Supplement 1. Study area and sampling

Text S1. We set the meal-load sampling site (ca 100 m in length) along the road near Akaiwa light house and the sites A and B, ca 30 m by 80 m each, for monitoring breeding performance (Fig. S1). Site A was set in 1984 and used throughout the study and B was set in 2014. So data was collected in site A in 1984 – 2020 and in site B in 2014 -- 2020. On average, sites show significant effects on the chick growth rate and the number of fledglings per nests with chicks (Linear Model, $P<0.05$) as well as year ($P<0.05$). However, this was because of exceptionally small growth rate of 3 chicks in site B and the greater number of fledglings in site A in 2018 (Fig. S2). Overall interannual trends are similar between sites. Therefore, to increase sample size and to give more reliable average annual trend, we combine data of these two sites in 2014 -- 2020.

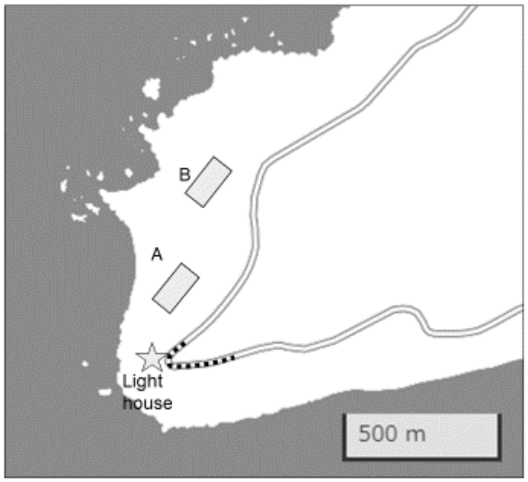

Fig. S1. Study sites in south-western part of Teuri Island. The dotted line on the road (open thick line) indicates meal-load sampling site. The squares (ca. 30 × 80 m) indicate the sites A and B for monitoring breeding performance. The star indicates the Akaiwa lighthouse.

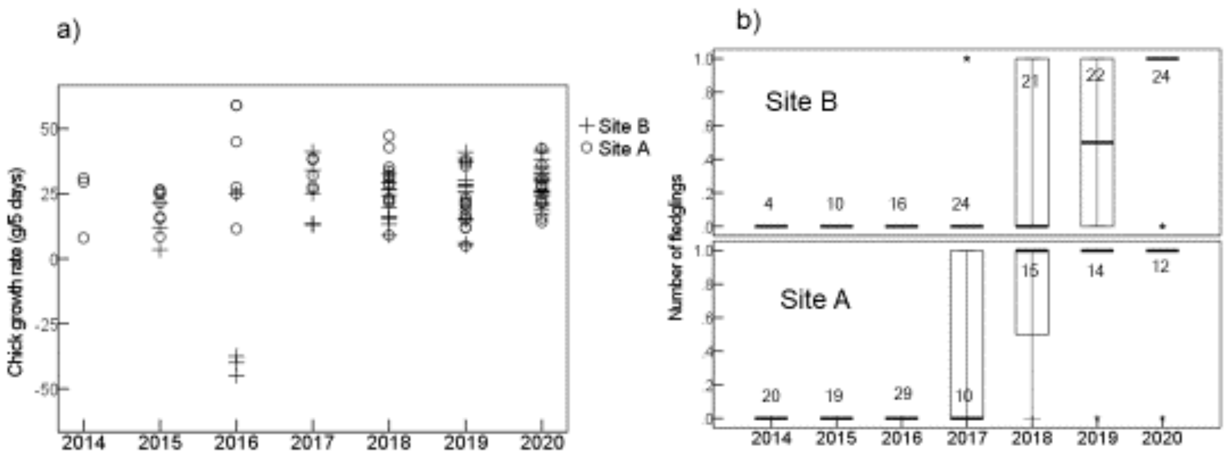

Fig. S2 Chick growth rate (a) and the number of fledglings per nests with chicks (b) in sites A and B in 2014 – 2020. In (b) the numbers of fledglings are shown as box-plot where the bottom and top of each box represent the 1st and 3rd quartiles, respectively, and the bold line indicates the median (2nd quartile). The number of nests in each site is also sown in (b).

Supplement 2. Energy value of meal-loads and effects on breeding performance

Text S2. The energy value of average meal-load in each year was estimated using energy densities of each prey species acquired from the literature, average mass of meal-load and the mass composition of nine major prey species/types in each year. We used median values of energy density of each prey species or that of the same genus from the literature (Table S1). Average mass of meal loads and prey species composition varied between years, so estimated energy density of average meal-loads did as shown in Table S2. Effects of the average meal-load mass and energy density of average meal-load on the chick growth, number of fledglings and fledgling mass are tested using Linear Model. Meal-load mass was selected as factors explaining the chick growth, number of fledglings and fledgling mass in all models (Table S3).

Table S1. Energy density of major fish species or the species belonging to the same genus of prey species from literatures.

Species	Energy density (KJ/g wet)	Reference
Sardine (*Sardinops* spp.)	8.6 - 10.5	Watanuki 1992, Grémillet et al. 2008
Anchovy (*Engraulis* spp.)	6.2 - 6.3	Takahashi et al. 2001, Grémillet et al. 2008
Herring (*Clupea* spp.)	6.5 - 8.0	Davis et al. 1998
Age-0 sand lance (*Ammodytes* spp.)	3.8 - 5.8	Harris & Hislop 1978, Anthony & Roby 1996, Takahashi et al. 2001
Age->1+sand lance (*Ammodytes* spp.)	4.8 - 6.5	Harris & Hislop 1978, Anthony & Roby 1996, Takahashi et al. 2001
Juvenile greenling (*Pleurogrammus* spp.)	3.2 - 5.0	Davis et al. 1998, Anthony et al. 2000, Takahashi et al. 2001
Pacific saury (*Cololabis saira*)	6.4	Davis et al. 1998
Juvenile salmon *(Onchorhynchus* sp.)	4	Anthony et al. 2000
Squid	4.1 - 4.7	Davis et al. 1998

References cited only in Table S1. See the references in the main text for others.

