Appendix S1

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Seabirds subsidize terrestrial food webs and coral reefs in a tropical rat-invaded archipelago

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Section S1: Guano inputs in the Abrolhos archipelago

Seabird biomass and nest density were estimated using peak seabird nest counts obtained in annual surveys of focal species in the Abrolhos archipelago between 2018 and 2019, conducted by the Abrolhos Marine National Park, led by Brazilian Federal Environmental Agency *Instituto Chico Mendes de Conservação da Biodiversidade* (ICMBio 2020). Seabird biomass per hectare was calculated using the mean mass of an individual of each species taken from the Handbook of the Birds of the World (del Hoyo et al. 2017; see Graham et al. 2018).

Seabird nitrogen inputs derived from guano were estimated using previously established methods (Young et al. 2010; Benkwitt et al. 2021), using formulas adapted from Graham et al. (2018):

$$\mathrm{NIY_{ij}} = \frac{\sum \mathrm{NIM_{ij}}}{\mathrm{IsArea_j}}$$

$$\mathrm{NIM_{ijm}} = \mathrm{Ng} \times Dr_i \times Bd_{ijm} \times Md$$

where nitrogen input per hectare per year (NIY) for each species (i) and island (j) is the sum of the nitrogen input per month (NIM) divided by the area of the island (IsArea). NIM was estimated from the nitrogen content of guano (Ng), the defecation rate in g per species per day (Dr), the number of that species of bird (Bd) on the island in a given month (m), and the number of days in

the month (Md; held as 30 days). Daily guano production by individual was estimated using data from *Sula sula*, assuming an allometric relationship with body mass to extrapolate for our study species (see Smith and Johnson 1995; Young et al. 2010; Graham et al. 2018; Benkwitt et al. 2021). We considered nitrogen content in excreted guano to be 18.1% (Young et al. 2010). To account for monthly fluctuations in seabird numbers derived from species-specific phenological patterns, we used the best available data from monthly nest surveys conducted by the Abrolhos Marine National Park (ICMBio, 2020) and counts of breeding adults conducted by a local seabird expert (Cynthia Campolina provided data on frigatebirds and brown noddies on Redonda and Guarita islands, respectively), all conducted between 2018–2021. Given that surveys for some species in some islands did not cover the entire islands, the fluctuation in numbers in standardized sampling areas was considered to vary similarly over the whole island throughout the year. Then, using the known island- and species-specific peak abundance (i.e. population size), monthly proportions were extrapolated for the total number in the island for the given month. We also adjusted Bd estimates to account for time spent off the island, at sea foraging, during the breeding season for each species, using the classification proposed by Graham et al. (2018).

Table S1 Parameter estimates of simple Generalized Linear Models used preliminarily to verify the difference between sampling years (2020 and 2021). The only significant difference ($p < 0.5$) is shown with p value in bold

	Estimate	Std. Error	*t*-value	*p*-value
Soil				
Intercept	18.8671	0.4378	43.091	<0.0001
2021	-0.6317	0.6153	-1.027	0.3080
C3 plants				
Intercept	19.2256	0.4146	46.376	<0.0001
2021	-2.5377	0.6127	-4.142	**<0.0001**
C4 plants				
Intercept	18.0946	0.4125	43.866	<0.0001
2021	-1.293	0.6539	-1.977	0.0509
Orthoptera				
Intercept	22.636	0.324	69.865	<0.0001
2021	0.503	0.511	0.984	0.3270
Lizards				
Intercept	20.3689	0.451	45.16	<0.0001
2021	-0.2103	0.7631	-0.276	0.7840

Table S2 Trophic discrimination factors (TDF) of carbon (ΔC) and nitrogen (ΔN) stable isotopes used in Bayesian mixing models of each consumer, based on available references. For consumers whose TDF standard deviations were unavailable in the literature, we considered a standard deviation of 0.1‰ in analysis.

Consumer	**Source**	**ΔC (‰)**	**ΔN (‰)**	**Animal model used in experiments**
Grasshoppers (Orthoptera)	All sources	0.5 ± 0.13	2.3 ± 0.18	Invertebrates
Tarantulas (Theraphosidae)	All sources	0.44	2.16	Wolf spider (*Pardosa lugubris*)
Black rats (*Rattus rattus*)	C3 plants	1.21	2.73	*Rattus rattus*
	C4 plants	-2.78	2.09	*Rattus rattus*
	Seabirds	-0.84	1.49	*Rattus rattus*
Lizards (*Tropidurus torquatus*)	All sources	2.5 ± 0.6	4.1 ± 0.4	Rock iguanas (*Cyclura* spp.)

Table S3 Analysis of variance of selected Generalized Linear Models, with computed percentage of the null deviance explained by each variable. Significant variables (p <0.05) are displayed with bold p values.

