Supplementary Materials

Changes in trophic structure of an exploited fish community at the centennial scale are linked to fisheries and climate forces.

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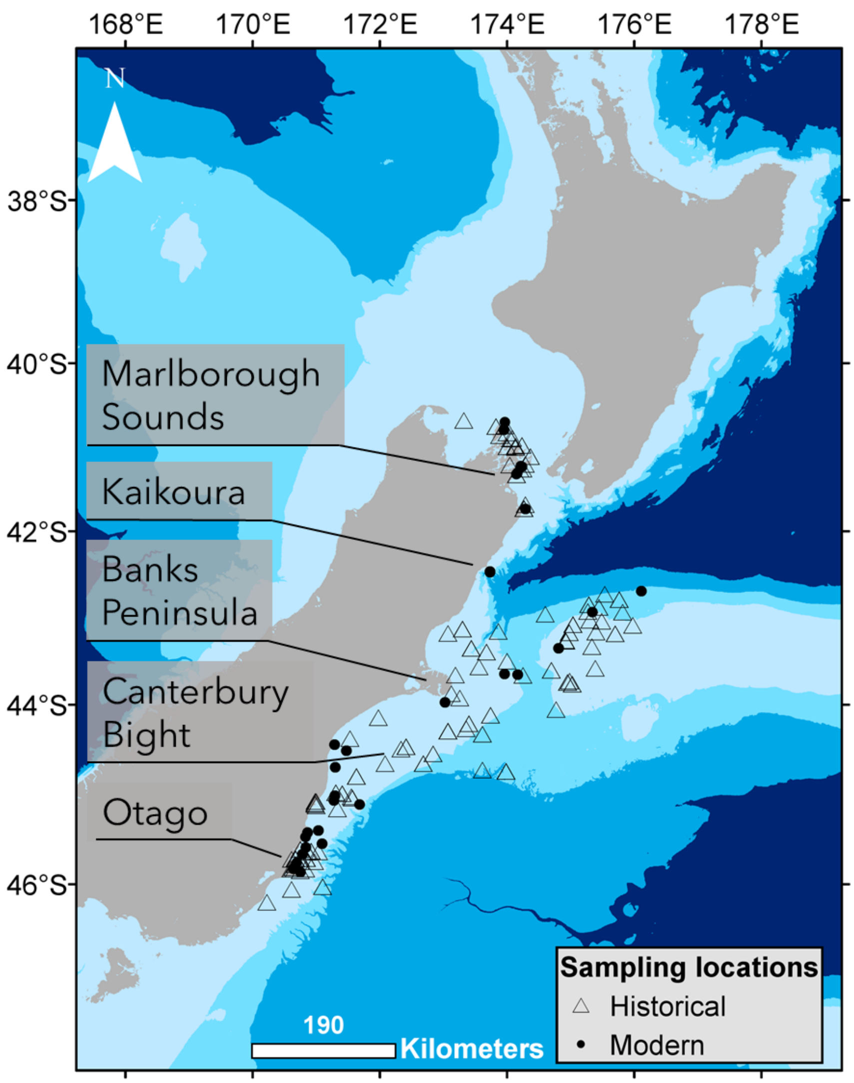


Fig. S1. Sample locations. Map of New Zealand marine environment with the location of historical (1919-1996) and modern (2000-2018) fish samples analyzed in the present study. Regions of interest are shown. Grey represents New Zealand landmass and blue shades (from light to dark) identify depth bands of 0 to 500, 500 to 1000, 1000 to 2000 and deeper than 2000 meters.

