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

Status update

Bjarki Þór Elvarsson, Gísli Víkingsson and Gunnar Stefánsson*†

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 further work 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., 2011). Considerable uncertainty has been on the role of minke whales in the Icelandic continental shelf ecosystem. 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 diet composition found in 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 (MRI, 2003).

The choice of a modelling approach used to assimilate the findings from the scientific survey needs some consideration. Typically models of marine resources are used to determine satisfactory utilization levels, i.e. quota, for the exploited resource. Due to this management perspective these models tend to focus solely on a particular species and its associated fishery. Single species models offer a simplistic view of the resource that can, while convenient, fail to predict changes due to interaction with other species. In the recent years there has been a call for the inclusion of multi–species considerations and a move towards a ecosystem based approach to management. These approaches attempt to account for the single species models short comings by capturing some or all interactions between species, both indirect or direct.

The IWC has has passed a number of resolutions (see summary in Commission, 2010) on matters related to ecosystem research and climate change (e.g. IWC 1995, 1996, 1998, 2010b). In

*Marine Resarch Institute, Skúlagata 4, 151 Reykjavík, Iceland, bthe@hafro.is
†Institute of Science, University of Iceland, Dunhagi 5, 107 Reykjavík, Iceland

particular the IWC agreed in 2001 to make the study of interactions between whales and fisheries a matter of priority (IWC 2002). Several other international organizations have also stressed the importance of studying these interactions in terms of management (e.g. FAO 2001, NAMMCO 2009).

There are a number of approaches to ecosystems models. According to Plagányi (2007) they broadly fall into four categories:

1. Whole ecosystem approaches, where all trophic levels of the ecosystem are modelled (Christensen and Walters, 2004).

2. Dynamic systems models, where where the whole ecosystem and possibly its effects to coastal communities is modelled (Link et al., 2010).

3. Extensions of single–species assesment models (eg. Livingston and Methot, 1998).

4. Minimum realistic models, where only a few but significant interactions are included. Examples of cases are models build using the Gadget framework (Begley and Howell, 2004).

Obviously these approaches differ substatiantly both in scope and objectives. Minimimum realistic models and singles species extensions are, as the names suggest, more focussed on answering key questions and their parameters are estimated statistically. Modelling approaches, like those using Atlantis or Ecopath with Ecosim, often try to include a larger part of the ecosystem where it becomes harder to estimate the model parameters through comparisons with real data. Currently a large research program is on the way to systematically evaluate the different modeling approaches for the Icelandic continental shelf area (and other areas) as a part of the MAREFRAME (Daníelsdóttir, 2013).

This document describes a preliminary update on the current work on the implementation of a model for the common minke whale in Icelandic waters in Gadget is presented. Gadget is a statistical framework to aid in the modelling of marine ecosystems. It is based on age-length structured forward-simulation model with optional processes defined by the user, coupled with an extensive set of data comparison and optimisation routines. Designed to accommodate multi-area, multi-fleet models, capable of including predation and mixed fisheries issues. The innner workings of Gadget (and its predecessors, BORMICON and Fleksibest) have been described in numerous sources, notably Begley and Howell (2004); Stefánsson and Pálsson (1997); Stefánsson (2003) with much of its statical properties implemented as a part of the dst^2 project (Taylor, 2004). Example implementation of Gadget include (single species) Cod in Icelandic waters (Taylor et al., 2007), tagging data and cod (Hannesson et al., 2008) and uncertainty methods for multi–species models using a specialized bootstrap (Taylor et al., 2012). Other notable implementations include Lindstrøm et al. (2009) and Howell and Bogstad (2010) where a multi–species harvest control rule is evaluated using a model that includes minke whales as a top predator of commercially exploited species in Norwegian waters.

Materials and methods

Stock description and management units

The current management scheme for Minke whales in the North Atlantic considers the population to be split into four distinct stock units (Donovan, 1991). In RMP terms minke whales in Icelandic coastal waters belong to CIC small area of the larger central stock. Minke whales are found all around the Icelandic coast, principally in the shallower waters. Recently significant changes in the abundance have detected, potentially due distributional shift within the central stock area (NAMMCO, 2009; Víkingsson et al., 2013).

Abundance data

Direct measurements of abundance of minke whales in CIC area, shown in figure 1 began in 1986 with an areial survey covering the continental shelf around Iceland (Borchers et al., 2007; Pike et al., 2011). Since then four complete surveys have been conducted in the CIC area, 1987, 2001, 2007 and 2009. In addition to these direct measurements partial surveys were conducted in the spring 2004 – 2005, autumn 2003 – 2005 and midsummer in a number of years (SC/F13/SP6). Shipboard surveys have been used to obtain abundance estimates on the C stock outside of the CIC subarea although these were designed for larger whales.

Significant fluctuations have been observed in abundance of minke whales within the central stock area although confidence intervals are large (fig 1). After a peak around 2001 there has been an appreaciable decline in abundance in the CIC and CIP,CG areas. However the CM small area there has been an increase over the survey period. Information on diet composition in CIC indicated a strong preference for sandeel (*Ammodytes sp.*) and a recent collapse in its abundance coincided with a decrease in the number of minke whales in Icelandic waters (Víkingsson et al., 2013). Unfortunately no reliable estimation of sandeel abundance prior to the stock collapse exists. Auxiliary information can be obtained from two sources, stomach content data from haddock (*Melanogrammus aeglefinus*) sampled during the annual survey (Bogason :pers. comm) and tagging data on Atlantic puffin (*Fratercula arctica*) in the Vestmann Islands whose diet consist mainly on small fish such as sandeel (Bjornsson pers. comm). An overview of this auxiliary data and its correlation with temperature at 50 m at Selvogsbanki south of Iceland is shown in figure 2 and 3. This is in line with results described in Arnott and Ruxton (2002).

Additional drivers for minke whale abundance in Icelandic waters have not been excluded. For instance capelin abundance has been identified as a important part of the diet of baleen whales (Sigurjónsson and Víkingsson, 1997) and a shift in capelin summer distribution away from Icelandic waters has been observed in recent years (Pálsson et al., 2012). Preliminary work of including capelin in a multi–species model has however been unsuccessful due to the nature of the data (Taylor, 2011).

