The predictive power of commercial fisheries stock assessments

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for the Master's in Science Degree in Biology

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Abstract

Organizations responsible for managing commercial fisheries conduct annual stock assessments to monitor stock and, in principle, reduce the risk of overexploitation. These are fundamental to setting the total allowable catch for the upcoming fishing year. While there have been many attempts to estimate uncertainty associated with certain components and estimates of stock assessments, to date there has been no systematic assessment of their forecasted predicted value. Using data from annual stock assessments from 65 commercial fisheries around the world, estimates were obtained of both predicted (from the previous year) and observed (in the current year) catch-at-age. When comparing observed (actual) and predicted catch-at-age for a given stock, estimates were obtained of the predictive power of next-season forecasts. Using other attributes of the fishery and the stock (biological (e.g. life history) and management (e.g. assessment model employed)), empirical models were constructed that attempt to determine variability in predictive power among stocks. It was observed that, on average, within-year predictive powers (age-series within time samples) were higher than year over year predictive powers (time-series within age samples). While focusing on time-series within age, it was observed that change over the period of record (in natural mortality rate, assessment model employed, etc.) reduced predictive power; while for age-series within time, it was shown that cumulative landings reduced predictive power. This study represents one of the first attempts to quantify systematically the predictive power of fisheries stock assessment models.

Résumé

Les organisations responsables de la gestion de la pêche commerciale effectuent des évaluations annuelles des stocks de poissons pour les surveiller et, en principe, pour réduire le risque de surexploitation. Ces organisations sont essentielles pour établir le total de prises admissibles pour l'année prochaine. Bien qu'il y ait eu de nombreuses tentatives pour estimer l'incertitude associée à certaines composantes et estimations des évaluations de stocks, il n'existe aucune évaluation systématique de leur valeur prédite prévue jusqu'à ce jour. En utilisant les données des évaluations annuelles des stocks de 65 pêcheries commerciales partout dans le monde, des estimations ont été obtenues pour les captures prévues (de l'année précédente) et observées (pour l'année en cours) en fonction de l'âge. Lorsque l'on compare les captures en fonction de l'âge observées (réelles) et prévues pour un stock donné, on obtient des estimations de la valeur prédictive des prévisions de la saison suivante. En utilisant d'autres attributs de la pêcherie et du stock (fonctions biologiques (p.ex. cycle de vie) et fonctions de gestion (p.ex. modèle d'évaluation utilisé)), des modèles empiriques ont été construits pour tenter de déterminer la variabilité de la valeur prédictive des stocks. Il a été observé qu'en moyenne, les valeurs prédictives intra-annuelles (séries d'âges selon échantillons temporelles) étaient supérieures aux valeurs prédictives d'une année à l'autre (séries temporelles selon échantillons d'âge). Tout en se concentrant sur la les séries temporelles selon l'âge, il a été observé que les changements au cours de la période d'enregistrement (taux de mortalité naturelle, modèle d'évaluation utilisé, etc.) réduisaient la valeur prédictive; tandis que pour la réplication en âge, il a été démontré que les débarquements cumulatifs réduisaient le pouvoir prédictif. Cette étude représente l'une des premières tentatives de quantification systématique de la valeur prédictive des modèles d'évaluation des stocks de pêche.

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List of Abbreviations

TAC	Total Allowable Catch
SAM	Stock Assessment Model
DFO	Department of Fisheries and Oceans
ICES	International Council of the Exploration of the Seas
TRAC	Transboundary Resources Assessment Committee
VPA	Virtual Population Abundance
XSA	Extended Survivor Analysis
ICA	Integrated Catch Analysis
IUU	Illegal, Unreported and Unregulated Fishing
FAO	Food and Agriculture Organization of the United Nations
SAR	Stock Advisory Report
RD	Research Document
R^2	Coefficient of Determination
RSME	Root Mean Square Error
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error

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1. Introduction

Commercial fisheries are an integral part of the economy of many countries, with an estimated 220 million jobs within the global fishing industry (FAO, 2013). In Canada in 2010, the fishing industry accounted for roughly 84,000 jobs, of which some 52,000 were associated with marine and freshwater fishing (DFO, 2011). Marine total landings accounted for $1.9 billion in gross revenue to the Canadian economy in 2008 (DFO, 2011).

Commercial fisheries in Canada and elsewhere face a number of threats, including climate change (Hutchings *et al*., 2012; Perry *et al.*, 2005; Sumaila *et al.*, 2011), invasive species (Groeneveld *et al.*, 2018 and references therein) and overexploitation (Hutchings & Myers, 1994; Worm *et al.*, 2009). Overexploitation occurs when the proportion of biomass removed per year (exploitation rate) is greater than the maximum that can reasonably be sustainably removed, also known as the maximum sustainable yield (Worm et al, 2009). Globally, between 1974 and 2009, the proportion of overexploited fish stocks increased from 10% to 30% while the proportion of under- or moderately exploited stocks decreased from 40% to 12% (FAO Statistical Yearbook, 2013).

The basis for most commercial fisheries management is an annual quota – the total allowable catch (TAC). The TAC is the maximum number of fish, or the fish biomass, that can be harvested annually (Borges, 2018). TACs are based on estimates of numbers-at-age (number of individuals at recorded age classes), mortality and annual recruitment for a given fish stock (Cotter et al, 2004). Such estimates permit projections of future stock dynamics under various levels of exploitation. These projections are then used to adjust exploitation rates to ensure a sustainable harvest, with the target exploitation rate managed through the setting of TACs (Borges, 2018). Unsurprisingly then, a fundamental goal of fisheries management is to forecast future attributes of a fishery, especially catch and recruitment, from historical information specific to the fishery itself (e.g. past catch histories) and/or additional environmental variables – which may or may not be susceptible to management intervention – that might be expected to influence stock dynamics.

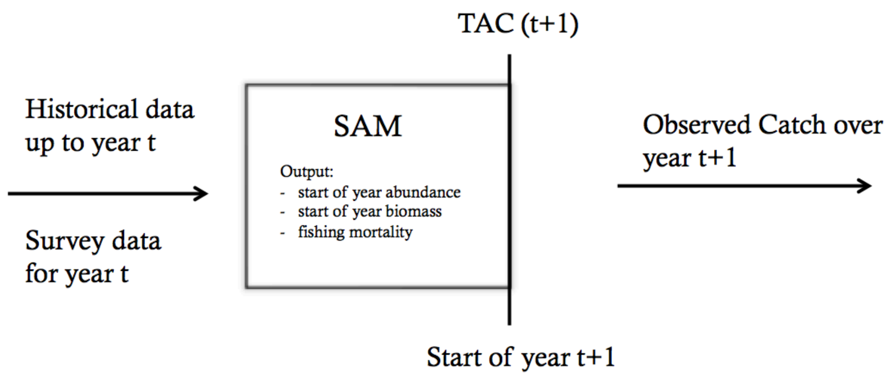

Figure 1.1. The process used in stock assessment models (SAM) to determine the following fishing year's TAC established at the beginning of the fishing season.

Commercial fisheries managers use annual stock assessments to generate forecasts. Stock assessments are critical to the modern management of commercial fisheries. The assessments provide information on the historical status of the fish population and any predictions on how the population is expected to respond to management procedures (NOAA, 2016). In particular, historical data and harvest measures from the stock assessment model generate forecasts of population parameters such as growth, recruitment or mortality provide. These estimates are then used by fishery managers to determine the TAC for the upcoming fishing season (Figure 1.1).

With such estimates in hand, one can overlay the predicted effects of fishing mortality and adjust TACs so as to achieve a sustainable harvest. As such, estimates based on stock assessment forecasts have potentially profound regulatory and statutory implications: for example, in the United States under the Magnuson-Stevens Act (MSA) reauthorization, legal overfishing limits must be established, with such limits determined largely by forecasted biomass. The accuracy of such forecasts will in part determine the extent to which a stock is sustainably managed, though, as Brander (2003) points out, it is unclear how much the blame for fisheries stock management failures can be assigned to the shortcomings and limitations of stock forecasting methods versus limited ability to control fishing activity.

Nonetheless, the evolution of fisheries models reflects a general sentiment that the accuracy of forecasts from stock assessments is lower than desirable (Schnute & Richards, 2001). The question is: why?

Various explanations have been offered. Peters (1991) argued that part of the problem – at least historically – has been methodological inertia, that is, the reliance on simple (e.g. stock-recruitment) models despite accumulating evidence that they are inaccurate, and perhaps wildly so. Schnute and Richards (2001) argued that there is a heavy reliance on models that have been historically used despite their use of arbitrary assumptions that, while they constrain the unknown or hidden states (information that was not able to be measured or observed), are not universal across all fish stocks. Ulltang (1996) suggested that while methodological inertia was a problem, larger still was the failure to incorporate relevant biological data, especially those pertaining to the portions of the life cycle (spawning, hatching and larval and juvenile growth and mortality). This hypothesis has some measure of empirical support: for example, incorporation of pre-recruit abundance into Western Australia invertebrate fishery stock assessments has substantially improved catch predictions (Caputi *et al*., 2014).

Another potential problem is the data sources that are used in constructing and fitting models. Several common methods use data generated from the commercial fisheries themselves, in particular catch-at-age, the number of fish of a given age class reported as being caught. Cook (2013) argued that assessment models that use commercial catch-at-age data are exposed to unreliable data due to misreporting of catch, such as the non-reporting of fish that are caught but not kept, i.e. "discards" (Rochet *et al.*, 2002; Cotter *et al.*, 2004). This can introduce substantial bias in population estimates and projected dynamics.

Despite long-standing concerns, the question arises: what is the evidence that the predictive power of stock assessment methods is indeed poor – or rather, poorer than is desirable? As Brander (2003) and others have pointed out, the pervasive occurrence of stock collapse (Myers *et al*., 1997; Walters & Maguire, 1996; Ghosh *et al*., 2015) is not of itself compelling evidence supporting the claim of stock assessment model inadequacy. Answering this question requires that we first define what, precisely, is being predicted and then consider how predictive power is measured and evaluated. Specifically, we must distinguish between predictive power and the uncertainty associated with estimates of stock characteristics that are the usual focus of conventional stock assessment models.

A forecasting model of any description is concerned with estimating some quantity (e.g. stock biomass) at some future time based on information and data available up until the time the forecast is made. The current thesis is concerned with this type of assessment of predictive power: I compare the predicted values in year t+1 based on estimates generated using data from years up to and including t, to the observed values in year t+1. This provides a direct test of (very) short-term predictive power of stock assessments with respect to three target variables: stock at age abundance (reported number of fish caught of a particular age), biomass (reported weight of fish caught, in metric tonnes) and biomass proportion (the biomass of a given age class within the reported range divided by the total biomass of all the reported age classes).

The current thesis has two objectives. First, I use data extracted from annual stock assessments conducted by three different commercial fisheries management organizations for a range of commercial species and stocks to estimate the predictive power of stock assessments based on a comparison of observed and predicted abundance and biomass at age over the period of record (the span of years for which annual stock assessment data were available for a given stock). Second, I explore associations between predictive power and (a) the biological characteristics of the species/stock being managed; (b) statistical attributes of the data series from which estimates of predictive power are derived; and (c) attributes of the stock assessment methods used to generate forecasts.

2. Methods

2.1. Inclusion criteria for commercial stocks

This analysis is restricted to Northern Atlantic Ocean commercial fish stocks that are managed by one of three national or international regulatory agencies: the Department of Fisheries and Oceans (DFO) in Canada; the International Council for the Exploration of the Seas (ICES), an organization responsible for national fisheries management of countries within the European Union; and the Transboundary Resources Assessment Committee (TRAC) which manages so-called "straddling stocks" between Canada and the United States (see Appendix B for more details on DFO, ICES and TRAC management areas). These three organizations were selected because annual stock assessments were publicly available and easily accessible. The set of 16 species and 65 separate stocks included in the analysis includes both groundfish and pelagic species (Table 2.1).

Stocks varied considerably in the time period ("period of record") over which assessments were conducted and which were included in the analysis: between 1996 and 2005 for DFO, 2004 and 2011 for TRAC, and 2000 and 2013 for ICES. For DFO, I evaluated stocks and associated assessments that were completed after the collapse of the Newfoundland Northern cod stock in 1992.

To be included in the sample, a stock must have had estimates of predicted and observed catch for 3 or more years during the period of record, and have an explicit TAC set for at least 50% of the years included in the period of record.

Table 2.1. Species included in the sample of commercial stocks. Also shown are the number of different stocks of each species managed by DFO, ICES and TRAC.

Common Name	Species	DFO	ICES	TRAC	Total
Atlantic Herring	*Clupea harengus*	-	10	-	**10**
Atlantic Cod	*Gadus morhua*	5	10	1	**16**
Atlantic Halibut	*Hippoglossus hippoglossus*	-	1	-	**1**
Black-bellied Anglerfish	*Lophius budegassa*	-	1	-	**1**
Four-spot Megrim	*Lepidorhombus boscii*	-	1	-	**1**
Megrim	*Lepidorhombus whiffiagonis*	-	2	-	**2**
Yellowtail Flounder	*Limanda ferruginea*	-	-	1	**1**
White Anglerfish	*Lophius piscatorius*	-	1	-	**1**
Haddock	*Melanogrammus aeglefinus*	2	6	1	**9**
Whiting	*Merlangius merlangus*	-	3	-	**3**
European Hake	*Merluccius merluccius*	-	2	-	**2**
European Plaice	*Pleuronectes platessa*	-	6	-	**6**
Pollock[1]	*Pollachius virens*	1	2	-	**3**
Atlantic Mackerel	*Scomber scombrus*	-	1	-	**1**
Common Sole	*Solea solea*	-	7	-	**7**
European Sprat	*Sprattus sprattus*	-	1	-	**1**
Total		**8**	**54**	**3**	**65**

[1] ICES stocks use Saithe as common name rather than Pollock

2.2. Data Sources

Annual stock assessments completed by DFO, TRAC and ICES are published as annual reports. DFO and TRAC publish two reports for a given stock: a Science Advisory Report (SAR) (known as the Stock Status Report until 2004) and a more detailed and complete Research Document (RD). RDs provide the complete scientific basis for the evaluation of the stock, while the SAR is a condensed report that includes the status of the stock, ecosystem information, and habitat considerations as well as management strategies, frameworks and guidelines for the reported year. Stocks that were not formally assessed in a particular year would not have an RD published. For the purposes of this study, the RD had to be available for the stock in a given year to be included in the data series, but a SAR was not required as the RD provides all the necessary information.

Unlike DFO and TRAC, ICES assessments do not provide a separate report for each stock, but rather a single report for a collection of stocks assessed under the same ICES Working Group. A working group is an advisory committee within ICES that focuses on similar fish species and/or similar management areas. The current sample includes 11 different ICES working groups (see Appendix C for complete list of ICES working groups).

The data extracted from annual assessments were used to populate a digital database (see Appendix G for an example data record for the ICES stock of sole in Division VIIfg). All data entries were annotated by reference to the DFO report (DFO, 2014), TRAC report (TRAC, 2015)) or ICES working group (ICES, 2014) responsible for the assessment, the year of the assessment, and the table number and/or page number of the report from which the data were extracted.

Thirteen variables were directly extracted from annual stock assessments and included in the digital database: the organization responsible for the report; the working group/management team responsible for the report (detailed in Appendix C); species of the stock assessed; number of countries in which the stock is fished; the natural mortality estimate of each recorded age class; TAC (in metric tonnes); recorded landings (in metric tonnes) and whether the landings included information about discards; age at which individuals are considered 100% mature and the method used to estimate age; and the assessment method used in the report (see also Tables 2.2 and 2.3 for a complete list of variables). A lack of available information pertaining to the biological life cycle of the species mentioned within the assessments resulted in the inclusion of only three variables relating to the biology of the fish stock (species, natural mortality and maturity).

2.3. Harvest Measures

The predictive power of stock assessments was determined with respect to three different variables, for a given age class x and year t: (1) catch-at-age abundance ($A(x,t)$), in thousands of fish; (2) catch-at-age biomass ($B(x,t)$), in metric tonnes; and (3) catch-at-age proportion of biomass ($P(x,t)$), i.e. the proportion of the total catch-at-age biomass contributed by age class x. For each harvest measure (A, *B, P*) for a given stock, for a given age class (x) and year (t), there are two values: (a) a predicted value, i.e. the *forecasted* catch based on a stock assessment conducted at year t-1; and (b) an observed value, i.e. the actual catch.

2.3.1. Abundance

For any stock, in any given year, the observed catch-at-age abundance is taken to be the reported catch, i.e., the number of fish of a given age reported as having been caught. In ICES cases, where harvests may include several countries, each country provides the total catch for the given stock to the ICES working group who compiles the total catch for all countries. This information is typically found explicitly in stock assessments documents.

For any stock, in any given year, the predicted catch-at-age abundance is the predicted number of fish of a given age caught at the end of the upcoming fishing season. This prediction is based on historical information and the various assumptions implicit (or explicit) to the stock assessment model employed (see Appendix A for a description of the various stock assessment models employed).

To calculate a predicted catch-at-age abundance, one begins with calculating the exploitation rate. The exploitation rate is the proportion of the fish population at age that is removed during the fishing year, and is calculated using fishing mortality and natural mortality. The exploitation rate (h_{ijt}) is calculated as:

$$h_{ijt} = (1\text{-}exp(-F_{ijt}\text{-}m_{ijt})) *(F_{ijt} /(F_{ijk} +m_{ijt})),$$

where F_{ijt} is the fishing mortality of stock i at age j in year t, and m_{ijt} is the natural mortality of stock i at age j in year t. With the exploitation rate in hand, the predicted catch is then:

$$PA_{ijt} = SYA_{ijt} * h_{ijt}$$

where PA_{ijt} is the predicted catch abundance of stock i at age j in year t, SYA_{ijt} is the expected start of year t population abundance of stock i at age j, and h_{ijt} is the exploitation rate. As abundance can vary dramatically among stocks, from hundreds to millions of fish, observed and predicted catch-at-age abundance were log 10 transformed for all analyses (See Appendix H for database example for Sole in Divisions VIIfg managed by ICES).

2.3.2. Biomass

For any stock, in any given year, the observed catch-at-age biomass is the reported catch biomass, i.e., the weight of fish in thousands of metric tonnes of a given age reported as having been caught. Reported biomass is monitored by regulatory agencies for the stock and management area in question.

In many of stock assessment reports, reported catch biomass is not explicitly stated, but rather the average weight of a fish in a given age class is provided. Observed catch-at-age abundance and average weight of a given age class can be used to calculate the catch biomass:

$$OB_{ijt} = CA_{ijt} * W_{ijt}$$

where OB_{ijt} is the observed catch biomass of stock i at age j in year t, CA_{ijt} is the observed catch-at-age abundance at year t of stock i at age j, and W_{ijt} is the average weight at year t of stock i at age j.

For any stock, in any given year, the predicted catch-at-age biomass, PB_{ijt} is the predicted weight of fish of a given age at the end of the fishing season. To calculate the predicted catch-at-age biomass, one begins by calculating the exploitation rate of the stock as described above. The predicted biomass is then:

$$PB_{ijt} = (SYA_{ijt} * W_{ijt}) * h_{ijt}$$

where PB_{ijt} is the predicted catch biomass of stock i at age j in year t, SYA_{ijt} is the expected start of year t population abundance of stock i at age j, W_{ijt} is the average weight at year t of stock i at age j, and h_{ijt} is the exploitation rate. As biomass can vary dramatically among stocks, from hundreds to millions of metric tonnes of fish, observed and predicted catch-at-age biomass were log 10 transformed for all analyses. (See Appendix H for database example for Sole in Divisions VIIfg managed by ICES).

2.3.3. Biomass Proportion

The proportion of the total reported catch biomass attributable to a given age class is given by:

$$OBP_{ijt} = OB_{ijt} / \left(\sum_{j=x_i(\min)}^{j=x_i(\max)} OB_{ijt} \right)$$

where OBP_{ijt} is the proportion of the total catch biomass of stock i attributable to age j in year t, OB_{ijt} is the observed catch biomass of stock i at age j in year t (as calculated above), and $\sum_{j=x_i(\min)}^{j=x_i(\max)} OB_{ijt}$ is the sum of the observed catch biomass of stock i in year t for all recorded age classes $j = x_i(\text{min})$ to $j = x_i(\text{max})$, the youngest and oldest age classes, respectively, for stock i. (See also Appendix H for database example for Sole in Divisions VIIfg managed by ICES).

2.4. Predictive Power

The coefficient of determination (R^2) of the regression of "out of sample" values (i.e. observed abundance or biomass in (year $t+1$) on forecasted values in year $t+1$ based on stock assessments that include information acquired up until year t) was used as the index of predictive power. Other measures of predictive power are possible, including the root mean square error (RMSE, the average squared differences between forecasted and observed values), the mean absolute error (MAE, the average absolute value of the difference between forecasted and observed values), the mean absolute percentage error (MAPE, 100 times the sum of absolute difference between forecasted and observed values divided by observed values), all of which have several limitations (see Appendix E). One limitation of R^2 is that, strictly speaking, it does not measure predictive accuracy. For example, systematic bias (e.g. under- or over-estimation of observed values from predicted values) may still occur even when the (linear) regression of observed on predicted values shows a high coefficient of determination. Rather, R^2 measures the *correlation* between observed and predicted values (Alexander *et al.*, 2015).

This limitation notwithstanding, R^2 was employed as the index of predictive power because it provides a quantitative index of the extent to which observed values are predictable from (i.e. "explained by") observed values. Because predicted values are forecasted by the underlying stock assessment model, R^2 gives the extent to which the assessment model is informationally complete with respect to a single-year forecast horizon. Low R^2 indicates that there is important information that is missing. By contrast, a high R^2 suggests that even though there may be systematic bias, the underlying stock assessment model is, informationally, more or less complete.

All stock assessments generate predictions of abundance (or biomass, or biomass proportion) for a given age class in the following year. So for every stock, for each age class and for each year in the period of record, one has both a predicted and observed value.

There are then two questions one can ask. First, for a given stock over the period of record, how does predictive power vary among age classes? In this case, predictive power is based upon a comparison of observed and predicted values for the age class in question for each year in the period of record (time series within age). Such an analysis might, for example, show that predictive power is generally better for older age classes compared to younger age classes, which might reflect, for example, greater year over year variation in cohort strength in younger age classes, variation that attenuates with age.

Second, for a given stock, over the set of age classes, how does predictive power vary over time? Here predictive power is based upon a comparison of observed and predicted values for a given age class for each year in the record (age series within time). Such an analysis might show, for example, that predictive power was comparatively poor in the early part of the record, but has improved as time went on as more information on the stock accumulates.

The set of factors influencing predictive power based on time-series within age, and age-series within time may be different. For example, real improvements in prediction over time can be detected in the latter analysis, but not the former. For this reason, this analysis considers predictive power based on two different samples.

The first sample (time-series within age) is based on the correlation between pairs of values (observed, predicted) over the period of record for a given age. In this case, the number of observations for a given stock and age is the number of years for which the corresponding observed and predicted values are available, i.e. the period of record (Figure 2.1a). A second sample (age-series within time) is based on the correlation between pairs of values (observed, predicted) over the set of age classes, for a given year. In this case, the number of observations, for a given stock and time (year), is the number of age-classes for which predicted and observed values are available for the year in question (Figure 2.1b). (See Appendix I for a complete set of plots; see also Appendix K for the complete set of estimates of predictive power (R^2)).

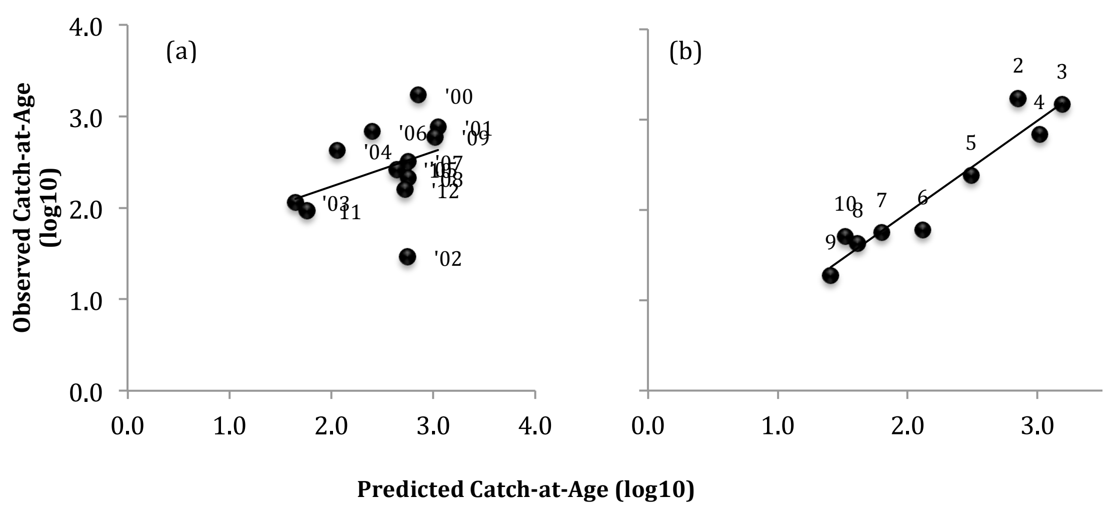

Figure 2.1. The log observed and predicted catch abundance for Sole in Division VIIfg using sample (a) time-series within age (age 2; R^2 = 0.14), and (b) age-series within time (year 2000; R^2 = 0.92). The numbers indicated over the data points are the (a) recorded year and (b) represented age class (Appendix H).

2.5. Correlates of Predictive Power

I examined associations between predictive power and three different sets of candidate explanatory variables: (1) statistical attributes of the data sample from which the estimate of predictive power was derived; (2) attributes of the species being managed; and (3) attributes of the stock management regime or the methods used in the stock assessment.

(1) *Statistical attributes of the sample*: These are attributes of the set of observations from which predictive power is estimated that might be expected to have some influence on the estimated association between observed and expected values, including the sample size and the distribution of observed and predicted values within the sample. These attributes include: (i) the length of the time series (for time-series within age) or the number of age classes (for age-series within time), i.e., the sample size; (ii) the extent to which the time/age series was continuous (with lack of continuity reflecting missing years and missing ages respectively); and (iii) the data distribution, in particular, whether, given a range of predicted values, observed values were more or less uniformly distributed over this range (Figure 2.2).