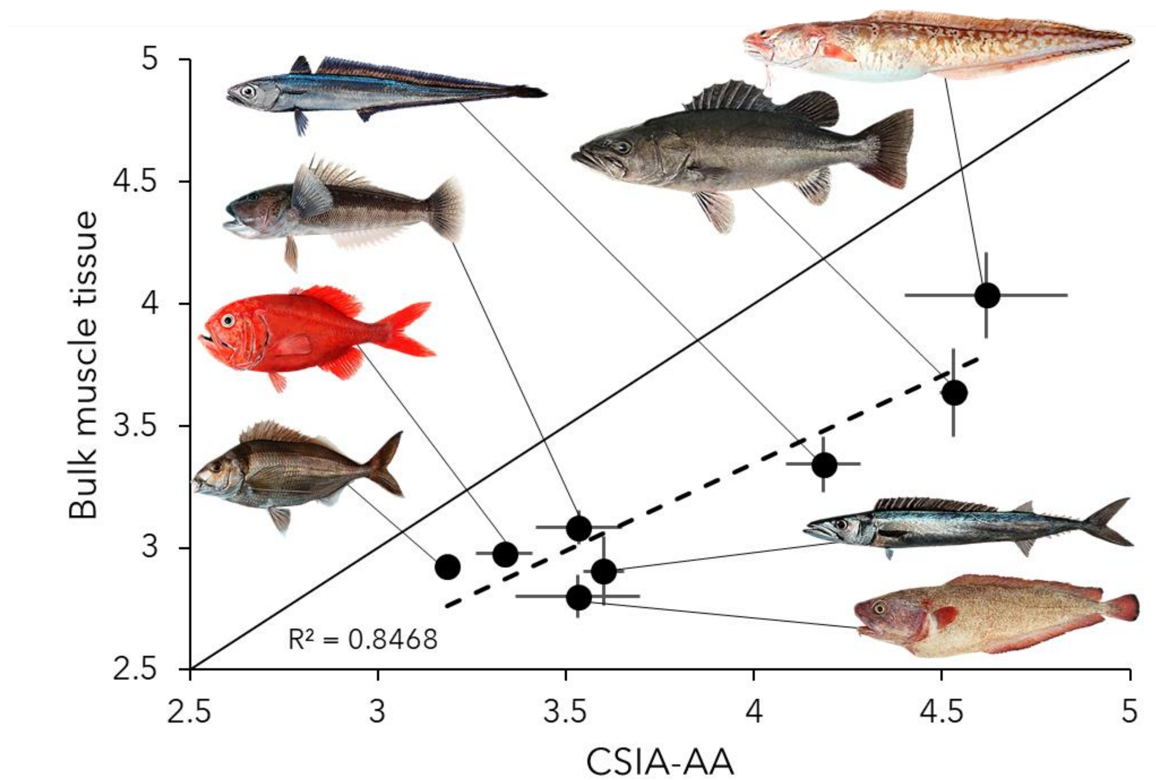
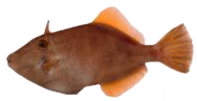
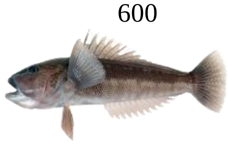
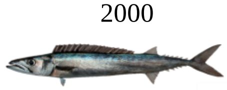
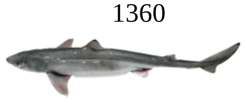


Fig. S2. Trophic level estimates for historical samples. Comparison between trophic level estimates (average ± SE) from bulk muscle tissue and compound-specific isotopic analysis of amino acids (CSIA-AA) for eight species of fishes sampled during the historical period (before 1996). Dashed line represents a linear regression between species estimates, while solid line is the 1:1 ratio between axes. Sample sizes: Blue cod (5), barracouta (6), red cod (7), tarakihi (8), hapuka (6), ling (7), hoki (6) and orange roughy (5).

Table S1.
Total length, habitat, depth distribution, assemblage group and common prey items of the fish species analyzed in the present study. Habitat data was retrieved from Fishbase.com, Beentjes *et al*. and Francis *et al*. Percentage of occurrence of food items were retrieved from Stevens *et al*.

Species	Total length (mm)	Habitat	Common prey items	Ref.
Leatherjacket *Meuschenia scaber*	310 	Inner shelf Demersal 0 - 100 m	Crustaceans Molluscs Sponges Tunicates Echinoderms Algae	[1] [2]
Blue cod *Parapercis colias*	600 	Inner shelf Demersal 0 - 150 m	Fish (47%) Crustaceans (23%) Tunicates (17%) Cephalopods Gastropods Bivalves Worms	[3] [2] [4] [5] Personal observation
Gurnard *Chelidonichthys kumu*	550 	Inner shelf Demersal 0 - 200 m	Crustaceans (50%) Fish (43%) Worms	[6] [5] [7]
Elephant fish *Callorhinchus milii*	970 	Inner shelf Demersal 0 - 200 m	Bivalves Jellyfish/hydroids	[5] [1] [8] [3]
Common warehou *Seriolella brama*	750 	Outer shelf Benthopelagic 0 - 400 m	Salps (97%) Crustaceans Jellyfish/hydroids Cephalopods	[9] [5] [7]
Barracouta *Thyrsites atun*	2000 	Outer shelf Benthopelagic 0 - 400 m	Crustaceans (77%) Fish (18%) Squid (9%)	[5] [3] [10] [11]
Tarakihi *Nemadactylus macropterus*	700 	Outer shelf Demersal 0 - 486 m	Chitons Gastropods Bivalves Crustaceans Echinoderms Polychaetas Cephalochordates	[12] [3] [2] [13] [14]
Spiny dogfish *Squalus acanthias*	1360 	Outer shelf Benthopelagic 0 - 500 m	Fish Squid/octopus Planktonic invertebrates Crustaceans	[5] [15] [16] [17]

