Northwest Atlantic Fisheries Organization

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SCIENTIFIC COUNCIL MEETING - JUNE 2007

NAFO SCIENTIFIC COUNCIL WORKING GROUP ON REPRODUCTIVE POTENTIAL

Progress of the NAFO Working Group on Reproductive Potential was provided by E.A. Trippel (Chair). The establishment of the Working Group on Reproductive Potential followed a recommendation of the Symposium on "Variations in Maturation, Growth, Condition and Spawning Stock Biomass Production in Groundfish" hosted by NAFO Scientific Council from 9-11 September 1998, Lisbon, Portugal. The Working Group is comprised of 21 members representing 8 countries (Canada, Denmark, Iceland, Norway, Russia, Spain, United Kingdom, and USA).

The 6th Meeting of the NAFO WG on Reproductive Potential was held in Klauster and Reykjavik (Askja Biology Building), Iceland, August 17-21, 2006. There were 16 WG participants spanning 8 countries: Tara Marshall (UK), Gudrun Marteinsdottir (Iceland), Richard Nash (Norway), Olav Kjesbu (Norway), Gerd Kraus (Germany), Joanne Morgan (Canada), Rosario Dominguez (Spain), Loretta O'Brien, (USA), Heidi Pardoe (Iceland), Nathalia Yaragina (Russia), Yvan Lambert (Canada), Rick Rideout (Canada), Hilario Murua (Spain), Charlotte Main (UK), Peter Wright (UK), and Ed Trippel (Canada). Local arrangements were provided by Gudrun Marteinsdottir which were greatly appreciated.

Significant progress on the majority of the second set of ToRs was achieved, both during the meeting and intersessionally. A brief summary of progress and future plans of each ToR are given below.

ToR 1: Co-Leaders: Jonna Tomkiewicz (Denmark) and Jay Burnett (USA)

Complete inventory of available data in standardized format on reproductive potential for fish stocks of the North Atlantic and Baltic Sea.

Members: everyone

The objective is to extend the tabulated information to comprise pelagic and demersal fish stocks in the North Atlantic, the Baltic Sea and the Western Mediterranean Sea. A total of 224 stocks have been identified, most of which have contributors. The existing 53 stock tables published in *NAFO Scientific Council Studies* Number 37 should be updated to reflect the modified tabular format. Progress has been slow to complete the additional tables. An additional ToR Co-Leader to help with this effort has been identified (Hilario Murua, (Spain). A re-evaluation is required of the number of stock tables that can be completed in concordance with available resources and obligations of staff at each institute where these data reside.

ToR 2: Co-Leaders: Yvan Lambert (Canada) and Gerd Kraus (Germany)

Explore the use of correlation analysis to estimate the reproductive potential of fish stocks having limited data availability.

Members: Hilario. Murua (Spain), Nathalia Yaragina (Russia), Gudrun Marteinsdottir (Iceland), Peter Wright (UK), Peter Witthames (UK)

ToR 3: Co-Leaders: Hilario Murua (Spain) and Gerd Kraus (Germany)

Model the inter-annual and inter-stock variability in size-dependent fecundity for stocks having multi-year estimates.

Members: Olav Kjesbu (Norway), Peter Witthames (UK), Rick Rideout (Canada), Tara Marshall (UK), Yvan Lambert (Canada), Gudrun Marteinsdottir (Iceland)

The above two terms of reference are related and have been joined.

The objectives of these two ToRs are to (i) identify patterns of variation in fecundity between different stocks of the same species, (ii) find environmental and biological factors that explain these patterns of variation and (iii) assign data poor stocks to environmental data groups and apply fecundity models of rich stocks of the same environmental data group to predict fecundity.

As a first step, the work for this term of reference was limited to Atlantic cod with, depending on the results of the approach used, the possibility of extending it to other species. As mentioned in previous reports, fecundity data were gathered for 13 different stocks and for periods of 2 to10 years for each stock (Table 1). All data were standardized to obtain power curves relating fecundity to length (Fig. 1) and the fecundity at a fixed size (i.e. 60 cm) derived from the relations and the slope of the regressions were used as input parameters to conduct cluster analysis. This approach allowed the identification of different groups of fecundity relationships (Fig. 2). Important environmental and biological influences were detected as stock membership and year within most clusters were very different. Different environmental and biological variables were identified as possible factors responsible for the separation of clusters. At the 6th WG Meeting, several variables describing fish condition, accumulation of reserves, growth, stock productivity, biomass level and temperature were selected as variables that could explain a large proportion of the variability in the fecundity of cod (Table 2.). A literature search was conducted to find data on the different variables corresponding to each fecundity relationship. These data will be used as variables to conduct a discriminant analysis to evaluate the classification power of each variable and the relative importance of each of these variables in explaining the variability in the fecundity of cod. Data on temperature and stock characteristics were gathered and documented from databases and reports of ICES, NAFO, MPO, NOAA and scientific journals. Up to now, data for most variables have been obtained for ~ 75% of the stocks and years. The completion and validation of the database and the writing of a manuscript is expected in the coming year.

Table 1. List of stocks and years used for comparison of fecundity of cod in the North Atlantic and Baltic Sea.

