

# “Growth limitation of marine fish by low iron availability in the open ocean”

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## 1 Conversion factors for previously-reported Fe measurements

The diversity of units in which Fe concentrations have been reported in the literature presents a challenge for comparison of Fe among organisms. Many studies on plankton report Fe:C ratios, but this is very rarely the case for higher trophic levels. Instead, most report the Fe concentration relative to biomass, either fresh (wet) or dessicated (dry). In order to compare the concentrations directly, we converted the biomass-specific Fe ratios to C-specific ratios (Table S1), assuming that 12.5% of fish wet weight is carbon (50% of organism dry weight is carbon and dry weight is 25% of wet weight) and assuming 6.2% of zooplankton wet weight is carbon (39% of organism dry weight is carbon and dry weight is 16% of wet weight) (Table S1). These conversions were chosen as representative averages based on the reported conversions given in tables S2 and S3, but it should be borne in mind that they have significant uncertainties, and could be greatly improved by further work. In the tables that follow, we indicate the units in which the iron contents were originally reported, as well as the converted Fe:C molar ratio.

Supplementary Table 1: Conversion factors used in this study, based on the mean values from tables S2 and S3.

Organism	dry weight : wet weight	C mass : dry weight	From ppm wet weight to $\mu\text{molFe/molC}$	From ppm dry weight to $\mu\text{molFe/molC}$
Zooplankton	0.16	0.39	~3.44	~0.55
Fish	0.25	0.50	~1.74	~0.43

Supplementary Table 2: Conversion factors between dry and wet weight for marine plankton and marine fish from the literature.

Organism	Dry matter content in wet matter	Ratio dry/wet	Reference
<b>Plankton</b>			
Euphausiids	wet:dry = 8.45	0.12	Martin and Knauer, 1973
Copepods	wet:dry = 10.78	0.09	Martin and Knauer, 1973
Radiolarians	wet:dry = 13.05	0.08	Martin and Knauer, 1973
Euphausiids	4.7 wet-dry ratio	0.21	Fowler, 1977
Krill	dw=23%wm	0.23	Nicol et al., 1992
Krill	14.4-26.2 %dm	0.14-0.26	Bernard and Allen, 2002
Krill, pacifica	18.9 %dm	0.19	Bernard and Allen, 2002
Krill, superba	19.2 %dm	0.19	Bernard and Allen, 2002
Zooplankton	dm=12%wm	0.12	Griffiths et al., 2006
Zoobenthos	dm=20%wm	0.20	Griffiths et al., 2006
<b>Gelatinous group</b>	<b>4-5 %wm</b>	<b>0.04-0.05</b>	
Ctenophores	4.0 +/- 0.4	0.04	
Tunicates	5.4 +/- 1.9	0.05	
Cnidarians	4.1 +/- 0.3	0.04	
<b>Non-gelatinous group</b>	<b>18.3 +/- 1.9 %wm</b>	<b>0.18 +/- 0.02</b>	
Chaetognaths	9.3 +/- 1.6	0.09	Kiorboe et al., 2013
Polychaetes	13.4 +/- 1.7	0.13	
Pteropods	23.0 +/- 19.4	0.23	
Copepods	16.2 +/- 2.4	0.16	
Euphausiids	22.8 +/- 1.4	0.23	
Amphipods	23.9 +/- 9.0	0.24	
Squid	17.2 %	0.17	Mazzaro et al., 2016
<b>Fish</b>			
Atlantic Salmon	18-40 % dry matter in ww	0.18-0.4	Shearer, 1994
Yellow perch	dw = 22-27.5 % ww	0.22-0.28	Hartman & Brandt, 1995
Rainbow trout	dw = 28-38 % ww	0.28-0.38	Hartman & Brandt, 1995
Bay anchovy	dw = 11-23 % ww	0.11-0.23	Hartman & Brandt, 1995
Anchovies	25.8-36.9 %dm	0.26-0.37	
Butterfish	31 % dm	0.31	
Capelin	14.6-22.8 %dm	0.15-0.23	
Goldfish	19.4 %dm	0.19	
Herring	23.9-32.1 %dm	0.24-0.32	
Herring, Atlantic	20.6-28.6 %dm	0.21-0.29	
Mackerel, Atlantic	31.2-36.9 %dm	0.31-0.37	
Mackerel, Pacific	23.7-33.4 %dm	0.24-0.33	
Mackerel, Spanish	33.8 %dm	0.34	Bernard and Allen, 2002
Minnows	18.6 %dm	0.19	
Salmon	22.3 %dm	0.22	
Shrimp, whole	18.8-23.3 %dm	0.19-0.23	
Silversides	26.7-29.3 %dm	0.27-0.29	
Smelt, ocean	20.4-25.4 %dm	0.20-0.25	
Squid	15.4-18.8 %dm	0.15-0.19	
Whitebait	20.4 %dm	0.20	
Fish	dm=22%wm	0.22	Griffiths et al., 2006
Atlantic herring	dm=25 % wm	0.25	Mazzaro et al., 2016
Atlantic mackerel	dm=31.3 +/- 1.6 % wm	0.31	Mazzaro et al., 2016
Capelin	dm=21.3 +/- 0.3 % wm	0.21	Mazzaro et al., 2016

Supplementary Table 3: Conversion factors between carbon content and dry weight for marine plankton and fish from the literature.