(2) *Biological attributes of the stock*: Life history attributes of the species and/or stocks might be expected to influence the extent to which future stock sizes are predictable. For example, short-lived species that show large variation in fecundity and/or survivorship in response to changing environmental conditions might be expected to show less predictability than longer-lived species that are less sensitive to variation n environmental conditions over short time-scales (King & McFarlane, 2003; Pecuchet *et al.*, 2016). These attributes include: (i) species; (ii) youngest age class included in the study; (iii) the oldest age class included in the study; (iv) age of 100% maturity and the method employed to determine how the age maturity was determined); and (v) the average weight at 100% maturity.

(3) Attributes of the management regime or the methods used in stock assessment: Predictive power might be influenced by the methods used or the data required in generating forecasts, including in particular whether the methods or underlying assumptions have changed over the period of record. For example, early stock assessments may be based on a number of simplifying assumptions (e.g., age-independent mortality or time-independent mortality) simply because there are insufficient data available to evaluate these assumptions. As time progresses, such data may become available so that these assumptions can be tested and, in some cases, rejected so that future assessments now include other (different) assumptions. Such changes might be expected to influence predictive power. These attributes include: (i) the assessment method itself, and whether it changed over the period of record; (ii) the organization responsible for the assessment; (iii) if natural maturity was constant throughout all age classes or not; (iv) the difference between the reported landings and the assigned TAC; and (v) the number of countries included in the stock management.

Values for all candidate variables (Table 2.2, 2.3; Appendix J) were explicitly reported in annual stock assessments and/or were easy to infer from information in the assessments.

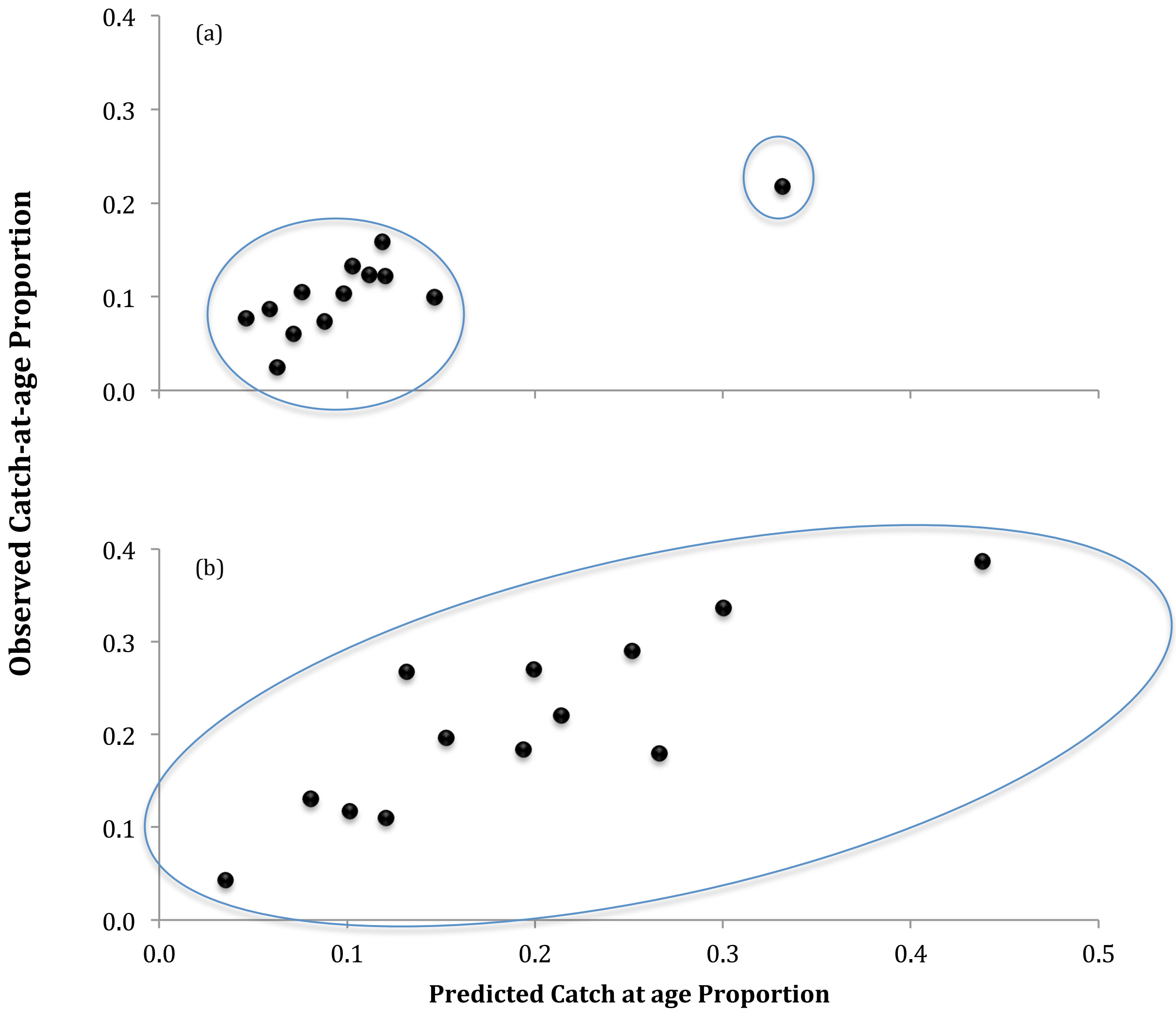

Figure 2.2: Graphical illustration of the uniformity of the distribution of observed values over the predicted value range: (a) low uniformity, and (b) high uniformity. Data source: Sole in Division VIIfg age 6 (a) and age 3 (b) for harvest measures biomass proportion (Appendix H).

Table 2.2. Candidate explanatory variables for the analysis of the time-series within age sample: statistical attributes of the sample (S); biological attributes of the stock (B), or attributes of the management regime or stock assessment methods (M).

Variable	**Attribute class**	**Description**	**Units of Measurement or Levels (Categorical Variables)**
Number of years (Y_N)	S	The total number of years for which both observed and predicted values are available.	
Normalized age (A*)	S	The age class in question divided by the maximum age for the stock/species.	Proportion ([0,1])
Coverage (C)	S	The percentage of years in the period of record for which (observed, predicted) values are available.	%
Uniformity (U)	S	The uniformity of the distribution of observed values over the range of predicted values.	0 – low uniformity; 1 – high uniformity
Organization (O)	M	The organization responsible for management of the stock in question	
N Working Group (WG_N)	M	Number of working groups/management teams involved in the management of the stock in question over the period of record.	
Species (Sp)	B	Species designation of the stock assessed	
Number of Countries (C_N)	M	Number of countries involved in harvesting the stock over the period of record.	1 – one country; 2 – two countries; 3 – three or more countries
Δ Natural Mortality (ΔM)	M	Whether the estimate of the natural mortality rate changed over the period of record	0 - constant over the period of record 1 – changed at least once over the period of record
Σ TAC (ΣT)	M	The sum over the period of record of the annual TACs.	Log_{10} (tonnes)
Σ Landings (ΣL)	M	The sum over the period of record of the annual landings.	Log_{10} (tonnes)
Δ Discards (ΔD)	M	Whether the inclusion of discards in the observed catch changed over the period of record	0 - constant over the period of record; 1 – changes at least once during the period of record.
Δ Maturity (ΔM)	M	Whether the method of determining age of 100% maturity changed over the period of record.	0 - constant over the period of record 1 – changes at least once during the period of record.
Δ Age of 100% Maturity ($ΔM_A$)	B	Whether the estimated age of 100% maturity changed over the period of record.	0 - constant over the period of record; 1 – changes at least once during the period of record.
Difference in Weight at Age of 100% Maturity ($ΔM_{WA}$)	B	The difference in estimated weight at age of 100% maturity between the beginning of the period of record and the end of the period of record.	Kg
Δ Assessment Method (ΔAM)	M	Whether the model used in the stock assessment changed over the period of record.	0 - constant over the period of record 1 – changes at least once during the period of record.

Table 2.3. Candidate explanatory variables for the analysis of the age-series within time sample: statistical attributes of the sample (S); biological attributes of the stock (B), or attributes of the management regime or stock assessment methods (M).

Variable	**Attribute Type**	**Description**	**Units of Measurement or Levels (Categorical Variables)**
Standardized year (Y*)	S	The year the report was completed	First year coded as 0 with all subsequent years increased by one.
Total # of Age Classes (A_N)	S	Total number of age classes for which abundance and biomass data are available for the stock in question	
Uniformity (U)	S	The uniformity of the distribution of observed values over the range of predicted values.	0 – low uniformity; 1 – high uniformity
Organization (O)	M	The organization responsible for management of the stock in question	
Working Group (WG)	M	The working group/management teams involved in the management of the stock in question.	
Species (Sp)	B	Species of the stock assessed	
Number of Countries (C_N)	M	Number of countries included in harvesting the stock over.	1 – one country; 2 – two countries; 3 – three or more countries
Natural Mortality (NM)	M	Whether natural mortality was age-independent	0 – natural mortality age-independent; 1 – natural mortality age-dependent
TAC (T)	M	The Total; Allowable Catch (TAC) for the stock for the year in question.	Tonnes (log10 transformed)
Landings (L)	M	The total harvested biomass of the stock over the fishing season	Tonnes (log10 transformed)
Discards (D)	M	Whether discards were included in the observed catch.	0 - not mentioned or not considered in assessment; 1 - discard information included in observed catch
Maturity (M)	M	The method used to estimate the age at which 100% of individuals are mature	0 - jack-knife value or a constant ogive; 1 - maturity based on an empirical ogive (for a description of these methods, see Appendix D)
Age of 100% Maturity (M_A)	B	The estimated age at which 100% of individuals are mature.	Years
Weight at age of 100% Maturity (M_{WA})	B	The average weight of estimated age at which 100% of individuals are mature.	Kg
Assessment Method (AM)	M	The model used in the assessment	Extended Survival Analysis (XSA) Virtual Population Analysis (VPA) Integrated Catch Analysis (ICA)

3. Results

This section contains the results of the comparative predictive measures. Regression statistics are compared for alternative time-series models within age, and age-series models within time. These results give an indication of the overall and specific predictability of catch variation from stock assessment models.

Linear mixed effects modelling with (i) series type (age-series within time or time-series within age); (ii) harvest measures (abundance, biomass, or biomass proportion); (iii) species; and (iv) regression samples size as four fixed effects and stock as a random effect shows a large effect of series type, with time-series within age having substantially lower average R^2 (Figure 3.1(a), mean $R^2 = 0.43$) than age-series within time (Figure 3.1(b), mean $R^2 = 0.75$). See also Figure 3.2 and Table 3.1).

Substantially smaller effects were detected for species (Appendix F), harvest measure (Figure 3.2) and sample size (i.e. predictive power was better for stocks with a greater sample size; Appendix F). Thus, on average, stock assessment models are better at predicting variation in catch among age classes within time than they are in predicting variation in catch for a given age class at different times. Model fit improved substantially with the addition of a random effect due to stock (standard deviation with random effect included = 0.08; likelihood ratio = 111.7), thus showing substantial inter-stock variation in predictive power.

Table 3.1. Results of linear mixed effect modelling of predictive power. Independent variables are: harvest measure (abundance, biomass, biomass proportion), series type (time-series within age or age-series within time), species (Sp), sample size of regression (either Y_N or A_N depending on sample type), the interaction between harvest measure and series type, and the interaction between species and sample size of the regression. Only fixed effects are shown. Total sample size N = 3411.

Variable	Df	F-value
(Intercept)	1	762.30
Harvest measure	2	28.10
Series type	1	1407.10
Species	16	16.16
Sample size of regression	1	91.85
Harvest measure : series type	2	11.72
Species: sample size of regression	16	7.61

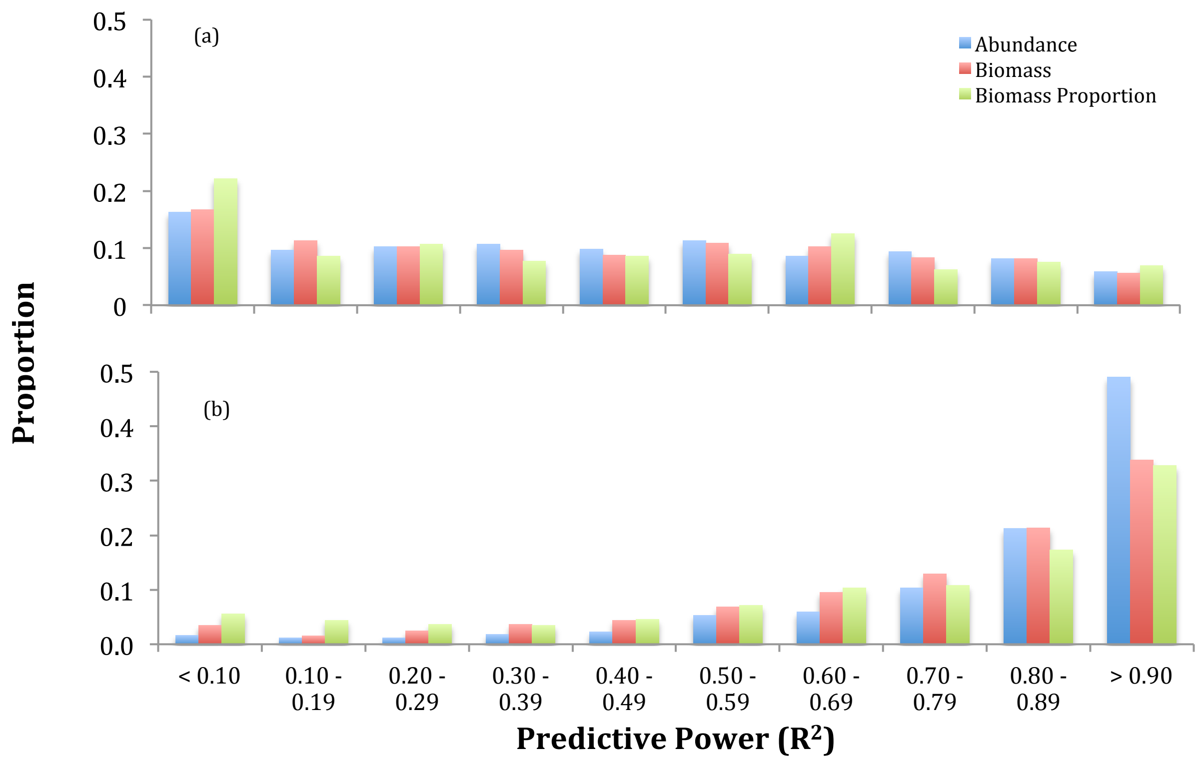

Figure 3.1. The distribution of estimates of predictive power (R^2) based on (a) time-series within age (n=478) and (b) age-series within time (n=659) for abundance (blue), biomass (red), and biomass proportion (green).

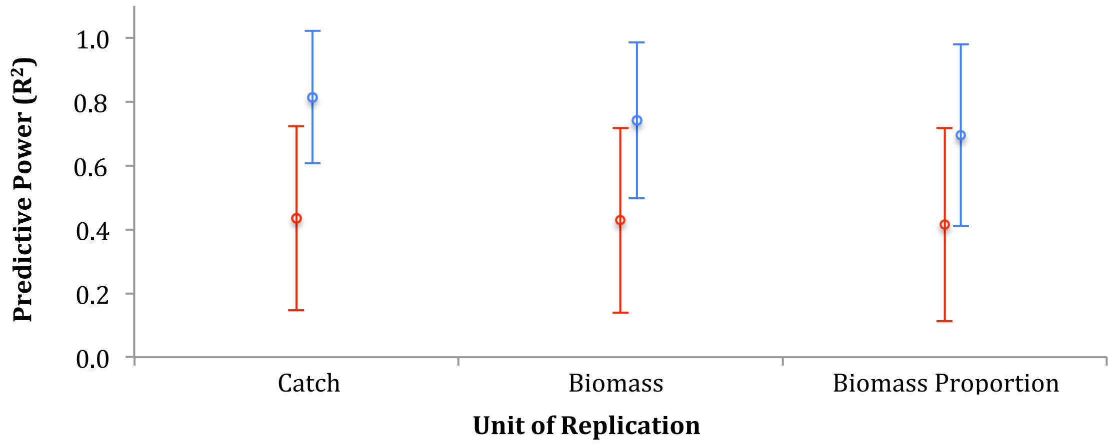

Figure 3.2. Average predictive power (R^2) and associated standard deviation for each of the three harvest measures of interest, as estimated from age-series within time (blue) and time-series within age (red).

The comparatively large effect of series type (Table 3.1) led us to stratify the analysis by series type and explore potential associations with different but overlapping sets of candidate predictor variables (Tables 2.2, 2.3). For the time-series within age sample, predictive power was positively associated with the number of countries involved in the assessment (C_N: Figure 3.5), and negatively associated with uniformity (U: Figure 3.3) and changes over the period of record in estimated mortality (Δ NM), the inclusion of discards (Δ D), the methods used for estimating age at 100% maturity (Δ M) and the stock assessment model (Δ AM: Figure 3.4). The effect of number of countries is, to some extent, confounded with the effects of management regime, as DFO and TRAC stocks by definition involve one and two countries respectively, whereas ICES stocks may involve anywhere from 1 to 15 countries. But whatever the harvest measure, changes over the period of record in either stock assessment model parameters or in the method of assessment are associated with reduced predictive power. However, all of these associations are comparatively weak, as indicated by the correspondingly low partial R^2 (Table 3.2)

Table 3.2. Detected fixed effects based on the best-model fitted to the time-series within age sample. For each variable, the partial R^2 is that proportion of the variance in the specified harvest measure uniquely attributable to the variable in question. Total sample size = 478. Other candidate variables shown in Table 2.3. did not appear in the final selected model.

		Abundance			Biomass			Biomass Proportion		
Variables	**Df**	**F Value**	**P Value**	**Partial R^2**	**F Value**	**P Value**	**Partial R^2**	**F Value**	**P Value**	**Partial R^2**
Species	16	6.2	<0.0001	0.24	5.8	<0.0001	0.21	8.6	<0.0001	0.26
U	1	11.7	0.0007	0.03	11.2	0.0009	0.02	8.2	0.0044	0.02
C_N	2	9.6	<0.0001	0.09	9.5	<0.0001	0.08	12.6	<0.0001	0.10
Δ NM	1	14.2	0.0002	0.06	13.3	0.0003	0.05	13.6	0.0003	0.06
Δ D	1	16.7	<0.0001	0.05	18.5	<0.0001	0.05	18.3	<0.0001	0.04
Δ M	1	8.2	0.0044	0.02	4.5	0.0349	0.01	3.3	0.0694	0.01
Δ AM	1	13.0	0.0003	0.03	7.8	0.0055	0.02	13.4	0.0003	0.03

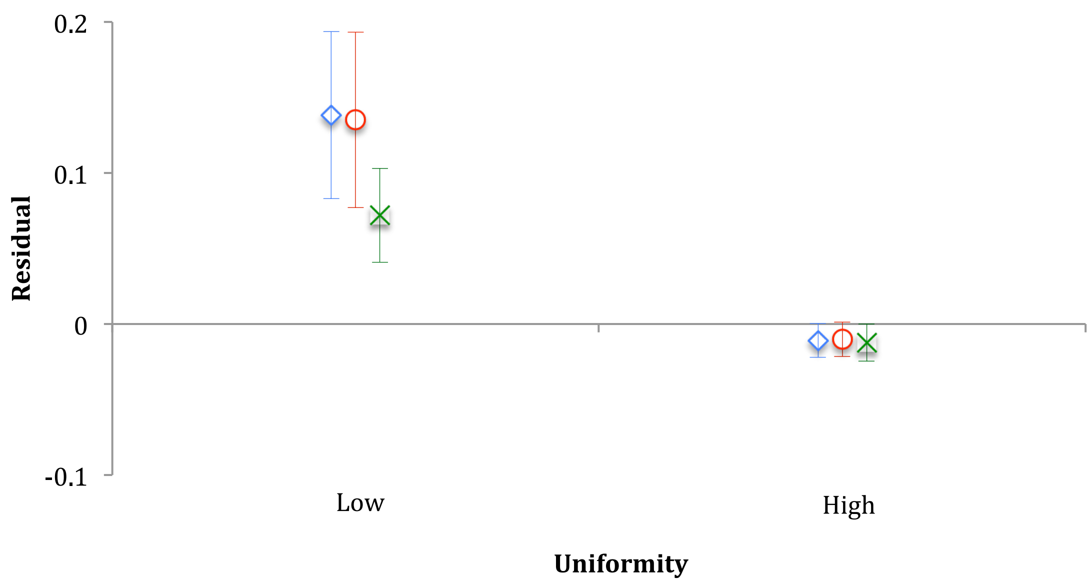

Figure 3.3. Partial plot (abundance (blue), biomass (red) and biomass proportion (green) of average model residuals and associated standard error) for uniformity (U) based on time-series within age. Residuals are based on the fitted model referred to in Table 3.2.

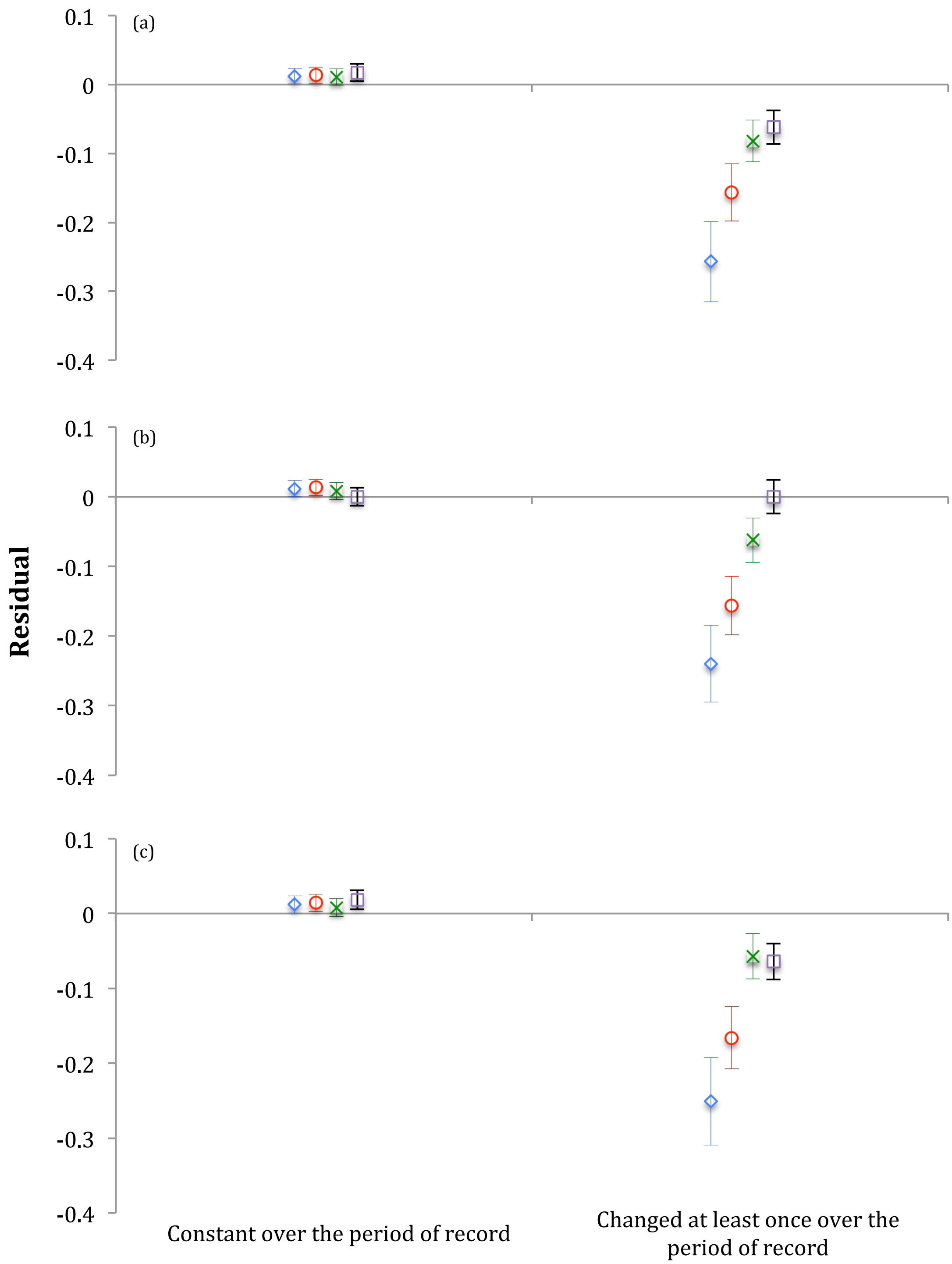

Figure 3.4. Partial plot (abundance (a), biomass (b) and biomass proportion (c) of average model residuals and associated standard error) for Δ natural mortality (blue), Δ discards (red), Δ maturity (green), and Δ assessment (purple) based on time-series within age. Residuals are based on the fitted model referred to in Table 3.2.

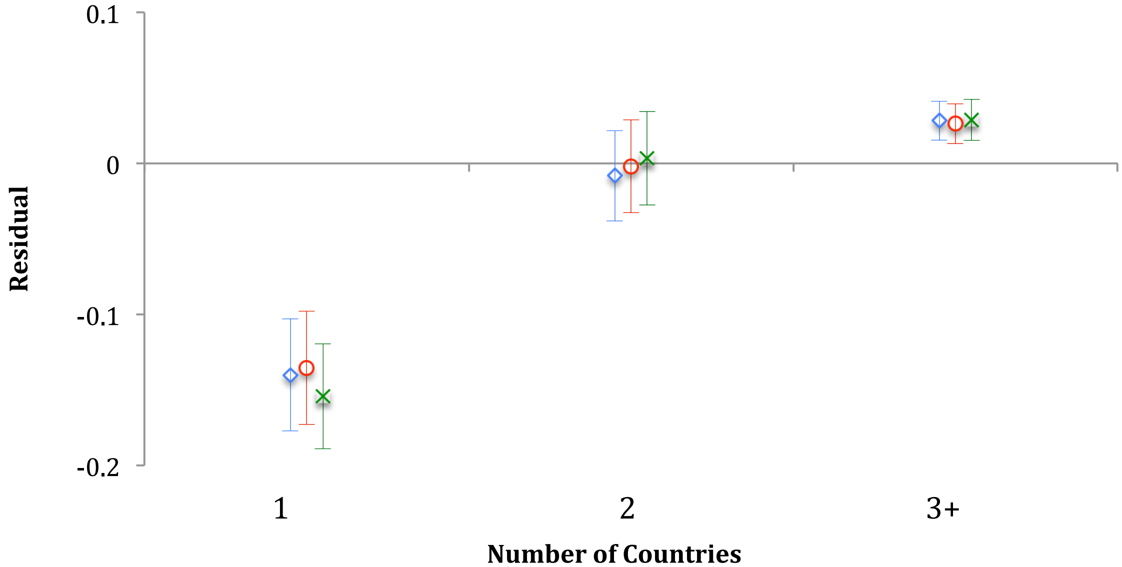

Figure 3.5. Partial plot (abundance (blue), biomass (red) and biomass proportion (green) of average model residuals and associated standard error) for number of countries (C_N) based on time-series within age. Residuals are based on the fitted model referred to in Table 3.2.