Stock	Division	Symbol	Time period	Reference
Eastern Baltic	ICES SD 25-32	BA	1987-1992, 1995-1996, 1998-1999	(Kraus et al. 2000) (Kraus et al. 2002)
Iceland	ICES Va	IC	1960, 1967, 1995-2000	(Joakimsson 1969) (Schopka 1971) (Marteinsdottir and Begg 2002)
Northeast Arctic	ICES I-II	NA	1986-1989, 1999-2000, 2003-2004	(Kjesbu et al. 1998) Kjesbu unpublished
North Sea	ICES IVa-c VIId	NS	1969-1972, 1999, 2002-2003	West 1970 in (Yoneda and Wright 2004) (Oosthuizen and Daan 1974) (Yoneda and Wright 2004)
West of Scotland	ICES Via	WS	1969-1970, 2002-2003	West 1970 in (Yoneda and Wright 2004) (Yoneda and Wright 2004)
Georges Bank	NAFO 5-6	GB	1999-2000	(McIntyre and Hutchings 2003)
Southern Labrador and Eastern Newfoundland	NAFO 2J3KL	NC	1964, 1966-1968	(May 1967) (Postolakii 1967) (Pinhorn 1984)
Northern Gulf of St. Lawrence	NAFO 3Pn4RS	NG	1995, 1998, 2001-2002	(Lambert et al. 2000) Lambert unpublished
Sidney Bight	NAFO 4Vn	SB	1998-1999	(McIntyre and Hutchings 2003)
Southern Grand Bank	NAFO 3NO	SC	1964-1965	(May 1967)
Southern Gulf of St. Lawrence	NAFO 4T-Vn (Nov.-April)	SG	1955-1956, 1980, 1998-1999	(Powles 1958) (Buzeta and Waiwood 1982) (McIntyre and Hutchings 2003)
Southern Newfoundland	NAFO 3Ps	SN	1966-1967, 1969-1970, 2001	(Pinhorn 1984) Lambert unpublished
Flemish Cap	NAFO 3M	FC	1979, 1984	(Wells 1986)

Table 2. Selected biological and environmental variables potentially explaining a significant proportion of the variability in the fecundity of cod.

- Fish condition (Fulton's condition factor (K) before spawning and during maturation)
- Accumulation of energy reserves (Annual change in Fulton's condition factor i.e. Δ K)
- Growth (based on lengths and weights at age)
- Size at maturity (size at 50% maturity)
- Productivity of the stock (based on VPA information: numbers and weights at age, catches etc..)
- Stock biomass level (compared to historic mean)
- Water temperature (before spawning and during maturation)

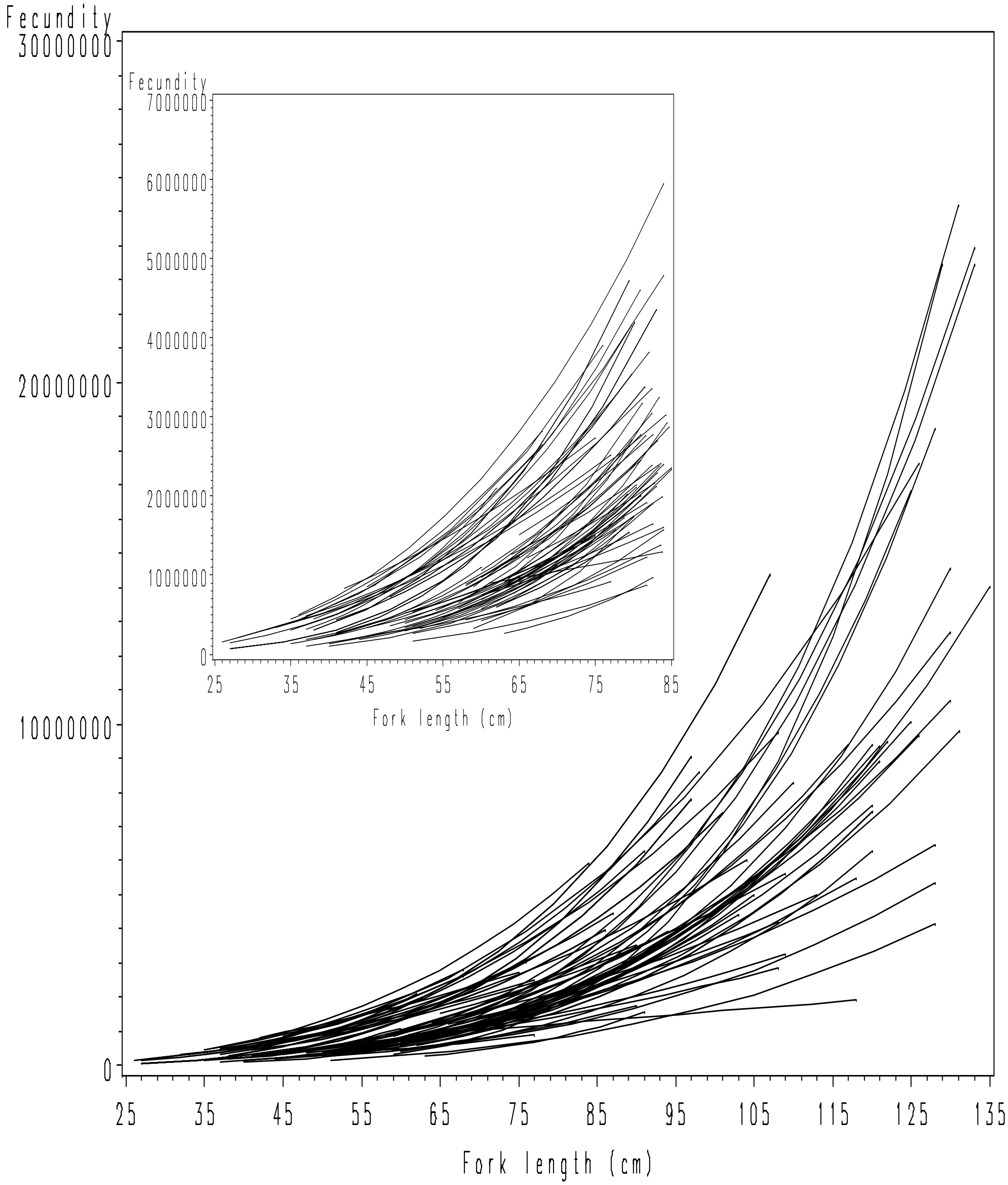


Fig. 1. Power regressions describing the relationships between potential fecundity and length of cod for the different stocks and years.