Anthony JA, Roby DD (1996) Variation in lipid content of forage fishes and its effect on energy provisioning rates to seabird nestlings. In: *Forage fishes in Marine Ecosystems*, University of Alaska Sea Grant College Program, Report No. 97-01, pp725-730.

Anthony JA, Roby DD, Turco KR (2000) Lipid content and energy density of forage fishes from the northern Gulf of Alaska. J Exp Mar Biol Ecol 248:53-78. https://doi.org/10.1016/S0022-0981(00)00159-3

Davis N, Myers K, Ishida Y (1998) Caloric value of high-seas salmon prey organisms and simulated salmon ocean growth and prey consumption. North Pacific Anadromous Fish Commission Bulletin 1:146-162.

Harris MP, Hislop JRG (1978) The food of young puffins *Fratercula arctica*. J Zool Lond 185:213-236. https://doi.org/10.1111/j.1469-7998.1978.tb03323.x

Watanuki Y (1992) Individual diet difference, parental care, and reproductive success in Slaty-backed Gulls. Condor 94:159-171. https://doi.org/10.2307/1368805

Table S2. Breeding performance and chick diet of Rhinoceros Auklets breeding at Teuri Island. Annual average of hatch date in May (HAT), the number of fledglings per nest with chicks (NF), the growth rate of chicks in linear growth phase (CG, g/5days), the mass of fledglings (FLM, g), the mass of meal-loads (BLM, g), energy density of meal-loads (EDN, KJ/g), energy value of meal-loads (EVU, KJ), and the mass proportion of sardine (SAR), anchovy (ENG), herring (HER), age-0 sand lance (SL0), age->1 sand lance (SL1), Pacific saury (PSA), age-0 Japan Sea greenling (JGR), juvenile salmon (SAL) and squid (SQD) in the meal-loads.

Year	HAT	NF	CG	FLM	BLM	EDN	EVU	SAR	ENG	HER	SL0	SL1	PSA	JGR	SAL	SQD
1984	41	0.27	29.8	235	24.2	6.6	159.65	0.252	0.005	0.020	0.106	0.315	0.214	0.074	0.013	0.002
1985	27	0.56	48.7	292.4	31.5	6.38	201.11	0.217	0.019	0.184	0.008	0.215	0.063	0.278	0.016	0.001
1987	35.5	0.55	30.5	199	23.6	6.31	148.83	0.178	0.026	0.000	0.184	0.286	0.264	0.049	0.003	0.009
1992	23	0.8	40.1	381.1	29.3	5.26	154.02	0.000	0.300	0.000	0.432	0.134	0.000	0.120	0.007	0.007
1993	23	0.9	40.9	410.9	30.8	5.61	172.73	0.000	0.575	0.000	0.256	0.055	0.001	0.088	0.003	0.022
1994	27	0.88	59.9	398.1	35.1	6.18	216.77	0.000	0.918	0.000	0.005	0.063	0.000	0.010	0.004	0.000
1995	21	0.84	41.6	379.6	32.1	5.36	172	0.000	0.501	0.000	0.227	0.015	0.000	0.247	0.010	0.000
1996	29	0.77	32.3	338.5	29.3	5.57	163.11	0.000	0.539	0.000	0.298	0.065	0.000	0.080	0.018	0.000
1997	33.5	0.67	23.1	257.3	23	4.74	108.95	0.000	0.160	0.000	0.148	0.091	0.015	0.529	0.009	0.048
1998	26.5	0.93	45.2	367.3	30.3	6.04	183.06	0.000	0.870	0.000	0.062	0.017	0.000	0.032	0.014	0.004
1999	36.5	0.83	54.5	385.7	30.3	5.78	175.15	0.000	0.748	0.000	0.097	0.003	0.000	0.148	0.000	0.005
2000	31	0.42	28.4	288.9	27.8	5.86	162.96	0.000	0.722	0.000	0.190	0.042	0.000	0.000	0.005	0.042
2001	38	0.93	48.9	350	28.8	6.05	174.37	0.000	0.881	0.000	0.032	0.022	0.000	0.043	0.005	0.017
2002	17.5	0.92	64.7	423.7	35.2	6.04	212.59	0.000	0.875	0.000	0.014	0.029	0.000	0.070	0.000	0.013
2003	27.5	0.71	56.7	401.4	33	6.12	201.94	0.000	0.915	0.000	0.047	0.013	0.000	0.024	0.000	0.002
2004	38	0.41	47.1	347.8	35.5	6.2	220.24	0.000	0.936	0.000	0.006	0.021	0.025	0.002	0.011	0.000
2005	30	0.7	39.9	373.8	29.9	5.51	164.84	0.000	0.637	0.000	0.060	0.000	0.000	0.299	0.000	0.004
2006	35.5	0.62	33.6	312	28.2	5.67	160.02	0.000	0.647	0.000	0.033	0.093	0.000	0.175	0.000	0.052
2007	34.5	0.65	41.1	342.7	35.9	6.18	221.75	0.000	0.946	0.000	0.001	0.027	0.000	0.020	0.004	0.001
2008	21.5	0.7	34.5	307.3	29.4	5.9	173.59	0.000	0.828	0.000	0.011	0.008	0.000	0.142	0.002	0.009
2009	31.5	0.69	42.7	379.3	28.4	5.84	165.8	0.000	0.796	0.000	0.039	0.000	0.000	0.160	0.005	0.000
2010	44	0.36	33.1	244.1	28.1	6.12	171.89	0.000	0.915	0.000	0.008	0.026	0.001	0.031	0.005	0.015
2011	34.5	0.71	45.2	305.1	31.2	6.08	189.55	0.000	0.919	0.000	0.000	0.000	0.000	0.081	0.000	0.000
2012	41.5	0.55	62.8	344.6	28.4	6.15	174.53	0.005	0.929	0.000	0.004	0.009	0.000	0.049	0.000	0.003
2013	49	0.42	42.9	230.6	26.8	6.15	164.71	0.000	0.911	0.002	0.053	0.027	0.000	0.002	0.000	0.005
2014	35	0	22.8	NA	18.8	4.42	83.19	0.000	0.000	0.067	0.078	0.018	0.003	0.746	0.003	0.086
2015	35.5	0	18.3	NA	17.9	4.65	83.22	0.000	0.054	0.067	0.195	0.000	0.000	0.402	0.004	0.277
2016	28	0	13	NA	16.6	4.69	77.82	0.041	0.000	0.000	0.274	0.015	0.023	0.242	0.067	0.338
2017	26	0.2	26.5	181.8	20.3	4.29	87	0.000	0.000	0.000	0.062	0.031	0.020	0.717	0.004	0.166
2018	29	0.52	25.6	238.8	20.9	5.68	118.62	0.178	0.008	0.000	0.525	0.133	0.005	0.115	0.016	0.021
2019	22.5	0.67	22.9	256.5	23	4.94	113.64	0.000	0.088	0.076	0.350	0.100	0.002	0.348	0.003	0.034
2020	19	0.86	28.3	244.5	20.9	5.23	109.07	0.000	0.008	0.104	0.400	0.319	0.000	0.147	0.000	0.023

