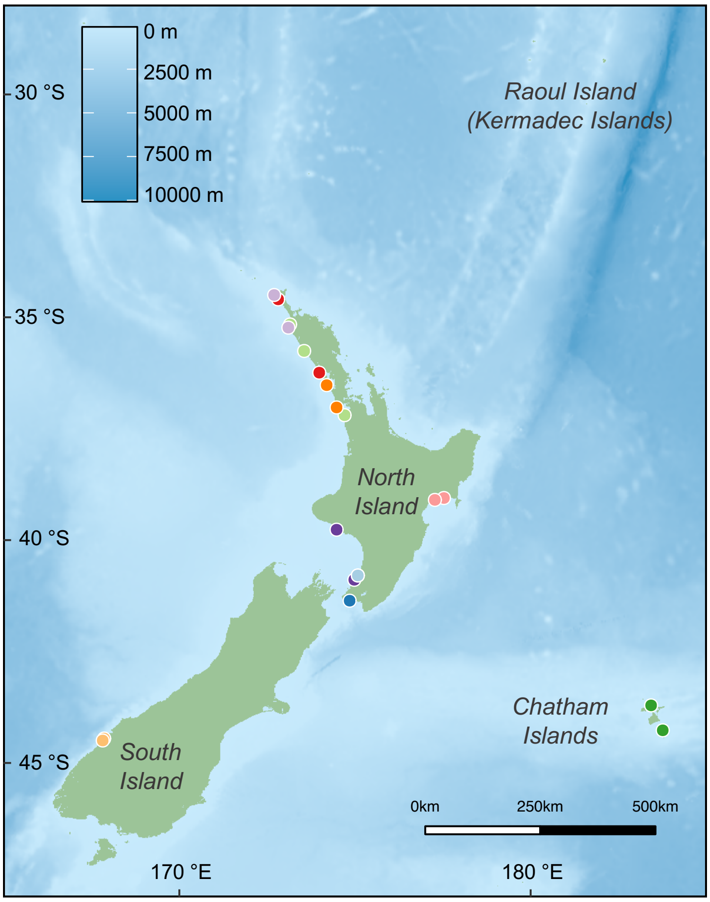


Figure S3. Locations of potential sperm whale (*Physeter macrocephalus*) mass strandings recorded in New Zealand as single strandings between 1873–2021. Colours denote the potential associations into mas stranding groupings. Bathymetry is depicted with darker shades of blue representing deeper waters.

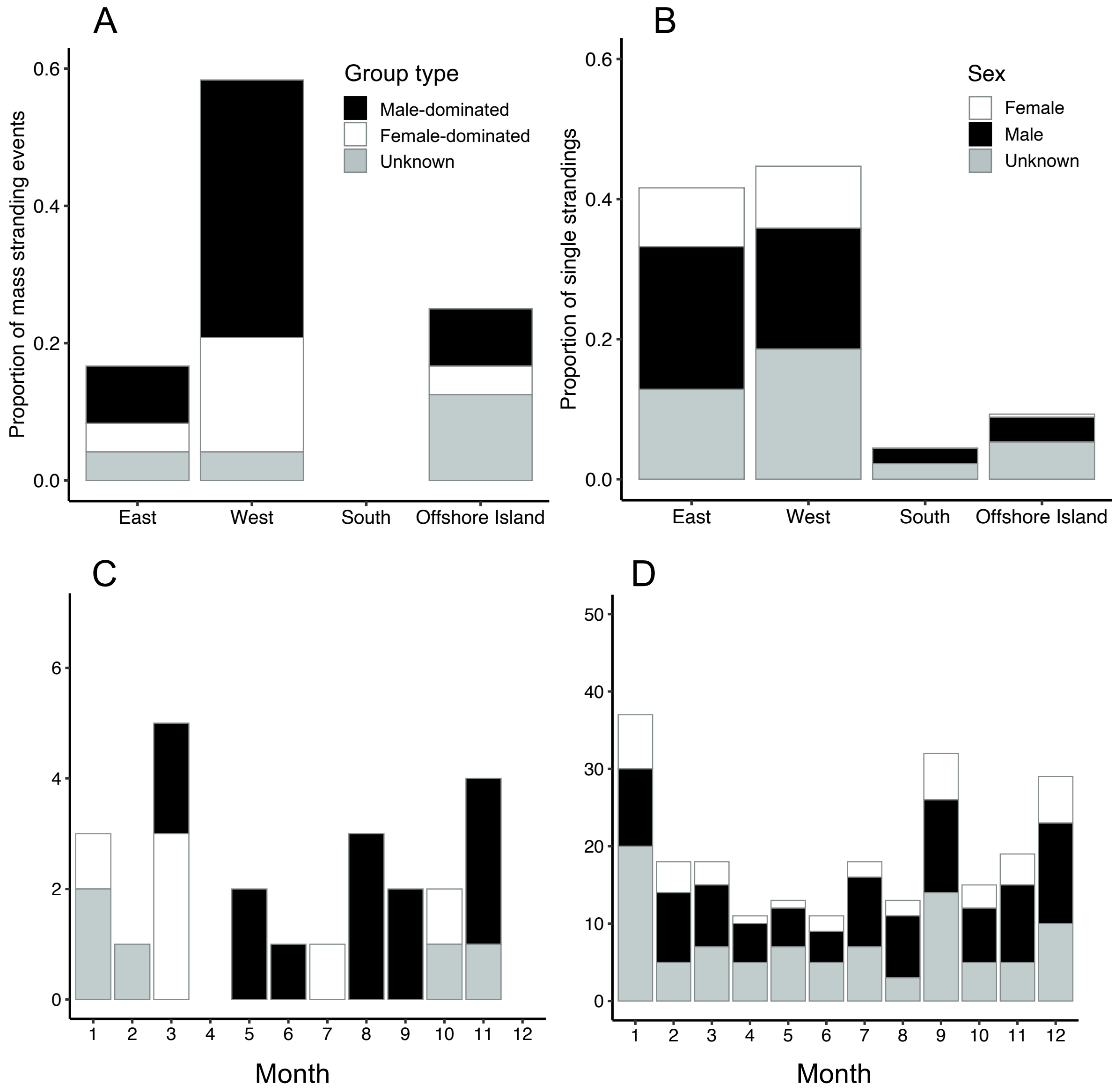


Figure S4. Spatial (A & B) and monthly (C & D) distribution of sperm whale (*Physeter macrocephalus*) stranding events recorded in New Zealand between 1873–2021 for mass (A & C) and single (B & D) strandings. For C & D, bars represent sum of events per month. Group type/sex is represented by colour. Months correspond to austral seasons: spring = September–November, summer = December–February, autumn = March–May, and winter = June–August).

Supplementary Literature Cited

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