Organism	C content (% dry mass)	Reference
<b>Plankton</b>		
Zooplankton	32	Baines et al., 2016
<b>Gelatinous group</b>	<b>9.5</b>	Kiorboe et al., 2013
Ctenophores	5.1 +/- 2.2	
Tunicates	10.3 +/- 3.9	
Cnidarians	13.2 +/- 2.1	
<b>Non-gelatinous group</b>	<b>43.5 +/- 1.3</b>	
Chaetognaths	36.7 +/- 3.1	
Polychaetes	37.0 +/- 3.6	
Pteropods	28.9 +/- 4.8	
Copepods	48 +/- 1.4	
Euphausiids	41.9 +/- 4.1	
Amphipods	34.5 +/- 3.2	
Amphipod ( <i>Parathemisto japonica</i> )	37	Masuzawa et al., 1988
Euphausiids ( <i>Thysanoessa longipes</i> )	43.9	
Copepod ( <i>Calanus plumchrus</i> )	39.1	
Chaetognath ( <i>Sagitta elegans</i> )	45.2	
Mixed zooplankton	37.1	
<b>Fish</b>		
Fish (muscles and organs)	44.3-56	Vinogradov, 1953
Various fishes (n=242)	46	Sterner and George, 2000
Wild caught marine fish (whole body)	38.8-47.5 (mean=41)	Czamanski et al., 2011
Aquacultured fish (whole body)	43.7-58.7 (mean=52.1)	
<i>E. japonicus</i> (whole fish tissue)	45	Huang et al., 2012

## 2 Iron content of phytoplankton

The Fe:C molar ratios of phytoplankton were calculated from studies in the literature. We divided the measurements between organisms that were living in “Very likely Fe-poor conditions” and “Very likely Fe-rich conditions”. For the former, we took only measurements that had been made on organisms isolated from iron-poor waters. We did not include organisms isolated from iron-rich coastal waters and grown under iron-limited conditions, given that they were not adapted to low-iron conditions and therefore may not be representative of iron-limited communities. Similarly, for the “Very likely Fe-rich conditions” category, we took only measurements that had been made on organisms isolated from coastal, presumably iron-rich waters and grown in culture under iron-replete conditions.

Supplementary Table 4: Iron to carbon ratios in phytoplankton

Common name	Latin name	Locality	Content in original units (μmolFe/molC)				Reference
			min	mean	max	std	
Phytoplankton		Whole ocean	2.13	60.5	258		Moore et al., 2013
Very likely Fe-poor conditions							
Diatoms	- <i>Pseudo-Nitzschia</i>	Southern Ocean Equatorial Pacific Subarctic Pacific	 2.8	6 12.3	 3.7		Twining et al., 2004 Twining et al., 2011 Marchetti et al., 2006
Autotrophic flagellates	- -	Southern Ocean Equatorial Pacific		8.7 14.2			Twining et al., 2004 Twining et al., 2011
Diatoms	<i>F. kerguelensis</i> <i>E. antarctica</i> <i>P. inermes</i>	Southern Ocean	0.8 0.9 0.4		4.2 1.0 2.6		Strzepek et al., 2011
Very likely Fe-rich conditions							
Diatoms	<i>T. oceanica</i>	Stony Brook Harbor		31.5		3.6	Chen et al., 2011
Cryptophyte	<i>R. salina</i>			23.5		3.5	
Prymnesiophyte	<i>I. galbana</i>			36.7		5.1	
Diatoms	- <i>T. weissflogii</i>	Southern Ocean -		22.8 35		 6	Twining et al., 2004 Schmidt et al., 1999
	<i>Pseudo-Nitzschia</i>	Northeast Pacific		222		26	Marchetti et al., 2006
	<i>Pseudo-Nitzschia</i>	Denmark		176		20	
	<i>T. oceanica</i>	Sargasso Sea		115		4	
		<i>T. weissflogii</i>	Estuaries on Long Island		30.8		
Autotrophic flagellates	-	Southern Ocean		36.1			Twining et al., 2004
Dinoflagellate	<i>P. minimum</i>	Estuaries on Long Island		36.5			Sunda and Huntsman, 1995
Cyanobacteria	<i>S. bacillaris</i>	-		250			Sunda and Huntsman, 1995

## 3 Iron content of zooplankton

The Fe:C molar ratios were calculated from studies in the literature, including both field samples and laboratory cultures. Because it is not clear to what degree zooplankton of a given species can alter their cellular Fe:C under iron limitation, we did not include zooplankton isolated from coastal waters and fed low-iron food in the “Very likely Fe-poor conditions” section, but only included zooplankton that had been collected from waters identified by the authors as iron-poor. Nor did we classify samples from coastal Antarctic waters as Fe-poor conditions. This leaves three observations as being very likely from iron-poor conditions, one of which is krill muscle only (rather than whole body). For the latter, we used the observed mean ratio between the

muscle iron content and the whole body iron content given by Ratnarajah et al., 2016 to compute a whole body iron to carbon ratio for this observation.

We also include “Uncertain/mixed status” measurements in order to provide a broader context, though we do not include these values in Figure 2. Notably, the reported iron contents of krill are highly variable, spanning more than an order of magnitude, as previously explored by Ratnarajah et al., 2016. It seems likely that at least some of the high concentrations are due to the inclusion of lithogenic iron in krill stomachs, as reported by Schmidt et al. (2011); we did not include whole krill or salps (e.g. Krishnamurthy et al., 1985) that had been explicitly identified as containing lithogenic iron in our table. The variability among krill is also likely to include spatial or seasonal variations (Ratnarajah et al., 2016).

Supplementary Table 5: Iron to carbon ratios in zooplankton. See section 3 above for conversion factors.