Commercial catches

The history of minke whale of exploitation dates back to early 1914. The minke whaling operation in Iceland was in the beginning a small scale coastal operation with the annual take probably amounting to less 30 whales in the early years. Prior the whaling moratorium (around 1975 – 1985) the annual catch was around 200 animals. Currently Icelandic whaling operations are limited to domestic demands with catches ranging between 40 – 80 since 2008. In 1974 systematic recording of catch locations, capture date, sex and lengths began. In figure 5 the number of catches per year are shown and their locations are shown in figure 6. In 1976 export of minke whale produce began and increased rapidly. This is believed to have shifted the fleet selection to larger whales . The effects of this selection shift are shown in figure 4.

Special permit whaling

As noted in the introduction a special scientific whaling operation was conducted in the years 2003 – 2007 (SC/F13/SP1). This was the first systematic research on the minke whale in Icelandic waters. The program had multiple objectives including studies on feeding ecology and biological parameters. Along with length, location and sex the whales' reproductive status recorded (SC/F7/SP12) and a novel age determination method was employed (SC/F7/SP15_Rev).

Stock dynamics

The general stock dynamics modules in Gadget are described in detail in Begley and Howell (2004). The following describes stock dynamics of the common minke whle as implemented within the Gadget framework. In the model the simulated quantity is the number of individuals, N_{ralsyt} where

r denotes the area, CIC or the "other" area, where the whales inhabit.

a is the age of the whales, ranging from 1 to 25.

l denotes a 10 cm lengthgroup, with length ranging from 300 cm to 1100cm.

s is the maturity status, $s = 0$ denotes immature animals while $s = 1$ mature.

y is the year, ranging from 1960 to 2011.

t is the quarter within the year.

The population is governed by the following equations:

$$\begin{aligned} N_{ralsy,t+1} &= \sum_{l'} G_l^{l'} \left[(N_{ral'syt} - C_{fral'st}) e^{-M_a \Delta t} + I_{ral'syt} \right] && \text{if } t < 4 \\ N_{ra+1,ls,y+1,1} &= \sum_{l'} G_l^{l'} \left[(N_{ral'sy,4} - C_{fral's,4}) e^{-M_a \Delta t} + I_{ral'sy,4} \right] && \text{if } t = 4 \text{ and } a < 12 \\ N_{ra,ls,y+1,1} &= \sum_{l'} G_l^{l'} (N_{ral'sy,4} - C_{fral'sy,4} + N_{ra-1,l'sy,4} - C_{fr,a-1,l'sy,4}) e^{-M_a \Delta t} && \text{if } t = 4 \text{ and } a = 12 \end{aligned} \tag{1}$$

where $G_l^{l'}$ is the proportion in lengthgroup l that has grown $l'-l$ lengthgroups in Δt, C_{falsyt} denotes the catches by fleet $f \in \{S, C\}$, S and C denote the survey and commercial fleets respectively, M_a the natural mortality at age a and I_{ralsyt} denotes the movement from the immmature to the mature stock components. A short note on notation, here l is used interchangeably as either the lengthgroup or the midpoint of the length interval for that particular lengthgroup, depending on the context.

The stock components are assumed to have started at their mutual carrying capacity in 1960 when the model simulation starts.

Growth in length is modeled as a two–stage process, an average length update in Δt and a growth dispersion around the mean update (as described in Stefansson, 2005). The average length update per time step is set according to a simplyfied form of the Von Bertanlanffy equation:

$$\Delta l = (l_\infty - l)(1 - e^{-k\Delta t}) \tag{2}$$

where l_∞ is the terminal length and k is the annual growth rate. In the second step the growth is dispersed according to a beta–binomial distribution parametrised by the following equation:

$$G_l^{l'} = \frac{\Gamma(n+1)}{\Gamma((l'-l)+1)} \frac{\Gamma((l'-l)+\alpha)\Gamma(n-(l'-l)+\beta)}{\Gamma(n-(l'-l)+1)\Gamma(n+\alpha+\beta)} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \tag{3}$$

where α is subject to

$$\alpha = \frac{\beta \Delta l}{n - \Delta l} \tag{4}$$

where n denotes the maximum length group growth and $(l' - l)$ the number of lengthgroups grown.

Spawning follows a variant of the Pella–Tomlinson spawning model (as in Punt, 1999; Stefánsson et al., 1997):

$$b_t = BN_{ft}\left[1 + A\left(1 - \left(\frac{N_{ft}}{K_f}\right)^z\right)\right]$$

where

- B_j is the birthrate per mature female in the pristine population.
- N_{ft} number of mature females (assumed to be 50% of the mature population).
- A and z are determined by MSY level and rate

- K_f the carrying capacity of mature females.

Two stage maturity is modeled and represented by the two stock components. The movement between the two components is formulated as

$$I_{alsyt} = \begin{cases} N_{al0yt} \times m_l & \text{if s} = 1 \\ -N_{al0yt} \times m_l & \text{if s} = 0 \end{cases} \tag{5}$$

where $s = 0$, as noted above, denotes the immmature stock component and m_l is the proportion mature defined as:

$$m_a = \frac{1}{1 + e^{-\lambda(a - a_{50})}} \tag{6}$$

where $\beta = 1/1.2$ and $a_{50} = 7$.

It is likely that the minke whales have a preference for sandeels and the drop in minke whale abundance could be explained by feeding migrations. Migration is therefore based on the following formulation:

$$\begin{pmatrix} 1 & \delta_s m + m_c \\ 0 & 1 - (\delta_s m + m_c) \end{pmatrix}$$

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

Catches are simulated based on reported total landings and a length based suitability function for the two fleets, commercial fleet and the autumn and spring survey. Total landings are assumed to be known and the total biomass is simply offset by the landed catch. The catches for lengthgroup l , fleet f at year y and timestep t are calculated as

$$C_{flsyt} = E_{ft} \frac{S_f(l) N_{lsyt} W_{ls}}{\sum_{s'} \sum_{l'} S_f(l') N_{l's'yt} W_{l's'}} \tag{7}$$

where E_{ft} is the landed biomass at time t and $S_f(l)$ is the suitability of lengthgroup l by fleet f defined as:

$$S_{new}(l) = \frac{\delta}{1 - e^{-(\alpha + \beta l)}} \qquad S_{old}(l) = p_0 + p_1 e^{-\frac{(\log(l/L) - p_2)^2}{p3}} \tag{8}$$

Observation model

In Gadget data is assimilated using a weighted log–likelihood function. Here four types of data enter the likelihood, absolute abundance, length distributions from survey and commercial fleets combined into a single likelihood, age – length distribution from from the survey and maturity at length for all ages.

