An implementation of the statistical framework Gadget for common minke whales in Icelandic waters

Status update on multispecies modeling effort

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Abstract

This report gives a status update on the current modeling effort for the common minke whales in Icelandic waters in a statistical multispecies framework (Gadget). It illustrates a single species two area model for minke whales in Gadget using abundance data from areal surveys, catches, length distributions and recent age data (described in SC/F13/SP15). Stock migrations between areas are estimated as function of sandeel abundance in Icelandic waters.

The model is seen to fit the available datasets reasonably well while improvements and possible additions are discussed.

Introduction

The common minke whale (Balaenoptera acutorostrata) is the most abundant whale species in Icelandic continental shelf waters (Borchers et al., 2007; Pike et al., 1011). Previous studies have indicated that cetaceans, and in particular minke whales play an important role in the marine ecosystem by consuming several times the total Icelandic fishery landings (Sigurjónsson and Víkingsson, 1997). Initial attempts to include three species of cetaceans, minke, fin and humpback whales, in a multispecies model indicate that their effect on the development of the stocks of cod and capelin may be considerable (Stefánsson et al., 1997). There was, however considerable uncertainty associated with this estimate. One of the greatest sources of uncertainty regarding the effects on the cod stock was associated with the very limited knowledge of the food selection by minke whales in Icelandic waters. It is therefore of prime importance for further development of multispecies modelling in Icelandic waters to obtain data on the diet of minke whales and investigate multi-species interactions in in more detail, in particular those between minke whales and the cod stock. The main objective of the research programme on common minke whales was to address these questions as a pilot study using various methods (Institute, 2003). The results are presented in several papers at this meeting (e.g. SC/F13/SP1, SC/F13/SP2, SC/F13/SP4, SC/F13/SP6, SC/F13/SP8, SC/F13/SP9, SC/F13/SP110, SC/F13/SP111).

Here a evaluation the suitability of an implementation of a model for the common minke whale in Icelandic waters in Gadget (Begley and Howell, 2004) is presented. In particular, the emphasis is on augmenting the current fisheries stock assessments, i.e. cod (*gadus morhua*) with information on the role of minke whales in the ecosystem.

Stock assessment using Gadget have been more common in recent years, current single species implementations include cod in Icelandic waters (Taylor et al., 2007), tusk (*brosme brosme*) and ling (*molva molva*) (Elvarsson and Þórðarson, 2012). Lindstrøm et al. (2009) introduced a model of cod, capelin, herring and minke whales in Norwegian waters and subsequently (Howell and Bogstad, 2010) used in assessing multispecies harvest control rules.

In this first phase of model implementation the following is considered:

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- What datasets were available on the whaling operations, migration, abundance and growth?
- What adjustments were needed to the Gadget modeling framework?
- How well does a single species model explain variations in abundance?

Materials and methods

Datasets

As is usual for Gadget models a number datasets can be incorporated into the model estimation via a weighted log-likelihood function. In this analysis the following datasets were considered:

- Abundance estimates from areal surveys.
- Catch series, both from commercial and survey fleets,
- Length distributions, both from commercial and survey fleets.
- Age–length distributions from the survey fleet.

In addition to these sources, information on diet composition indicated a strong preference for sandeel (*Ammodytes tobianus*) and a recent collapse in its abundance coincided with a dramatic decrease in the number of minke whales in Icelandic waters. Unfortunately no reliable estimation of sandeel abundance prior to the stock collapse exists. Auxiliary information can be obtained from stomach content data from haddock (*Melanogrammus aeglefinus*) and cod samples taken during the annual survey (Bogason pers. comm).

Stock dynamics

The general stock dynamics implemented in Gadget are described in detail in Begley and Howell (2004). The key attributes of the model are the following:

- Single stock model, two area model where migrations to Icelandic water is proportional to sandeel abundance. The spring migration matrix is of the form:

  $$\begin{pmatrix} 1 & \delta_s m \\ 0 & 1-\delta_s m \end{pmatrix}$$

  where δ_s is the sandeel abundance index and m is the relative proportion of minke whales that migrate to the Icelandic continental shelve during the summer. Autumn migration are estimated similarly.