Common name	Latin name	Locality	Comment	Content in original units				Original units	Content in SI units (μmolFe/molC)				Reference
				min	mean	max	std		min	mean	max	std	
Very likely Fe-poor conditions													
Heterotrophic flagellates		Southern Ocean Equatorial Pacific			14.1 9.4			μmolFe/molC		14.1 9.4			Twining et al., 2004 Twining et al., 2011
Krill	Euphausia superba	Scotia sea	muscle only whole krill using Ratnarajah et al., 2016 mean whole/ muscle ratio		2400  7440			μgFe/kg dry matter		1.3  4.1			Schmidt et al., 2011 Ratnarajah et al., 2016
Very likely Fe-rich conditions													
Copepods	A. tonsa Calanus plumchus	Stony Brook Harbor Japan Sea	Fe-rich food		47.8 33		7.9	μmolFe/molC μgFe/g dry weight		47.8 18		7.9	Chen et al., 2011 Masuzawa et al., 1988
Microflagellates	P. imperforata P. butcheri	Vineyard Sound Sargasso Sea	Fe-rich food		98 101		3 12	μmolFe/molC		98 101		3 12	Chase and Price, 1997
Euphausiids	Thysanoessa longipes -	Japan Sea NW Med Sea			110 64			μgFe/g dry weight μgFe/g dry matter		60.5 35.2			Masuzawa et al., 1988 Fowler, 1977
Amphipods	Parathemisto japonica	Japan Sea			240			μgFe/g dry weight		132			Masuzawa et al., 1988
Chaetognaths	Sagitta elegans	Japan Sea			190			μgFe/g dry weight		104.5			Masuzawa et al., 1988
Mixed zooplankton		Japan Sea			450			μgFe/g dry weight		247.5			Masuzawa et al., 1988
Copepod	Amonalocera patersoni	Off Monaco coast, Mediterranean Sea			191			μgFe/g dry weight		105.05			Krishnaswami et al., 1985
					306			μgFe/g dry weight		168.3			
Crab larvae	-				85			μgFe/g dry weight		46.75			
	-				248			μgFe/g dry weight		136.4			
Mixed copepods	-				278			μgFe/g dry weight		152.9			
Uncertain/Mixed status													
Copepods	- A. tonsa - - -	Coastal Antarctic Stony Brook Harbour - - Monterray Bay	Whole Fe-poor food Fe-poor food Fe-rich food		208 54.8 5 12 197		8.7  3 10	μgFe/g dry matter μmolFe/molC μmolFe/molC μgFe/g dry weight		114.4 54.8 5 12 108		8.7  3 10	Honda et al., 1987 Chen et al., 2011 Schmidt et al., 1999 Martin and Knauer, 1973
	Euphausiids	Monterray Bay			92			μgFe/g dry weight		51			Martin and Knauer, 1973
	Radiolarians	Monterray Bay			315			μgFe/g dry weight		173			Martin and Knauer, 1973
	Heterotrophic flagellates		Southern Ocean			21.9			μmolFe/molC		21.9		
Krill	Euphausia superba Euphausia superba Euphausia superba Euphausia superba Euphausia superba Euphausia superba Euphausia superba Pseudeuphausia latifrons Nyctiphanes australis Euphausia pacifica Euphausia similis Euphausia krohnii Maganyctiphanes norvegica Euphausia superba	Coastal Antarctic Scotia sea Western Antarctic Peninsula Ross Sea Marguerite Bay Livingston island Southern Ocean Southern Ocean Southern Ocean Southern Ocean Southern Ocean Southern Ocean Southern Ocean Prydz Bay, Antarctica	Whole Whole Whole      digestive gland stomach krill body (no stomach and digestive gland) whole krill	5.55 27.5 8.50  <									

Common name	Latin name	Locality	Comment	Content in original units				Original units	Content in SI units (μmolFe/molC)				Reference
				min	mean	max	std		min	mean	max	std	
			muscle		5		1			2.8		0.6	
Microflagellates	<i>P. imperforata</i>	Vineyard Sound	Fe-poor food		8.2		0.1	μmolFe/molC		8.2		0.1	Chase and Price, 1997
	<i>P. butcheri</i>	Sargasso Sea			12.5		0.2	μmolFe/molC		12.5		0.2	
Mesozooplankton					1230			nmolFe/g dry weight		38.1			Baines et al., 2016
Large migrant zooplankton		Coasta Rica		15				μmolFe/molC	15				
Resident mixed layer zooplankton		Upwelling Dome		60				μmolFe/molC	60				

## 4 Iron content of fish

The iron content of edible fish tissues has been widely measured for nutritional purposes. All fish-tissue iron content measurements we identified in the peer-reviewed literature since 1977 are given in Table S6. In addition, we include three peer-reviewed sources that unambiguously reported the Fe content of the whole body for marine fish (Shearer et al., 1994; Andersen et al., 1996 and Honda et al., 1987), which is the quantity of most relevance here. These values are highlighted with a grey background in the table.

A number of whole body Fe contents are provided by Bernard and Allen (1997), cited in Moreno and Haffa (2014), but these are not peer-reviewed and are therefore given in a separate table (Table S7). We would emphasize the limitations of the existing data constraints, which would greatly benefit from further work.

A large number of fish muscle Fe content has also been compiled in Vinogradov (1953), these values are listed in Table S8 but are not included in the figures as the measurements were likely biased due to practical limitations.

Supplementary Table 6: Iron to carbon ratios in marine fish. See section 3 above for conversion factors.

