A new stock assessment model for the Icelandic cod stock based on cohort growth analysis and spawning stock biomass.

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Summary.
This presentation proposes a new virtual population (VP) model for stock assessment of Icelandic cod (*Gadus morhua*). The model is based on growth curve modeling (GCM), a new analytical approach developed at the MRI in Iceland. GCM-modeling provides a new perspective on the von Bertalanffy crowth curve, revealing the underlying growth dynamics. Applying GCM to historical data from the Icelandic cod stock, reveals a striking long-term stability in cohort growth performance, indicating a relatively minor long-term influence of external factors, such as prey abundance. The growth performance is, however, highly variable between cohorts but appears to be linked to the mean weight of mature spawners (SSW10+) and follow a 10-year fluctuation pattern. Furthermore, analysis of historical data indicates a strong correlation between stock recruitment (R) and the mature spawner biomass (SSB10+). Cohort growth potential (GP) and reproductive potential (RP) can be suggested as new reference points for stock assessment. The new VPA-model offers long-term prediction of recruitment and cohort growth potential and may perhaps lead to an improvement of the traditional VPA-methodology.

Introduction.
Virtual population analysis (VPA) is the most common method used for stock assessment and fisheries management (Shepherd and Pope 2002). The method, offers good short term predictions but much poorer long-term predictions, being based on fixed parameters for growth, natural mortality (M), recruitment (R) and fishing patterns. A predictive ability for these parameters could potentially improve the long-term prediction power of the VPA. Yield per recruit (Y/R) models, used for calculating sustainable yield and optimized harvesting, are subject to the same limitations. In recent years, there has been accumulating evidence about the importance of old, large spawners for cod recruitment (Marteinsdóttir and Steinarsson 1998). Variations in cohort weight-at-age in the Icelandic cod stock have, however, been attributed primarily to variable prey abundance. GCM-modeling is a new analytical approach, developed at the MRI in Iceland, that can be applied in stock assessment for long-term prediction of cohort growth potential. GCM-modeling provides a new perspective on the von Bertalanffy crowth curve, revealing the underlying growth dynamics and linking larval- to long-term growth performance.

Material and methods.
The concept of GCM-modeling was constructed from the results from a project run at the MRI Aquaculture Laboratory in Grindavík Iceland in 2008-2011. Atlantic cod juveniles were produced from domestic broodstock and reared communally in tanks until the age of 30 months post-hatch. The fish were fed a commercial dry pellet diet and reared at 8°C after the first year. Individual live weight was measured at regular intervals. GCM-modeling provides a new perspective on the von Bertalanffy growth curve and is explained in detail in a poster at this symposium (Steinarsson 2013). GCM-modeling was applied to historical weight-at-age data (age range 5-10 years) for the Icelandic cod stock from 1950-2004. The absolute growth potential (ABS) was calculated for each cohort. The mature spawner (10 years+) mean weight (SSW10+) and biomass (SSB10+) were further extracted from historical data and correlated with recruitment (3 year old recruits) and cohort growth performance. An improved VPA-model for stock assessment was created, based on the regression equations for recruitment and growth potential.

Results and Discussion.

GCM-modeling was applied to historical weight-at-age data (age range 5-10 years) for the Icelandic cod stock from 1950-2004. The absolute growth potential (ABS) of each cohort was remarkably stable over the 5-year period (R^2 > 0.97 for all cohorts), indicating a relatively minor long-term influence of external factors, such as prey abundance. Figure 1 shows a twofold variation in cohort-ABS, which appears to follow a relatively smooth 10-year fluctuation pattern up into the 1990's. This cohort growth pattern is correlated with the SSW10+ (not shown), indicating a link between spawner size and offspring growth performance. The disrupted pattern after 1990 may be explained by the scarcity of large spawners in the stock during that period. The observed increase after the millennium may suggest a recovery of the growth pattern, due to the ongoing recovery of the cod stock.

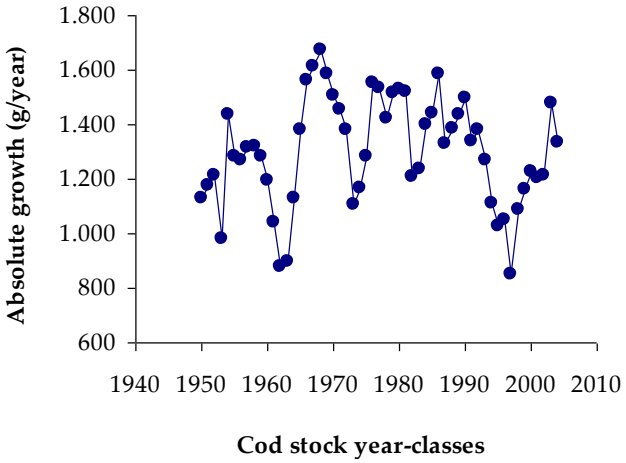

Figure 1. Absolute growth potential during ages 5-10 years for successive cohorts of the Icelandic cod stock, based on GCM-modeling of historical data.

During the period studied, there was a negative correlation between spawning stock biomass (SSB) and recruitment (R). The recruitment was, however, positively correlated with the mature spawner biomass, SSB10+ (R^2 = 0.28). A moving average is commonly used with time series data to smooth out short-term fluctuations and highlight long-term trends (Stefánsson 1992). In figure 2, a 5-year moving average reveals the underlying relationship between SSB10+ and recruitment. The highly significant correlation (R^2 = 0.64) confirms the key role of the mature spawners for the recruitment of the cod stock, as claimed by f.ex. Marteinsdóttir and Steinarsson (1998). The analysis may suggest that an SSB10+ of approximately 50,000 tons is required to sustain maximum long-term recruitment into the stock. The higher R/SSB10+ ratio during the last 20 years of low recruitment may suggest a higher input from smaller spawners when SSB10+ is very low. The new VPA-model offers long-term prediction of recruitment and cohort growth potential and may perhaps lead to an improvement of the traditional VPA-methodology.

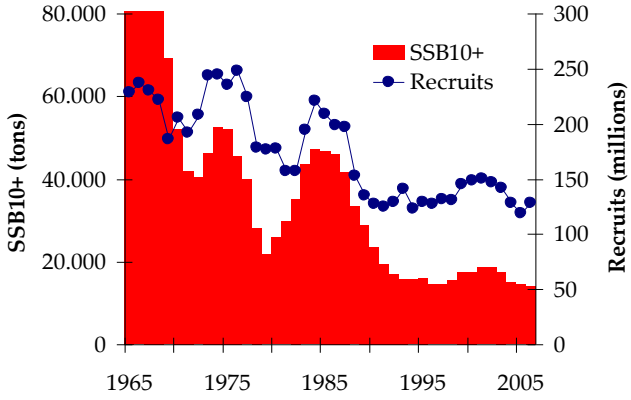

Figure 2. A 5-year moving average of mature spawner biomass (SSB10+) and recruitment (number of 3-year old recruits) into the Icelandic cod stock in the period 1965-2006.

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