The best model fitted to the age-series within time data indicates an effect of species and organization (O) (with DFO having, on average, higher predictive power than the other 2 organizations – Figure 3.6), and a negative association with landings (L) for all 3 harvest measures (Table 3.3; Figure 3.8(b); Appendix F) suggesting stocks with a higher annual TAC, and therefore higher annual recorded landings, tend to have a lower predictive power. For abundance, predictive power was also positively associated with normalized year (Y*) (i.e. predictive power was better for later assessments than earlier assessments; Figure 3.8a) and with the method used to estimate age of 100% maturity (M) (i.e. predictive power was better for assessments that were based on an empirical year-specific ogive versus using a jack-knife age or constant ogive that was determined in previous assessments; Figure 3.9). For biomass, predictive power was, on average, better when natural mortality was considered to be age-dependent rather than age-independent (Figure 3.9), positively associated with normalized year (i.e. predictive power was better for later assessments than earlier assessments; Appendix F) and negatively associated with total number of age classes (i.e. predictive power decreased as the number of age classes increase; Figure 3.7). For biomass proportion, predictive power was also better when natural mortality was considered to be age-dependent rather than age-independent (Figure 3.9), and was negatively associated with uniformity (i.e. low uniformity was associated with generally lower predictive power; Figure 3.9). As was the case for the time-series within age sample, all of these detected associations are weak (Table 3.3)

Table 3.3. Detected fixed effects based on the best-model fitted to the age-series within time sample. For each variable, the partial R^2 is that proportion of the variance in the specified harvest measure uniquely attributable to the variable in question. Total sample size = 659. Other candidate variables shown in Table 2.3. did not appear in the final selected model.

		Abundance			**Biomass**			**Biomass Proportion**		
Variables	**Df**	**F Value**	**P Value**	**Partial R^2**	**F Value**	**P Value**	**Partial R^2**	**F Value**	**P Value**	**Partial R^2**
Species	16	5.6	<0.0001	0.17	5.1	<0.0001	0.14	4.9	<0.0001	0.11
O	2	9.4	<0.0001	0.02	4.9	0.0074	0.02	9.5	<0.0001	0.02
L	1	52.7	<0.0001	0.08	31.1	<0.0001	0.02	7.4	0.0068	0.02
NM	1	-	-	-	6.2	0.0128	0.01	8.7	0.0032	0.02
A_N	1	-	-	-	12.9	0.0004	0.02	-	-	-
M	1	5.3	0.0213	0.01	-	-	-	-	-	-
Y*	1	18.8	<0.0001	0.03	13.9	0.0002	0.02	-	-	-
U	1	-	-	-	-	-	-	15.0	0.0001	0.02

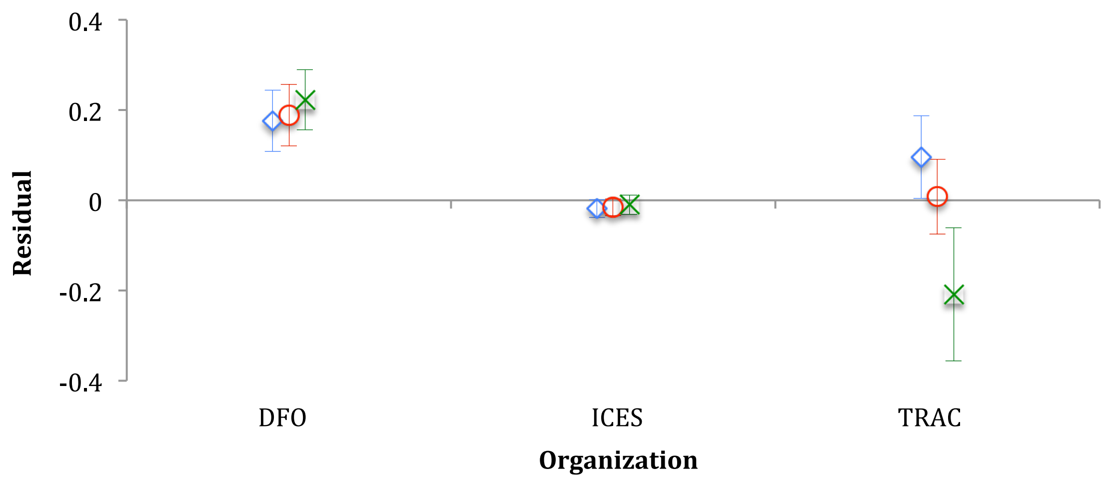

Figure 3.6. Partial plot (abundance (blue), biomass (red) and biomass proportion (green) of average model residuals and associated standard error) for the three organizations (O) based on the age-series within time sample. Residuals are based on the fitted model referred to in Table 3.3.

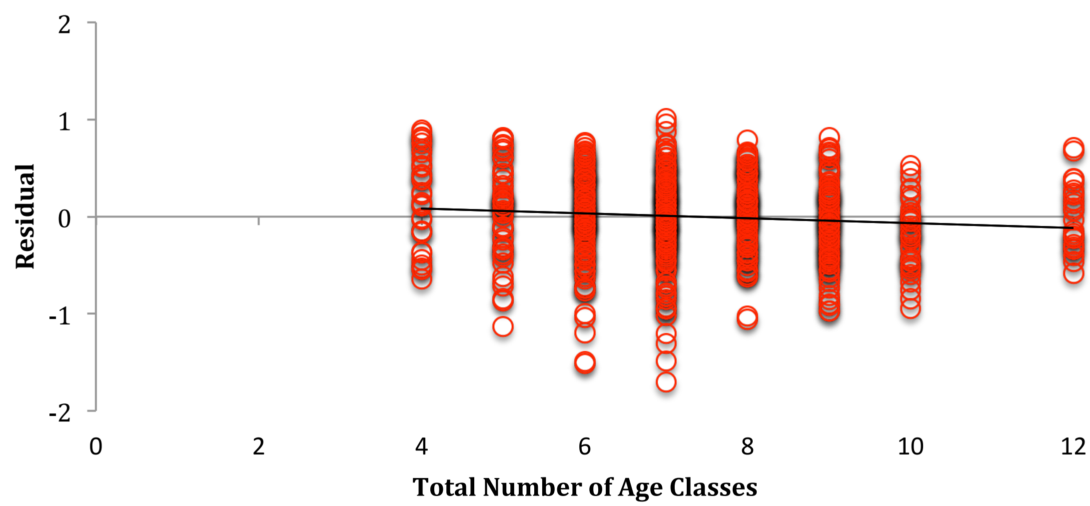

Figure 3.7. Partial plot for total number of age classes (A_N) based on the age-series within time sample for biomass. Residuals are based on the fitted model referred to in Table 3.3.

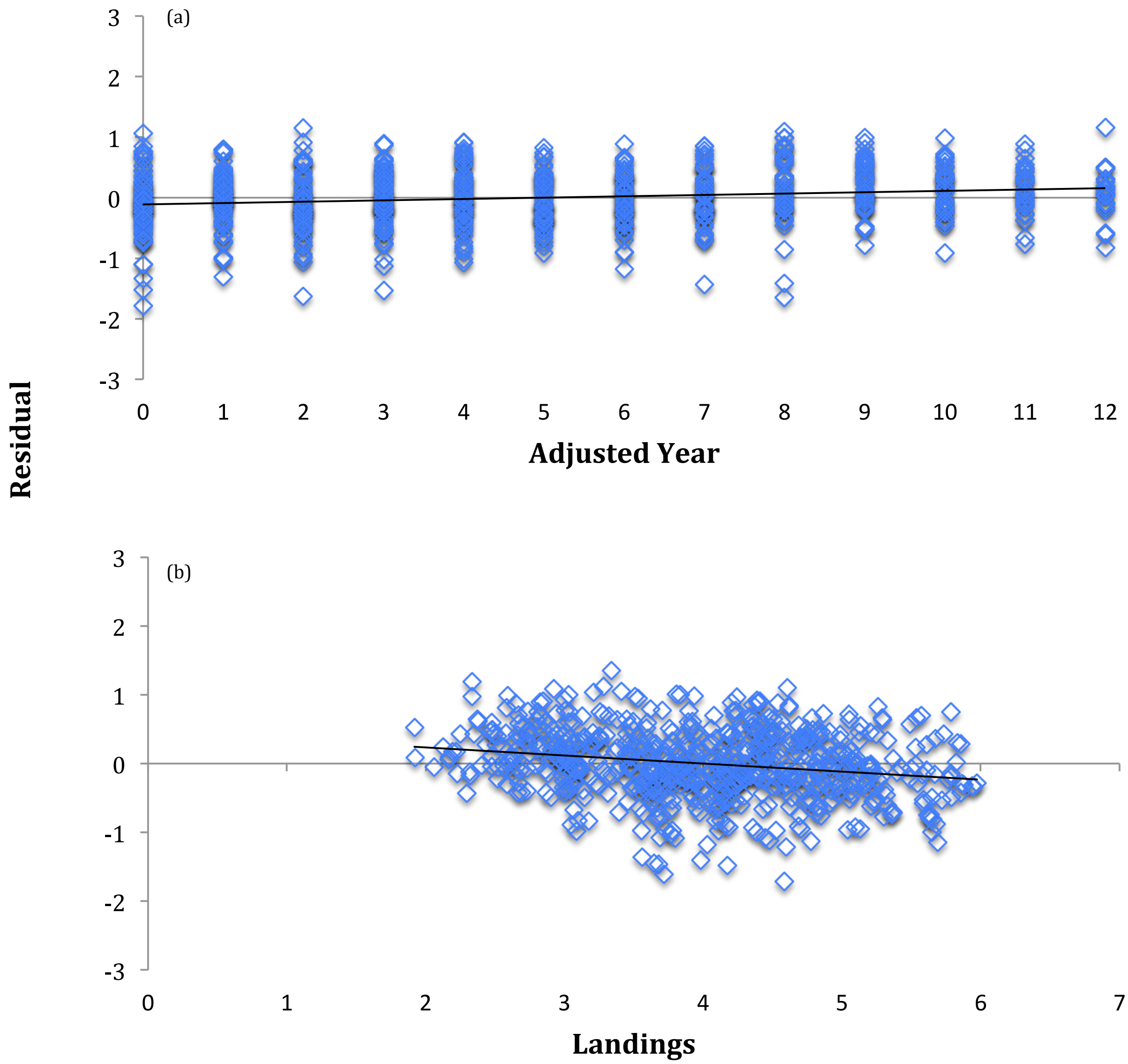

Figure 3.8. Partial plot for (a) adjusted year (Y*) and (b) landings (log10) (L) based on the age-series within time sample for abundance. Residuals are based on the fitted model referred to in Table 3.3.

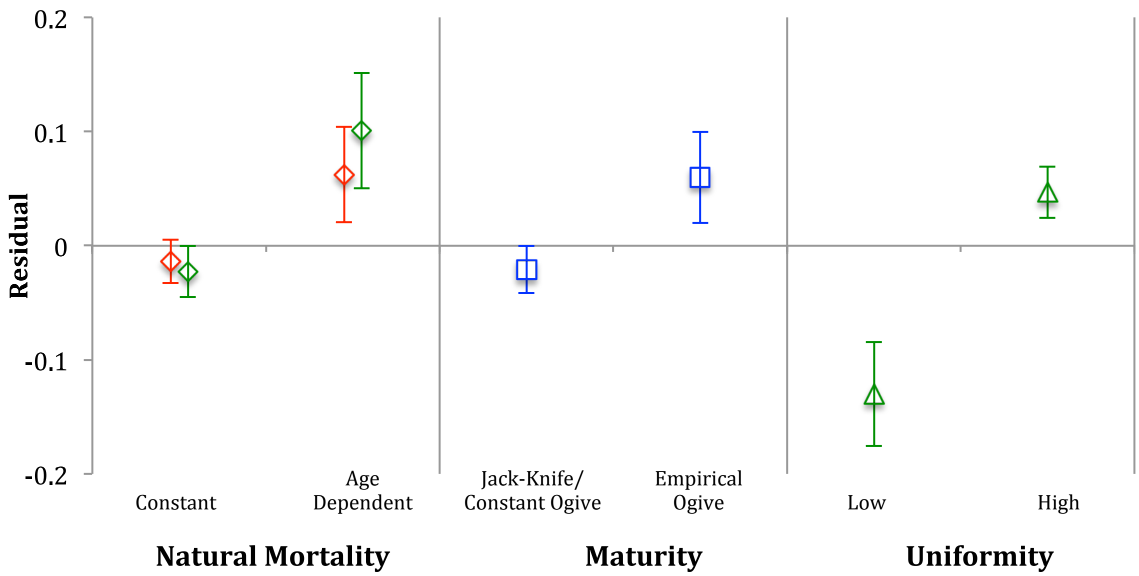

Figure 3.9. Partial plot (abundance (blue), biomass (red) and biomass proportion (red) of average model residuals and associated standard error) for natural mortality (NM) (diamond), maturity (M) (square) and uniformity (U) (triangle) based on age-series within time. Residuals are derived from the fitted models referred to in Table 3.3. Only the harvest measures for which the final model indicated an association with the variable in question are shown.

4. Discussion

This work represents one of few attempts to estimate the predictive power of stock assessments in commercial fisheries. I found considerable variation among stocks in predictive power as measured by the coefficient of determination of the regression of observed and predicted abundance, biomass and biomass proportion. Overall, I found that, on average, within-year predictive power (where predictive power is based on the regression of observed on predicted abundance, biomass or biomass proportion for different age classes within a given year) is higher than year-over-year predictive power (where predictive power is based on the regression of observed on predicted abundance, biomass or biomass proportion for different years within a given age class).

Some of the variation among stocks in estimated predictive power is undoubtedly related to inter-stock differences in temporal variability in abundance and biomass over the period of record. Such differences can arise from differences in sensitivity of a stock to fluctuations in the abiotic factors that can affect fecundity, growth and maturation, or natural mortality; the strength of biotic interactions, including predation and disease; and/or the extent to which the stocks exhibit intrinsic non-linear dynamics (Shelton & Mangel, 2011). For commercial fish stocks, it has been suggested that exploitation itself can lead to larger temporal fluctuations by increasing population growth rates and increasing the risk of transition to chaotic dynamical regimes (Hsieh *et al*., 2006; Anderson *et al*., 2008; Stenseth & Rouyer, 2008; Shelton & Mangel, 2011). As all assessment methods employed for the stocks considered here make use of historical information to generate forecasts, greater temporal fluctuations will result in greater forecast uncertainty, and a commensurate reduction in predictive power.

Inter-stock variation in predictive power may also reflect variation in quality of the stock assessments themselves. Stocks differ not only with respect to the stock assessment methods employed, but also in the amount and quality of data used to inform the assessment (Hilborn & Walters, 1992). Some stocks – especially those with high commercial value – are comparatively information-rich. Managers of these stocks devote considerable effort to acquiring data over comparatively long time intervals, and report not only landings, but also discards, growth and maturation, fecundity, natural mortality and age/size structure (Ralston *et al*., 2011), as well as estimates of temporal variation in population parameters and environmental variables (e.g., temperature, salinity, etc.) from which statistical associations with population parameters can be estimated (O'Brien *et al*., 2000; Perry *et al*., 2005; Fieberg & Ellner, 2001). By contrast, data-poor stocks may have little more than annual estimates of landings and (possibly) age-structure data collected over short time periods. Unsurprisingly, such differences determine not only the stock assessment methods that can – even in principle - be employed, (Pilling *et al*., 2008) but also their associated uncertainties. Several studies have shown that stocks for which fewer data are available show greater uncertainties in stock assessments (Chen *et al*., 2003; Edwards *et al*., 2012), as do those with poorer quality data (Ramirez *et al*., 2017).

The observed difference in predictive power based on the time-series within age sample versus age-series within time sample has several possible explanations. One obvious explanation is that because predictive power based on age-series within time is year-specific, actual temporal fluctuations in population parameters such as stock-recruitment relationships (Britton *et al*., 2016; Subbey *et al*., 2014), growth and maturation (Anderson *et al.,* 2008) or natural mortality (Shelton & Mangel, 2011) will introduce greater uncertainty into stock assessments that assume that these parameters are constant over the period of record. The longer the period of record, the more unlikely it is that the assumption of stationarity will be met, i.e. the greater the probability of *bona fide* changes in production and/or recruitment sometime during the period. Recent evidence suggests that irregular regime shifts may be more common than was previously thought (Vert-pre *et al*., 2013), resulting in greater uncertainty and lower predictive power. For example, Britten *et al.* (2016) have recently provided evidence that recruitment capacity has been reduced by an average of 3% of the historical maximum per decade in many commercial fisheries as a result of environmental changes and biological changes brought about by overfishing.

A second class of explanations relates to the properties of the data themselves. For example, catch-at-age (within time) abundance estimates from vessel surveys show positively correlated errors (Myers & Cadigan, 1993). A greater positive autocorrelation of errors in estimated catch-at-age would induce a higher correlation between observed and predicted values in the age-series within time sample compared to the time-series within ages sample, as in the latter case the positive autocorrelation would reflect positively correlated errors in catch-at-time (within age).

4.1. Statistical (S) correlates of predictive power

For the time-series within age sample, predictive power was greater for low uniformity compared to high uniformity. By contrast, this pattern was reversed in the age-series within time sample.

One explanation is simply the fact that low uniformity reflects a generally larger range of forecast values for any harvest measure. Given a fixed average root mean square error (RMSE) of the regression of predicted on observed values, R^2 increases with the range of the predicted values in the sample. Hence, all else being equal, non-uniform distributions will show a greater average R^2 if, on average, they have a greater range of predicted values.

On the other hand, for linear regression where sample size is small, outlier values of the independent variable have high leverage (i.e., large influence on the estimated slope.) If the extreme value is also an outlier with respect to the slope that would have been estimated had the extreme value been excluded, the high leverage of the extreme value will result in a greater RMSE – and hence, lower R^2 - than would otherwise be obtained. Thus, all else being equal, high uniformity may either reduce (as was the case for the time-series within age sample) or increase (as was the case for the age-series within time sample) R^2 relative to that which would be obtained in the low uniformity case. This suggests that we should expect greater variation in predictive power in the low uniformity case – precisely as observed for all three harvest measures for both samples (see Figures 3.3. and 3.9)

4.2. Management regime and stock assessment method (M) correlates of predictive power

For the time-series within age sample, a change over the period of record was consistently associated with a reduced predictive power (Figure 3.4). Such changes include changes in the assumed/estimated natural mortality rate; whether discards were included in the catch; the assumed/estimated age of 100% maturity; or the methods/models employed in stock assessment.

These associations are unlikely to reflect a causal relationship. Changes over the period of record in the assumed values of parameters, which are required inputs to virtually all stock assessment models (e.g., natural mortality, age of maturity, etc.), are not made arbitrarily. Rather, they reflect the fact that sufficient evidence has accumulated to justify a change in the assumed values of these parameters. Delays in detection of productivity regime shifts may be inevitable in long-lived species, since the data required will be available only when surviving juveniles are recruited into the breeding population (i.e., a lag corresponding to at least the age of maturity)(King *et al*., 2015). Moreover, a recent analysis suggests that the required evidentiary standard is high (Klaer *et al*., 2015), which in turn suggests that considerable time may pass before managers are sufficiently convinced a regime shift has occurred to justify a change in stock assessment model input parameter values.

The detection of regime shifts - or more generally, nonstationarity in important population parameters - that are employed in stock assessments has been an area of intense focus over the last several decades (Walters, 1987;Britton *et al*., 2016; Vert-pre *et al.,* 2013) and various methods have been developed to do so (Perala & Kuparinen, 2015; Johnson *et al*., 2015). But if indeed a regime shift occurred at some point (say, *t**) during the period of record, and incorporation of this change into stock assessments is delayed until time *T*, then during the period [*t**, *T*], we would expect the performance (e.g. predictive power) of stock assessment models to be reduced, with improved performance occurring only after regime shift information has been incorporated into the assessments. Thus, stocks for which changes have occurred during the period of record – presumably in (lagged) response to evidence of regime shifts, or at last non-stationarity – would be expected to have lower average predictive power than where such changes have not occurred.

The same would be expected to apply to species and stocks for which the method of assessment changed during the period of record. Often such changes reflect the transition from single-species assessments to multi-species or ecosystem-based fisheries management (Pikitch *et al*., 2004). As is the case with, for instance, the incorporation of productivity shifts, stocks for which such transitions have occurred are likely to show reduced performance during some interval during the period of record compared to stocks for which performance was judged sufficient, or there was insufficient evidence to justify, a transition to more complex ecosystem-based fisheries management.

The results also indicate that predictive power is greater for species/stocks for which the inclusion/exclusion of discards in catch-at-age estimates was constant over the period of record, compared to those for which there were intervals where estimates of discards were included, others where they were excluded (Figure 3.4). Discards are a fact of life in many – arguably all – fisheries (Kelleher, 2005; Cook, 2013). Although landing data (of variable quality) are available for most commercial fisheries, and the resulting time series are comparatively long, for most fisheries the systematic collection of discard data has been more recent. Moreover, discard estimates are generally less precise, and arguably less accurate, than landing estimates, as they are generally based on fewer samples (Rochet *et al*., 2002). These two aspects (shorter time-series within age and more imprecise estimates) have hampered the incorporation of discards in stock assessments (Dickey-Collas *et al*., 2007), which often use the long time-series within age of landings as proxies for catches. Nonetheless, if discards are substantial, failure to incorporate discards in stock assessments can result in substantial biases (Dickey-Collas *et al*., 2007; Jardim *et al*., 2010). Presumably in cases where inclusion of discards in estimating catch changed over the period of record, it was because such information was simply not available during the first part of the record. Hence, for these cases, there was important missing information during part of the period of record whose absence would be expected to reduce predictive power.

For time-series within age, predictive power increases with normalized year, indicating that predictive power was, on average, greater at the end of the period of record compared to the beginning. Or, put another way, stock assessment performance improved over the period of record. This presumably reflects the cumulative value (with respect to improved performance) of the accumulation of data and information. Much of stock assessment is based on fitting statistical models to data. The more data to be fit, the lower the statistical uncertainty associated with fitted models, and the greater opportunity for more informative performance evaluation (e.g. using one set of data (the training set) to fit the model, and a second independent set (the training set) to evaluate model fit). More data allows for the possibility of detecting regime shifts or non-stationarity in population parameters (Vert-pre *et al.,* 2013), age-specific natural and fishing mortality rates or fecundity (Froese *et al*., 2015). Finally, more data and a greater diversity of data (i.e. data-richness) allow for the application of multiple different models (Cadrin & Dickey-Collas, 2015), results from which can be used as one measure of scientific uncertainty (Ralston *et al*., 2011).

Age at 100% maturity is estimated by three methods: knife-edge, constant ogive and updated ogive (described in Appendix D). Knife-edge ogives are clearly an oversimplification for many species – especially longer-lived species – that have a (reasonably) well-defined spawning stock structure and can result in substantially biased estimates of spawning stock biomass and stock reproductive potential (Bromley, 2003), which are expected to result in reduced predictive power. In the same way, failure to account for temporal changes in age at maturity as a consequence of changing environmental conditions (Wheeler *et al*., 2009; Vainikka *et al*., 2009) or exploitation (Hutchings, 2005; Kuparinen & Merila, 2007; Jennings *et al*., 1998) will eventually generate substantial bias in estimates of spawning stock biomass and reproductive potential, with associated reductions in subsequent predictive power. By contrast, maturity ogives that are periodically updated to reflect changing environmental conditions and/or the effects of exploitation are expected to result in reduced bias in spawning stock biomass estimates and/or reproductive potential, and hence, increased predictive power.

The natural mortality rate is a critical parameter in all stock assessments, and various methods exist to estimate it (Casini *et al*., 2016; Aanes *et al.,* 2007). For the purposes of stock assessments, natural mortality may be assumed to be independent of age (Vinther, 2001) or modelled as a function of age or size (Aanes *et al*., 2007; Horbowy, 2016). Because target fishing mortality (and hence, the TAC) depends on the estimated natural mortality (which in most stock assessments is estimated externally to the age-structured models employed to estimate abundance and biomass), bias in estimated natural mortality can have profound consequences on stock dynamics: in particular, stock decline as a result of inflated TACs (Mertz & Myers, 1997; Clark, 1999; He *et al*., 2011; Horbowy, 2016)

In stock assessments, natural mortality may be assumed to either be constant throughout all age classes, or to be age-dependent (Horbowy, 2016; He *et al*., 2011). In general, one begins with the null hypothesis that natural mortality is age-independent, and examines the resulting goodness of fit to catch-at-age data, with poor fits resulting in rejection of the null and the development of alternate age-dependent models (Horbowy, 2016; Aanes *et al*., 2007). Misspecification of age-dependency and the resulting biased estimates of natural mortality can substantially undermine stock assessment model performance (Deroba & Scheuller, 2014; Lee *et al*., 2011). However, the ability to detect and to distinguish age-dependence natural mortality from temporal variation in the natural mortality rate depends on the quality and quantity of available data (He *et al*., 2011). If stocks in the age-independence natural mortality sample are relatively data-poor, then rejection of the null of age-independence may be difficult, even when there exists substantial age-dependence. The result will be reduced predictive power compared to stocks whose assessment incorporates age-dependence natural mortality.

The landings recorded over the fishing season are, as defined by DFO (2017), part of the catch that is brought ashore. For some fisheries, the primary source of information on total landings will come from logbooks kept by the fisherman, and poorly kept documentation within logbooks results in decreased accuracy in the reported landings used within the assessment model (Sampson, 2011). Bastardie *et al*. (2010) suggest that misreporting of area declaration (e.g. declaring landings for area 'A' when in reality landings were caught in area 'B') by fisherman can also have a negative effect on landing accuracy. Stocks with greater recorded annual landings are more susceptible to potential inaccuracies from declared landings by fisherman, and will result in a reduced predictive power.

