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Reproductive Potential of Fish Populations of the North Atlantic

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Foreword

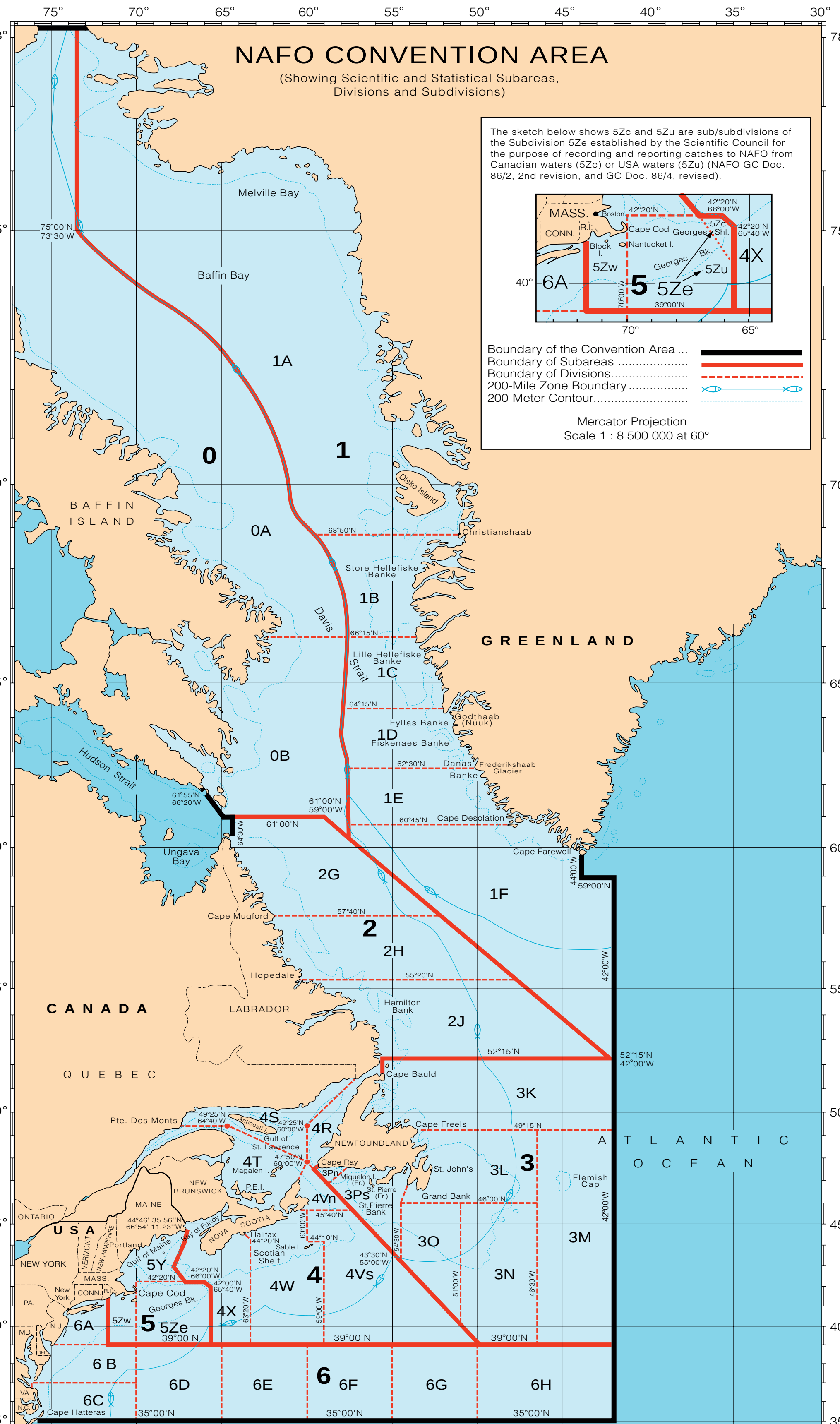
In accordance with its mandate to disseminate information on fisheries research to the scientific community, the Scientific Council of NAFO publishes the *Journal of Northwest Atlantic Fishery Science*, which contains peer-reviewed primary papers and notes on original research, and *NAFO Scientific Council Studies*, which contains review papers of topical interest and importance. Each year since 1981, the Scientific Council has held at least one Special Session on a topic of particular interest, and many of the contributions to those sessions have been published in either of these Publications. For 1998, Scientific Council in 1996 initiated a Special Session titled "*Variations in Maturation, Growth, Condition and Spawning Stock Biomass Production in Groundfish*", inviting M. Joanne Morgan (Canada) to lead the program (*NAFO Sci. Coun. Rep.,* 1996). The Symposium co-convened by M. J. Morgan (Canada), E. Aro (Finland) and J. Burnett (USA) resulted with stimulating discussions among participants from 19 countries that brought a North Atlantic perspective. The Symposium resulted in a special issue of the *Journal of Northwest Atlantic Fishery Science,* Volume 25.