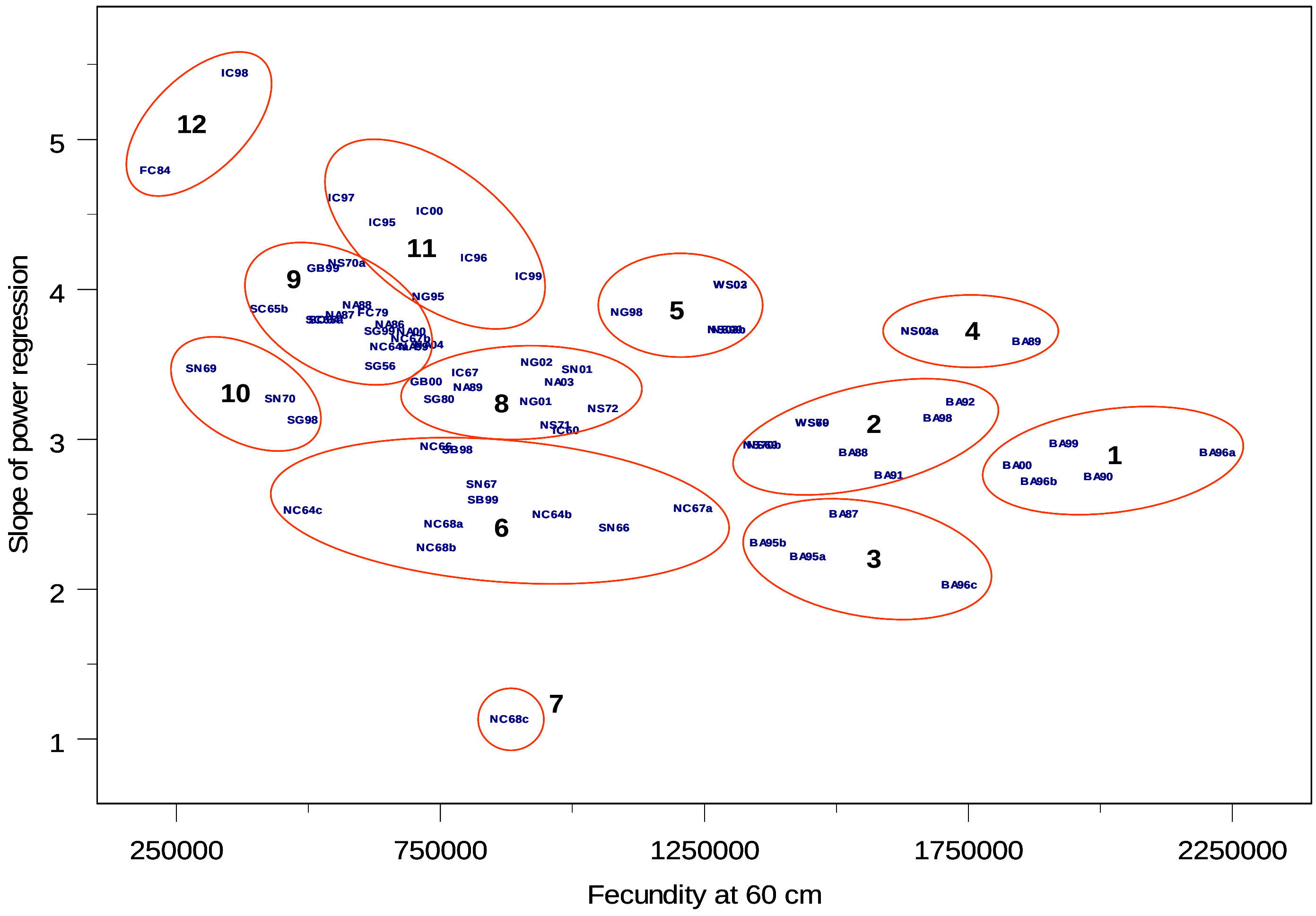


Fig. 2. Groups of cod stocks and years resulting from cluster analysis realised with potential fecundity at 60 cm and the slope of the regressions between potential fecundity and fork length. Data points represent stock membership and year of sampling.

ToR 4: Co-Leaders: Tara Marshall (UK) and Joanne Morgan (Canada)

Explore how the current use of biological reference points and medium-term projections can be adapted to include new information on reproductive potential.

Members: Loretta O'Brien (USA), Hilario Murua (Spain), Gudrun Marteinsdóttirr (Iceland), Gerd Kraus (Germany), Yvan Lambert (Canada), Jonna Tomkiewicz (Denamark).

For this ToR a study is being conducted to examine how estimates of population productivity vary depending on what index of reproductive potential is used (RP). In addition the use of different indices of RP in the setting of limit reference points and in stock projections is being studied.

Data from 8 populations from across the north Atlantic were available. These were Georges Bank cod (*Gadus morhua*, NAFO Div. 5Z), northern Gulf of St. Lawrence cod (NAFO Div. 3Pn4RS), southern Grand Bank cod (NAFO Div. 3NO), Grand Bank American plaice (*Hippoglossoides platessoides*, NAFO Div. 3LNO), Icelandic cod (ICES Div. Va), Northeast Arctic cod (ICES Subareas I and II), Baltic cod (ICES IIId SD 25-32), and northern hake (*Merluccius merluccius*, ICES Div. IIIa, SA II, IV, VI, VII and Div. VIIIa, b, d). For each population, four indices of reproductive potential were calculated.

