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Predicting nutrient content of ray-finned fishes using phylogenetic information

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Human food and nutrition security is dependent on marine ecosystems threatened by overfishing, climate change, and other processes. The consequences on human nutritional status are uncertain, in part because current methods of analyzing fish nutrient content are expensive. Here, we evaluate the possibility of predicting nutrient content of ray-finned fishes using existing phylogenetic and life history information. We focus on nutrients for which fish are important sources: protein, total fat, omega-3 and omega-6 fatty acids, iron, zinc, vitamin A, vitamin B12, and vitamin D. Our results show that life history traits are weak predictors of species nutrient content, but phylogenetic relatedness is associated with similar nutrient profiles. Further, we develop a method for predicting the nutrient content of 7500+ species based on phylogenetic relationships to species with known nutrient content. Our approach is a cost-effective means for estimating potential changes in human nutrient intake associated with altered access to ray-finned fishes.

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Human activity is rapidly transforming marine ecosystems worldwide. Total catch appears to be declining in fisheries around the world, largely due to intense industrial pressure[1]. Climate change-driven increases in sea temperature threaten to alter the abundance and distribution of hundreds of economically and nutritionally important species[2–5], and are leading to mass coral bleaching[6]. Ocean acidification, caused by greater absorption of atmospheric carbon dioxide, is inflicting severe damage on biologically rich coral reef habitats[7]. Coastal development, pollution, and other anthropogenic forces are impacting nearly every marine ecosystem in the world[8].

The consequences of these changes for human health, and especially for nutrient intake, are likely to be severe because fish provide critical nutrients essential to human nutrition, including iron, zinc, vitamin A, vitamin B12, omega-3 and omega-6 fatty acids, and others[9–11]. In many societies, seafood is the foundation for healthy diets, and its decline presents a significant risk in destabilizing food and nutrition security[12]. The consumption of fish is associated with a wide range of health benefits, including the prevention of various non-communicable diseases and the promotion of cognitive development[13,14]. Ray-finned fish—the class *Actinopterygii*—are particularly important to low-income populations, comprising 80.6% of the total global tonnage of subsistence marine capture fish and seafood in 2010[15].

A lack of information about the nutrient composition of fish species, however, hampers quantification of the nutritional threat to human populations of reduced consumption of wild-harvested fish. Measuring nutrient content is expensive and, as a result, nutrient analyses rarely capture the full breadth of vitamins, minerals, and macronutrients relevant to nutrition. This is exacerbated by the need to collect multiple samples of each species to assess variability across individuals, as well across subpopulations of species. This information gap prevents the design of rational fisheries management strategies and nutritional interventions to optimize public health outcomes in the face of rapidly changing marine conditions.

In this paper, we investigate the possibility that phylogenetic relatedness and life history information explain variation in the nutrient content of key fish species in the most commercially and nutritionally important class, *Actinopterygii* (ray-finned fishes). To our knowledge, this is the first time that such an approach has been explored. We then use the results of this analysis to develop a method for using shared phylogenetic history as a means of predicting the nutrient content of fish whose nutrient information has not yet been assessed. Such predictions are especially critical in regions of the world with known nutrient deficiencies—which are often the same areas where laboratory capacity is often limited. For fish specifically, recent years have seen an emerging desire among policymakers to design fisheries management and aquaculture development interventions with the specific goal of enhancing nutritional security. We note that these methods, if successful, could be used for a broad range of terrestrial animal and plant species as well—wild and domestic—as well as subspecies, varieties, and breeds.

Our results indicate that life history traits predict species nutrient content only weakly; larger datasets and/or use of missing-data imputation techniques may strengthen these models. We find, however, that phylogenetic relatedness is associated with similar nutrient profiles. This finding allows us to create a method for predicting the nutrient content of 7500+ *Actinopterygii* species based on phylogenetic relationships to species with known nutrient content.

Results

Interspecific variability in nutrient content and life history. We sourced nutrient content information for 371 species in the class *Actinopterygii* (see Supplementary Table 1 for full list of species, and see Methods section and refs.[16–28] for data sources). Supplementary Table 2 summarizes the number of species with data, as well as the observed range by nutrient. The dataset includes 26 orders, 126 families, and 279 genera; about 42% of species are in the order *Perciformes* (perch-like fishes). The set of 371 species represents over half of all global capture fisheries by weight, with all 22 of the world's most harvested marine fish species included[29].

We used life history traits and phylogenetic relatedness to predict protein, total fat, omega-3 and omega-6 fatty acids, iron, zinc, vitamin A, vitamin B12, and vitamin D content in *Actinopterygii*. These nutrients are critical for human nutrition and are generally present in relatively high concentrations in seafood—although, as we describe below, not all species are rich sources of the all the above nutrients. As predictors of nutrient content, we initially considered six continuous and two categorical life history traits describing body size, trophic level, habitat characteristics, and geographic range (Table 1).

Summaries of nutrient content across species indicate that ray-finned fishes make substantial contributions to human nutrition, particularly for low-income coastal populations (Supplementary Tables 2, 3). Of species with available information for a given nutrient, 98% are sources or rich sources of protein, 94% rich sources of vitamin D, and 81% rich sources of vitamin B12. In addition, 13% of species are either sources or rich sources of iron, 14% sources or rich sources of zinc, and 10% sources or rich sources of Vitamin A (see Supplementary Table 1 for data by species and threshold designations of source and rich source by nutrient).

We see a great deal of variation across ray-finned fish species for which we have nutrient information (Supplementary Table 3). In particular, the ranges of minimum and maximum depth, habitat preferences, and latitudinal range are especially wide. Nearly 40% of fish are demersal, but significant fractions are benthopelagic, pelagic, or reef-associated. The chosen set is divided roughly equally into tropical, subtropical, and temperate species. As calculated by trophic level, the mean *Actinopterygii* species in this dataset is a carnivore, and some are apex predators, but many species are also herbivores, zooplanktivores, detrivores, or omnivores.

Correlations among nutrients and life history variables. We first examined the relationship between nutrient content and life history variables by estimating evolutionary correlations (i.e., the correlations between evolutionary changes inferred using observations among species and their phylogenetic relationships; see Methods section). For this analysis (and all regression models described below), we used the ray-finned fish phylogeny reconstructed in Rabosky et al.[30]. Due to sample size restrictions, we exclude omega-3 and omega-6 fatty acids from the correlation matrix below; however, correlations with fatty acids included are given in Supplementary Table 4.

We found the expected associations between pairs of life history variables (top left corner of Fig. 1, lightly shaded). Maximum depth, maximum fish length, and trophic level are moderately associated with each other, suggesting that larger fish tend to live at greater depths and consume a diet higher on the food chain. The *a* and *b* parameters describing species' mass-length scaling relationships are well-correlated to each other, but not to other life history traits.

Patterns are also apparent within the set of nutrients (bottom right corner of Fig. 1, darkly shaded). Fish with more protein tend to contain less Vitamin A and total fat. Fish that are high in total fat also tend to be good sources of Vitamins A, B12, and D. Fish high in iron also tend to be good sources of zinc and all included

Table 1 Nutrient and life history traits used in the analysis*

Nutrients	Description
Protein	"Serves as the major structural component of all cells of the body, and functions as enzymes, in membranes, as transport carriers, and as some hormones"
Total fat	"Energy source and, when found in foods, is a source of n-6 and n-3 polyunsaturated fatty acids"
Omega-6 polyunsaturated fatty acids (linoleic acid)	"Essential component of structural membrane lipids, involved with cell signaling, and precursor of eicosanoids. Required for normal skin function"
Omega-3 polyunsaturated fatty acids (α-linoleic acid)	"Involved with neurological development and growth. Precursor of eicosanoids"
Iron	"Component of hemoglobin and numerous enzymes; prevents microcytic hypochromic anemia"
Zinc	"Component of multiple enzymes and proteins; involved in the regulation of gene expression"
Vitamin A	"Required for normal vision, gene expression, reproduction, embryonic development and immune function"
Vitamin B12	"Coenzyme in nucleic acid metabolism; prevents megaloblastic anemia"
Vitamin D	"Maintains serum calcium and phosphorus concentrations, and, in turn, bone health"
Life history traits	
Maximum length	Largest value ever reported for a given species, in cm (may not correspond to maximum length for subpopulation)
Trophic level	Weighted mean of the trophic level of the organisms that form the diet of the species; primary producers are assigned a value of one
Habitat	Categorical; bathydemersal, benthopelagic, demersal, pelagic, pelagic-neritic, pelagic-oceanic, reef-associated
Latitudinal range	Categorical; tropical, subtropical, temperate, boreal/austral, polar
Minimum depth	Minimum distance (m) below sea surface where species generally live
Maximum depth	Maximum distance (m) below sea surface where species generally live
a length–weight parameter	Empirically determined scalar parameter of the function $W = aL^b$
b length–weight parameter	Empirically determined exponential parameter of the function $W = aL^b$

*Refs. [51-55]. All nutrient function descriptions taken from National Academies (2017); see ref. [50] for more details. See FishBase glossary at www.fishbase.org for detailed descriptions of life history traits

vitamins. Vitamin A and Vitamin D are positively associated, and the latter is correlated with Vitamin B12. Overall, this set of correlations suggests that specific sets of nutrients tend to cluster together. Given that nutritional analyses, due to cost considerations, tend to focus on a small set of nutrients, such observed correlations may be important for roughly inferring levels of unmeasured nutrients.

Finally, we see that life history parameters, controlling for phylogeny, vary in their association to key nutrients (top right of Fig. 1, unshaded). Fish living at greater oceanic depths contain more total fat and Vitamin A, but less zinc. Longer fish contain proportionally less zinc and Vitamin B12, but more Vitamin A; smaller fish, often overlooked in conservation, livelihoods, and nutrition programs, may be richer sources of key micronutrients[31].

These bivariate associations were tested in multiple regression models fit by phylogenetic least squares (PGLS) in a manner that accounts for phylogenetic signal in species residuals[16,32–34].

These phylogenetic regressions find that life history parameters are either insignificant predictors of nutrient content or have small effects (Table 2). Longer fish at higher trophic levels but closer to the surface contain more protein, although the coefficient magnitudes are relatively small: 100 cm greater length is associated with 0.69 g more protein; a one-unit higher trophic level is associated with 1.29 g more protein per 100 g of fish weight; and 100 meters greater (i.e., deeper) maximum depth is associated with 0.14 g less protein. Maximum depth is also a significant predictor for total fat, omega-3 and omega-6 fatty acids, and vitamin A, but regression coefficients are small in these cases as well. Other relationships are insignificant. Overall, regression models suggest that life history variables are generally poor predictors of fish nutrient content when accounting for phylogenetic dependence in the data.

Predicting nutrient content of unmeasured species. All nutrients exhibit significant phylogenetic signal; that is, covariance among species in nutrient content tends to be moderately to strongly associated with phylogenetic relatedness. Estimates of Pagel's λ vary[17,18] are highest (indicating strong phylogenetic signal) in zinc, vitamin D, and vitamin A, intermediate in total fat, omega-3 and omega-6 fatty acids, and vitamin B12, and weaker in protein and iron (Table 3).

The phylogenetic structuring of nutrient content can be seen in the heatmap of Fig. 2, which shows some clustering of nutrient values among closely related species, although the location of these clusters varies depending on nutrient. For example, various species of the genus *Thunnus* contain high levels of protein, as indicated by the dark red region near the top of the phylogeny in the first column of the heatmap. We also observe such clustering at close phylogenetic distance but across genera; for example, *Engraulis encrasicolus, Tribolodon hakoensis*, *Misgurnus anguillicaudatus*, and *Anguilla japonicus* all fall within the top 10% of zinc levels in the database, as indicated by the dark red region near the bottom of the phylogeny in the fourth column of the heatmap; other nearby species also contain relatively large amounts of zinc.