The Symposium recommendation to form the NAFO Scientific Council Working Group on Reproductive Potential was endorsed, and in June 1999 the Working Group was struck inviting Ed A. Trippel (Canada) to chair it. The long and dedicated work of members of the Working Group since then has resulted in this issue of the Journal. The work of the group also resulted in a companion issue in August 2003 of *NAFO Scientific Council Studies,* Number 37*,* titled "*The Availability of Data for Estimating Rreproductive Potential for Selected Stocks in the North Atlantic*" authored by M. J. Morgan, J. Burnett, J. Tomkiewicz and F. Saborido-Rey.

In accordance with the decision of the Scientific Council, Ed Trippel was invited to undertake the normal Journal editorial work on the papers submitted for this issue. At the NAFO Secretariat final editorial work was also done as needed to bring this volume to print. This issue captures quality information of current interest particularly relating to North Atlantic fish stocks, the considerations discussed at the 1998 Symposium, and the comprehensive information coverage achieved through the Working Group on Reproductive Potential.

December 2003

Tissa Amaratunga, NAFO, Deputy Executive Secretary
Technical Editor
Journal of Northwest Atlantic Fishery Science


NAFO CONVENTION AREA
(Showing Scientific and Statistical Subareas, Divisions and Subdivisions)
The sketch below shows 5Zc and 5Zu are sub/subdivisions of the Subdivision 5Ze established by the Scientific Council for the purpose of recording and reporting catches to NAFO from Canadian waters (5Zc) or USA waters (5Zu) (NAFO GC Doc. 86/2, 2nd revision, and GC Doc. 86/4, revised).
MASS.
Boston
42°20'N
42°20'N 66°00'W
R.I.
CONN.
Cape Cod
Georges
5Zc
Shl.
42°20'N 65°40'W
Block I.
Nantucket I.
Bk.
4X
5Zw
Georges
5Zu
40°
6A
5
5Ze
70°00'W
39°00'N
70°
65°
Boundary of the Convention Area
Boundary of Subareas
Boundary of Divisions
200-Mile Zone Boundary
200-Meter Contour
Mercator Projection
Scale 1 : 8 500 000 at 60°
75° 70° 65° 60° 55° 50° 45° 40° 35° 30°
78° 75° 70° 65° 60° 55° 50° 45° 40° 35°
Melville Bay
75°00'N 73°30'W
Baffin Bay
1A
0
1
Disko Island
BAFFIN ISLAND
0A
68°50'N
Christianshaab
Store Hellefiske Banke
1B
Davis Strait
66°15'N
GREENLAND
Lille Hellefiske Banke
1C
64°15'N
Godthaab (Nuuk)
Fyllas Banke
1D
Fiskenaes Banke
0B
Hudson Strait
62°30'N
Danas Banke
Frederikshaab Glacier
61°55'N 66°20'W
61°00'N 59°00'W
1E
61°00'N
60°45'N
Cape Desolation
64°30'W
Ungava Bay
Cape Farewell
2G
44°00'W
59°00'N
1F
Cape Mugford
57°40'N
2
2H
Hopedale
55°20'N
42°00'W
CANADA
LABRADOR
Hamilton Bank
2J
52°15'N
52°15'N 42°00'W
QUEBEC
Cape Bauld
3K
Pte. Des Monts
49°25'N 64°40'W
4S
Anticosti I.
49°25'N 60°00'W
4R
Cape Freels
49°15'N
ATLANTIC OCEAN
Gulf of St. Lawrence
NEWFOUNDLAND
47°50'N 60°00'W
4T
Magalen I.
Cape Ray
3Pn
St. John's
3L
3
Flemish Cap
NEW BRUNSWICK
P.E.I.
Miquelon I. (Fr)
St Pierre (Fr.)
3Ps
4Vn
Grand Bank
46°00'N
MAINE
St.Pierre Bank
45°40'N
ONTARIO
44°46' 35.56"N 66°54' 11.23"W
USA
Bay of Fundy
NOVA SCOTIA
VERMONT
NEW HAMPSHIRE
Halifax 44°20'N
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60°00'W
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3O
3M
Portland
Sable I.
Gulf of Maine
Scotian Shelf
43°30'N 55°00'W
NEW YORK
5Y
42°20'N 66°00'W
4
4Vs
3N
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42°00'N 65°40'W
51°00'W
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MASS.
4W
PA.
New York
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Cape Cod
Georges Bk.
63°20'W
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DEL.
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6E
6
6F
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6H
VA.
6C
N.C.
Cape Hatteras
35°00'N
35°00'N
35°00'N