- The model is length based where the average yearly growth rate is set according to a von Bertalanffy curve and the growth implementation is set according to a beta-binomial distribution.

- Recruitment is governed by a similar stock–recruitment function as in Punt (1999) and implemented into Gadget specially for this application. The formulation in the current model, assuming equal sex ratio, is:

  $$b_t = \frac{BN_t}{2}\left[1 + A\left(1 - \left(\frac{N_t}{K}\right)^z\right)\right] \tag{1}$$

  where B is the average number of births per female, A and z are the resilience and compensation parameters, $N_t = \sum_{a=1} N_{ta}$ the number of whales a time t and K is the carrying capacity. Values for the recruitment parameters are chosen such that the MSYR is 0.04 and is obtained at $0.72K$.

- Single (combined) commercial and survey fleet with a length–based exponential suitability function of the form:

$$S_l = \frac{\delta}{1 + e^{-\alpha(l - l_{50})}}$$

Observation model

The model has six likelihood components:

- Penalty function to ensure that the parameter values stay within limits.
- Understocking function that penalizes parameter values indication lower biomass than is consumed by the fleet.
- Migration penalty function to ensure that the migration matrices are internally consistent.
- Abundance time series as a survey index, assumes a linear relationship with a catchability coefficient of 1.
- Survey and commercial fleet length distributions compared using sum of squares function.
- Age–length distribution from the survey fleet compared using sum of squares.

Estimation procedure

The parameters estimated by this model are:

- Three parameters for growth, two for Von Bertalanffy and one for the length update
- Two parameter for the initial conditions, initial number of individuals in 1970 and initial proportion of the stock in Icelandic waters.
- Two parameters for the migration, proportions of the stock that migrate to and from Iceland.
- Three parameters for the stock recruitment relationship, additional two were fixed in order to maintain MSY at 0.72 and MSYR at 0.04.
- Two parameters for fleet selection, l_{50} and α.
- Two parameters for the recruitment length.

Model parameters were estimated using a three–step minimization procedure, Simulated annealing, Hooke & Jeeves and BFGS. The final parameter estimate is obtained after an iterative reweighting scheme (described in Elvarsson and Þórðarson, 2011) has been applied to estimate the weights of the weighted likelihood function.

Results

Likelihood weights

The results from the iterative reweighting is shown in table 1. It is fairly clear that the age–length data has a strong contrast with other two datasets, as the residual sum of squares rises dramatically for these datasets when the age–length data is emphasised. However this can possibly be explained by the timeperiods in which these data are collected. Age–length data is only available for whales caught in 2004 – 2007 while length and abundance series cove a larger time period.

Fit to data

The fit to length distribution from commercial and survey operations is shown in figure 1. A residual plot is show in figure 2. It appears that the model underestimates the number of small whales caught and overestimates the number of large whales caught. It is apparent from the data thatin the beginning of the model period that the whaling focussed on smaller whales than in later years.

A comparison of the fitted age–length distribution to actual data is shown in figure 3. It apperars to be a resonable fit, the largest discrepancies are in the oldest agegroup (25 and older) in the autumn of 2006 and spring 2007.

Figure 4 shows the fitted abundance to the estimate from the areal survey. The abundance in Icelandic water is primarily governed by the abundance of sandeel whose relative recruitment index is shown in figure 6

A overview of the harvestable numbers, breeding population, whaling mortality and recruitment can be found in figure 5.

Discussion and further work

The single stock model described here appears to fit the data reasonably well. There are however a few notable shortcomings. The abundance in Icelandic waters in the first year of simulation is rather incredible and could be adjusted if desired. However this does not pose any significant problems for the model as the harvest is started a few years later in the model. Similarly the initial number recruitment, which determined by the inital conditions not the stock recruitment relationship, in the stock appears to be rather unnatural. However as there are no age readings for the stock until 2004 it is hard to estimate this number without including additional restrictions to the model.