Common name	Latin name	Locality	Comment	Content in original units				Original units	Content in SI units (μmolFe/molC)				Reference
				min	mean	max	std		min	mean	max	std	
Sockeye salmon	<i>Oncorhynchus ner</i>	Bristol Bay, Alaska	muscle		23.9		4.6	μgFe/g dry weight		10.3		2.0	Gordon and Roberts, 1977
Pacific cod	<i>Gadus macrocephalus</i>				13.7		1.6			5.9		0.7	
Dover sole	<i>Microstomus pacificus</i>				14.7		1.2			6.3		0.5	
Rockfish, black	<i>Sebastes melanops</i>				15.1		1			6.5		0.4	
Rockfish, orange	<i>Sebastes pinniger</i>				21.3		2.6			9.2		1.1	
Ling cod	<i>Ophiodon elongatus</i>				15.7		2.2			6.8		0.9	
Petrale sole	<i>Eopsetta jordani</i>				9.1		1			3.9		0.4	
English sole	<i>Parophrys vetulus</i>				16.6		2.1			7.1		0.9	
Pacific hake	<i>Merluccius productus</i>				24.3		3			10.4		1.3	
Emerald rockcod	<i>Trematomus bernacchii</i>	Antarctic	muscle	0.95	2.1	8.25		μgFe/g wet weight	1.6	3.6	14.2		Honda et al., 1987
			liver	14.9	44.9	102			25.6	77.2	175.4		
			whole	6.93	14.9	46.5			11.9	25.6	80.0		
			muscle	1.42	2.84	5.95			2.4	4.9	10.2		
			liver	10	43.2	114			17.2	74.3	196.1		
Bald notothen	<i>Pagotenia bochgrevinki</i>		whole	4.04	6.51	9.25			6.9	11.2	15.9		
	<i>Notothenioides</i>		whole	3.71	5.81	7			6.4	10.0	12.0		
	<i>Myctophid</i>		whole	10.8	12.3	13.8			18.6	21.2	23.7		
Seer	<i>Scomberomorus guttatus</i>	India			1.1			mgFe/100g muscle		18.9			Chandrashekar and Deosthale, 1993
Hilsa	<i>Hilsa hilsa</i>				1.2					20.6			
Anchovy	<i>Thryssa purava</i>				1.5					25.8			
Pomfret (black)	-				0.8					13.8			
Jew fish	<i>Pseudosciaena diacanthus</i>				0.9					15.5			
Mullet	<i>Mugil cephalus</i>				0.8					13.8			
Mackerel	<i>Rastrelliger kanagurta</i>				1.3					22.3			
Conger eel	<i>Muraenesox talabon</i>				0.8					13.8			
Pomfret	<i>Pampus argenteus</i>				0.5					8.6			
Trevally	<i>Caranx sansun</i>				1.8					30.9			
Pink Perch	<i>Nemipterus japonicus</i>				1.7					29.2			
Lesser Sardine	<i>Sardinella fimbriata</i>				1.1					18.9			
Thread fins	<i>Polynemus indicus</i>				0.8					13.8			
Atlantic salmon	<i>Salmo salar</i>		Whole body - juveniles	15		20		ppm, wet weight	26		34		Shearer et al., 1994
			Whole body - mature fish	15		25			26		43		
Atlantic salmon	<i>Salmo salar L.</i>	Fe limited Fe limited Fe replete Fe replete	Whole body	6.3		9.5		mg/kg wet weight	11		16		Andersen 1996
			Liver	18		56			31		96		
			Whole body	9.5		15			16		26		
Atlantic salmon		different Fe supplementation	Liver	56		124			96		213		
Atlantic salmon			whole body	7.0	10.1	18.7		mg/kg wet weight	12.0	17.4	32.1		Andersen et al., 1997
Anchovy	<i>Engraulis encrasicolus</i>	Black sea			1.13		0.02	mgFe/100g edible		19.4		0.3	Güner et al., 1998
Sprat	<i>Sprattus sprattus sprattus</i>				0.47		0.04			8.1		0.7	
Scad	<i>Trachurus mediterraneus</i>				0.45		0.03			7.7		0.5	
Whiting	<i>Merlangius merlangus</i>				0.25		0.01			4.3		0.2	
Red Mullet	<i>Mullus barbatus</i>				0.45		0.04			7.7		0.7	
Garfish	<i>Belone belone</i>				0.59		0.04			10.1		0.7	
Shad	<i>Alosa alosa</i>				1.58		0.09			27.2		1.5	
Sea bream	<i>Sparus alcedo</i>				0.35		0.04			6.0		0.7	
Bonito	<i>Sarda sarda</i>				1.56		0.11			26.8		1.9	
Cultured Sea bass	<i>Dicentrarchus labrax</i>	Greece			51.22		2.83	μgFe/g dry weight		22.0		1.2	Alasalvar et al., 2002
Wild Sea bass	<i>Dicentrarchus labrax</i>				63.1		5.86			27.1		2.5	
Gilthead	<i>Sparus auratus</i>	NE Med Sea	muscle		19.6		7.84	μgFe/g dry weight		8.4		3.4	Canli and Atli, 2003
			liver		256.5		108.8			110.2		46.8	
			gill		152.91		62.33			65.7		26.8	
Smelt	<i>Atherina hepsetus</i>		muscle		78.4		36.84			33.7		15.8	
			liver		393.22		171.4			169.0		73.7	
			gill		793.73		411.1			341.1		176.7	
Grey mullet	<i>Mugil cephalus</i>		muscle		38.71		18.28			16.6		7.9	
			liver		370.43		252.7			159.2		108.6	
			gill		275.67		71.28			118.5		30.6	
Red gurnard	<i>Trigla cuculus</i>		muscle		30.68		10.2			13.2		4.4	
			liver		582.37		208.9			250.3		89.8	
			gill		499.05		339.9			214.5		146.1	
Sardine	<i>Sardina pilchardus</i>		muscle		39.6		8.62			17.0		3.7	
			liver		225.47		51.49			96.9		22.1	
			gill		227.42		32.46			97.7		14.0	
Saury Pike	<i>Scomberesox saurus</i>		muscle		29.82		16.24			12.8		7.0	
			liver		407.08		144.9			174.9		62.3	
			gill		885.49		514.3			380.5		221.0	
Brushtooth lizardfish	<i>Saurida undosquamis</i>	Iskenderun Bay	muscle	0.82	4.175	11.28		mgFe/kg dry weight	0.4	1.8	4.8		Türkmen et al., 2005
Red mullet	<i>Mullus barbatus</i>			2.45	9.682	17.92			1.1	4.2	7.7		
Gilthead sea bream	<i>Sparus aurata</i>			4.59	13.166	27.35			2.0	5.7	11.8		
European anchovy	<i>Engraulis encrasicolus</i>	Black and Aegean Seas			95.6		8.1	μgFe/g dry matter		41.1		3.5	Uluozlu et al., 2007
Gilthead seabream	<i>Sparus aurata</i>				69.7		5.6			30.0		2.4	
Whiting	<i>Merlangius merlangus</i>				104		9.8			44.7		4.2	
Black scorpionfish	<i>Scorpaena porcus</i>				81.5		7.1			35.0		3.1	
Red mullet	<i>Mullus barbatus</i>				163		12			70.1		5.2	
Bluefish	<i>Pomatus saltor</i>				68.6		5.3			29.5		2.3	
Atlantic horse mackerel	<i>Trachurus trachurus</i>				74.3		6.1			31.9		2.6	
Flathead mullet	<i>Mugil cephalus</i>				82.7		5.6			35.5		2.4	
Atlantic bonito	<i>Sarda sarda</i>				73.5		6.3			31.6		2.7	
Gizzard shad	<i>Nematolosa nasus</i>	Parangipettai coast, south-	edible	39.6	45.2	71.5		μgFe/g dry weight	17.0	19.4	30.7		Raja et al., 2009
Scad	<i>Alepes para</i>			3.5	24.11	46.8			1.5	10.4	20.1		
Cleftbelly trevally	<i>Atropus atropus</i>			42.6	50.3	78.5			18.3	21.6	33.7		