Survey indices

$$l^{\text{SI}} = \sum_y \sum_t (\bar{N}y - \widehat{N_{yt}})^2 \tag{9}$$

where $\bar{N}_y$ is the observed abundance estimate and

$$\widehat{N_{yt}} = \sum_l \sum_a \sum_s N_{alsyt}$$

Maturity at length

Length at maturity comparison uses the number of mature males observed in the scientific survey. The observed proportions are compared to the modelled proportion using sum of squares:

$$l^{\text{M}} = \sum_y \sum_t \sum_l (\pi_{lyt} - \hat{\pi}_{lyt})^2 \tag{10}$$

where π_{lyt} and $\hat{\pi}_{lyt}$ are the observed and modelled proportions mature respectively in length group l, year y and timestep t.

Fleet data

Length distributions are compared using 50 cm lengthgroups for both commercial and survey fleets using

$$l_f^{\text{LD}} = \sum_y \sum_t \sum_l \sum_s (\pi_{lsyt} - \hat{\pi}_{lsyt})^2 \tag{11}$$

where f denotes the fleet where data was sampled from. Similarly age – length data are compared using 4 cm length groups:

$$l_f^{\text{AL}} = \sum_y \sum_t \sum_a \sum_l \sum_s (\pi_{falsyt} - \hat{\pi}_{falsyt})^2 \tag{12}$$

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.

Iterative re–weighting

The total objective function used the modelling process combines equations 9 to 12 using the following formula:

$$l^{\text{T}} = \sum_g \sum_{f \in \{S,A\}} w^{\text{SI}} l^{\text{SI}} + \sum_{f \in \{S,C\}} \left(w_f^{\text{LD}} l_f^{\text{LD}} + w_f^{\text{AL}} l_f^{\text{AL}} \right) + w^{\text{M}} l^{\text{M}} \tag{13}$$

where $f = S$ or C denotes the survey and commercial fleets respectively and w's are the weights assigned to each likelihood components.

The weights, w_i, are necessary for several reasons. First of all it is used to to prevent some components from dominating the likelihood function. Another would be to reduce the effect of low quality data. It can be used as an a priori estimates of the variance in each subset of the data.

Assigning likelihood weigths is not a trivial matter, has in the past been the most time consuming part of a Gadget model. Commonly this has been done using some form of 'expert judgement'. General heuristics have recently been developed to estimated these weights objectively. Here the iterative re–weighting heuristic introduced by Stefánsson (2003), and subsequently implemented in Taylor et al. (2007), is used.

The general idea behind the iterative re-weighing is to assign the inverse variance of the fitted residuals as component weights. The variances, and hence the final weights, are calculated according the following algorithm:

1. Calculate the initial sums of squares (SS) given the initial parametrization. Assign the inverse SS as the initial weight for all likelihood components.
2. For each likelihood component, do an optimization run with the initial score for that component set to 10000. Then estimate the residual variance using the resulting SS of that component divided by the degrees of freedom (df^*), i.e. $\hat{\sigma}^2 = \frac{SS}{df^*}$.

3. After the optimization set the final weight for that all components as the inverse of the estimated variance from the step above (weight $= 1/\hat{\sigma}^2$).

The effective number of data-points (df^*) is used as a proxy for the degrees of freedom determined from the number of non-zero data-points. It is viewed as satisfactory proxy when the data-set is large while for smaller data-sets this could be a gross overestimate.

In particular, if the survey indices are weighed on their own while the yearly recruitment is estimated they could be over-fitted. In general problem such as these can be solved with component grouping, that is in step 2 the likelihood components that should behave similarly, such as survey indices, should be heavily weighted and optimized together.

Results

Likelihood weights

The results from the iterative reweighting is shown in table 1. It is fairly clear that the age–length and length distribution have a strong contrast with the abundance, as the residual sum of squares rises dramatically when the these distributions data are emphasised. However this can possibly be explained by the timeperiods in which these data are collected. Age–length data from surveys are only available for whales caught in 2004 – 2007 and some older samples in 1977. Length distributions however cover a longer timeperiod than the abundance series and information on maturity which appear to have bring conflicting information.

Fit to data

The fit to length distribution from commercial and survey operations is shown in figure 7. A residual plot is show in figure 8. It appears that the model slightly underestimates the number of small whales caught and overestimates the number of large whales caught. It is apparent from the data that in the beginning of the model period that the whaling focussed on smaller whales than in later years.

Figure 9 shows the fitted abundance to the estimate from the areial survey. The abundance in Icelandic water is primarily governed by the abundance of sandeel whose relative recruitment index is shown in figure 3

Discussion and further work

The single stock model described here appears to fit the data reasonably, given the data. There are however notable shortcomings. The abundance in Icelandic waters in the first year of simulation decreases substantially in the first. However this does not pose any significant problems for the model as the harvest is started a few years later in the model. Similarly initial abundance is assumed be the carrying capacity, a assumption that needs to be tested. Additional data should be included in the model, e.g. data available on the central stock outside the CIC area illustrated in figure 1 and data on catch lengths recorded in the IWC database.

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 changes in the ecosystem and in availability of other species in Icelandic waters that are a part of the minke whale diet in other geographical area.

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. The data will also be used in a large collaborative project, where several different modelling approaches will applied on the same datasets (Daníelsdóttir, 2013). This will extend current models used in stock assesement and potentially improve current management of exploited species.

References

Stephen A Arnott and Graeme D Ruxton. Sandeel recruitment in the north sea: demographic, climatic and trophic effects. *Marine Ecology Progress Series*, 238:199–210, 2002.

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.