The fit to length distributions from catches, shown in figure 2, could potentially be improved by allowing (some) variation in the parameters of suitability function used in this analysis. Potentially an Andersen suitability function, which is a bell shaped suitability function, could improve the fit in the early years of whaling. There is annectotal evidence that whalers targeted smaller whales before quota was set on minke whales.

Whaling mortality, shown in figure 5, is estimated to be rather low, at least when compared to similar numbers for harvested fish stocks. However marine mammals on average live longer and on average slower reproduction cycles. After whaling operations resumed in 2003 the mortality has been even lower. However considering that the actual takes have been considerably lower than allocated quota this is hardly surprising.

The addition of a migration function which is related to the sandeel otoliths from haddock stomachs improves the fit to the areal survey abundance data substantially. This is of course based on the theory that minke whales have a preference for sandeel, which is supported by the analysis of stomach content data (SC/F13/SP2). This is of course subject to change in availability of other species in Icelandic waters that are a part of the minke whale diet in other geographical areas.

Further work is needed to model the role of minke whales in Icelandic waters. Current work focuses on updating and merging the model implemented in Taylor et al. (2007) to the minke whale model. Data collected in SC/F13/SP2 allows for the statistical evaluation of prey suitability of cod, and other prey–species within Gadget. This will extend current models used in stock assesement and potentially improve current management of exploited species.

References

J. Begley and D. Howell. An overview of Gadget, the globally applicable area-disaggregated general ecosystem toolbox. *ICES CM*, pages 1–15, 2004. URL `http://www.hafro.is/gadget/`.

D.L. Borchers, D.G. Pike, Th. Gunnlaugsson, and G.A. Víkingsson. Minke whale abundance estimation from the nass 1987 and 2001 aerial cue-counting surveys taking appropriate account of distance estimation errors. *NAMMCO Sci. Publ.*, 7:95 – 110, 2007.

Bjarki Þór Elvarsson and Guðmundur Þórðarson. Iterative re-weighing of likelihood components in gadget using tusk in va as a case study. Technical report, Marine Research Institute, 2011.

Bjarki Þór Elvarsson and Guðmundur Þórðarson. Evaluating trade-offs for multi-species management procedures for exploited marine populations using bootstrap for highly disparate datasets: Application to tusk and ling in va, 2012.

D. Howell and B. Bogstad. A combined Gadget/FLR model for management strategy evaluations of the Barents Sea fisheries. *ICES Journal of Marine Science: Journal du Conseil*, 2010. ISSN 1054-3139.

Marine Research Institute. A programme for a two year feasibility study on cetaceans in icelandic waters, 2003.

U. Lindstrøm, S. Smout, D. Howell, and B. Bogstad. Modelling multi-species interactions in the Barents Sea ecosystem with special emphasis on minke whales and their interactions with cod, herring and capelin. *Deep Sea Research Part II: Topical Studies in Oceanography*, 56(21-22): 2068–2079, 2009. ISSN 0967-0645.

DG Pike, T. Gunnlaugsson, B. Elvarsson, and GA Víkingsson. Correcting perception bias for icelandic aerial surveys, 2007 and 2009. *NAMMCO SC/18/AESP/08*, 1011.

A.E. Punt. A full description of the standard baleen ii model and some variants thereof. *J. Cetacean Res. Manage*, 1:267–276, 1999.

J. Sigurjónsson and G.A. Víkingsson. Seasonal abundance of and estimated food consumption by cetaceans in icelandic and adjacent waters. *Journal of Northwest Atlantic Fishery Science*, 22: 271–287, 1997.

G. Stefánsson, J. Sigurjónsson, and G.A. Víkingsson. On dynamic interactions between some fish resources and cetaceans off iceland based on a simulation model. *J. Northwest Atl. Fish. Sci.*, 22:357–370, 1997.

L. Taylor, J. Begley, V. Kupca, and G. Stefansson. A simple implementation of the statistical modelling framework Gadget for cod in Icelandic waters. *African Journal of Marine Science*, 29(2):223–245, 2007.