	% explained	Deviance	Residual df	Residual deviance	*F*	*p*-value
δ^{15}N						
Soil (*n* = 79)						
NULL			78	583.57		
Area	16.92	98.76	77	484.81	19.49	**<0.0001**
Island	13.30	77.64	76	407.17	15.32	**0.0002**
Area:Island	4.64	27.05	75	380.12	5.34	**0.0236**
Total explained	34.86	203.45				
C3 plants (*n* = 83)						
NULL			82	759.11		
Area	2.66	20.17	81	738.94	3.10	0.0824
Island	26.88	204.07	80	534.87	31.32	**<0.0001**
Area:Island	2.66	20.17	79	514.71	3.10	0.0824
Total explained	32.20	244.40				
C4 plants (*n* = 96)						
NULL			95	951.37		
Area	3.04	28.88	94	922.49	3.07	0.0832
Island	4.87	46.33	93	876.16	4.92	**0.0290**
Total explained	7.91	86.75				
Grasshoppers (*n* = 102)						
NULL			101	646.55		
Area	2.62	16.95	100	629.59	2.88	0.0926
Island	7.37	47.66	99	581.93	8.11	**0.0054**
Total explained	9.99	64.62				
Tarantulas (*n* = 16)						
NULL			15	129.9		
Area	1.04	1.35	14	128.55	0.15	0.7072

Total explained	1.04	1.35				
Lizards (*n* = 83)						
NULL			82	890.67		
Area	59.73	532.03	81	358.64	156.97	**<0.0001**
Island	1.10	9.79	80	348.85	2.89	0.0931
Area:Island	9.10	81.09	79	267.76	23.92	**<0.0001**
Total explained	69.94	622.91				
Rats (*n* = 29)						
NULL			28	411.17		
Area	34.74	142.84	27	268.33	20.45	**0.0001**
Island	17.12	70.39	26	197.94	10.08	**0.0040**
Area:Island	5.67	23.32	25	174.62	3.34	0.0796
Total explained	57.53	236.55				
%N						
Soil (*n* = 79)						
NULL			78	79.86		
Area	5.92	4.73	77	75.13	5.64	**0.0201**
Island	14.36	11.47	76	63.67	13.69	**0.0004**
Total explained	20.30	16.19				
C3 Plant (*n* = 83)						
NULL			82	111.24		
Area	47.38	52.71	81	58.53	102.50	**<0.0001**
Island	11.65	12.96	80	45.58	25.19	**<0.0001**
Area:Island	4.45	4.95	79	40.63	9.63	**0.0027**
Total explained	63.50	70.62				
C4 Plant (*n* = 96)						
NULL			95	51.55		
Area	55.87	28.80	94	22.74	172.04	**<0.0001**
Island	1.76	0.91	93	21.84	5.41	**0.0222**
Area:Island	12.47	6.43	92	15.40	38.44	**<0.0001**
Total explained	70.10	36.14				

Table S4 Parameter estimates of selected Generalized Linear Models to explain variation in δ^{15}N and %N

Source of variation	Estimate	Std. Error	*t*-value	*p*-value
δ^{15}N				
Soil				
(Intercept)	19.2374	0.5034	38.215	<0.0001
Area (Colony)	-3.3663	0.7119	-4.729	**<0.0001**
Island (Siriba)	0.8277	0.7119	1.163	0.2487
Area (Colony):Island (Siriba)	2.3412	1.0134	2.31	**0.0236**
C3 plants				
(Intercept)	19.6405	0.5322	36.902	<0.0001
Area (Colony)	-0.283	0.7704	-0.367	0.7143
Island (Siriba)	-2.2693	0.7527	-3.015	**0.0035**
Area (Colony):Island (Siriba)	-1.9935	1.1331	-1.759	0.0824
C4 plants				
(Intercept)	18.7149	0.5149	36.345	<0.0001
Area (Colony)	-1.0773	0.6278	-1.716	0.0895
Island (Siriba)	-1.3944	0.6288	-2.218	**0.0290**
Grasshoppers				
(Intercept)	23.9132	0.4095	58.397	<0.0001
Area (Colony)	-0.6729	0.4836	-1.391	0.1675
Island (Siriba)	-1.3813	0.4851	-2.848	**0.0054**
Tarantulas				
(Intercept)	24.2889	1.0713	22.672	<0.0001
Area (Colony)	-0.5808	1.5151	-0.383	0.7070
Lizards				
(Intercept)	24.953	0.4603	54.216	<0.0001
Area (Colony)	-7.1731	0.5733	-12.511	**<0.0001**
Island (Siriba)	-3.0566	0.6326	-4.832	**<0.0001**
Area (Colony):Island (Siriba)	4.0526	0.8285	4.891	**<0.0001**