V. Christensen and C.J. Walters. Ecopath with Ecosim: methods, capabilities and limitations* 1. *Ecological Modelling*, 172(2-4):109–139, 2004. URL `http://www.ecopath.org/`.

International Whaling Commission. Report of the expert workshop to review the ongoing jarpn ii programme, 26-30 january 2009, yokohama, japan. annex h. recent resolutions of the commission relevant to this review. *J. Cetacean Res. Manage. (Suppl.)*, 11(2):448–49, 2010.

Anna K. Daníelsdóttir. Mareframe: Co-creating ecosystem-based fisheries management solutions. Technical report, 2013.

GP Donovan. A review of iwc stock boundaries. *Rept. Int. Whal. Commn., Special*, 13:39–68, 1991.

S. Hannesson, A. Jakobsdottir, J. Begley, L. Taylor, and G. Stefansson. On the use of tagging data in statistical multispecies multi-area models of marine populations. *ICES Journal of Marine Science*, 65(9):1762, 2008.

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.

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.

J.S. Link, E.A. Fulton, and R.J. Gamble. The Northeast US Application of ATLANTIS: A full system model exploring marine ecosystem dynamics in a living marine resource management context. *Progress In Oceanography*, 2010.

Patricia A Livingston and Richard D Methot. Incorporation of predation into a population assessment model of eastern bering sea walleye pollock. *Fishery stock assessment models*, pages 663–678, 1998.

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

NAMMCO. Nammco annual report 2008, 2009.

Ólafur K. Pálsson, Astthor Gislason, Hafsteinn G. Guðfinnsson, Bjœrn Gunnarsson, Sólveig R. Ólafsdóttir, Hildur Petursdottir, Sveinn SveinbjÃűrnsson, Konrad Thorisson, and HÃľÃřinn Valdimarsson. Ecosystem structure in the iceland sea and recent changes to the capelin (mallotus villosus) population. *ICES Journal of Marine Science: Journal du Conseil*, 69(7):1242–1254, 2012. doi: 10.1093/icesjms/fss071. URL `http://icesjms.oxfordjournals.org/content/69/7/1242.abstract`.

DG Pike, T. Gunnlaugsson, B. Elvarsson, and GA Víkingsson. Correcting perception bias for icelandic aerial surveys, 2007 and 2009. *NAMMCO SC/18/AESP/08*, 2011.

É.E. Plagányi. *Models for an ecosystem approach to fisheries*. Food & Agriculture Org, 2007.

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 and ÓK Pálsson. BORMICON. boreal migration and consumption model. *Marine Research Institute Report. 58. 223 p.*, 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.

Gunnar Stefánsson. Issues in multispecies models. *Natural Resource Modeling*, 16(4):415–437, 2003. ISSN 1939-7445.

Gunnar Stefansson. Growth models in population simulations. *Final Report DST2: Development of Structurally Detailed Statistically Testable Models of Marine Populations, Technical Report*, 118:73–80, 2005.

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.

LA Taylor. Gadget models of cod–shrimp interactions in icelandic waters. Technical report, Technical Report RH–03–2011, Science Institute, University of Iceland, 2011.

Lorna Taylor, Bjarki Þór Elvarsson, Verena M. Trenkel, Vojtech Kupca, and Gunnar Stefánsson. A bootstrap method for estimating bias and variance in statistical multispecies. *Submitted*, 0807, 2012.

Lorna A. Taylor, editor. *Final Report: dst^2: Development of structurally detailed statistically testable models of marine populations*, volume 118. Marine Research Institute, Reykjavik, 2004.

Gísli Víkingsson, Bjarki Þór Elvarsson, Droplaug ÃŤlafsdóttir, Valerie Chosson, Jóhann Sigurjónsson, and Anton Galan. Recent changes in the diet composition of common minke whales (balaenoptera acutorostrata) in icelandic waters. âĂŞ consequence of climate change? *Marine Biology Research*, 2013. Accected for publication.

	Mat	LD	ALKs	ALKc	Abundance
Mat	71.75	0.47	9.23	1.79	235400
LD	92.99	0.55	5.62	1.55	2261000
ALs	94.06	0.32	7.34	0.59	2211000
ALc	95.27	0.29	9.01	0.95	1159000
Abundance	200.40	0.50	15.14	1.85	70020
Final	111.80	0.48	6.29	1.04	463100

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.

