Northwest Atlantic Fisheries Organization

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SCIENTIFIC COUNCIL MEETING – JUNE 2012

Report of the NAFO Scientific Council Working Group on Reproductive Potential

The NAFO Working Group on Reproductive Potential is comprised of 21 members representing 10 countries (Canada, Denmark, Germany, Greece, Iceland, Norway, Russia, Spain, United Kingdom, and USA). Progress of the Working Group was provided by E.A. Trippel (Chair).

Over the past year, Working Group members worked inter-sessionally by correspondence and ad hoc meetings at other scientific forums to address the ToRs approved by Scientific Council. The EU COST Research Network Action Fish Reproduction and Fisheries (FRESH) (Coordinator: Fran Saborido-Rey, Spain) was successfully completed in June, 2011, yet many initiated activities in support of the NAFO WG on Reproductive Potential were carried forward over the past year. This enabled the development of collaborations among scientists that benefited addressing NAFO ToRs, avoided duplication of effort between the two groups, and brought more results to the attention of Scientific Council.

FUTURE ACTIVITIES

The 10th Meeting of the NAFO Working Group on Reproductive Potential is proposed to be held in 2013 in conjunction with the ICES (and possibly NAFO sponsored) symposium on "Gadoid Fisheries: The Ecology and Management of Rebuilding" to be held in St. Andrews, Canada. This will be the third and proposed final meeting for the 3rd Set of ToRs.

A brief summary of progress and future plans of each ToR are given below:

ToR 1: Explore and conduct evaluation of underlying assumptions of protocols used to estimate total realized egg production of selected marine species and stocks. Co-Leaders: Rick Rideout (DFO, Canada) and Rosario Dominguez (CSIC, Spain)

Several marine laboratories in the North Atlantic have initiated routine fecundity estimation for key fish stocks. This information is being used to (i) help improve the estimation of stock reproductive potential (ii) understand population productivity and (iii) predict stock recovery rates. However, there is a lack of standardization and calibration of various methods to estimate fecundity among laboratories. For example, some laboratories have only recently initiated the autodiametric method and are developing appropriate calibration curves. On the other hand, observations have been made that indicate atresia and timing of sampling can influence estimates of total egg production. Techniques to quantify atresia (vitellogenic oocyte resorption) will be developed and evaluated in this ToR. This will involve histological analyses accompanied by computerized image analysis.

<u>Establish Standard Operating Procedures</u>:

- Provide uniform and standardized procedures for routine fecundity analyses in laboratories using a variety of methods, i.e. autodiametric method, image analysis
- Evaluate histological techniques for assessment of atresia

<u>Validation of Assumptions:</u>

- Test assumptions of different fecundity methods (i.e. the autodiametric method) and parameters associated with fecundity estimation
- Estimate down regulation of fecundity and quantification of atresia and non-annual spawning

Two initiatives have been made to further understand Greenland halibut reproductive biology. Research led by J. Kennedy and others (Norway) demonstrated that this species spawns annually but successive cohorts of oocytes

develop over 2 years, complicating correct assessment of maturity. Similarly, collaborative research led by R. Rideout (Canada) on sexual maturity of this species revealed an unusual oocyte development pattern of fish collected in the Canadian multi-species surveys. The maturing ovary contained two groups of developing oocytes, a larger group developing for the upcoming spawning season and a smaller group developing for next year (i.e., duration of vitellogenesis is >1 yr). These findings indicate that at-sea assessment of maturity could overestimate the number of spawners as some individuals, particulary young first-time spawners, with ripening ovaries may not spawn in the year of capture. The results have implications for assessment of age at sexual maturity and female spawning stock biomass estimation.