The first estimate of RP (constant maturity) assumed no change in the maturity schedule of the fish and applied a constant proportion mature at age.

$$RP_{constant} = \sum_{a=i}^{j} N_{ay} W_{ay} M_{a} \qquad (1)$$

where N_{ay} is the population number at age a in year y, W_{ay} the weight at age a in year y, M_a is the proportion mature at age a, and the age range is that in the sequential population analyses for the population.

The second estimate, RP_{SSB}, is calculated in the same way as $RP_{constant}$ but incorporates the estimated proportion mature at age for each cohort or year, that is, variable rather than constant maturity at age. This estimate will show the impact of any changes in maturation over time.

$$RP_{SSB} = \sum_{a=i}^{j} N_{ay} W_{ay} M_{ay} \qquad (2)$$

In the third estimate of RP (sex ratio), we applied the variable sex ratios estimated along with the variable estimates of proportion mature at age:

$$RP_{FSB} = \sum_{a=i}^{j} N_{ay} W_{ay} M_{ay} R_{ay} \qquad (3)$$

where R_{ay} is the proportion female at age a in year y, and the other symbols are as defined above.

The fourth estimate of RP incorporated estimates of fecundity at age and is an estimate of total egg production (TEP). Fecundity at age was multiplied by the population number at age times the proportion mature at age times the sex ratio at age:

$$RP_{TEP} = \sum_{a=i}^{j} N_{ay} M_{ay} R_{ay} E_{ay} \qquad (4)$$

where E_{ay} is the number of eggs produced per female at age a in year y, and the other symbols are as defined above.

Comparing time series

Each index of RP for each stock was divided by $RP_{constant}$ for the stock to determine if the relationship between them was constant. For RP_{TEP} the ratio was scaled to be in a similar range as those for RP_{SSB} and RP_{FSB}.

For all stocks the relationships between the alternative indices of RP and $RP_{constant}$ were not constant over time (Fig. 3). The trends over time differed between indices of RP for the same populations, although in some cases they were quite similar. Where the ratios diverge it indicates a change in relationship among the different indices. For instance, for Northeast Arctic cod, the ratio of SSB to $RP_{constant}$ diverges from the other ratios starting in about 1980, indicating a change in the relationship among SSB, FSB and TEP at that point.

Limit reference points

To compare biomass and fishing mortality (F) reference points (B_{lim} and F_{lim} respectively) the RP and F giving maximum sustainable yield were calculated. This was done by applying various F levels to each population in long term simulations running for 500 years. This was done separately for each index of RP. Recruitment came from a Loess smoother of the relationship between the relevant RP and recruitment. Partial recruitment, weights, maturities, sex ratio, and fecundity at age average were average over the entire time series for each population and used, as appropriate to calculate RP. F_{MSY} and 30% RP_{MSY} were taken as F_{lim} and B_{lim}. These calculated reference points are not being suggested as the ones to use for these populations but rather are calculated as a way to determine the effect of different indices of RP on reference points.

Simulations of reference points showed that in no case were the estimates from the 4 indices of RP all the same. Differences in maximum sustainable yield varied from less than 5% to 38%. There tended to be more variation in stock status relative to B_{lim} than to $F_{lim.}$ In no population was the time series of stock status with respect to the reference points the same for all indices of RP. There was no indication that any particular index of RP had a tendency to result in higher or lower reference point estimates.

Productivity over time

Changes in productivity over time were compared among the indices of RP by calculating reproductive potential per recruit (RPPR) for each index in each year. In each case number at age was produced by starting with 1 recruit at age zero applying natural mortality at each age until the last age used in the assessment, such that

$$N_a = N_{a-1}e^{-0.2} \tag{5}$$

For each age from 0 to the maximum age in the sequential population analysis for each population, the reproductive potential produced was calculated according to the equations given above, and inserting the number at age from equation (5). The result was then summed across all ages to give the RPPR for each index. Each series of RPPR was standardized to its mean for comparison.

There was generally some coherence in the long term patterns in productivity among indices of RP for a population as measured by RPPR at F=0 (Fig 4). This reflects changes in size at age (weight or length) over time. However, it is also evident that each index of RP shows different detail in that trend. For example, for Georges Bank cod, RP_{TEP} ranged from 0.7 to 1.4 times its mean while $RP_{constant}$ showed only a range of 0.8 to 1.1 times its mean. For Northeast Arctic cod, all indices of RP showed an increase in RPPR up until the 1960’s, after which $RP_{constant}$ remained relatively constant, while the other 3 indices continued to increase. For northern Hake, all indices started out in the late 1970’s at a similar level relative to their mean. In the most recent year for which data was available there was a 20% difference between the indices of RP in estimates of RPPR. For Baltic cod, $RP_{constant}$ started the time series as the highest of the standardized indices of RPPR. In 1990, there was an abrupt change and the standardized $RP_{constant}$ index became the lowest of the standardized indices. Although the details are specific to each population, differences between estimated productivity using the different indices of RP, are evident for every population.

Projections

As another indicator of differences in perceived productivity among the different indices of RP, 15 year deterministic projections were carried out for each population using each index of RP. Population numbers were projected assuming F = 0 and M = 0.2.