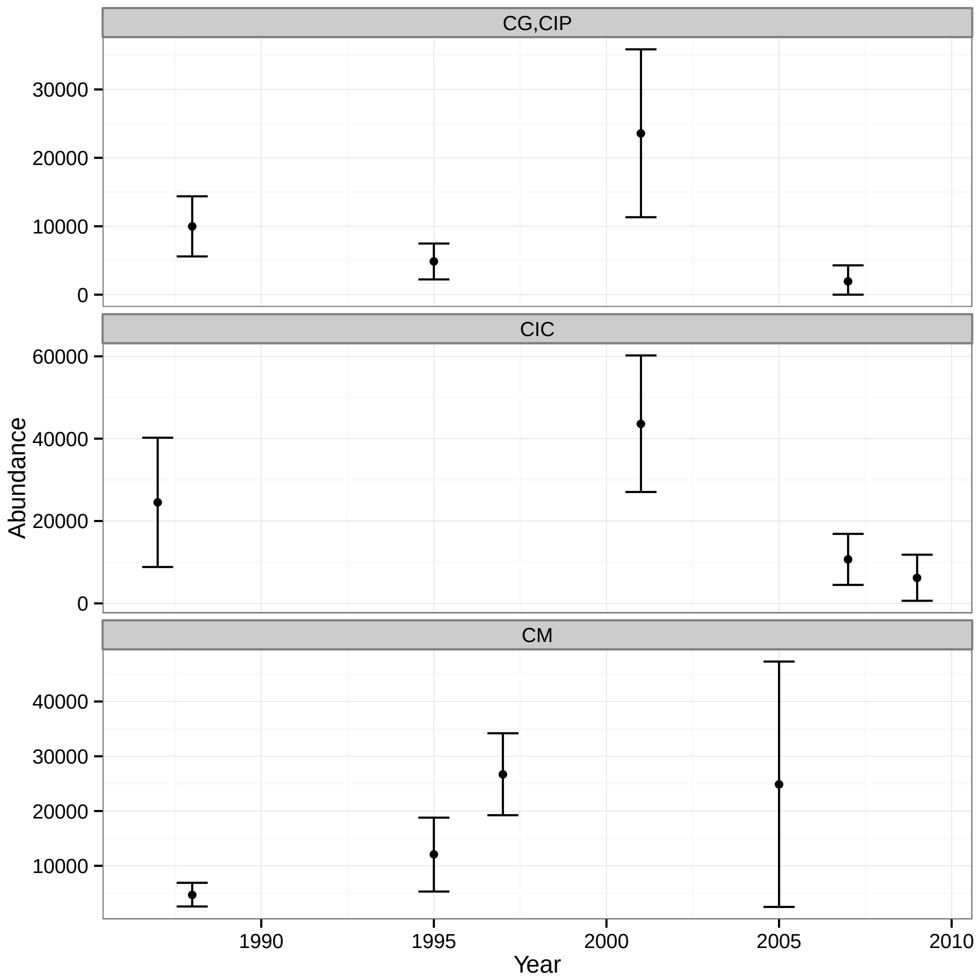

Figure 1: Abundance estimates by year for the C stock by sub–area.

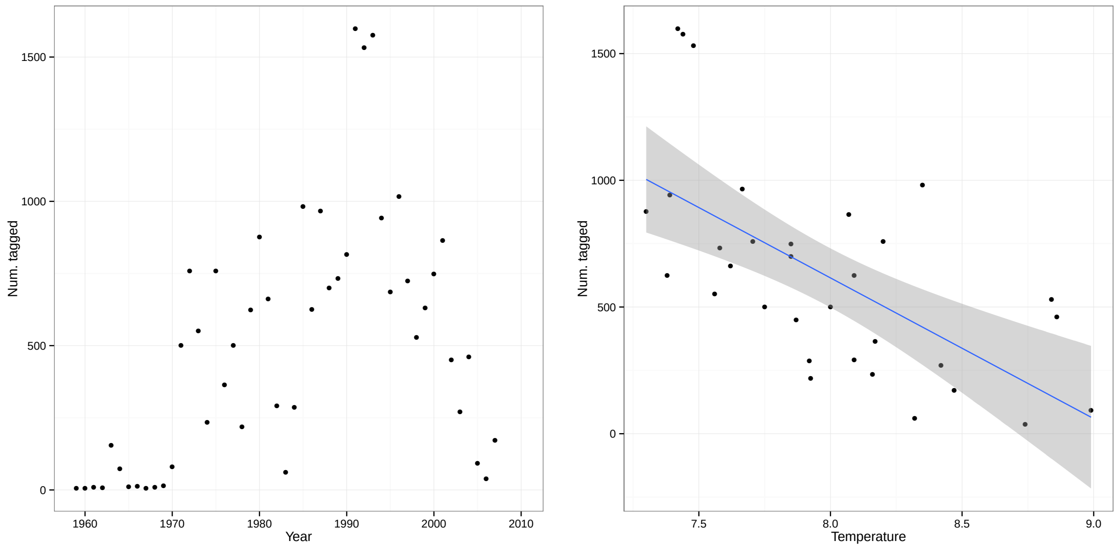

Figure 2: Number of puffins tagged in Vestmann islands (left) and number of tags as a function of temperature at 50 m in Selvogsbanki (south of Iceland).

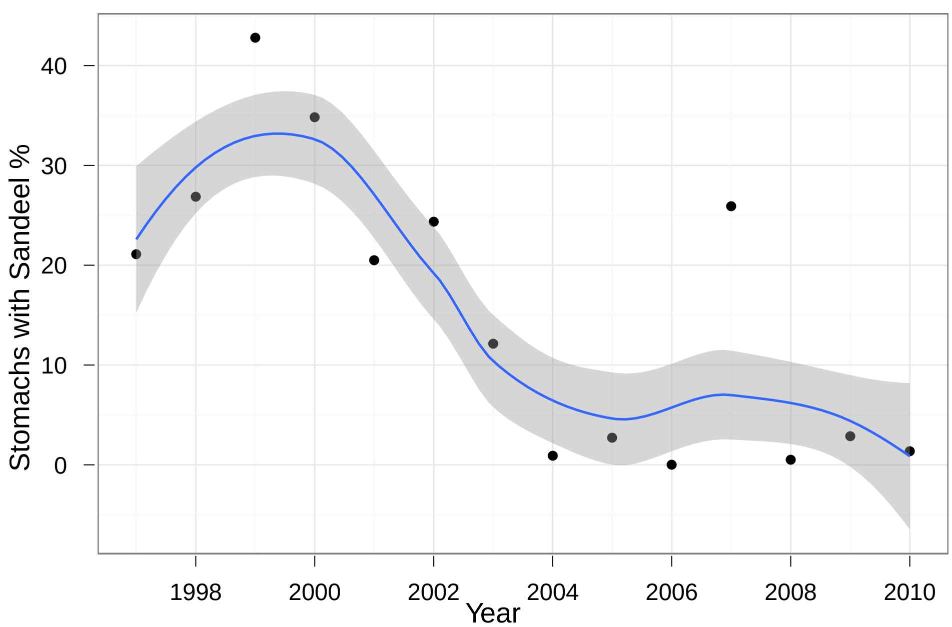

Figure 3: Percentage of haddock stomachs containing sandeel otoliths analyses in the Icelandic groundfish survey.

