A hierarchical mixed effects approach to estimating the length-weight relationship parameters of fish and invertebrate taxa, with application to observations from the annual southern Gulf of St. Lawrence ecosystem September survey (1971-2023)

Daniel Ricard, Quentin Stoyel, Tobie Surette and Pablo Vergara

Science Branch
Gulf Region
Fisheries and Oceans Canada
Moncton, New Brunswick, E1C 5K4, Canada

2024

Canadian Technical Report of
Fisheries and Aquatic Sciences ####

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. II n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of
Fisheries and Aquatic Sciences nnn

2023

A HIERARCHICAL MIXED EFFECTS APPROACH TO ESTIMATING THE LENGTH-WEIGHT RELATIONSHIP PARAMETERS OF FISH AND INVERTEBRATE TAXA, WITH APPLICATION TO OBSERVATIONS FROM THE ANNUAL SOUTHERN GULF OF ST. LAWRENCE ECOSYSTEM SEPTEMBER SURVEY (1971-2023)

by

Daniel Ricard, Quentin Stoyel, Tobie Surette and Pablo Vergara

Science Branch
Gulf Region
Fisheries and Oceans Canada
Moncton, New Brunswick, E1C 5K4, Canada

Cat. No. Fs97-6/nnnE-PDF ISBN ISSN 1488-5379

Correct citation for this publication:

Ricard, D., Stoyel, Q., Surette, T. and Vergara, P. 2023. A hierarchical mixed effects approach to estimating the length-weight relationship parameters of fish and invertebrate taxa, with application to observations from the annual southern Gulf of St. Lawrence ecosystem September survey (1971-2023). Can. Tech. Rep. Fish. Aquat. Sci. nnn: v + 14 p.

CONTENTS

ABSTRACT

Ricard, D., Stoyel, Q., Surette, T. and Vergara, P. 2023. A hierarchical mixed effects approach to estimating the length-weight relationship parameters of fish and invertebrate taxa, with application to observations from the annual southern Gulf of St. Lawrence ecosystem September survey (1971-2023). Can. Tech. Rep. Fish. Aquat. Sci. nnn: v + 14 p.

A cohesive approach is used to obtain length-weight relationship parameter estimates for taxa caught in the annual southern Gulf of St. Lawrence September survey. The approach utilises the number of available observations and the range of observed lengths and weights to determine where annual estimates can be derived with confidence. The sampling protocols used in the survey are incorporated in the framework so that sex-specific parameters can also be calculated when available data is available. When annual estimates can be meaningfully estimated, a single model is fitted to available observations and the parameter estimates are reported. The approach provides a robust and reproducible method that can be used to annually update length-weight relationship estimates.

RÉSUMÉ

Ricard, D., Stoyel, Q., Surette, T. and Vergara, P. 2023. A hierarchical mixed effects approach to estimating the length-weight relationship parameters of fish and invertebrate taxa, with application to observations from the annual southern Gulf of St. Lawrence ecosystem September survey (1971-2023). Can. Tech. Rep. Fish. Aquat. Sci. nnn: v + 14 p.

Voici le résumé.

1 Introduction

Length measurements are easier to obtain than weight measurements.

The precision associated with weight measurements has changed over the survey period, whereas the length measurements are more comparable.

Length-weight relationships are used to predict weight based on length observations. This is an essential analytical component of many stock assessments since commercial landings and many reference points are in weight units.

The relationship between length and weight is dictated by the cubic nature of growth in three dimensions. Allometric models estimate the relationship between length and weight.

Mixed effects models have been used to estimate length-weight relationship parameters by other practitioners (Lai and Helser 2004; Ma et al. 2017).

When year-specific estimates are desired, it is often the case that a length-weight relationship will be estimated using data for a specific year only. While this is a defensible method, it may be limited if not enough samples are available or available observations only cover a narrow range of lengths and weights. A superior alternative would be to use all available observations in the same model and obtain annual estimates whose uncertainty will reflect the data limitations.

The protocol used in the annual September survey of the southern Gulf of St. Lawrence contains sex-specific sampling for species that exhibit sexual dimorphism in growth. As such, sex-dependent parameters should be derived for these species.