			Jellyfish/hydroids Worms Bivalves	18 19

Continue in the next page

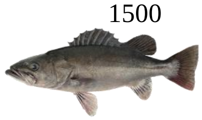
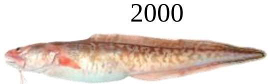
Species	Total length (mm)	Habitat	Common prey items	Ref.
Giant stargazer *Kathetostoma giganteum*	780 	Outer shelf Demersal 0 – 600	Fish (58%) Cephalopods (38%) Crustaceans (12%)	20 21 7
Red cod *Pseudophycis bachus*	900 	Outer shelf Demersal 0 - 700 m	Crustaceans (79%) Fish (25%) Molluscs Worms Echinoderms	20 22 5 3 23
Sea perch *Helicolenus percoides*	470 	Slope Demersal 0 - 500 m	Crustaceans (62%) Fish (18%) Worms	24 25 3
Lookdown dory *Cyttus traversi*	700 	Slope Bathydemersal 200 - 600 m	Crustaceans (82%) Fish (20%) Cnidarians Worms	1 26 27 28
Hoki *Macruronus novaezelandiae*	1020 	Slope Benthopelagic 200 - 600 m	Fish (60%) Crustaceans (43%) Cephalopods (5%) Sponges Tunicates Planktonic invertebrates	5 29 28 30 31
Hapuka *Polyprion oxygeneious*	1500 	Slope Demersal 0 – 850	Fish (68%) Cephalopods (25%) Crustaceans (18%)	32 33 34
Ling *Genypterus blacodes*	2000 	Slope Bathydemersal 0 - 1000 m	Fish (65%) Crustaceans (37%) Cephalopods (3%) Ophiuroids	35 20 36 3 37
Orange roughy *Hoplostethus atlanticus*	500 	Mid shelf Bathypelagic 700 - 1500 m	Crustaceans (58%) Fish (41%) Cephalopods Planktonic invertebrates Worms	38 5 39

Table S2.

Layman’s metrics calculated for the whole fish community and for specific assemblages (table S1). Mean and 95% credible interval of metrics were calculated with Bayesian framework using the SIBER package in R [40–42] and applying corrected carbon and nitrogen isotope values of fish muscle tissue from historical and modern periods. Mid-slope assemblage is comprised by orange roughy only and therefore is not shown. Using the description used by Jackson *et al.*: Total area of convex hull (TA): indication of niche breadth; Mean distance from species to community centroid (CD): additional information on niche breadth and species spacing; Mean nearest neighborhood distance (MNND): measure of density and clustering of species within the community; Standard deviation od MNND (SDNND): measure of evenness of spatial density and packing; Standard Ellipse Area corrected for small sample sizes (SEA_c): indication of niche breadth unbiased by different and small sample sizes. Bold values represent metrics that differed at the 95% credible interval between time periods.