The effects of age and temperature on spawning time were investigated for cod and haddock for stocks on both sides of the Atlantic The effect of age was opposite between the northeast and northwest side of the Atlantic, with younger fish spawning later than older fish in the North Sea and the opposite occurring in the northwest Atlantic. In Div. 3L and Div. 3NO, cod spawned later in recent years. The fact that mean age of spawners has declined in both Divisions and young fish in these areas tend to spawn earlier than old fish suggests that the later spawning in recent years is unlikely related to changes in age structure. Analyses by age suggest fish of all ages are now spawning later than in previous years in these stocks. Such findings point to the underlying complexity of the processes governing spawning time. Contributors: J. Morgan, R. Rideout and P. Wright.

Long-term fecundity analyses of Flemish Cap cod by Spanish and Canadian scientists revealed the necessity of making annual estimates of potential fecundity and studying its relation not only to length but to other variables, such as fish condition, in obtaining an improvement of total egg production (TEP) over female spawning stock biomass (FSSB) as a predictive variable in recruitment assessments. Measurements of fecundity from 1978-2008 showed that six significantly different fecundity curves existed over this time period relating to the allometric coefficient in weight-length and fecundity-length equations. The TEP time series using the higher fecundity allometric coefficient explained a greater proportion of recruitment variation.

A key deliverable for this ToR is the development of a resource handbook that provides detailed methodology for the estimation of input variables (e.g., age/size at sexual maturity, egg production) for the estimation of stock reproductive potential over a wide suite of fish species. The "Handbook of Applied Reproductive Biology for Fish Stock Assessment and Management" will provide uniform and standardized procedures along with the pros and cons of various methods. The Chapter titles include (1) Fish Reproductive Biology, (O. Kjesbu and M. Dickey-Collas) (2) Data Collection and Statistics for Reproductive Biology Studies (C. Stransky), (3) Maturity (C. Van Damme), (4) Egg Production (K. Ganias), (5) Sperm Production (E. Trippel), and (6) Elasmobranch Reproductive Potential (L. Serrano). Some chapters are completed and others are ongoing, they include contributions from over 30 scientists. A Spanish initiative has been submitted to raise funds to help support travel to hold a meeting to help bring this activity to completion. Editors are R. Dominguez-Petit, H. Murua, F. Saborido-Rey, and E.A. Trippel.

Associated ToR 1contributions include:

Kennedy, J., Gundersen, A.C., Høines, A.S., and Kjesbu, O.S. 2011. Greenland halibut (*Reinhardtius hippoglossoides*) spawn annually but successive cohorts of oocytes develop over 2 years, complicating correct assessment of maturity. Canadian Journal of Fisheries and Aquatic Sciences **68**(2): 201-209.

Rideout, R.M., Morgan, M.J., Lambert, Y., Cohen, A.M., Banoub, J.H., Treble, M. (in press) Oocyte development and vitellogenin production in northwest Atlantic Greenland halibut *Reinhardtius hippoglossoides*. Journal of Northwest Atlantic Fishery Science.

Morgan, M.J., Wright, P., and Rideout, R.M. (in press) Effect of age and temperature on spawning time in gadoids. Fisheries Research.

Pérez-Rodríguez, A., Morgan, M.J., Rideout, R.M., Domínguez-Petit, R., and Saborido-Rey, F. 2011. Study of the relationship between total egg production, female spawning stock biomass and recruitment in Flemish Cap cod (*Gadus morhua*). *Ciencias Marinas*. 37: 675-687.

Lowerre-Barbieri, S., Ganias, K., Sabordio-Rey, F., Murua, M., and Hunter, J. 2011. Reproductive timing in marine fishes: variability, temporal scales, and methods. *Marine and Coastal Fisheries* 3: 71-91.

Lowerre-Barbieri, S., Brown Peterson, N., Murua, H., Tomkiewicz, J., Wyanski, D., and Saborido-Rey, F. 2011. Emerging issues and methodological advances in fisheries reproductive biology: the importance of histological tools. *Marine and Coastal Fisheries* 3: 32-51.