We present a logical, statistically sound and reproducible framework to estimate length-weight relationship parameters, and apply it to observations of various fish and invertebrate taxa captured in the annual September ecosystem survey of the southern Gulf of St. Lawrence.

A cohesive approach is used to obtain length-weight relationship parameter estimates for taxa caught in the annual southern Gulf of St. Lawrence September survey. The approach utilises the number of available observations and the range of observed lengths and weights to determine where annual estimates can be derived with confidence. The sampling protocols used in the survey are incorporated in the framework so that sex-specific parameters can also be calculated when available data is available. When annual estimates can be meaningfully estimated, a single model is fitted to available observations and the parameter estimates are reported. The approach provides a robust and reproducible method that can be used to annually update length-weight relationship estimates.

2 Methods

The length-weight relationship we use is the following:

$$W = \alpha L^{\beta} \tag{1}$$

where W is weight, L is length, and a and b are the allometric parameters to be estimated. Individual fish observations of length-weight pairs are used to estimate model parameters.

The units of length and weight will influence the parameter values, so in all analyses presented, lengths are in centimeters and weights are in grams.

2.1 Hierarchical approach

A minimum number of samples must be available in order to meaningfully estimate a and b parameters. The available length information must also cover a wide range of lengths so that estimated parameter values can be used in predictions.

Hierarchical approach

1. overall relationship, sex-independent and time-independent
2. sex-dependent relationship
3. time-dependent relationship
4. sex- and time-dependent relationship

2.2 Mixed effects models

To estimate sex and year effects on the length-weight relationship, a mixed effects framework is adopted to analyse the available individual observations of fish length-weight pairs. For species with no sex-specific observations, yearly effects are added to both parameters:

$$W = \left(\alpha + \delta_y^{\alpha}\right) L^{\left(\beta + \delta_y^{\beta}\right)} \tag{2}$$

For species with sex-specific observations, yearly and sex effects are added to both parameters:

$$W = \left(\alpha + \delta_{ys}^{\alpha}\right) L^{\left(\beta + \delta_{ys}^{\beta}\right)} \tag{3}$$

The model is implemented as a Generalized Mixed Effects Model with a Gamma error distribution and a log link:

$$\mu = exp(\beta_0 + \beta_1 l + \epsilon) \tag{4}$$

2.3 Southern Gulf of St. Lawrence ecosystem survey

Observations of fish and invertebrate taxa collected during the annual southern Gulf of St. Lawrence September survey are used to obtain taxon-specific estimates of the length-weight relationship.

The taxa used in the analyses appear in Table 1.

2.3.1 Annual update of length-weight parameter estimates

3 Results

3.1 Sex effects

For species with known sexually dimorphic growth, sex-specific estimates are estimated.

3.2 Year effects

3.3 Species-specific model predictions

Estimated length-weight relationship parameters can be found in Table 2.

4 Discussion

The values of a and b parameters are used to flag erroneous lengths and weights measurements during data collection.

The predicted weights obtained from the fitted model are used in computations of biomass indices based on individual length observations.

If the yearly changes in estimated values of a and b are auto-correlated, it may be indicative of gradual changes in condition. An alternative modelling approach that accounts for this auto-correlation should be investigated.

The availability of a sufficient number of samples is key to estimating a meaningful length-weight relationship.

Base 10 logarithm versus natural logarithm

Froese et al. (2014)

5 Tables

Table 1. Species and groups of species used the analyses. Each species code, species common English name and scientific name appear in this Table. Whether a species is subjected to sex-dependent sampling appears in the last column of the Table.

species.code	species.english	species.latin	species.sex
40	American Plaice	Hippoglossoides platessoides	Yes

Table 2. Length-weight relationship parameters for species captured in the southern Gulf of St. Lawrence.