Contents

Introduction

The set of papers that appears in this special volume is the result of a decision by the Scientific Council of the Northwest Atlantic Fisheries Organization to establish a Working Group on Reproductive Potential at the conclusion of the NAFO September 1998 Symposium entitled "*Variations in Maturation, Growth, Condition and Spawning Stock Biomass Production in Groundfish*". The Working Group, since 1999, addressed a set of terms of reference assigned by the Scientific Council and during this period conducted two meetings. The first meeting was held at the Aquarium, San Sebastian, Spain, 10–13 October 2000. The second meeting was held at Giprorybflot (State Research and Design Institute for Fishing Fleet), St. Petersburg, Russia, 23–26 October 2001.

A report of the Working Group as prepared follows to provide details of rationale, objectives, terms of reference, participants, brief overviews of contributions, and recommendations. Nine papers from the Working Group appear in this volume entitled "*Reproductive Potential of Fish Populations of the North Atlantic*". All papers were subject to the normal peer review process of the *Journal of the Northwest Atlantic Fishery Science*. An additional volume providing reference sources of available data on the reproductive biology of 53 fish stocks is published separately in the *NAFO Scientific Council Studies*, Number 37.

The papers presented in the present Journal volume and the *NAFO Scientific Council Studies* represent an integrated effort to review available data, synthesize and recommend state-of-the-art procedures for estimation of a stock's reproductive potential, and provide examples of how this information can be used to improve scientific advice to fisheries managers. It is hoped that these volumes will contribute to further development of this growing area of fishery science and thereby lead to greater integration of reproductive biology into fish stock assessment, management and conservation.

This volume would not have been possible without the dedicated work of the Working Group members and that of the NAFO Secretariat. As well, many people contributed by providing thorough peer reviews of submitted manuscripts. A list of the reviewers follows:

M.P.M. Burton (Canada), R.C. Chambers (USA), G.A. Chouinard (Canada), R.M. Cook (UK), A.C. Gundersen (Norway), R.G. Halliday (Canada), J.R.G. Hislop (UK), J.A. Hutchings (Canada), B.R. MacKenzie (Denmark), D.G. Nichol (USA), P. Ouellet (Canada), W.J. Overholtz (USA), A. Rakitin (Canada), R.M. Rideout (Canada), F.M. Serchuk (USA), P.A. Shelton (Canada), and M. Suquet (France).