Common name	Latin name	Locality	Comment	Content in original units				Original units	Content in SI units (μmolFe/molC)				Reference
				min	mean	max	std		min	mean	max	std	
Black pomfret	<i>Parastromateus niger</i>	east India	muscle	16.7	28.4	50.4			7.2	12.2	21.7		
Sea bass	<i>Lates calchifer</i>	Coastal waters off Kochi	muscle		604.75			ppm, dry weight		259.9			Rejomon et al., 2010
		Coastal waters off Mangalore			500.75					215.2			
Pink Perch	<i>Nemipterus japonicus</i>	Coastal waters off Kochi			438.30					188.4			
		Coastal waters off Mangalore			333.30					143.2			
Bluefin trevally	<i>Caranx melampygus</i>	Coastal waters off Kochi			649.60					279.2			
		Coastal waters off Mangalore			541.60					232.8			
Indian mackerel	<i>Rastrelliger kanagurta</i>	Coastal waters off Kochi			604.75					259.9			
		Coastal waters off Mangalore			500.75					215.2			
		Coastal waters off Mangalore			602.75					259.0			
Malabar tongue sole	<i>Cyanoglossus macrostomus</i>	Coastal waters off Kochi			500.75					215.2			
Zebrafish					39.7			mgFe/kg dry matter		17			Kaushik et al., 2011
Nine commercial species		Coastal waters of Kalpakkam, east of India	muscle	17.67	75.83	117	32.32	μgFe/g dry weight	7.6	32.6	50.3	13.9	Biswas et al., 2012
Atlantic herring	<i>Clupea harengus</i>	1 month frozen post-harvest	Whole body		71			ppm, dry weight		30.5			Mazzaro et al., 2016
Atlantic mackerel	<i>Scomber scombrus</i>				70		4			30.1		1.7	
Capelin	<i>Mallotus villosus</i>				71		7			30.5		3.0	
Common sole	<i>Solea solea</i>	Mersin, Turkey	muscle	3.86	13.52	25.76	1.61	mgFe/kg wet weight	6.6	23.3	44.3	2.8	Korkmaz et al., 2017
Red mullet	<i>Mullus barbatus</i>			0.93	10.40	19.58	1.36		1.6	17.9	33.7	2.3	
Sardine	<i>Sardina pilchardus</i>			1.66	10.3	21.2	1.24		2.9	17.7	36.5	2.1	
Larval marine medaka	<i>Oryzias melastigma</i>		whole	36		81		mgFe/kg dry matter	15.5		34.8		Wang and Wang, 2018
Larval golden pompano	<i>Trachinotus ovatus</i>		(smallest value at hatching)	25		80			10.7		34.4		
Larval Gilthead sea bream	<i>Sparus aurata</i>			20		110			8.6		47.3		
Newly hatched larvae	the 3 above		whole	20		40			8.6		17.2		

Supplementary Table 7: Iron to carbon ratios in zooplankton and marine fish from Bernard and Allen (2002) (non peer-reviewed paper). See section 3 above for conversion factors.