	species	sex	number	rsquare	a	b	length.unit	comments
2	10	0	16,687	0.99	-2.251000	3.1260	1	
3	10	1	16,687	0.99	-2.251000	3.1260	1	
4	10	2	16,687	0.99	-2.251000	3.1260	1	
1	10	9	16,687	0.99	-2.251000	3.1260	1	
6	11	0	95	0.98	-2.092000	3.0690	1	
7	11	1	95	0.98	-2.092000	3.0690	1	
8	11	2	95	0.98	-2.092000	3.0690	1	
5	11	9	95	0.98	-2.092000	3.0690	1	
9	12	0	5,628	0.99	-2.287000	3.0980	1	
10	12	1	2,729	0.99	-2.348000	3.1360	1	
11	12	2	2,702	0.99	-2.385000	3.1610	1	
13	14	0	22	0.96	-2.409000	3.1630	1	
14	14	1	22	0.96	-2.409000	3.1630	1	
15	14	2	22	0.96	-2.409000	3.1630	1	
12	14	9	22	0.96	-2.409000	3.1630	1	
17	16	0	33	1.00	-2.202000	3.1650	1	
18	16	1	33	1.00	-2.202000	3.1650	1	
19	16	2	33	1.00	-2.202000	3.1650	1	
16	16	9	33	1.00	-2.202000	3.1650	1	
23	23	0	2,654	0.99	-2.017000	3.1240	1	
20	23	1	1,144	0.98	-1.913000	3.0490	1	
21	23	2	1,191	0.99	-1.974000	3.0980	1	
22	23	9	2,654	0.99	-2.017000	3.1240	1	
24	30	0	80	0.95	-2.014000	3.0390	1	
25	30	1	40	0.90	-1.861000	2.9520	1	
26	30	2	38	1.00	-2.172000	3.1270	1	
27	31	0	2,075	0.99	-2.422000	3.2240	1	
28	31	1	1,030	0.99	-2.403000	3.2080	1	
29	31	2	1,003	0.99	-2.461000	3.2530	1	
30	40	0	28,389	0.99	-2.357000	3.1800	1	
31	40	1	11,210	0.98	-2.376000	3.1910	1	
32	40	2	15,155	0.99	-2.455000	3.2490	1	
33	41	0	1,527	0.98	-2.797000	3.3910	1	
34	41	1	631	0.97	-2.746000	3.3560	1	
35	41	2	865	0.98	-2.883000	3.4480	1	
36	42	0	5,074	0.97	-2.256000	3.1360	1	
37	42	1	2,000	0.96	-2.273000	3.1440	1	
38	42	2	2,925	0.97	-2.291000	3.1640	1	
39	43	0	5,950	0.99	-2.194000	3.1920	1	
40	43	1	2,543	0.98	-2.176000	3.1760	1	
41	43	2	3,325	0.98	-2.280000	3.2550	1	
43	50	0	88	0.99	-2.211000	3.0890	1	

Continued on next page ...

... Continued from previous page

	species	sex	number	rsquare	a	b	length.unit	comments
44	50	1	88	0.99	-2.211000	3.0890	1	
45	50	2	88	0.99	-2.211000	3.0890	1	
42	50	9	88	0.99	-2.211000	3.0890	1	
47	52	0	29	0.94	-1.780000	2.8150	1	
48	52	1	29	0.94	-1.780000	2.8150	1	
49	52	2	29	0.94	-1.780000	2.8150	1	
46	52	9	29	0.94	-1.780000	2.8150	1	
51	60	0	4,795	0.98	-2.351000	3.1610	1	
52	60	1	4,795	0.98	-2.351000	3.1610	1	
53	60	2	4,795	0.98	-2.351000	3.1610	1	
50	60	9	4,795	0.98	-2.351000	3.1610	1	
55	61	0	55	0.97	-2.126000	3.1290	1	
56	61	1	55	0.97	-2.126000	3.1290	1	
57	61	2	55	0.97	-2.126000	3.1290	1	
54	61	9	55	0.97	-2.126000	3.1290	1	
59	62	0	494	0.97	-2.036000	3.0460	1	
60	62	1	494	0.97	-2.036000	3.0460	1	
61	62	2	494	0.97	-2.036000	3.0460	1	
58	62	9	494	0.97	-2.036000	3.0460	1	
63	63	0	674	0.94	-2.186000	3.0080	1	
64	63	1	674	0.94	-2.186000	3.0080	1	
65	63	2	674	0.94	-2.186000	3.0080	1	
62	63	9	674	0.94	-2.186000	3.0080	1	
67	64	0	1,638	0.84	-2.444000	3.1240	1	
68	64	1	1,638	0.84	-2.444000	3.1240	1	
69	64	2	1,638	0.84	-2.444000	3.1240	1	
66	64	9	1,638	0.84	-2.444000	3.1240	1	
71	70	0	261	0.95	-2.365000	3.2620	1	
72	70	1	261	0.95	-2.365000	3.2620	1	
73	70	2	261	0.95	-2.365000	3.2620	1	
70	70	9	261	0.95	-2.365000	3.2620	1	
75	110	0	51	0.95	-1.935000	2.8340	1	
76	110	1	51	0.95	-1.935000	2.8340	1	
77	110	2	51	0.95	-1.935000	2.8340	1	
74	110	9	51	0.95	-1.935000	2.8340	1	
79	112	0	233	0.97	-2.663000	3.3090	1	
80	112	1	233	0.97	-2.663000	3.3090	1	
81	112	2	233	0.97	-2.663000	3.3090	1	
78	112	9	233	0.97	-2.663000	3.3090	1	
83	114	0	481	0.95	-2.538000	3.1260	1	
84	114	1	481	0.95	-2.538000	3.1260	1	
85	114	2	481	0.95	-2.538000	3.1260	1	