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Report of the Working Group

The Scientific Council Working Group on Reproductive Potential was created following a recommendation at the conclusion of the Symposium on "*Variations in Maturation, Growth, Condition and Spawning Stock Biomass in Groundfish*" held during 9–11 September 1998 in Lisbon, Portugal. The Working Group on Reproductive Potential initiated its activities in November 1999.

There were 18 participants from 10 countries. They were E. A. Trippel, Chairman (Canada), J. Burnett (USA), S. Junquera (Belgium), O. S. Kjesbu (Norway), G. Kraus (Germany), Y. Lambert (Canada), G. Lilly (Canada), C. T. Marshall (United Kingdom), G. Marteinsdottir (Iceland), M. J. Morgan (Canada), H. Murua (Spain), L. O'Brien (USA), F. Saborido-Rey (Spain), A. Thorsen (Norway), J. Tomkiewicz (Denmark), P. R. Witthames (UK), P. J. Wright (UK), and N. A. Yaragina (Russia). The list of Working Group members and their full addresses are given below.

Introduction and Objectives

Many coastal communities and maritime economies rely on harvest fisheries for their livelihood and prosperity. Marked reductions in finfish resources, unfortunately, have occurred in the North Atlantic and Baltic Sea since the early-1990s. The current depressed condition of the majority of demersal fishery resources in these regions is thus of significant concern to the health, conservation and protection of fish stocks and the economic prosperity of the impacted coastal communities. Scientific agencies have consequently made substantial investments in understanding the reproductive processes and capacity of fish stocks, as it is widely acknowledged that self-population replenishment is the sole mechanism by which these stocks might recover.

During 1993–97, several symposia and scientific working groups have examined fisheries management advice, with some concentrating on spawning stock biomass (SSB) levels as a key element in precautionary advice for the avoidance of recruitment overfishing. Biological reference points were established that would alert managers to appropriate levels of fishing mortality to permit sustainable exploitation and safeguard against stock collapse. These initiatives included: (i) Risk evaluation and biological reference points for fisheries management (Smith *et al*., 1993), (ii) Precautionary approaches to fisheries (FAO, MS 1995), (iii) A groundfish conservation framework for Atlantic Canada (FRCC, MS 1997), (iv) Report of the study group on the precautionary approach to fisheries management (ICES, MS 1997), and more recently (v) Report of the *ad hoc* working group of the NAFO Scientific Council on the precautionary approach (NAFO, MS 2003). These efforts articulated a variety of methods that scientific agencies could adopt for the protection and wise utilization of fishery resources. Some recommendations encouraged the adherence to low exploitation levels such as $F_{0.1}$ (~20% of stock biomass annually), whereas others explored SSB-based harvest guidelines. Further expansion of SSB or egg- production based management advice in these reports, however, was limited and revealed only a simplistic portrayal of the reproductive capacity of a population.

Recognition of the gap between fisheries management practices and the growing knowledge of reproductive processes led the Northwest Atlantic Fisheries Organization (NAFO) Scientific Council to establish a lead role in expanding and highlighting the integration of new knowledge on this subject. Prior to the mid-1990s, only a limited amount of data on reproductive biology was used to understand recruitment mechanisms in fish stocks. The September 1998 Symposium in Lisbon on "*Variations in Maturation, Growth, Condition and Spawning Stock Biomass Production in Groundfish*" sponsored by the NAFO Scientific Council generated a co-edited volume representing 19 articles spanning a wide variety of species and areas under the symposium theme (Morgan *et al*., 1999).

Noting the significant progress made by contributors to the Lisbon symposium, and the general widespread interest to maintain a concerted momentum in applying reproductive biology to fisheries management, it was recommended during the conclusion of the symposium that the Working Group of Reproductive Potential (WG) be established. The Scientific Council assigned four Terms of References to the Working Group which when completed would provide a solid foundation for continued study on fish reproductive processes and their links to improve the representation of reproductive potential in stock assessments. These improved estimates of stock

reproductive capacity could in turn further the understanding of recruitment fluctuations, population re-building rates, and critical levels of stock size to prevent recruitment overfishing.

