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Supplementary material

Migratory species strongly affect seabird biomass in seasonal assemblages off northeast Aotearoa/New Zealand

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Briefly, in this supplementary material you will find:

- List of detailed software used in the analyses;
- Table S1: Species recorded, distribution status, and breeding period;
- Fig. S1: Scatterplot showing the lack of relationship of the eight most frequent species and environmental variables;
- Fig. S2: Maps showing SST (A) and CHL-a (B) values by voyage;
- Fig. S3: Violin plot showing SST (A) and CHL-a (B) values by voyage (see also Fig. S2);
- Table S2: Frequency of occurrence and relative abundance for each species/season;
- Table S3: Summary table with BIC values for each GLLVM, used to select the best model;
- Fig. S4: Residual plot for the best GLLVM 'null' model;
- Fig. S5: Residual plot for the best GLLVM model including 'predictors';
- Fig. S6: Coefficient plot for 'season', from the best GLLVM model including 'predictors', without adjusting the x-axis;
- Fig. S7: Diversity (species richness; A) and sample completeness (B) curves;
- List of references related to *this* document.

Detailed list of software

In addition to the packages mentioned in the main text, the following packages were used: plyr 1.8.8 (Wickham, 2011), dplyr 1.1.2 (Wickham et al., 2023a), tidyr 1.3.0 (Wickham et al., 2023c), readr 2.1.4 (Wickham et al., 2023b), lubridate 1.9.2 (Grolemund and Wickham, 2011), stringr 1.5.1 (Wickham, 2022), purrr 1.0.2 (Wickham and Henry, 2023), forcats 1.0.0 (Wickham, 2023), janitor 2.2.0 (Firke, 2023), sp 1.6-0 (Pebesma and Bivand, 2005; Bivand et al., 2013), sf 1.0-8 (Pebesma, 2018), raster 3.5-21 (Hijmans, 2022), lwgeom 0.2-11 (Pebesma, 2023), corrplot 0.92 (Wei and Simko, 2021), ggspatial 1.1.7 (Dunnington, 2022), ggrepel 0.9.6 (Slowikowski, 2024), ggExtra 0.10.0 (Attali and Baker, 2022), patchwork 1.1.2 (Pedersen, 2022).

A hard-copy of the code is archived at the Open Science Framework at https://osf.io/vpyd6/, where you will find a detailed walk-through on the analyses. Package dependencies are all listed under a 'renv.lock' file in the repository, obtained through renv 1.0.3 (Ushey and Wickham, 2023).

If you are interested in the raw data, please contact the Far Out Ocean Research Collective (https://www.farout.org.nz/), who will liaise with Ngāti Kuri.

Table S1. Recorded species, their Te reo Māori, English and scientific names, breeding (BR) status and periods (months), and distribution and conservation status (in the format 'national (global)'). Distribution and breeding status according to Williams et al. (2006), conservation status following Robertson et al. (2021) (national) and BirdLife International (2024) (global). Some species did not have a distribution classification in Williams et al. (2006), so we manually input these, which are shown in parenthesis.

Te reo Māori name	Common English name	Scientific name	BR status[1]	BR months	Distribution[2]	Conservation status
–	Arctic skua	*Stercorarius parasiticus*	(RM)	(Apr–Sep)	M–NH	Migrant (LC)
Tākapu	Australasian gannet	*Morus serrator*	(N)	Jul–Jan	M–TS/A	Not threatened (LC)
Tāiko	Black petrel	*Procellaria parkinsoni*	E	Nov–Jul	M–EP	Threatened (VU)
Takahikare-rangi	Black-bellied storm petrel	*Fregetta tropica*	N	Dec–May	M–SWP	Not threatened (LC)
Toroa	Black-browed mollymawk	*Thalassarche melanophris*	N	Sep–Apr	D–SO	Vagrant (LC)
Karetai kapa mangu	Black-winged petrel	*Pterodroma nigripennis*	N	Dec–Jun	M–NP	Not threatened (LC)
Hākoakoa	Brown skua	*Catharacta antartica*	(N)	Sep–Mar	(D–SO)	Threatened (LC)
Rako	Buller's shearwater	*Ardenna bulleri*	E	Sep–May	M–NP, EP	At-risk (VU)
Karetai hurukoko	Cape petrel	*Daption capense*	RM	Nov–Mar	D–SWP, SO	Migrant (LC)
Tītī	Cook's/Pycoft's petrel	*Pterodroma cookii/pycrofti*	E/E	Oct–May/Nov–Apr	M–NP, EP	At-risk (VU) [both sp.]
Kuaka	Diving petrel	*Pelecanoides urinatrix*	N	Aug–Feb	D–SWP	At-risk (LC)
Tītī wainui	Fairy prion	*Pachyptila turtur*	N	Oct–Mar	D–SWP, SO	At-risk (LC)
Toanui	Flesh-footed shearwater	*Ardenna carneipes*	N	Nov–May	M–NP	At-risk (NT)
Pakahā	Fluttering shearwater	*Puffinus gavia*	E	Sep–Feb	M–TS/A, (S)[3]	At-risk (LC)
Ōi	Grey-faced petrel	*Pterodroma gouldi*	E	Jun–Jan	D–SP	Not threatened (LC)
Takahikare-raro	New Zealand storm petrel	*Fregetta maoriana*	(E)	Feb–Jun	(S)	Threatened (CR)
Pāngurunguru	Northern giant petrel	*Macronectes halli*	N	Aug–Feb	D–SO	At-risk (LC)
Toroa	Northern royal albatross	*Diomedea sanfordi*	E	All year	M–SA, SO	Threatened (EN)
Tītī	Sooty shearwater	*Ardenna grisea*	N	Nov–May	M–NP, EP	At-risk (NT)
Toroa	Wandering albatross	*Diomedea [exulans]*	[RM/N/E]	All year	D–SO	–
–	White-bellied storm petrel	*Fregetta grallaria*	N	Mar–Aug	D–SWP	Threatened (LC)
Toroa	White-capped mollymawk	*Thalassarche steadi*	E	Nov–Aug	M–SA, SO	At-risk (NT)
Takahikare-moana	White-faced storm petrel	*Pelagodroma marina (maoriana)*	E	Oct–Mar	M–EP	At-risk (LC)
–	White-napped petrel	*Pterodroma cervicalis*	N	Dec–Jun	M–NP	At-risk (VU)
–	Wilson's storm petrel	*Oceanites oceanicus*	RM	Dec–Apr	(M–NP)	Migrant (LC)