4.3. Implications

Of the list of candidate variables used in this study (Table 2.2), one of the common ways to evaluate multiple variables in the database was to determine if a given variable changed at least once over the period of record or if it stayed consistent. It was determined that switching between methods of: estimating the variable (Δ natural mortality, Δ maturity and Δ age of 100% maturity), model used (Δ assessment) and/or inclusion of information (Δ discards), showed a decrease in predictive power. A potential factor behind this trend may be a regime shift occurring within the fish stock population that is not immediately noticed by managers. The time lag between a shift and the subsequent adjustment in the assessment model would cause the predictive power to decrease until the adjustment is made. To better understand the effect of a time lag will need to be studied in further depth in future research.

As it stands, DFO has been shown to have a better predictive power than the two other studied organizations (ICES and TRAC) (Figure 3.6). The potential reasoning behind this is the difference in how the data are presented in the different reports/organizations. DFO's assessments generally provide their information in a more straightforward and simplistic style, leading to easier extraction and interpretation of the data. In contrast, ICES provides its assessments in one large document per working group for multiple fish stocks thus creating a more convoluted, and time consuming, source for data gathering, unreliability and opportunities for data misreporting. A secondary reason behind this is the implementation of the TAC by the countries responsible for managing a certain fish stock. As DFO is a Canadian government agency, the recommended TAC from stock assessments may be more directly enforced; however, ICES is a council rather than government agency and therefore the TAC recommended by their scientific reports are advice that countries are not required to follow. The influence that the data source selection (in this case, the organization) may play when evaluating and interpreting specific stocks will need to be studied in more depth in future research.

Some species tended, on average, to have a better predictive power than other species used within this study. For example, haddock had an average R^2 value of 0.70, while megrim and anglerfish (factoring in all assessed sub-species) had average R^2 values between 0.33 – 0.43 (Appendix F). Species that are more economically valuable and have been fished commercially over a longer period of time may have better monitoring systems in place thus leading to more detailed information for the stock assessments than stocks considered less valuable. Some species may also have a higher prevalence of being caught as a bycatch and of being discarded without being reported to the managing organization. The exact reason as to what may cause the difference between species was not determined in this study and will need to be researched further in future studies by expanding the candidate variables used.

4.4. Future research

The current work represents one of the first attempts to systematically quantify the predictive power of commercial fisheries stock assessments by comparing predicted with observed values. This type of analysis is rare in fisheries research, as most considerations of stock assessment uncertainty tend to focus on the uncertainty arising from different parameter values, model specifications or data (Ralston *et al*., 2011; Glaser *et al*., 2014). While this type of analysis can provide useful information on assessment uncertainty, it does not directly assess predictive power.

There are at least four future directions to explore based on the current work:

(1) *Extension of the current type of analysis to a larger sample of fisheries stocks*. The current sample represents a small proportion of the commercial fisheries stocks for which: (a) periodic (not necessarily annual) stock assessments are conducted; and (b) from which forecast values for a range of harvest measures (catch, landings, biomass, etc.) can be derived. For example, Ralston *et al*. (2011) provide an assessment of uncertainty in the assessments of 17 Pacific stocks, none of which are included in the current sample. Similarly, the analysis by Glaser *et al*. (2014) of non-linear dynamics in west coast fisheries time series include 85 fished stocks, many of which have periodic stock assessments but which are not included in this analysis. Expansion of the current sample would require considerable effort, as data must be extracted from the set of annual stock assessments associated with a particular fishery. However, the resulting increase in sample size and range for a number of candidate predictors of predictive power (such as those examined here, and see (2) below) would allow for more detailed, and thus more statistically powerful, investigation of correlates of predictive power.

(2) *Expanding the set of measures of predictive power*. As noted in Appendix E, there are a number of different measures of predictive power derived from out of sample testing. Each has its merits and demerits. This study used the coefficient of determination (R^2), but other standard measures such as RMSE,

MAE and MAPE could also be calculated. This extension would not only allow an empirical determination of the correlation between different measures, but also allow for the empirical modelling of a vector of predictive power measures, each of which captures different elements (dimensions) of predictive power.

(3) *Increasing the forecast time-horizon*. The current analysis is concerned strictly with a one-year time horizon. However, it would be expected that the estimates derived here set an upper bound on predictive power for the simple reason that predictive power generally declines with increasing time-horizon. For example, Glaser *et al.* (2014) showed that *forecast skill* (their term to describe the Pearson correlation coefficient between observed values and out-of-sample model forecasts of that value based on either linear or non-linear models fitted to catch or abundance time series) declined exponentially over a 1-5 year time horizon. An empirical evaluation of the relationship between predictive power and the forecast time-horizon is critical, especially since under some important management regimes (e.g., the Magnuson-Stevens Act reauthorization), these forecasted values at times > 1 year into the future are used to set present overfishing limits. Yet Storch *et al*. (2017) suggests that the tendency of fisheries managers to overestimate stability of the stocks they are managing results in far too much reliance being placed on estimates derived from future forecasts and too little effort devoted to acquiring the information required for what amounts to real-time (in fisheries terms) adjustments

(4) *Expanding the set of predictive power covariates*. The current analysis considers a limited set of covariates in modelling predictive power. This set could, and should, be expanded to include other variables. One obvious set of additional covariates pertains to the quality and quantity of data/information that is incorporated into the stock assessments. Intuitively, one might expect that data-rich stocks would have lower uncertainty and hence, greater predictive power. But Ralston *et al*. (2011) point out that,

somewhat paradoxically, data-rich stock assessments may have greater cumulative uncertainty because they are based on models that include a larger number of parameters, each of which as an associated (estimation) uncertainty which are compounded in the overall assessment. Such an analysis could potentially provide quantitative estimates of the value of different types of information, with value being estimated with respect to the incremental increase (if any) in predictive power associated with a particular type of stock assessment data.

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Appendix A – Stock Assessment Methods

There are 3 broad classes of methods to estimate the TAC: (1) catch-based methods, (2) depletion-based methods, and (3) abundance-based methods. Catch-based methods and depletion-based methods are used for stocks that are data-limited (Carruthers *et al.*, 2014). Catch-based methods determine the TAC by using the historical recorded catches of the stock. Depletion-based methods rely on the estimated depletion compared to an un-fished stock or adjusting historical catch with the historical depletion to achieve a TAC recommendation (Pauly & Zeller, 2014; Carruthers *et al.*, 2014). Finally, abundance-based methods rely on the abundance (usually in terms of spawning stock biomass) and the maximum sustainable fishing mortality rate to determine a TAC (Carruthers *et al.*, 2014; Dicosimo *et al.*, 2010).

Catch-based methods are the most frequently used in current stock assessments for DFO, ICES and TRAC. There are multiple catch-based methods. Among them, the Virtual Population Analysis (VPA) model is the most commonly used. VPA was introduced in 1965 and provides a good estimate of the recruitment throughout the age classes in a stock that has been heavily exploited (Lassen & Medley, 2001). It uses a time series of detailed fishery catch-at-age data in order to recreate the virtual population abundance and works best when the fishing mortality is higher than the natural mortality (Methot & Wetzel, 2013). The VPA model includes, when a full assessment is completed, the inputs from both catch and survey data as stated in Table A-1. In instances when catch data were not obtained for the assessment, scientists use survey data to estimate stock status (as used in DFO's Stock Status Reports). The total catch is the only input that must be present for the model to be applicable (Lassen & Medley, 2001). However, there are some issues associated with the VPA. The VPA harvest measures information is sensitive to observational errors in the final year because the data are treated to be exact, and does not efficiently use all available data within the assessment (Shepherd, 1999).

Table A-1. The different inputs (both catch and survey data) used in the VPA model for a full assessment.

Input	**Catch (C) or Survey (S) Data**
Total catch in number by age and year	C
Mean weights by age and year	C
Abundance estimates in absolute terms	C
Abundance indices (e.g., bottom trawl CPUE (catch per unit effort) from research vessels surveys)	S
Biomass indices (e.g., spawning stock biomass indices from egg or larval surveys)	S
Effort indices (e.g., partial fishing mortality on group of age classes)	S

Similar to the VPA, a model called extended survivor analysis (XSA) has been used in stock assessments. XSA uses total catch numbers by age and year similarly to the VPA but is tuned with age-specific catch per unit effort indices (Lassen & Medley, 2001). XSA does not use biomass indices within the modelling procedure. There have been concerns relating to this method as the algorithm adopted to estimate the survivors has been known to provide a negative estimate of survivors, which is not possible, so negative estimates are typically replaced by zeros (Shepherd, 1999).

Another model, developed within the past 20 years, is called integrated catch analysis (ICA) and is based closely on the VPA model (Methot & Wetzel, 2013). ICA is a model that uses the least-squares fit based on similar inputs used in the VPA, but unlike the VPA, separates the fishing mortality into exploitation rate and selectivity to produce estimates of catches that can be fitted to observed catches even when no indices are available (Lassen & Medley, 2001). Some concerns about this method include considerable computational demand as well as considerable skill and judgement from the analyst conducting the ICA that is not universally consistent (Shepherd, 1999).

Appendix B – Stock Management Areas

Commercial fish stocks within the northern Atlantic Ocean have different organizations (typically governments) that are responsible for their management. In Canada, the federal government created the Department of Fisheries and Oceans (DFO) in 1977 when the Canadian jurisdiction along the Atlantic coastline was extended to 200 miles under the *United Nations Law of the Sea* (Walters & Maguire, 1996). In Canada, as well as the United States and Greenland, geographic areas are designated into fishing areas according to the Northwest Atlantic Fisheries Organization (NAFO). NAFO was established at the beginning of 1979 and divides the Northwest Atlantic Ocean into subareas, divisions and subdivisions (Figure B-1). The divisions created by NAFO are to promote and coordinate fishery research in the Northwest Atlantic (Halliday & Pinhorn, 1990). In 2004, a scientific committee was created as a joint management effort between Canada and the United States for stocks that cross the border and focuses primarily on stocks located in the 5Z management area (Figure B-1). The committee is called the Transboundary Resources Assessment Committee (TRAC).

In the Northern Atlantic Ocean area, the International Council for the Exploration of the Seas (ICES) has 20 different member countries that work together to research and support the sustainable use of the ocean. Member countries include Canada, the United States and Iceland, as well as many countries along the coastline in Europe. ICES was established in 1902, but it wasn't until 1964 that it received a legal foundation and full international status (ICES, 2015). ICES divides the remaining area of the North Atlantic Ocean into subareas, divisions and subdivisions (Figure B-2) similar to the NAFO-created divisions.

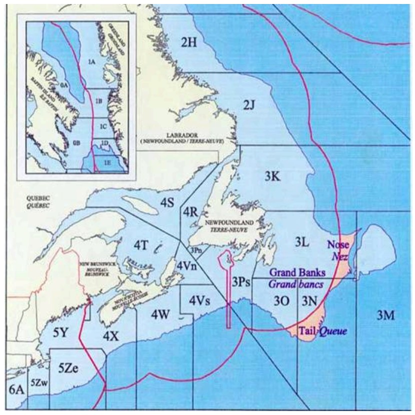

Figure B-1. Management areas located off the eastern coast of Canada as indicated by NAFO. (Source: DFO, 2007)

The key priorities for management assessments vary according to the organization conducting the assessment. ICES priority focuses on the advancement of the scientific understanding of marine ecosystems and provides advice on the sustainable management of such ecosystems to member governments (ICES, 2013). For DFO, their priority focuses on 3 key aspects as outlined in the Fisheries Act: environmental sustainability, economic viability, and the inclusion of stakeholders (DFO, 2010).

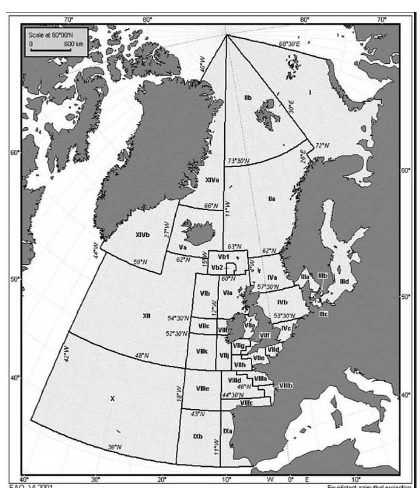

Figure B-2. Management areas located in the western Atlantic Ocean as indicated by ICES. (Source: Swan, 2003)

Appendix C – ICES Working Groups

This appendix contains the complete list of the working groups that produce the stock assessment documents for ICES and the species they are responsible to assess.

Table C-1. List of ICES working groups and the fish species assessed by each group.

Working Group	**Species Assessed**
Arctic Fisheries Working Group	Cod, Haddock, Halibut, Saithe
Baltic Fisheries Assessment Working Group	Cod, Herring, Sole, Sprat
Report of the Working Group on the Celtic Seas Ecoregion (WGCSE)	Cod, Haddock, Plaice, Sole, Whiting
Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak	Cod, Haddock, Plaice, Saithe, Sole, Whiting
Herring Assessment Working Group for the Area South of 62ºN	Herring
Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine, and Anchovy	Mackerel
North-Western Working Group	Cod, Haddock
Working Group on the Assessment of Northern Shelf Demersal Stocks	Cod, Haddock, Plaice, Sole, Whiting
Working Group on the Assessment of Southern Shelf Demersal Stocks	Anglerfish *(L. piscatorius* and *L. budegassa)*, Cod, Haddock, Hake, Megrim *(L. whiffiagonis)*, Plaice, Sole, Whiting
Working Group on the Assessment of Southern Stocks of Hake, Monk, and Megrim	Anglerfish *(L. piscatorius* and *L. budegassa)*, Hake, Megrim *(L. whiffiagonis* and *L. boscii)*, Sole
Report of the Working Group on Widely Distributed Stocks (WGWIDE)	Mackerel

Appendix D – Age of 100% Maturity

This appendix provides a description of how the variable age of 100% maturity was classified as referenced in Section 2.4, Table 2.3.

Age of 100% maturity (i.e. the age at which 100% of individuals in the age class will have spawned at least once) can be estimated using several different approaches. A common method involves considering the proportion of individuals in a given age or size (length) class that are reproductively mature, estimating the cumulative frequency distribution (the maturity ogive), and using this fitted distribution to estimate the age of 100% maturity. In the current sample of species and stocks, maturity ogives may have been estimated once and considered constant during the period of record (constant ogive) or updated periodically (updated ogive). In addition, knife-edge or fixed maturity ogives assume that below some threshold age/size A*, no individuals are mature, whereas above A*, 100% of individuals are mature.

Appendix E – Measures of Predictive Power

The coefficient of determination (R^2) was used of the regression of "out of sample" values (e.g. observed abundance or biomass in year *t+1*) on predicted (forecasted) values in year *t+1* based on stock assessments that include information acquired up until year *t*. Other measures of predictive power are possible, including the root mean square error (RMSE, the average squared differences between forecasted and observed values), the mean absolute error (MAE, the average absolute value of the difference between forecasted and observed values), the mean absolute percentage error (MAPE, 100 times the sum of absolute difference between forecasted and observed values divided by observed values).

There is an ongoing debate among researchers about the extent to which metric ought to properly be employed as a measure of predictive power (Chai & Draxler, 2014). The issue would seem to depend of precisely what data are being fitted. Here – as in any forecast model - the data that are employed to generate a predicted value in year *t+1* are different than those employed to generate the predictions. Hence, prediction is, technically, "out of sample" with predictive accuracy being evaluated (by whatever measure) using a "test" data set.

The RMSE as an index of predictive power suffers from several disadvantages. First and obviously, it depends on the scale of the measured variable. In the current analysis, estimated abundances varies dramatically among stocks in the sample (e.g. under the management of ICES, Cod in Subarea VIa had on average a start of year population of 6.4 million pieces, while North East Arctic Cod in Subareas I and II had on average a start of year population of 1.1 billion pieces); all else being equal, RMSE will be larger for those stocks with larger abundances than those with smaller abundances. Second, even in cases where differences in scale are not an issue (e.g. when one is comparing predictive power of alternate models with respect to the *same* train-test data set), the RMSE gives increasingly greater weight to larger prediction errors (absolute differences between observed and predicted values) than smaller prediction errors. The consequence is that it is difficult, using the RMSE, to distinguish between models that generate small prediction errors for most estimates, but large prediction errors for a few, compared to those for which most estimates generate moderate prediction errors, with almost none producing large errors (Willmott *et al*., 2009; Chai & Draxler, 2014).

On the other hand, the coefficient of determination (R^2) is not without its limitations. First, it depends on the range of predicted values for the stock under consideration, such that stocks that show larger variation over the sample (either larger inter-annual variation in the case of time-series within age, or larger variation among age classes in the case of age-series within time) will have larger R^2, even if the average prediction error (RMSE or MAE) remains the same. A second drawback is that R^2 does not provide an estimate of predictive *accuracy*. For example, systematic bias (e.g. under- or over-estimation of observed values from predicted values) may still occur even when the (linear) regression of observed on predicted values shows a high coefficient of determination, for the simple reason that R^2 is independent of the slope (and intercept) of the fitted regression. In other words, it measures the *correlation* between observed and predicted values (Alexander *et al*., 2015).

These limitations notwithstanding, R^2 was employed as the index of predictive power because it provides a quantitative index of the extent to which observed values are predictable from (i.e. "explained by") observed values. Because predicted values are forecasted by the underlying stock assessment model, R^2 gives the extent to which the assessment model is informationally complete with respect to a single-year forecast horizon. Low R^2 indicates that there is important information that is missing. This could include, for example, inadequate characterization of measurement or sampling error, often assumed to be effectively zero despite the fact that violation of this assumption can have profound effects on stock assessments (Walters & Ludwig, 1981; Maunder & Piner, 2015). By contrast, a high R^2 suggests that even though there may be systematic bias, the underlying stock assessment model is, informationally, more or less complete.

Appendix F – Additional Graphs from Results

This appendix contains additional supporting graphs for the results of the linear mixed effect modeling of predictive power (Table 3.1), detected fixed effects based on the best- model fitted to the time-series within age sample (Table 3.2) and the age-series within time sample (Table 3.3).

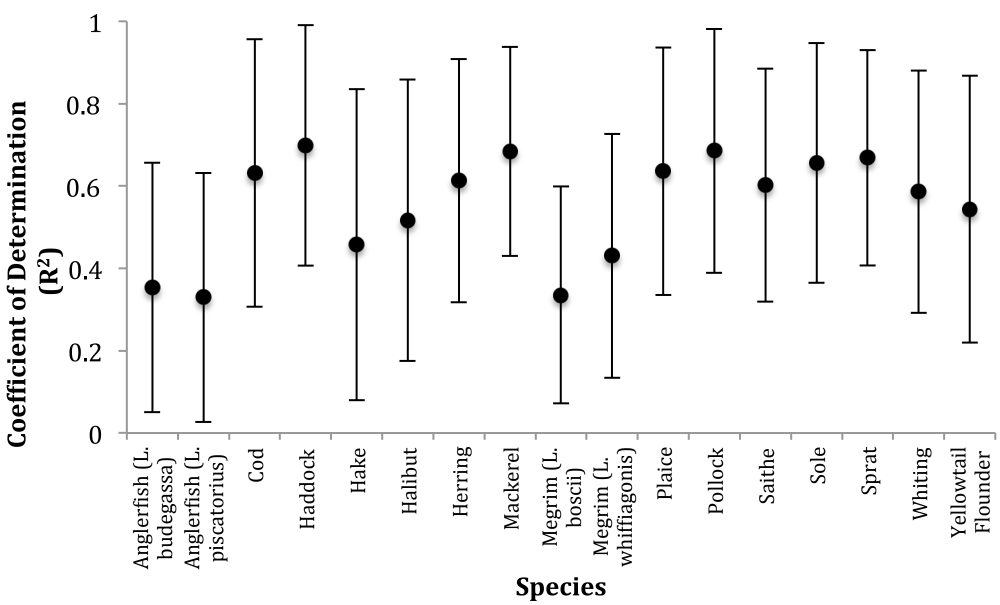

Figure F-1. Average predictive value (R^2) based on both time-series within age and age-series within time, and associated standard deviation (calculated over multiple ages and stocks) for individual species.

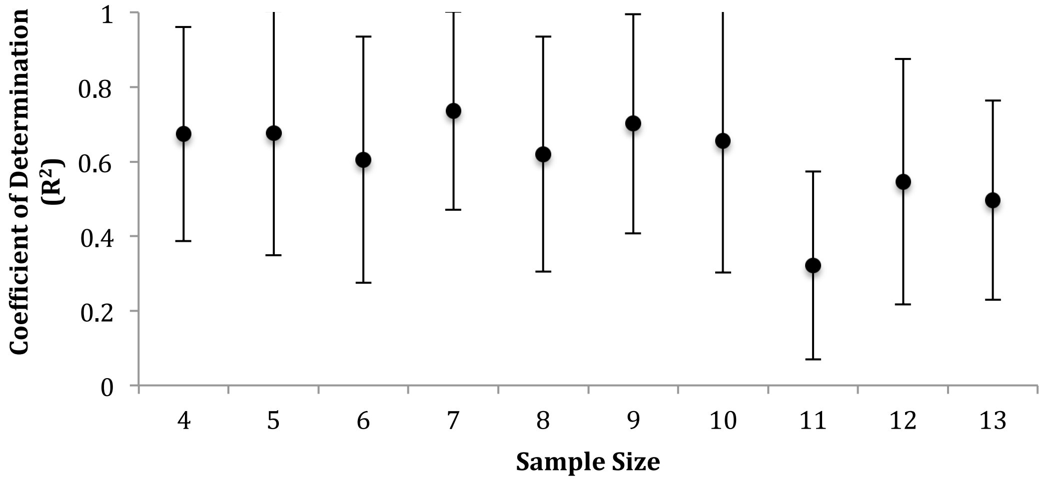

Figure F-2. Average predictive value (R^2) based on both time-series within age and age-series within time, and associated standard deviation (calculated over multiple ages and stocks) for sample size.

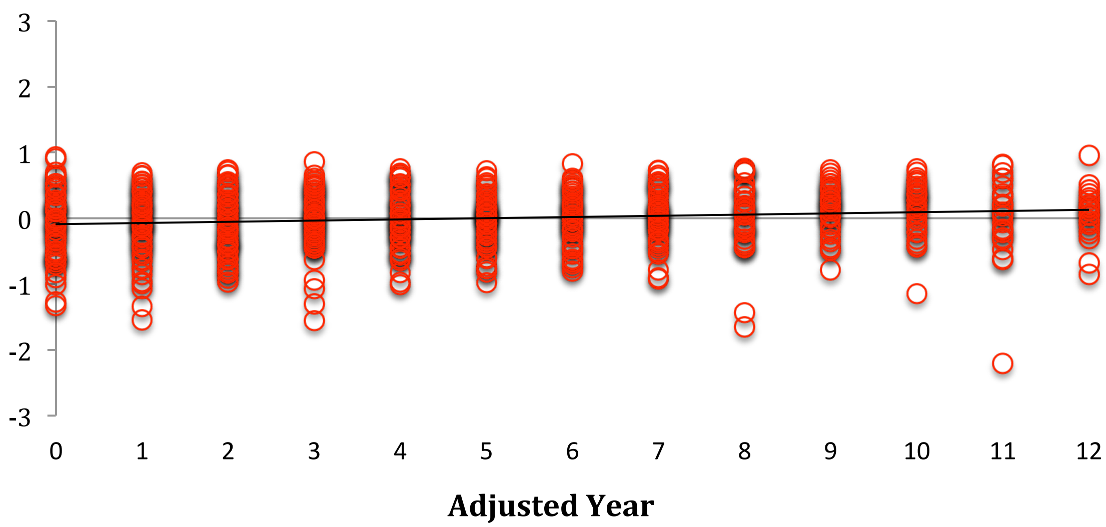

Figure F-3. Partial plot for the adjusted year based on age-series within time for biomass. Residuals are derived from the fitted models shown in Table 3.3.

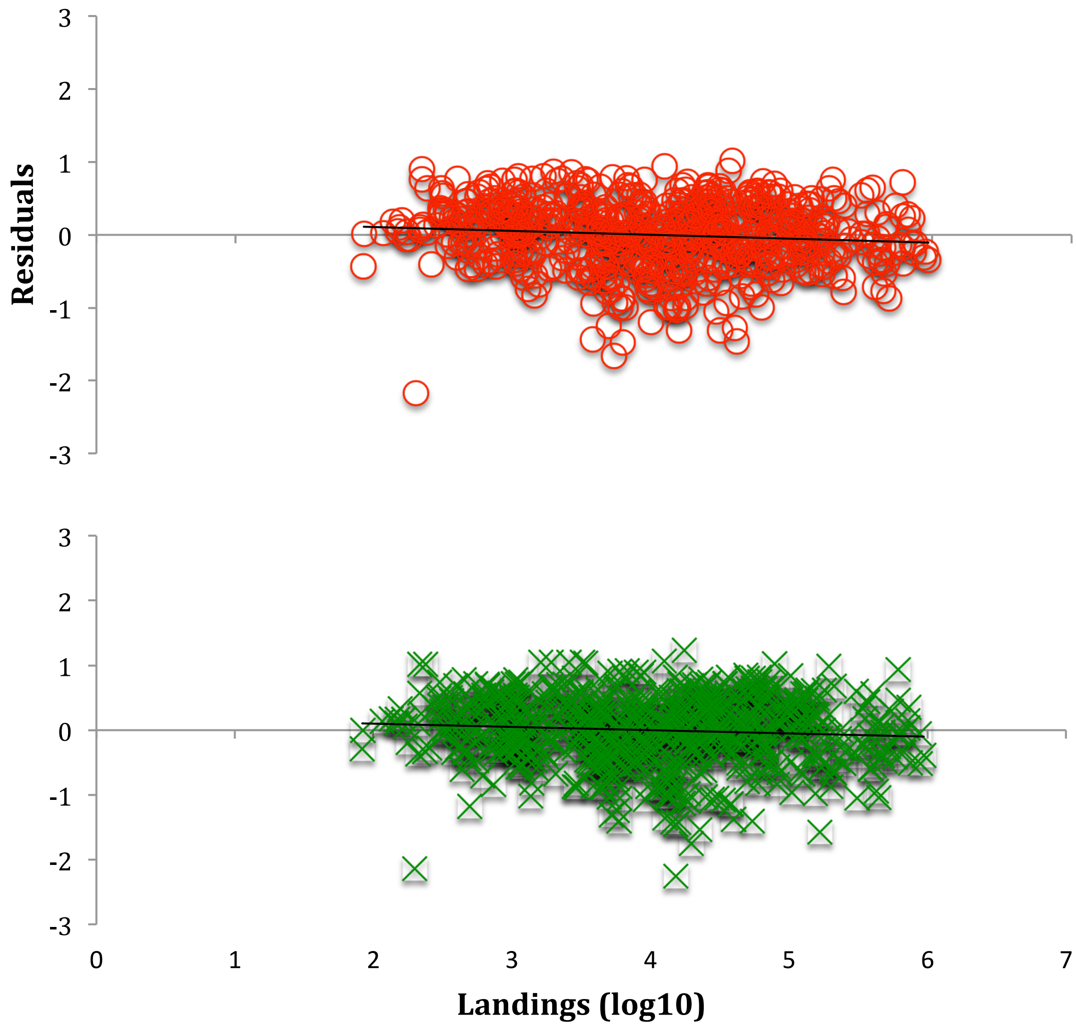

Figure F-4. Partial plot for landings (log 10) based on age-series within time for biomass (red) and biomass proportion (green). Residuals are derived from the fitted models shown in Table 3.3.

