

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

Daniel Ricard and Tobie Surette

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

2024

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



Fisheries and Oceans
Canada

Pêches et Océans
Canada

Canada 

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

by

Daniel Ricard and Tobie Surette

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

© His Majesty the King in Right of Canada, as represented by the Minister of the
Department of Fisheries and Oceans, 2023
Cat. No. Fs97-6/nnnE-PDF ISBN ISSN 1488-5379

Correct citation for this publication:

Ricard, D. and Surette, T. 2023. A mixed-effects approach to estimating appropriate length-weight relationship parameters for 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 + 8 p.

CONTENTS

ABSTRACT	iv
RÉSUMÉ	v
1 Introduction	1
2 Methods	2
2.1 Exploratory analyses	2
2.2 Allometric function	2
2.3 Sequential approach	2
2.4 Mixed effects models	3
2.5 Southern Gulf of St. Lawrence ecosystem survey	3
2.5.1 Annual update of length-weight parameter estimates	3
2.6 Estimates obtained from SAS	3
3 Results	4
3.1 Sex and year effects	4
3.2 Sex effects	4
3.3 Year effects	4
3.4 Species-specific model predictions	4
3.5 Comparison to previous estimates obtained in SAS	4
4 Discussion	4
5 Tables	5
6 Figures	7
7 References	8

ABSTRACT

Ricard, D. and Surette, T. 2023. A mixed-effects approach to estimating appropriate length-weight relationship parameters for 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 + 8 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. and Surette, T. 2023. A mixed-effects approach to estimating appropriate length-weight relationship parameters for 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 + 8 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.

Relevant literature citations (Kulbicki et al. 2005; Froese 2006; Froese et al. 2011; Jin et al. 2015; Hajjej et al. 2016; Aydin 2018; Pauly et al. 2022; Yin et al. 2022).

issues to deal with

- small sample size
- small size values and weight measurement precision

- limited size range
- taxonomic misidentification which requires grouping, this changes with time
- mismeasurement and transcription errors

uses: 1 - predict weight from size - list of taxa, annual weight-at-size predictor for observations in September

2 - flag outliers when entering data

do we need to include the stratification and/or a catch-weighted estimation?

2 Methods

2.1 Exploratory analyses

The empirical weight-at-size estimates are presented for the list of taxa in Table 2. For each taxon, a figure showing the distribution of measured weight at given lengths over time.

2.2 Allometric function

The length-weight relationship we use is the following:

$$W = \alpha L^{\beta} \quad (1)$$

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.

2.3 Sequential approach

For each taxon examined, the number of available paired observations of weight and size, and the range of their observed measurements, will determine whether a more complex model can be estimated.

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.

Sequential approach

1. Full Model: sex- and time-dependent relationship

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

The models considered can be found in Table ??.

2.4 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:

$$W = (\alpha + \delta_y^\alpha) L^{(\beta + \delta_y^\beta)} \quad (2)$$

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

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

Models are implemented using the *lme4* R package.

2.5 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 2.

2.5.1 Annual update of length-weight parameter estimates

The analyses presented herein are encapsulated in an R function that allows for an annual update of the estimated values for each taxon.

2.6 Estimates obtained from SAS

A SAS script was developed by scientists at Fisheries and Oceans Canada to estimate the parameters of the relationship between weight and length. This script manually removed outliers for different taxa and also assigns each taxon to the type of estimates that will be calculated. The values derived from this script can be found in Table ?? (Appendix ??)

3 Results

3.1 Sex and year effects

Taxon listed in Table ??.

3.2 Sex effects

Taxon listed in Table ??.

3.3 Year effects

Taxon listed in Table ??.

3.4 Species-specific model predictions

Overall length-weight relationship parameters can be found in Table ??.

3.5 Comparison to previous estimates obtained in SAS

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.

Discuss the use of base 10 logarithm versus natural logarithm

Froese et al. (2014)

5 Tables

Table 1. Models considered.

model.number	model.type	formula	notes
1	lm	lweight llength*year*sex	Full model

Table 2. 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.year	species.sex
40	American Plaice	Hippoglossoides platessoides	Yes	Yes