Given our findings that nutrient content is weakly predicted by life history but tends to be phylogenetically structured, we developed a procedure for predicting nutrient content in unmeasured species based on their phylogenetic relationships to measured species and empirical estimates of phylogenetic signal (see Methods for details). We used a jackknifing procedure to determine that this method has acceptable accuracy. Observed nutrient values fell within the prediction 95% confidence intervals for at least 89.7% of cases across all variables (see Fig. 3, as well as Supplementary Fig. 1 for residual plots) and median deviations between predicted and observed values were within 40% of the among-species standard deviation. We note that the method can lead to wide confidence intervals when long phylogenetic branches separate unmeasured from measured species. This prediction method also compares favorably to predictions based on life history regression models; average accuracy and median

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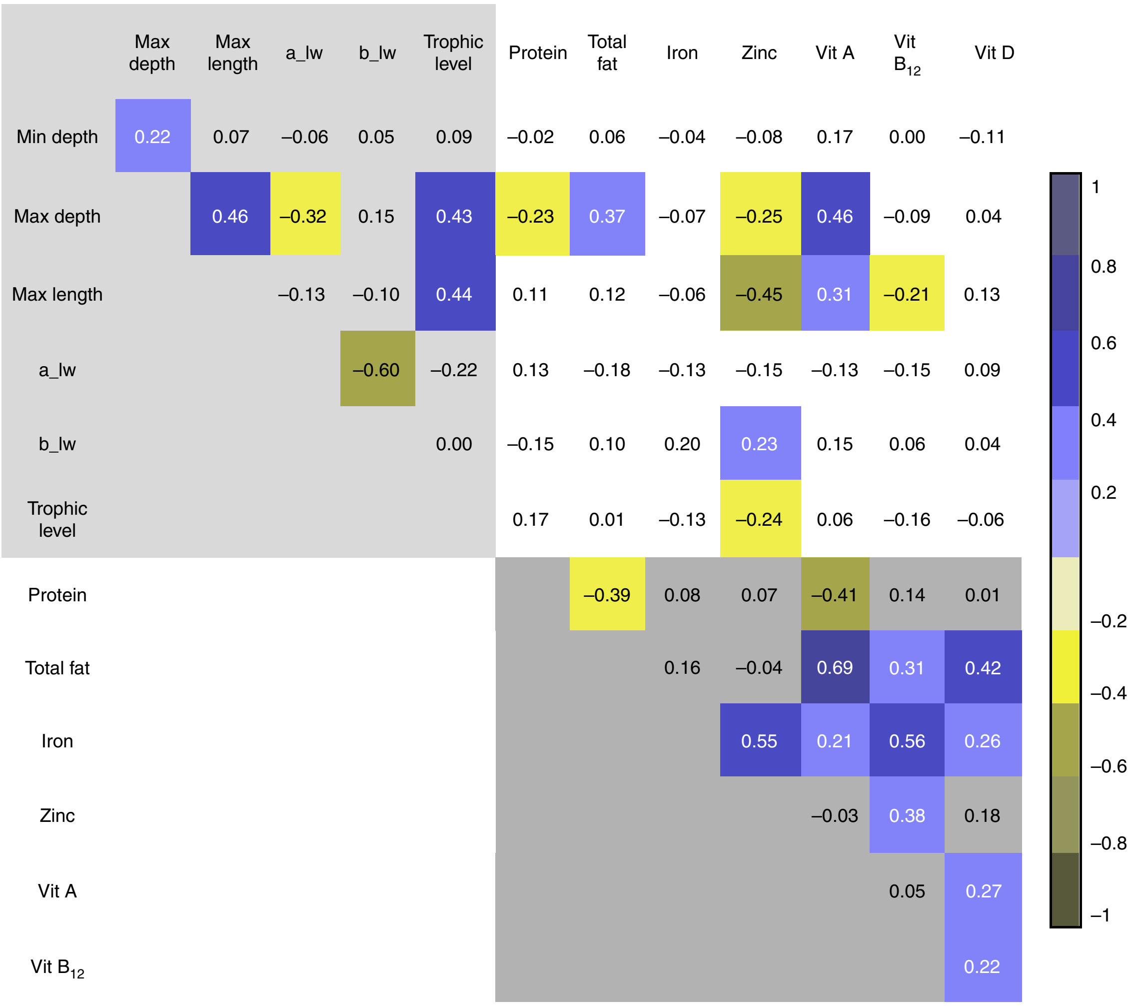

Fig. 1 Evolutionary correlation matrix of key variables, log-transformed. Colored cells indicate correlations significant at $p < 0.1$ (Pearson's r). Lightly shaded top left corner shows correlations between life history variables; darkly shaded bottom right corner shows correlations between nutrient variables. Unshaded top right corner shows correlations between life history and nutrient variables. The variables 'min depth' and 'max depth' refer to habitat preferences. 'Max length' refers to maximum reported length of the species. The variables 'a_lw' and 'b_lw' refer to the scalar and exponential parameters in the length-weight relationship equation $W = aL^b$, wherein W is weight and L is length. 'Trophic level' refers to the weighted mean of the trophic level of the diet of the species. See Table 1 for more details

differences are lower in the phylogenetic signal-only method (Table 4). Moreover, the phylogenetic prediction method can be readily applied to any species whose phylogenetic relationship to measured species has been estimated. Regression-based prediction requires this information in addition to information on species life history, although imputation methods may help to predict missing observations from a combination of other life history predictors and phylogenetic information[19].

Because our phylogenetic method performed well in validation tests, we used it to estimate missing nutrient values for all commercially valuable species in our original 371 species, as well as for all 7500+ unmeasured species in the *Actinopterygii* phylogeny (see Supplementary Data Files 2–10)[14]. Moreover, we used this approach to identify ray-finned fish families representing promising sources of key nutrients (Table 5). Some of the families we identify contain no or relatively few measured species, but our phylogenetic method predicts their potential to contain species rich in specific nutrients.

Discussion

At least one-tenth of the global population is vulnerable to future deficiencies in micronutrient intake linked to the degradation of marine ecosystems[7]. Unsustainable fishing practices, the effects of climate change on sea temperature and dissolved oxygen content, and pollution are all major threats to a wide range of commonly consumed fish stocks. Quantifying the exact magnitude of these risks depends on knowing the nutrient content of key species—information that is extremely expensive to obtain, given the cost of directly evaluating nutrient composition data in a laboratory setting. In this study, we develop a modeling framework for using phylogenetic and life history information to predict nutrient content in fish species of the economically and nutritionally important class *Actinopterygii* (ray-finned fishes). We focus on nine nutrients—protein, total fat, omega-3 and omega-6 fatty acids, iron, zinc, vitamin A, vitamin D, and vitamin B12. Fish can be important sources of each of these, especially among coastal populations in the developing world.

We find that most nutrients exhibit substantial phylogenetic signal—i.e., covariance among species in nutrient values is proportional to their shared evolutionary history—and a model based solely on phylogenetic relationships and empirical estimates of phylogenetic signal provide reasonable predictions of species nutrient content. This phylogenetic signal-based model provides better predictive ability than the multiple regression

Table 2 Phylogenetic generalized least squares models predicting nutrient content

	(1) Protein	(2) Total fat	(3) Omega-3	(4) Omega-6	(5) Iron	(6) Zinc	(7) Vitamin A	(8) Vitamin B12	(9) Vitamin D
Intercept	14.27***	1.98***	0.70	0.21	0.90***	0.71***	4.11***	2.60***	2.48***
	(11.06)	(4.22)	(1.80)	(1.83)	(4.67)	(3.92)	(3.47)	(4.81)	(3.59)
Max length	0.0069*	−0.0003	−0.0006	−0.0001	0.0002	−0.0006	0.0016	−0.0004	0.0018
	(2.52)	(−0.36)	(−1.04)	(−0.76)	(0.63)	(−1.82)	(0.90)	(−0.52)	(1.79)
Trophic level	1.29***	−0.17	−0.0262	0.0196	−0.07	0.01	−0.43	−0.24	−0.21
	(3.44)	(−1.54)	(−0.25)	(−0.62)	(−1.21)	(−0.16)	(−1.39)	(−1.59)	(−1.19)
Max depth	−0.0014***	0.0004***	0.0002**	0.0001**	−0.0001	−0.0001	0.0011***	−0.0001	0.0001
	(−3.99)	(4.30)	(3.21)	(2.87)	(−1.67)	(−1.30)	(5.22)	(−1.32)	(−0.61)
N	183	183	81	81	175	111	101	89	93
Pagel's λ	0.000	0.627	0.672	0.637	0.165	0.607	0.725	0.480	0.784
Log-likelihood	34.99	53.89	15.31	9.83	9.34	19.82	33.82	25.86	32.29
p-Value	<0.0001	<0.0001	0.0018	0.0180	0.0219	0.0002	<0.0001	<0.0001	<0.0001

T-statistics in parentheses. All outcome variables except protein are logged
$^{***}p < 0.001$ $^{**}p < 0.01$ $^{*}p < 0.05$

Table 3 Unconditional phylogenetic signal (Pagel's λ) of each nutrient across subsets of *Actinopterygii*

Nutrient	*N*	λ	*p* ($\lambda = 0$, likelihood ratio test)
Protein	270	0.4188	<0.0001
Total fat	267	0.6627	<0.0001
Omega-3 fatty acids	89	0.6036	0.0014
Omega-6 fatty acids	89	0.5366	0.1782
Iron	254	0.3461	0.0008
Zinc	146	0.8538	<0.0001
Vitamin A	122	0.7444	1.0000
Vitamin B12	102	0.5080	0.0008
Vitamin D	103	0.7640	<0.0001

model (Table 4), although the latter accounts for both phylogenetic signal and life history trait values. This seemingly counterintuitive result can be explained by two factors. First, the sample size for estimating parameters of phylogenetic signal-based model is greater than that of phylogenetic regression model for all nutrients (see Tables 2, 3). Some of the increased predictive capacity of the phylogenetic signal model may be a consequence of better parameter estimation associated with a larger sample of species. Second, even though some life history variables (such as maximum depth) are significant predictors of some nutrients, the magnitude of effect is relatively small (Table 2). Therefore, inclusion of life history variables in nutrient predictions, as in the phylogenetic regression models, does not seem to offset the loss of sample size imposed by the additional requirement of having data on species life history. Note that we do not intend for our results to suggest that life history is unimportant in determining fish nutrient content, but rather that based on available data, incorporation of life history information does not improve predictions of species nutrient values. With the addition of more life history data and/or use of missing-data imputation techniques, phylogenetic regression models may ultimately yield better predictions than the phylogenetic signal model.

In addition, the method developed in this paper provides the basis for targeting new potential sources of key nutrients. The tendency for variation in nutrients to be phylogenetically structured means that groups of species that are closely related to nutrient-rich species are also reasonably likely to be nutrient-rich. As noted above, we explored this possibility by looking across predicted and observed nutrient values for more than 7000 ray-finned fish species, and identified families that are likely to contain species rich in key nutrients. The nutritional quality of the members of some of these families is well known; scombrids, carangids, salmonids, and clupeids make large contributions to existing fisheries. However, we also identify as potentially nutrient-rich several fish families for which species nutrient content of their species is mostly unknown (Table 5). For example, our predictions suggest that exocoetids (flying fish), sphyraenids (barracuda), and centropomids (snook) may be high in protein even though protein content has been measured for no more than one species in any of these families. In addition, even though no species of muraenid, ophichthid, congrid, or channichthyid has been assayed for total fat content, their close phylogenetic relationships to species high in fats lead us to suggest that they may be good sources of this nutrient. To be clear, we recommend that our predictions be used to inform the selection of potentially nutrient-rich species for nutrient content measurement, and we caution against use of our predictions as strong statements on which species should be exploited for nutrition.

Moreover, our identification of nutrient-rich families is limited in some important ways. First, we could only predict nutrient content in species represented in the Rabosky et al. phylogeny, and so some families may be over- or under-represented in our predictions[14]. For example, some nutrient-rich families may not appear in Table 5 if they have relatively few species in the phylogeny. Conversely, some families may appear to contain a large number of nutrient-rich species because they are well sampled in the phylogeny and because they contain one or more species known to be high in particular nutrients or are closely related to species of high nutritional quality. In fact, our phylogenetic prediction method is unable to make distinctions between unmeasured species of the same phylogenetic distance from measured relatives, though new nutritional data would likely help resolve this issue. Finally, we acknowledge that our predictions are contingent on Rabosky et al.'s estimation of phylogenetic relationships among these ray-finned fishes[14], whose relation to the true phylogeny is unknown. Future work will refine these predictions as increasing phylogenetic information becomes available. Despite these limitations, we view our approach as a first step toward more precise estimates of the consequences of marine ecosystem transformation.