Butts, I.A.E., Ward, M., Litvak, M., Pitcher, T., Alavi, H., Trippel, E.A., Rideout, R.M. (2011) Automated sperm head morphology analyzer for open-source software. Theriogenology 76: 1756-1761.

Rideout, R.M. and Tomkiewicz, J. (2011) Skipped spawning in fishes: more common than you might think. Marine and Coastal Fisheries 3: 176-189.

Haslob H., G. Kraus, F. Saborido-Rey (2012) The dynamics of postovulatory follicle degeneration and oocyte growth in Baltic sprat. Journal of Sea Research 67: 27-33.

Kjesbu, O.S., Thorsen, A., and Fonn, M. 2011. Quantification of primary and secondary oocyte production in Atlantic cod (*Gadus morhua*) by simple oocyte packing density theory. Marine and Coastal Fisheries 3: 92-105.

Schismenou, E., Somarakis, S., Thorsen, A., and Kjesbu, O. 2012. Dynamics of de novo vitellogenesis in fish with indeterminate fecundity: an application of oocyte packing density theory to European anchovy, *Engraulis encrasicolus*. Marine Biology 159: 757-768.

McPherson, L.R., and Kjesbu, O.S. 2012. Emergence of an oocytic circumnuclear ring in response to increasing day length in Atlantic herring (*Clupea harengus*). Marine Biology 159: 341-353.

Domínguez-Petit, R.,Alonsi-Fernández and and Saborido-Rey, F. 2011. Incidence and significance of cystic structures in the ovaries of gadoid fish. *Scientia Marina*. 75(2): 359-368.

ToR 2: Explore and investigate the potential effects of changes in water temperature and food supply on reproductive success in selected marine species and stocks. Co-Leaders: Richard McBride (NMFS, USA) and Stylianos Somarakis (HCMR, Greece)

Environmental factors can modify the reproductive potential of fish stocks and thereby influence recruitment. Annual variations and potential increases in water temperature due to climatic warming will presumably act strongly to influence gonadal development and reproductive success. Prey resources also vary and influence fish condition which in turn affects reproductive output. In this ToR, using data on specific stocks and laboratory experiments, the influence of specific abiotic and biotic factors on gonadal development and spawning will be evaluated pending available data.

Abiotic: Examine changes in water temperature (short and long-term) and their effects on timing and duration of spawning, fecundity, egg size and fertilization success

Biotic: Assess variation in prey resource type and abundance and their effects on egg production and gamete quality

ToR 2 was divided into two components

(a) Explore and investigate the potential effects of changes in water temperature on reproductive success in selected marine species and stocks.

Sexual maturation patterns of 22 North Atlantic stocks of cod (*Gadus morhua*) were examined by F Köster (Denmark) and others and related to geographical distribution area, ambient water temperature, growth and surplus production. Four patterns were identified, i.e. sexual maturation early in life at small size, early in life at large size, late in life at small size and lastly, late in life at large size. These maturation patterns were geographically clustered and associated with differences in growth and surplus production. Stocks maturing late in life at small size were characterized by slow growth and low surplus production (e.g. stocks in the Gulf of St. Lawrence, Labrador/Newfoundland). Stocks maturing early in life at large size exhibited high to intermediate growth and surplus production (e.g. Celtic Sea, North Sea). Stocks maturing late in life at large size had low to intermediate growth rates and surplus production (e.g. Iceland, North East Arctic), while stocks maturing early in life at small size generally showed intermediate growth and surplus production (e.g. Baltic stocks). Production of recruits per unit biomass showed a latitudinal trend, but appeared largely independent of maturation pattern, growth rate and surplus production. Recruit production of northernmost stocks was lowest and variability highest, mid-latitude stocks exhibited highest productivity and least variability, while stocks at the southern distribution range also showed low productivity. Thus, southern Gulf of St. Lawrence and eastern Scotian Shelf cod maturing late in life at small size with slow growth and low surplus production showed highest recruit production in the Western Atlantic,

while the early maturing, fast growing and productive Icelandic and Faroese stocks showed the lowest recruitment production of all Eastern Atlantic stocks. This comparative analysis suggests that maturation patterns relate to growth potential and surplus production whereas annual production of recruits per unit biomass appears unrelated to average size at sexual maturation. A manuscript has been submitted on this material to *Fisheries Research.*