Recruitment in each year was calculated as average recruits per RP from the last 3 years before projection period calculated for each index of RP multiplied by the index of RP in year the cohort was born. Weights, maturities, sex ratio and fecundity at age were the average of the last 3 years before the projection period. The same population model was used as in the calculations of RPPR (equation 5) and indices of RP were calculated as given above in equations 1-4. For each year of the projection period each index of RP was divided by the B_{lim} estimated in the long term simulations described above. This allowed a comparison of the trajectories in RP over the projection period.

The different indices of RP gave sometimes very different perceptions of stock status relative to B_{lim} over the 15 year projection period (Fig. 5). The largest difference was for Baltic cod where RP_{TEP} gave a population size 600 times B_{lim} at the end of the projection period while that for $RP_{constant}$ was only 30 times B_{lim}. The index of RP giving the greatest increase in population size relative to B_{lim} was not always the same. For Baltic cod, northern hake and southern Grand Bank cod, RP_{TEP} clearly gave the largest population size relative to B_{lim}. However, for Icelandic cod, $RP_{constant}$ gave the largest population size relative to $B_{lim,}$ while for American plaice and Northeast Arctic cod, there was little difference in 3 of 4 indices of RP.

Variation in reproductive biology relative to variation in F_{MSY}

The relationship between the variation in F_{MSY} and variation in maturation, sex ratio and fecundity was examined. The range in reproductive factors was compared to the range in $F_{MSY.}$ A variable that represented the annual value of each reproductive factor was produced by calculating the weighted average of each of these factors for each year, with the weighting being the population number at age. For example the proportion mature at age and weighting by the number of fish at age estimated from the population model. In order to compare across these factors the weighted average in each year was standardized by dividing by the mean over all years for the factor and population. From these standardized measures the range was calculated as a measure of deviation. This was plotted against the absolute value of the difference between the F_{MSY} estimated for the particular index of RP and the F_{MSY} estimated for that population for $RP_{constant}$.

The different indices of RP vary by the sequential addition of more biological data, first adding maturity at age, then sex ratio and then fecundity. A comparison the amount of variability in these reproductive characteristics and the amount of variation in F_{MSY} shows that populations where there is more variability in the underlying reproductive biology tended to show more variation in estimates of F_{MSY}. For example, Northeast Arctic cod showed substantial variation in all aspects of reproductive biology measured and a large range in F_{MSY}.

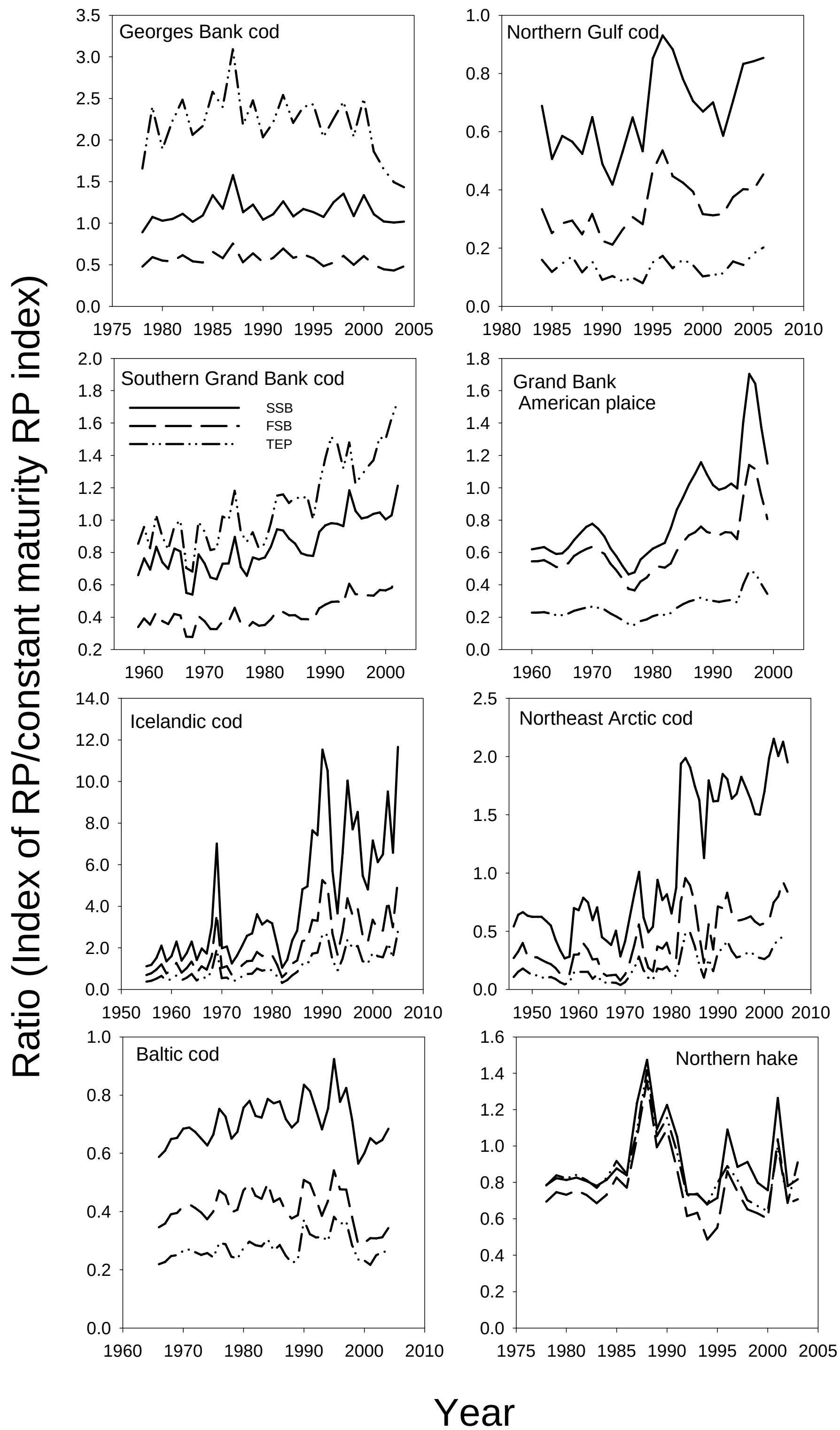


Fig 3. Ratio of each index of RP to $RP_{constant}$ for each of 8 stocks.