Terms of Reference

The following four Terms of Reference (ToR) were addressed:

1. Explore and review availability of information and existing data on reproductive potential by area and species.
2. Explore possibilities to develop standard internationally co-ordinated research protocols to estimate egg and larval production.
3. Explore and evaluate alternative methods to estimate reproductive potential annually as part of routine in monitoring and sampling schemes (such as HSI, hepatosomatic index).
4. Review possibilities to develop methods and application to estimate stock reproductive potential for assessment and management.

To undertake this task, the WG comprised 18 scientists representing 9 countries and 14 laboratories, each having responsibilities for scientific advise in the exploitation of fishery resources in the North Atlantic and Baltic Sea. A broad perspective was sought among membership and included individuals with a range of expertise, some external to NAFO member countries. Given the large-scale initiative and growth in this area of fishery science it was believed critical to involve experts from a wide background. Their expertise on new knowledge on data rich stocks of a given species could assist with the understanding and improved management with data limited stocks of the same species that exist in some NAFO areas. It was also apparent during the Lisbon symposium that the problems identified in stock assessments were not restricted to NAFO stocks but included many of the International Council for Exploration of the Sea (ICES) stocks and by integration the WG also could assist and gain from endeavours by other lead agencies. These initiatives include the recent formation of the ICES Study Group on Growth, Maturity and Condition in Stock Projections (ICES, MS 2003) and the increasing attention given to this problem by the ICES Working Group on Recruitment Processes.

In total, 10 contributions are being published to complete the WG ToR. Nine peer-reviewed papers are published in the present Journal volume entitled "*Reproductive Potential of Fish Populations of the North Atlantic*" and an additional extensive report on stock reproductive data was published in *NAFO Scientific Council Studies* Number 37 (all are on-line on the NAFO web site (*www.nafo.int*)). A separate publication in the *NAFO Scientific Council Studies* became a necessity as the amount of available data on reproductive potential of >50 fish stocks was too large to include in the primary literature. These publications were completed through the dedicated work of each ToR Sub-Group comprised of the following individuals:

ToR 1 Co-leaders: J. Burnett and J. Tomkiewicz
Participants: M.J. Morgan, H. Murua, L. O'Brien, P. Wright.

ToR 2 Co-leaders: H. Murua and A. Thorsen
Participants: S. Junquera, O.S. Kjesbu, G. Kraus, Y. Lambert, G. Lilly, F. Saborido-Rey, P. Witthames.

ToR 3 Co-leaders: Y. Lambert and N. Yaragina
Participants: G. Kraus, T. Marshall, G. Marteinsdottir, P. Wright.

ToR 4 Co-leaders: T. Marshall and G. Marteinsdottir
Participants: L. O'Brien, F. Saborido-Rey , J. Tomkiewicz.

The activities culminating in the present volume can be summarized as follows:

The WG membership was finalized in November 1999 and the participants developed work plans which were distributed and appraised by April 2000. These were presented to NAFO Scientific Council in Dartmouth, Nova Scotia, Canada in June, 2000, reviewed and approved (NAFO, 2000). Thirteen WG members participated in the first meeting at the Aquarium, San Sebastian, Spain, 10–13 October 2000. This provided an excellent forum to review progress and to develop a publication format for the WG's findings. Proposed manuscripts and associated authors were confirmed during this meeting. WG progress was presented at the June 2001 Scientific Council meeting in

Participants from 1st Meeting of the Working Group on Reproductive Potentiasl, Aquarium, San Sebastian, Spain: (*Left to right*): L. Motos, J. Tomkiewicz, N. Yaragina, M. J. Morgan, H. Murua, Y. Lambert, S. Junquera, T. Marshall, F. Saborido-Rey, J. Burnett, E. Trippel (Chair), A. Thorsen, L. O'Brien, and G. Lilly.