Table S3. Model selection and parameter estimates for the models (Linear Model) explaining the chick growth rates, the number of fledglings per nests with chicks, and mass of fledglings. Candidate of factors are the mass (BLM, g) and the energy density (EDN, KJ/g) of meal-loads. Annual average values are used. Model selection is based on AICc. AICc, ⊿AICc and Akaike weight are shown. Equally supported models (⊿AICc<2.00) are in bold. Parameter estimates are for the best model or average model (full average). Sample size is 32 years for the chick growth rate and the number of fledglings but 29 for the mass of fledglings.

Chick growth rate

Model selection					
Models	df	logLik	AICc	⊿AICc	weight
BLM	3	-109.182	225.2	0	0.648
BLM+EDN	4	-108.482	226.4	1.22	0.352
EDN	3	-118.606	244.1	18.85	0
NULL	2	-127.19	258.8	33.57	0
Parameter estimates (model averaging, full average)					
	Estimate	Std. Error	Adjusted SE	Z- value	P
(Intercept)	-22.9326	11.6626	12.0342	1.906	0.057
BLM	1.9142	0.3274	0.3391	5.645	<0.001
EDN	1.4664	2.6078	2.6734	0.549	0.5833

Number of fledglings

Model selection					
Models	df	logLik	AICc	⊿AICc	weight
BLM	3	5.501	-4.1	0	0.764
BLM+EDN	4	5.631	-1.8	2.36	0.234
EDN	3	-0.726	8.3	12.45	0.002
NULL	2	-3.421	11.3	15.4	0
Parameter estimates (best model)					
	Estimate	Std. Error	t -value	P	
(Intercept)	-17.7753	7.2208	-2.462	0.02	
BLM	2.0287	0.2567	7.903	<0.001	

Mass of fledglings

Model selection					
Models	df	logLik	AICc	⊿AICc	weight
BLM+EDN	4	-146.454	302.6	0	0.716
BLM	3	-148.732	304.4	1.85	0.284
EDN	2	-163.303	331.1	28.49	0
NULL	3	-162.669	332.3	29.72	0
Paramater estimates (model averaging, full average)					
	Estimate	Std. Error	Adjusted SE	z-value	P
(Intercept)	75.773	98.695	101.77	0.745	0.457
BLM	14.044	2.135	2.221	6.324	<0.001
EDN	-27.722	20.884	21.408	1.295	0.195

Supplement 3. Effects of prey species composition and fish size on the mass of meal-loads

Text S3. Prey composition indexed by PC1 and PC2 affected the mass of meal-loads. The effects were determined by comparing fitness of linear or parabolic regressions using coefficient of determination (r^2) and AICc. Model selection shows that parabolic effects have smaller AICc and so are more appropriate than linear effects (Table S4 ab). This is because the mass of meal loads varied greatly between prey species (Fig. S3). Using meal-loads comprised of a single fish species and of all intact fish, linear and parabolic effects of the number of fish in each meal-loads on the size of fish (Fig. S4, Table S5) and the mass of meal-loads (Table S6) are tested. Models showing larger coefficient of determination (r^2) and smaller AICc are more appropriate and shown by bold.

Table S4a. Parabolic and linear regressions of the index of forage fish prey composition (PC1 and PC2) on the annual average of mass of meal-loads (BLM). Coefficient of determination (r^2), significance level (P) and AICc are shown. Best models (see Table S4b) are in bold. Sample size is 32 years.