		Mean		95% credible interval	
Assemblage	Metric	Historical	Modern	Historical	Modern
Whole community	$\delta^{15}N$ range	3.79	3.62	2.83 - 4.71	2.95 - 4.29
	$\delta^{13}C$ range	2.22	3.21	1.42 - 3.09	2.54 - 3.9
	TA*	3.60	5.87	2.05 - 5.28	4.42 - 7.36
	CD	**0.91**	**1.25**	0.73 - 1.1	1.1 - 1.41
	MNND	0.40	0.46	0.29 - 0.51	0.22 - 0.58
	SDNND	0.36	0.24	0.18 - 0.55	0.12 - 0.37
	TA**	12.48	23.09	-	-
	SEAc**	**1.89**	**3.73**	1.61 - 2.18	3.32 - 4.17
Inner shelf	$\delta^{15}N$ range	1.71	1.63	0.9 - 2.53	0.91 - 2.41
	$\delta^{13}C$ range	1.20	1.46	0.37 - 2.07	0.59 - 2.42
	TA*	0.77	1.00	0.1 - 1.48	0.36 - 1.72
	CD	0.75	0.81	0.41 - 1.1	0.53 - 1.1
	MNND	0.75	0.86	0.39 - 1.15	0.55 - 1.17
	SDNND	0.35	0.36	0.01 - 0.71	0.01 - 0.73
	TA**	10.21	11.00	-	-
	SEAc**	2.55	2.27	1.79 - 3.34	1.78 - 2.79
Outer shelf	$\delta^{15}N$ range	3.33	2.33	2.38 - 4.34	1.75 - 2.9
	$\delta^{13}C$ range	1.79	2.00	0.94 - 2.73	1.41 - 2.59
	TA*	2.30	1.97	0.88 - 3.84	0.99 - 3
	CD	1.06	0.94	0.78 - 1.37	0.73 - 1.15
	MNND	0.83	0.75	0.57 - 1.1	0.49 - 1
	SDNND	0.74	0.37	0.37 - 1.11	0.12 - 0.61
	TA**	7.45	20.64	-	-
	SEAc**	**2.16**	**3.54**	1.64 - 2.69	2.94 - 4.19
Slope	$\delta^{15}N$ range	1.71	3.15	0.81 - 2.63	2.26 - 4.04
	$\delta^{13}C$ range	1.47	2.09	0.62 - 2.37	1.52 - 2.67
	TA*	**0.80**	**2.60**	0.18 - 1.5	1.54 - 3.75
	CD	0.76	1.19	0.41 - 1.13	0.93 - 1.48
	MNND	0.56	1.00	0.25 - 0.9	0.7 - 1.3
	SDNND	0.28	0.55	0.02 - 0.56	0.16 - 0.95
	TA**	4.83	11.13	-	-
	SEAc**	**1.25**	**2.96**	0.94 - 1.59	2.33 - 3.6

*Calculated between species centroids

**Calculated using all data points of each ssemblage

Table S3.

Results from PERMANOVA analysis of interspecific value-predicted percentage phytoplankton supporting the food webs and trophic level between historical (before 1996) and modern (after 2000) periods. Numbers represent pseudo-F statistics calculated through at least 7281 unique permutations during PERMANOVA analysis, followed by its significance level.

	Percentage of phytoplankton			Trophic level		
Species	Historical	Modern	Pseudo-F	Historical	Modern	Pseudo-F
Leatherjacket	0.04 ± 0.01	0.0002 ± 0.0138	3.092	-0.2 ± -0.04	-0.0001 ± 0.0363	16.623***
Blue cod	-0.06 ± -0.02	-0.0001 ± 0.0107	4.059*	0.05 ± 0.02	0.0005 ± 0.0369	0.32
Gurnard	-0.05 ± -0.01	0.0014 ± 0.0078	4.497*	-0.3 ± -0.07	-0.0003 ± 0.0256	58.833***
Elephant fish	0.11 ± 0.03	0.0002 ± 0.0379	2.97	-0.26 ± -0.07	-0.0001 ± 0.0111	2.262
Common warehou	-0.01 ± -0.01	0.0005 ± 0.0118	0.282	0.03 ± 0.01	-0.0003 ± 0.0482	0.242
Barracouta	-0.03 ± -0.01	-0.0002 ± 0.0113	1.378	-0.16 ± -0.06	0.0002 ± 0.0308	1.821
Tarakihi	-0.12 ± -0.03	0 ± 0.0159	14.133***	-0.15 ± -0.03	0.0003 ± 0.0363	4.9*
Spiny dogfish	-0.07 ± -0.02	0 ± 0.0295	3.73	-0.57 ± -0.16	0.0005 ± 0.0784	33.507***
Giant stargazer	-0.01 ± 0	-0.0014 ± 0.0078	0.153	0.23 ± 0.06	-0.0003 ± 0.0599	4.34*
Red cod	0.05 ± 0.01	-0.0012 ± 0.0084	4.357*	-0.38 ± -0.1	-0.0004 ± 0.026	46.188***
Sea perch	-0.03 ± -0.01	0.0007 ± 0.008	3.784	0.34 ± 0.06	-0.0004 ± 0.0418	37.343***
Lookdown dory	-0.01 ± 0	-0.0026 ± 0.0098	0.014	0.13 ± 0.03	0.0014 ± 0.0389	0.2802
Hoki	-0.01 ± 0	-0.0003 ± 0.0115	0.043	-0.35 ± -0.11	0.0002 ± 0.0335	16.23**
Hapuka	0.14 ± 0.05	-0.0004 ± 0.026	8.657*	-0.48 ± -0.17	0.0031 ± 0.0389	18.652**
Ling	-0.12 ± -0.03	0.0047 ± 0.011	28.48***	-0.2 ± -0.05	0 ± 0.0556	5.685*
Orange roughy	-0.06 ± -0.01	0.0001 ± 0.0087	1.275	-0.54 ± -0.13	-0.0003 ± 0.0376	40.555***