Assistance with local arrangements was generously provided by H. Murua, L. Motos and V. Zaragueta.

Dartmouth, Nova Scotia (NAFO, MS 2001) and approval was given to hold a second meeting to complete the ToRs. The second WG meeting was held at Hydropyflot, St. Petersburg, 23–26 October 2001. This provided an opportunity to present draft versions of manuscripts, integrate information where necessary and allocate assignments to meet final targets. For some papers, additional co-authors were invited (P. Berrien (USA), H. Björnsson (Iceland), J.L. Blanchard (UK), F.W. Köster (Denmark), R.G. Lough (USA), N.V. Mukhina (Russia), and P.J. Rago (USA)) and their involvement in this volume is appreciated. Submitted manuscripts underwent scientific peer review during 2002–2003 and an overview of the final versions together with 27 recommendations were presented to NAFO Scientific Council in June 2003 (NAFO, 2003).

Participants present at the 2nd Meeting of the Working Group on Reproductive Potential, State Research and Design Institute for Fishing Fleet (Giprorybflot), St. Petersburg, Russia:

(*Left to Right*): L. O'Brien, P. Wright, N. Yaragina, H. Murua, T. Marshall, G. Kraus, Y. Lambert, A. Thorsen, F. Saborido-Rey, and E. Trippel (Chair).

Assistance with local arrangement was generously provided by N. Yaragina, L. Zazlavskaya and V. Romanov.

A brief description of the various contributions and sequential listing of the 27 recommendations made by the WG related to the ToR follow:

ToR 1: Explore and review availability of information and existing data on reproductive potential by area and species.

Two papers represent the contribution of this ToR. The first prepared by Morgan *et al*. (2003) published in the *NAFO Scientific Council Studies* Number 37 lists, in extensive tabular format, several kinds of reproductive data collected over time for a wide variety of fish species and stocks. These data sources span both the primary and secondary literature and are required to build estimates of stock reproductive potential over specific time series. A number of biologists and scientists in various laboratories of the North Atlantic and Baltic Sea kindly contributed their time to complete these tables and are acknowledged for respective stocks as key contact persons. A second contribution (Tomkiewicz *et al*.), published in the present volume, was based on the detailed data from the first contribution and judged the relative degree of data availability by decade for 42 demersal stocks assessed by NAFO. Data on fish age, weight, maturity and sex ratio have been extensively collected. However, possibilities for estimating stock egg production are constrained by scarcity of fecundity data. Data on fish condition, which can be used to develop fecundity models, were seldom collected in earlier time periods, but have become more prevalent in recent years. In general, greater data availability occurred along a gradient from redfish and grenadiers to flatfish

to gadoids, though extensive variation among stocks of a given species occurred. It is noted that sufficient data currently exists to estimate reproductive potential of many fish stocks.

1. Substantial information exists on the reproductive potential of fish stocks in the Northwest Atlantic, however, there is a scarcity of fecundity data. It is recommended that a number of studies be initiated to collect fecundity data for grenadier, redfish, flatfish and gadoid stocks.

2. Greater effort should be made to utilize existing data on reproductive potential in fish stock assessments, beyond reporting estimates of total spawning stock biomass.

ToR 2: Explore possibilities to develop standard internationally co-ordinated research protocols to estimate egg and larval production.

This ToR is a key element of the WG's activities and through five papers is addressed by description, critical evaluation, and recommendation of various procedures required to estimate stock reproductive potential. Given the increasing interest in this field, appropriate guidelines in sampling and analyses to estimate stock reproductive potential should be provided to prospective investigators. This is important as often investigators of various laboratories use different techniques or approaches. This could introduce laboratory bias in results and hence reduce the ability to compare findings among studies of the same species.

The first paper (Murua and Saborido-Rey) describes the most common reproductive strategies of a large number of commercially important fish species of the North Atlantic. The second paper (Murua *et al*.) lists for each reproductive strategy the necessary procedures needed to undertake the estimation of fecundity of wild collected fish. Reference is made to both the advantages and disadvantages of each method and of protocols at sea for ovarian sample preservation and in the laboratory for sample analyses. This paper is of particular value, given the paucity of fecundity data for fish stocks outlined in ToR 1.