	Abundance	L.dist	ALK
Abundance data	0.29	10.81	1.13
Length distribution	1.09	5.96	0.65
Age–length distribution	13.15	11.41	0.57
Final SS	0.29	6.18	0.64

Table 1: Interim sums of squares from the iterative reweighting of each likelihood component compared to the final sums of squares. Rows represent the emphasised dataset and the columns are the residual sum of squares from the corresponding likelihood component.

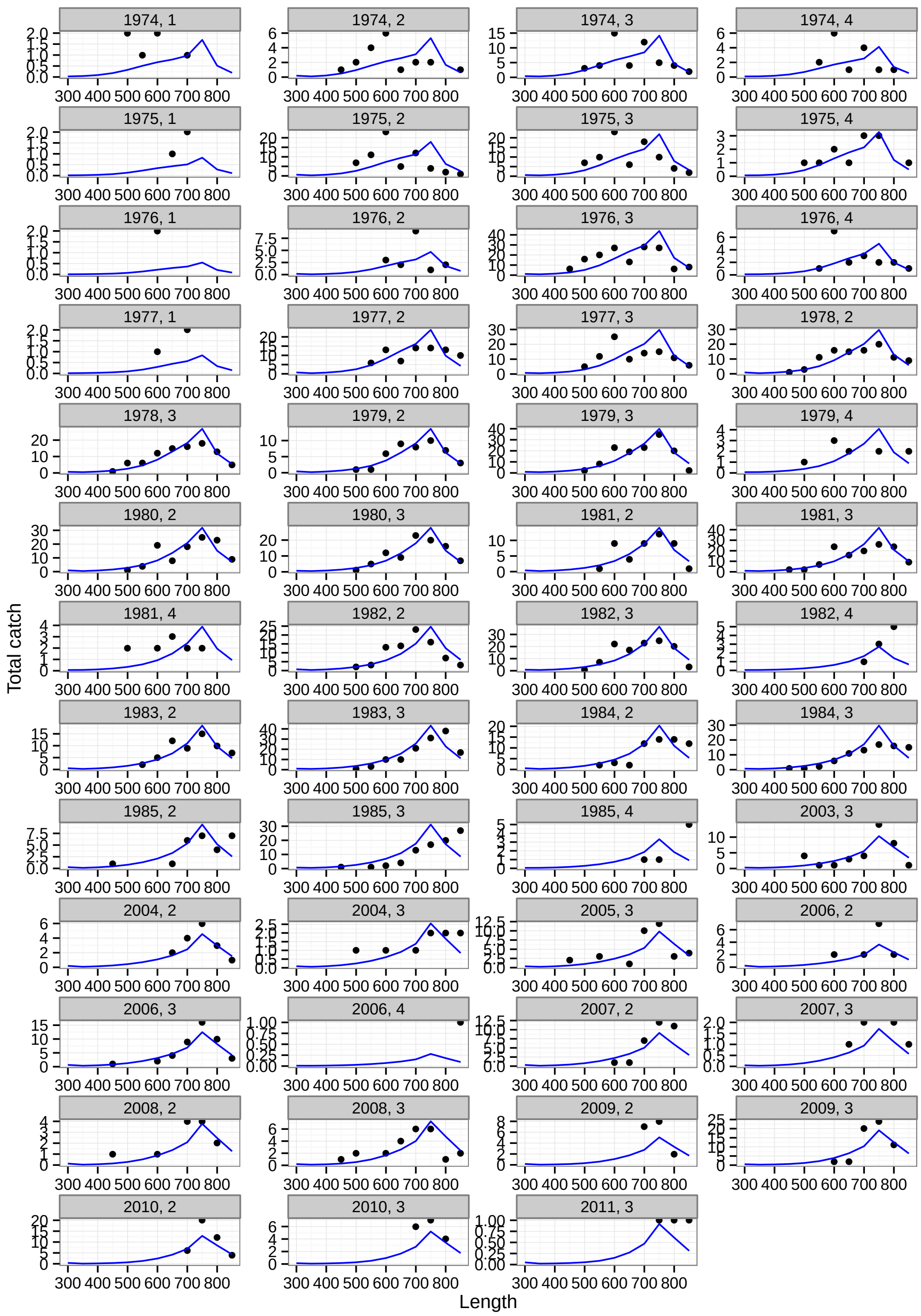

Figure 1: Fitted length distribution (solid line) with 50 cm lengthgroups from the commercial and survey operations compared to actual data (points). Results are by year and timestep.