Appendix G – Raw Data Collection

This appendix contains the raw data collected for the fish stock Sole in Divisions VIIfg under ICES management. The data was collected from stock assessments conducted by the 'Working Group on the Assessment of Southern Shelf Demersal Stocks' from 2000 to 2008, and by the 'Working Group on the Celtic Seas Ecoregion' from 2009 to 2013. The following tables show the catch-at-age observed (number of 000's of pieces), weight-at-age observed (kg), beginning of the year population numbers (000's of pieces), estimated natural mortality (continuous %), estimated fishing mortality (continuous %), calculated exploitation rate (continuous %), total allowable catch (t), recorded landings (t), discards, maturity, age of 100% maturity, weight of 100% maturity (kg) and assessment model used. A reference is provided for each variable and is in the following format: working group/year assessment was published, table number (if required), page in document where information found. This appendix adds to the thesis by showing an example of the raw database created to gather all required information needed for this study. All 64 other fish stocks used in this study followed the same format during data collection.

Table G-1: Raw observed catch-at-age (000's of pieces) data from Sole in Divisions VIIfg managed by ICES

	Catch-at-Age Observed (000's of pieces)										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	Reference
1999	-	-	-	-	-	-	-	-	-	-	-
2000	0	1,721	1,480	683	241	60	56	43	19	51	SS/02, t4.3.4, pg256
2001	0	767	2,089	937	475	264	71	42	28	87	SS/03, t4.3.4, pg239
2002	0	29	1,465	2,202	660	249	95	54	36	51	SS/04, t4.3.4, pg240
2003	0	116	684	1,114	1,826	395	219	79	26	72	SS/05, t4.3.4, pg255
2004	0	425	1,721	792	794	721	114	60	34	49	SS/06[1], t4.3.4, pg272
2005	0	271	855	837	473	398	348	48	41	43	SS/06[2], t4.3.4, pg315
2006	0	685	1,330	715	576	163	148	178	44	51	SS/07, t4.3.4, pg323
2007	0	322	847	739	476	317	150	147	177	72	SS/08, t4.3.5, pg296
2008	0	211	447	552	558	274	196	75	108	171	CS/09, t7.13.3, pg802
2009	0	599	458	421	343	289	172	102	43	190	CS/10, t7.13.3, pg932
2010	0	264	1,260	715	333	247	157	114	64	112	CS/11, t7.13.3, pg960
2011	0	93	758	1,079	297	204	145	99	49	149	CS/12, t7.13.3, pg1005
2012	0	159	230	1,032	1,327	363	205	136	89	242	CS/13, t7.13.3, pg983

Table G-2: Raw observed weight-at-age (kg) data from Sole in Divisions VIIfg managed by ICES

	Weight-at-Age Observed (kg)										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	Reference
1999	0.100	0.141	0.197	0.304	0.401	0.487	0.593	0.600	0.694	0.773	SS/01, t4.3.5, pg242
2000	0.078	0.166	0.248	0.322	0.390	0.451	0.506	0.553	0.594	0.665	SS/02, t4.3.5, pg257
2001	0.134	0.175	0.216	0.257	0.299	0.341	0.383	0.425	0.467	0.591	SS/03, t4.3.5, pg240
2002	0.054	0.130	0.202	0.271	0.336	0.399	0.457	0.513	0.564	0.705	SS/04, t4.3.5, pg241
2003	0.123	0.171	0.218	0.266	0.313	0.361	0.408	0.454	0.501	0.636	SS/05, t4.3.5, pg256
2004	0.066	0.130	0.194	0.256	0.317	0.377	0.435	0.493	0.549	0.722	SS/06[1], t4.3.5, pg273
2005	0.068	0.145	0.219	0.288	0.354	0.415	0.473	0.528	0.578	0.692	SS/06[2], t4.3.5, pg316
2006	0.085	0.139	0.192	0.245	0.297	0.349	0.400	0.451	0.501	0.618	SS/07, t4.3.5, pg324
2007	0.085	0.144	0.203	0.260	0.314	0.365	0.414	0.460	0.503	0.609	SS/08, t4.3.6, pg297
2008	0.098	0.155	0.209	0.260	0.310	0.356	0.401	0.443	0.482	0.545	CS/09, t7.13.4, pg803
2009	0.132	0.178	0.225	0.271	0.317	0.363	0.408	0.454	0.499	0.604	CS/10, t7.13.4, pg933
2010	0.091	0.145	0.198	0.249	0.299	0.348	0.395	0.440	0.485	0.593	CS/11, t7.13.4, pg961
2011	0.140	0.204	0.266	0.325	0.382	0.437	0.489	0.539	0.586	0.686	CS/12, t7.13.4, pg1006
2012	0.134	0.169	0.204	0.240	0.276	0.313	0.351	0.389	0.428	0.551	CS/13, t7.13.4, pg984

Table G-3: Estimated beginning of year population-at-age (000’s of pieces) data from Sole in Divisions VIIfg managed by ICES

	Beginning of Year Population-at-age (000's of pieces)										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	Reference
1999	-	-	-	-	-	-	-	-	-	-	-
2000	0	5,129	3,480	1,990	682	314	173	124	61	79	SS/01, t4.3.11, pg254
2001	0	5,128	5,557	1,973	1,171	381	105	120	81	94	SS/02, t4.3.11, pg269
2002	0	4,459	4,839	5,172	1,042	616	193	68	71	151	SS/03, t4.3.11, pg253
2003	0	5,191	3,035	3,687	3,639	640	335	121	47	94	SS/04, t4.3.11, pg254
2004	0	4,555	4,109	1,883	2,122	2,272	391	196	73	118	SS/05, t4.3.11, pg269
2005	0	5,581	3,879	2,305	855	935	1,051	180	81	36	SS/06[1], t4.3.11, pg286
2006	0	4,352	4,003	2,465	1,303	444	520	1,061	147	219	SS/06[2], t4.3.11, pg330
2007	0	3,518	3,184	2,822	1,550	1,018	350	382	854	240	SS/07, t4.3.11, pg337
2008	0	4,589	2,063	2,688	1,824	1,230	882	310	359	1,065	SS/08, t4.3.12, pg310
2009	0	13,317	2,276	2,233	2,139	1,171	864	683	254	745	CS/09, t7.3.12, pg815
2010	0	6,624	7,615	2,634	1,972	1,847	1,027	625	585	1,187	CS/10, t7.13.12, pg947
2011	0	1,069	4,206	5,360	1,536	929	1,062	696	392	1,170	CS/11, t7.13.12, pg975
2012	0	6,310	926	3,773	4,122	941	530	623	442	1,146	CS/12, t7.13.12, pg1020

Table G-4: Estimated natural mortality data (continuous rate %) from Sole in Divisions VIIfg managed by ICES

	Natural Mortality (%)										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	Reference
1999	-	-	-	-	-	-	-	-	-	-	-
2000	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	SS/01, pg234
2001	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	SS/02, pg248
2002	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	SS/03, pg231
2003	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	SS/04, pg230
2004	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	SS/05, pg247
2005	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	SS/06[1], pg261
2006	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	SS/06[2], pg303
2007	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	SS/07, pg312
2008	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	SS/08, pg285
2009	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	CS/09, pg793
2010	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	CS/10, pg923
2011	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	CS/11, pg951
2012	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	CS/12, pg995

Table G-5: Estimated fishing mortality data (continuous rate %) from Sole in Divisions VIIfg managed by ICES

	Fishing Mortality (%)										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	Reference
1999	-	-	-	-	-	-	-	-	-	-	-
2000	0.0000	0.1573	0.6246	0.7936	0.6382	0.5711	0.4818	0.4283	0.5773	0.5773	SS/01, t4.3.10, pg253
2001	0.0000	0.2582	0.5385	0.4414	0.4707	0.4328	0.3667	0.4083	0.5354	0.5354	SS/02, t4.3.10, pg268
2002	0.0000	0.1404	0.3251	0.6182	0.5502	0.8345	0.6906	0.4478	0.5433	0.5433	SS/03, t4.3.10, pg252
2003	0.0000	0.0090	0.3206	0.4546	0.6832	0.5349	0.5588	0.7404	0.6321	0.6321	SS/04, t4.3.10, pg253
2004	0.0000	0.0265	0.1968	0.4050	0.5679	0.6738	0.7253	0.7092	0.5816	0.5816	SS/05, t4.3.10, pg268
2005	0.0000	0.0991	0.5366	0.6321	0.5920	0.5025	0.4706	0.5322	1.1531	1.1531	SS/06[1], t4.3.10, pg285
2006	0.0000	0.0624	0.2851	0.4770	0.6994	0.5471	0.2717	0.2709	0.3104	0.3104	SS/06[2], t4.3.10, pg329
2007	0.0000	0.1862	0.3704	0.3638	0.4306	0.3668	0.3138	0.1809	0.3198	0.3198	SS/07, t4.3.10, pg336
2008	0.0000	0.1390	0.2620	0.3260	0.3140	0.2940	0.3790	0.3290	0.2010	0.2010	SS/08, t4.3.11, pg309
2009	0.0000	0.0850	0.1740	0.2200	0.3740	0.2640	0.2410	0.2480	0.3040	0.3040	CS/09, t7.13.11, pg814
2010	0.0000	0.0722	0.1531	0.1849	0.1627	0.2372	0.2325	0.1534	0.1709	0.1709	CS/10, t7.13.11, pg946
2011	0.0000	0.0580	0.2018	0.3665	0.2933	0.1998	0.1943	0.2443	0.1336	0.1336	CS/11, t7.13.11, pg974
2012	0.0000	0.0912	0.1749	0.2223	0.2624	0.3119	0.2001	0.1931	0.1520	0.1520	CS/12, t7.13.11, pg1019

Table G-6: Calculated exploitation rate (%) for Sole in Divisions VIIfg managed by ICES

	Exploitation Rate (%)									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
1999	-	-	-	-	-	-	-	-	-	-
2000	0.0000	0.1387	0.4443	0.5247	0.4513	0.4160	0.3653	0.3327	0.4194	0.4194
2001	0.0000	0.2170	0.3980	0.3408	0.3587	0.3355	0.2930	0.3201	0.3963	0.3963
2002	0.0000	0.1248	0.2648	0.4410	0.4045	0.5422	0.4773	0.3448	0.4007	0.4007
2003	0.0000	0.0085	0.2617	0.3489	0.4737	0.3960	0.4093	0.5008	0.4482	0.4482
2004	0.0000	0.0249	0.1703	0.3180	0.4143	0.4691	0.4938	0.4862	0.4217	0.4217
2005	0.0000	0.0899	0.3969	0.4482	0.4273	0.3774	0.3586	0.3945	0.6574	0.6574
2006	0.0000	0.0576	0.2366	0.3624	0.4815	0.4028	0.2269	0.2263	0.2546	0.2546
2007	0.0000	0.1619	0.2955	0.2911	0.3341	0.2931	0.2570	0.1577	0.2612	0.2612
2008	0.0000	0.1236	0.2198	0.2655	0.2571	0.2430	0.3011	0.2675	0.1736	0.1736
2009	0.0000	0.0776	0.1522	0.1883	0.2979	0.2213	0.2042	0.2094	0.2501	0.2501
2010	0.0000	0.0663	0.1353	0.1609	0.1431	0.2013	0.1978	0.1355	0.1497	0.1497
2011	0.0000	0.0537	0.1742	0.2929	0.2425	0.1726	0.1683	0.2067	0.1191	0.1191
2012	0.0000	0.0830	0.1529	0.1900	0.2201	0.2556	0.1729	0.1674	0.1344	0.1344

Table G-7: Additional variables gathered directly from the assessment of Sole in Divisions VIIfg managed by ICES

Year	**Total Allowable Catch (t)**	Reference	**Recorded Landings (t)**	Reference	**Discard[3]**
1999	-	-	-	-	-
2000	1,160	CS/14, t5.3.50.7, pg5	1,091	SS/02, t4.3.1, pg253	0
2001	1,020	SS/02, pg247	1,168	SS/03, t4.3.1, pg236	0
2002	1,070	SS/03, pg230	1,345	SS/04, t4.3.1, pg236	0
2003	1,240	SS/04, pg229	1,365	SS/05, t4.3.1, pg251	0
2004	1,050	SS/05, pg246	1,249	SS/06[1], t4.3.1, pg268	0
2005	1,000	SS/06[1], pg260	1,044	SS/06[2], t4.3.1, pg311	0
2006	950	SS/06[2], pg301	946	SS/07, t4.3.1, pg319	0
2007	893	SS/07, pg310	938	SS/08, t4.3.1, pg292	0
2008	964	SS/08, pg290	800	CS/09, t7.13.1, pg800	0
2009	993	CS/09, pg792	790	CS/10, t7.13.1, pg930	0
2010	993	CS/10, pg922	862	CS/11, t7.13.1, pg958	0
2011	1,241	CS/11, pg949	1,029	CS/12, t7.13.1, pg1003	0
2012	1,060	CS/12, pg994	1,096	CS/13, t7.13.1, pg980	0

Table G-7: (Continued)

Maturity[4]	**Age of 100% Maturity**	Reference	**Weight of 100% Mature (Kg)**	**Assessment Method**	Reference
-	-	-	-	-	-
0	6	SS/01, pg234	0.451	Extended Survivor Analysis (XSA)	SS/01, pg235
0	6	SS/02, pg248	0.341	Extended Survivor Analysis (XSA)	SS/02, pg249
0	6	SS/03, pg231	0.399	Extended Survivor Analysis (XSA)	SS/03, pg232
0	6	SS/04, pg230	0.361	Extended Survivor Analysis (XSA)	SS/04, pg231
0	6	SS/05, pg247	0.377	Extended Survivor Analysis (XSA)	SS/05, pg248
0	6	SS/06[1], pg261	0.415	Extended Survivor Analysis (XSA)	SS/06[1], pg263
0	6	SS/06[2], pg303	0.349	Extended Survivor Analysis (XSA)	SS/06[2], pg305
0	6	SS/07, pg312	0.365	Extended Survivor Analysis (XSA)	SS/07, pg314
0	6	SS/08, pg285	0.356	Extended Survivor Analysis (XSA)	SS/08, pg286
0	6	CS/09, pg793	0.363	Extended Survivor Analysis (XSA)	CS/09, pg795
0	6	CS/10, pg923	0.348	Extended Survivor Analysis (XSA)	CS/10, pg924
0	6	CS/11, pg951	0.437	Extended Survivor Analysis (XSA)	CS/11, pg952
0	6	CS/12, pg995	0.313	Extended Survivor Analysis (XSA)	CS/12, pg996

[3] discards negligible/not mentioned (0); discards included (1)
[4] knife-edge ogive/constant ogive (0); empirical ogive (1)

Appendix H – Calculated Observed and Predicted Catch

This appendix contains the calculated observed and predicted catch-at-age for the fish stock Sole in Division VIIfg under ICES management from 2000 to 2012. The harvest measures were calculated using the information gathered in the previous appendix (see Appendix A – Raw Data Collection). The following tables show the calculated observed catch-at-age biomass (in 000's metric tonnes, MT), calculated predicted catch-at-age biomass (in 000's MT), calculated observed catch-at-age biomass proportion, calculated predicted catch-at-age biomass proportion, observed catch-at-age abundance (000's of pieces) converted to log10, predicted catch-at-age abundance (000's of pieces) converted to log10, observed catch-at-age biomass (000's of MT) converted to log10, predicted catch-at-age biomass (000's of MT) converted to log10. All 64 other fish stocks used in this study followed the same format when calculating observed and predicted catch.

Table H-1: Calculated observed catch biomass (in 000's, MT) from the raw data in Sole in Divisions VIIfg managed by ICES

	Catch-at-age Biomass Observed (000's MT)									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2000	-	286	367	220	94	27	28	24	11	34
2001	-	134	451	241	142	90	27	18	13	51
2002	-	4	296	597	222	99	43	28	20	36
2003	-	20	149	296	572	143	89	36	13	46
2004	-	55	334	203	252	272	50	30	19	35
2005	-	39	187	241	167	165	165	25	24	30
2006	-	95	255	175	171	57	59	80	22	32
2007	-	46	172	192	149	116	62	68	89	44
2008	-	33	93	144	173	98	79	33	52	93
2009	-	107	103	114	109	105	70	46	21	115
2010	-	38	249	178	100	86	62	50	31	66
2011	-	19	202	351	113	89	71	53	29	102
2012	-	27	47	248	366	114	72	53	38	133

Table H-2: Calculated predicted catch biomass (in 000's MT) from the raw data in Sole in Divisions VIIfg managed by ICES

	Catch-at-age Biomass Predicted (000's MT)									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2000	-	100	305	317	123	64	37	25	18	26
2001	-	185	549	217	164	58	16	21	19	25
2002	-	97	277	586	126	114	35	10	13	36
2003	-	6	160	349	579	101	63	31	12	30
2004	-	19	153	159	275	385	79	43	15	32
2005	-	65	299	264	116	133	164	35	29	17
2006	-	36	207	257	222	74	56	127	22	39
2007	-	79	181	201	154	104	36	27	112	39
2008	-	82	92	186	147	109	110	38	31	113
2009	-	160	72	109	198	92	71	63	31	102
2010	-	78	232	115	89	135	83	38	44	107
2011	-	8	145	391	111	56	71	63	23	83
2012	-	107	38	233	347	105	45	56	35	106

Table H-3: Calculated observed catch biomass proportion from the raw data in Sole in Divisions VIIfg managed by ICES

	Catch-at-age Biomass Observed Proportion									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2000	-	0.2619	0.3364	0.2016	0.0861	0.0248	0.0260	0.0218	0.0103	0.0311
2001	-	0.1149	0.3864	0.2062	0.1216	0.0771	0.0233	0.0153	0.0112	0.0440
2002	-	0.0028	0.2200	0.4437	0.1649	0.0739	0.0323	0.0206	0.0151	0.0267
2003	-	0.0145	0.1094	0.2173	0.4192	0.1046	0.0655	0.0263	0.0096	0.0336
2004	-	0.0442	0.2674	0.1624	0.2016	0.2177	0.0397	0.0237	0.0149	0.0283
2005	-	0.0377	0.1794	0.2310	0.1604	0.1583	0.1577	0.0243	0.0227	0.0285
2006	-	0.1006	0.2697	0.1850	0.1807	0.0601	0.0625	0.0848	0.0233	0.0333
2007	-	0.0494	0.1833	0.2048	0.1593	0.1233	0.0662	0.0721	0.0949	0.0467
2008	-	0.0410	0.1172	0.1800	0.2170	0.1224	0.0986	0.0417	0.0653	0.1169
2009	-	0.1350	0.1304	0.1444	0.1376	0.1328	0.0888	0.0586	0.0272	0.1452
2010	-	0.0445	0.2898	0.2068	0.1156	0.0998	0.0720	0.0583	0.0361	0.0771
2011	-	0.0184	0.1959	0.3408	0.1103	0.0866	0.0689	0.0519	0.0279	0.0993
2012	-	0.0245	0.0427	0.2257	0.3337	0.1035	0.0656	0.0482	0.0347	0.1214

Table H-4: Calculated predicted catch biomass proportion from the raw data in Sole in Divisions VIIfg managed by ICES

	Catch-at-age Biomass Predicted Proportion									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2000	-	0.0988	0.3001	0.3127	0.1216	0.0627	0.0369	0.0244	0.0175	0.0252
2001	-	0.1476	0.4381	0.1730	0.1308	0.0461	0.0124	0.0170	0.0152	0.0198
2002	-	0.0752	0.2138	0.4528	0.0974	0.0880	0.0273	0.0077	0.0103	0.0276
2003	-	0.0043	0.1206	0.2620	0.4353	0.0760	0.0471	0.0234	0.0089	0.0223
2004	-	0.0167	0.1315	0.1373	0.2372	0.3316	0.0679	0.0373	0.0133	0.0273
2005	-	0.0581	0.2661	0.2356	0.1032	0.1185	0.1461	0.0312	0.0260	0.0152
2006	-	0.0349	0.1994	0.2473	0.2135	0.0714	0.0537	0.1219	0.0208	0.0371
2007	-	0.0849	0.1937	0.2158	0.1649	0.1117	0.0386	0.0291	0.1198	0.0415
2008	-	0.0900	0.1014	0.2044	0.1622	0.1202	0.1211	0.0420	0.0345	0.1240
2009	-	0.1784	0.0806	0.1217	0.2200	0.1027	0.0788	0.0706	0.0341	0.1131
2010	-	0.0849	0.2515	0.1246	0.0971	0.1465	0.0899	0.0417	0.0474	0.1164
2011	-	0.0087	0.1526	0.4112	0.1171	0.0587	0.0743	0.0666	0.0238	0.0870
2012	-	0.0998	0.0352	0.2177	0.3237	0.0982	0.0418	0.0525	0.0325	0.0986

Table H-5: Calculated observed catch-at-age abundance (in 000's of pieces) converted to log10 from the raw data in Sole in Divisions VIIfg managed by ICES

	Catch-at-age Abundance Observed (log10 of 000's of pieces)									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2000	-	3.24	3.17	2.83	2.38	1.78	1.75	1.63	1.28	1.71
2001	-	2.88	3.32	2.97	2.68	2.42	1.85	1.62	1.45	1.94
2002	-	1.46	3.17	3.34	2.82	2.40	1.98	1.73	1.56	1.71
2003	-	2.06	2.84	3.05	3.26	2.60	2.34	1.90	1.41	1.86
2004	-	2.63	3.24	2.90	2.90	2.86	2.06	1.78	1.53	1.69
2005	-	2.43	2.93	2.92	2.67	2.60	2.54	1.68	1.61	1.63
2006	-	2.84	3.12	2.85	2.76	2.21	2.17	2.25	1.64	1.71
2007	-	2.51	2.93	2.87	2.68	2.50	2.18	2.17	2.25	1.86
2008	-	2.32	2.65	2.74	2.75	2.44	2.29	1.88	2.03	2.23
2009	-	2.78	2.66	2.62	2.54	2.46	2.24	2.01	1.63	2.28
2010	-	2.42	3.10	2.85	2.52	2.39	2.20	2.06	1.81	2.05
2011	-	1.97	2.88	3.03	2.47	2.31	2.16	2.00	1.69	2.17
2012	-	2.20	2.36	3.01	3.12	2.56	2.31	2.13	1.95	2.38

Table H-6: Calculated predicted catch-at-age abundance (in 000's of pieces) converted to log10 from the raw data in Sole in Divisions VIIfg managed by ICES for each year within the period of record.

	Catch-at-age Abundance Predicted (log10 of 000's of pieces)									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2000	-	2.85	3.19	3.02	2.49	2.12	1.80	1.62	1.41	1.52
2001	-	3.05	3.34	2.83	2.62	2.11	1.49	1.58	1.51	1.57
2002	-	2.75	3.11	3.36	2.62	2.52	1.96	1.37	1.45	1.78
2003	-	1.65	2.90	3.11	3.24	2.40	2.14	1.78	1.32	1.62
2004	-	2.05	2.84	2.78	2.94	3.03	2.29	1.98	1.49	1.70
2005	-	2.70	3.19	3.01	2.56	2.55	2.58	1.85	1.73	1.37
2006	-	2.40	2.98	2.95	2.80	2.25	2.07	2.38	1.57	1.75
2007	-	2.76	2.97	2.91	2.71	2.47	1.95	1.78	2.35	1.80
2008	-	2.75	2.66	2.85	2.67	2.48	2.42	1.92	1.79	2.27
2009	-	3.01	2.54	2.62	2.80	2.41	2.25	2.16	1.80	2.27
2010	-	2.64	3.01	2.63	2.45	2.57	2.31	1.93	1.94	2.25
2011	-	1.76	2.86	3.20	2.57	2.21	2.25	2.16	1.67	2.14
2012	-	2.72	2.15	2.86	2.96	2.38	1.96	2.02	1.77	2.19

Table H-7: Calculated observed catch-at-age biomass (in 000's MT) converted to log10 from the raw data in Sole in Divisions VIIfg managed by ICES for each year within the period of record.

	Catch-at-age Biomass Observed (log10 of 000's MT)									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2000	-	2.46	2.56	2.34	1.97	1.43	1.45	1.38	1.05	1.53
2001	-	2.13	2.65	2.38	2.15	1.95	1.43	1.25	1.12	1.71
2002	-	0.58	2.47	2.78	2.35	2.00	1.64	1.44	1.31	1.56
2003	-	1.30	2.17	2.47	2.76	2.15	1.95	1.55	1.11	1.66
2004	-	1.74	2.52	2.31	2.40	2.43	1.70	1.47	1.27	1.55
2005	-	1.59	2.27	2.38	2.22	2.22	2.22	1.40	1.37	1.47
2006	-	1.98	2.41	2.24	2.23	1.76	1.77	1.90	1.34	1.50
2007	-	1.67	2.24	2.28	2.17	2.06	1.79	1.83	1.95	1.64
2008	-	1.51	1.97	2.16	2.24	1.99	1.90	1.52	1.72	1.97
2009	-	2.03	2.01	2.06	2.04	2.02	1.85	1.67	1.33	2.06
2010	-	1.58	2.40	2.25	2.00	1.93	1.79	1.70	1.49	1.82
2011	-	1.28	2.30	2.54	2.05	1.95	1.85	1.73	1.46	2.01
2012	-	1.43	1.67	2.39	2.56	2.06	1.86	1.72	1.58	2.12

Table H-8: Calculated predicted catch-at-age biomass (in 000's MT) converted to log10 from the raw data in Sole in Divisions VIIfg managed by ICES for each year within the period of record.