Controlled captive fish studies used to supplement knowledge gained from wild fish stocks have become increasingly important in the estimation of stock reproductive potential. Factors such as reproductive experience, condition, food supply, and water temperature can be examined. In the third paper of this ToR, Thorsen *et al*. review and recommend a variety of methods used to conduct experiments on estimating production and quality of eggs of captive marine fish within this context. A fourth paper (Lambert and Thorsen), cautions investigators to take appropriate steps when designing captive fish studies so that their findings can be extrapolated to the reproductive performance of wild fish.

The final paper of ToR 2 by Trippel reviews experimental techniques used to measure the reproductive success of male marine fish. This gender is rarely integrated in the estimation of stock reproductive potential and demands further attention. An equation is introduced that quantifies a population's viable sperm production and is applied to Atlantic cod of Newfoundland and Labrador.

3. Samples for maturity ogive estimation should be taken during prespawning, preferably when the population is about to spawn, and during the spawning season, though before peak spawning time so as to evaluate inactive mature fish.

4. In order to obtain representative maturity ogives, we strongly recommend sampling the entire distributional area of a given stock (including adult and juvenile areas) and the use of histological criteria for the classification of gonads to replace (or at least verify) a less-costly more extensive survey based on macroscopic criteria.

5. Prior to the application of any fecundity estimation method, homogeneity in oocyte distribution in the ovary should be investigated to ensure that the sub-sample to be analysed represents the entire ovary.

6. To estimate potential- or batch fecundity, ovaries should be screened histologically to check for the occurrence of post-ovulatory follicles (POF). Ovaries containing POFs should be eliminated from potential

fecundity calculations, since the presence of POFs indicate that spawning has already started and the number of oocytes in the ovary has consequently decreased. For batch fecundity estimations, only hydrated ovaries which do not contain early stage POFs should be used because the presence of these follicles indicate that some eggs have been already released.

7. For atresia estimation, before applying a quantitative approach we recommend histological screening as a first step to check the relevance of oocyte atresia for the stock under investigation. Only if a significant proportion of the fish stock shows intensive atresia, is a quantitative estimation recommended.

8. To estimate realized fecundity in batch spawning fish it is recommended to conduct experimental egg production studies on spawning pairs.

9. Special care should be taken to give the spawning fish good conditions and to avoid unnecessary stress. Stress is well known to have a negative influence on courtship behaviour and spawning performance.

10. The quality of the eggs produced should be evaluated. Key factors are usually fertilization rate, mortality and size.

11. More experiments on the reproduction of captive marine fish species should be conducted since this type of experimental approach improves our understanding and our capacity to predict changes in the reproductive potential of fish populations in natural environments.

12. Species-specific approaches used to study the reproduction of captive marine fish need to be carefully evaluated before extrapolating experimentally-determined reproductive parameters to wild fish.

13. Repeatability of experimental results need to be evaluated by comparing the results of more than one experiment and/or by comparing the results obtained with the same protocol in different laboratories.

14. Experiments on the reproduction of marine fish should preferably use wild fish captured before the onset of maturation, kept in captivity for limited periods of time and fed with natural prey.

15. The possibility exists that sex-selective harvesting has skewed sex ratios and this should be accounted for in the estimation of stock reproductive potential.

16. Estimation of viable sperm production of stocks and evaluation of their correlation with recruitment should be explored.

17. Research should be undertaken to estimate the relative role of paternal and maternal influences and their synergistic effects on reproductive and early life history success of marine fish species.

18. Male- and female-based causal factors of phenotypes of early life history traits should be explored and a search for possible proxies of male reproductive potential be undertaken.

ToR 3: Explore and evaluate alternative methods to estimate reproductive potential annually as part of routine in monitoring and sampling schemes (such as HSI, hepatosomatic index).