6 Figures

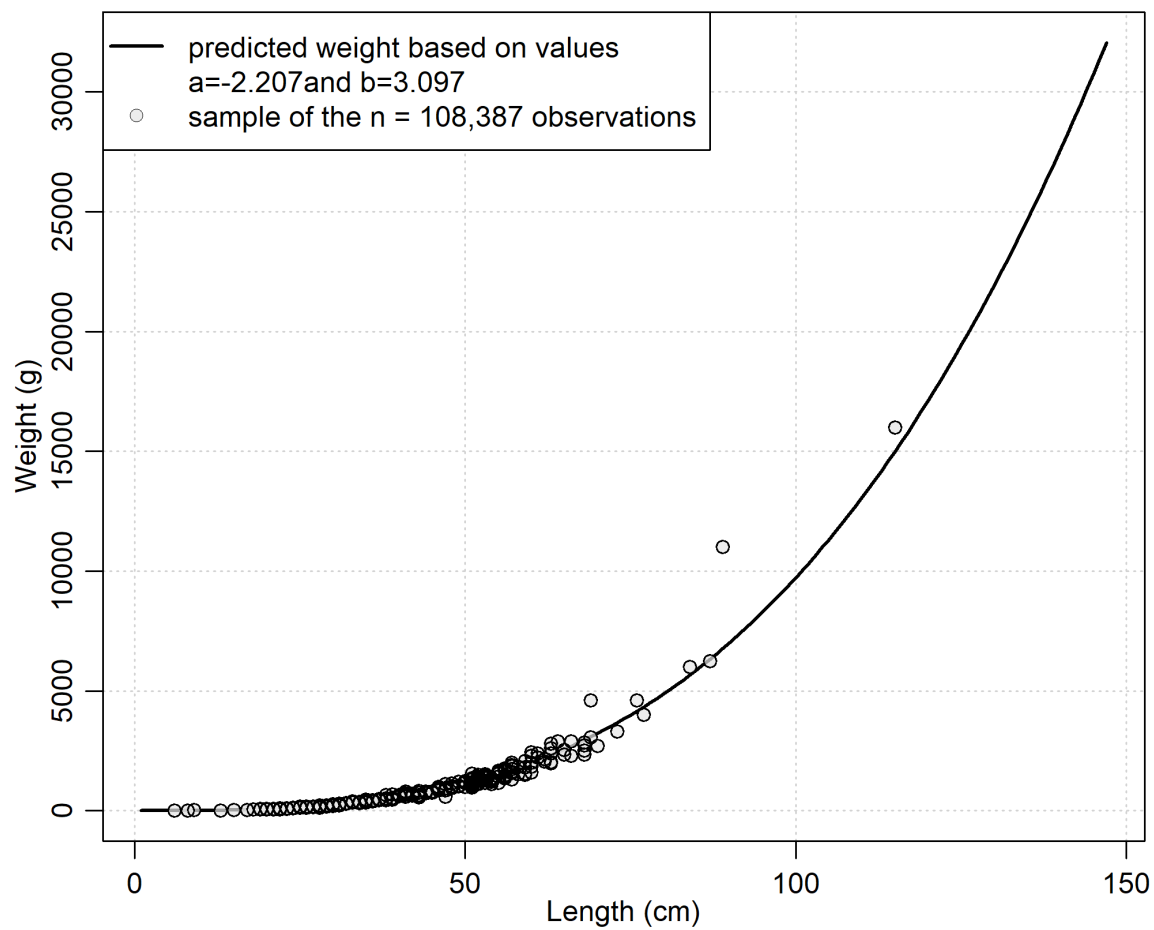


Figure 1. Example of a length-weight relationship.

7 References

- Aydin, M. 2018. Length-weight relationships and condition factors of five crab species (Decapoda) in the Black Sea. *Pakistan J. Zool.* 50: 1519–1524.
- Froese, R. 2006. Cube law, condition factor and weight–length relationships: History, meta-analysis and recommendations. *J. Appl. Ichthyol.* 22: 241–253.
- 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.
- Froese, R., Tsikliras, A.C., and Stergiou, K.I. 2011. EDITORIAL NOTE ON WEIGHT–LENGTH RELATIONS OF FISHES. *ACTA ICHTHYOLOGICA ET PISCATORIA* 41: 261–263.
- Hajjej, G., Sley, A., and Jarboui, O. 2016. Morphometrics and length weight relationship in the blue swimming crab, portunus segnis (Decapoda, Brachyura) from the gulf of Gabes, Tunisia. *International Journal of Engineering and Applied Sciences* 3: 2394–3661.
- Jin, S., Yan, H., Xiaodongand Zhang, and Fan, W. 2015. Weight–length relationships and Fulton’s condition factors of skipjack tuna (*Katsuwonus pelamis*) in the western and central Pacific Ocean. *PeerJ* 3.
- Kulbicki, M., Guillemot, N., and Amand, M. 2005. A general approach to length-weight relationships for New Caledonian lagoon fishes. *Cybium* 29: 235–252.
- 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*.
- Pauly, D., Matsushige, L., Malacane, J., Hay, A., Chu, E., and Warren, M. 2022. Length–weight relationships and growth parameters of common and leafy seadragons (Syngnathidae) from a public aquarium. *Fishes*.
- Yin, Y., Sameoto, J.A., Keith, D.M., and Mills Flemming, J. 2022. Improving estimation of length–weight relationships using spatiotemporal models. *Can. J. Fish. Aquat. Sci.* 79: 1896–1910.