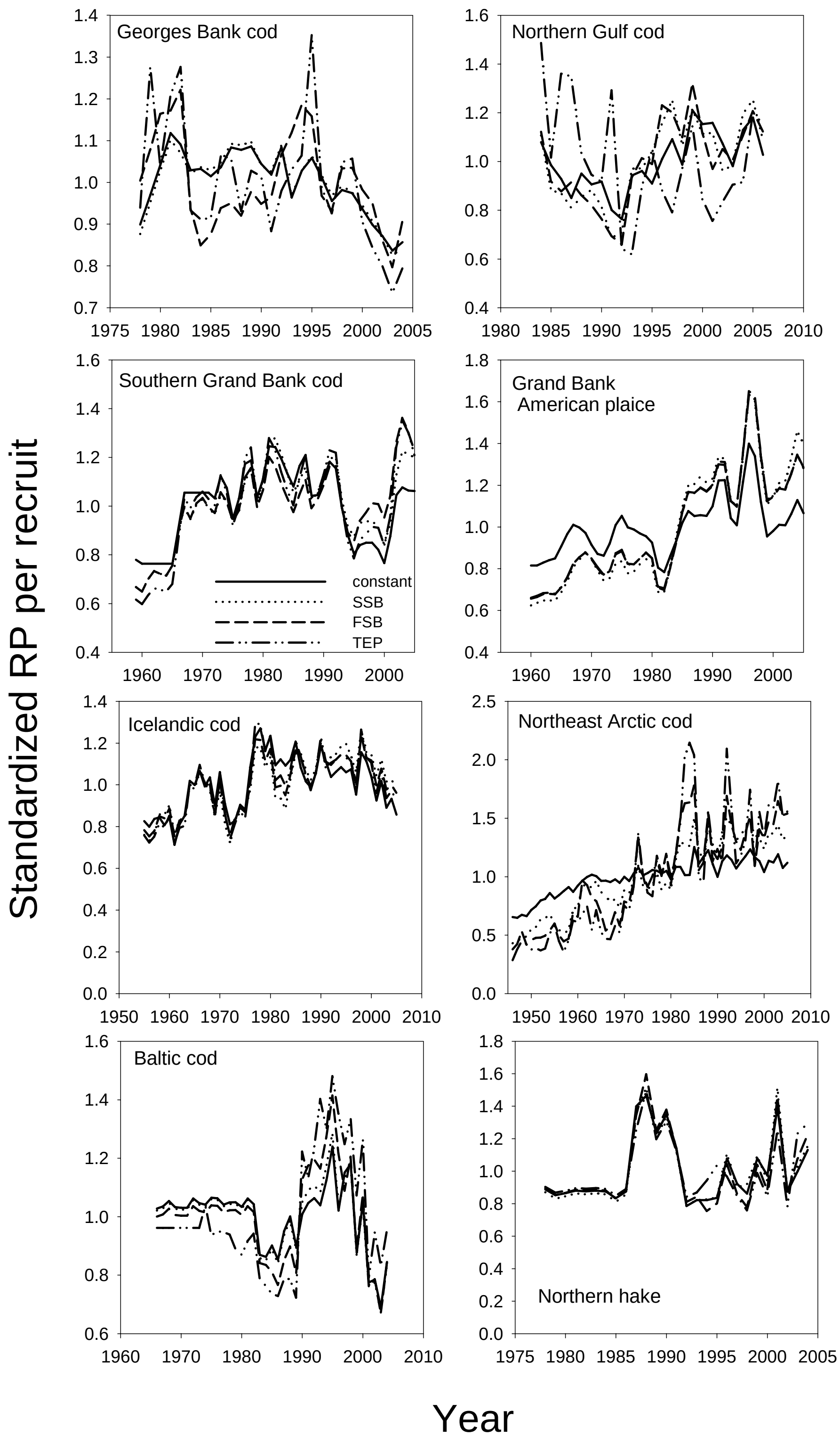


Fig. 4 Time series of standardized reproductive potential per recruit for each index of RP for each population. Each index is standardized to its own mean.

