

Electronic Supplementary Materials

Title: Broad-Scale Trophic Shift in the Pelagic North Pacific Revealed by an Oceanic Seabird

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Table S1. Stable nitrogen isotope data, trophic position estimates, and age for Hawaiian petrel samples. For samples in the Prehuman, Foundation and Expansion periods, age denotes median probability of calibrated radiocarbon date [15]. For Modern period samples, age denotes year of collection. Calendar years are Common Era, except where noted. Trophic position (TP) was calculated using $TP = (\delta^{15}N_{Glu} - \delta^{15}N_{Phe} - TDF_{bird} - 3.4) / TDF_{typical} + 2$; where the trophic discrimination factor (TDF) for birds (TDF_{bird}) is 3.6 ‰ and $TDF_{typical}$ is the TDF for lower trophic levels = 7.6 ‰ [17,19]. Owing to on-going research on TDF [i.e. 42], the precise estimate of trophic position reported herein is subject to revision. Further, a single step model with $TDF = 7.6$ does not change our conclusions that trophic position declined between ancient and modern time periods. For example, using a TDF of 7.6 ‰, the decline in trophic level between Prehuman and Modern time periods for Hawaii is 0.6 ‰ rather than the estimate of 0.4 ‰ based on our multi-step model. Moreover, our interpretation of a trophic level decline in the Hawaiian petrel is clearly indicated by the statistical outcomes for $\delta^{15}N_{glu-Phe}$ (electronic supplementary material table S2).

	Time Period	Sample ID	Age (calendar year)	$\delta^{15}N_{bulk}$	$\delta^{15}N_{Glu}$	$\delta^{15}N_{Phe}$	$\delta^{15}N_{Glu-Phe}$	Trophic position
<i>Hawaii</i>	Prehuman	DP.03.53	1108 BC	16.8	27.7	3.9	23.8	4.2
	Prehuman	DP.03.64	710 BC	18.2	29.5	6.5	23.0	4.1
	Prehuman	DP.03.68	107 BC	18.4	28.3	4.7	23.6	4.2
	Prehuman	DP.03.127	318	17.2	27.3	4.2	23.0	4.1
	Prehuman	DP.03.142	296	17.4	28.8	3.2	25.6	4.4
		average	262 BC	17.6	28.3	4.5	23.8	4.2
		<i>SD</i>	<i>630</i>	<i>0.7</i>	<i>0.9</i>	<i>1.2</i>	<i>1.1</i>	<i>0.1</i>
	Expansion	DP.03.73	1542	16.4	28.8	4.6	24.1	4.2
	Expansion	DP.03.74	1511	16.0	28.2	3.1	25.0	4.4
	Expansion	DP.03.121	1567	16.5	27.2	5.2	22.0	4.0
	Expansion	DP.03.132	1736	17.5	28.4	5.9	22.4	4.0
	Expansion	DP.03.139	1740	16.4	28.4	5.9	22.4	4.0
	Expansion	DP.03.146	1747	17.3	24.3	1.8	22.5	4.0
	Expansion	DP.03.149	1668	16.9	29.2	5.2	24.0	4.2
	Expansion	DP.03.166	1519	17.4	29.0	4.8	24.1	4.2
		average	1682	16.8	27.9	4.6	23.3	4.1
		<i>SD</i>	<i>96</i>	<i>0.6</i>	<i>1.6</i>	<i>1.4</i>	<i>1.1</i>	<i>0.1</i>
	Modern	DP.35.9	2006	14.0	25.5	5.9	19.6	3.7
	Modern	DP.35.15	2001	15.0	28.1	6.6	21.5	3.9
	Modern	DP.35.24	2001	16.2	26.7	6.0	20.8	3.8
	Modern	DP.35.25	2006	14.0	25.7	6.4	19.3	3.6
	Modern	DP.35.95	2006	13.1	24.4	3.6	20.8	3.8
	Modern	DP.35.96	2001	14.7	26.9	4.2	22.7	4.1
	Modern	DP.35.98	2001	14.4	26.6	5.3	21.3	3.9
	Modern	DP.35.99	2001	14.1	26.5	6.2	20.4	3.8
		average	2003	14.4	26.3	5.5	20.8	3.8
		<i>SD</i>	<i>3</i>	<i>0.9</i>	<i>1.1</i>	<i>1.1</i>	<i>1.1</i>	<i>0.2</i>