Continued on next page ...

... Continued from previous page

	species	sex	number	rsquare	a	b	length.unit	comments
82	114	9	481	0.95	-2.538000	3.1260	1	
87	118	0	520	0.97	-2.438000	3.3340	1	
88	118	1	520	0.97	-2.438000	3.3340	1	
89	118	2	520	0.97	-2.438000	3.3340	1	
86	118	9	520	0.97	-2.438000	3.3340	1	
91	122	0	309	0.98	-2.056000	3.1510	1	
92	122	1	309	0.98	-2.056000	3.1510	1	
93	122	2	309	0.98	-2.056000	3.1510	1	
90	122	9	309	0.98	-2.056000	3.1510	1	
94	143	0	530	0.97	-1.859000	2.9250	1	
95	143	1	212	0.91	-2.013000	3.0400	1	
96	143	2	234	0.96	-1.942000	2.9970	1	
98	160	0	10	0.80	-2.368000	3.1220	1	
99	160	1	10	0.80	-2.368000	3.1220	1	
100	160	2	10	0.80	-2.368000	3.1220	1	
97	160	9	10	0.80	-2.368000	3.1220	1	
101	200	0	6	0.96	-2.171000	3.0100	1	
102	200	1	6	0.96	-2.171000	3.0100	1	
103	200	2	6	0.96	-2.171000	3.0100	1	
104	201	0	2,156	0.98	-2.130000	3.1020	1	
105	201	1	1,099	0.98	-2.151000	3.1150	1	
106	201	2	1,055	0.97	-2.106000	3.0870	1	
107	202	0	521	0.97	-2.476000	3.1120	1	
108	202	1	241	0.98	-2.521000	3.1390	1	
109	202	2	279	0.96	-2.449000	3.0960	1	
110	204	0	380	0.98	-2.413000	3.1810	1	
111	204	1	169	0.98	-2.468000	3.2090	1	
112	204	2	210	0.98	-2.380000	3.1660	1	
113	220	0	635	0.90	-3.264000	3.4650	1	
114	220	1	297	0.77	-2.743000	3.1760	1	
115	220	2	337	0.94	-3.115000	3.3970	1	
116	221	0	181	0.96	-2.556000	3.1520	1	
117	221	1	79	0.98	-2.116000	2.8770	1	
118	221	2	100	0.95	-2.801000	3.3070	1	
119	241	9	312	0.79	-2.398000	2.6280	1	
121	300	0	2,477	0.97	-2.219000	3.1740	1	
122	300	1	2,477	0.97	-2.219000	3.1740	1	
123	300	2	2,477	0.97	-2.219000	3.1740	1	
120	300	9	2,477	0.97	-2.219000	3.1740	1	
125	301	0	390	0.97	-2.247000	3.2930	1	
126	301	1	390	0.97	-2.247000	3.2930	1	
127	301	2	390	0.97	-2.247000	3.2930	1	

Continued on next page ...