Common name	Latin name	Number of samples	Content in original units			Original units	Content in SI units (μmolFe/molC)		
			min	mean	max		min	mean	max
<b>Anchovies</b>	<i>Engraulis mordax</i>	10	98		2060	ppm of dry matter	42		886
<b>Butterfish</b>	<i>Peprilus</i> sp.	1		147				63	
<b>Capelin</b>	<i>Mallotus villosus</i>	16	36		140		15		60
<b>Goldfish</b>	<i>Cyprinus carpio</i>	1		307				132	
<b>Herring</b>	Not indicated	6	64		274		28		118
<b>Herring, Atlantic</b>	<i>Clupea harengus</i>	5	64		132		28		57
<b>Krill</b>	<i>Euphasia</i> sp.	3	96		138		53		76
<b>Krill, pacifica</b>	<i>Euphasia pacifica</i>	1		19				10	
<b>Krill, superba</b>	<i>Euphasia superba</i>	1		432				238	
<b>Mackerel, Atlantic</b>	<i>Scomberomorus scombrus</i>	3	63		100		27		43
<b>Mackerel, Pacific</b>	<i>Scomberomorus japonicus</i>	3	153		184		66		79
<b>Mackerel, Spanish</b>	<i>Scomberomorus maculatus</i>	1		83				36	
<b>Minnows</b>	<i>Cyprinidae</i>	1		225				97	
<b>Shrimp, whole</b>	<i>Penaeus</i> sp.	2	18		180		8		77
<b>Silversides</b>	<i>Menidia andens</i>	4	32		54		14		23
<b>Smelt, ocean</b>	<i>Osmerus</i> sp.	2	29		36		12		15
<b>Squid</b>	<i>Illex and Loligo</i> sp.	2	12		29		5		12
<b>Whitebait</b>	<i>Clupea harengus</i> or <i>sprattus</i>	1		112				48	

Supplementary Table 8: Iron to carbon ratios in fish from Vinogradov (1953)'s compilation. See section 3 above for conversion factors.

Common name	Latin name	Comment	Content in original units			Original units	Content in SI units (μmolFe/molC)			Reference
			min	mean	max		min	mean	max	
	<i>Sardinia melanostica</i>	white muscle		0.001		% living matter		17.2		Fujikawa and Naganuma, 1936
	<i>Sardinia melanostica</i>	red muscle		0.0015				25.8		
Common torpedo	<i>Torpedo ocellata</i>	soft parts and muscle		0.0025		% living matter		43.0		Weyl, 1881
European pilchard (sardina)	<i>Clupea pilchardus</i>	soft parts and muscle		0.0012		% living matter		20.6		Carteni and Aloj, 1934
European hake	<i>Merluccius vulgaris</i>			0.0056				96.3		
Wreckfish	<i>Polyprion americanus</i>			0.0032				55.0		
European anchovy	<i>Engraulis encrasicolus</i>			0.0049				84.2		
Tench	<i>Tinca tinca</i>	soft parts and muscle. whole organism		0.00145		% living matter		24.9		Skanavi-Griigorieva, 1939
Common carp	<i>Cyprinus carpio</i>	soft parts and muscle. 5month		0.00136				23.4		
Common carp	<i>Cyprinus carpio</i>	soft parts and muscle. whole organism		0.0013		% living matter		22.3		Bezold, 1857
Northern pike	<i>Esox lucius</i>	soft parts and muscle		0.0042		% living matter		72.2		Katz, 1896
European eel	<i>Anguilla anguilla</i>			0.0056				96.3		
Haddock	<i>Gadus aeglefinus</i>			0.0056				96.3		
	<i>Gadus</i> sp.	soft parts and muscle. dry		0.024		% living matter		412.6		Yamamura, 1934
Six-lined trumpeter	<i>Pelates sexlineatus</i>	soft parts and muscle		0.001		% living matter		17.2		Clements and Hutchinson, 1939
	<i>Sillago</i> sp.									
Bluefish	<i>Pomatomus pedica</i>									
	<i>Leptocephalus</i> sp.									
White trevally	<i>Caranx georgianus</i>									
	<i>Regificola grandis</i>									
Australian herring	<i>Arripis georgianus</i>									
Australian salmon	<i>Arripis trutta</i>									
Australian salmon	<i>Arripis trutta</i>									
	<i>Sciaena antarctica</i>									
	<i>Cynoscion atelodus</i>									
	<i>Chrysophrys guttulatus</i>									
	<i>Roughleyia australis</i>									
Parore	<i>Girella tricuspidata</i>									
Spotted scat	<i>Scatophagus argus</i>									
Tarakihi	<i>Cheilodactylus macropterus</i>									
Snoek	<i>Thyrsites atun</i>									
Blue mackerel	<i>Scomber australasicus</i>									
	<i>Neoplatycephalus macrodon</i>									
Trout cod	<i>Maccullochella macquariensis</i>									
	<i>Pleuronectes arsius</i>									
	<i>Synaptura nigra</i>									
Fan-bellied leatherjacket	<i>Monacanthus chinensis</i>									
	<i>Pseudomonacanthus ayraudi</i>									
	<i>Reporhamphus australis</i>									
Gummy shark	<i>Mustelus antarcticus</i>									
	<i>Raja</i> sp.									
	<i>Potamalosa novaehollandiae</i>									
	<i>Trachichthodes affinis</i>									
	<i>Zeus australis</i>									
Australian barracuda	<i>Sphyræna novaehollandiae</i>									
Flathead grey mullet	<i>Mugil cephalus</i>									
Australian threadfin	<i>Polynemus</i> sp.									