Equations for PC1	r^2	P	AICc
$BLM=25.040-5.835PC1+2.684PC1^2$	**0.582**	**<0.001**	**178.1**
$BLM=27.643-3.338PC1$	0.397	<0.001	187.2
Equations for PC2	r^2	P	AICc
$BLM=29.022-1.845PC2-1.426PC2^2$	**0.518**	**<0.001**	**182.7**
$BLM=27.641-2.786PC2$	0.276	0.002	193.1

Table S4b. Selection for models explaining the annual average mass of meal-loads basing on AICc. Linear Models are constructed. AICc, ⊿AICc and Akaike weight are shown. Best models are in bold. Parameter estimates of the best model are shown with significance level (P).

Models for PC1	df	logLik	AICc	⊿AICc	weight
$PC1+PC1^2$	**4**	**-84.316**	**178.1**	**0**	**0.99**
PC1	3	-90.184	187.2	9.11	0.01
NULL	2	-98.277	201	22.85	0
$PC1^2$	3	-97.779	202.4	24.3	0
Parameter estimates	Estimate	Std. Error	t value	P	
(Intercept)	25.0401	0.959	26.111	<0.001	
PC1	-5.8348	0.9432	-6.186	<0.001	
$PC1^2$	2.6844	0.7489	3.584	0.001	
Models for PC2	df	logLik	AICc	⊿AICc	weight
$PC2+PC2^2$	**4**	**-86.612**	**182.7**	**0**	**0.865**
$PC2^2$	3	-89.82	186.5	3.79	0.13
PC2	3	-93.111	193.1	10.37	0.005
NULL	2	-98.277	201	18.26	0
Parameter estimates	Estimate	Std. Error	t value	P	
(Intercept)	29.0221	0.7644	37.966	<0.001	
PC2	-1.8447	0.7271	-2.537	0.017	
$PC2^2$	-1.4263	0.3742	-3.812	<0.001	

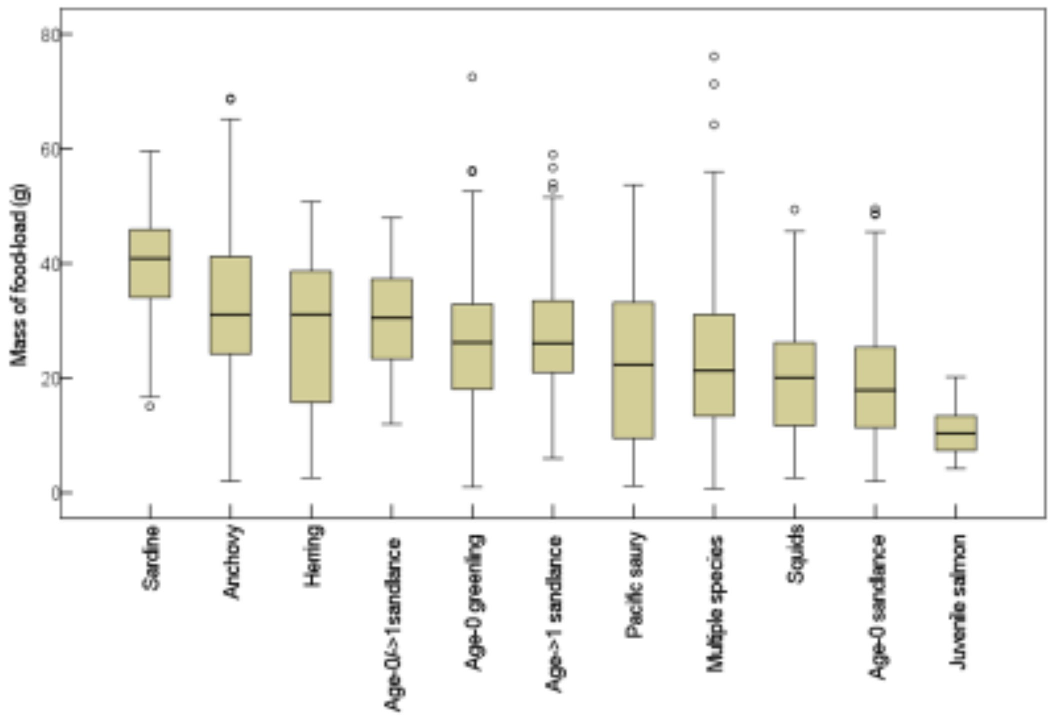

Fig. S3. Box plots of the mass of food-loads comprised of a single species of fish, those of multiple species and of the mixture of age-0 and age->1 sandlance. The bottom and top of each box represent the 1st and 3rd quartiles, respectively, and the bold line indicates the median (2nd quartile) of the distribution. The bottom and top whiskers are the minimum and maximum values, respectively, excluding outlier values shown as open circles (outside 1.5 × interquartile range). See Table 1 for detail.