0.05(*), 0.005(**) and 0.0005(***) significance level

Table S4.

Results of generalized linear models (slope estimates ± SE) describing the effects of abundance of pelagic prey (MUN), temperature (SST), Southern Oscillation Index (SOI) and fisheries (MTI) on the variability of percentage phytoplankton supporting the food webs and trophic level for each fish assemblage. Significance of species random effects are also presented in the form of p values.

	Percentage phytoplankton (value-predicted ± SE)	p value	Trophic level (value-predicted ± SE)	p value
Inner shelf	n = 181		n = 181	
Intercept	0.015 ± 0.021	0.509	-0.152 ± 0.025	<0.0001
MUN	0.0001 ± 0.0007	0.909	-0.008 ± 0.002	<0.0001
SST	-0.008 ± 0.019	0.688	-0.027 ± 0.052	0.607
SOI	-0.048 ± 0.033	0.138	0.117 ± 0.086	0.176
MTI	0.076 ± 0.065	0.242	-0.295 ± 0.169	0.089
Random effect (Species)	0.263		0.695	
Adjusted R^2	0.13		0.196	
Outer shelf	n = 220		n = 224	
Intercept	-0.03 ± 0.014	0.05	-0.126 ± 0.046	0.026
MUN	-0.001 ± 0.001	0.055	-0.005 ± 0.001	0.0003
SST	0.026 ± 0.021	0.213	0.042 ± 0.056	0.452
SOI	-0.044 ± 0.024	0.071	0.055 ± 0.066	0.403
MTI	-0.075 ± 0.071	0.29	-0.381 ± 0.189	0.046
Random effect (Species)	0.359		0.255	
Adjusted R^2	0.057		0.211	
Slope	n = 172		n = 171	
Intercept	-0.015 ± 0.026	0.585	-0.027 ± 0.086	0.767
MUN	0.0002 ± 0.0005	0.6715	-0.001 ± 0.001	0.6963
SST	-0.003 ± 0.025	0.911	0.266 ± 0.07	0.0002
SOI	0.138 ± 0.018	<0.0001	-0.366 ± 0.049	<0.0001
MTI	0.075 ± 0.092	0.416	-1.213 ± 0.26	<0.0001
Random effect (Species)	0.279		0.214	
Adjusted R^2	0.358		0.363	
Mid slope	n = 33		n = 33	
Intercept	-0.154 ± 0.073	0.044	-0.759 ± 0.09	<0.0001
MUN	0.0001 ± 0.002	0.947	0.01 ± 0.002	0.001
SST	0.035 ± 0.063	0.581	0.691 ± 0.078	<0.0001
SOI	-0.069 ± 0.09	0.452	-0.292 ± 0.111	0.014
MTI	0.93 ± 0.623	0.147	2.467 ± 0.77	0.004
Adjusted R^2	0.045		0.76	

