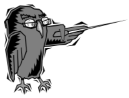
9 Mixed effects modelling in R-INLA to analyse otolith data

In this chapter we show how to fit linear mixed-effects models in R-INLA. We will use a fisheries data set to illustrate the important steps.

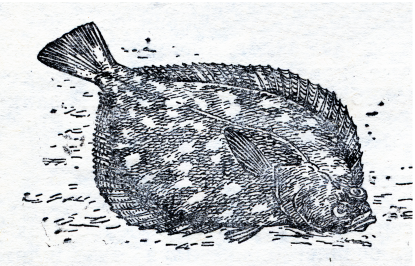


Prerequisite for this chapter: Knowledge of multiple linear regression and linear mixed effects models and how to fit these models in R-INLA is required (see Chapters 7 and 8).

9.1 Otoliths in plaice

Otoliths are earstones produced by 96% of fish species. Just like trees otoliths have rings, which can be used to determine the age of a fish. The otolith is made of calcium carbonate, which is primarily derived from water. Studying the trace elemental composition of the otolith, fisheries biologists hope to determine in which water bodies a fish has been (e.g. for stock identification). But if you want to say where a fish has been based on its trace elemental composition of the otolith, it is rather important to know what is more relevant for this composition: environmental or physiological factors.

The data used in this chapter were taken from Sturrock et al. (2015), who carried out an experiment to identify the main controls on otolith microchemistry in European plaice (*Pleuronectes platessa* L.). In the experiment, 25 fish were kept in near-natural conditions in a tank for 7–12 months. Physiological variables from each fish (total length, weight, Fulton's condition factor, growth rate, blood plasma protein, and elemental concentrations) and environmental variables (salinity, temperature, seawater elemental concentrations) were measured at least monthly. At the end of the experiment, otolith measurements were quantified retrospectively.



Concentrations like ^{7}Li, ^{26}Mg, ^{41}K, ^{48}Ca, ^{88}Sr, ^{138}Ba, and element / calcium ratios were determined for the seawater (environmental variables), the blood plasma (physiological variable), and from the otolith (response variable).

Other factors that may influence the response variable are sex of the fish (male versus female), origin of the fish (Irish Sea versus English Channel), and whether the fish received a certain hormone (GnRH) to encourage spawning.

9.2 Model formulation

Sturrock et al. (2015) applied a series of models using different response variables, for example the Li / Ca ratio in the otoliths, the K / Ca ratio in the otoliths, the Sr / Ca ratio in the otoliths, etc. In this chapter we will repeat one of their analyses, namely for the Sr / Ca ratio. It is one of the most used ratios in this field. Sr stands for strontium.

As covariates we will use sex of the fish, GnRH treatment, origin of the fish, the environmental variables salinity, temperature, Sr concentration in the water, the Sr / Ca ratio of the water, and the physiological variables age, total length, weight, Fulton's condition factor, growth rate, blood plasma protein, Sr concentration in the blood, and Sr / Ca ratio in the blood. This leads to a model of the form (in words):

Sr / Ca ratio = Intercept + Sex + GnRH treatment + Origin +
Lots of environmental variables +
Lots of physiological variables +
Noise (9.1)

Sturrock et al. (2015) also included all two-way interactions, but the data set is not large enough for our liking for interactions.

9.3 Dependency

The experiment consisted of 25 fish, but only 19 fish exhibited sufficient otolith growth suitable for the statistical analyses. We have multiple observations over time from the same fish, as can be seen from Figure 9.1. This means that we have dependency. We have time series that consist of only a few observations per fish, so perhaps we may be able to avoid a more complicated model with temporal dependency by applying a linear mixed-effects model with random intercept 'fish'. Such a mixed-effects model assumes that all Sr / Ca ratio values from the same fish are correlations with a value ϕ (the intraclass correlation) and Sr / Ca ratios from different fish are independent. This means that we need to implement a model of the form:

Sr / Ca ratio = Intercept + Sex + GnRH treatment + Origin +
Lots of environmental variables +
Lots of physiological variables +
Random intercept Fish +
Noise (9.2)

The Sr / Ca ratio is continuous and strictly positive. A Gaussian distribution, or perhaps better a gamma distribution, is the obvious candidate for the distribution in the model. To keep the analysis simple we will use the Gaussian distribution, which means that the model in Equation (9.2) is a linear mixed-effects model. Once we have fitted this model we will need to assess the residuals for any temporal dependency.