We identify several priorities in taking the conclusions of this research forward. First, improving the phylogenies of other classes important for human nutrition, including other marine seafood species as well as freshwater fish, is essential. Second, increasing the size of the nutrient validation sample—that is,

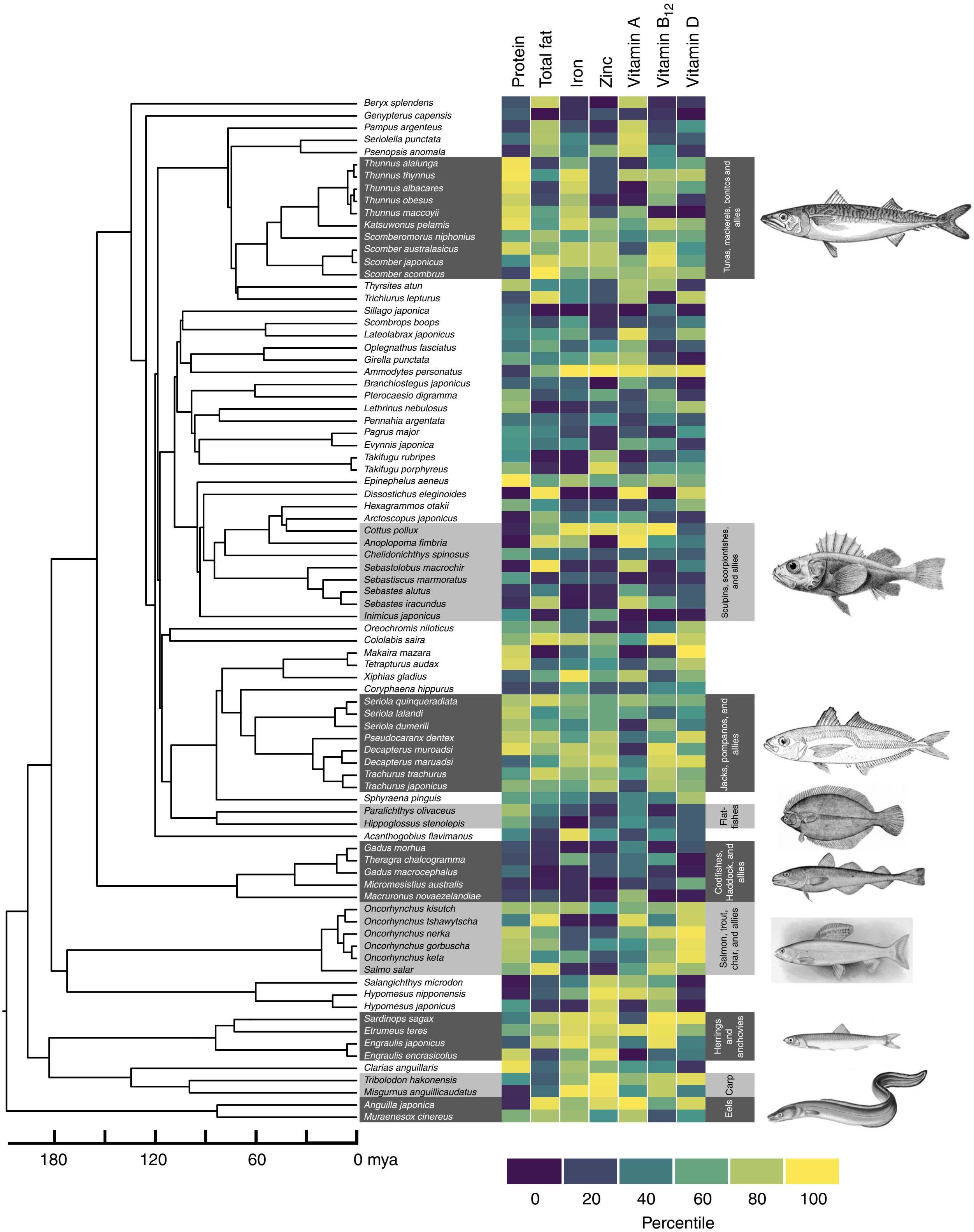

Fig. 2 Phylogenetic relationships and nutrient content, expressed in percentiles. Eighty-four of the most commercially and nutritionally important of the 371 species in the database described above are shown. The time-scale is shown as millions of years ago (mya). The color scales indicate percentiles of nutrient content; see Supplementary Table 1 for ranges of each variable. Common names and pictorial representations of select groups of fishes are shown. All images are taken from Wikipedia, and are Public Domain images

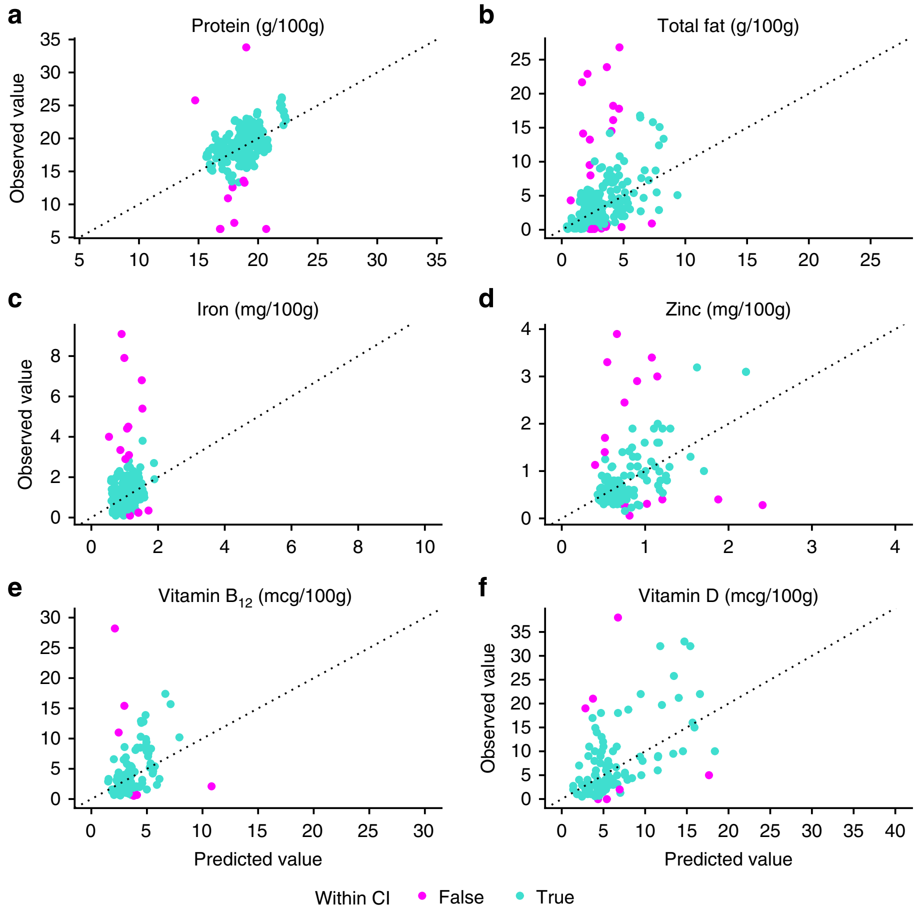

Fig. 3 Predicted versus observed values for selected nutrients using phylogenetic signal only. Points in green fall within the 95% prediction interval; points in red are outside the interval. The diagonal represents points where predictions are equal to observed values

Table 4 Confidence interval coverage and median deviation of nutrient prediction using phylogenetic signal only and phylogenetic signal plus life history information

	Phylogenetic signal only		Phylogenetic signal + life history variables	
	95% confidence interval coverage	Median difference (proportion of SD)	95% confidence interval coverage	Median difference (proportion of SD)
Protein	95.9	0.366	95.1	0.448
Total fat	92.1	0.304	91.8	0.316
Iron	94.5	0.395	97.1	0.473
Zinc	89.7	0.289	91.9	0.310
Vitamin A	91.0	0.036	88.1	0.034
Vitamin B12	94.1	0.364	92.1	0.338
Vitamin D	93.2	0.346	91.4	0.347
Mean	92.9	0.300	92.5	0.323

Confidence interval coverage is the proportion of measured values falling inside the 95% prediction interval. Median percent difference is calculated as (measured value – predicted value)/sample standard deviation of species values

measuring the nutrient content of more species directly—would enable a better utilization of the large amount of life history information available. It is possible, perhaps even likely, that the weak associations between life history variables and nutrient content in this study is due to an overly restrictive validation sample. We recommend expanding the sample by prioritizing nutrient assays in species that belong to families identified as potentially nutrient-rich, as presented in Table 5. Third—approaching the small sample problem from the opposite direction—use of techniques like that of Thorson et al. (2017) to predict life history parameters would allow more existing nutrient information to be utilized[19].

We utilize several methods in this paper: evolutionary correlations, Brownian-motion models of trait evolution, and phylogenetic least squares regression. We believe that the availability of data is the key determinant of which of these methods is preferable in predicting fish nutrient content. In the absence of life history information, evolutionary correlations and phylogenetic signal-based models provide a rough sense of which nutrients are likely to be found together in *Actinopterygii*. As phylogenies expand and nutrient and life history datasets grow, life history regression models will likely improve on the predictive power of these methods. Overall, we believe that the combination of phylogenetic and life history information holds great potential for inexpensively inferring the nutrient content of a wide range of wild foods, and thereby quantifying the impacts of ecosystem transformation on human food and nutrition security.

Methods

Data sources. We utilized fish nutrient information from food composition tables from Argentina, Bangladesh, Cambodia, Canada, Chile, Denmark, Japan, Finland, Gambia, Greece, Italy, Japan, Malaysia, South Korea, Peru, Turkey, and the United States; 89% of the species we examined have entries in either the Korea, Japan, Bangladesh, or Argentina tables[20–28,35–38]. The life history data come from

Table 5 Ray-finned fish families identified as potentially nutrient-rich based on phylogenetic prediction and observation of nutrient content

Nutrient	Family name	Types of fishes	Number of total species in family	Number of measured species in family	Number of nutrient-rich measured species in family
Protein	Serranidae	Sea basses	111	7	2
	Carangidae	Jacks, pompanos	80	12	10
	Scombridae	Tunas, mackerels	37	22	18
	Exocoetidae	Flying fishes	32	1	1
	Sphyraenidae	Barracudas	14	1	1
	Centropomidae	Snooks	12	0	0
	Salmonidae	Salmon, trout	12	12	7
	Istiophoridae	Billfishes	8	1	1
Total fat	Muraenidae	Moray eels	56	0	0
	Clupeidae	Herrings	49	10	8
	Nototheniidae	Cod icefishes	28	1	1
	Engraulidae	Anchovies	22	6	4
	Ophichthidae	Snake eels	20	0	0
	Scombridae	Tunas, mackerels	19	21	10
	Anguillidae	Freshwater eels	15	1	1
	Carangidae	Jacks, pompano	14	12	6
	Channichthyidae	Crocodile icefishes	13	0	0
	Congridae	Garden eels	13	0	0
	Salmonidae	Salmon, trout	12	12	5
	Centrolophidae	Medusafishes	10	2	2
Iron	Cyprinidae	Minnows, carp	118	20	9
	Cobitidae	Loaches	102	2	2
	Nemacheilidae	Stone loaches	36	0	0
	Balitoridae	River loaches	34	0	0
	Catostomidae	Suckers	10	0	0
	Scombridae	Tunas, mackerels	10	19	10
Zinc	Cyprinidae	Minnows, carp	162	14	6
	Cobitidae	Loaches	102	1	1
	Nemacheilidae	Stone loaches	36	0	0
	Balitoridae	River loaches	34	0	0
Vitamin A	Muraenidae	Moray eels	56	0	0
	Cyprinidae	Minnows, carp	44	6	1
	Cottidae	Sculpins	32	1	1
	Nototheniidae	Cod icefishes	28	1	1
	Mastacemblidae	Spiny eels	21	1	1
	Ophtichthidae	Snake eels	20	0	0
	Anguillidae	Freshwater eels	15	1	1
	Abyssocottidae	Deep water sculpins	14	0	0
	Channidae	Snakeheads	14	1	1
	Channichthyidae	Crocodile icefishes	13	0	0
	Congridae	Garden eels	13	0	0
	Centrolophidae	Medusafishes	10	2	2
Vitamin B12	Cyprinidae	Minnows, carp	136	4	2
	Cobitidae	Loaches	57	1	1
	Clupeidae	Herrings	54	4	4
	Carangidae	Jacks, pompanos	25	8	5
	Engraulidae	Anchovies	23	2	1
	Salmonidae	Salmon, trout	21	6	4
	Osmeridae	Smelts	13	2	2
Vitamin D	Carangidae	Jacks, pompanos	60	8	5
	Muraenidae	Moray eels	56	0	0
	Clupeidae	Herrings	54	6	6
	Salmonidae	Salmon, trout	30	8	7
	Nototheniidae	Cod icefishes	28	1	1
	Cyprinidae	Minnows, carp	20	3	1
	Anguillidae	Freshwater eels	15	1	1
	Channichthyidae	Crocodile icefishes	13	0	0
	Sphyraenidae	Barracudas	11	1	1

Final column lists number of species in each family identified as potentially nutrient-rich, based on phylogenetic prediction and observation of nutrient content. Species are considered nutrient-rich if their nutrient content rank within the 500 largest values out of more than 7000 species from the Rabosky et al. phylogeny with predicted or known nutrient content[14]. Values in parentheses indicate the number of measured species that are nutrient-rich over the total number of species measured for that family

FishBase, a publicly accessible database containing taxonomic, biological, ecological, life history, and human use information on finfishes[39]. We utilized the species-level, time-calibrated, multi-gene phylogeny for *Actinopterygii* assembled by Rabosky et al.[14]. Although other large-scale species-level phylogenetic trees are also available for this group[40,41], we chose the Rabosky et al. phylogeny because it maximizes overlap with nutrient content data. Rabosky et al.'s reconstruction of the phylogeny was based on maximum likelihood phylogenetic analysis of 13 genes with subsequent smoothing of among-lineage substitution rate heterogeneity and divergence date estimation using fossil calibrations. The original phylogeny includes over 7500 ray-finned fish species. As described in more detail further below, we used this phylogeny in combination with life history predictor variables and estimates of phylogenetic signal (i.e., the tendency for phenotypic similarity among species to be proportional to their time of shared evolution) to predict nutrient content in species lacking such information.