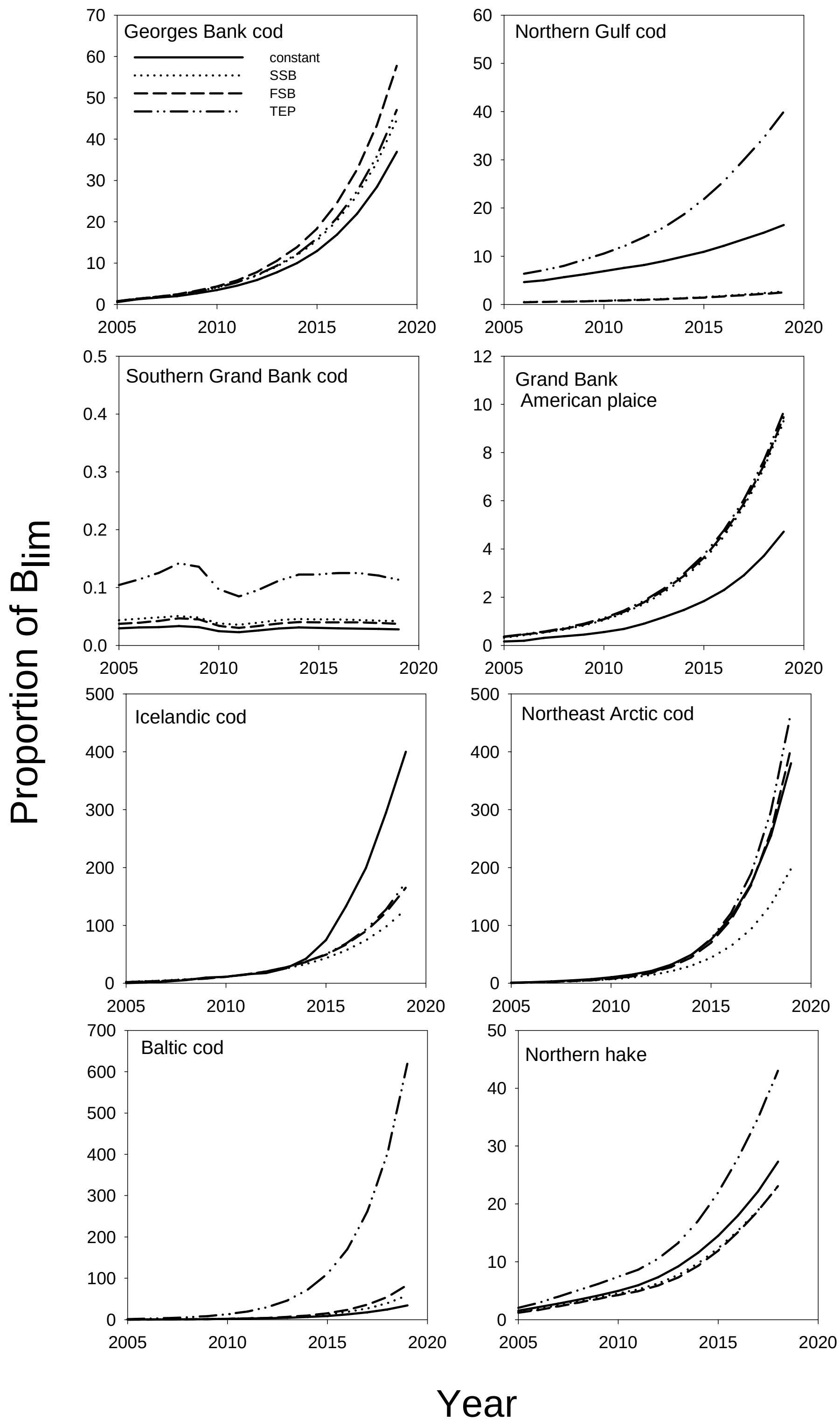


Fig. 5. Proportion of B_{lim} in each year of a 15 year projection for each index of RP for each population.

ToR 5: Co-Leaders: Peter Wright (UK) and Ed Trippel (Canada)

Explore the consequences of fishery-induced changes in the timing and location of spawning to reproductive success.

Members: Jonna Tomkiewicz (Denmark), Saborido-Rey (Spain), Rick Rideout (Canada), Chris Chambers (USA), and Gudrun Marteinsdottir (Iceland)

This topic is being evaluated by a review of the theory and evidence that spawning time varies and early survivorship of progeny is related to birth date. A manuscript entitled "Consequences of fishery-induced changes in the timing of spawning to reproductive success" has been produced and drafts have been revised both at the 2006 Iceland meeting and by subsequent correspondence. The intention is to submit this manuscript to a review journal, probably either Reviews in Fish & Fisheries or Fish and Fisheries by late summer 2007.
Analysis of results for a second manuscript on the effect of age on spawning time in gadoids were also discussed at the Iceland meeting and despite some progress in further analyses in the latter part of 2006 this work is not close to completion. Hopefully, progress on the manuscript will be made so that at least a draft manuscript will be available for review by the time of the next NAFO meeting in 2007.

ToR 6: Co-Leaders: Fran Saborido-Rey (Spain) and Joanne Morgan (Canada)

Provide recommendations for the collection of required data in existing research surveys, sentinel fisheries and captive fish experiments that are required to improve annual estimates of reproductive potential for stocks varying in data availability.

Members: Anders Thorsen (Norway), Rick Rideout (Canada), Ed Trippel (Canada), Jonna Tomkiewicz (Denmark), Pauline King (Ireland), and Jay Burnett (USA).

The output of this ToR will come from a variety of activities, the combination of which should provide a guide to the requirements for the data to estimate reproductive potential.

Work will continue to examine the frequency and sampling intensity needed when sampling maturity, with Baltic cod being used as the case study. This work will likely result in a primary publication with Hans Gerritsen, Jonna Tomkiewicz and Pauline King as co-authors. A tentative title for this publication is 'Sampling intensity and frequency needed for estimating Baltic cod maturity'.

The project *Reproduction and Stock Evaluation for Recovery (RASER)* includes some members of the Working Group. RASER plans to produce a manuscript on fecundity sampling. This manuscript will form the basis of the fecundity sampling component of this ToR.

The need of having different workshops on methodology was discussed, and as result four (4) workshops are being considered:

1. *Methodology and quantification using stereology (relatively limited number of species)*

- Gametogenesis patterns in our commercial species males and females, comparison of macroscopic vs. histology assessment and linking macroscopic images and histological descriptions.
- Criteria to interpret follicle stages in whole mounts. Rates of follicle growth and regression and identification of females that skip spawning using POFS and ovary Tunica diameter.
- Quantification using auto diametric and Dissector methods.