[1]BR status are coded as endemic (E), native (N), or regular migrant (RM).

[2]Distribution are coded as migratory (M), dispersive (D), or sedentary (S), followed by their geographic range North Pacific (NP), South Pacific (SP), eastern Pacific (EP), South Atlantic (SA), circum-polar southern ocean (SO), Tasman Sea/Australian coast (TS/A), southwest Pacific (SWP), and North Hemisphere (NH). Sedentary species remain within New Zealand territory year-round.

[3]Williams et al. (2006) classified fluttering shearwater as migratory, but note that fluttering shearwaters mostly remain in New Zealand (as sedentary residents) although some individuals may, indeed, migrate to TS/A (see Berg et al. 2019).

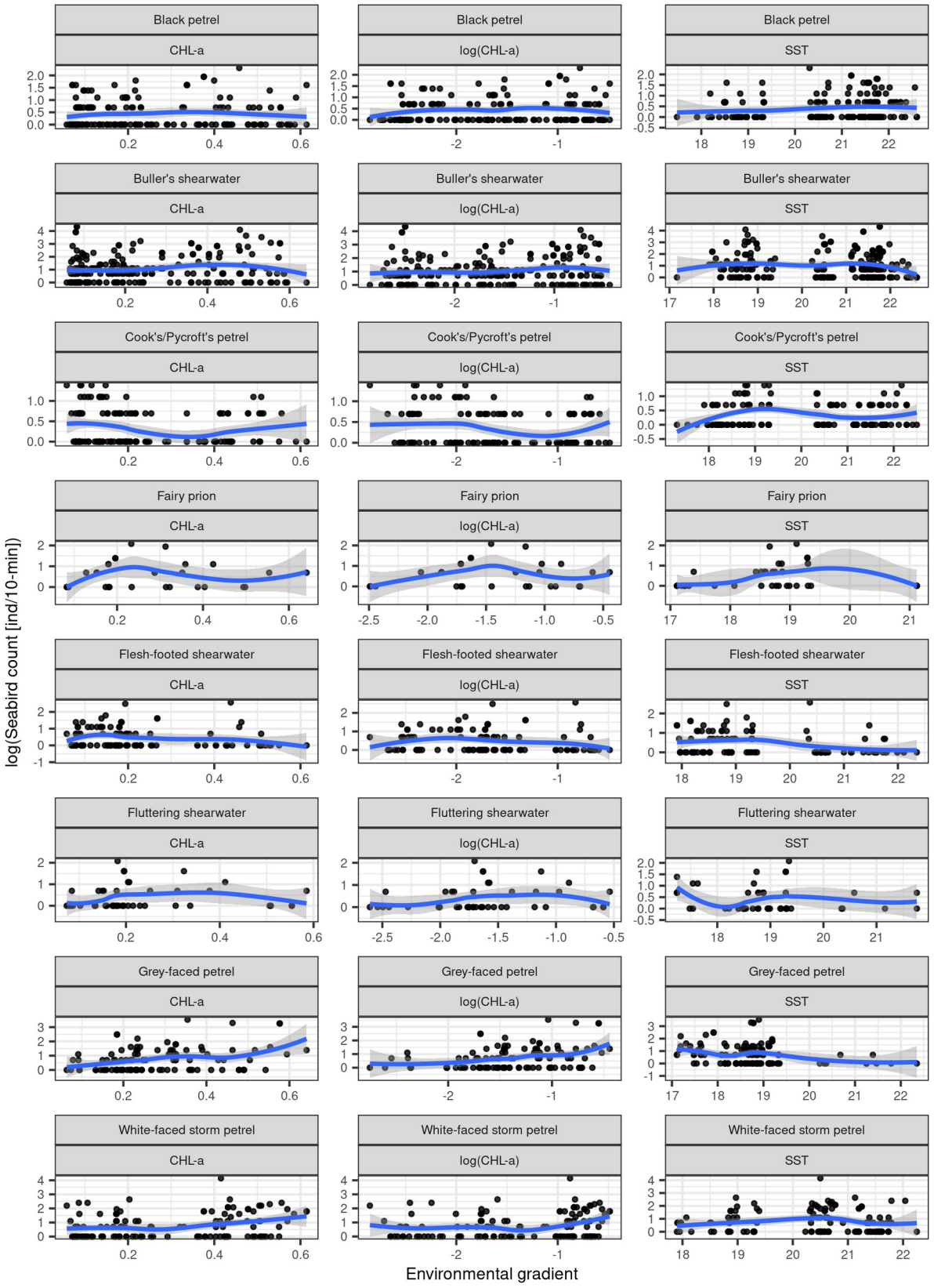

Fig S1. Scatterplot showing the relationship of the eight most frequent species (rows; note we log transformed the counts – see Table S2) recorded off Northland, Aotearoa/New Zealand, 2019–2024, and environmental variables (columns; chlorophyll-*a* [CHL-a, mg/m³], log chlorophyll-*a* [log(CHL-a)] and sea surface temperature [SST, °C]). The blue line shows a LOESS curve fitted to the data to ease visualization; the shadded area is the standard deviation around the LOESS estimate.