... Continued from previous page

	species	sex	number	rsquare	a	b	length.unit	comments
124	301	9	390	0.97	-2.247000	3.2930	1	
129	302	0	13	0.94	-2.627000	3.6940	1	
130	302	1	13	0.94	-2.627000	3.6940	1	
131	302	2	13	0.94	-2.627000	3.6940	1	
128	302	9	13	0.94	-2.627000	3.6940	1	
133	304	0	1,806	0.85	-1.969000	2.8170	1	
134	304	1	1,806	0.85	-1.969000	2.8170	1	
135	304	2	1,806	0.85	-1.969000	2.8170	1	
132	304	9	1,806	0.85	-1.969000	2.8170	1	
137	306	0	404	0.72	-1.617000	2.6280	1	
138	306	1	404	0.72	-1.617000	2.6280	1	
139	306	2	404	0.72	-1.617000	2.6280	1	
136	306	9	404	0.72	-1.617000	2.6280	1	
141	307	0	38	0.83	-1.871000	3.0180	1	
142	307	1	38	0.83	-1.871000	3.0180	1	
143	307	2	38	0.83	-1.871000	3.0180	1	
140	307	9	38	0.83	-1.871000	3.0180	1	
145	311	0	26	0.88	-1.600000	2.5950	1	
146	311	1	26	0.88	-1.600000	2.5950	1	
147	311	2	26	0.88	-1.600000	2.5950	1	
144	311	9	26	0.88	-1.600000	2.5950	1	
149	314	0	239	0.83	-1.962000	2.9750	1	
150	314	1	239	0.83	-1.962000	2.9750	1	
151	314	2	239	0.83	-1.962000	2.9750	1	
148	314	9	239	0.83	-1.962000	2.9750	1	
153	316	0	50	0.89	-2.148000	3.1740	1	
154	316	1	50	0.89	-2.148000	3.1740	1	
155	316	2	50	0.89	-2.148000	3.1740	1	
152	316	9	50	0.89	-2.148000	3.1740	1	
157	320	0	493	0.92	-1.912000	3.1140	1	
158	320	1	493	0.92	-1.912000	3.1140	1	
159	320	2	493	0.92	-1.912000	3.1140	1	
156	320	9	493	0.92	-1.912000	3.1140	1	
161	340	0	987	0.63	-1.640000	1.9710	1	
162	340	1	987	0.63	-1.640000	1.9710	1	
163	340	2	987	0.63	-1.640000	1.9710	1	
160	340	9	987	0.63	-1.640000	1.9710	1	
165	350	0	595	0.92	-2.082000	2.6790	1	
166	350	1	595	0.92	-2.082000	2.6790	1	
167	350	2	595	0.92	-2.082000	2.6790	1	
164	350	9	595	0.92	-2.082000	2.6790	1	
169	361	0	451	0.62	-1.067000	1.7790	1	

Continued on next page ...