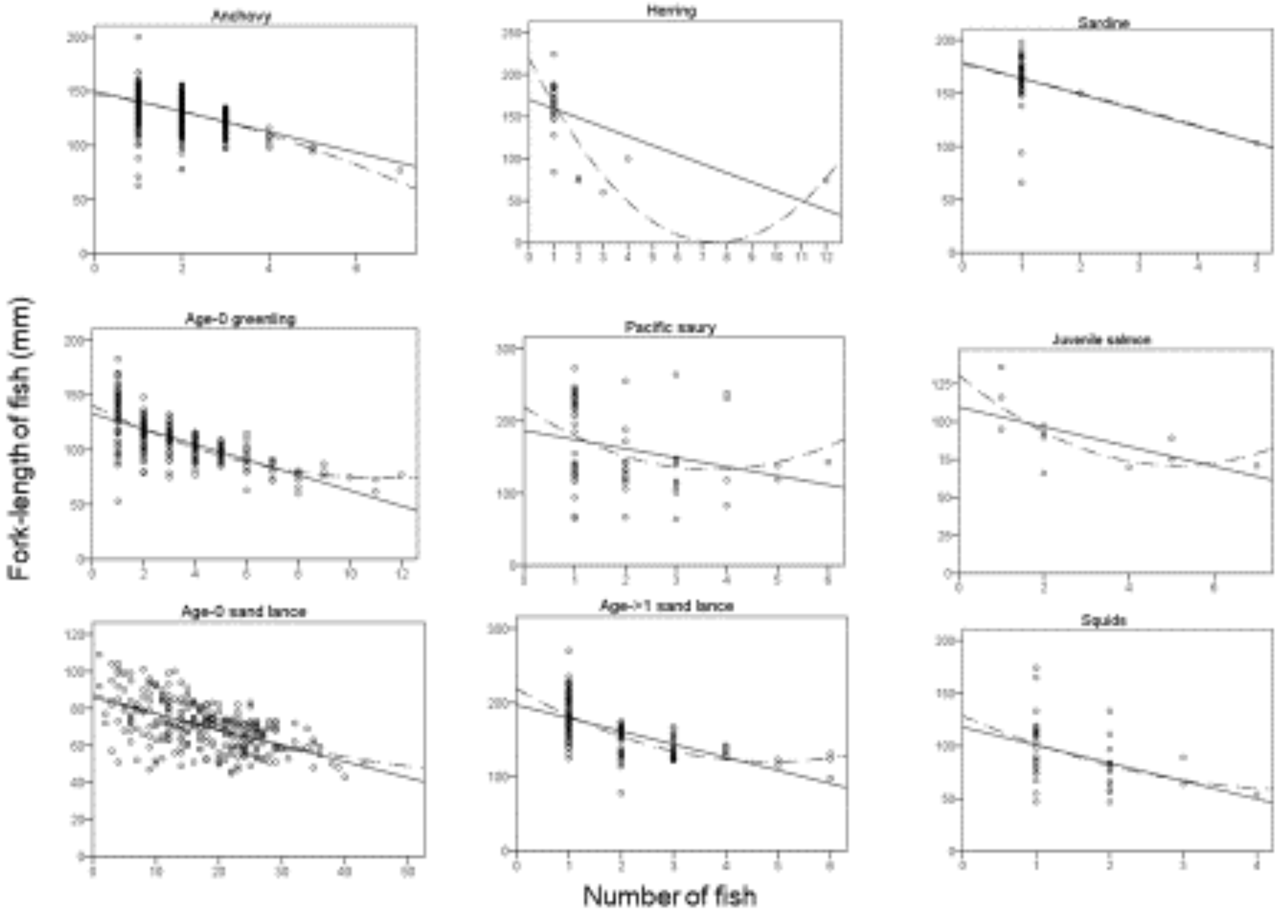

Fig. S4. Linear (strait line) and parabolic (broken line) regression lines for effects of the number of fish on the average fork-length of fish in a meal-load for nine major fish species/types including intact fish only.

Table S5a. Linear and parabolic regressions of the number of fish (N) on the average fork-length of fish in meal- load (L). Meal-loads including single prey species and only fish with intact body are used. Model selection is performed basing on AICc (see Table S5b). More appropriate models showing smaller AICc and significant coefficient of determination (r^2) is in bold. Number of meal-loads is in parenthesis.

Species	Effect	Equation	r^2	P	AICc
Anchovy (1,225)	**Parabolic**	**$L=147.421-6.375N-0.749N^2$**	**0.286**	**<0.001**	**9135.4**
	Linear	L=150.027-9.433N	0.282	<0.001	9139.9
Age-0 greenling (282)	**Parabolic**	**$L=140.582-11.784N+0.523N^2$**	**0.495**	**<0.001**	**2343.2**
	Linear	L=132.954-7.016N	0.469	<0.001	2355.1
Age-0 sand lance (310)	**Linear**	**L=85.782-0.863N**	**0.319**	**<0.001**	**2338.6**
	Parabolic	$L=87.642-1.113N+0.007N^2$	0.321	<0.001	2339.7
Age->1 sand lance (148)	Parabolic	$L=218.631-40.414N+4.149N^2$	0.429	<0.001	1369.9
	Linear	L=196.73-17.641N	0.375	<0.001	1381
Sardine (62)	Linear	L=179.174-15.176N	0.14	0.003	443.7
	Parabolic	$L=177.125-12.721N-0.421N^2$	0.14	0.012	444.5
Pacific saury (66)	Parabolic	$L=219.326-46.623N+6.261N^2$	0.103	0.032	701.8
	Linear	L=186.664-12.531N	0.069	0.034	704.4
Herring (32)	**Parabolic**	**$L=219.282-57.928N+3.835N^2$**	**0.556**	**<0.001**	**310.3**
	Linear	L=170.261-10.907N	0.293	0.001	322.5
Juvenile salmon (11)	Linear	L=109.578-6.511N	0.392	0.039	101.2
	Parabolic	$L=130.675-23.256N+2.267N^2$	0.519	0.054	103.8
Squid (42)	**Linear**	**L=117.762-17.000N**	**0.172**	**0.006**	**399.6**
	Parabolic	$L=128.323-29.886N+3.202N^2$	0.178	0.022	401.7

Table S5b. Model selection and parameter estimates for the models (Linear Mixed Model) explaining the size of fish in meal-loads comprised of a single species of fish with intact body. To test if the number of fish in each meal-loads showed quadratic or linear effects, candidate of factors are the number of fish (N) and its square (N^2). Meal-load is random factor. Model selection is based on AICc and the best or equally supported models (⊿AICc<2.00) are in bold. Parameter estimates are for the best model or average model (full average) when multiple models are equally supported. Sample size (n) is the number of meal-loads.