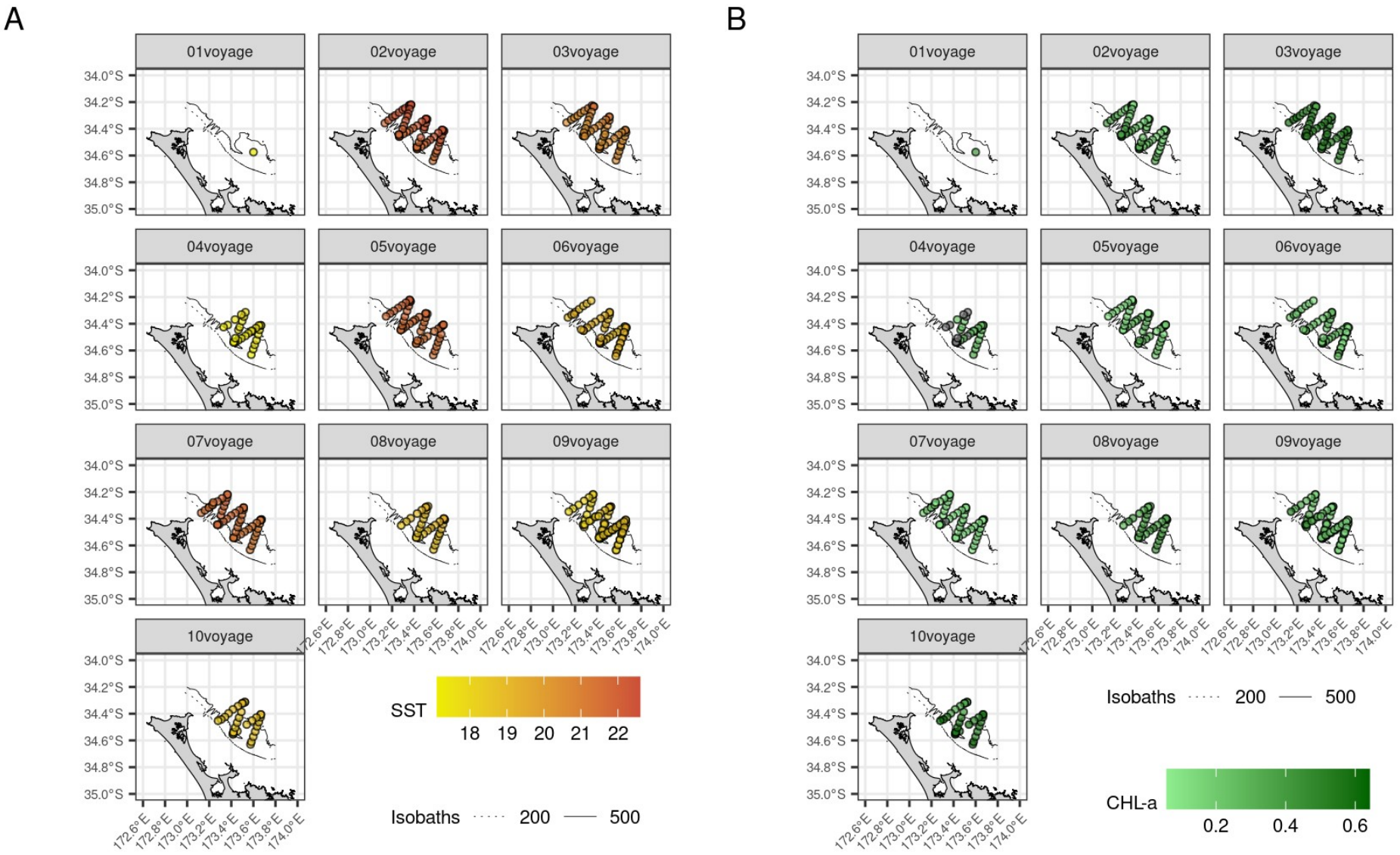

Fig S2. Map representing the surface environmental conditions for each 10-min seabird count off Northland, Aotearoa/New Zealand, 2019–2024, for each voyage. In (A), sea surface temperature (SST, °C) and in (B) chlorophyll-*a* (CHL-a, mg/m³).

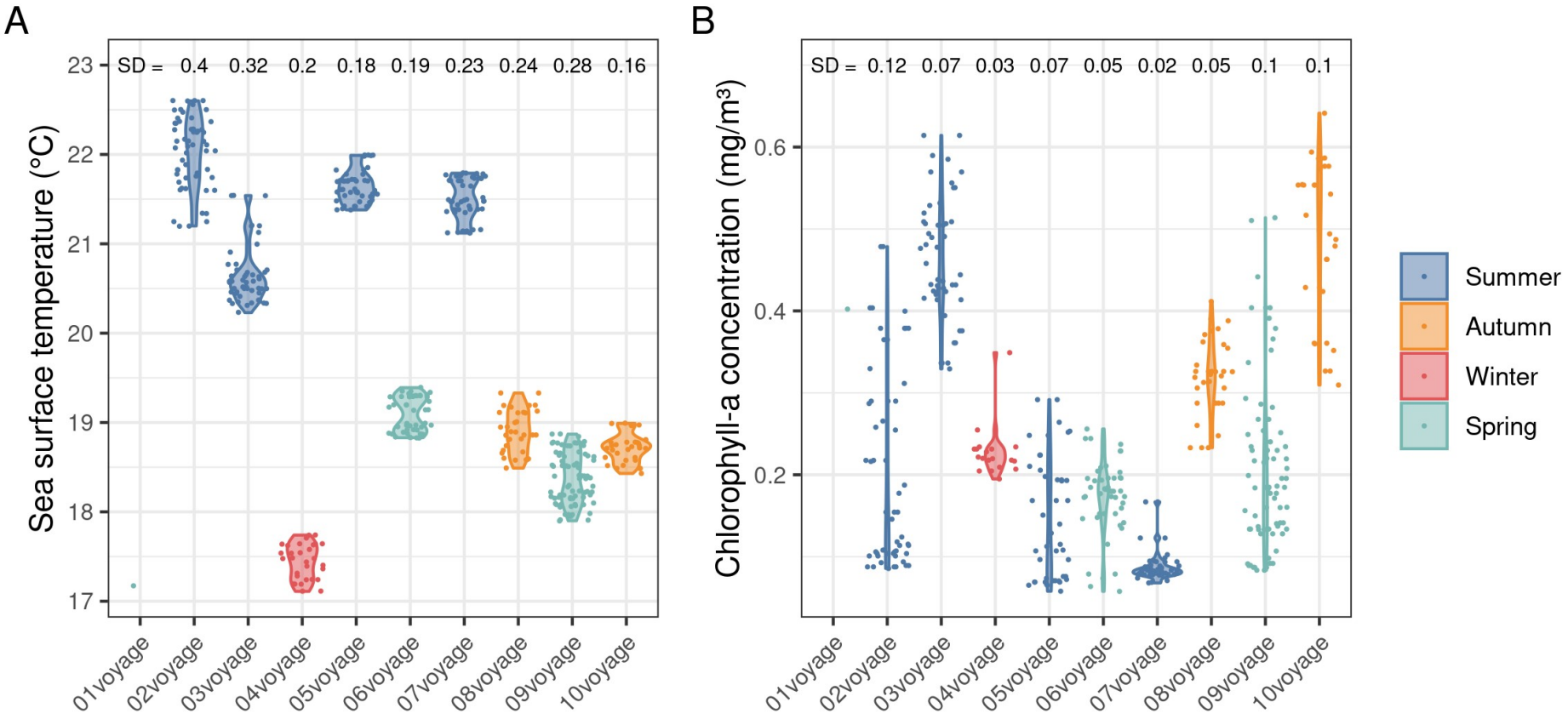

Fig S3. Violin plots showing the surface environmental characteristics for each voyage, based on the values extracted for each 10-min seabird count (see Fig. S2 above) off Northland, Aotearoa/New Zealand, 2019–2024. (A) Sea surface temperatures (SST) on the left and (B) chlorophyll-*a* (CHL-a) concentrations on the right; at the top of each plot, the standard deviation (SD) is shown as a measurement of variability.