Evolutionary correlations. We first explored bivariate evolutionary correlations between all pairwise combinations of life history and nutrient variables. Here, evolutionary correlations are the Pearson correlation coefficients describing associations between evolutionary changes in pairs of variables[42,43]. We estimated these correlations for log-transformed species values given the Rabosky et al. phylogeny and a Brownian motion model with Pagel's λ correction for the degree of phylogenetic signal using the *ratematrix* function of the *geiger* package[44] for R[45].

Multivariable regression models. To evaluate the capacity to predict nutrient content from life history information, we fit multiple regression models using phylogenetic least squares (PGLS) as implemented in the R package *phylolm*[46]. Because species with a recent common ancestor are expected to have more similar trait values, the assumptions of ordinary least squares (OLS) are violated[47]. PGLS accounts for phylogenetic non-independence using shared ancestry as inverse weights on the elements of the residual variance-covariance matrix used in the model[15,29–31]. Thus, in matrix notation, a coefficient β is estimated as follows:

$$\beta = \left(\mathbf{X}' V^{-1}\mathbf{X}\right)^{-1}\mathbf{X}' V^{-1}\mathbf{y} \tag{1}$$

where X is a matrix of n species and $m+1$ life history trait values (with an intercept column); X′ is the transpose of X; y is a vector of values for a given nutrient; and V is the residual variance-covariance matrix. Under OLS assumptions, the diagonal elements of V are the variance of the residuals; the residuals are expected to be normally distributed with mean zero. Under PGLS, the residual covariances are computed using branch lengths from each member of a species pair to their common ancestor. Instead of assuming covariance among species to be proportional to their time of shared evolution, we used a maximum likelihood procedure to identify a scalar of V^{-1}, called Pagel's λ, that best fits the observed data; $\lambda = 0$, the OLS approximation, would indicate trait evolution completely independent of phylogeny, $\lambda = 1$ would indicate that shared evolutionary history (i.e., shared phylogenetic branch length) predicts phenotypic similarity among species, and intermediate λ ($0 < \lambda < 1$) discounts the phylogenetic dependence of trait values among species[30,32,33]. The best-fit inverse matrix V^{-1} is then used to estimate the predictor coefficient β[30,31,48].

Phylogenetic prediction. The objective of the PGLS modeling exercise is to advance towards methods for predicting the nutrient content of species for which information is not available. Although our analysis shows that life history parameters are generally weak predictors of all nutrients, phylogeny is more promising. We thus predict nutrient content of unmeasured *Actinopterygii* fish species using nutrient data for measured species and the Rabosky et al. phylogenetic tree relating both measured and unmeasured species[14], assuming a λ-corrected Brownian motion model of evolution. Under this model, character change along any branch of the phylogeny is a normally distributed random variate with expected value equal to zero and variance proportional to the length of the branch[24]. Because the character has no tendency to increase or decrease under the model, the predicted value for an unmeasured species is equal to the estimated state for the most recent common ancestor (MRCA) between that species and the measured species most closely related to it. The state of this ancestor is evaluated as the branch length-weighted mean of the estimated character states in the next node deeper and the next more recent node that connect measured species (though, in some cases, the more recent node is a tip species). We estimated the states of these nodes using the *phytools* function *fastAnc*[49].

Although the expectation under the Brownian model is that the character will remain unchanged in the unmeasured species from the time of its split from the measured species most closely related to it, the uncertainty in the predicted value increases with time since this split. Therefore, the variance around each predicted value incorporates the branch length (t) subtending the unmeasured species, and is evaluated as

$$t \times \sigma^2 \tag{2}$$

where σ^2 is the time-independent variance of the Brownian motion process[24]. The parameter σ^2 was estimated from the data and phylogeny using methods described in the next paragraph. We constructed 95% confidence intervals around each predicted value as $\pm 1.96 \times \sqrt{t \times \sigma^2}$.

Our predictions also incorporate empirical estimates of the degree of phylogenetic signal in measured species nutrient values. We fit Pagel's λ separately for each nutrient using the *phylosig* function of the *phytools* package for *R*[22,32,33,44], which returns the maximum likelihood estimates for both σ^2 and λ. We then transformed branch lengths of the phylogeny by the empirical estimates for λ using the *rescale* function of the R package *geiger*;[21] $\lambda = 1$ recovers the original phylogeny, $\lambda < 1$ compresses internal branches relative to terminals, and $\lambda = 0$ is a star phylogeny. We then estimated ancestral character states, predicted states for unmeasured species, and their confidence intervals on this branch length-transformed tree.

Validation. We used a jackknifing approach to validate the method for phylogenetic prediction of nutrient content. For each nutrient, we removed one measured species from the dataset and applied the method to predict the species' nutrient value and calculate its prediction interval. We then determined whether the prediction interval contained the measured value. If it does not, we label that trial as an error, and then calculated the error rate for each nutrient over all measured species. We also calculated the median percent deviation between predicted and measured values as a proportion of the standard deviation of the sample of all species nutrient values. We then compared error rates and accuracy of phylogeny-only predictions to predictions based on the best-fit multiple regression models. These latter predictions were obtained following the method of Garland and Ives[50], and were restricted to the sample of species for which life history data were available.

Code availability. All code used in the analysis is made available as Supplementary Data 11–15. SD11 is the script for evolutionary correlations. SD12 is the script for phylogenetic least squares. SD13 is the script for estimating the phylogenetic signal of nutrient variables. SD14 is the script for validating the predications under the lambda model. SD15 is the script for validating predictions under the lambda plus phylogenetic regression model.

Data availability

We declare all data used in the above analysis, tables, and figures to be available within the paper and in the supplementary information files. Supplementary Data 1 is the fish life history and nutrient content database. Phylogenetically predicted nutrient values are labeled as Supplementary Data 2–10.

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Author contributions

B.V. led writing of the manuscript and contributed to the analysis. D.C. led analysis. M.R.S. and S.S.M. created the underlying fish nutrient database. B.L.R. contributed to draft revisions and designed Fig. 2. C.D.G. conceptualized the research idea and overall study design, and all authors contributed to writing and draft revision.

Additional information

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Supplementary Tables

Supplementary Table 1. List of included species and sources and rich sources of key nutrients. See below for units and thresholds for "source" and "rich source" as designated by FAO.[1] Values above the source threshold are highlighted in blue, values above the rich source threshold are highlighted in dark blue.

Nutrient	Source threshold (/100g)	Rich source threshold (/100g)
Protein	7.65 g	15.3 g
Iron	1.95 mg	3.9 mg
Zinc	1.425 mg	2.85 mg
Vitamin A	120 mcg	240 mcg
Vitamin B12	0.75 mcg	1.5 mcg
Vitamin D	0.36 mcg	0.72 mcg

Summary	Protein	Iron	Zinc	Vitamin A	Vitamin B12	Vitamin D
Valid species, n	372	345	178	143	122	122
# Source	17	33	15	7	15	4
# Rich Source	348	11	10	7	99	115
# Source or Rich Source	365	44	25	14	114	119
% Source	4.57	9.57	8.43	4.90	12.30	3.28
% Rich Source	93.55	3.19	5.62	4.90	81.15	94.26
% Source or Rich Source	98.12	12.75	14.04	9.79	93.44	97.54

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Acanthistius brasilianus	Argentine Seabass	Perciformes	Serranidae	17.90					
Acanthogobius flavimanus	Goby	Gobioidei	Gobiidae	18.90	2.10	0.60	7	2.70	3.00
Acanthogobius hasta	Javelin goby	Gobioidei	Gobiidae	16.40	0.90				
Acanthopagrus schlegelii	Black sea bream	Perciformes	Sparidae	19.60	0.75	0.80	12	3.70	4.00
Acheilognathus rhombeus	Flat bitterling	Cypriniformes	Cyprinidae	17.50	1.20				
Ailia coila	Gangetic Ailia	Siluriformes	Schilbeidae	15.30	0.90				
Alcichthys alcicornis	Elkhorn sculpin	Scorpaeniformes	Cottidae	17.10	0.80				
Allothunnus fallai	Slender Tuna	Perciformes	Scombridae	19.80	1.30	1.10	227	0.70	
Amblypharyngodon mola	Mola Carplet	Cypriniformes	Cyprinidae	17.10	3.80	3.19	2680		
Ammodytes personatus	Sandlance	Perciformes	Ammodytidae	16.60	7.90	3.90	200	11.00	21.00
Anabas testudineus	Climbing Perch	Perciformes	Abantidae	17.50	1.20	1.13	215		
Anchoa compressa	Deep-bodied anchovy	Clupeiformes	Engraulidae	16.90	1.40				
Anguilla japonica	Eel	Anguilliformes	Anguillidae	15.75	1.05	1.40	2400	3.50	18.00
Anoplopoma fimbria	Sablefish	Scorpaeniformes	Anoplopomatidae	13.35	1.25	0.30	1500	2.80	3.50
Arctoscopus japonicus	Sailfin Sandfish/Sandfish	Perciformes	Trichodontidae	14.10	0.50	0.60	20	1.70	2.00
Argyrops bleekeri	Taiwan tai	Perciformes	Sparidae	17.80	9.10				
Auxis rochei	Frigate mackerel	Perciformes	Scombridae	24.10	1.70				
Auxis thazard	Bullet mackerel	Perciformes	Scombridae	23.40	1.90				
Bagrus bajad	Bayad	Siluriformes	Bagridae	27.50	1.10	0.73	9	2.80	0.80
Banjos banjos	Banjo fish	Perciformes	Banjosidae	20.80	1.40				

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Barbonymus gonionotus	Silver Barb	Cypriniformes	Cyprinidae	6.25				2.00	
Belone belone	Needle fish Gar fish Pacific	Beloniformes	Belonidae	19.80	0.50				
Bero elegans	Elegant sculpin	Scorpaeniformes	Cottidae	19.50	0.90				
Beryx decadactylus	Broad alfonsino	Beryciformes	Berycidae	18.50	2.00				
Beryx splendens	Splended Alfonsino	Beryciformes	Berycidae	17.80	0.30	0.30	63	1.10	2.00
Bodianus bilunulatus	Crescent-banded wrasse	Perciformes	Labridae	20.30	1.50				
Boreogadus saida	Polar Cod	Gadiformes	Gadidae		0.25	0.37	24		
Brama japonica	Pacific pomfret	Perciformes	Bramidae	18.90	0.40				
Branchiostegus japonicus	Blanquillo	Perciformes	Branchiostegidae	18.45	0.45	0.30	27	2.10	1.00
Caesio xanthonota	Yellowback Fusilier	Perciformes	Caesionidae	21.10	0.40	0.40	19	0.41	
Callanthias japonicus	Yellowtail red bass	Perciformes	Callanthiidae	17.30	0.70				
Callionymus lunatus	Moon dragonet	Perciformes	Callionymidae	18.50	0.80				
Calliurichthys japonicus	Dragonet	Perciformes	Callionymidae	16.50	1.30				
Carangoides equula	Whitefin trevally	Perciformes	Carangidae	19.60	1.00				
Caranx sexfasciatus	Six-bed jack	Perciformes	Carangidae	24.00	1.70				
Carassius auratus	Crucian carp	Cypriniformes	Cyprinidae	18.15	1.95	1.90	12	5.50	4.00
Catla catla	Catla	Cypriniformes	Cyprinidae	19.90	0.60	0.48	3		0.00
Cephalopholis miniata	Coral Hind	Perciformes	Serranidae	18.40	0.40	0.40	0	1.00	
Channa punctata	Spotted Snakehead	Perciformes	Channidae	17.30	1.50	1.08	191		
Channa striata	Striped Snakehead	Perciformes	Channidae	17.70	1.00	0.31			
Chanodichthys dabryi	Humpback	Cypriniformes	Cyprinidae	18.70	1.10				
Cheilodactylus quadricornis	Black-barred morwong	Perciformes	Cheilodactylidae	19.20	1.30				
Cheilodactylus zonatus	Spottedtail morwong	Scorpaeniformes	Scorpaenidae	19.80	1.30				
Cheilopogon agoo	Japanese flying fish	Beloniformes	Exocoetidae	22.20	0.90				
Chelidonichthys spinosus	Bluefin searobin	Scorpaeniformes	Triglidae	19.75	0.50	0.50	9	2.20	3.00
Chelidoperca hirundinacea	Princess porgy	Perciformes	Serranidae	20.10	1.50				
Chelon parsia	Goldspot Mullet	Mugiliformes	Mugilidae	18.70	2.10	1.43			
Chirolophis japonicus	Fringed blenny	Perciformes	Stichaeidae	17.20	0.60				
Chitala chitala	Clown Knifefish	Osteoglossiformes	Notopteridae	17.80	1.60	0.61	30		
Choerodon azurio	Azurio tuskfish	Perciformes	Labridae	20.30	0.70				
Chromis notata	Pearl-spot chromis	Perciformes	Pomacentridae	19.50	0.70				
Cirrhinus cirrhosus	Mrigal Carp	Cypriniformes	Cyprinidae	18.60	1.80	0.29	11		
Clarias anguillaris	Mudfish	Siluriformes	Clariidae	25.80	1.40	0.80	16	2.60	1.30
Clarias batrachus	Philippine Catfish	Siluriformes	Clariidae	10.93	0.80	0.53	15		
Cleisthenes pinetorum	Pointhead flounder	Pleuronectiformes	Pleuronectidae	18.10	4.00				
Clidoderma asperrimum	Roughscale sole	Pleuronectiformes	Pleuronectidae	17.40	0.60				
Clupea harengus	Atlantic Herring	Clupeiformes	Clupeidae	17.96	1.10	0.99			9.50
Clupea pallasii	Pacific herring	Clupeiformes	Clupeidae	16.85	0.90	1.10	18	17.40	22.00
Cobitis sinensis	Siberian spiny loach	Salmoniformes	Salmonidae	17.50	2.70				