... Continued from previous page

	species	sex	number	rsquare	a	b	length.unit	comments
170	361	1	451	0.62	-1.067000	1.7790	1	
171	361	2	451	0.62	-1.067000	1.7790	1	
168	361	9	451	0.62	-1.067000	1.7790	1	
173	400	9	37	0.99	-1.429000	2.7690	1	
175	410	0	459	0.92	-2.649000	3.0780	1	
176	410	1	459	0.92	-2.649000	3.0780	1	
177	410	2	459	0.92	-2.649000	3.0780	1	
174	410	9	459	0.92	-2.649000	3.0780	1	
179	500	0	460	0.97	-1.899000	3.0650	1	
180	500	1	460	0.97	-1.899000	3.0650	1	
181	500	2	460	0.97	-1.899000	3.0650	1	
178	500	9	460	0.97	-1.899000	3.0650	1	
183	501	0	94	0.99	-1.499000	3.1140	1	
184	501	1	94	0.99	-1.499000	3.1140	1	
185	501	2	94	0.99	-1.499000	3.1140	1	
182	501	9	94	0.99	-1.499000	3.1140	1	
187	502	0	287	0.87	-1.210000	3.0010	1	
188	502	1	287	0.87	-1.210000	3.0010	1	
189	502	2	287	0.87	-1.210000	3.0010	1	
186	502	9	287	0.87	-1.210000	3.0010	1	
191	610	0	56	0.94	-2.378000	2.8470	1	
192	610	1	56	0.94	-2.378000	2.8470	1	
193	610	2	56	0.94	-2.378000	2.8470	1	
190	610	9	56	0.94	-2.378000	2.8470	1	
195	616	0	102	0.76	-2.742000	3.1520	1	
196	616	1	102	0.76	-2.742000	3.1520	1	
197	616	2	102	0.76	-2.742000	3.1520	1	
194	616	9	102	0.76	-2.742000	3.1520	1	
199	622	0	294	0.91	-1.462000	1.9390	1	
200	622	1	294	0.91	-1.462000	1.9390	1	
201	622	2	294	0.91	-1.462000	1.9390	1	
198	622	9	294	0.91	-1.462000	1.9390	1	
203	623	0	1,212	0.68	-2.086000	2.5410	1	
204	623	1	1,212	0.68	-2.086000	2.5410	1	
205	623	2	1,212	0.68	-2.086000	2.5410	1	
202	623	9	1,212	0.68	-2.086000	2.5410	1	
207	624	0	20	0.70	-1.984000	2.7150	1	
208	624	1	20	0.70	-1.984000	2.7150	1	
209	624	2	20	0.70	-1.984000	2.7150	1	
206	624	9	20	0.70	-1.984000	2.7150	1	
211	625	0	108	0.53	-2.051000	2.8400	1	
212	625	1	108	0.53	-2.051000	2.8400	1	

Continued on next page ...

... Continued from previous page

	species	sex	number	rsquare	a	b	length.unit	comments
213	625	2	108	0.53	-2.051000	2.8400	1	
210	625	9	108	0.53	-2.051000	2.8400	1	
215	626	0	823	0.94	-2.414000	3.2340	1	
216	626	1	823	0.94	-2.414000	3.2340	1	
217	626	2	823	0.94	-2.414000	3.2340	1	
214	626	9	823	0.94	-2.414000	3.2340	1	
219	628	0	11	0.81	-2.423000	2.9690	1	
220	628	1	11	0.81	-2.423000	2.9690	1	
221	628	2	11	0.81	-2.423000	2.9690	1	
218	628	9	11	0.81	-2.423000	2.9690	1	
223	630	0	99	0.98	-2.983000	3.2040	1	
224	630	1	99	0.98	-2.983000	3.2040	1	
225	630	2	99	0.98	-2.983000	3.2040	1	
222	630	9	99	0.98	-2.983000	3.2040	1	
227	631	0	259	0.93	-1.451000	1.9190	1	
228	631	1	259	0.93	-1.451000	1.9190	1	
229	631	2	259	0.93	-1.451000	1.9190	1	
226	631	9	259	0.93	-1.451000	1.9190	1	
231	632	0	33	0.77	-1.967000	2.4340	1	
232	632	1	33	0.77	-1.967000	2.4340	1	
233	632	2	33	0.77	-1.967000	2.4340	1	
230	632	9	33	0.77	-1.967000	2.4340	1	
235	640	0	378	0.98	-2.795000	3.2840	1	
236	640	1	378	0.98	-2.795000	3.2840	1	
237	640	2	378	0.98	-2.795000	3.2840	1	
234	640	9	378	0.98	-2.795000	3.2840	1	
239	642	0	2,725	0.97	-2.552000	3.1690	1	
240	642	1	2,725	0.97	-2.552000	3.1690	1	
241	642	2	2,725	0.97	-2.552000	3.1690	1	
238	642	9	2,725	0.97	-2.552000	3.1690	1	
243	646	0	185	0.53	-1.767000	2.1800	1	
244	646	1	185	0.53	-1.767000	2.1800	1	
245	646	2	185	0.53	-1.767000	2.1800	1	
242	646	9	185	0.53	-1.767000	2.1800	1	
247	701	0	77	0.87	-1.799000	3.0520	1	
248	701	1	77	0.87	-1.799000	3.0520	1	
249	701	2	77	0.87	-1.799000	3.0520	1	
246	701	9	77	0.87	-1.799000	3.0520	1	
251	713	0	223	0.78	-2.416000	2.6440	1	
252	713	1	223	0.78	-2.416000	2.6440	1	
253	713	2	223	0.78	-2.416000	2.6440	1	
250	713	9	223	0.78	-2.416000	2.6440	1	