Table S2. Seasonal frequencies of occurrence (FO) and relative abundances (RA) for each seabird species recorded off Northland, Aotearoa/New Zealand, 2019–2024. For scientific names, check Table S1.

		Summer		Autumn		Winter		Spring	
Te reo Māori name	**Common English name**	**FO**	**RA**	**FO**	**RA**	**FO**	**RA**	**FO**	**RA**
–	Arctic skua	0	0	1.56	0.19	0	0	0	0
Tākapu	Australasian gannet	4.81	1.99	1.56	0.19	3.33	0.88	5.51	0.81
Tāiko	Black petrel	60.58	14.44	20.31	3.37	3.33	0.88	25.20	5.94
Takahikare-rangi	Black-bellied storm petrel	1.44	0.18	1.56	0.19	0	0	0.79	0.12
Toroa	Black-browed mollymawk	0	0	7.81	0.94	6.67	1.75	0.79	0.12
Karetai kapa mangu	Black-winged petrel	12.02	3.10	0	0	0	0	1.57	0.35
Hākoakoa	Brown skua	0	0	1.56	0.19	0	0	0	0
Rako	Buller’s shearwater	67.79	48.19	29.69	39.14	0	0	41.73	27.47
Karetai hurukoko	Cape petrel	0	0	0	0	10.00	2.63	0	0
Tītī	Cook’s/Pycoft’s petrel	34.13	6.02	0	0	10.00	2.63	48.03	12.22
Kuaka	Diving petrel	0.96	0.12	3.12	0.37	0	0	1.57	0.23
Tītī wainui	Fairy prion	0.96	0.12	21.88	6.74	30.00	8.77	9.45	2.91
Toanui	Flesh-footed shearwater	17.79	3.39	1.56	0.75	0	0	49.61	16.30
Pakahā	Fluttering shearwater	2.88	0.47	10.94	2.81	23.33	14.04	21.26	5.47
Ōi	Grey-faced petrel	4.81	0.70	60.94	40.26	63.33	56.14	33.07	10.48
Takahikare-raro	New Zealand storm petrel	2.40	0.29	4.69	1.81	0	0	0.79	0.12
Pāngurunguru	Northern giant petrel	0	0	0	0	10.00	2.63	2.36	0.47
Toroa	Northern royal albatross	0.96	0.12	0	0	0	0	0	0
Tītī	Sooty shearwater	0.48	0.06	1.56	0.19	0	0	0.79	0.12
Toroa	Wandering albatross	1.44	0.18	9.38	1.12	3.33	0.88	5.51	0.93
–	White-bellied storm petrel	1.44	0.35	0	0	0	0	2.36	0.47
Toroa	White-capped mollymawk	0	0	1.56	0.19	6.67	1.75	3.94	0.70
Takahikare-moana	White-faced storm petrel	39.90	19.24	3.12	0.56	0	0	28.35	11.64
–	White-napped petrel	0.48	0.06	0	0	0	0	0	0
–	Wilson’s storm petrel	0.48	0.06	0	0	0	0	0.79	0.12

Table S3. Summary of Bayesian Information Criteria (BIC) values used to select the best GLLVM model; (a) null model (selecting only the number of LVs); (b) selecting the optimal combination of latent variables and covariates. BIC highlighted in bold indicates the chosen model.

Model	Latent variables	BIC
(a) Null		
~ 1	LV 1	**4816.920**
~ 1	LV 2	4960.562
~ 1	LV 3	5121.778
(b) With predictors (covariate selection)		
~ Season + CHL + SST	LV 1	4483.720
~ Season + CHL	LV 1	4392.524
~ Season + SST	LV 1	4421.030
~ Season	LV 1	4318.018
~ Season + CHL + SST	LV 0	4350.364
~ Season + CHL	LV 0	4255.435
~ Season + SST	LV 0	4278.204
~ Season	LV 0	**4188.074**