Latitudinal analyses of winter flounder size and age-at-maturity data were also conducted (led by R. McBride). The importance of utilizing a comparative stock approach along a gradient of water temperature is an ideal way to explore the potential directional shift in maturity with an increase in water temperature for a specific fish stock. Other elements of reproductive potential in relation to latitude were also examined and reported in a separate manuscript.

(b) Explore and investigate the potential effects of changes in food supply on reproductive success in selected marine species and stocks.

Fish reproductive strategies in relation to trophic dynamics of their environment are being investigated for over 30 fish species. The reproductive traits being evaluated include between year spawning frequency (semelparity vs iteroparity), synchrony of vitellogenic follicle development (synchronous, group-synchronous or asynchronous), recruitment of vitellogenic follicles with the ovary each year (determinate vs indeterminate) and with-in year spawning frequency (batch vs. total spawning). These reproductive traits are being matched with evidence that food amount or food type affect egg production in fishes. A manuscript for publication has been completed and is under internal NOAA review (lead R. McBride).

Understanding the causes of variation in stock reproductive potential (SRP) is challenging due to the difficulty in assessing the relative contribution of environmental, demographic and genotypic influences. A review was prepared by P. Wright (UK) to be published in *Fisheries Research* that explores how experimental and comparative field studies have been used to disentangle sources of variation in maturity, fecundity and the timing of spawning. By comparing reproductive parameters and corresponding environmental conditions among stocks of a species it is clear that demography, energetic state and temperature are important factors affecting variation in SRP. Common garden and environment experiments have confirmed that there is also a substantial genetic component to regional differences in reproductive investment and timing of spawning. Environmental manipulation experiments have helped to elucidate the proximate mechanisms underlying many reproductive processes. Together these different sources of information have provided a foundation for the development of statistical and individual based modelling approaches that help explain variation in SRP. In the near future, genomic investigations may provide a direct means to account for genetic influences on reproductive variation. Given that the age and size structure of many fish stocks has become truncated through fishing, a greater focus on the contribution of reproductive life span to SRP is also needed.

A number of contributions were made that described the linkages between fish nutritional condition and reproductive output. These findings underscore the importance of obtaining and integrating measures of fish condition (liver, condition factor, energy value) in developing improved predictive equations of fecundity from easily measured body metrics collected during annual bottom trawl surveys.

Associated ToR 2 contributions include:

Köster, F.W, Trippel E.A., and Tomkiewicz, J**.** Linking size and age at sexual maturation to body growth, productivity and recruitment of Atlantic cod stocks spanning the North Atlantic. *Fisheries Research* (*Submitted*).

McBride, R.S., Wuenschel, M.J., Nitschke, P., Thornton, G. and King, J.R. 2012. Latitudinal and stock-specific variation in size- and age-at-maturity of female winter flounder, *Pseudopleuronectes americanus*, as determined with gonad histology. Journal of Sea Research. (http://dx.doi.org/10.1016/j.seares.2012.04.005)

McElroy, D., Wuenschel, M.J. Yvonna K. Press, Towle, E.K. and McBride. R.S.. Accepted/2012 Differences in female individual reproductive potential among three stocks of winter flounder, *Pseudopleuronectes americanus*. Journal of Sea Research.

Wuenschel, M.J., McBride, R.S., and Fitzhugh, G.R.. Accepted/2012. Relations between total gonad energy and physiological measures of condition in the period leading up to spawning: results of a laboratory experiment on black sea bass (*Centropristis striata*). Fisheries Research.