Continued on next page ...

... Continued from previous page

	species	sex	number	rsquare	a	b	length.unit	comments
255	720	0	8	0.92	-3.367000	3.6040	1	
256	720	1	8	0.92	-3.367000	3.6040	1	
257	720	2	8	0.92	-3.367000	3.6040	1	
254	720	9	8	0.92	-3.367000	3.6040	1	
260	2,513	0	13	0.99	-3.670000	2.9390	2	
258	2,513	1	13	0.99	-3.670000	2.9390	2	
259	2,513	2	13	0.99	-3.670000	2.9390	2	
263	2,521	0	11	1.00	-3.745000	3.0000	2	
261	2,521	1	11	1.00	-3.114000	3.3000	2	
262	2,521	2	11	1.00	-2.797000	2.7960	2	
266	2,523	0	3	0.99	-2.521000	2.6550	2	
264	2,523	1	3	0.99	-2.521000	2.6550	2	
265	2,523	2	3	0.99	-2.521000	2.6550	2	
269	2,526	0	60	0.98	-2.400000	2.5430	2	
267	2,526	1	14	0.99	-2.659000	2.7070	2	
268	2,526	2	45	0.97	-2.188000	2.4060	2	
272	2,527	0	61	0.98	-2.400000	2.5430	2	
270	2,527	1	15	0.99	-2.659000	2.7070	2	
271	2,527	2	46	0.97	-2.188000	2.4060	2	
275	2,550	0	89	0.85	-2.974000	2.8970	2	
273	2,550	1	NA	NA	-2.851570	2.8675	2	Maynard et al. 1992
274	2,550	2	NA	NA	-2.508638	2.6838	2	Maynard et al. 1992
277	4,321	0	31	0.97	-4.234000	3.1640	2	
278	4,321	1	31	0.97	-4.234000	3.1640	2	
279	4,321	2	31	0.97	-4.234000	3.1640	2	
276	4,321	9	31	0.97	-4.234000	3.1640	2	
281	4,322	0	43	0.81	-2.655000	2.3260	2	
282	4,322	1	43	0.81	-2.655000	2.3260	2	
283	4,322	2	43	0.81	-2.655000	2.3260	2	
280	4,322	9	43	0.81	-2.655000	2.3260	2	
285	4,511	0	12	0.94	-2.159000	3.3870	2	
286	4,511	1	12	0.94	-2.159000	3.3870	2	
287	4,511	2	12	0.94	-2.159000	3.3870	2	
284	4,511	9	12	0.94	-2.159000	3.3870	2	
289	4,512	0	54	0.89	-1.430000	2.7900	2	
290	4,512	1	54	0.89	-1.430000	2.7900	2	
291	4,512	2	54	0.89	-1.430000	2.7900	2	
288	4,512	9	54	0.89	-1.430000	2.7900	2	
293	4,514	0	14	0.89	-0.813000	2.3220	2	
294	4,514	1	14	0.89	-0.813000	2.3220	2	
295	4,514	2	14	0.89	-0.813000	2.3220	2	
292	4,514	9	14	0.89	-0.813000	2.3220	2	

Continued on next page ...