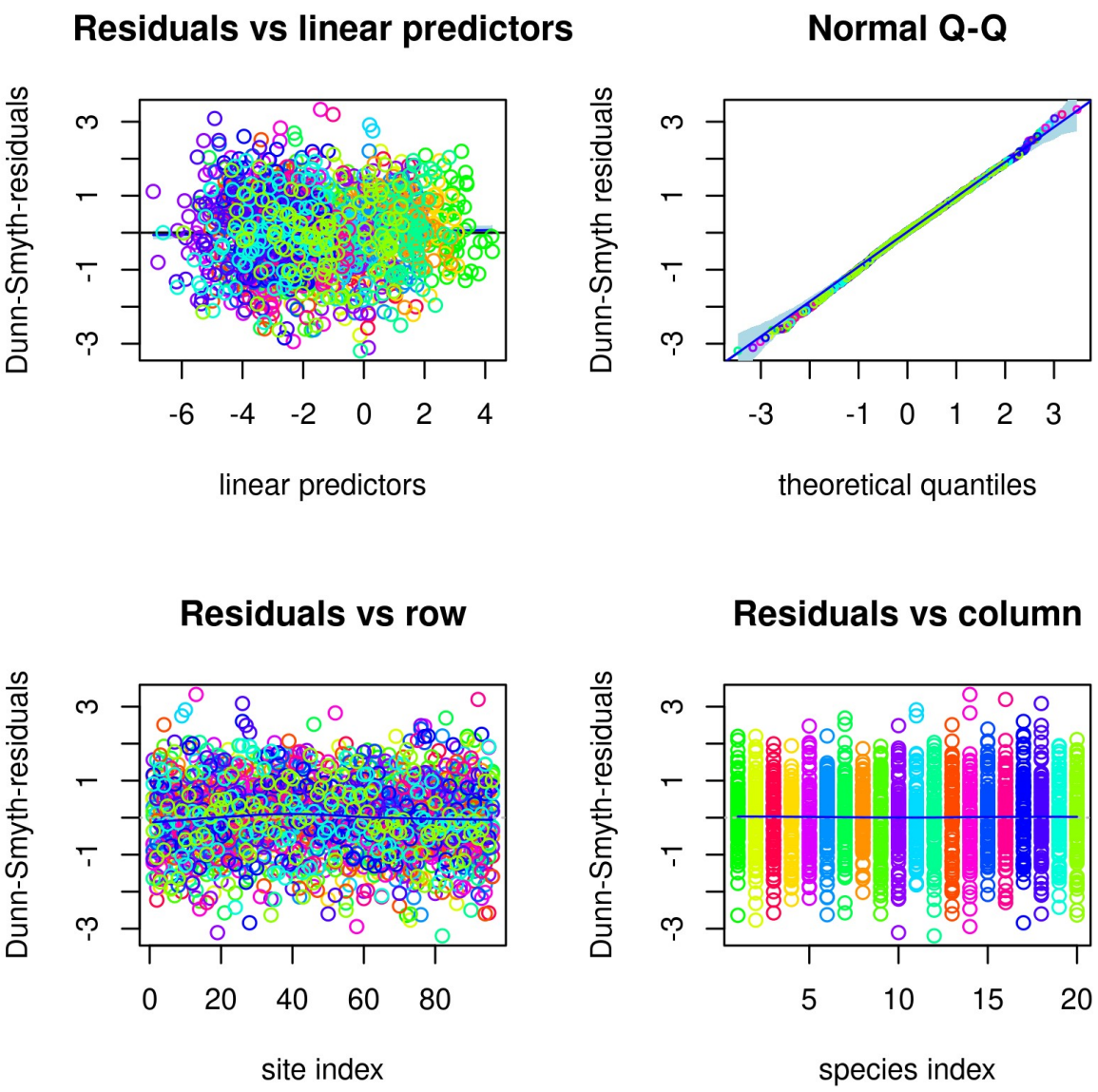

Fig S4. Residual plot for the best GLLVM 'null' model, fitted to seabird counts off Northland, Aotearoa/New Zealand, 2019–2024. See the main text for details.