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Coilia dussumieri	Goldspotted Gredier Anchovy	Clupeiformes	Engraulidae	13.20	4.50	1.25			
Coilia nasus	Japanese gredier anchovy	Clupeiformes	Engraulidae	15.90	1.10				
Collichthys niveatus	Collichthys niveatus	Perciformes	Sciaenidae	17.00	1.30				
Cololabis saira	Pacific saury	Beloniformes	Scomberesocidae	20.15	1.50	0.80	16	15.40	14.90
Conger myriaster	Conger eel	Anguilliformes	Congridae	17.35	0.65	0.70	500	2.30	0.40
Conger orbignianus	Argentine Conger	Anguilliformes	Congridae	17.20					
Coregonus autumnalis	Arctic Cisco	Salmoniformes	Coregonidae	16.70	0.82	0.63			
Coregonus clupeaformis	Lake Whitefish	Salmoniformes	Coregonidae	16.88	0.31	0.51	11		4.40
Coreoperca kawamebari	Spotear brook perch	Perciformes	Percichthyidae	19.50	1.10				
Coryphaena hippurus	Dolphinfish	Perciformes	Coryphaenidae	17.30	0.70	0.50	8	2.60	5.00
Cottus poecilopterus	Alpine bullhead	Scorpaeniformes	Cottidae	15.00	2.80				
Cottus pollux	Japanese Sculpin/Japanese Fluvial Sculpin	Scorpaeniformes	Cottidae	15.00	2.80	1.70	180	28.20	3.00
Crossocheilus latius	Stone Roller	Cypriniformes	Cyprinidae	15.30	2.20	1.09			
Ctenopharyngodon idella	Grass carp	Cypriniformes	Cyprinidae	17.10	1.70				
Cynoglossus joyneri	Red tonguesole	Pleuronectiformes	Cynoglossidae	18.60	1.00				
Cynoglossus semilaevis	Tongue sole	Pleuronectiformes	Cynoglossidae	19.20	0.30				
Cynoscion striatus	Striped Weakfish	Perciformes	Sciaenidae	17.80	2.20				
Cyprinus carpio	Common carp	Cypriniformes	Cyprinidae	17.97	0.93	0.97	3	10.00	10.30
Cyprinus carpio nudus	Israeli carp	Cypriniformes	Cyprinidae	16.80	1.20				
Dactyloptena petersenі	Starry flying gurrd	Scorpaeniformes	Dactylopteridae	19.20	1.20				
Decapterus maruadsi	White-tipped mackerel scad	Perciformes	Cheilodactylidae	18.45	1.45	1.30	11	9.90	18.70
Decapterus muroadsi	Brownstriped Mackerel Scad	Perciformes	Carangidae	23.60	1.60	1.00	4	12.80	6.00
Dentex tumifrons	Yellow Sea Bream	Lophiiformes	Lophiidae	19.40	0.35	0.40	50	3.20	4.00
Dexistes rikuzenius	Rikuzen flounder	Pleuronectiformes	Pleuronectidae	19.40	0.60				
Diagramma pictum	Painted Sweetlips	Perciformes	Haemulidae	19.80	0.40	0.60	29	2.11	
Dictyosoma burgeri	Ribbed gunnel	Perciformes	Stichaeidae	22.00	1.20				
Dissostichus eleginoides	Patagonian Toothfish	Perciformes	Nototheniidae	13.30	0.10	0.30	1800	0.60	17.00
Ditrema temminckii temminckii	Surffish	Perciformes	Embiotocidae	18.90	1.00				
Doederleinia berycoides	Blackthroat seaperch	Perciformes	Acropomatidae	22.30	0.30				
Eleginus gracilis	Saffron cod	Gadiformes	Gadidae	12.60	4.00				
Engraulis anchoita hubbs larini	Argentine Anchovy	Clupeiformes	Engraulidae	19.20					
Engraulis encrasicolus	European Anchovy	Clupeiformes	Engraulidae	22.80	0.90	1.90	1	2.10	3.50
Engraulis japonicus	Anchovy	Clupeiformes	Engraulidae	17.95	2.25	1.00	11	13.90	4.00
Engraulis ringens	Anchoveta	Clupeiformes	Engraulidae	21.00	1.40				
Epinephelus aeneus	White Grouper	Perciformes	Serranidae	33.80	1.40	0.65	30	6.60	7.50
Epinephelus akaara	Red-spotted grouper	Perciformes	Serranidae	21.00	1.30				
Epinephelus awoara	Yellow grouper	Perciformes	Serranidae	19.40	0.90				

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Epinephelus epistictus	Dotted grouper	Perciformes	Serranidae	19.30	1.00				
Esox lucius	Northern Pike	Esociformes	Esocidae	17.83	0.18	0.70			
Ethmalosa fimbriata	Bonga Shad	Clupeiformes	Clupeidae	19.10	1.70	1.60			
Etrumeus teres	Bigeye sardine	Clupeiformes	Clupeidae	19.90	1.90	1.30	130	14.20	9.00
Eumicrotremus orbis	Pacific spiny lumpsucker	Scorpaeniformes	Cyclopteridae	7.20	1.20				
Euthynnus affinis	Kawakawa	Perciformes	Scombridae	25.00	1.30	0.27	31		3.12
Eutropiichthys vacha	Batchwa Vacha	Siluriformes	Schilbeidae	16.10	0.70				
Evistias acutirostris	Striped boarfish	Perciformes	Pentacerotidae	18.60	1.20				
Gadus macrocephalus	Pacific cod	Gadiformes	Gadidae	18.55	0.30	0.50	10	1.30	1.00
Gadus morhua	Atlantic cod	Gadiformes	Gadidae	17.76	0.25	0.40	12	0.91	2.76
Genypterus blacodes	Pink Cusk-Eel	Ophidiiformes	Ophidiidae	15.80					
Genypterus capensis	Kingclip	Ophidiiformes	Ophidiidae	18.20	0.30	0.50	5	1.30	0.00
Girella punctata	Girella	Perciformes	Kyphosidae	19.80	0.70	0.90	55	1.80	1.00
Glossanodon semifasciatus	Deep-sea smelt	Salmoniformes	Argentinidae	18.70	0.40	0.40	75	3.40	0.00
Glossogobius giuris	Tank Goby	Perciformes	Gobiidae	14.70	1.20	0.93			
Glyptocephalus stelleri	Blackfin flounder	Pleuronectiformes	Pleuronectidae	18.20	0.60				
Gnathopogon caerulescens	Willow Shiner	Cypriniformes	Cyprinidae	17.50	1.30	3.40	250	9.00	5.00
Gudusia chapra	Indian River Shad	Clupeiformes	Clupeidae	15.40	4.80	1.97	6		
Gymnocanthus herzensteini	Black edged sculpin	Scorpaeniformes	Cottidae	19.50	2.50				
Halichoeres tenuispinis	Motley stripe rainbowfish	Perciformes	Labridae	19.20	1.10				
Halieutaea stellata	Minipizza bat fish	Lophiiformes	Ogcocephalidae	15.80	1.00				
Hapalogenys mucronatus	Broadbanded velvetchin	Perciformes	Haemulidae	18.50	1.10				
Hapalogenys nigripinnis	Short barbeled velvetchin	Perciformes	Haemulidae	19.00	1.30				
Helicolenus dactylopterus	Blackbelly Rosefish	Scorpaeniformes	Scorpaenidae	17.10					
Helicolenus hilgendorfii	Hilgendorf saucord; Rosefish	Scorpaeniformes	Scorpaenidae	16.70	0.70				
Hemibarbus labeo	Barbel steed	Cypriniformes	Cyprinidae	17.30	1.00				
Hemibarbus longirostris	Long-nose barbel	Cypriniformes	Cyprinidae	17.70	1.40				
Hemitripterus villosus	Shaggy sea raven	Scorpaeniformes	Hemitripteridae	18.60	0.50				
Henicorhynchus siamensis	Siamese Mud Carp	Cypriniformes	Cyprinidae	6.25				1.60	
Heteropneustes fossilis	Stinging Catfish	Siluriformes	Heteropneustidae	17.20	2.10	0.55	16		
Heteropriacanthus cruentatus	Glasseye	Perciformes	Priacanthidae	18.00	1.10				
Hexagrammos agrammus	Spottybelly greenling	Scorpaeniformes	Hexagrammidae	17.50	2.90				
Hexagrammos octogrammus	Masked greenling	Scorpaeniformes	Hexagrammidae	17.50	1.80				
Hexagrammos otakii	Fat greenling	Scorpaeniformes	Hexagrammidae	20.05	0.35	0.50	6	2.20	9.00
Hime japonica	Hime japonica	Aulopiformes	Aulopidae	20.90	1.00				
Hippoglossus stenolepis	Pacific Halibut	Pleuronectiformes	Pleuronectidae	19.90	0.10	0.50	13	2.10	3.00
Histiopterus typus	Sailfin armourhead	Perciformes	Pentacerotidae	19.30	1.20				
Hoplias malabaricus	Trahira	Characiformes	Erythrinidae	18.10					

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Hoplobrotula armata	Armored weasel-fish	Ophidiiformes	Ophidiidae	18.20	1.00				
Hypomesus japonicus	Japanese Surf Smelt	Osmeriformes	Osmeridae	19.50	0.30	1.30	4	5.40	1.00
Hypomesus nipponensis	Japanese Smelt/Pond Smelt	Osmeriformes	Osmeridae	14.40	0.90	2.00	99	7.90	2.00
Hypomesus olidus	Pond smelt	Salmoniformes	Osmeridae	18.40	0.90				
Hypophthalmichthys molitrix	Silver big-head carp	Cypriniformes	Cyprinidae	18.25	1.35	0.28			
Hypophthalmichthys nobilis	Big-head carp	Cypriniformes	Cyprinidae	17.50	1.20				
Hypoptychus dybowskii	Korean sandlance	Gasterosteiformes	Hypoptychidae	21.50	1.70				
Hyporhamphus sajori	Half beak	Beloniformes	Hemiramphidae	18.70	1.90	1.90		5.50	3.00
Hyporthodus septemfasciatus	Convict grouper	Perciformes	Serranidae	18.80	1.00				
Ilisha elongata	Elongate ilisha	Clupeiformes	Pristigasteridae	20.10	0.80				
Inimicus japonicus	Devil stingfish	Scorpaeniformes	Synceiidae	19.05	0.50	0.70	2	0.60	1.00
Johnius grypotus	Corvi	Perciformes	Sciaenidae	15.20	2.60				
Kajikia audax	Barred marlin	Perciformes	Istiophoridae	23.10	0.60	0.60	8	4.30	12.00
Kareius bicoloratus	Stone flounder	Pleuronectiformes	Pleuronectidae	20.00	0.20				
Katsuwonus pelamis	Skipjack tuna	Perciformes	Scombridae	25.45	1.85	0.90	20	8.60	9.00
Konosirus punctatus	Gizzard shad	Clupeiformes	Clupeidae	19.10	1.25	0.70		10.20	9.00
Labeo bata	Bata	Cypriniformes	Cyprinidae	15.90	1.20	0.94			
Labeo calbasu	Orangefin Labeo	Cypriniformes	Cyprinidae	17.00	1.10	0.36			
Labeo gonius	Kuria Labeo	Cypriniformes	Cyprinidae	17.60	0.30	0.06			
Labeo rohita	Roho Labeo	Cypriniformes	Cyprinidae	20.60	0.40	1.13	4		
Labracoglossa argenteiventris	Yellowstriped butterfish	Perciformes	Kyphosidae	18.70	0.60	1.30	16	2.00	4.00
Lagocephalus lunaris	Lurtail puffer	Tetraodontiformes	Tetraodontidae	17.30	1.00				
Larimichthys crocea	Large yellow croaker	Perciformes	Sciaenidae	17.20	1.20				
Larimichthys polyactis	Yellow croaker	Perciformes	Sciaenidae	15.80	0.50				
Lateolabrax japonicus	Common sea bass	Perciformes	Percichthyidae	18.83	0.80	0.50	180	2.00	10.00
Lates calcarifer	Barramundi	Perciformes	Centropomidae	18.60	1.00	0.16	8		1.50
Lepidopsetta mochigarei	Dusky sole	Pleuronectiformes	Pleuronectidae	16.80	1.20				
Lepidotrigla alata	Fork-snout searobin	Scorpaeniformes	Triglidae	16.90	1.00				
Lepidotrigla microptera	Red-wing searobin	Scorpaeniformes	Triglidae	19.70	0.40				
Lepomis macrochirus	Bluegill	Perciformes	Centrarchidae	17.80	1.40				
Leptomelanosoma indicum	Indian Threadfin	Perciformes	Polynemidae	20.30	0.50	1.35			
Lethrinus haematopterus	Chinese emperor	Perciformes	Lethrinidae	20.40	1.00				
Lethrinus nebulosus	Spangled Emperor	Perciformes	Lethrinidae	20.50	0.30	0.50	8	3.70	11.00
Limanda aspera	Yellowfin sole	Pleuronectiformes	Pleuronectidae	16.80	1.20				
Liparis tanakai	Taka's silfish	Scorpaeniformes	Liparidae	16.40	0.50				
Liparis tessellatus	Cubed silfish	Scorpaeniformes	Liparidae	16.40	1.00				
Lobotes surinamensis	Tripletail	Perciformes	Lobotidae	21.00	1.10				
Lophiomus setigerus	Angler	Lophiiformes	Lophiidae	14.10	2.50				