Common name	Latin name	Comment	Content in original units			Original units	Content in SI units (µmolFe/molC)			Reference
			min	mean	max		min	mean	max	
Barramundi	<i>Lates calcarifer</i>									
Sevenbar grouper	<i>Epinephelus</i> sp. (?) <i>Epinephelus ergastularius</i> <i>Plectroplites ambiguus</i> <i>Rubralga jacksoniensis</i>									
starspotted smooth-hound	<i>Mustelus manazo</i>	3		0.24				4.1		Oya and Shimada, 1933
	<i>Raja latiss</i>			0.33				5.7		Shackleton and McCance, 1936
Sterlet sturgeon	<i>Acipenser ruthenus</i>			1.6				27.5		Kostychev, 1883
	<i>Acipenser</i> sp.			1.5				25.8		Kostychev, 1883
	<i>Acipenser</i> sp.	soft parts and muscle. ROE		3.3				56.7		Kostychev, 1883
American shad	<i>Alosa sapidissima</i>			0.48				8.3		Parks and Rose, 1933
American shad	<i>Alosa sapidissima</i>			0.53				9.1		Peterson and Elvehjem, 1928
Atlantic herring	<i>Clupea harengus</i>			0.57				9.8		Parks and Rose, 1933
Atlantic herring	<i>Clupea harengus</i>			0.59				10.1		Peterson and Elvehjem, 1928
Atlantic herring	<i>Clupea harengus</i>			1.02				17.5		Shackleton and McCance, 1936
Atlantic herring	<i>Clupea harengus</i>			0.63				10.8		Shackleton and McCance, 1936
European pilchard	<i>Clupea pilchardus</i>			1.2				20.6		Carteni and Aloj, 1934
South American pilchard	<i>Sardina caerulea</i>			2.483				42.7		Nilson and Coulson, 1939
	<i>Sardinia melanostica</i>	white muscle		0.7				12.0		Fujikawa and Naganuma, 1936
	<i>Sardinia melanostica</i>	red muscle		1				17.2		Fujikawa and Naganuma, 1936
	<i>Sardinia melanostica</i>	2		1.28				22.0		Oya and Shimada, 1933
	<i>Sardinia</i> sp.			0.028				0.5		Lepierre, 1938
European anchovy	<i>Engraulis encrasicolus</i>			4.9				84.2		Carteni and Aloj, 1934
Whitefish	<i>Coregonus</i> sp.			0.42				7.2		Peterson and Elvehjem, 1928
Whitefish	<i>Coregonus</i> sp.			2.1				36.1		Kostychev, 1883
Salmon		Roe		2.5		mgFe/100g living matter		43.0		Greig, 1898
Salmon		Muscles		0.83				14.3		Peterson and Elvehjem, 1928
Salmon		3		0.87				15.0		Toscani and Reznikoff, 1934
Salmon				0.86				14.8		Parks and Rose, 1933
Salmon				1.2				20.6		Rose, 1933
Salmon				2.45				42.1		Kostychev, 1883
	<i>Salmo fario</i>			2.8				48.1		Kostychev, 1883
	<i>Salmo fario</i>			0.78				13.4		Peterson and Elvehjem, 1928
	<i>Salmo fario</i>			0.72				12.4		Parks and Rose, 1933
European smelt	<i>Osmerus eperlanus</i>			0.41				7.0		Parks and Rose, 1933
		Liver	4.9		5.3		84		91	
		Spleen	9.5		10.9		163		187	
		Bones	4.8		5		83		86	
		Heart	6.4		7.7		110		132	
		Kidneys	8.2		8.8		141		151	
Common carp (freshwater)	<i>Cyprinus carpio</i>	White muscle	1.3		1.5		22		26	Kojima, 1930
		Red muscle	5		5.6		86		96	
		Stomach	6.5		7.3		112		125	
		Intestines	5.6		9		96		154	
		Ovaries	4.1		4.4		70		75	
		Brain	2.6		3		45		51	
Common carp (freshwater)	<i>Cyprinus carpio</i>	3		0.78				13.4		Oya and Shimada, 1933
	<i>Silurus</i> sp.			0.94				16.1		Parks and Rose, 1933
	<i>Esox</i> sp.			2.4				41.1		Kostychev, 1883
	<i>Esox</i> sp.	Young		0.8				13.7		Peterson and Elvehjem, 1928
	<i>Esox</i> sp.	Young		0.3				5.1		Peterson and Elvehjem, 1928
	<i>Esox</i> sp.	Young		0.58				9.9		Parks and Rose, 1933
European eel	<i>Anguilla anguilla</i>			0.51				8.7		Parks and Rose, 1933
European eel	<i>Anguilla anguilla</i>	Muscle		2.2		mg Fe/100g dm		9.5		Henriques and Roche, 1933
Silver eel		Liver		105				1805		McCance, 1944
Haddock	<i>Gadus aeglefinus</i>			0.42				7.2		Peterson and Elvehjem, 1928
Whiting	<i>Gadus merlangus</i>	Flesh		1.5				25.8		
		Whole		82				1409.6		Boussingault, 1872
		Bone		10				171.9		