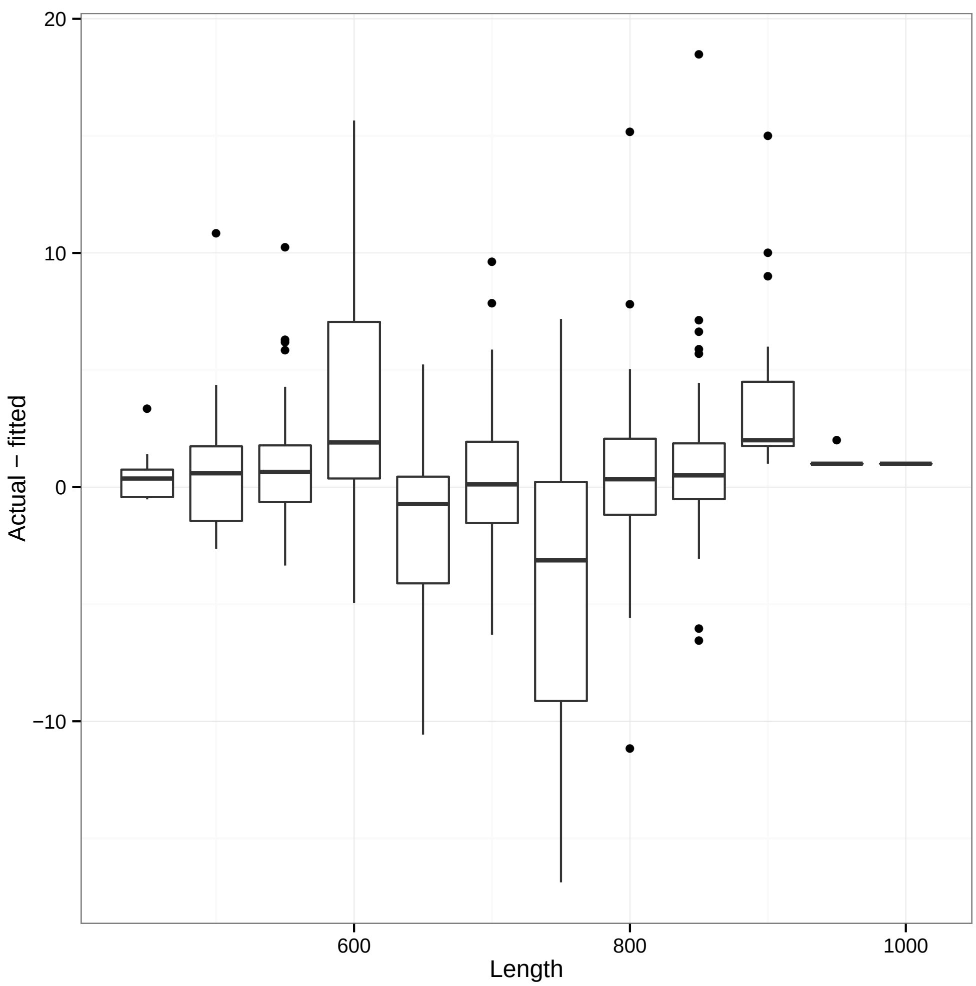

Figure 2: A boxplot of the length residuals by length.