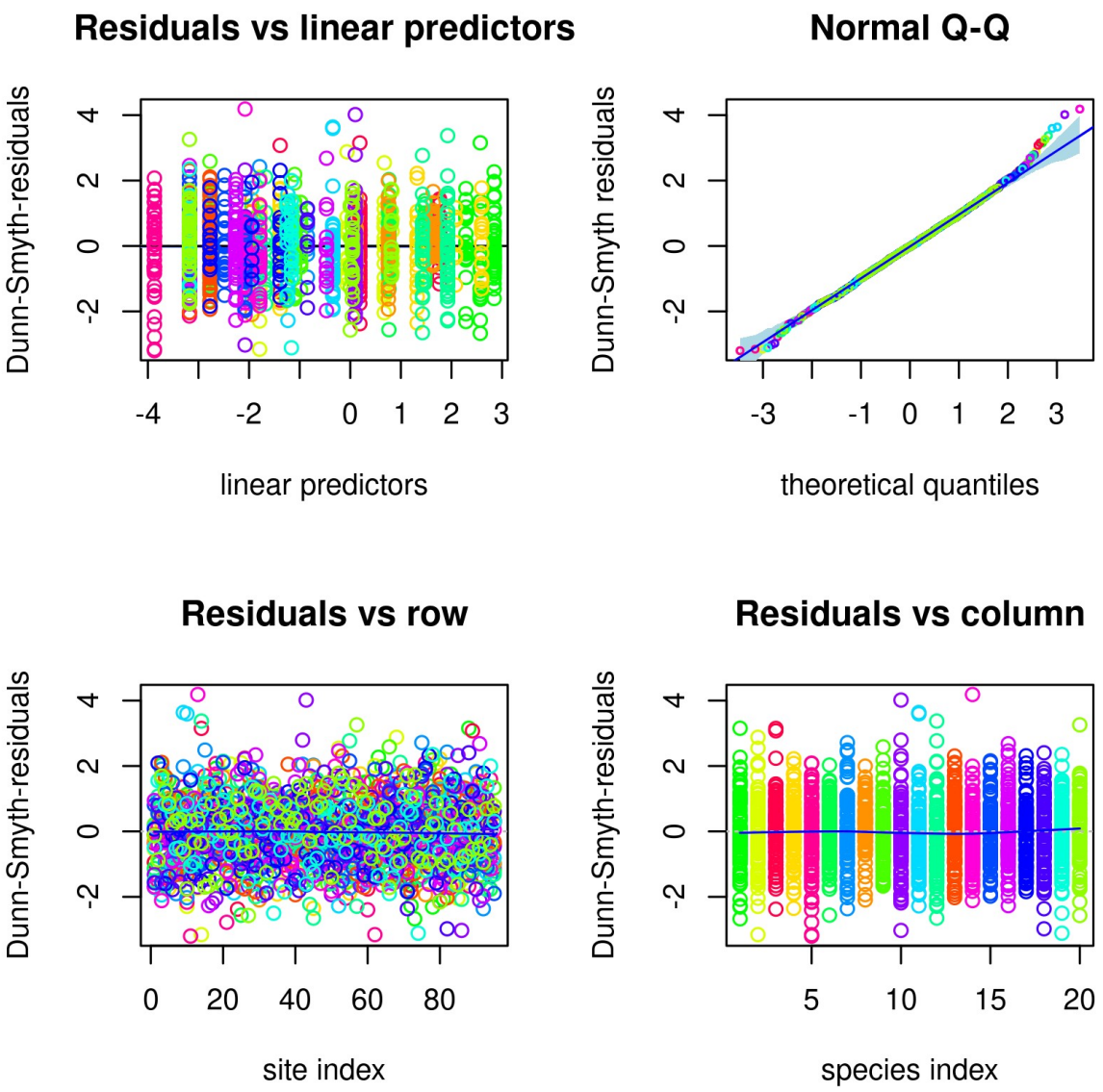

Fig S5. Residual plot for the selected GLLVM model including 'predictors' (season only, zero latent variables), fitted to seabird counts off Northland, Aotearoa/New Zealand, 2019–2024. See the main text for details.