McBride, R.S., Somarakis, S., Fitzhugh, G.R., Albert, A. Yaragina, N.A., Wuenschel, M.J..Alonso-Fernández, A. and Basilone, G. Fish reproductive strategies in relation to the trophic dynamics of their environment. Completed and under internal departmental review.

Røjbek, M.C., Jacobsen, C., Tomkiewicz, J. and Støttrup. J.G. Linking lipid dynamics with reproductive cycle in Baltic cod (*Gadus morhua* L.) *Marine Ecology Progress Series. (Submitted*).

Haslob, H., Tomkiewicz, J., Hinrichsen, H.H., and Kraus G. (2011). Spatial and interannual variability in Baltic sprat (*Sprattus sprattus balticus* S.) batch fecundity. Fisheries Research 110, 289-297.

Wright, P.J. Methodological challenges to examining the causes of variation in stock reproductive potential. Fisheries Research (accepted).

Skjæraasen, J.E., Korsbrekke, K., Kjesbu, O.S., Fonn, M., Nilsen, T., and Nash, R.D.M. In press. Size-, energy- and stage-dependent fecundity and the occurrence of atresia in the Northeast Arctic haddock *Melanogrammus aeglefinus*. Fisheries Research.

Kennedy, J., Nash, R.D.M., Slotte, A., and Kjesbu, O.S. 2011. The role of fecundity regulation and abortive maturation in the reproductive strategy of Norwegian spring-spawning herring (*Clupea harengus*). Marine Biology 158(6): 1287-1299.

Kennedy, J., Skjæraasen, J.E., Nash, R.D.M., Slotte, A., Geffen, A.J., and Kjesbu, O.S. 2011. Evaluation of the frequency of skipped spawning in Norwegian spring-spawning herring. Journal of Sea Research 65(3): 327-332.

ToR 3: Undertake appraisal of methods to improve fish stock assessments and fishery management advice that incorporate new biological data for highly exploited and closed fisheries. Co-Leaders: Joanne Morgan (DFO, Canada) and Loretta O'Brien (NMFS, USA)

The depressed and age-altered state of many marine fish stocks has led to reduced landings and in some instances fishery closures. New biological data associated with these altered states will be used to forecast recruitment and improve the accuracy of stock assessment advice. Building on information from previous WG ToRs, the intrinsic rate of population increase will be utilized to assess the timeframe for selected stocks to recover under various fishing and environmental conditions.

Recruitment prediction: Improve prediction of incoming year class size and develop new stock-recruitment models and biological reference points based on better estimates of stock reproductive potential. This includes testing whether more complex indices of reproductive potential result in better estimates of recruitment and limit reference points. Develop scenarios which model population reproductive responses to extrinsic factor data developed in ToR 2.

Stock recovery: Evaluate the intrinsic rate of increase of selected stocks under differing conditions of reproductive potential and levels of fishing mortality to aid in the development of reopening criteria. Estimate recovery time for specific stocks to achieve target biomass levels.

Egg production methods can estimate spawner biomass and/or stock numbers independently of commercial fisheries data. Improved information on stock reproductive potential is improving the accuracy of these methods. The daily egg production method is being explored to evaluate adult stock size for determinate spawning species in the Baltic and North Seas.

Large variations in the life history traits determining the reproductive potential of fish stocks have been observed. Depending on stocks, these variations are often large enough to invalidate the use of spawning stock biomass (SSB) as an unbiased index of reproductive potential. In northern Gulf of St. Lawrence (nGSL) cod, observed annual total egg production (TEP) differed from estimated TEP based on constant life history traits (i.e., direct proportionality between SSB and TEP). Variability in the age structure, sex ration, growth, maturity and fecundity were of different amplitude with different relative importance and cumulate or opposite effects on TEP depending on time period. The relative importance of the different life history traits in determining in determining the reproductive rate was quantified using demographic models based on age-specific reproduction and mortality. The sensitivity of

reproductive rate to independent changes of each life history trait was examined. The analysis indicated that natural mortality (M) had a larger influence on reproductive rate than variations in growth, maturation and fecundity and that M should be included as a dynamic parameter in the estimation of TEP. Contributor Y. Lambert (Canada).