	Catch-at-age Biomass Predicted (log10 of 000's MT)									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2000	-	2.00	2.48	2.50	2.09	1.80	1.57	1.39	1.25	1.41
2001	-	2.27	2.74	2.34	2.21	1.76	1.19	1.33	1.28	1.39
2002	-	1.99	2.44	2.77	2.10	2.06	1.55	1.00	1.12	1.55
2003	-	0.76	2.21	2.54	2.76	2.00	1.80	1.49	1.07	1.47
2004	-	1.29	2.18	2.20	2.44	2.59	1.90	1.64	1.19	1.50
2005	-	1.81	2.48	2.42	2.06	2.12	2.21	1.54	1.47	1.23
2006	-	1.56	2.32	2.41	2.35	1.87	1.75	2.10	1.34	1.59
2007	-	1.90	2.26	2.30	2.19	2.02	1.56	1.43	2.05	1.59
2008	-	1.91	1.96	2.27	2.17	2.04	2.04	1.58	1.50	2.05
2009	-	2.20	1.86	2.04	2.30	1.96	1.85	1.80	1.49	2.01
2010	-	1.89	2.37	2.06	1.95	2.13	1.92	1.58	1.64	2.03
2011	-	0.92	2.16	2.59	2.05	1.75	1.85	1.80	1.36	1.92
2012	-	2.03	1.58	2.37	2.54	2.02	1.65	1.75	1.54	2.02

Appendix I – Calculating Predictive Power

This appendix contains the observed vs. predicted catch-at-age abundance (000's of pieces) for the fish stock Sole in Division VIIfg under ICES management. The following figures show the observed vs. predicted catch-at-age abundance for each age class (2-10) and for each year within the period of record (2000 – 2012). This appendix adds to the thesis by showing the method of how the R^2 value was calculated within the stock. All 64 other fish stocks used in this study followed the same format when calculating the R^2 value.

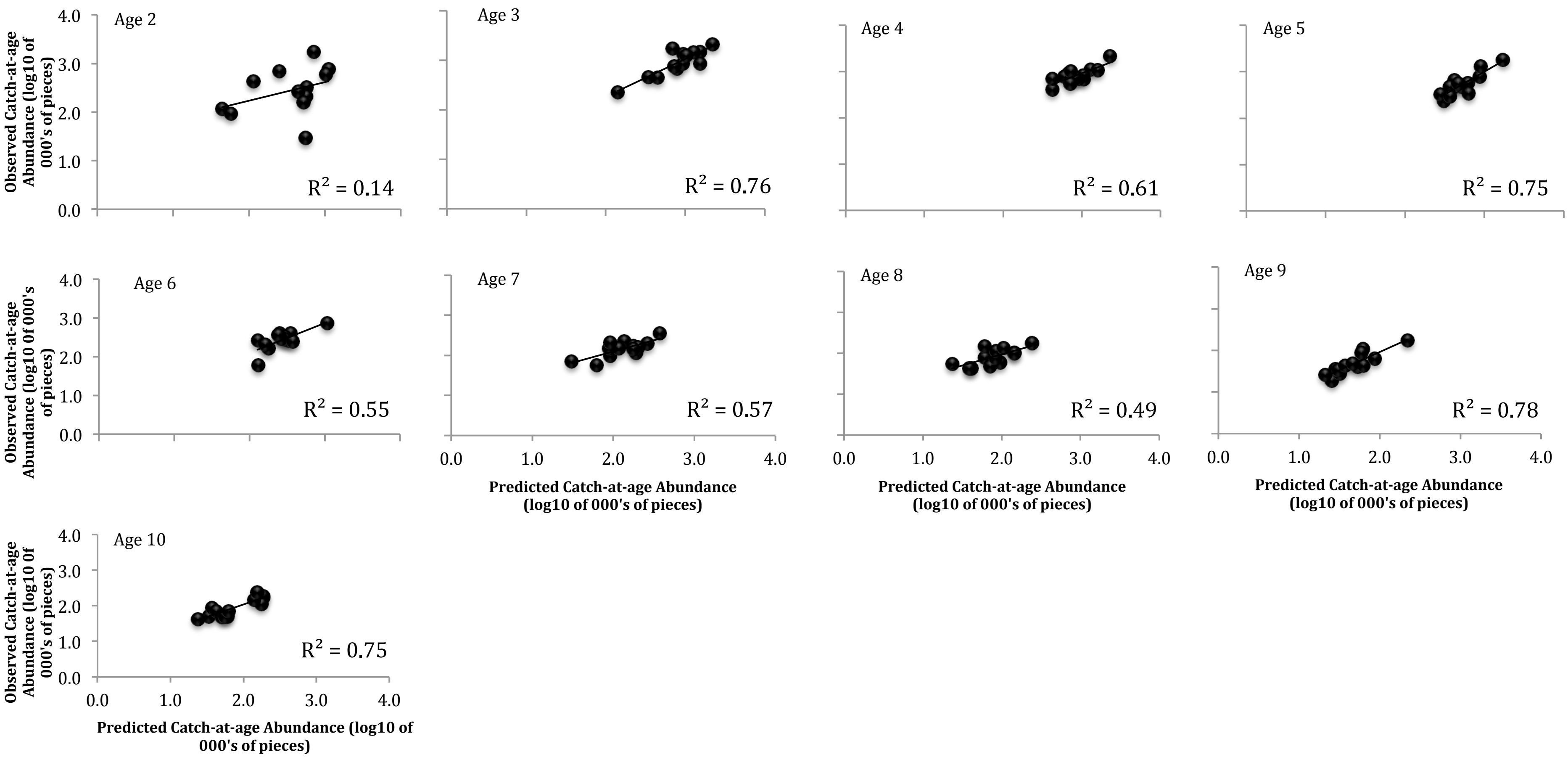

Figure I-1: Sole in Divisions VIIfg managed by ICES observed catch-at-age (log10 of 000's of pieces) versus predicted catch-at-age (log10 of 000's of pieces) for age classes 2 – 10. Each data point represents an individual year (2000 – 2012). The R^2 value for each graph is indicated on the graph.

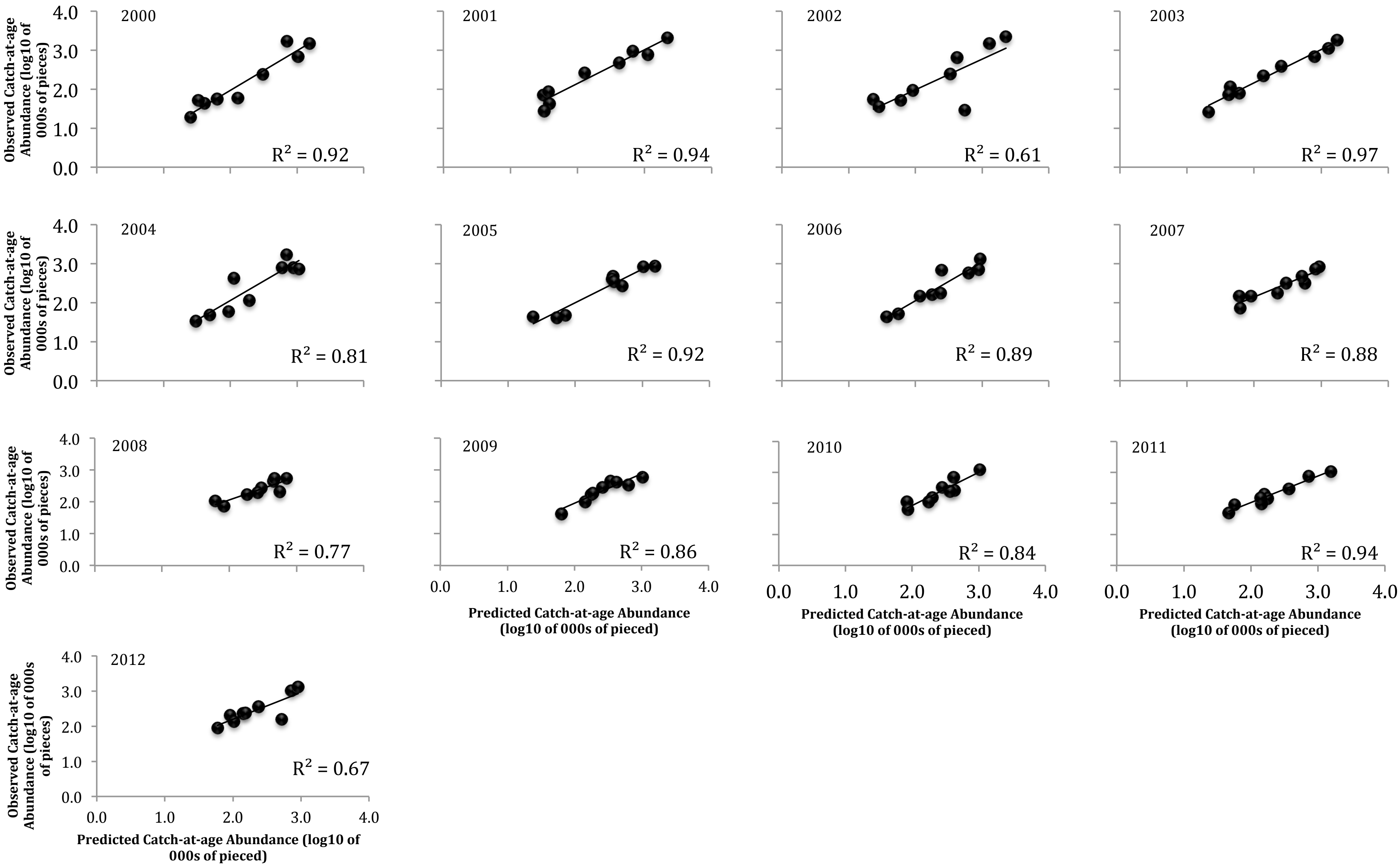

Figure I-2: Sole in Divisions VIIfg managed by ICES observed catch-at-age (log10 of 000's of pieces) versus predicted catch-at-age (log10 of 000's of pieces) for years 2000 – 2012. Each data point represents an individual age class (ages 2-10). The R^2 value for each graph is indicated on the graph.

Appendix J – Example of Final Database

The appendix contains the final database used in the analysis for the fish stock Sole in Division VIIfg under ICES management. The following tables shows the R^2 value and uniformity for each harvest measures (abundance, biomass and biomass proportion), organization, working group, species, number of countries, TAC, landings, discards, maturity, age of 100% maturity, and assessment method for both time-series within age and age-series within time. The following table for time-series within age also shows total number of years, normalized age, coverage, and difference of weight at age at 100% maturity, while the table of age-series within time also shows total number of age classes, normalized year, and weight at age at 100% maturity. The variable description and classification are explained in section 2.5 (Table 2.3 and Table 2.4 respectively). All 64 other fish stocks used in this study followed the same format for the final database.

Table J-1: Time-series within age for Sole in Divisions VIIfg managed by ICES

					Abundance		**Biomass**	
Stock	**Age**	**Age (normalized)**	**Total Number of Years**	**Coverage (%)**	**R^2**	**Uniformity**	**R^2**	**Uniformity**
Sole in Divisions VIIfg	2	0.2	13	100	0.14	0	0.10	0
Sole in Divisions VIIfg	3	0.3	13	100	0.76	0	0.81	0
Sole in Divisions VIIfg	4	0.4	13	100	0.61	0	0.76	0
Sole in Divisions VIIfg	5	0.5	13	100	0.75	0	0.71	0
Sole in Divisions VIIfg	6	0.6	13	100	0.55	0	0.53	0
Sole in Divisions VIIfg	7	0.7	13	100	0.57	0	0.66	0
Sole in Divisions VIIfg	8	0.8	13	100	0.49	0	0.44	0
Sole in Divisions VIIfg	9	0.9	13	100	0.78	1	0.73	1
Sole in Divisions VIIfg	10	1	13	100	0.75	1	0.77	1

Table J-1: (continued)

Biomass Proportion						
R^2	**Uniformity**	**Organization**	**N Working Group**	**Species**	**Number of Countries**	**Δ Natural Mortality**
0.22	0	ICES	2	Sole	3	0
0.74	0	ICES	2	Sole	3	0
0.76	0	ICES	2	Sole	3	0
0.82	0	ICES	2	Sole	3	0
0.68	1	ICES	2	Sole	3	0
0.78	0	ICES	2	Sole	3	0
0.60	1	ICES	2	Sole	3	0
0.82	1	ICES	2	Sole	3	0
0.83	1	ICES	2	Sole	3	0

Table J-1: (continued)

Σ TAC	**Σ Landings**	**Δ Discards**	**Δ Maturity**	**Δ Age of 100% Maturity**	**Δ Weight at Age at 100% Maturity**	**Δ Assessment Method**
13,634	13,723	0	0	0	0.003	0
13,634	13,723	0	0	0	-0.044	0
13,634	13,723	0	0	0	-0.082	0
13,634	13,723	0	0	0	-0.114	0
13,634	13,723	0	0	0	-0.138	0
13,634	13,723	0	0	0	-0.155	0
13,634	13,723	0	0	0	-0.164	0
13,634	13,723	0	0	0	-0.166	0
13,634	13,723	0	0	0	-0.114	0

Table J-2: Age-series within time for Sole in Divisions VIIfg managed by ICES

				Abundance		Biomass	
Stock	**Year**	**Year (normalized)**	**Total Number of Age Classes**	**R^2**	**Uniformity**	**R^2**	**Uniformity**
Sole in Divisions VIIfg	2000	0	9	0.92	0	0.82	0
Sole in Divisions VIIfg	2001	1	9	0.94	0	0.90	0
Sole in Divisions VIIfg	2002	2	9	0.61	0	0.43	0
Sole in Divisions VIIfg	2003	3	9	0.97	0	0.95	0
Sole in Divisions VIIfg	2004	4	9	0.81	0	0.80	0
Sole in Divisions VIIfg	2005	5	9	0.92	0	0.87	0
Sole in Divisions VIIfg	2006	6	9	0.89	0	0.77	0
Sole in Divisions VIIfg	2007	7	9	0.88	0	0.68	0
Sole in Divisions VIIfg	2008	8	9	0.77	0	0.61	0
Sole in Divisions VIIfg	2009	9	9	0.86	0	0.71	0
Sole in Divisions VIIfg	2010	10	9	0.84	0	0.68	0
Sole in Divisions VIIfg	2011	11	9	0.94	0	0.94	0
Sole in Divisions VIIfg	2012	12	9	0.67	0	0.65	0

Table J-2: (continued)

Biomass Proportion							
R^2	**Uniformity**	**Organization**	**Working Group**	**Species**	**Number of Countries**	**Natural Mortality**	**TAC**
0.66	2	ICES	Southern Shelf Demersal	Sole	3	0	1,160
0.97	2	ICES	Southern Shelf Demersal	Sole	3	0	1,020
0.94	1	ICES	Southern Shelf Demersal	Sole	3	0	1,070
0.98	1	ICES	Southern Shelf Demersal	Sole	3	0	1,240
0.65	1	ICES	Southern Shelf Demersal	Sole	3	0	1,050
0.80	1	ICES	Southern Shelf Demersal	Sole	3	0	1,000
0.75	1	ICES	Southern Shelf Demersal	Sole	3	0	950
0.88	1	ICES	Southern Shelf Demersal	Sole	3	0	893
0.73	1	ICES	Southern Shelf Demersal	Sole	3	0	964
0.47	1	ICES	Celtic Seas Ecoregion	Sole	3	0	993
0.76	2	ICES	Celtic Seas Ecoregion	Sole	3	0	993
0.95	2	ICES	Celtic Seas Ecoregion	Sole	3	0	1,241
0.92	1	ICES	Celtic Seas Ecoregion	Sole	3	0	1,060

Table J-2: (continued)

Landings	Discards	Maturity	Age of 100% Maturity	Weight of Age of Maturity	Assessment
1,091	0	1	6	0.451	Extended Survivor Analysis (XSA)
1,168	0	1	6	0.341	Extended Survivor Analysis (XSA)
1,345	0	1	6	0.399	Extended Survivor Analysis (XSA)
1,365	0	1	6	0.361	Extended Survivor Analysis (XSA)
1,249	0	1	6	0.377	Extended Survivor Analysis (XSA)
1,044	0	1	6	0.415	Extended Survivor Analysis (XSA)
946	0	1	6	0.349	Extended Survivor Analysis (XSA)
938	0	1	6	0.365	Extended Survivor Analysis (XSA)
800	0	1	6	0.356	Extended Survivor Analysis (XSA)
790	0	1	6	0.363	Extended Survivor Analysis (XSA)
862	0	1	6	0.348	Extended Survivor Analysis (XSA)
1,029	0	1	6	0.437	Extended Survivor Analysis (XSA)
1,096	0	1	6	0.313	Extended Survivor Analysis (XSA)

Appendix K – Calculated R^2 Values

This appendix contains the calculated predictive power (R^2) values for all 65 fish stocks included in this study. They show the species, stock, organization, and harvest measures for both time-series within age and age-series within time. The following table for time-series within age also shows the total number (N) of age classes and the R^2 value for each year within the period of record, while the table for age-series within time also shows the total number (N) of years within the period of record, and the R^2 value for each age class. This appendix adds to the thesis by showing all the R^2 values that are used within the final analysis.

Table K-1: The time-series within age R^2 values for abundance, biomass and biomass proportion over 65 stocks from ages 0 to 15 years old

					Age Classes															
Species	**Stock**	**Organization**	**N(year)**	**Harvest measures**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Anglerfish *(L. budegassa)*	Divisions VIIb-k and VIIIa,b	ICES	6	Abundance	-	-	-	0.04	0.24	0.76	0.09	0.21	0.33	0.26	0.00	0.15	0.02	0.11	0.04	-
				Biomass	-	-	-	0.01	0.22	0.78	0.12	0.26	0.23	0.38	0.01	0.11	0.00	0.06	0.09	-
				Proportion	-	-	-	0.07	0.23	0.67	0.00	0.07	0.26	0.40	0.00	0.06	0.12	0.26	0.04	-
Anglerfish *(L. piscatorius)*	Divisions VIIb-k and VIIIa,b	ICES	6	Abundance	-	-	0.45	0.01	0.02	0.00	0.23	0.59	0.36	0.38	0.31	0.38	0.73	0.02	-	-
				Biomass	-	-	0.30	0.00	0.10	0.17	0.33	0.53	0.37	0.32	0.25	0.24	0.51	0.06	-	-
				Proportion	-	-	0.28	0.08	0.00	0.20	0.00	0.16	0.01	0.03	0.03	0.01	0.00	0.00	-	-
Cod	3Pn4RS	DFO	4	Abundance	-	-	-	-	-	0.24	0.02	0.01	0.22	0.00	0.78	0.08	0.04	-	-	-
				Biomass	-	-	-	-	-	0.16	0.06	0.01	0.19	0.00	0.64	0.06	0.21	-	-	-
				Proportion	-	-	-	-	-	0.91	0.37	0.83	0.31	0.37	0.69	0.04	0.03	-	-	-
Cod	3Ps	DFO	5	Abundance	-	-	-	-	-	0.98	0.98	0.90	0.94	0.97	0.94	0.99	-	-	-	-
				Biomass	-	-	-	-	-	0.98	0.98	0.98	0.98	0.98	0.98	0.98	-	-	-	-
				Proportion	-	-	-	-	-	0.67	0.50	0.60	0.00	0.40	0.02	0.70	-	-	-	-
Cod	4TVn	DFO	8	Abundance	-	-	-	-	-	-	0.02	0.00	0.00	0.00	0.13	0.38	0.42	0.55	0.51	-
				Biomass	-	-	-	-	-	-	0.05	0.00	0.00	0.01	0.11	0.05	0.47	0.44	0.49	-
				Proportion	-	-	-	-	-	-	0.14	0.01	0.00	0.12	0.35	0.00	0.04	0.01	0.17	-
Cod	4X5Y	DFO	6	Abundance	-	-	-	0.07	0.03	0.64	0.55	0.44	0.37	-	-	-	-	-	-	-
				Biomass	-	-	-	0.02	0.04	0.66	0.69	0.22	0.04	-	-	-	-	-	-	-
				Proportion	-	-	-	0.00	0.37	0.07	0.01	0.52	0.03	-	-	-	-	-	-	-

Table K-1: (Continued)

Species	Stock	Organization	N(year)	Harvest measures	Age Classes 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cod	5Z	DFO	6	Abundance	-	-	0.57	0.50	0.51	0.38	0.37	0.07	0.40	-	-	-	-	-	-	-
				Biomass	-	-	0.59	0.61	0.32	0.44	0.27	0.07	0.35	-	-	-	-	-	-	-
				Proportion	-	-	0.69	0.05	0.05	0.61	0.50	0.30	0.66	-	-	-	-	-	-	-
Cod	Subareas I and II (Norwegian Coast)	ICES	13	Abundance	-	-	-	0.00	0.08	0.75	0.53	0.14	0.00	0.01	-	-	-	-	-	-
				Biomass	-	-	-	0.00	0.00	0.56	0.48	0.18	0.04	0.00	-	-	-	-	-	-
				Proportion	-	-	-	0.21	0.23	0.18	0.02	0.03	0.05	0.11	-	-	-	-	-	-
Cod	Subareas I and II (North-East Arctic)	ICES	13	Abundance	-	-	-	-	0.61	0.59	0.51	0.81	0.92	0.78	0.84	0.90	0.91	0.72	-	-
				Biomass	-	-	-	-	0.55	0.51	0.54	0.82	0.93	0.81	0.85	0.88	0.90	0.75	-	-
				Proportion	-	-	-	-	0.58	0.56	0.63	0.64	0.86	0.62	0.72	0.62	0.92	0.43	-	-
Cod	Kattegat	ICES	9	Abundance	-	-	0.30	0.50	0.57	0.40	-	-	-	-	-	-	-	-	-	-
				Biomass	-	-	0.22	0.26	0.41	0.51	-	-	-	-	-	-	-	-	-	-
				Proportion	-	-	0.30	0.49	0.93	0.23	-	-	-	-	-	-	-	-	-	-
Cod	Subdivision 22-24	ICES	13	Abundance	-	-	0.19	0.77	0.46	0.44	0.59	0.32	-	-	-	-	-	-	-	-
				Biomass	-	-	0.16	0.80	0.48	0.40	0.50	0.08	-	-	-	-	-	-	-	-
				Proportion	-	-	0.46	0.76	0.54	0.51	0.52	0.25	-	-	-	-	-	-	-	-
Cod	Subdivision 25-32	ICES	13	Abundance	-	-	-	0.10	0.14	0.17	0.50	0.43	-	-	-	-	-	-	-	-
				Biomass	-	-	-	0.06	0.16	0.10	0.14	0.05	-	-	-	-	-	-	-	-
				Proportion	-	-	-	0.46	0.76	0.54	0.51	0.52	-	-	-	-	-	-	-	-
Cod	Subarea VIa	ICES	10	Abundance	-	-	0.00	0.12	0.07	0.03	0.23	0.02	-	-	-	-	-	-	-	-
				Biomass	-	-	0.01	0.11	0.12	0.01	0.12	0.02	-	-	-	-	-	-	-	-
				Proportion	-	-	0.17	0.58	0.62	0.49	0.10	0.04	-	-	-	-	-	-	-	-
Cod	VIIa	ICES	12	Abundance	-	0.54	0.43	0.30	0.64	-	-	-	-	-	-	-	-	-	-	-
				Biomass	-	0.50	0.34	0.25	0.61	-	-	-	-	-	-	-	-	-	-	-
				Proportion	-	0.62	0.54	0.56	0.45	-	-	-	-	-	-	-	-	-	-	-
Cod	Division VIIe-k	ICES	10	Abundance	-	-	0.47	0.84	0.83	0.84	0.56	0.25	-	-	-	-	-	-	-	-
				Biomass	-	-	0.62	0.88	0.88	0.82	0.57	0.30	-	-	-	-	-	-	-	-
				Proportion	-	-	0.66	0.83	0.89	0.83	0.61	0.13	-	-	-	-	-	-	-	-

Table K-1: (Continued)

Species	Stock	Organization	N(year)	Harvest measures	Age Classes 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cod	Subareas IIIa, IV and VIId	ICES	12	Abundance	-	-	0.06	0.10	0.45	0.35	0.76	0.52	-	-	-	-	-	-	-	-
				Biomass	-	-	0.03	0.12	0.40	0.36	0.74	0.45	-	-	-	-	-	-	-	-
				Proportion	-	-	0.18	0.22	0.16	0.19	0.15	0.26	-	-	-	-	-	-	-	-
Cod	Division Va	ICES	11	Abundance	-	-	-	0.60	0.87	0.74	0.96	0.85	0.47	0.51	0.55	0.88	-	-	-	-
				Biomass	-	-	-	0.62	0.83	0.75	0.96	0.79	0.30	0.29	0.63	0.87	-	-	-	-
				Proportion	-	-	-	0.51	0.77	0.84	0.55	0.44	0.68	0.07	0.61	0.97	-	-	-	-
Cod	5Z	TRAC	8	Abundance	-	-	0.66	0.01	0.77	0.24	0.80	0.06	0.03	-	-	-	-	-	-	-
				Biomass	-	-	0.57	0.00	0.80	0.26	0.77	0.09	0.01	-	-	-	-	-	-	-
				Proportion	-	-	0.12	0.03	0.82	0.36	0.68	0.31	0.69	-	-	-	-	-	-	-
Haddock	4X5Y	DFO	7	Abundance	-	-	-	0.40	0.31	0.33	0.43	0.25	0.25	0.02	0.15	-	-	-	-	-
				Biomass	-	-	-	0.46	0.57	0.29	0.58	0.09	0.24	0.00	0.23	-	-	-	-	-
				Proportion	-	-	-	0.39	0.58	0.17	0.73	0.23	0.23	0.00	0.01	-	-	-	-	-
Haddock	5Z	DFO	7	Abundance	-	-	0.39	0.32	0.88	0.31	0.88	0.91	0.83	-	-	-	-	-	-	-
				Biomass	-	-	0.36	0.29	0.83	0.34	0.85	0.15	0.90	-	-	-	-	-	-	-
				Proportion	-	-	0.23	0.56	0.60	0.65	0.82	0.80	0.96	-	-	-	-	-	-	-
Haddock	Subareas I and II (Northeast Arctic)	ICES	13	Abundance	-	-	-	-	0.61	0.63	0.88	0.83	0.93	0.66	0.72	0.05	-	-	-	-
				Biomass	-	-	-	-	0.53	0.59	0.88	0.80	0.92	0.65	0.78	0.11	-	-	-	-
				Proportion	-	-	-	-	0.37	0.37	0.59	0.60	0.89	0.49	0.75	0.06	-	-	-	-
Haddock	Division VIa	ICES	12	Abundance	-	-	0.49	0.84	0.93	0.60	0.74	0.74	0.38	-	-	-	-	-	-	-
				Biomass	-	-	0.54	0.80	0.93	0.64	0.80	0.78	0.32	-	-	-	-	-	-	-
				Proportion	-	-	0.63	0.72	0.94	0.93	0.85	0.67	0.36	-	-	-	-	-	-	-
Haddock	Division VIb	ICES	11	Abundance	-	-	-	0.36	0.60	0.67	0.17	0.44	-	-	-	-	-	-	-	-
				Biomass	-	-	-	0.24	0.59	0.64	0.32	0.37	-	-	-	-	-	-	-	-
				Proportion	-	-	-	0.20	0.19	0.07	0.54	0.93	-	-	-	-	-	-	-	-
Haddock	Division VIIb-k	ICES	12	Abundance	-	-	-	-	0.14	0.11	0.01	0.23	-	-	-	-	-	-	-	-
				Biomass	-	-	-	-	0.34	0.32	0.06	0.16	-	-	-	-	-	-	-	-
				Proportion	-	-	-	-	0.39	0.22	0.04	0.03	-	-	-	-	-	-	-	-