Rats				
(Intercept)	18.7648	0.9344	20.08	<0.0001
Area (Colony)	-3.0405	1.3678	-2.223	**0.0355**
Island (Siriba)	5.0179	1.4273	3.516	**0.0017**
Area (Colony):Island (Siriba)	-3.6120	1.9769	-1.827	0.0796
Feces				
Intercept	19.4996	0.6426	30.347	<0.0001
Rats	-4.5005	0.8878	-5.069	**<0.0001**
Seabirds	-10.0248	0.9087	-11.032	**<0.0001**
Corals				
Intercept	2.9788	0.2127	14.005	<0.0001
Guarita	3.6455	0.3684	9.896	**<0.0001**
North Redonda	0.1191	0.3979	0.299	0.7670
South Redonda	0.4495	0.3684	1.22	0.2330
Santa Bárbara	0.4603	0.3684	1.249	0.2220
Siriba	3.5593	0.3684	9.662	**<0.0001**
%N				
Soil				
(Intercept)	0.7613	0.1776	4.286	<0.0001
Area (Colony)	0.499	0.206	2.423	**0.0178**
Island (Siriba)	0.762	0.206	3.699	**0.0004**
C3 plant				
(Intercept)	3.3554	0.1495	22.44	<0.0001
Area (Colony)	1.0931	0.2164	5.05	**<0.0001**
Island (Siriba)	-1.2292	0.2115	-5.813	**<0.0001**
Area (Colony):Island (Siriba)	0.9878	0.3183	3.103	**0.0027**
C4 Plant				
(Intercept)	1.11063	0.07733	14.363	<0.0001
Area (Colony)	0.61636	0.11382	5.415	**<0.0001**
Island (Siriba)	-0.29447	0.11515	-2.557	**0.0122**
Area (Colony):Island (Siriba)	1.04128	0.16795	6.200	**<0.0001**

Table S5 Variation of δ^{15}N across ecosystem compartments in the terrestrial foodweb and on corals in the marine environment. Mean δ^{15}N values are provided with their standard deviations, with sample size informed within parentheses

	Terrestrial areas		**Marine stations**
	Control	Colony	
Terrestrial foodweb			
Santa Bárbara			
Soil	19.2 ± 2.1‰ (20)	15.9 ± 2.5‰ (20)	-
C3 Plants	19.6 ± 1.9‰ (23)	19.4 ± 1.7‰ (21)	-
C4 Plants	19.0 ± 4.0‰ (28)	17.1 ± 2.7‰ (24)	-
Grasshoppers	23.9 ± 2.9‰ (27)	23.2 ± 2.4‰ (19)	-
Lizards	25.0 ± 2.3‰ (16)	17.8 ± 1.8‰ (29)	-
Rats	18.8 ± 4.1‰ (8)	15.7 ± 0.7‰ (7)	-
Tarantulas	24.3 ± 3.5‰ (8)	23.7 ± 2.5‰ (8)	-
Siriba			
Soil	20.1 ± 1.9‰ (20)	19.0 ± 2.4‰ (19)	-
C3 Plants	17.4 ± 2.6‰ (23)	15.1 ± 3.9‰ (16)	-
C4 Plans	17.0 ± 2.9‰ (23)	16.6 ± 2.2‰ (21)	-
Grasshoppers	22.5 ± 2.4‰ (27)	21.9 ± 2.0‰ (29)	-
Lizards	21.9 ± 1.4‰ (18)	18.8 ± 1.9‰ (20)	-
Rats	23.8 ± 1.2‰ (6)	17.1 ± 2.6‰ (8)	-
Corals			
Guarita	-	-	6.6 ± 0.6‰ (5)
Santa Bárbara	-	-	3.4 ± 0.6‰ (5)
Redonda (North)	-	-	3.1 ± 0.8‰ (4)
Redonda (South)	-	-	3.4 ± 0.3‰ (5)
Siriba	-	-	6.5 ± 0.9‰ (5)
Reference stations	-	-	3.0 ± 0.7‰ (10)

Table S6 Contrast analysis results from differences in δ^{15}N and %N between control and colony sites for each island and averaged among the islands, as well as pairwise comparisons of feces samples from seabirds (guano), rats and goats. Contrasts between control and colony sites were only performed in case the selected model included the interaction term between area and island. Significant differences (p <0.05) are displayed with p-values in bold.

Contrast	Estimated difference	SE	z-ratio	p-value
δ^{15}N (Control - Colony)				
Soil				
Santa Barbara	3.370	0.712	4.729	**<0.0001**
Siriba	1.030	0.721	1.421	0.1552
Averaged (two islands)	2.200	0.507	4.333	**<0.0001**
C3 plants				
Santa Barbara	0.283	0.77	0.367	0.7133
Siriba	2.277	0.831	2.74	**0.0062**
Averaged (two islands)	1.280	0.567	2.259	**0.0239**
Rats				
Santa Barbara	3.040	1.370	2.223	**0.0262**
Siriba	6.650	1.430	4.661	**<0.0001**
Averaged (two islands)	4.850	0.989	4.903	**<0.0001**
δ^{15}N (organism)				
Feces				
Goats-Rats	4.500	0.888	5.069	**<0.0001**
Goats-Seabirds	10.020	0.909	11.032	**<0.0001**
Rats-Seabirds	5.520	0.888	6.222	**<0.0001**
%N (Control - Colony)				
C3 plants				
Santa Barbara	-1.090	0.216	-5.05	**<0.0001**
Siriba	-2.080	0.233	-8.914	**<0.0001**
Averaged (two islands)	-1.590	0.159	-9.97	**<0.0001**
C4 plants				
Santa Barbara	-0.616	0.114	-5.415	**<0.0001**

Siriba	-1.658	0.123	-13.422	**<0.0001**
Averaged (two islands)	-1.140	0.084	-13.540	**<0.0001**

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