	Percentage phytoplankton				
Species	Predictor equation/ average ± SD	Adjusted r^2	ΔAICc	p value (TOTAL LENGTH)	p value (LAT)
Barracouta	2.09667 + 0.03528 * LAT	0.68	2.01	-	0.0001
Blue cod	0.573 ± 0.081	-	-	-	-
Common warehou	0.564 ± 0.039	-	-	-	-
Ellephant fish	0.335 ± 0.085	-	-	-	-
Giant stargazer	0.65207 + -0.00033 * TOTAL LENGTH	0.42	2.63	0.003	-
Gurnard	0.68149 + -0.00079 * TOTAL LENGTH	0.65	2.44	<0.0001	-
Hapuka	0.486 ± 0.089	-	-	-	-
Hoki	0.708 ± 0.03	-	-	-	-
Leatherjacket	1.82423 + 0.03004 *LAT	0.33	-	-	0.001
Ling	1.66216 + -0.00027*TOTAL LENGTH + 0.02082*LAT	0.45	3.31	0.0002	0.021
Lookdown dory	-15.89447 -0.00039*TOTA LENGTH + -0.38175 *LAT	0.59	0.56	0.053	0.002
Orange roughy	0.696 ± 0.032	-	-	-	-
Red cod	2.03625 + -0.00052*TOTAL LENGTH + 0.02837*LAT	0.61	10.32	0.0007	0.0005
Sea perch	1.80186 + -0.00094*TOTAL LENGTH + 0.02267*LAT	0.37	9.9	0.0008	0.0001
Spiny dogfish	0.582 ± 0.121	-	-	-	-
Tarakihi	0.58 ± 0.119	-	-	-	-

	Trophic level				
Species	Predictor equation/ average ± SD	Adjusted r^2	ΔAICc	p value (TOTAL LENGTH)	p value (LAT)
Barracouta	9.34184 + 0.14702 * LAT	0.83	2.72	-	<0.0001
Blue cod	3.079 ± 0.281	-	-	-	-
Common warehou	3.175 ± 0.159	-	-	-	-
Ellephant fish	2.974 ± 0.025	-	-	-	-
Giant stargazer	3.902 ± 0.247	-	-	-	-
Gurnard	3.431 ± 0.123	-	-	-	-
Hapuka	-3.07412 + 0.00214 * TOTAL LENGH + -0.14006 *LAT	0.53	-0.27[1]	0.011	0.023
Hoki	3.679 ± 0.089	-	-	-	-
Leatherjacket	-0.33825 + -0.07838 *LAT	0.33	-	-	0.001
Ling	14.32206 + 0.22977*LAT	0.65	1.61	-	<0.0001
Lookdown dory	65.25656 + 0.00158*TOTAL LENGTH + 1.44929 *LAT	0.57	0.63	0.051	0.003
Orange roughy	3.476 ± 0.141	-	-	-	-
Red cod	3.228 ± 0.142	-	-	-	-
Sea perch	4.8621 + 0.00264*TOTAL LENGTH + 0.0674*LAT	0.3	1.5	0.056	0.019
Spiny dogfish	2.882 ± 0.323	-	-	-	-
Tarakihi	3.116 ± 0.274	-	-	-	-

Table S5.

Predicted equations and their fit of percentage phytoplankton supporting the food webs and trophic level for fish species sampled in the modern period. Latitude (LAT) and total length were used as predictors, but only variables contributing significantly to the general linear model ($p < 0.05$) were kept. When percentage phytoplankton and trophic level could not be predicted by any of the variables an average of values was used as te predicted value in the present study (see Materials and Methods).

Table S6.

Linear relationship between head length (HL) and total length for species analyzed in the present study, with respective summary of fit.

Common name	Total length regression equation	Sample size	r^2	p
Barracouta	163.32 + 3.3*HL	32	0.83	<0.0001
Blue cod	26.36 + 3.5*HL	84	0.98	<0.0001
Common warehou	-109.85 + 5.45*HL	12	0.94	<0.0001
Elephant fish	141.35 + 2.4*HL	9	0.59	0.015
Giant stargazer	7.66 + 4.02*HL	6	0.8	0.015
Gurnard	36.78 + 3.55*HL	27	0.96	<0.0001
Hapuka	-40.26 + 2.8*HL	4	0.99	0.0018
Leatherjacket	48.84 + 3.45*HL	29	0.83	<0.0001
Ling	150.81 + 3.8*HL	9	0.86	0.0003
Red cod	127.16 + 3.47*HL	14	0.52	0.0036
Sea perch	62.32 + 2.56*HL	56	0.88	<0.0001
Spiny dogfish	7.19 + 4.79*HL	20	0.93	<0.0001
Tarakihi	-13.95 + 4.21*HL	38	0.92	<0.0001

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