Anchovy (n=1,225)

Models	df	logLik	AICc	⊿AICc	weight
$N+N^2$	**4**	**-4563.683**	**9135.4**	**0**	**0.907**
N	3	-4566.963	9139.9	4.55	0.093
N^2	3	-4576.204	9158.4	23.03	0
NULL	2	-4769.612	9543.2	407.84	0

Parameter estimates (best model)	Estimate	Std. Error	t value	P
(Intercept)	147.4209	1.2529	117.666	<0.001
N	-6.3746	1.2689	-5.024	<0.001
N^2	-0.7529	0.2939	-2.561	0.011

Age-0 greenling(n=282)					
Models	df	logLik	AICc	⊿AICc	weight
$N+N^2$	**4**	**-1167.521**	**2343.2**	**0**	**0.997**
N	3	-1174.525	2355.1	11.95	0.003
N^2	3	-1202.095	2410.3	67.09	0
NULL	2	-1263.807	2531.7	188.47	0
Parameter estimates (best model)	Estimate	Std. Error	t value	P	
(Intercept)	140.5822	2.6212	53.633	<0.001	
N	-11.7843	1.3384	-8.805	<0.001	
N^2	0.5232	0.1388	3.769	<0.001	
Age-0 sand lance (n=309)					
Models	df	logLik	AICc	⊿AICc	weight
N	**3**	**-1166.253**	**2338.6**	**0**	**0.636**
$N+N^2$	**4**	**-1165.787**	**2339.7**	**1.12**	**0.363**
N^2	3	-1174.153	2354.4	15.8	0
NULL	2	-1225.673	2455.4	116.8	0
Parameter estimates (model averaging)	Estimate	Std. Error	Adjusted SE	z value	P
(Intercept)	86.467763	2.054883	2.061452	41.945	<0.001
N	-0.955464	0.211989	0.212554	4.495	<0.001
N^2	0.002472	0.005343	0.005356	0.461	0.644
Age>1 sand lance (n=148)					
Models	df	logLik	AICc	⊿AICc	weight
$N+N^2$	**4**	**-680.82**	**1369.9**	**0**	**0.996**
N	3	-687.419	1381	11.08	0.004
N^2	3	-698.547	1403.3	33.34	0
NULL	2	-722.255	1448.6	78.67	0
Parameter estimates (best model)	Estimate	Std. Error	zvalue	P	
(Intercept)	218.631	7.017	31.159	<0.001	
N	-40.414	6.451	-6.265	<0.001	
N^2	4.149	1.128	3.677	<0.001	
Sardine (n=62)					
Models	df	logLik	AICc	⊿AICc	weight
NULL	**2**	**-218.789**	**441.8**	**0**	**0.487**
N^2	**3**	**-218.567**	**443.5**	**1.77**	**0.201**
N	**3**	**-218.653**	**443.7**	**1.94**	**0.185**
$N+N^2$	4	-217.885	444.5	2.69	0.127
Parameter estimates (model averaging)	Estimate	Std. Error	Adjusted SE	zvalue	P
(Intercept)	39.8669	8.1435	8.2272	4.846	<0.001
N	2.7186	9.6538	9.7494	0.279	0.78
N^2	-0.5752	1.6728	1.6888	0.341	0.733

Pacific Saury (n=66)					
Models	df	logLik	AICc	⊿AICc	weight
$N+N^2$	**4**	**-346.595**	**701.8**	**0**	**0.776**
N	3	-349.003	704.4	2.55	0.217
N^2	3	-352.386	711.2	9.31	0.007
NULL	2	-360.797	725.8	23.94	0
Parameter estimates (best model)	Estimate	Std. Error	t value	P	
(Intercept)	250.955	20.806	12.062	<0.001	
N	-66.899	19.245	-3.476	<0.001	
N^2	7.467	3.42	2.184	0.033	
Herring (n=32)					
Models	df	logLik	AICc	delta	weight
$N+N^2$	**4**	**-150.406**	**310.3**	**0**	**0.998**
N	3	-157.84	322.5	12.24	0.002
N^2	3	-160.304	327.5	17.17	0
NULL	2	-163.397	331.2	20.92	0
Parameter estimates (best model)	Estimate	Std. Error	t value	P	
(Intercept)	219.2816	13.4043	16.359	<0.001	
N	-57.928	11.624	-4.983	<0.001	
N^2	3.8353	0.9261	4.141	<0.001	
Juvenile salmon (n=11)					
Models	df	logLik	AICc	delta	weight
N	**3**	**-45.864**	**101.2**	**0**	**0.467**
NULL	**2**	**-48.597**	**102.7**	**1.54**	**0.217**
N^2	**3**	**-46.752**	**102.9**	**1.78**	**0.192**
$N+N^2$	4	-44.575	103.8	2.66	0.124
Parameter estimates (model avraging)	Estimate	Std. Error	Adjusted SE	z-value	P
(Intercept)	116.6587	19.023	20.6434	5.651	<0.001
N^2	0.9318	1.639	1.7664	0.527	0.598
N	-12.8469	12.7479	13.7031	0.938	0.348
Squids (n=42)					
Model selection					
Models	df	logLik	AICc	delta	weight
N	**3**	**-196.487**	**399.6**	**0**	**0.514**
N^2	**3**	**-197.097**	**400.8**	**1.22**	**0.279**
$N+N^2$	4	-196.334	401.7	2.14	0.176
NULL	2	-200.458	405.2	5.62	0.031
Parameter estimates (model averaging)	Estimate	Std. Error	Adjusted SE	value	P
(Intercept)	115.3	15.973	16.292	7.077	<0.001
N	-14.735	16.224	16.518	0.892	0.372
N^2	-0.342	3.758	3.828	0.089	0.929