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Lophius litulon	Yellow goosefish	Perciformes	Sciaenidae	14.65	0.25	0.60	13	1.20	1.00
Lota lota	Burbot	Gadiformes	Lotidae	17.83	0.35	0.65	3		
Luciopimelodus pati	Pati	Siluriformes	Pimelodidae	18.20	1.90				
Lumpenus sagitta	Ske prickleback	Perciformes	Stichaeidae	19.30	0.90				
Macruronus novaezelandiae	Hoki	Gadiformes	Merlucciidae	17.00	0.30	0.40	43	0.70	1.00
Makaira mazara	Pacific Blue Marlin/Blue Marlin/Black Marlin	Perciformes	Istiophoridae	22.90	0.50	0.70	2	1.50	38.00
Malakichthys wakiyae	Silver-belly sea perch	Perciformes	Acropomatidae	18.70	0.70				
Mallotus villosus	Capelin	Salmoniformes	Osmeridae						
Mastocembellus armatus	Zig-Zag Eel	Synbranchiformes	Mastacembelidae	16.10	0.80	1.30	829	2.40	
Merluccius merluccius	European Hake	Gadiformes	Merlucciidae	17.10	1.90				
Microcanthus strigatus	Stripey	Perciformes	Kyphosidae	19.50	0.90				
Micromesistius australis	Southern Blue Whiting	Gadiformes	Gadidae	16.40	0.30	0.30	6	1.60	7.00
Micromesistius poutassou	Blue Whiting	Gadiformes	Gadidae	17.50	1.00				
Micropogonias undulatus	Atlantic Croaker	Perciformes	Sciaenidae	19.50					
Micropterus salmoides	Largemouth black bass	Perciformes	Centrarchidae	18.20	4.50				
Miichthys miiuy	Mi-iuy croaker	Perciformes	Sciaenidae	18.00	0.30				
Misgurnus anguillicaudatus	Loach	Cypriniformes	Cobitidae	16.15	6.80	2.90	15	8.50	4.00
Monopterus albus	Asian swamp eel	Synbranchiformes	Synbranchidae	17.90	1.40				
Mugil cephalus	Common mullet	Mugiliformes	Mugilidae	20.45	0.85	0.50	8	4.70	10.00
Muraenesox cinereus	Silver conger eel	Anguilliformes	Muraenesocidae	20.10	1.15	0.60	59	1.90	5.00
Mystus cavasius	Gangetic Mystus	Siluriformes	Bagridae	15.40	1.30	0.88			
Mystus gulio	Long Whiskers Catfish	Siluriformes	Bagridae	17.00	0.90	0.23			
Mystus wolffi	Mystus wolfii	Siluriformes	Bagridae	6.25					
Nandus nandus	Gangetic Leaffish	Perciformes	ndidae	15.80	1.90	1.42			
Nemadactylus bergi	Castaneda	Perciformes	Cheilodactylidae	18.40					
Nemipterus japonicus	Japanese Threadfin Bream	Perciformes	Nemipteridae	18.40	0.80	0.30	0	2.00	
Nemipterus virgatus	Golden threadfin bream	Perciformes	Nemipteridae	19.80	0.70				
Neoditrema ransonnetii	Surfperch	Perciformes	Embiotocidae	21.80	1.80				
Niphon spinosus	Ara	Perciformes	Serranidae	19.30	1.40				
Notopterus notopterus	Bronze Featherback	Osteoglossiformes	Notopteridae	17.80	1.00	0.74	30		
Odentesthes incisa	Silverside	Atheriniformes	Atherinidae	16.00	2.00				
Odontesthes bonariensis	Argentinian Silverside	Atheriniformes	Atherinopsidae	18.30	1.90				
Odontesthes regia	Chilean Silverside	Atheriniformes	Atherinopsidae	18.60					
Odontobutis platycephala	Fresh-water goby	Gobioidei	Odontobutidae	16.90	1.00				
Ompok pabda	Pabdah Catfish	Siluriformes	Siluridae	17.30	1.20	1.25			
Oncorhynchus gorbuscha	Pink Salmon	Salmoniformes	Salmonidae	21.70	0.40	0.60	13	4.60	22.00
Oncorhynchus keta	Chum salmon	Salmoniformes	Salmonidae	21.45	0.80	0.50	11	5.90	32.00
Oncorhynchus kisutch	Coho salmon	Salmoniformes	Salmonidae	20.65	1.40	0.60	36	5.20	15.00

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Oncorhynchus masou	Cherry salmon	Salmoniformes	Salmonidae	20.60	1.20	0.50	63	7.60	10.00
Oncorhynchus masou ishikawae	Masu Salmon	Salmoniformes	Salmonidae	18.30	0.40	0.80	7	5.50	9.00
Oncorhynchus mykiss	Rainbow trout	Salmoniformes	Salmonidae	21.10	1.80				
Oncorhynchus nerka	Sockeye salmon	Salmoniformes	Salmonidae	22.50	0.40	0.50	27	9.40	33.00
Oncorhynchus tshawytscha	Chinook Salmon	Salmoniformes	Salmonidae	18.80	0.25	0.35	111	2.35	16.00
Oplegnathus fasciatus	Rock bream	Perciformes	Oplegthidae	18.65	0.45	0.60	39	1.30	3.00
Oplegnathus punctatus	Spotted knifejaw	Perciformes	Oplegthidae	18.90	0.70				
Oreochromis mossambicus	Mozambique tilapia	Perciformes	Cichlidae	20.05	0.80	1.40	2		5.50
Oreochromis niloticus	Nile Tilapia	Perciformes	Cichlidae	19.80	0.50	0.40	3	2.30	11.00
Osmerus mordax	Pacific rainbow smelt	Salmoniformes	Osmeridae	17.40	1.40				
Ostichthys japonicus	Big-eye soldierfish	Beryciformes	Holocentridae	21.30	1.20				
Pagrus major	Genuine porgy	Perciformes	Sparidae	19.50	0.35	0.40	8	1.20	5.00
Pagrus pagrus	Red Porgy	Perciformes	Sparidae	20.40	1.80	3.30			
Pampus argenteus	Silver/white pomfret	Perciformes	Stromateidae	17.13	0.40	0.39	90	1.40	5.00
Pampus chinensis	Chinese Silver Pomfret	Perciformes	Stromateidae	15.90	0.40	0.59			
Pangasianodon hypophthalmus	Striped Catfish	Siluriformes	Pangasiidae	6.25				4.50	
Pangasius pangasius	Pangas Catfish	Siluriformes	Pangasiidae	15.90	0.10	1.85	5		
Parabembras curtus	Matron flathead	Scorpaeniformes	Bembridae	20.10	1.30				
Parajulis poecilopterus	Multicolor finfish	Perciformes	Labridae	19.30	2.60				
Paralichthys olivaceus	Bastard halibut	Pleuronectiformes	Paralichthyidae	20.75	0.38	0.40	12	1.00	3.00
Parapercis multifasciata	Bicolor-barred weever	Perciformes	Pinguipedidae	18.30	0.90				
Parapercis sexfasciata	Grub fish	Perciformes	Pinguipedidae	20.80	1.30				
Parapristipoma trilineatum	Grunt	Perciformes	Haemulidae	17.10	0.80	0.60	41	5.80	15.00
Parascolopsis inermis	Unarmed dwarf monocle bream	Perciformes	Nemipteridae	19.20	0.60				
Parastromateus niger	Black Pomfret	Perciformes	Carangidae	19.60	0.90	0.48			
Parona signata	Paro Leatherjacket	Perciformes	Carangidae	20.10					
Pennahia argentata	White croaker	Perciformes	Sciaenidae	18.65	0.40	0.60	5	2.50	2.90
Percophis brasiliensis	Brazilian Flathead	Perciformes	Percophidae	20.10					
Pholis nebulosa	Tidepool gunnel	Perciformes	Pholidae	20.70	1.10				
Platycephalus indicus	Bartailed flathead	Scorpaeniformes	Platycephalidae	20.00	0.60				
Plecoglossus altivelis	Sweet fish	Salmoniformes	Plecoglossidae	17.50	1.10	0.80	35	10.30	1.00
Plectorhynchus cinctus	Crescent sweetlips	Perciformes	Haemulidae	19.50	0.70				
Pleurogrammus azonus	Arabesque greenling	Scorpaeniformes	Hexagrammidae	18.45	4.15	1.10	25	10.70	3.00
Pleuronectes herzensteini	Brown sole	Pleuronectiformes	Pleuronectidae	19.50	0.35	0.80	5	3.10	13.00
Pleuronectes yokohamae	Marbled sole	Pleuronectiformes	Pleuronectidae	18.95	0.35	0.80	6	1.80	6.70
Pleuronichthys cornutus	Ridged-eye flounder	Pleuronectiformes	Pleuronectidae	17.60	1.10				
Polynemus quadrifilis	Giant African Threadfin	Perciformes	Polynemidae	17.60	0.30	1.00			
Pomatomus saltatrix	Bluefish	Perciformes	Pomatomidae	21.50	1.40				