... Continued from previous page

	species	sex	number	rsquare	a	b	length.unit	comments
297	4,521	0	23	0.74	-0.680000	1.9440	2	
298	4,521	1	23	0.74	-0.680000	1.9440	2	
299	4,521	2	23	0.74	-0.680000	1.9440	2	
296	4,521	9	23	0.74	-0.680000	1.9440	2	

6 Figures

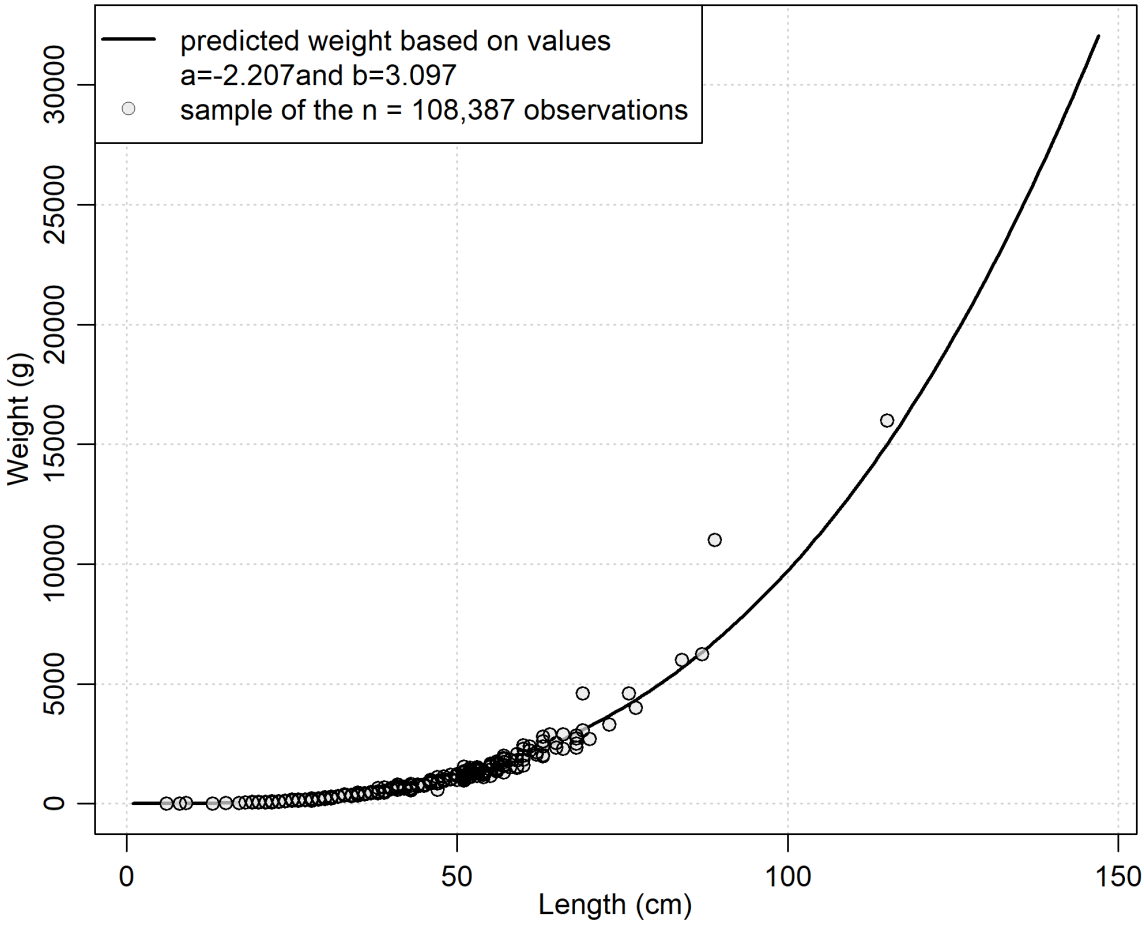

Figure 1. Example of a length-weight relationship.

7 References

Froese, R., Thorson, J.T., and Reyes Jr, R.B. 2014. A bayesian approach for estimating length-weight relationships in fishes. Journal of Applied Ichthyology 30(1): 78–85.

Lai, H.-L., and Helser, T. 2004. Linear mixed-effects models for weight–length relationships. Fisheries Research 70(2): 377–387.

Ma, Q., Y., J., and Ren, Y. 2017. Linear mixed-effects models to describe length-weight relationships for yellow croaker (*Larimichthys polyactis*) along the north coast of china. PLoS One.