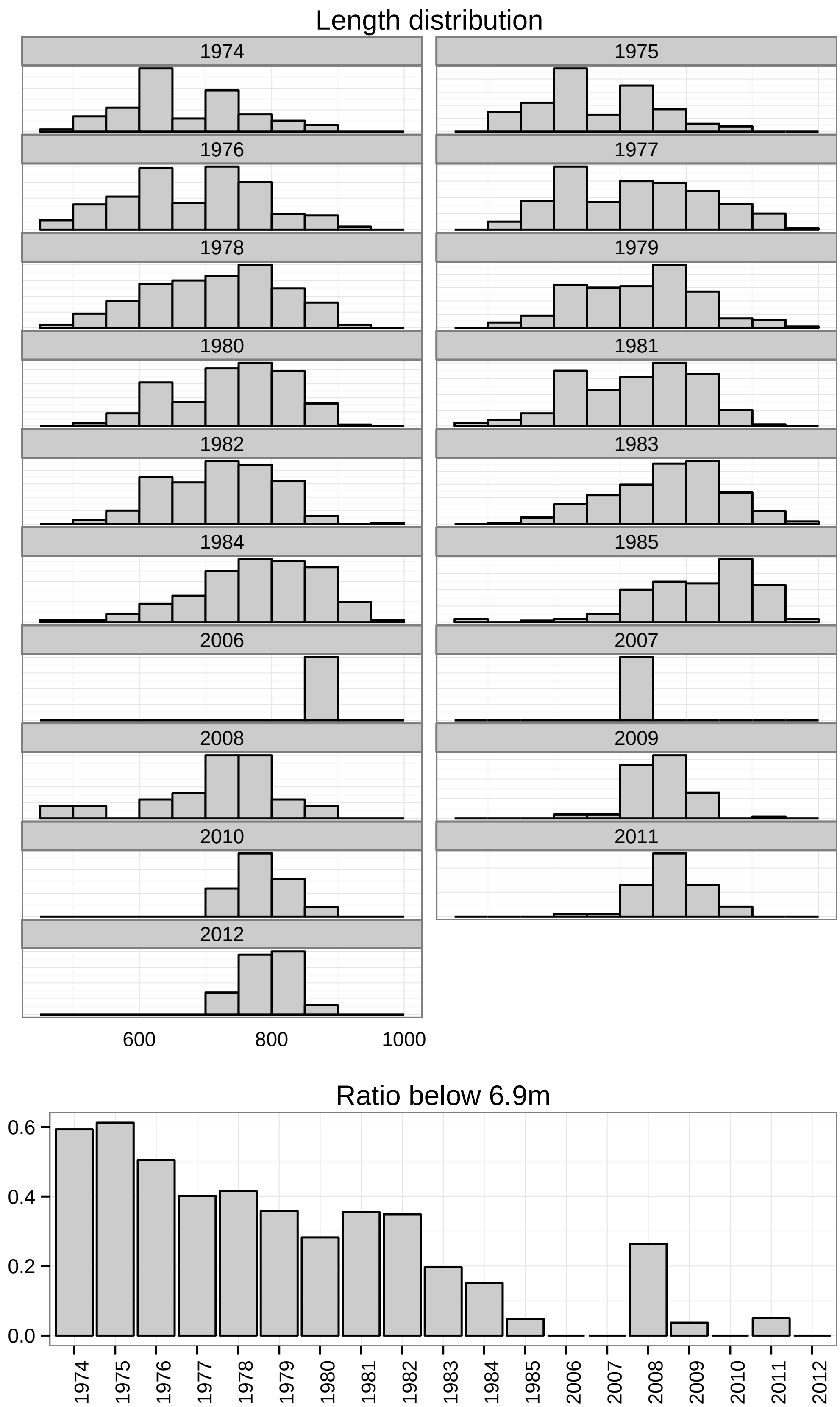

Figure 4: The development of the lengthdistributions from catches by year.