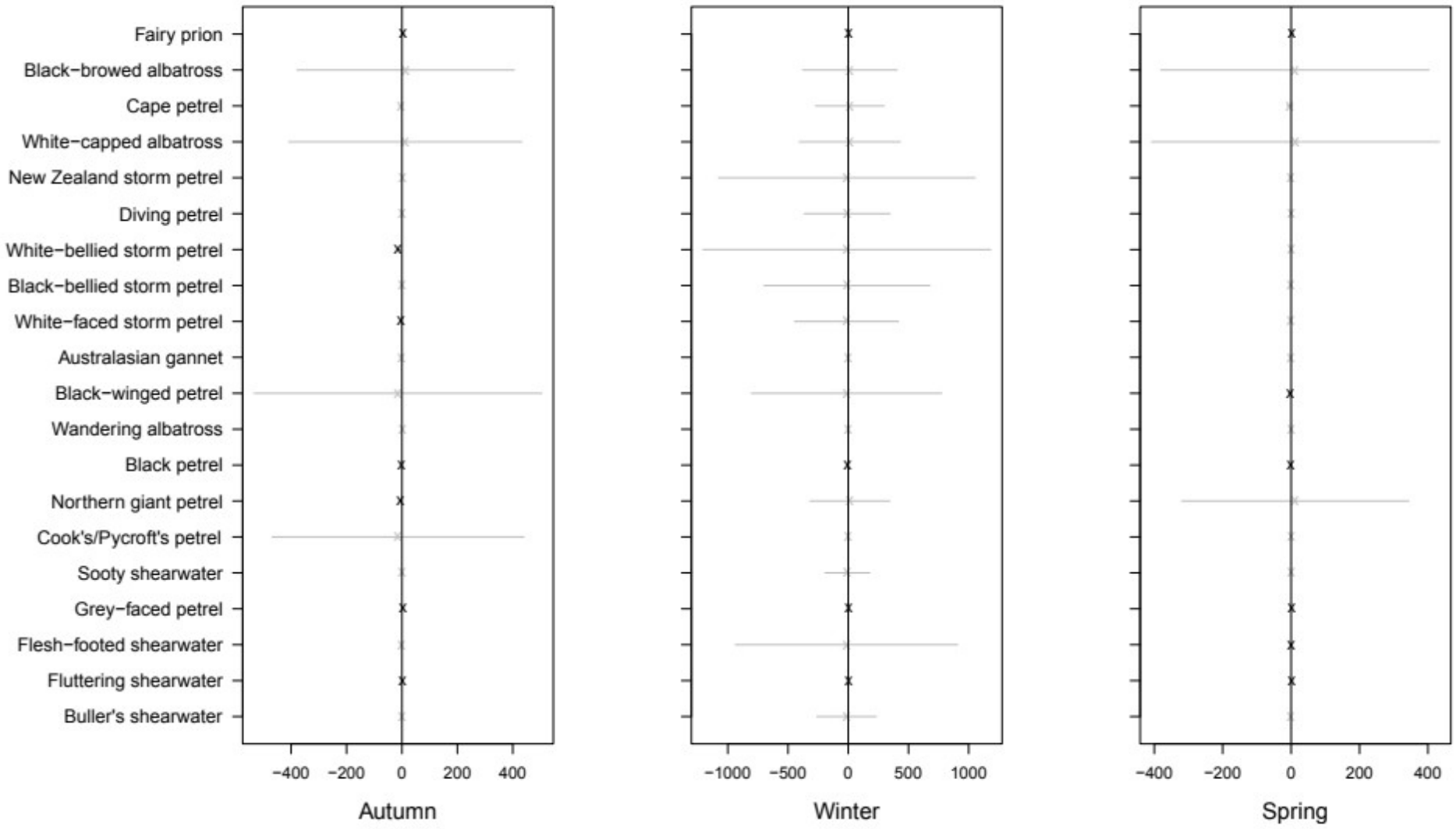

Fig S6. Coefficient plot for the predictor 'season', from the best GLLVM model including 'predictors', without adjusting the x-axis. Values are in relation to 'summer', which was specified as the intercept. See the main text for details.

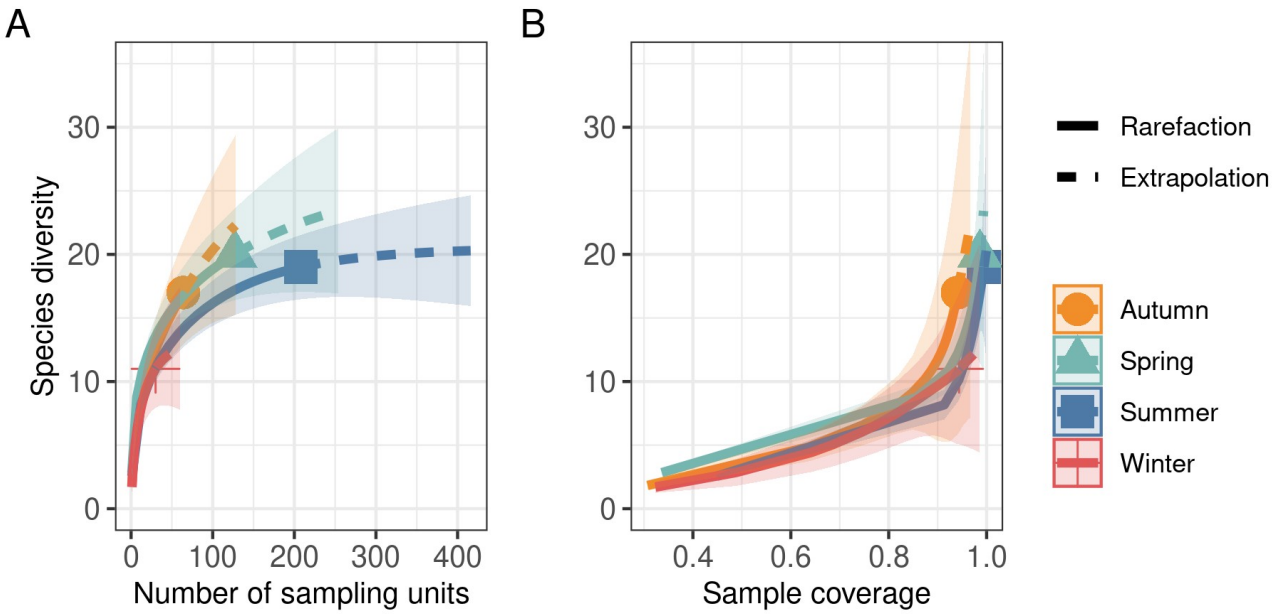

Fig S7. Rarefaction curves showing diversity (species richness; A) and sample completeness (B) based on 10-min seabird counts off Northland, Aotearoa/New Zealand, 2019–2024.

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