Table S6. Model selection and parameter estimates for the models explaining the mass of meal-loads comprised of a single species of fish by the number of fish. LMM (Linear Mixed Model) are constructed where meal-load is random factor. To test if the number of fish in each meal-loads showed parabolic or linear effects, candidate of factors are the number of fish (N) and its square (N^2). Model selection is based on AICc and the best or equally supported models (⊿AICc<2.00) are in bold. Parameter estimates are for the best model or average model (full average) when multiple models are equally supported. Sample size (n) is the number of meal-loads.

Anchovy (n=1,231)

Models	df	logLik	AICc	⊿AICc	weight
N+N²	**4**	**-4317.467**	**8643**	**0**	**1**
N	3	-4445.591	8897.2	254.23	0
N²	3	-4593.635	9193.3	550.32	0
NULL	2	-4747.962	9499.9	856.97	0
Parameter estimates (best model)	Estimate	Std. Error	t value	P	
(Intercept)	3.4549	0.9992	3.458	<0.001	
N	26.4876	1.0045	26.37	<0.001	
N²	-3.8748	0.2299	-16.857	<0.001	

Age-0 greenling (n=284)

Models	df	logLik	AICc	⊿AICc	weight
N+N²	**4**	**-1064.99**	**2138.1**	**0**	**1**
N	3	-1079.783	2165.7	27.53	0
N²	3	-1088.75	2183.6	45.46	0
NULL	2	-1094.523	2193.1	54.97	0
Parameter estimates (best model)	Estimate	Std. Error	t value	P	
(Intercept)	14.24686	1.76412	8.076	<0.001	
N	6.46211	0.90327	7.154	<0.001	
N²	-0.52099	0.09379	-5.555	<0.001	

Age-0 sand lance (n=315)

Models	df	logLik	AICc	⊿AICc	weight
N+N²	**4**	**-1128.755**	**2265.6**	**0**	**1**
N	3	-1145.016	2296.1	30.47	0
N²	3	-1150.895	2307.9	42.23	0
NULL	2	-1154.779	2313.6	47.96	0
Parameter estimates (best model)	Estimate	Std. Error	t value	P	
(Intercept)	5.079339	1.980637	2.564	0.011	
N	1.522068	0.221803	6.862	<0.001	
N²	-0.033247	0.005707	-5.825	<0.001	

Age->1 sand lance (n=148)

Models	df	logLik	AICc	⊿AICc	weight
N	**3**	**-550.875**	**1107.9**	**0**	**0.423**
N^2	**3**	**-550.915**	**1108**	**0.08**	**0.407**
$N+N^2$	**4**	**-550.733**	**1109.7**	**1.83**	**0.17**
NULL	2	-558.408	1120.9	12.98	0.001
Parameter estimates (model averaging)	Estimate	Std. Error	Adjusted SE	zvalue	P
(Intercept)	24.0128	2.1651	2.1763	11.034	<0.001
N	1.5252	1.8199	1.8269	0.835	0.404
N^2	0.2519	0.3173	0.3185	0.791	0.429

Sardine (n=62)

Models	df	logLik	AICc	⊿AICc	weight
NULL	**2**	**-218.789**	**441.8**	**0**	**0.487**
N^2	**3**	**-218.567**	**443.5**	**1.77**	**0.201**
N	**3**	**-218.653**	**443.7**	**1.94**	**0.185**
$N+N^2$	4	-217.885	444.5	2.69	0.127
Parameter estimates (model averaging)	Estimate	Std. Error	Adjusted SE	zvalue	P
(Intercept)	39.8669	8.1435	8.2272	4.846	<0.001
N	2.7186	9.6538	9.7494	0.279	0.78
N^2	-0.5752	1.6728	1.6888	0.341	0.733

Pacific Saury (n=66)

Models	df	logLik	AICc	⊿AICc	weight
N	**3**	**-258.73**	**523.8**	**0**	**0.464**
N^2	**3**	**-259.422**	**525.2**	**1.38**	**0.232**
$N+N^2$	**4**	**-258.326**	**525.3**	**1.46**	**0.224**
NULL	2	-261.585	527.4	3.51	0.08
Parameter estimates (model averaging)	Estimate	Std. Error	Adjusted SE	Z-value	P
(Intercept)	27.74086	4.58867	4.63978	5.979	<0.001
N	-3.2267	3.80738	3.84404	0.839	0.401
N^2	0.08928	0.64217	0.64869	0.138	0.891

Herring (n=34)