Common name	Latin name	Comment	Content in original units			Original units	Content in SI units (μmolFe/molC)			Reference
			min	mean	max		min	mean	max	
Atlantic cod	<i>Gadus morrhua</i>			0.518		mgFe/100g living matter		8.9		Nilson and Coulson, 1939 Peterson and Elvehjem, 1928 Peterson and Elvehjem, 1928 Parks and Rose, 1933 Kostychev, 1883 Yamamura, 1934 Boussingault, 1872
Atlantic cod	<i>Gadus morrhua</i>			0.36				6.2		
Atlantic cod	<i>Gadus morrhua</i>			0.34				5.8		
Atlantic cod	<i>Gadus morrhua</i>			0.34				5.8		
Atlantic cod	<i>Gadus morrhua</i>			1.26				21.7		
Atlantic cod	<i>Gadus morrhua</i>			4				68.8		
Atlantic cod	<i>Gadus morrhua</i>			4.2				72.2		Boussingault, 1872
Atlantic cod	<i>Gadus morrhua</i>	6		2.35		mg Fe/100g dm		10.1		Henriques and Roche, 1933 McHargue, 1925
Atlantic cod	<i>Gadus morrhua</i>	Liver		17.3				74.4		
Atlantic cod	<i>Gadus morrhua</i>			0.34		mgFe/100g living matter		5.8		Shackleton and McCance, 1936 Parks and Rose, 1933 Parks and Rose, 1933 Nilson and Coulson, 1939 Carteni and Aloj, 1934 Parks and Rose, 1933 Parks and Rose, 1933 Nilson and Coulson, 1939 Kojima, 1930
	<i>Gadus navaga</i> (?)			2.8				48.1		
Burbot	<i>Lota vulgaris</i> (?)			0.96				16.5		
Haddock	<i>Melanogrammus aeglefinus</i>			0.516				8.9		
European hake	<i>Merluccius vulgaris</i>			5.6				96.3		
Moon fish	<i>Molva</i> sp. (?)			0.34				5.8		
Wachna cod				0.48				8.3		
Flathead grey mullet	<i>Mugil cephalus</i>			1.1779				20.2		
		Liver	8		14.1		137.5		242.4	
		Spleen	38		48		653.2		825.1	
		Bones	5		6.3		86.0		108.3	
		Heart	3.5		3.9		60.2		67.0	
		Kidneys	4.7		5.1		80.8		87.7	
		White muscle	1.6		1.7		27.5		29.2	
		Red muscle	3.4		4.3		58.4		73.9	
		Stomach	3.5		4.2		60.2		72.2	
		Intestines	3.5		3.6		60.2		61.9	
		Brain	2.7		3		46.4		51.6	
European seabass	<i>Labrax lupus</i>			0.26				4.5		
Japanese seabass	<i>Lateolabrax japonicus</i>			0.57				9.8		
Wreckfish	<i>Polyprion americanus</i>			3.2				55.0		
Pike-perch	<i>Lucioperca sandra</i>			1.6				27.5		
European perch	<i>Perca fluviatilis</i>			0.48				8.3		
European perch	<i>Perca fluviatilis</i>			0.42				7.2		
Bluefish	<i>Pomatomus</i> sp.			0.6				10.3		
Red snapper	<i>Lutjanus</i> sp.			0.4				6.9		
Northern red snapper	<i>Lutjanus blackfordii</i>			1.158				19.9		
	<i>Sparus batus</i>			0.24				4.1		
	<i>Anarchichas lupus</i>			0.36				6.2		
Dragonet	<i>Callionymus lyra</i>	Postlarvae		31		mg Fe/100g dm		133.3		Cooper, 1939
Atlantic mackerel	<i>Scomber scombrus</i>			1.224		mgFe/100g living matter		21.0		Nilson and Coulson, 1939 Peterson and Elvehjem, 1928 Parks and Rose, 1933 Toscani and Reznikoff, 1934 Rose, 1933 Oya and Shimada, 1933 Oya and Shimada, 1933 Parks and Rose, 1933 Peterson and Elvehjem, 1928 Peterson and Elvehjem, 1928 Shackleton and McCance, 1936
Atlantic mackerel	<i>Scomber scombrus</i>			0.75				12.9		
Atlantic mackerel	<i>Scomber scombrus</i>			0.87				15.0		
Tuna	<i>Thunnus</i> sp.			1.8				30.9		
Tuna	<i>Thunnus</i> sp.			1.2				20.6		
Pacific bluefin tuna	<i>Thunnus orientalis</i>	3		1.29				22.2		
	<i>Limanda</i> sp.			1.69				29.1		
	<i>Pleuronectes</i> sp.	2		0.52				8.9		
	<i>Pleuronectes</i> sp.			0.73				12.5		
Atlantic halibut	<i>Hippoglossus hippoglossus</i>			0.93				16.0		
Halibut	<i>Hippoglossus vulgaris</i>			0.44				7.6		

## 5 Aquaculture feed recommendations

In Table S8 we compile recommended minimum iron concentrations for fish feed in aquaculture. Aquaculture studies have shown that the availability of iron can vary with the feed composition (e.g. Sugiura et al., 1998). In nature, iron bioavailability can be linked to the amount of cytoplasm within the prey and whether iron is bound externally to the prey or is internal (e.g. Reinfelder and Fisher, 1994). It is therefore possible that aquaculture feeds, because of their lack of refractory material such as the exoskeleton of zooplankton, may have more bioavailable iron than some natural prey.

Supplementary Table 9: Iron to carbon ratios recommended in fish food from aquaculture studies. See section 3 above for conversion factors.

Common name	Concentration in food in original units (mgFe/kg dry matter)	Concentration in SI units ( $\mu\text{molFe/molC}$ )	Reference
Larval fish	70	30.1	Wang and Wang, 2018
Larval medaka	83.9	36	Wang and Wang, 2016
Red drum	330	141.8	Zhou et al., 2009
Orange grouper	245	105.3	Ye et al., 2007
Tilapia	85-160	36.5-68.8	Shiau and Su, 2003
Hybrid striped bass	66	28.4	Webster and Lim, 2002
Puffer fish	90-140	38.7-60.2	Zibdeh et al., 2001
Atlantic salmon	60	25.8	Naser 2000
Teleost fish	30-170	12.9-73.1	Watanabe et al., 1997
Atlantic salmon	60-100	25.8-43	Andersen et al., 1996
Yellow tail	101	43.4	Ukawa et al., 1994
Atlantic Salmon	148-156	63.6-67	Tacon & De Silva, 1983
Red sea bream	150	64.5	Sakamoto and Yone, 1978
Japanese eel	170	73.1	Nose and Arai, 1976

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