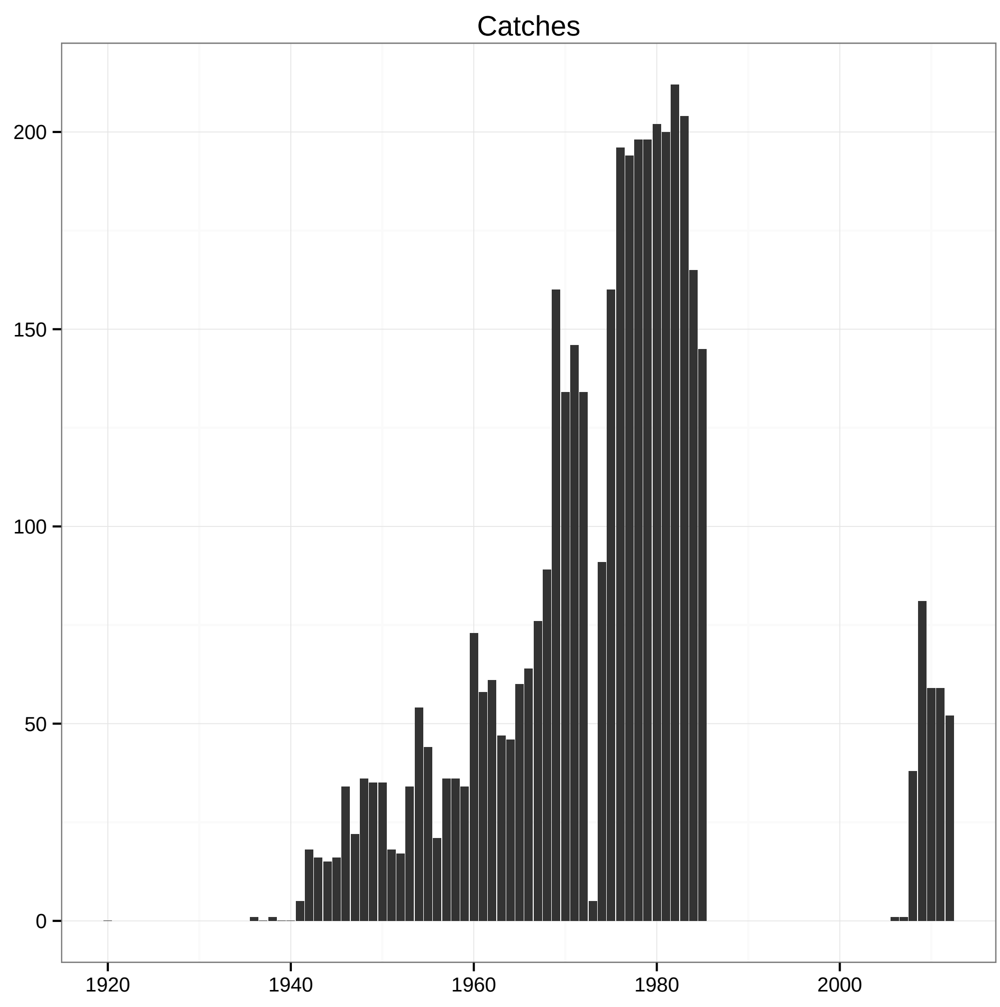

Figure 5: Catch by year

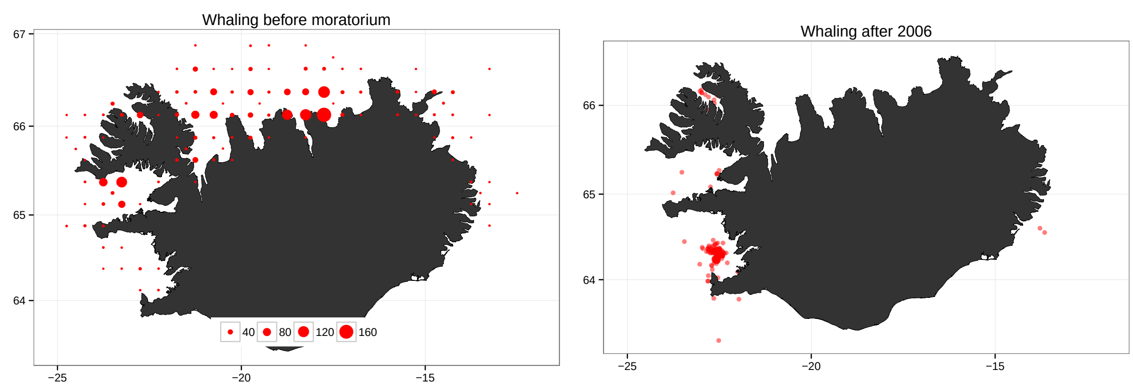

Figure 6: Locations of the minke whales caught pre–moratorium (left) and after whaling operations were resumed (right).

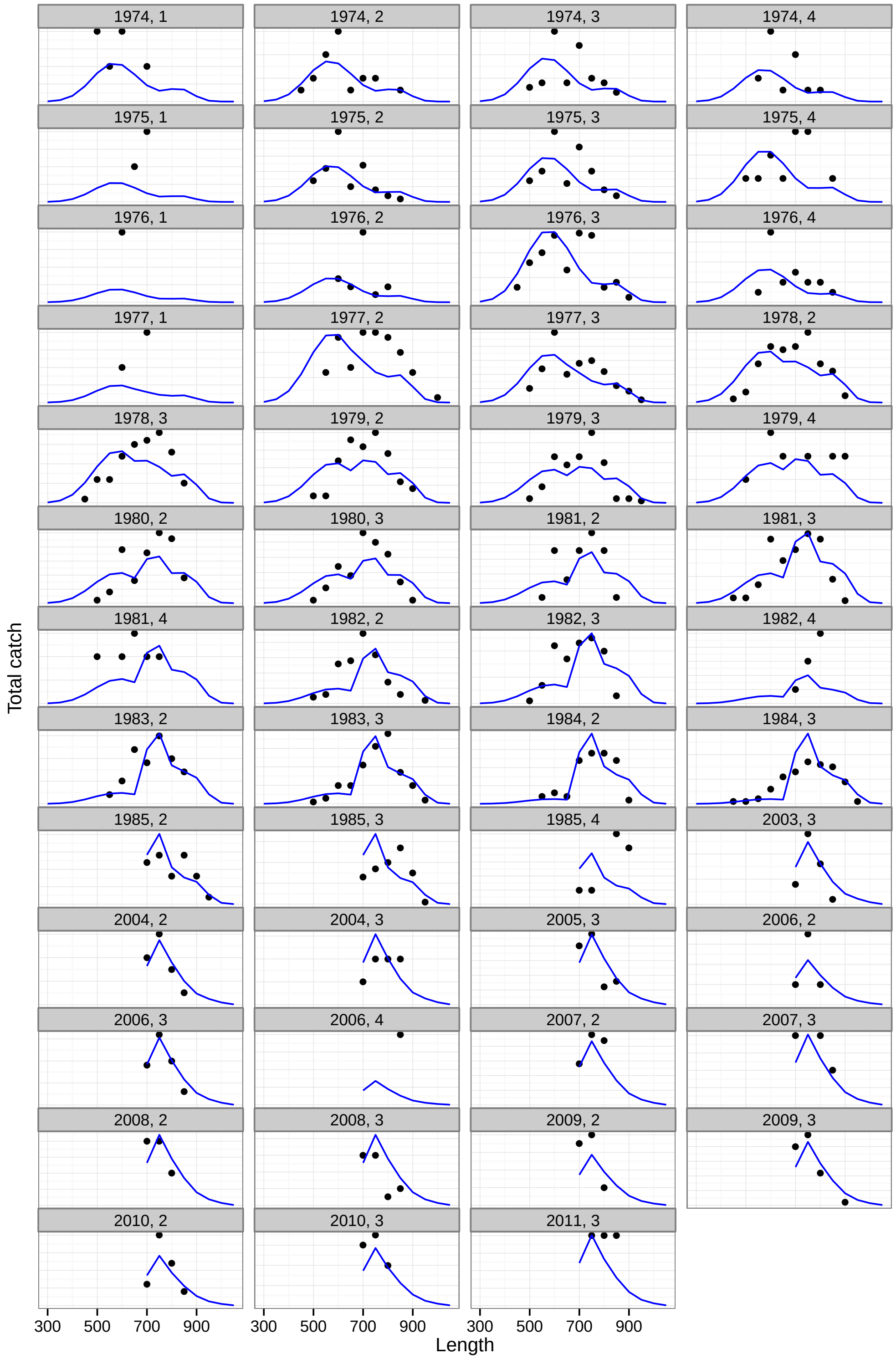

Figure 7: Fitted length distribution (solid line) with 50 cm lengthgroups from the commercial and survey operations compared to actual data (points). Results are by year and timestep.