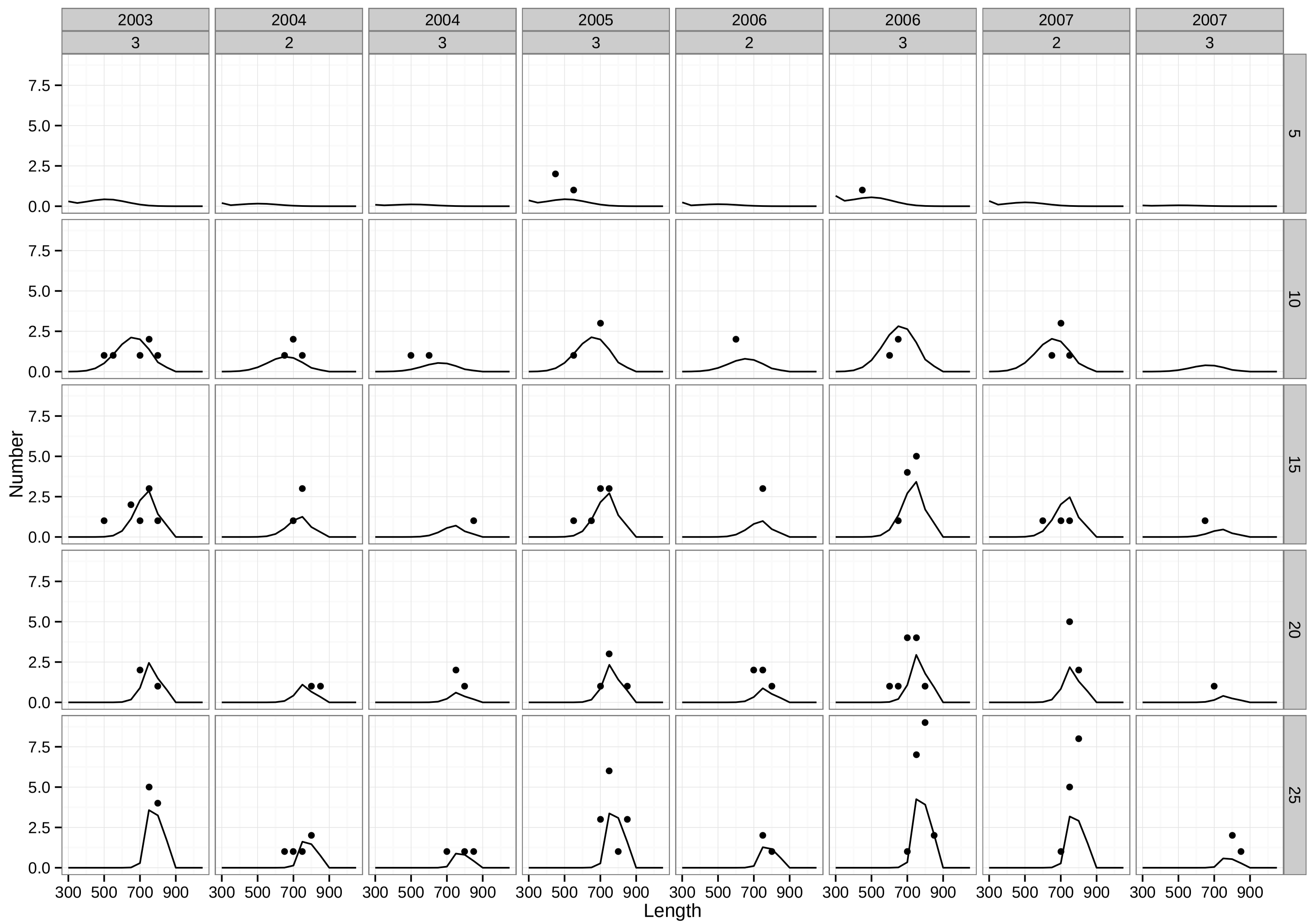

Figure 3: Fitted age-length distribution (solid line) with 5 year agegroups from the commercial and survey operations compared to actual data (points). Results are by year and timestep.