Models	df	logLik	AICc	⊿AICc	weight
$N+N^2$	**4**	**-131.667**	**272.7**	**0**	**0.723**
NULL	2	-135.671	275.7	3.02	0.16
N	3	-135.325	277.5	4.74	0.068
N^2	3	-135.637	278.1	5.36	0.05
Parameter estimates (best model)	Estimate	Std. Error	t value	P	
(Intercept)	48.5064	5.7564	8.427	<0.001	
N	-14.4156	5.0483	-2.856	0.008	
N^2	1.0984	0.4026	2.728	0.01	

Juvenile salmon (n=11)

Models	df	logLik	AICc	⊿AICc	weight
NULL	**2**	**-33.2**	**71.9**	**0**	**0.71**
N	3	-32.813	75.1	3.15	0.147
N^2	3	-32.923	75.3	3.37	0.131
$N+N^2$	4	-32.675	80	8.12	0.012
Parameter estimates (best model)	Estimate	Std. Error	t value	P	
(Intercept)	11.591	1.565	7.406	<0.001	

Squids (n=52)

Models	df	logLik	AICc	⊿AICc	weight
NULL	**2**	**-197.998**	**400.2**	**0**	**0.398**
N	**3**	**-197.243**	**401**	**0.74**	**0.274**
N^2	**3**	**-197.394**	**401.3**	**1.05**	**0.236**
$N+N^2$	4	-197.162	403.2	2.93	0.092
Parameter estimates (model averaging)	Estimate	Std. Error	Adjusted SE	z-value	P
(Intercept)	18.1674	4.0965	4.1712	4.355	<0.001
N	1.3526	3.6726	3.7402	0.362	0.718
N^2	0.0348	0.7983	0.8144	0.043	0.966

Supplement 4. SST of the sea around Teuri Island

Text S4. To look at the annual trends of sea surface temperature (SST) and to examine if the shift of PDO is associated with the change of SST, we use SST of the coastal area of the north and south Rumoi region (Fig. S5a) where Teuri Island is located in the middle in https://www.jma-net.go.jp/sapporo/kaiyou/engan/data/engandata.html 2020.9.25. To look at the trends at larger scale we also use SST anomaly of north eastern Japan Sea (Fig. S5b) in http://www.data.jma.go.jp/kaiyou/data/shindan/a_1/japan_warm/japan_warm_data.html 2020.9.25. The shifts determined by sequential t test analysis (Rodionov 2004) at 5-year (5AV, gross broken line) and 10-year cut off (10AV, thin broken line) are also shown.

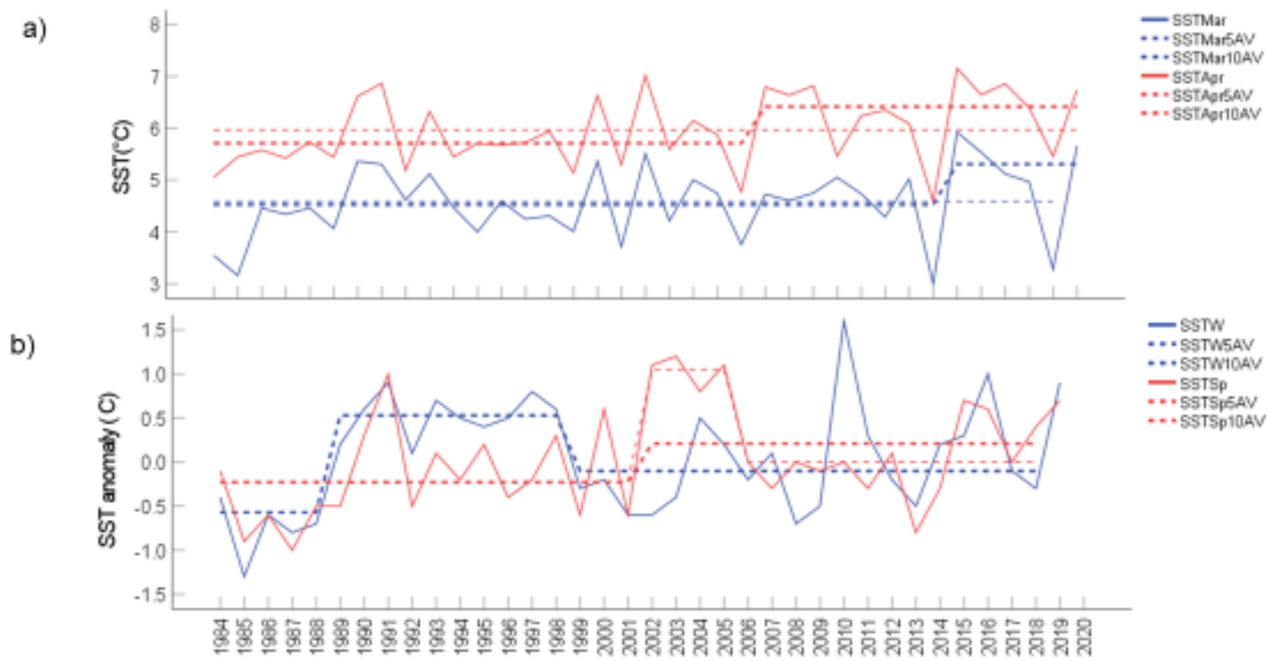

Fig. S5. Average SST of the coastal area of the north and south Rumoi region in March (SSTMar) and April (SSTApr) (a) and SST anomaly of north eastern Japan Sea in winter (Jan – Mar) (SSTW) and in spring (Apr to June) (SSTSp) from (b). Shifts are determined by sequential t-test and the weighted average SST during each phase are indicated by gross broken lines (5 year cut off, 5AV) and thin broken lines (10 year cut off, 10AV).