Simulation models were used to investigate various Stock Reproductive Potential hypotheses for four Atlantic cod stocks. Varying conditions of SRP were generated by adjusting growth based on a highly modified von Bertalanffy growth equation with temperature as a covariate, and by varying the egg to recruitment survival rate. The intrinsic rate of increase was estimated for each stock by applying the scenarios of surviorship and fecundity at age in a life table analysis for various fishing mortality rates. A number of model outcomes were reported which supported that time trajectories for recovery to sustainable levels are faster for fish in warmer waters than colder, but are reduced by increases in fishing mortality rate. (L. O'Brien, Y. Lambert, T. Marshall, P. Wright and N. Yaragina).

Egg production survey methods, in contrast to assessment methods based on catch statistics presently used for all assessments of demersal stocks, have a major advantage that spawner biomass and/or stock numbers can be estimated independent of any commercial fisheries data. Moreover, egg production based stock assessment models incorporate the different aspects of stock reproductive potential providing additional insights into population dynamics. These aspects of reproductive biology for Atlantic cod have since the 1990s being extensively studied making possible the use of daily egg production method (DEPM) originally designed for small pelagic species having indeterminate fecundity. However, the accuracy of the methods strongly depends on the survey coverage of the spawning area. As many temperate, marine species with pelagic eggs have very large spawning areas such that the required spawning effort for annual egg production methods based stock assessments is often not affordable. Given the often high cost of egg production surveys, particularly the annual method, there is a need for simulation studies to determine the relative performance of simpler and less expensive approaches to tracking SSB from egg surveys used in stock assessments.

Associated ToR 3 contributions include:

Lambert, Y. (Accepted). Long-term changes in life history characteristics and their impact on reproductive potential and consequences for the reproductive rate and productivity of northern Gulf of St. Lawrence cod (*Gadus morhua*). Fisheries Research.

Lambert, Y. 2011. Environmental and fishing limitations to the rebuilding of the northern Gulf of St. Lawrence cod stock. Can. J. Fish. Aquat. Sci. 68: 618-631.

Kraus, G. Hinrichsen, H.H., Voss, R., Teschner, E. ,Tomkiewicz, J., and Köster, F.W. (2012). Comparing egg production methods as fishery independent alternatives to assess the Eastern Baltic cod stock (*Gadus morhua* L.). *Fisheries Research* 117, 75-85.

Armstrong M.J.P. & Witthames P.R., 2012. Developments in understanding of fecundity of fish stocks in relation to egg production methods for estimating spawning stock biomass. Fisheries Research 117-118, 35-47.

Skjæraasen, J.E., Nash, R.D.M., Korsbrekke, K., Fonn, M., Nilsen, T., Kennedy, J., Nedreaas, K., Thorsen, A., Witthames, P.R., Geffen, A.J., Høie, H., and Kjesbu, O.S. In press. Frequent skipped spawning in the world's largest cod population. Proceedings of the National Academy of Sciences of the United States of America

A highlight for ToR 3 is the FRESH/NAFO Workshop 'Implementation of Stock Reproductive Potential into Assessment and Management Advice for Harvested Marine Species" that was held at the University of Aberdeen, Scotland on April 12-14, 2011. Co-convenors: C.T. Marshall (Univ of Abdn, UK), M.J. Morgan (DFO, Canada), I. Mosquiera (Cefas, UK), L. O'Brien (NMFS, USA). The proceedings of this Workshop are close to being published in a NAFO Scientific Council Report (led by J. Morgan). For further details on the Workshop findings those interested should look there.