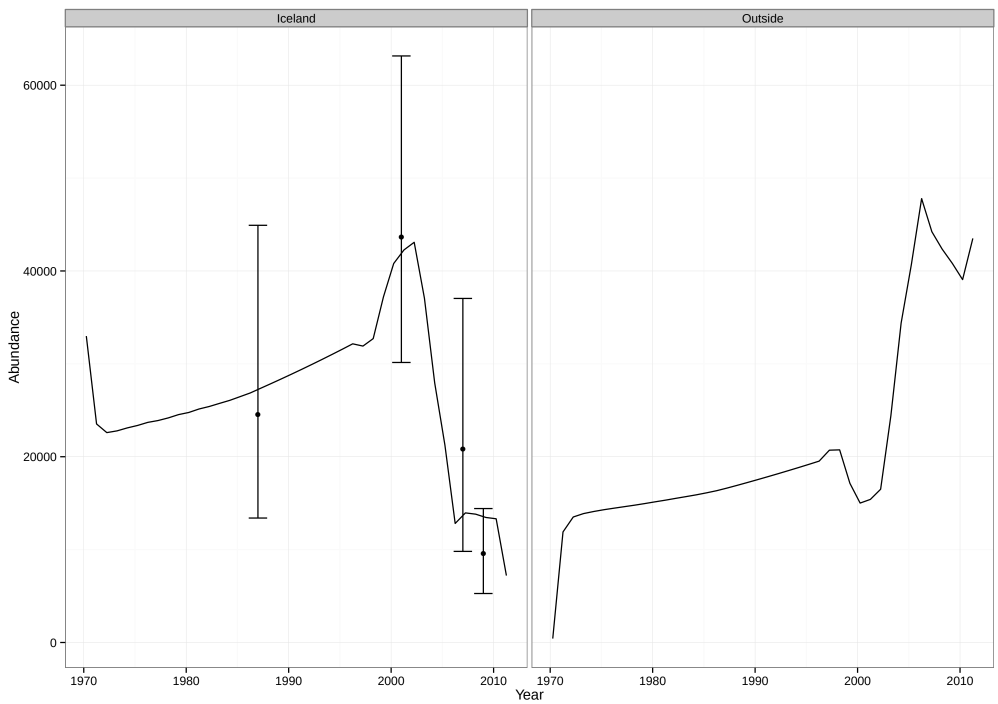

Figure 4: Fitted abundance (solid line) from the commercial and survey operations compared to actual data (points with errorbars). Results are shown by area.