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Priacanthus macracanthus	Red bigeye	Perciformes	Priacanthidae	18.90	1.20				
Prionotus punctatus	Bluewing Searobin	Scorpaeniformes	Triglidae	18.90					
Protonibea diacanthus	Blacksotted Croaker	Perciformes	Sciaenidae	18.60	0.40	0.65	17		0.60
Psenopsis anomala	Butterfish	Perciformes	Centrolophidae	16.35	0.55	0.80	95	2.70	2.00
Pseudaesopia japonica	Wavy-banded sole	Pleuronectiformes	Soleidae	18.40	1.10				
Pseudambassis ranga	Indian Glassy Catfish	Perciformes	Ambassidae	15.50	2.00	2.45	106		
Pseudoblennius cottoides	Sunrise sculpin	Scorpaeniformes	Cottidae	22.40	1.70				
Pseudocaranx dentex	Striped Jack/White Trevally	Perciformes	Carangidae	21.90	0.70	1.10	10	3.20	18.00
Pseudogobio esocinus	Pike gudgeon	Cypriniformes	Cyprinidae	15.70	1.20				
Pseudolabrus japonicus	Bambooleaf wrasse	Perciformes	Labridae	18.90	1.10				
Pseudoplatystoma corruscans	Spotted Sorubim	Siluriformes	Pimelodidae	18.20	1.90				
Pseudorasbora parva	Stone moroko	Cypriniformes	Cyprinidae	16.40	2.50				
Pterocaesio digramma	Double-Lined Fusilier	Perciformes	Caesionidae	20.20	0.50	0.70	7	4.40	2.00
Puntius sophore	Pool Barb	Cypriniformes	Cyprinidae	17.60	2.00	3.00			
Rastrelliger brachysoma	Short Mackerel	Perciformes	Scombridae	6.25					
Rastrelliger kanagurta	Indian mackerel	Perciformes	Scombridae	20.51					
Rexea prometheoides	Royal escolar	Perciformes	Gempylidae	20.00	0.80				
Salangichthys microdon	Icefish	Salmoniformes	Salangidae	13.45	0.55	1.20	50	3.30	1.00
Salminus maxillosus	Dorado	Characiformes	Bryconidae	18.80					
Salmo salar	Atlantic Salmon	Salmoniformes	Salmonidae	20.10	0.30	0.40	17	8.90	10.00
Salmophasia bacaila	Large Razorbelly Minnow	Cypriniformes	Cyprinidae	18.10	5.40	3.10			
Salmophasia phulo	Finescale Razorbelly Minnow	Cypriniformes	Cyprinidae	15.30	1.90	3.10			
Salvelinus alpinus	Arctic Char	Salmoniformes	Salmonidae	18.75	0.34	0.42	32		25.80
Salvelinus leucomaenis	White-Spotted Char/Char/Japanese Char	Salmoniformes	Salmonidae	19.00	0.30	0.80	5	4.20	5.00
Salvelinus namaycush	Lake Trout	Salmoniformes	Salmonidae	15.78	0.23	0.62	40		19.70
Sarda orientalis	Striped bonito	Perciformes	Scombridae	24.60	2.10				
Sarda sarda	Atlantic Bonito	Perciformes	Scombridae	22.00					
Sardina pilchardus	European pilchard	Clupeiformes	Clupeidae	17.33					21.20
Sardinella zunasi	Japanese sardinella	Clupeiformes	Clupeidae	16.30	1.90				
Sardinops sagax	South American Pilchard	Clupeiformes	Clupeidae	18.77	2.00	1.60	8	15.70	32.00
Satyrichthys rieffeli	Spotted armored-gurrd	Scorpaeniformes	Peristediidae	19.30	2.10				
Saurida undosquamis	Lizard fish	Aulopiformes	Synodontidae	20.80	0.40				
Scomber australasicus	Blue Mackerel	Perciformes	Scombridae	23.00	1.60	1.10	8	12.60	4.30
Scomber colias	Black Drum	Perciformes	Sciaenidae	18.80					
Scomber japonicus	Mackerel	Perciformes	Scombridae	19.00	1.60	1.10	37	12.90	5.10
Scomber scombrus	Atlantic Mackerel	Perciformes	Scombridae	17.20	0.90	0.90	44	8.10	10.00
Scomberomorus cavalla	King Mackerel	Perciformes	Scombridae	20.90	0.50	0.60	17	0.55	

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Scomberomorus commerson	rrow-Barred Spanish Mackerel	Perciformes	Scombridae	19.80	2.00	0.40	30		
Scomberomorus guttatus	Indo-Pacific King Mackerel	Perciformes	Scombridae	20.90	0.80	0.78			
Scomberomorus koreanus	Korean seerfish	Perciformes	Scombridae	17.90	0.70				
Scomberomorus niphonius	Spanish mackerel	Perciformes	Scombridae	19.73	0.70	0.80	12	4.00	7.00
Scombrops boops	Japanese blue fish	Perciformes	Scombropidae	18.75	0.65	0.40	8	1.90	4.00
Scorpaena neglecta	Izu scorpionfish sting fish	Scorpaeniformes	Scorpaenidae	15.50	0.90				
Scorpaenopsis cirrhosa	Weedy stingfish	Scorpaeniformes	Scorpaenidae	19.00	1.10				
Sebastes alutus	Pacific Ocean perch, Longjaw rockfish	Scorpaeniformes	Scorpaenidae	16.45	0.25	0.40	20	1.60	3.00
Sebastes hubbsi	Amorclad rockfish	Scorpaeniformes	Scorpaenidae	18.30	0.90				
Sebastes inermis	Black rock fish	Scorpaeniformes	Scorpaenidae	19.30	0.60				
Sebastes iracundus	Angry Rockfish	Scorpaeniformes	Scorpaenidae	16.30	0.20	0.40	85	3.30	3.00
Sebastes matsubarae	Matsubara's Red Rockfish	Scorpaeniformes	Scorpaenidae	16.80	0.30	0.40	26	0.70	1.00
Sebastes oblongus	Oblong rockfish	Scorpaeniformes	Scorpaenidae	21.30	0.70				
Sebastes pachycephalus	Spotbelly rockfish	Salmoniformes	Salmonidae	19.10	0.80				
Sebastes schlegelii	Korean rockfish	Scorpaeniformes	Scorpaenidae	21.40	0.50				
Sebastes taczanowskii	White-edged rockfish	Perciformes	Sciaenidae	19.70	1.70				
Sebastes thompsoni	Gold eye rockfish	Scorpaeniformes	Scorpaenidae	18.60	1.50				
Sebastes vulpes	Fox jacopever	Scorpaeniformes	Scorpaenidae	22.40	1.00				
Sebastiscus marmoratus	Scorpion fish	Scorpaeniformes	Scorpaenidae	19.60	0.45	0.50	3	1.20	2.00
Sebastolobus macrochir	Kichiji Rockfish/ Broadbanded Thornyhead	Scorpaeniformes	Sebastidae	13.60	0.30	0.40	65	1.00	4.00
Semicossyphus reticulatus	Cold porgy	Perciformes	Labridae	18.50	0.30				
Seriola dumerili	Greater Amberjack	Perciformes	Carangidae	21.00	0.60	0.70	4	5.30	4.00
Seriola lalandi	Amberjack	Perciformes	Carangidae	22.45	0.85	0.70	19	2.10	5.00
Seriola quinqueradiata	Yellow tail	Perciformes	Carangidae	21.20	1.00	0.70	50	3.80	8.00
Seriolella punctata	Silver Warehou	Perciformes	Centrolophidae	18.60	0.60	0.50	100	1.80	3.00
Setipinna phasa	Gangetic Hairfin Anchovy	Clupeiformes	Engraulidae	17.70	1.80	3.20	12		
Setipinna taty	Scaly Hairfin Anchovy	Clupeiformes	Engraulidae	19.30	2.30	1.60	8		
Siganus fuscescens	Mottled spinefooot	Perciformes	Siganidae	20.30	1.20				
Sillago japonica	Japanese Whiting	Perciformes	Sillaginidae	18.50	0.10	0.40	1	2.20	0.70
Sillago sihama	Silver sillago	Perciformes	Sillaginidae	19.50	2.30				
Silurus asotus	Amur catfish	Siluriformes	Siluridae	15.10	0.80				
Siniperca scherzeri	Leopard mandarin fish	Perciformes	Percichthyidae	17.20	2.10				
Sperata seenghala	Giant River-Catfish	Siluriformes	Bagridae	15.90	0.70	0.23			
Sphyraena japonica	Japanese barracuda	Perciformes	Sphyraenidae	18.90	0.30				
Sphyraena pinguis	Red barracuda	Perciformes	Sphyraenidae	19.70	0.60	0.50	12	2.30	11.00
Spratelloides gracilis	Blue Sprat	Clupeiformes	Clupeidae	18.80	1.10	1.90		8.30	10.00
Sprattus fuegensis	Falkland Sprat	Clupeiformes	Clupeidae	14.00					

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Sprattus sprattus	Sprat	Clupeiformes	Clupeidae	22.63					
Stenodus leucichthys	Sheefish	Salmoniformes	Salmonidae	19.00	0.40	0.30			
Stephanolepis cirrhifer	Thread-sail filefish	Tetraodontiformes	Mocanthidae	18.95	0.30	0.40	2	1.30	43.00
Stichaeus grigorjewi	Long shanny	Perciformes	Stichaeidae	19.10	1.20				
Strangomera bentincki	Araucanian herring	Clupeiformes	Clupeidae	16.50					
Suggrundus meerdervoorti	Big-eyed flathead	Scorpaeniformes	Platycephalidae	17.50	0.20	0.60	2	3.00	11.00
Synchiropus altivelis	Highfin bigeye dragonet	Perciformes	Callionymidae	16.90	0.60				
Synodus myops	Snakefish	Aulopiformes	Synodontidae	20.00	0.60				
Systomus sarana	Olive Barb	Cypriniformes	Cyprinidae	17.40	0.60	0.74			
Tachysurus fulvidraco	Yellow catfish	Siluriformes	Bagridae	15.55	0.90				
Takifugu pardalis	Panther puffer	Tetraodontiformes	Tetraodontidae	18.90	2.50				
Takifugu poecilonotus	Fine-patterned puffer	Tetraodontiformes	Tetraodontidae	15.90	1.00				
Takifugu porphyreus	Purple puffer	Tetraodontiformes	Tetraodontidae	20.20	0.25	1.50	7	3.00	6.00
Takifugu rubripes	Tiger puffer	Tetraodontiformes	Tetraodontidae	19.05	0.25	0.90	3	1.90	4.00
Takifugu stictonotus	Spotty-back puffer	Tetraodontiformes	Tetraodontidae	19.30	3.10				
Takifugu vermicularis	Purple puffer	Tetraodontiformes	Tetraodontidae	20.25	1.20				
Takifugu xanthopterus	Yellowfin puffer	Tetraodontiformes	Tetraodontidae	19.30	4.40				
Tanakius kitaharae	Willowy flounder	Perciformes	Carangidae	18.30	1.90				
Tenualosa ilisha	Hilsha Shad	Clupeiformes	Clupeidae	18.00	1.30	0.54			
Thamnaconus modestus	Black scraper	Tetraodontiformes	Mocanthidae	18.05	0.45	0.50		1.40	8.00
Theragra chalcogramma	Alaska pollack	Gadiformes	Gadidae	17.45	0.85	0.50	10	2.90	0.50
Thunnus alalunga	Albacore	Perciformes	Scombridae	26.00	0.90	0.50	4	2.80	7.00
Thunnus albacares	Yellowfin tuna	Perciformes	Scombridae	24.10	1.80	0.50	2	5.80	6.00
Thunnus maccoyii	Southern Bluefin Tuna	Perciformes	Scombridae	23.30	1.60	0.50	39	0.70	
Thunnus obesus	Big-Eye Tuna	Perciformes	Scombridae	22.80	1.40	0.40	3	4.50	2.00
Thunnus thynnus	Bluefin tuna	Perciformes	Scombridae	26.20	2.05	0.50	61	6.90	12.00
Thymallus arcticus	Arctic Grayling	Salmoniformes	Salmonidae	20.00	1.00	0.70			
Thyrsites atun	Barracouta	Perciformes	Gempylidae	21.70	0.60	0.50	55	6.50	2.00
Trachipterus ishikawae	Slender ribbonfish	Lampriformes	Trachipteridae	18.10	0.30				
Trachurus japonicus	Horse mackerel	Perciformes	Carangidae	20.20	0.75	1.10	7	7.10	8.90
Trachurus picturatus	Bluejack Mackerel	Perciformes	Carangidae	19.00					
Trachurus trachurus	Atlantic Horse Mackerel	Perciformes	Carangidae	19.60	1.00	0.90	16	8.10	8.00
Tribolodon hakonensis	Far eastern dace	Cypriniformes	Cyprinidae	19.20	1.10	3.40	41	8.50	19.00
Trichiurus lepturus	Hair tail	Perciformes	Trichiuridae	17.50	0.60	0.50	52	0.90	14.00
Trichogaster fasciata	Banded Gourami	Perciformes	Belontiidae	15.80	0.90	1.35	39		
Umbrina canosai	Argentine Croaker	Perciformes	Sciaenidae	19.10					
Upeneus japonicus	Bensasi goatfish	Perciformes	Mullidae	7.10	1.40				
Uranoscopus japonicus	Stargazer	Perciformes	Uranoscopidae	18.20	0.70				
Urophycis brasiliensis	Brazilian Codling	Gadiformes	Phycidae	17.60	2.10				

Species	Common name	Order	Family	Protein	Iron	Zinc	Vit A	Vit B12	Vit D
Verasper variegatus	Spotted halibut	Pleuronectiformes	Pleuronectidae	18.20	0.20				
Wallago attu	Wallago	Siluriformes	Siluridae	15.40	0.80	0.27	1		
Xenentodon cancila	Freshwater Garfish	Beloniformes	Belonidae	16.60	0.80	0.94	65		
Xenocephalus elongatus	Blue-spotted stargazer	Perciformes	Uranoscopidae	17.40	0.40				
Xiphias gladius	Swordfish	Perciformes	Xiphiidae	18.10	3.35	0.70	61	1.90	8.80
Zacco platypus	Common minnow	Cypriniformes	Cyprinidae	18.85	1.25	2.50	10	11.30	10.00
Zalanthias kelloggi	Eastern flower porgy	Perciformes	Serranidae	19.00	1.00				
Zebrias zebra	Zebra sole	Pleuronectiformes	Soleidae	18.90	1.20				
Zenopsis nebulosa	Mirror dory	Zeiformes	Zeidae	20.30	0.80				
Zeus faber	John dory	Zeiformes	Zeidae	19.10	0.60				
Zoarces gillii	Blotched eelpout	Perciformes	Zoarcidae	18.50	0.40				

Supplementary Table 2. Nutrient content of fish species in dataset.[2,3,4,5,6,7,8,9,10,11,12,13,14,15]

Category	**Nutrient**	# Valid Species	Min	Max	Median	Mean	SD
Protein, fats (g/100g)	Protein	371	6.3	33.8	18.6	18.5	2.9
	Total fat	367	0.1	26.8	2.3	3.6	4.1
	Omega-3 fatty acids	238	0.01	7.68	0.69	0.97	1.12
	Omega-6 fatty acids	238	0.00	4.41	0.11	0.20	0.41
Minerals (mg/100g)	Iron	344	0.10	9.10	1.00	1.19	1.04
	Zinc	177	0.06	3.90	0.65	0.91	0.73
Vitamins (μg/100g)	Vitamin A (retinol activity equivalents)	146	0.0	2680.0	15.0	96.6	356.5
	Vitamin B12	124	0.0	28.2	2.9	4.6	4.4
	Vitamin D	122	0.0	43.0	5.0	8.1	8.2

Supplementary Table 3. Summary statistics for life history traits.