Table K-1: (Continued)

Species	Stock	Organization	N(year)	Harvest measures	Age Classes 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Haddock	Subarea IV and Division IIIa	ICES	13	Abundance	-	0.88	0.95	0.97	0.83	0.89	0.91	0.86	-	-	-	-	-	-	-	-
				Biomass	-	0.93	0.90	0.84	0.82	0.68	0.92	0.84	-	-	-	-	-	-	-	-
				Proportion	-	0.68	0.92	0.95	0.96	0.96	0.96	0.96	-	-	-	-	-	-	-	-
Haddock	Division Va (Icelandic)	ICES	5	Abundance	-	-	-	0.65	0.98	0.98	0.96	0.85	0.75	0.78	-	-	-	-	-	-
				Biomass	-	-	-	0.60	0.99	0.99	0.96	0.80	0.65	0.92	-	-	-	-	-	-
				Proportion	-	-	-	0.76	0.99	0.99	0.97	0.60	0.52	0.92	-	-	-	-	-	-
Haddock	5Z	TRAC	8	Abundance	-	-	0.62	0.81	0.90	0.91	0.89	0.95	0.79	-	-	-	-	-	-	-
				Biomass	-	-	0.54	0.78	0.88	0.90	0.89	0.96	0.67	-	-	-	-	-	-	-
				Proportion	-	-	0.43	0.99	0.98	0.81	0.88	0.98	0.99	-	-	-	-	-	-	-
Hake	Subarea IIIa - VIIIabd	ICES	7	Abundance	-	0.30	0.05	0.33	0.11	0.01	0.26	0.11	0.04	-	-	-	-	-	-	-
				Biomass	-	0.06	0.01	0.05	0.06	0.13	0.09	0.08	0.06	-	-	-	-	-	-	-
				Proportion	-	0.41	0.27	0.16	0.15	0.01	0.06	0.01	0.00	-	-	-	-	-	-	-
Hake	Divisions VIIIc and IXa	ICES	8	Abundance	-	-	0.03	0.52	0.23	0.08	0.07	0.00	0.03	-	-	-	-	-	-	-
				Biomass	-	-	0.06	0.73	0.34	0.07	0.12	0.01	0.10	-	-	-	-	-	-	-
				Proportion	-	-	0.00	0.13	0.18	0.00	0.03	0.04	0.04	-	-	-	-	-	-	-
Halibut	Subareas I and II	ICES	13	Abundance	-	-	-	-	-	-	0.03	0.15	0.02	0.14	0.68	0.17	0.20	0.64	0.40	0.78
				Biomass	-	-	-	-	-	-	0.10	0.43	0.00	0.02	0.70	0.22	0.03	0.62	0.27	0.78
				Proportion	-	-	-	-	-	-	0.00	0.45	0.03	0.02	0.71	0.09	0.01	0.71	0.09	0.47
Herring	Subdivison s 25-27, 28.2, 29, 32	ICES	11	Abundance	-	-	0.35	0.37	0.65	0.56	0.57	0.05	-	-	-	-	-	-	-	-
				Biomass	-	-	0.35	0.45	0.55	0.50	0.66	0.01	-	-	-	-	-	-	-	-
				Proportion	-	-	0.24	0.37	0.54	0.72	0.92	0.00	-	-	-	-	-	-	-	-
Herring	Subdivison 28.1	ICES	13	Abundance	-	-	0.75	0.77	0.83	0.73	0.76	0.84	0.36	-	-	-	-	-	-	-
				Biomass	-	-	0.77	0.72	0.82	0.77	0.78	0.85	0.35	-	-	-	-	-	-	-
				Proportion	-	-	0.66	0.74	0.71	0.86	0.66	0.83	0.28	-	-	-	-	-	-	-
Herring	Subdivison 30	ICES	11	Abundance	-	-	0.09	0.60	0.53	0.57	0.29	0.87	0.69	0.25	-	-	-	-	-	-
				Biomass	-	-	0.19	0.60	0.57	0.56	0.24	0.86	0.55	0.13	-	-	-	-	-	-
				Proportion	-	-	0.02	0.61	0.62	0.81	0.65	0.82	0.65	0.08	-	-	-	-	-	-

Table K-1: (Continued)

Species	Stock	Organization	N(year)	Harvest measures	Age Classes															
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Herring	Subdivison 31	ICES	8	Abundance	-	-	0.11	0.64	0.41	0.26	0.89	0.25	0.39	0.43	-	-	-	-	-	-
				Biomass	-	-	0.14	0.66	0.46	0.21	0.87	0.14	0.18	0.46	-	-	-	-	-	-
				Proportion	-	-	0.04	0.77	0.71	0.38	0.89	0.17	0.84	0.00	-	-	-	-	-	-
Herring	Division VIIa	ICES	9	Abundance	-	-	0.29	0.01	0.00	0.24	0.26	0.12	0.02	-	-	-	-	-	-	-
				Biomass	-	-	0.31	0.01	0.01	0.26	0.29	0.14	0.01	-	-	-	-	-	-	-
				Proportion	-	-	0.21	0.00	0.45	0.67	0.82	0.52	0.13	-	-	-	-	-	-	-
Herring	Sub-area IV	ICES	13	Abundance	0.12	0.07	0.55	0.57	0.73	0.81	0.77	0.73	0.82	-	-	-	-	-	-	-
				Biomass	0.28	0.07	0.55	0.52	0.72	0.80	0.78	0.69	0.80	-	-	-	-	-	-	-
				Proportion	0.27	0.35	0.43	0.62	0.73	0.89	0.96	0.95	0.94	-	-	-	-	-	-	-
Herring	Division IIIa and Subdivision 22-32	ICES	13	Abundance	-	0.23	0.46	0.72	0.82	0.64	0.52	0.40	0.14	-	-	-	-	-	-	-
				Biomass	-	0.08	0.35	0.57	0.80	0.52	0.44	0.45	0.21	-	-	-	-	-	-	-
				Proportion	-	0.03	0.05	0.12	0.11	0.22	0.29	0.47	0.60	-	-	-	-	-	-	-
Herring	Celtic Sea and Division VIIj	ICES	9	Abundance	-	-	0.34	0.59	0.52	0.59	0.50	-	-	-	-	-	-	-	-	-
				Biomass	-	-	0.40	0.59	0.49	0.61	0.48	-	-	-	-	-	-	-	-	-
				Proportion	-	-	0.76	0.54	0.87	0.97	0.75	-	-	-	-	-	-	-	-	-
Herring	Division VIa (North)	ICES	13	Abundance	-	-	0.22	0.27	0.66	0.34	0.16	0.57	0.55	0.52	-	-	-	-	-	-
				Biomass	-	-	0.19	0.24	0.61	0.35	0.18	0.68	0.66	0.48	-	-	-	-	-	-
				Proportion	-	-	0.35	0.52	0.21	0.77	0.51	0.73	0.75	0.27	-	-	-	-	-	-
Herring	Division VIa (South) and VIIb,c	ICES	6	Abundance	-	-	0.05	0.14	0.34	0.18	0.43	0.13	0.09	0.62	-	-	-	-	-	-
				Biomass	-	-	0.00	0.13	0.35	0.14	0.42	0.05	0.17	0.51	-	-	-	-	-	-
				Proportion	-	-	0.00	0.36	0.62	0.02	0.22	0.24	0.02	0.06	-	-	-	-	-	-
Mackerel	Northeast Atlantic	ICES	13	Abundance	-	0.09	0.30	0.26	0.35	0.75	0.73	0.60	0.59	0.60	0.55	0.44	0.74	-	-	-
				Biomass	-	0.84	0.90	0.85	0.96	0.48	0.73	0.86	0.92	0.92	0.93	0.93	0.94	-	-	-
				Proportion	-	0.21	0.47	0.57	0.62	0.83	0.64	0.46	0.21	0.37	0.33	0.50	0.83	-	-	-
Megrim *(L. boscii)*	Divisions VIIIc and IXa	ICES	8	Abundance	-	-	0.27	0.38	0.29	0.23	0.17	0.02	-	-	-	-	-	-	-	-
				Biomass	-	-	0.13	0.37	0.36	0.38	0.10	0.03	-	-	-	-	-	-	-	-
				Proportion	-	-	0.11	0.18	0.46	0.46	0.02	0.15	-	-	-	-	-	-	-	-

Table K-1: (Continued)

Species	Stock	Organization	N(year)	Harvest measures	Age Classes															
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Megrim *(L. whiffiagonis)*	Divisions VIIb,c,e-k and VIIIa,b,d	ICES	6	Abundance	-	-	0.24	0.18	0.04	0.45	0.02	0.22	0.21	0.05	0.04	-	-	-	-	-
				Biomass	-	-	0.22	0.06	0.33	0.60	0.06	0.16	0.59	0.02	0.05	-	-	-	-	-
				Proportion	-	-	0.35	0.00	0.37	0.65	0.00	0.06	0.42	0.00	0.02	-	-	-	-	-
Megrim *(L. whiffiagonis)*	Divisions VIIIc and IXa	ICES	10	Abundance	-	-	0.46	0.62	0.46	0.23	0.09	0.15	-	-	-	-	-	-	-	-
				Biomass	-	-	0.38	0.46	0.40	0.16	0.09	0.17	-	-	-	-	-	-	-	-
				Proportion	-	-	0.13	0.02	0.32	0.05	0.06	0.01	-	-	-	-	-	-	-	-
Plaice	Division VIIa	ICES	10	Abundance	-	-	-	0.83	0.77	0.70	0.45	0.30	0.16	0.00	-	-	-	-	-	-
				Biomass	-	-	-	0.78	0.83	0.76	0.62	0.49	0.30	0.03	-	-	-	-	-	-
				Proportion	-	-	-	0.17	0.01	0.06	0.64	0.55	0.57	0.26	-	-	-	-	-	-
Plaice	Divison VIIe	ICES	13	Abundance	-	-	0.04	0.45	0.76	0.41	0.55	0.75	0.66	0.62	0.21	-	-	-	-	-
				Biomass	-	-	0.03	0.41	0.78	0.44	0.51	0.79	0.62	0.63	0.18	-	-	-	-	-
				Proportion	-	-	0.05	0.48	0.45	0.32	0.69	0.81	0.59	0.51	0.27	-	-	-	-	-
Plaice	Division VIIf,g	ICES	11	Abundance	-	-	0.02	0.44	0.32	0.22	0.36	0.56	0.32	0.63	-	-	-	-	-	-
				Biomass	-	-	0.00	0.66	0.44	0.38	0.34	0.58	0.35	0.67	-	-	-	-	-	-
				Proportion	-	-	0.03	0.40	0.16	0.23	0.05	0.31	0.08	0.00	-	-	-	-	-	-
Plaice	Division VIId	ICES	13	Abundance	-	-	0.18	0.29	0.77	0.59	0.41	0.21	-	-	-	-	-	-	-	-
				Biomass	-	-	0.13	0.14	0.74	0.56	0.45	0.20	-	-	-	-	-	-	-	-
				Proportion	-	-	0.11	0.51	0.56	0.46	0.57	0.20	-	-	-	-	-	-	-	-
Plaice	Subarea IIIa	ICES	8	Abundance	-	-	-	0.26	0.22	0.25	0.11	0.00	0.16	0.22	0.13	-	-	-	-	-
				Biomass	-	-	-	0.28	0.25	0.21	0.16	0.01	0.20	0.30	0.14	-	-	-	-	-
				Proportion	-	-	-	0.43	0.51	0.32	0.02	0.05	0.29	0.23	0.23	-	-	-	-	-
Plaice	Subarea IV	ICES	13	Abundance	-	-	0.20	0.29	0.61	0.83	0.70	0.62	0.63	0.45	0.37	-	-	-	-	-
				Biomass	-	-	0.17	0.29	0.68	0.83	0.77	0.64	0.63	0.49	0.43	-	-	-	-	-
				Proportion	-	-	0.01	0.67	0.65	0.67	0.60	0.68	0.62	0.27	0.19	-	-	-	-	-
Pollock	4VWX5Z	DFO	5	Abundance	-	-	-	0.64	0.66	0.81	0.42	0.46	0.64	0.01	-	-	-	-	-	-
				Biomass	-	-	-	0.70	0.66	0.90	0.26	0.59	0.63	0.01	-	-	-	-	-	-
				Proportion	-	-	-	0.26	0.90	0.46	0.27	0.87	0.34	0.27	-	-	-	-	-	-

Table K-1: (Continued)

Species	Stock	Organization	N(year)	Harvest measures	Age Classes 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Saithe	Subareas I and II	ICES	13	Abundance	-	-	-	-	0.32	0.48	0.80	0.60	0.68	0.78	0.20	0.35	-	-	-	-
				Biomass	-	-	-	-	0.30	0.53	0.79	0.61	0.77	0.83	0.25	0.20	-	-	-	-
				Proportion	-	-	-	-	0.28	0.39	0.89	0.49	0.88	0.67	0.28	0.02	-	-	-	-
Saithe	Subarea IV, VI and Division IIIa	ICES	12	Abundance	-	-	-	-	0.26	0.53	0.76	0.06	0.39	0.17	0.19	-	-	-	-	-
				Biomass	-	-	-	-	0.25	0.48	0.69	0.00	0.32	0.14	0.07	-	-	-	-	-
				Proportion	-	-	-	-	0.34	0.49	0.62	0.01	0.45	0.25	0.22	-	-	-	-	-
Sole	Division IIIA	ICES	13	Abundance	-	-	-	0.00	0.13	0.62	0.50	0.31	0.23	0.26	-	-	-	-	-	-
				Biomass	-	-	-	0.00	0.12	0.69	0.57	0.66	0.28	0.33	-	-	-	-	-	-
				Proportion	-	-	-	0.01	0.33	0.58	0.21	0.26	0.13	0.17	-	-	-	-	-	-
Sole	Division VIIa	ICES	11	Abundance	-	-	-	0.62	0.79	0.59	0.65	0.59	0.08	-	-	-	-	-	-	-
				Biomass	-	-	-	0.56	0.77	0.57	0.70	0.57	0.29	-	-	-	-	-	-	-
				Proportion	-	-	-	0.56	0.63	0.09	0.42	0.43	0.01	-	-	-	-	-	-	-
Sole	Division VIIe	ICES	12	Abundance	-	-	0.37	0.11	0.34	0.14	0.02	0.50	0.43	0.54	0.51	-	-	-	-	-
				Biomass	-	-	0.25	0.08	0.20	0.10	0.05	0.50	0.42	0.62	0.24	-	-	-	-	-
				Proportion	-	-	0.05	0.00	0.03	0.10	0.03	0.34	0.49	0.53	0.49	-	-	-	-	-
Sole	Division VIIfg	ICES	13	Abundance	-	-	0.14	0.76	0.61	0.75	0.55	0.57	0.49	0.78	0.75	-	-	-	-	-
				Biomass	-	-	0.10	0.81	0.76	0.71	0.53	0.66	0.44	0.73	0.77	-	-	-	-	-
				Proportion	-	-	0.22	0.74	0.76	0.82	0.68	0.78	0.60	0.82	0.83	-	-	-	-	-
Sole	Division VIId	ICES	13	Abundance	-	-	0.34	0.43	0.27	0.38	0.36	0.33	0.49	0.39	0.54	0.03	-	-	-	-
				Biomass	-	-	0.33	0.42	0.30	0.34	0.51	0.55	0.52	0.34	0.59	0.06	-	-	-	-
				Proportion	-	-	0.47	0.49	0.47	0.27	0.50	0.60	0.65	0.36	0.45	0.18	-	-	-	-
Sole	Subarea IV	ICES	13	Abundance	-	-	0.58	0.92	0.92	0.85	0.89	0.63	0.50	0.85	0.08	-	-	-	-	-
				Biomass	-	-	0.60	0.94	0.95	0.91	0.86	0.77	0.61	0.83	0.18	-	-	-	-	-
				Proportion	-	-	0.84	0.96	0.96	0.97	0.95	0.85	0.69	0.88	0.25	-	-	-	-	-
Sole	Division VIIIa,b	ICES	12	Abundance	-	-	-	0.01	0.04	0.02	0.00	0.19	0.30	-	-	-	-	-	-	-
				Biomass	-	-	-	0.01	0.05	0.09	0.00	0.26	0.25	-	-	-	-	-	-	-
				Proportion	-	-	-	0.02	0.20	0.07	0.06	0.00	0.13	-	-	-	-	-	-	-

Table K-1: (Continued)

					Age Classes															
Species	**Stock**	**Organization**	**N(year)**	**Harvest measures**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Sprat	Subdivisions 22-32	ICES	13	Abundance	-	-	0.20	0.58	0.11	0.16	0.40	0.43	0.34	-	-	-	-	-	-	-
				Biomass	-	-	0.24	0.61	0.11	0.16	0.40	0.46	0.34	-	-	-	-	-	-	-
				Proportion	-	-	0.61	0.72	0.66	0.52	0.41	0.31	0.50	-	-	-	-	-	-	-
Whiting	Subarea Via	ICES	5	Abundance	-	0.70	0.96	0.75	0.86	0.90	0.56	0.16	-	-	-	-	-	-	-	-
				Biomass	-	0.65	0.95	0.70	0.77	0.91	0.81	0.14	-	-	-	-	-	-	-	-
				Proportion	-	0.15	0.92	0.72	0.39	0.73	0.43	0.59	-	-	-	-	-	-	-	-
Whiting	Division VIIe-k	ICES	13	Abundance	-	0.13	0.49	0.36	0.48	0.42	0.77	-	-	-	-	-	-	-	-	-
				Biomass	-	0.11	0.55	0.33	0.58	0.38	0.73	-	-	-	-	-	-	-	-	-
				Proportion	-	0.21	0.67	0.33	0.74	0.76	0.82	-	-	-	-	-	-	-	-	-
Whiting	Subarea IV and Divisions VIId and IIIA	ICES	11	Abundance	-	-	0.06	0.57	0.90	0.85	0.75	-	-	-	-	-	-	-	-	-
				Biomass	-	-	0.66	0.73	0.69	0.47	0.45	-	-	-	-	-	-	-	-	-
				Proportion	-	-	0.61	0.54	0.52	0.61	0.88	-	-	-	-	-	-	-	-	-
Yellowtail Flounder	5Z	TRAC	8	Abundance	-	-	0.85	0.05	0.45	0.42	0.40	-	-	-	-	-	-	-	-	-
				Biomass	-	-	0.81	0.05	0.50	0.44	0.41	-	-	-	-	-	-	-	-	-
				Proportion	-	-	0.71	0.07	0.01	0.50	0.03	-	-	-	-	-	-	-	-	-

Table K-2: The age-series within time R^2 values for abundance, biomass and biomass proportion over 65 stocks from 1996 to 2013

Species	Stock	Organization	N(age)	Harvest measures	Year																
					'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
Anglerfish *(L. budegassa)*	Divisions VIIb-k and VIIIa,b	ICES	12	Abundance	-	-	-	-	-	0.58	0.73	0.90	0.66	0.41	0.78	-	-	-	-	-	-
				Biomass	-	-	-	-	-	0.66	0.05	0.91	0.80	0.90	0.85	-	-	-	-	-	-
				Proportion	-	-	-	-	-	0.38	0.15	0.66	0.26	0.86	0.56	-	-	-	-	-	-
Anglerfish *(L. piscatorius)*	Divisions VIIb-k and VIIIa,b	ICES	12	Abundance	-	-	-	-	-	0.83	0.86	0.83	0.91	0.90	0.66	-	-	-	-	-	-
				Biomass	-	-	-	-	-	0.55	0.22	0.27	0.89	0.91	0.51	-	-	-	-	-	-
				Proportion	-	-	-	-	-	0.39	0.34	0.58	0.86	0.92	0.22	-	-	-	-	-	-
Cod	3Pn4RS	DFO	8	Abundance	-	-	0.86	-	-	-	0.92	0.83	-	0.82	-	-	-	-	-	-	-
				Biomass	-	-	0.68	-	-	-	0.91	0.65	-	0.86	-	-	-	-	-	-	-
				Proportion	-	-	0.63	-	-	-	0.85	0.70	-	0.84	-	-	-	-	-	-	-
Cod	3Ps	DFO	7	Abundance	0.01	-	-	0.76	0.58	0.93	0.97	-	-	-	-	-	-	-	-	-	-
				Biomass	0.00	-	-	0.48	0.27	0.82	0.68	-	-	-	-	-	-	-	-	-	-
				Proportion	0.04	-	-	0.42	0.22	0.72	0.57	-	-	-	-	-	-	-	-	-	-
Cod	4TVn	DFO	9	Abundance	0.96	-	0.87	0.99	0.97	0.94	0.98	0.88	-	0.92	-	-	-	-	-	-	-
				Biomass	0.95	-	0.71	0.98	0.94	0.90	0.97	0.69	-	0.89	-	-	-	-	-	-	-
				Proportion	0.75	-	0.17	0.96	0.81	0.66	0.90	0.53	-	0.83	-	-	-	-	-	-	-
Cod	4X5Y	DFO	6	Abundance	0.81	0.92	0.62	0.90	0.89	-	0.99	-	-	-	-	-	-	-	-	-	-
				Biomass	0.63	0.76	0.34	0.77	0.80	-	0.96	-	-	-	-	-	-	-	-	-	-
				Proportion	0.17	0.78	0.07	0.48	0.64	-	0.99	-	-	-	-	-	-	-	-	-	-
Cod	5Z	DFO	7	Abundance	0.92	0.91	-	0.75	0.62	0.29	0.95	-	-	-	-	-	-	-	-	-	-
				Biomass	0.94	0.91	-	0.74	0.52	0.67	0.97	-	-	-	-	-	-	-	-	-	-
				Proportion	0.77	0.96	-	0.54	0.48	0.48	0.95	-	-	-	-	-	-	-	-	-	-
Cod	Subareas I and II (Norwegian Coast)	ICES	7	Abundance	-	-	-	-	0.82	0.77	0.89	0.59	0.53	0.72	0.86	0.83	0.42	0.42	0.42	0.89	0.83
				Biomass	-	-	-	-	0.28	0.69	0.89	0.40	0.60	0.90	0.68	0.69	0.84	0.52	0.86	0.81	0.84
				Proportion	-	-	-	-	0.04	0.57	0.48	0.24	0.54	0.91	0.27	0.31	0.62	0.48	0.69	0.77	0.56
Cod	Subareas I and II (North-East Arctic)	ICES	10	Abundance	-	-	-	-	0.99	0.99	0.99	0.99	1.00	0.99	0.95	0.98	0.99	0.98	0.94	0.97	0.96
				Biomass	-	-	-	-	0.98	0.98	0.99	0.98	0.99	0.98	0.93	0.96	0.98	0.97	0.88	0.95	0.95
				Proportion	-	-	-	-	0.96	0.98	0.99	0.90	0.95	0.86	0.83	0.79	0.93	0.92	0.88	0.84	0.95

Table K-2: (Continued)