An extensive review is undertaken by Lambert *et al*. of various correlations and regressions that have been published to predict aspects of stock reproductive potential. The review concentrates on biological and environmental proxies including condition factor to estimate egg production, and viability of eggs and larvae. These alternative measures of reproductive potential require relatively less effort than undertaking extensive field collections of gonads and subsequent subsample analyses. The development of alternative measures of reproductive characteristics of fish could result in more precise estimates of reproductive potential of fish stocks that could be used for hindcasting and predicting egg and/or larval production and viability.

19. The large variability observed in maturity at size or age, fecundity, egg viability, and/or larval hatching success both within and between stocks emphasizes the importance of monitoring on a routine basis the reproductive characteristics of fish stocks in order to obtain accurate measurements of stock reproductive potential.

20. Case studies using different populations of the same species are needed to evaluate the possibility of using the relationships between reproductive characteristics and specific biological and environmental indices as proxies for the estimation of egg production on a scale encompassing the distribution of different populations.

21. Although routine monitoring of reproductive potential is preferable, the significant relationships observed between many reproductive characteristics (e.g., fecundity, egg and larval characteristics and viability) and environmental and biological indices support the exploration of correlation analysis to develop alternative means of estimating reproductive potential. Such indices may be applied to data moderate or limited stocks, when general relationships for species have been demonstrated by case studies.

22. The use of correlation analysis to estimate egg production has to be justified by an increase in precision in the determination of reproductive potential, as e.g., indicated by an improved stock-recruitment relationship, by the simplicity of measurement of the selected proxies, and the availability of pre-existing data on selected proxies.

ToR 4: Review possibilities to develop methods and application to estimate stock reproductive potential for assessment and management.

Two contributions comprise this ToR. In the first (Marshall *et al*.), nine stocks illustrate the range of approaches that are being taken to develop alternative indices of reproductive potential from existing data sources. Several stocks covered include Baltic cod, Northeast Arctic cod, Icelandic cod, Scotian Shelf haddock (*Melanogrammus aeglefinus*), Atlantic striped bass (*Morone saxatilis*), and American plaice (*Hippoglossoides platessoides*) of the Grand Bank. Management protocols should be adapted to incorporate the detailed information on reproductive potential that is increasingly becoming available rather than being restricted to approaches that have been designed for data-poor situations.

The final paper by O'Brien *et al*. details an approach used for Atlantic cod of Georges Bank that improves the ability to predict egg survivorship and recruitment by incorporating in regression analyses existing data on age diversity, reproductive experience, and shelf bottom temperature. It illustrates the gains that can be made over simple use of SSB.

23. Explore the effect of truncated age/size structure on reproductive potential using strategic laboratory, field and modelling studies.

24. Explore the effects of age- or size-dependent spatial distribution of spawners on egg survival to hatch (i.e., realized total egg production) using strategic laboratory, field and modelling studies.

25. Quantify the divergence between spawning stock biomass and alternative indices of reproductive potential recognizing that the latter are to be preferred if they incorporate factors whose importance to reproductive potential is self-evident (e.g., sex ratios, female-only maturity ogives, fecundity) but unaccounted for in conventional estimates.

26. The precautionary approach should be formulated so that it can accommodate additional information on reproductive potential rather than being restricted to approaches developed for data-limited stocks.

27. For many stocks the estimation of alternative indices of reproductive potential would be facilitated by improved accessibility of historical data particularly when these are not archived electronically.

It is hoped that the efforts of members of this Working Group on Reproductive Potential will contribute to further development of this advancing field of fishery science and thereby lead to greater integration of reproductive biology in fisheries management advice.

Acknowledgements

I would like to dedicate this volume to the memory of Edwin J. Crossman (1929–2003) former Curator, Department of Ichthyology and Herpetology, Royal Ontario Museum, Toronto, Canada, who through his breath of knowledge, zest for scientific inquiry, and strict yet good-hearted mentoring inspired students to enter into and further the study of fishes.

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