Continuous Variables	# Valid Species	Min	Max	Median	Mean	SD
Minimum depth (m)	259	0	320	3.0	28.15	59.4
Maximum depth (m)	249	2	3850	200.0	247.5	484.8
Maximum length (cm)	370	8.0	505.1	48.0	71.7	70.4
***a* (L/W scalar)**	333	.0004	.0263	0.0089	0.0097	0.0055
***b* (L/W exponent)**	332	2.79	3.39	3.05	3.05	0.08
Trophic level	373	2.0	4.7	3.6	3.6	0.5

Categorical Variables	Categories	# Species	Percent
Habitat	Bathydemersal	15	4.0
	Benthopelagic	90	23.9
	Demersal	149	39.6
	Pelagic	25	6.6
	Pelagic-neritic	51	13.6
	Reef-associated	44	11.7
Latitudinal range	Tropical	126	33.5
	Subtropical	104	27.7
	Temperate	126	33.5
	Boreal/austral	5	1.3
	Polar	8	2.1

*Supplementary Table 4. Evolutionary correlation matrix, with omega-3 and omega-6 fatty acids included. Correlations with $p<0.1$ are in **bold**.*

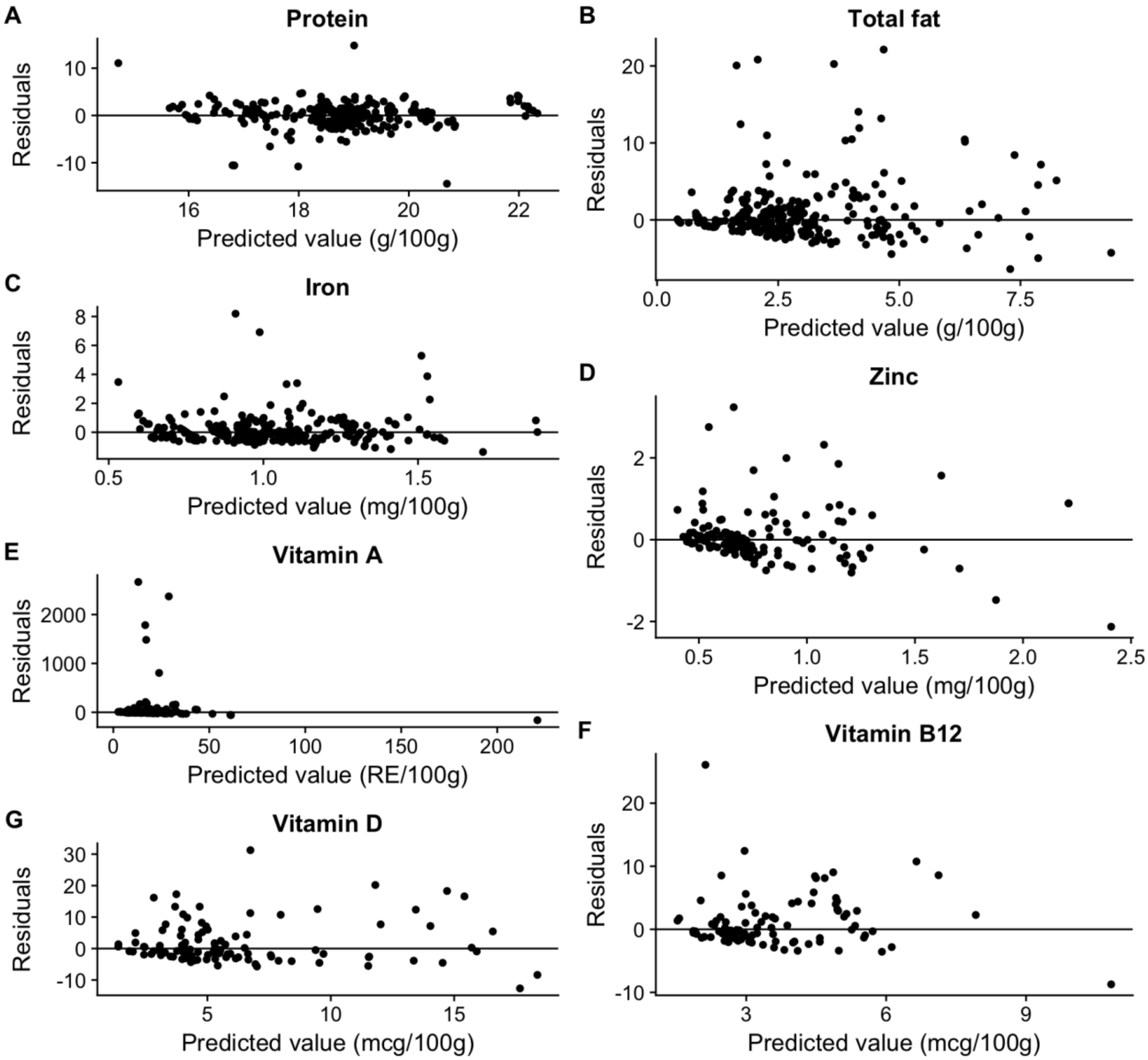
	depmin	depmax	maxlen	a_lw	b_lw	troph	protein	fat	iron	zinc	vitA	vitb12	vitd
depmin	1.00	**0.22**	0.07	-0.06	0.05	0.09	-0.02	0.06	-0.04	-0.08	0.17	0.00	-0.11
depmax	0.22	1.00	**0.46**	**-0.32**	0.15	**0.43**	-0.23	**0.37**	-0.07	-0.25	**0.46**	-0.09	0.04
maxlen	0.07	**0.46**	1.00	-0.13	-0.10	**0.44**	0.11	0.12	-0.06	**-0.45**	**0.31**	**-0.21**	0.13
a_lw	-0.06	**-0.32**	-0.13	1.00	**-0.60**	-0.22	0.13	-0.18	-0.13	-0.11	-0.13	-0.15	0.09
b_lw	0.05	0.15	-0.10	**-0.60**	1.00	0.00	-0.15	0.10	0.20	0.23	0.15	0.06	0.04
troph	0.09	**0.43**	**0.44**	-0.22	0.00	1.00	0.17	0.01	-0.13	-0.24	0.06	-0.16	-0.06
protein	-0.02	-0.23	0.11	0.13	-0.15	0.17	1.00	**-0.39**	0.08	0.07	**-0.41**	0.14	0.01
lipid	0.06	**0.37**	0.12	-0.18	0.10	0.01	**-0.39**	1.00	0.16	-0.04	**0.69**	**0.31**	**0.42**
iron	-0.04	-0.07	-0.06	-0.13	0.20	-0.13	0.08	0.16	1.00	**0.55**	0.21	**0.56**	**0.26**
zinc	-0.08	-0.25	**-0.45**	-0.11	0.23	-0.24	0.07	-0.04	**0.55**	1.00	-0.03	**0.38**	0.18
ret_eq	0.17	**0.46**	**0.31**	-0.13	0.15	0.06	**-0.41**	**0.69**	0.21	-0.03	1.00	0.05	**0.27**
vitb12	0.00	-0.09	-0.21	-0.15	0.06	-0.16	0.14	**0.31**	**0.56**	**0.38**	0.05	1.00	**0.22**
vitd	-0.11	0.04	0.13	0.09	0.04	-0.06	0.01	**0.42**	**0.26**	0.18	**0.27**	0.22	1.00

P-VALUES

	depmin	depmax	maxlen	a_lw	b_lw	troph	protein	fat	iron	zinc	vitA	vitb12	vitd
depmin	NA	0.085	0.340	0.351	0.372	0.301	0.392	0.351	0.376	0.322	0.157	0.397	0.271
depmax	0.085	NA	**0.000**	**0.014**	0.186	**0.001**	0.071	**0.004**	0.337	0.050	**0.000**	0.308	0.381
maxlen	0.340	**0.000**	NA	0.232	0.281	**0.000**	0.269	0.258	0.355	**0.000**	**0.016**	**0.097**	0.223
a_lw	0.351	**0.014**	0.232	NA	**0.000**	0.087	0.234	0.135	0.228	0.267	0.226	0.188	0.308
b_lw	0.372	0.186	0.281	**0.000**	NA	0.397	0.198	0.283	0.112	0.068	0.199	0.351	0.379
troph	0.301	**0.001**	**0.000**	0.087	0.397	NA	0.150	0.396	0.240	0.064	0.354	0.175	0.359
protein	0.392	0.071	0.269	0.234	0.198	0.150	NA	**0.002**	0.317	0.333	**0.001**	0.207	0.395
lipid	0.351	**0.004**	0.258	0.135	0.283	0.396	**0.002**	NA	0.170	0.374	**0.000**	**0.017**	**0.001**
iron	0.376	0.337	0.355	0.228	0.112	0.240	0.317	0.170	NA	**0.000**	0.097	**0.000**	**0.041**
zinc	0.322	0.050	**0.000**	0.267	0.068	0.064	0.333	0.374	**0.000**	NA	0.385	**0.003**	0.134
ret_eq	0.157	**0.000**	**0.016**	0.226	0.199	0.354	**0.001**	**0.000**	0.097	0.385	NA	0.362	**0.034**
vitb12	0.397	0.308	0.097	0.188	0.351	0.175	0.207	**0.017**	**0.000**	**0.003**	0.362	NA	0.082
vitd	0.271	0.381	0.223	0.308	0.379	0.359	0.395	**0.001**	**0.041**	0.134	**0.034**	0.082	NA

Supplementary Figures

Supplementary Figure 1. Residual plots for nutrient prediction: protein (A), total fat (B), iron (C), zinc (D), vitamin A (E), vitamin B12 (F), and vitamin D (G).



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Description of Additional Supplementary Files:

- **Supplementary data file 1**. *SD1_fish _database.csv*. Database of life history and nutrient content values for all included species.
- **Supplementary data file 2**. *SD2_phyloPred_lambda.totalfat.csv*. Predicted total fat content for Actinopterygii species.
- **Supplementary data file 3**. *SD3_phyloPred_lambda.omega3.csv*. Predicted omega-3 fatty acids content for Actinopterygii species.
- **Supplementary data file 4**. *SD4_phyloPred_lambda.omega6.csv*. Predicted omega-6 fatty acids content for Actinopterygii species.
- **Supplementary data file 5**. *SD5_phyloPred_lambda.iron.csv*. Predicted iron content for Actinopterygii species.
- **Supplementary data file 6**. *SD6_phyloPred_lambda.zinc.csv*. Predicted zinc content for Actinopterygii species.
- **Supplementary data file 7**. *SD7_phyloPred_lambda.vitA.csv*. Predicted vitamin A content for Actinopterygii species.
- **Supplementary data file 8**. *SD8_phyloPred_lambda.vitB12.csv*. Predicted vitamin B12 content for Actinopterygii species.
- **Supplementary data file 9**. *SD9_phyloPred_lambda.vitD.csv*. Predicted vitamin D content for Actinopterygii species.
- **Supplementary data file 10**. *SD1_phyloPred_lambda.protein.csv*. Predicted protein content for Actinopterygii species.
- **Supplementary data file 11.** *SD11_bionut.evolCorMat.R*. Script for evolutionary correlations.
- **Supplementary data file 12.** *SD12_bionut.PGLS.R*. Script for phylogenetic least squares regression.
- **Supplementary data file 13.** *SD13_phylosigByVar.R*. Script for estimating phylogenetic signal of nutrient variables.
- **Supplementary data file 14.** *SD14_predValidation.lambda-only.R*. Script for carrying out validation for predictions under the lambda model.
- **Supplementary data file 15.** *SD15_predValidation.pgls-lambda.R*. Script for carrying out validation for predictions under the lambda plus phylogenetic regression model.