2. *Identication and classification of reproductive strategies (including range of species with families having different reproductive strategies)*

- Comparison of female and male gametogenesis across species and reproductive strategies.
- Consideration of different aspects for classifying the reproductive strategy of teleosts.
- Discussion of methodology needed to assess reproductive strategies.
- Useful protocols for staining various cells components and structures.
- Agree on guidelines and produce an illustrated atlas on reproductive strategies and comparative gametogenesis.

3. *Fecundity of determinate and indeterminate teleosts (examples of different types)*

- Different methodologies to assess fecundity of determinate and indeterminate female spawners.
- Methods to identify and quantify atresia.
- Estimation of potential and realized egg production of determinate and indeterminate spawners.
- Methods to determine male spermatozoa production and fertilization capacity?

4. *Incorporating estimates of reproductive potential into stock assessment*

- Data necessary for estimating reproductive potential.
- Considerations for the collection and analyses of data on reproductive potential.
- Hands on work on incorporating existing data.

Recently a COST Research Network Action has been approved (COST Action FA0601 "Fish Reproduction and Fisheries"). The NAFO WG recommended including workshops 1-3 as part of the events to be organized within the COST Action. These 3 workshops will be organized in 2008-2010, in connection with NAFO, if Scientific Council supports this initiative. The fourth workshop could be a workshop of Scientific Council and/or could also possibly be in conjunction with the COST action.

TOR 7: Co-Leaders: Loretta O'Brien (USA) and Nathalia Yaragina (Russia)

Explore the effects of the environment on Stock reproductive Potential and how these relate to TORs 2-4.

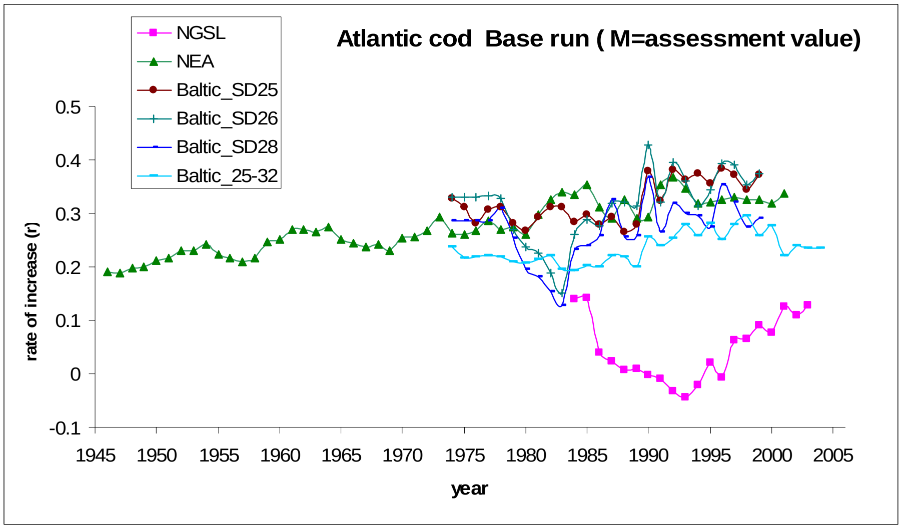
Members: Chris Chambers (USA), Gerd Kraus (Denmark), Rick Rideout (Canada), Yvan Lambert (Canada), Olav Kjesu (Norway), Anders Thorsen (Norway) and Tara Marshall (UK)

Using life history models, estimates of the intrinsic rate of increase (r) will be used as a metric to determine how environment influences stock reproductive potential (SRP). Initially, 9 cod stocks were to be compared (Northern Gulf of St. Lawrence, Northeast Arctic, Georges Bank, Gulf of Maine, Baltic, Icelandic, Flemish Cap, Western Scotland, and Irish Sea) in this analysis, but not all stocks have a sufficiently long time series of fecundity. Therefore, only three stocks (Fig. 1) , (Northern Gulf of St. Lawrence, Northeast Arctic, and Baltic) with year specific fecundity time series, will be used for the final analysis.

Analyses will be conducted to determine how much of the variation in annual estimates of 'r' can be explained by environmental factors, e.g. temperature, salinity, oxygen, age diversity, that likely influence reproduction for each stock.

A methodological manuscript has been completed at this point: "Differences in the intrinsic rate of population growth explain the differential resiliency of collapsed and non-collapsed cod stocks to fishing" by Y. Lambert and T. Marshall.

The analyses and manuscript described above will be presented at the NAFO/ICES / PICES Symposium in Lisbon , October 2007.



FUTURE ACTIVITIES

The 7th Meeting of the NAFO Working Group on Reproductive Potential will be held in Lisbon, Portugal, during October 5-6 , 2007 after the completion of the NAFO/PICES/ICES Symposium on Reproductive and Recruitment Processes of Exploited Marine Fish Stocks. Dr. Fran Saborido-Rey (Spain) has kindly agreed to help coordinate local arrangements with the support of IPIMAR in Lisbon.

The proposed Workshops under ToR 6 that help to integrate the findings of the WG in stock assessment advice are potentially eligible for financial support from the EU COST Action FA0601 “Fish Reproduction and Fisheries”. The format for publication of results for the second set of ToRs will likely include both peer and nonpeer reviewed outlets and has yet to be determined for each specific ToR. Discussions among NAFO and COST will be conducted as COST would like to invite NAFO to become part of the COST action in order to help facilitate travel to future NAFO WG meetings and Workshops.