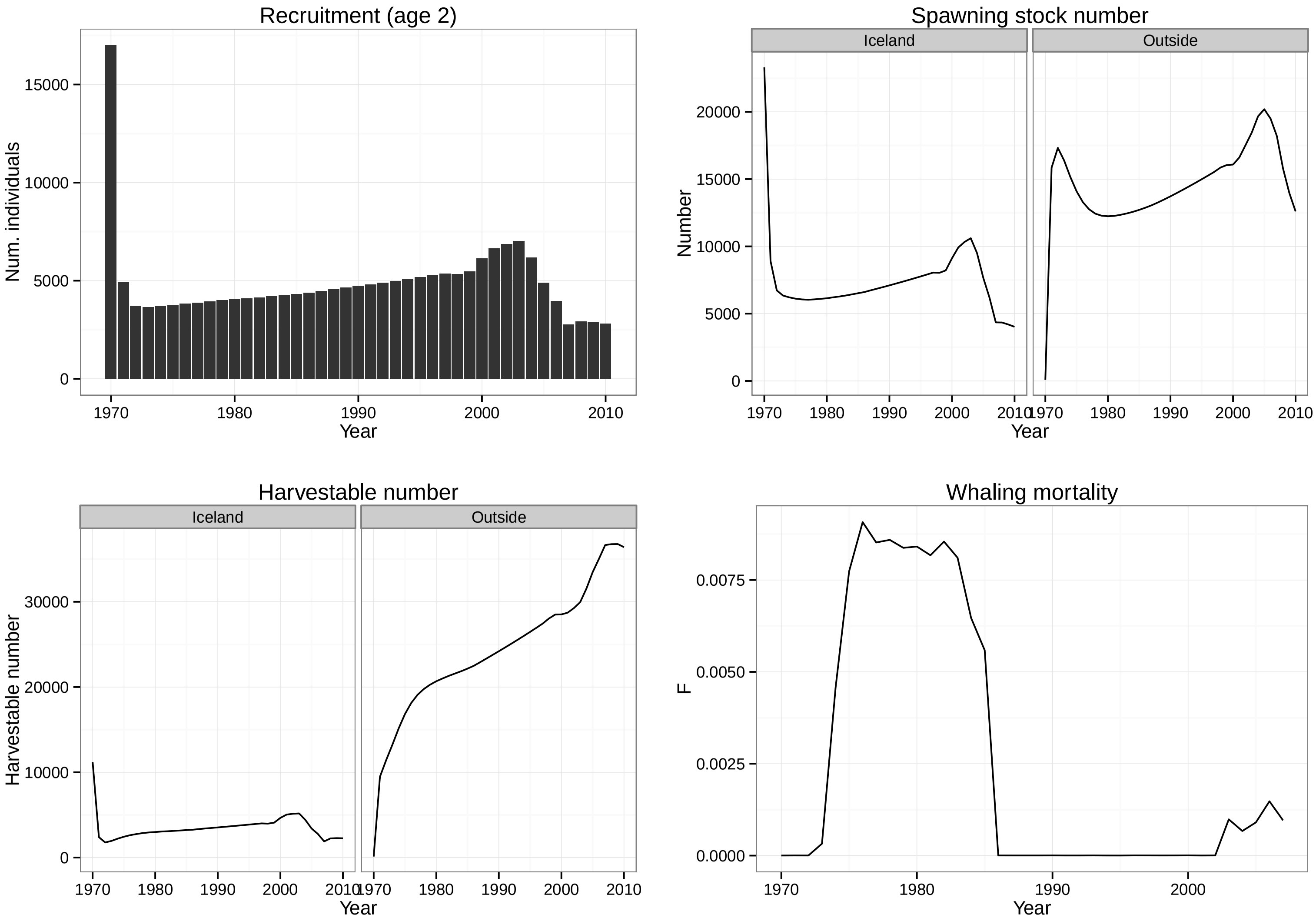

Figure 5: Estimated recruitment, mature and harvestable stock numbers and whaling mortality.

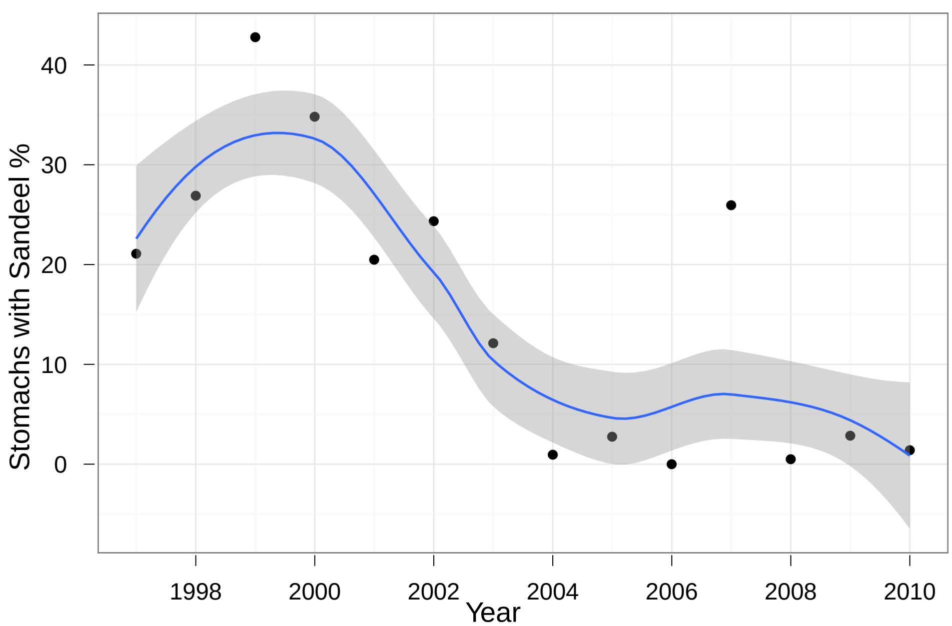

Figure 6: Percentage of haddock stomachs containing sandeel otoliths analyses in the Icelandic groundfish survey.