Maui

Prehuman	DP.03.B177	995	15.3	28.0	1.4	26.6	4.6
Prehuman	DP.03.B11	806	16.0	28.9	2.2	26.6	4.6
Prehuman	DP.03.B50	278 BC	15.1	27.4	-1.1	28.5	4.8
Prehuman	DP.03.B171	1145 BC	17.5	31.2	4.2	27.0	4.6
Prehuman	DP.03.B167	1410 BC	16.8	31.0	3.2	27.7	4.7
Prehuman	DP.03.B48	2242 BC	14.5	27.7	-2.2	29.9	5.0
Prehuman	DP.03.B49	2445 BC	17.0	31.0	2.9	28.1	4.8
	average	817 BC	16.0	29.3	1.5	27.8	4.7
	<i>SD</i>	1375	1.1	1.7	2.3	1.2	0.1
Foundation	DP.03.B54	1395	16.2	30.7	2.9	27.7	4.7
Foundation	DP.03.B89	1299	14.9	25.0	-1.6	26.6	4.6
Foundation	DP.03.B174	1113	15.7	29.4	0.3	29.1	4.9
Foundation	DP.03.B169	1095	15.2	28.0	0.3	27.7	4.7
Foundation	DP.03.B176	1036	15.8	30.6	3.8	26.8	4.6
	average	1188	15.6	28.7	1.1	27.6	4.7
	<i>SD</i>	152	0.5	2.4	2.2	1.0	0.1
Modern	DP.35.B41	2007	13.3	27.6	3.4	24.2	4.3
Modern	DP.35.B244	2009	13.6	25.6	1.0	24.6	4.3
Modern	DP.35.B252	2008	13.0	25.5	0.7	24.8	4.4
Modern	DP.35.B258	2008	13.2	28.3	3.3	24.9	4.4
Modern	DP.35.B241	2008	15.0	32.7	6.3	26.4	4.6
Modern	DP.35.B242	2010	13.6	29.8	3.2	26.5	4.6
Modern	DP.35.B240	2009	14.3	26.8	2.2	24.6	4.3
	average	2008	13.7	28.0	2.9	25.2	4.4
	<i>SD</i>	1	0.7	2.6	1.9	0.9	0.1

Table S2. Probability of differences in $\delta^{15}\text{N}_{\text{Phe}}$, $\delta^{15}\text{N}_{\text{Glu}} - \delta^{15}\text{N}_{\text{Phe}}$ and trophic position between Late Expansion (Hawaii), Foundation (Maui) or Prehuman vs. Modern time periods.

Island	Time Period		Probability Ancient>Modern		
	Ancient	Modern	$\delta^{15}\text{N}_{\text{Phe}}$	$\delta^{15}\text{N}_{\text{Glu}} - \delta^{15}\text{N}_{\text{Phe}}$	Trophic Position
Hawaii	Prehuman	Modern	0.09	>0.99	>0.99
Hawaii	Late Expansion	Modern	0.08	>0.99	>0.99
Maui	Prehuman	Modern	0.13	>0.99	>0.99
Maui	Foundation	Modern	0.10	>0.99	>0.99

Table S3. Point estimates (means) and 95% credible intervals for $\delta^{15}\text{N}_a$ data by time period and location (Hawaii Island or Maui).

HAWAII ISLAND				
			Credible Interval	
Variable	Time Period	mean	2.50%	97.50%
$\delta^{15}\text{N}_{\text{phe}}$	Prehuman	4.5	3.3	5.7
	Late Expansion	4.6	3.6	5.5
	Modern	5.5	4.6	6.5
$\delta^{15}\text{N}_{\text{glu-phe}}$	Prehuman	23.8	22.8	24.9
	Late Expansion	23.4	22.5	24.2
	Modern	20.8	19.9	21.6
MAUI				
			Credible Interval	
		mean	2.50%	97.50%
$\delta^{15}\text{N}_{\text{phe}}$	Prehuman	1.5	-0.3	3.3
	Foundation	1.1	-1.0	3.3
	Modern	2.9	1.1	4.7
$\delta^{15}\text{N}_{\text{glu-phe}}$	Prehuman	27.8	26.9	28.7
	Foundation	27.6	26.6	28.6
	Modern	25.2	24.3	26.0

1. Steffan SA, Chikaraishi Y, Currie CR, Horn H, Gaines-day HR, Pauli JN, Zalapa JE, Ohkouchi N. 2015 Microbes are trophic analogs of animals. *Proc. Natl Acad. Sci. USA* 112, 15 119–15 124. (doi:10.1073/pnas.1508782112)