Species	Stock	Organization	N(age)	Harvest measures	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
Cod	Kattegat	ICES	4	Abundance	-	-	-	-	1.00	0.81	0.99	0.98	0.86	0.76	0.66	0.62	0.47	-	-	-	-
				Biomass	-	-	-	-	0.97	0.87	0.89	0.24	0.96	0.04	0.79	0.14	0.49	-	-	-	-
				Proportion	-	-	-	-	0.97	0.96	0.84	0.44	0.85	0.13	0.87	0.74	0.12	-	-	-	-
Cod	Subdivision 22-24	ICES	6	Abundance	-	-	-	-	1.00	0.87	0.99	0.84	0.91	0.96	0.99	0.90	0.96	0.93	0.85	0.78	0.80
				Biomass	-	-	-	-	1.00	0.73	0.98	0.63	0.81	0.90	0.98	0.86	0.94	0.77	0.60	0.58	0.67
				Proportion	-	-	-	-	0.99	0.49	0.85	0.91	0.53	0.90	1.00	0.90	0.93	0.70	0.69	0.50	0.73
Cod	Subdivision 25-32	ICES	5	Abundance	-	-	-	-	0.96	0.98	0.99	0.98	0.97	0.97	0.99	0.95	0.96	0.96	0.94	0.83	0.97
				Biomass	-	-	-	-	0.90	0.95	0.96	0.89	0.94	0.83	0.96	0.91	0.96	0.94	0.84	0.49	0.88
				Proportion	-	-	-	-	0.74	0.91	0.92	0.70	0.93	0.69	0.97	0.87	0.90	0.77	0.77	0.36	0.96
Cod	Subarea VIa	ICES	6	Abundance	-	-	-	-	-	-	0.97	0.97	0.98	-	0.93	0.96	0.96	0.86	0.77	0.44	0.04
				Biomass	-	-	-	-	-	-	0.93	0.92	0.94	-	0.80	0.87	0.87	0.85	0.50	0.03	0.00
				Proportion	-	-	-	-	-	-	0.98	0.93	0.78	-	0.78	0.79	0.96	0.83	0.00	0.00	0.10
Cod	VIIa	ICES	4	Abundance	-	-	-	-	0.15	0.87	1.00	0.75	0.54	-	0.40	0.58	0.90	0.77	0.68	0.94	0.97
				Biomass	-	-	-	-	0.30	0.75	0.96	0.78	0.67	-	0.74	0.85	0.93	0.87	0.34	0.85	1.00
				Proportion	-	-	-	-	0.27	0.99	0.98	0.61	0.54	-	0.93	0.91	0.52	0.89	0.47	0.73	1.00
Cod	Division VIIe-k	ICES	6	Abundance	-	-	-	-	0.95	0.95	0.96	0.99	0.89	0.95	0.98	0.98	1.00	-	-	-	0.97
				Biomass	-	-	-	-	0.90	0.92	0.93	1.00	0.86	0.86	0.96	0.95	1.00	-	-	-	0.95
				Proportion	-	-	-	-	0.69	0.96	0.99	0.99	0.87	0.67	0.90	0.85	0.96	-	-	-	0.97
Cod	Subareas IIIa, IV and VIId	ICES	6	Abundance	-	-	-	-	0.99	0.99	0.98	0.85	0.95	-	0.98	0.96	0.86	0.85	0.89	0.94	0.91
				Biomass	-	-	-	-	0.97	0.98	0.98	0.67	0.89	-	0.89	0.87	0.62	0.61	0.71	0.75	0.68
				Proportion	-	-	-	-	0.93	0.96	0.99	0.61	0.75	-	0.79	0.61	0.12	0.21	0.38	0.39	0.72
Cod	Division Va	ICES	9	Abundance	-	-	-	-	0.95	0.99	0.98	0.98	0.99	0.99	0.70	0.98	-	0.52	0.95	0.96	-
				Biomass	-	-	-	-	0.88	0.96	0.94	0.97	0.99	0.97	0.64	0.94	-	0.70	0.92	0.90	-
				Proportion	-	-	-	-	0.86	0.92	0.97	0.98	0.95	0.97	0.08	0.96	-	0.40	0.89	0.96	-
Cod	5Z	TRAC	7	Abundance	-	-	-	-	-	-	-	-	0.88	0.65	0.01	0.75	0.75	0.83	0.91	0.86	-
				Biomass	-	-	-	-	-	-	-	-	0.97	0.63	0.26	0.69	0.76	0.80	0.80	0.86	-
				Proportion	-	-	-	-	-	-	-	-	0.81	0.53	0.04	0.96	0.93	0.91	0.65	0.93	-

Table K-2: (Continued)

Species	Stock	Organization	N(age)	Harvest measures	Year '96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
Haddock	4X5Y	DFO	8	Abundance	0.42	0.83	0.63	0.49	-	-	0.24	0.33	-	0.66	-	-	-	-	-	-	-
				Biomass	0.36	0.81	0.68	0.59	-	-	0.45	0.35	-	0.76	-	-	-	-	-	-	-
				Proportion	0.14	0.92	0.73	0.59	-	-	0.66	0.62	-	0.60	-	-	-	-	-	-	-
Haddock	5Z	DFO	7	Abundance	0.92	0.77	0.77	0.96	0.70	0.67	0.59	-	-	-	-	-	-	-	-	-	-
				Biomass	0.94	0.75	0.60	0.97	0.76	0.71	0.44	-	-	-	-	-	-	-	-	-	-
				Proportion	0.90	0.75	0.71	0.90	0.95	0.71	0.78	-	-	-	-	-	-	-	-	-	-
Haddock	Subareas I and II (Northeast Arctic)	ICES	8	Abundance	-	-	-	-	0.93	0.74	0.96	0.96	0.94	0.89	0.88	0.94	0.93	0.98	0.89	0.90	0.85
				Biomass	-	-	-	-	0.89	0.59	0.95	0.94	0.93	0.84	0.78	0.90	0.87	0.96	0.82	0.87	0.82
				Proportion	-	-	-	-	0.84	0.25	0.79	0.87	0.66	0.71	0.57	0.89	0.64	0.96	0.95	0.99	0.94
Haddock	Division VIa	ICES	7	Abundance	-	-	-	-	0.93	0.99	0.97	1.00	0.92	-	0.93	0.94	0.53	0.84	0.76	0.87	0.20
				Biomass	-	-	-	-	0.83	0.99	0.98	0.99	0.89	-	0.88	0.60	0.39	0.81	0.57	0.83	0.12
				Proportion	-	-	-	-	0.84	0.99	1.00	0.99	0.91	-	0.56	0.71	0.86	0.99	0.95	0.96	0.34
Haddock	Division VIb	ICES	5	Abundance	-	-	-	-	0.29	0.01	0.11	-	-	0.96	0.86	0.84	0.95	0.00	0.00	0.38	0.62
				Biomass	-	-	-	-	0.26	0.04	0.02	-	-	0.93	0.69	0.79	0.94	0.00	0.00	0.65	0.59
				Proportion	-	-	-	-	0.43	0.02	0.02	-	-	0.96	0.80	0.88	0.96	0.01	0.03	0.58	0.97
Haddock	Division VIIb-k	ICES	4	Abundance	-	-	-	-	-	0.33	0.26	0.68	0.51	0.18	0.98	0.85	0.39	0.34	0.59	0.82	0.84
				Biomass	-	-	-	-	-	0.16	0.30	0.59	0.39	0.03	0.97	0.96	0.94	0.80	0.43	0.61	0.89
				Proportion	-	-	-	-	-	0.38	0.27	0.98	0.31	0.01	0.99	0.94	0.82	0.83	0.66	0.96	0.87
Haddock	Subarea IV and Division IIIa	ICES	7	Abundance	-	-	-	-	0.95	0.98	0.93	0.93	0.91	0.97	0.97	0.95	0.96	0.92	0.95	0.92	0.90
				Biomass	-	-	-	-	0.72	0.97	0.96	0.92	0.88	0.93	0.96	0.93	0.93	0.89	0.89	0.87	0.91
				Proportion	-	-	-	-	0.39	1.00	0.99	0.95	0.94	0.97	0.93	0.98	0.96	0.98	0.91	0.77	1.00
Haddock	Division Va (Icelandic)	ICES	7	Abundance	-	-	-	-	0.98	0.99	0.99	0.97	0.97	-	-	-	-	-	-	-	-
				Biomass	-	-	-	-	0.94	1.00	0.98	0.94	0.97	-	-	-	-	-	-	-	-
				Proportion	-	-	-	-	0.96	1.00	0.96	0.96	0.98	-	-	-	-	-	-	-	-
Haddock	5Z	TRAC	7	Abundance	-	-	-	-	-	-	-	-	0.90	0.55	0.95	0.90	0.95	0.93	0.95	0.92	-
				Biomass	-	-	-	-	-	-	-	-	0.91	0.65	0.96	0.86	0.95	0.95	0.89	0.91	-
				Proportion	-	-	-	-	-	-	-	-	0.79	0.65	0.60	0.99	1.00	1.00	1.00	0.97	-

Table K-2: (Continued)

Species	Stock	Organization	N(age)	Harvest measures	Year '96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
Hake	Subarea IIIa - VIIIabd	ICES	8	Abundance	-	-	-	-	0.59	0.82	0.17	0.54	0.95	-	-	0.89	0.84	-	-	-	-
				Biomass	-	-	-	-	0.85	0.96	0.81	0.94	0.95	-	-	0.68	0.60	-	-	-	-
				Proportion	-	-	-	-	0.77	0.83	0.75	0.71	0.75	-	-	0.46	0.20	-	-	-	-
Hake	Divisions VIIIc and IXa	ICES	7	Abundance	-	-	-	-	0.96	0.94	0.94	0.94	0.96	0.94	0.99	1.00	-	-	-	-	-
				Biomass	-	-	-	-	0.86	0.77	0.78	0.56	0.86	0.81	0.97	0.98	-	-	-	-	-
				Proportion	-	-	-	-	0.69	0.82	0.77	0.51	0.95	0.49	0.97	0.97	-	-	-	-	-
Halibut	Subareas I and II	ICES	10	Abundance	-	-	-	-	0.97	0.96	0.98	0.94	0.73	0.95	0.95	0.96	0.87	0.78	0.75	0.82	0.84
				Biomass	-	-	-	-	0.93	0.92	0.96	0.84	0.20	0.75	0.75	0.57	0.41	0.21	0.06	0.67	0.63
				Proportion	-	-	-	-	0.93	0.75	0.85	0.75	0.00	0.82	0.76	0.58	0.52	0.18	0.07	0.55	0.52
Herring	Subdivisons 25-27, 28.2, 29, 32	ICES	6	Abundance	-	-	-	-	-	-	0.94	0.62	0.96	0.95	0.99	0.83	0.86	0.65	0.54	0.85	0.68
				Biomass	-	-	-	-	-	-	0.89	0.51	0.80	0.38	0.63	0.59	0.27	0.37	0.05	0.69	0.56
				Proportion	-	-	-	-	-	-	0.80	0.40	0.61	0.34	0.58	0.68	0.13	0.13	0.00	0.66	0.34
Herring	Subdivison 28.1	ICES	7	Abundance	-	-	-	-	0.95	0.93	0.95	0.94	0.95	0.93	0.91	0.94	0.94	0.99	0.99	0.96	0.99
				Biomass	-	-	-	-	0.92	0.88	0.93	0.91	0.90	0.94	0.88	0.93	0.88	0.98	0.99	0.95	0.98
				Proportion	-	-	-	-	0.87	0.93	0.90	0.71	0.94	0.93	0.88	0.99	0.84	0.91	0.99	0.86	0.99
Herring	Subdivison 30	ICES	8	Abundance	-	-	-	-	0.54	0.89	0.86	0.72	0.74	0.92	0.66	0.93	-	0.57	0.53	0.69	-
				Biomass	-	-	-	-	0.44	0.82	0.68	0.54	0.51	0.88	0.67	0.82	-	0.42	0.46	0.44	-
				Proportion	-	-	-	-	0.20	0.86	0.86	0.53	0.37	0.92	0.93	0.95	-	0.54	0.20	0.02	-
Herring	Subdivison 31	ICES	8	Abundance	-	-	-	-	0.66	0.72	0.79	0.82	0.65	0.84	0.80	0.93	-	-	-	-	-
				Biomass	-	-	-	-	0.50	0.53	0.75	0.77	0.50	0.79	0.66	0.85	-	-	-	-	-
				Proportion	-	-	-	-	0.90	0.11	0.75	0.81	0.24	0.89	0.54	0.80	-	-	-	-	-
Herring	Division VIIa	ICES	7	Abundance	-	-	-	-	0.74	0.97	0.91	0.48	0.88	0.91	0.96	0.97	-	-	-	1.00	-
				Biomass	-	-	-	-	0.66	0.96	0.89	0.30	0.77	0.87	0.95	0.96	-	-	-	0.99	-
				Proportion	-	-	-	-	0.28	0.81	0.89	0.19	0.45	0.68	0.81	0.95	-	-	-	0.99	-
Herring	Sub-area IV	ICES	9	Abundance	-	-	-	-	0.73	0.67	0.93	0.75	0.72	0.87	0.51	0.05	0.31	0.75	0.74	0.86	0.76
				Biomass	-	-	-	-	0.59	0.54	0.74	0.87	0.77	0.94	0.84	0.68	0.81	0.71	0.83	0.77	0.84
				Proportion	-	-	-	-	0.53	0.63	0.86	0.94	0.84	0.95	0.99	0.93	0.89	0.48	0.65	0.90	0.63

Table K-2: (Continued)

Species	Stock	Organization	N(age)	Harvest measures	Year '96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
Herring	Division IIIa and Subdivision 22-32	ICES	8	Abundance	-	-	-	-	0.98	0.92	0.99	0.87	0.95	0.97	0.83	0.88	0.88	0.82	0.62	0.81	0.98
				Biomass	-	-	-	-	0.96	0.88	0.95	0.84	0.90	0.84	0.60	0.72	0.76	0.59	0.08	0.32	0.74
				Proportion	-	-	-	-	0.90	0.90	0.95	0.74	0.78	0.68	0.37	0.71	0.62	0.30	0.00	0.11	0.83
Herring	Celtic Sea and Division VIIj	ICES	5	Abundance	-	-	-	-	0.98	0.99	0.93	0.89	0.91	-	-	-	-	0.98	0.52	0.60	0.38
				Biomass	-	-	-	-	0.97	0.99	0.91	0.78	0.85	-	-	-	-	0.97	0.45	0.68	0.33
				Proportion	-	-	-	-	0.99	0.99	0.74	0.93	0.99	-	-	-	-	0.99	0.37	0.86	0.19
Herring	Division VIa (North)	ICES	8	Abundance	-	-	-	-	0.58	0.92	0.50	0.76	0.55	0.35	0.70	0.14	0.00	0.53	0.72	0.91	0.86
				Biomass	-	-	-	-	0.48	0.93	0.38	0.76	0.50	0.25	0.72	0.08	0.01	0.67	0.58	0.87	0.83
				Proportion	-	-	-	-	0.03	0.99	0.84	0.77	0.91	0.02	0.62	0.12	0.01	0.49	0.23	0.87	0.84
Herring	Division VIa (South) and VIIb,c	ICES	8	Abundance	-	-	-	-	0.95	0.89	0.91	0.99	0.98	0.95	-	-	-	-	-	-	-
				Biomass	-	-	-	-	0.95	0.85	0.86	0.98	0.99	0.93	-	-	-	-	-	-	-
				Proportion	-	-	-	-	0.94	0.65	0.71	0.98	0.98	0.85	-	-	-	-	-	-	-
Mackerel	Northeast Atlantic	ICES	12	Abundance	-	-	-	-	0.92	0.87	0.86	0.98	0.56	0.77	0.80	0.95	0.94	0.95	0.95	0.94	0.94
				Biomass	-	-	-	-	0.21	0.37	0.26	0.26	0.71	0.67	0.55	0.52	0.61	0.51	0.44	0.76	0.21
				Proportion	-	-	-	-	0.91	0.95	0.85	0.91	0.11	0.87	0.96	0.96	0.70	0.77	0.91	0.96	0.97
Megrim *(L. boscii)*	Divisions VIIIc and IXa	ICES	6	Abundance	-	-	-	-	-	-	0.32	0.74	0.92	0.93	0.91	0.83	-	0.79	0.83	-	-
				Biomass	-	-	-	-	-	-	0.11	0.28	0.81	0.77	0.62	0.55	-	0.73	0.74	-	-
				Proportion	-	-	-	-	-	-	0.10	0.51	0.70	0.79	0.78	0.70	-	0.86	0.75	-	-
Megrim *(L. whiffiagonis)*	Divisions VIIb,c,e-k and VIIIa,b,d	ICES	9	Abundance	-	-	-	-	-	0.79	0.83	0.82	0.86	0.92	0.79	-	-	-	-	-	-
				Biomass	-	-	-	-	-	0.77	0.53	0.68	0.60	0.36	0.36	-	-	-	-	-	-
				Proportion	-	-	-	-	-	0.58	0.61	0.64	0.25	0.14	0.61	-	-	-	-	-	-
Megrim *(L. whiffiagonis)*	Divisions VIIIc and IXa	ICES	6	Abundance	-	-	-	-	0.81	0.42	0.84	0.58	0.68	0.69	0.81	0.73	-	0.75	0.28	-	-
				Biomass	-	-	-	-	0.78	0.48	0.32	0.01	0.13	0.20	0.04	0.18	-	0.42	0.78	-	-
				Proportion	-	-	-	-	0.66	0.59	0.27	0.04	0.06	0.18	0.20	0.13	-	0.36	0.67	-	-
Plaice	Division VIIa	ICES	7	Abundance	-	-	-	-	0.88	0.93	0.89	0.89	0.99	0.88	-	0.88	0.79	0.78	0.76	-	-
				Biomass	-	-	-	-	0.75	0.82	0.80	0.73	0.95	0.75	-	0.76	0.39	0.52	0.73	-	-
				Proportion	-	-	-	-	0.87	0.93	0.42	0.83	0.94	0.73	-	0.87	0.50	0.50	0.71	-	-

Table K-2: (Continued)

Species	Stock	Organization	N(age)	Harvest measures	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
					Year																
Plaice	Divison VIIe	ICES	9	Abundance	-	-	-	-	0.93	0.96	0.94	0.99	0.95	0.96	0.99	0.94	0.89	0.90	0.93	0.99	0.93
				Biomass	-	-	-	-	0.89	0.94	0.89	0.97	0.90	0.94	0.98	0.88	0.81	0.87	0.83	0.97	0.87
				Proportion	-	-	-	-	0.93	0.57	0.73	0.91	0.90	0.89	0.90	0.85	0.51	0.93	0.83	0.95	0.90
Plaice	Division VIIf,g	ICES	8	Abundance	-	-	-	-	0.98	0.92	0.75	0.80	0.98	0.97	0.92	0.93	0.90	0.97	0.94	-	-
				Biomass	-	-	-	-	0.97	0.79	0.55	0.76	0.96	0.94	0.79	0.81	0.72	0.95	0.88	-	-
				Proportion	-	-	-	-	0.97	0.45	0.26	0.93	0.92	0.79	0.68	0.89	0.82	0.91	0.88	-	-
Plaice	Division VIId	ICES	6	Abundance	-	-	-	-	0.89	0.99	0.96	0.95	0.84	0.98	0.70	0.92	0.97	0.98	0.72	0.80	0.91
				Biomass	-	-	-	-	0.76	0.98	0.91	0.94	0.75	0.96	0.50	0.77	0.93	0.95	0.45	0.65	0.92
				Proportion	-	-	-	-	0.80	0.96	0.94	0.97	0.68	0.85	0.49	0.67	0.93	0.91	0.16	0.83	0.97
Plaice	Subarea IIIa	ICES	8	Abundance	-	-	-	-	0.93	0.89	0.97	0.92	0.89	0.96	0.98	0.96	-	-	-	-	-
				Biomass	-	-	-	-	0.92	0.87	0.97	0.92	0.90	0.95	0.97	0.95	-	-	-	-	-
				Proportion	-	-	-	-	0.68	0.88	0.91	0.86	0.49	0.89	0.89	0.69	-	-	-	-	-
Plaice	Subarea IV	ICES	9	Abundance	-	-	-	-	0.93	0.99	0.91	0.99	0.80	0.78	0.82	0.83	0.70	0.80	0.80	0.70	0.46
				Biomass	-	-	-	-	0.88	0.98	0.85	0.96	0.67	0.66	0.74	0.75	0.58	0.70	0.68	0.49	0.30
				Proportion	-	-	-	-	0.96	0.98	0.53	0.88	0.51	0.06	0.17	0.12	0.01	0.14	0.09	0.07	0.08
Pollock	4VWX5Z	DFO	7	Abundance	-	0.91	0.98	0.99	-	-	-	-	0.94	1.00	-	-	-	-	-	-	-
				Biomass	-	0.76	0.97	0.99	-	-	-	-	0.93	1.00	-	-	-	-	-	-	-
				Proportion	-	0.85	0.99	0.98	-	-	-	-	0.65	0.99	-	-	-	-	-	-	-
Saithe	Subareas I and II	ICES	8	Abundance	-	-	-	-	0.99	0.80	0.96	0.70	0.90	0.69	0.73	0.43	0.92	0.87	0.90	0.89	0.83
				Biomass	-	-	-	-	0.94	0.48	0.92	0.32	0.87	0.64	0.27	0.17	0.88	0.60	0.81	0.70	0.41
				Proportion	-	-	-	-	0.89	0.60	0.98	0.09	0.93	0.71	0.07	0.66	0.94	0.68	0.76	0.66	0.52
Saithe	Subarea IV, VI and Division IIIa	ICES	7	Abundance	-	-	-	-	0.94	0.89	0.91	0.93	0.96	0.96	0.95	0.84	0.96	0.37	-	0.66	0.87
				Biomass	-	-	-	-	0.71	0.63	0.78	0.81	0.89	0.83	0.78	0.53	0.89	0.11	-	0.33	0.80
				Proportion	-	-	-	-	0.37	0.42	0.86	0.85	0.90	0.76	0.56	0.68	0.96	0.18	-	0.53	0.70
Sole	Division IIIA	ICES	7	Abundance	-	-	-	-	0.95	0.80	0.89	0.74	0.13	0.62	0.92	0.91	0.36	0.60	0.95	0.75	0.75
				Biomass	-	-	-	-	0.93	0.76	0.93	0.70	0.09	0.49	0.89	0.88	0.37	0.52	0.93	0.70	0.61
				Proportion	-	-	-	-	0.93	0.89	0.84	0.12	0.21	0.28	0.81	0.84	0.17	0.68	0.90	0.81	0.49

Table K-2: (Continued)

Species	Stock	Organization	N(age)	Harvest measures	Year '96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
Sole	Division VIIa	ICES	6	Abundance	-	-	-	-	0.83	0.90	0.56	0.50	0.30	-	-	0.77	0.91	0.80	0.79	0.71	0.64
				Biomass	-	-	-	-	0.84	0.84	0.34	0.50	0.16	-	-	0.73	0.86	0.55	0.70	0.76	0.42
				Proportion	-	-	-	-	0.47	0.45	0.46	0.53	0.22	-	-	0.61	0.82	0.84	0.65	0.65	0.51
Sole	Division VIIe	ICES	9	Abundance	-	-	-	-	0.88	0.81	0.97	0.86	0.82	0.74	0.85	0.87	0.86	-	0.78	0.96	0.66
				Biomass	-	-	-	-	0.83	0.77	0.95	0.76	0.58	0.55	0.85	0.80	0.83	-	0.72	0.94	0.79
				Proportion	-	-	-	-	0.62	0.64	0.86	0.68	0.49	0.17	0.90	0.90	0.92	-	0.83	0.83	0.65
Sole	Division VIIfg	ICES	9	Abundance	-	-	-	-	0.92	0.94	0.61	0.97	0.81	0.92	0.89	0.88	0.77	0.86	0.84	0.94	0.67
				Biomass	-	-	-	-	0.82	0.90	0.43	0.95	0.80	0.87	0.77	0.68	0.61	0.71	0.68	0.94	0.65
				Proportion	-	-	-	-	0.66	0.97	0.94	0.98	0.65	0.80	0.75	0.88	0.73	0.47	0.76	0.95	0.92
Sole	Division VIId	ICES	10	Abundance	-	-	-	-	0.96	0.97	0.95	0.95	0.99	0.96	0.98	0.96	0.82	0.91	0.94	0.89	0.89
				Biomass	-	-	-	-	0.97	0.97	0.94	0.92	0.98	0.91	0.96	0.92	0.74	0.87	0.91	0.85	0.85
				Proportion	-	-	-	-	0.96	0.94	0.88	0.98	0.96	0.72	0.94	0.82	0.71	0.65	0.68	0.81	0.88
Sole	Subarea IV	ICES	9	Abundance	-	-	-	-	0.95	0.95	0.96	0.95	0.94	0.95	0.94	0.99	0.96	0.96	0.97	0.96	0.89
				Biomass	-	-	-	-	0.96	0.98	0.99	0.92	0.95	0.97	0.93	0.99	0.94	0.96	0.96	0.95	0.89
				Proportion	-	-	-	-	0.96	0.90	0.96	0.95	0.99	0.98	0.92	0.99	0.98	0.99	0.96	0.86	0.98
Sole	Division VIIIa,b	ICES	6	Abundance	-	-	-	-	-	1.00	0.94	0.97	0.94	0.92	0.82	0.91	0.92	0.99	0.93	0.81	0.74
				Biomass	-	-	-	-	-	0.99	0.87	0.92	0.81	0.78	0.69	0.90	0.90	0.94	0.75	0.55	0.49
				Proportion	-	-	-	-	-	0.98	0.89	0.89	0.87	0.50	0.60	0.95	0.79	0.92	0.75	0.66	0.36
Sprat	Subdivisions 22-32	ICES	7	Abundance	-	-	-	-	0.98	0.84	0.55	0.62	0.46	0.78	0.94	0.96	0.91	0.88	0.85	0.86	0.97
				Biomass	-	-	-	-	0.98	0.79	0.54	0.59	0.45	0.74	0.93	0.94	0.89	0.86	0.83	0.85	0.97
				Proportion	-	-	-	-	0.98	0.93	0.74	0.52	0.66	0.71	0.82	0.97	0.90	0.86	0.95	0.94	0.91
Whiting	Subarea VIa	ICES	7	Abundance	-	-	-	-	-	0.66	0.53	0.54	0.25	-	-	-	-	-	-	-	0.01
				Biomass	-	-	-	-	-	0.52	0.42	0.46	0.11	-	-	-	-	-	-	-	0.00
				Proportion	-	-	-	-	-	0.25	0.37	0.00	0.01	-	-	-	-	-	-	-	0.01
Whiting	Division VIIe-k	ICES	6	Abundance	-	-	-	-	0.44	0.94	0.76	0.79	0.89	0.69	0.82	0.93	0.81	0.63	0.89	0.78	0.83
				Biomass	-	-	-	-	0.33	0.98	0.86	0.79	0.85	0.83	0.93	0.93	0.75	0.56	0.91	0.95	0.88
				Proportion	-	-	-	-	0.57	0.99	0.96	0.83	0.68	0.64	0.89	0.80	0.95	0.84	0.80	0.83	0.48

Table K-2: (Continued)

Species	Stock	Organization	N(age)	Harvest measures	Year '96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
Whiting	Subarea IV and Divisions VIId and IIIA	ICES	5	Abundance	-	-	-	-	0.99	-	-	0.59	0.85	0.12	0.27	0.62	0.94	0.59	0.04	0.19	0.51
				Biomass	-	-	-	-	0.97	-	-	0.96	0.05	0.01	0.65	0.65	0.22	0.60	0.57	0.47	0.07
				Proportion	-	-	-	-	0.93	-	-	0.88	0.03	0.03	0.40	0.22	0.02	0.89	0.58	0.52	0.08
Yellowtail Flounder	5Z	TRAC	5	Abundance	-	-	-	-	-	-	-	-	0.61	0.02	0.89	0.91	0.83	0.91	0.57	0.95	-
				Biomass	-	-	-	-	-	-	-	-	0.29	0.02	0.89	0.81	0.69	0.91	0.58	0.93	-
				Proportion	-	-	-	-	-	-	-	-	0.38	0.00	0.68	0.39	0.88	0.86	0.59	0.90	-