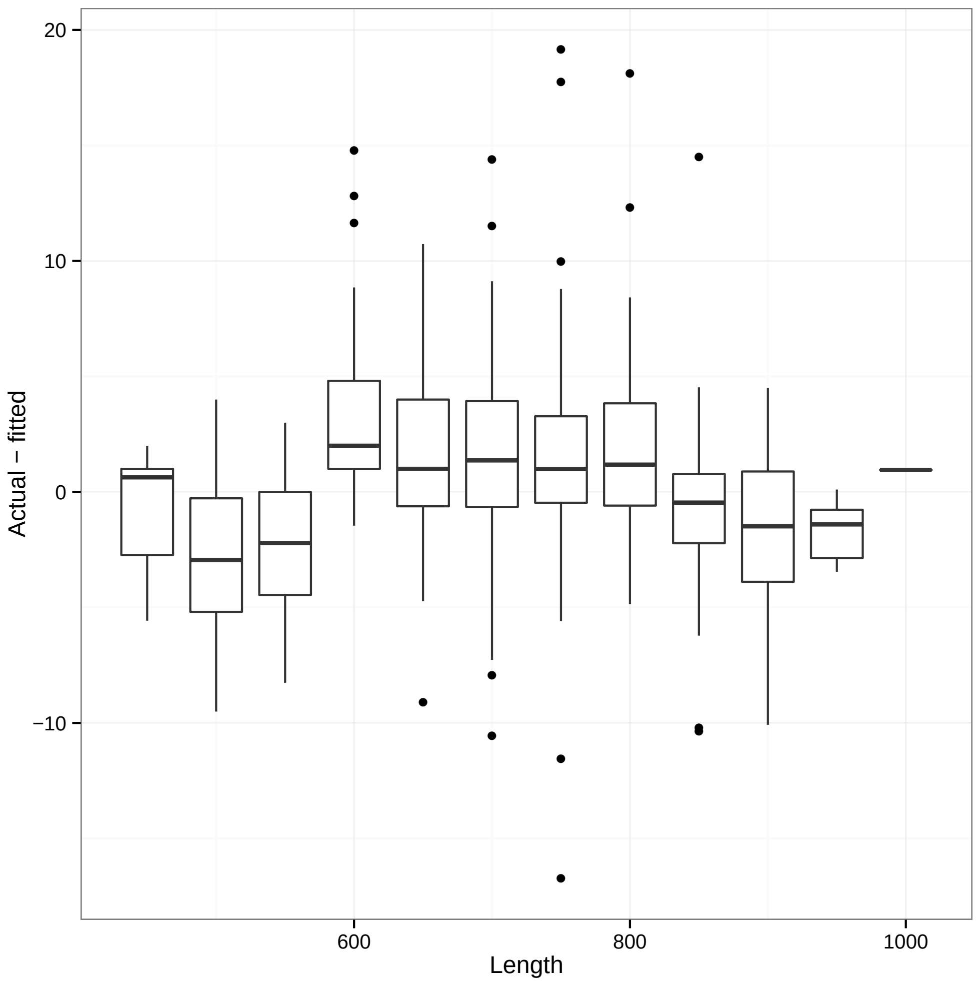

Figure 8: A boxplot of the length residuals by lengthgroup.

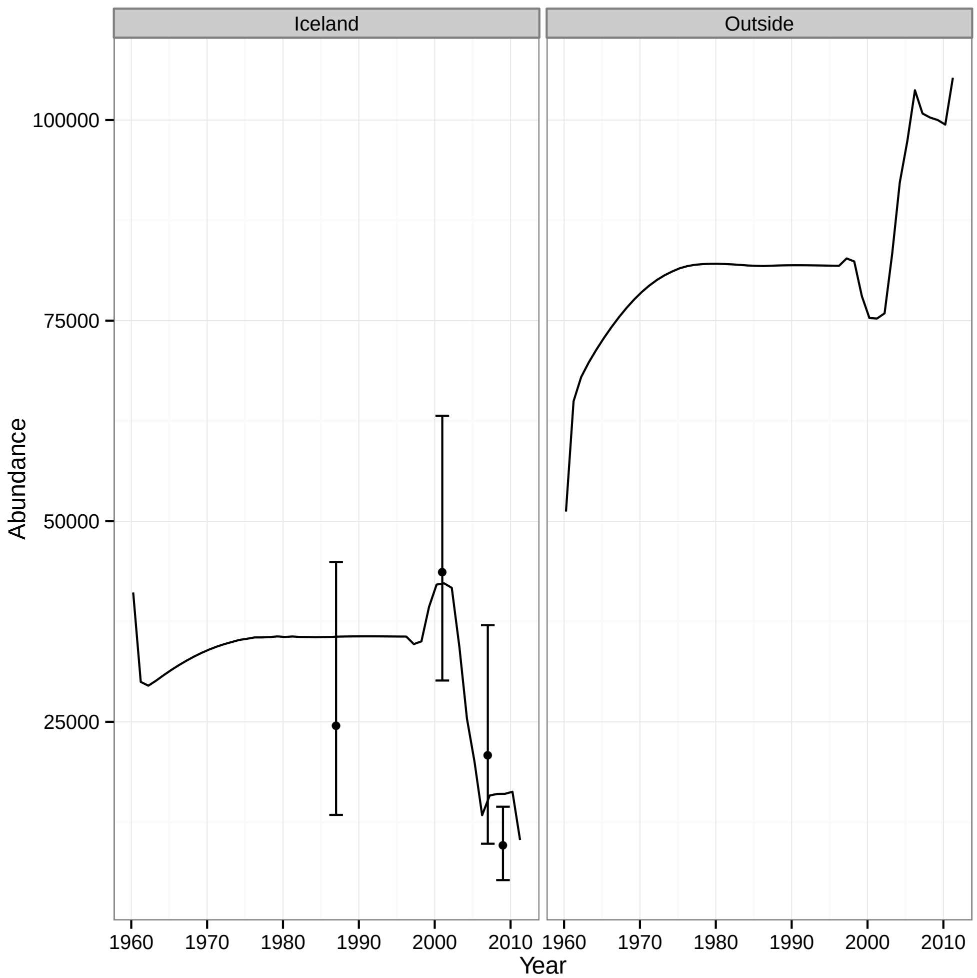

Figure 9: Fitted abundance (solid line) from the commercial and survey operations compared to actual data (points with errorbars). Results are shown by area.