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# Proceedings of the workshop on Strategies for strengthening the Link between the Atlantic Zone Monitoring Program (AZMP) and Stock Assessment

**November 13 to 15, 2002**
**Crowne Plaza Hotel**
**Montreal, Québec**

**Patrick Ouellet**

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**850 route de la mer**
**Mont-Joli, Québec**
**Canada G5H 3Z4**

**February 2003**


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# Executive summary

## Introduction

The workshop was co-sponsored by the Fisheries Oceanography Committee (FOC) and the Atlantic Zone Monitoring Program (AZMP) of the Department of Fisheries and Oceans and was attended by fisheries assessment biologists and oceanographers. Its principal objectives were to discuss how stock assessment might benefit from ecosystem information and in particular to identify data products from the AZMP that could improve our capability to foresee and to understand the causes of variation in the distribution, abundance, and productivity of fish and shellfish resources. The agenda consisted of an initial day of overview presentations on the topics of AZMP, the stock assessment process, environment-fish relationships in the Atlantic Zone, and contributions from two external participants, Dr. Keith Brander from the ICES GLOBEC Office and Dr. Brian Mackenzie from the Danish Institute for Fisheries Research. During the second day, the participants were divided into three break-out groups to address specific questions concerning stock and regional needs for environmental information within the stock assessment process and how to improve exchange and communication between scientists involved in the AZMP, the FOC and stock assessments. The final day was in plenary session to discuss the findings of the break-out groups and to develop recommendations.

## Overview presentations

Pierre Pepin (Chair of AZMP) opened the first day with an overview of the goal, activities and data products of the AZMP. This was followed by a presentation on the stock assessment process and how environmental information could be used in the exercise. The stock assessment process was divided into three parts: (a) evaluation of stock size, (b) prediction of yield, and (c) understanding the mechanisms. Environmental information could potentially be useful for all parts. The effects of the environment on catchability could potentially help part (a) but it was suggested that environmental information would probably be most useful in addressing the last two parts, especially in association with longer-term predictions for fish stocks such as it is being done within ICES. Environmental information was seen as being most important if it could be used to imply changes in productivity regimes (i.e. regime-shifts). Environmental information is presently used in a qualitative manner for a number of stocks but there is little quantitative use of environmental data in stock assessments. This is for several reasons. First, although there have been several statistical relationships between the environment and population parameters these usually were obtained through exploratory correlation analysis and often do not hold when further data are obtained. Second, the assessment models have not been designed to easily incorporate environmental information. Third, currently, there are no medium- or even short-term projections of the environmental indices The workshop felt that it is important to continue research directed towards uncovering relationships between the environment and population characteristics and to attempt to understand the mechanisms involved. An important point is to examine, where possible, the relative importance of the environment compared to other potential controlling factors. This can be done progressively but progress might be quicker if we adopt a systematic approach and a sustained collaborative effort that incorporated long-term monitoring (i.e., AZMP) and short-term process studies to test hypotheses.

The use of numerical models was recognized as a potentially valuable tool in helping to define key variables or processes and to provide environmental indices for stock assessments. Numerical methods include hydrodynamical/physical models, biophysical models and data assimilation. Biophysical models can provide information on the major components of the food web, i.e. phytoplankton, zooplankton, invertebrates and fishes. Phytoplankton-Zooplankton-Nutrients-Detritus (PZND) models are useful to simulate the lower trophic interactions of the food web. Early Life Stage (ELS) models and Individual Based Models (IBM) are used to better understand the effect of the environment on the growth, drift, mortality, survival and retention of eggs and larvae of fishes and invertebrates. Monitoring programs such as the AZMP provide the necessary information for model initialization and validation.

There is also a need for programs that involve iterative communication among oceanographers and biologists, and among data collectors and modelers, throughout the Atlantic Zone, that will help to test old hypotheses, generate new hypotheses, and identify data requirements.

**Break-out group reports**

Participants in all three break-out groups (two focusing upon fishes species and one on invertebrate species) were unanimous in declaring that monitoring of the environment is the basis of all ecological studies on marine species. Currently, AZMP provides broad overviews of physical and biological oceanographic conditions through the FOC. The associated generic indices presented to the FOC were considered useful and should be continued. In some regions, stock-specific physical indices are presented along with the generic indices to certain stock assessment meetings. The development of more stock-specific indices was encouraged. Biological indices are presented to assessment meetings on a less routine basis. This is in large part because most of the biological time series are relatively short but with continuation of the AZMP these should provide useful information for assessments.

However, the importance of monitoring data from programs not funded by the AZMP (e.g. multispecies trawl species, etc.) was not generally known by assessment scientists. In addition, concerns were expressed about communication issues (e.g., the scope and mandate of AZMP is not always well known among assessment scientists) and how to increase awareness of AZMP activities and data products (e.g., AZMP website, CSAS status reports presented and reviewed at FOC, CSAS Res Docs, annual bulletin highlighting important environmental events).

It was felt that the FOC should remain the principal forum to channel environment-assessment interactions. However, it was also recognized that assessment scientists should be encouraged to examine environmental information (physical as well as biological) as well as to seek collaborations with oceanographers.

**Recommendations**

From the break-out group discussions and the plenary session on the last day, the following recommendations were formulated:

(1) Several gaps were identified in the present AZMP collections. These included trophic levels (e.g., primary/secondary production indices, macrozooplankton, gelatinous plankton, fish larvae, benthos), remote geographic areas that are presently not covered (the Strait of Belle Isle, Southern Newfoundland), and the near-shore zone. **It was recommended that the AZMP consider if or how these identified gaps might be incorporated into the AZMP.**

(2) Numerous climate indices could be used to produce customized data products for stock assessments. It was felt desirable to increase the availability of these data to the users (assessment biologists and fisheries scientists) in order that they could explore and develop their own data products. **It was recommended that a virtual data center be developed that would allow open access to as much of these data as possible**.

(3) The AZMP website was recognized as being helpful in accessing data and climate indices but it was felt that improvements could be made to further help the fisheries and assessment scientists in their task of exploring environmental relationships with fish stocks and fisheries. **It was recommended that additional information concerning background information on the AZMP (mandate, scope, etc.), procedures for data collection and processing, and on the data themselves (quality assurance, representativeness, and any caveats) be provided on the AZMP website.**

(4) **It was recommended that the spatial scales of variability of the data collected by AZMP and how this relates to their representativeness needs to be assessed by the AZMP**. While this process is already underway and nearing completion for some of the physical variables it was felt to be of significant enough importance, especially for biological variables, that it needed to be emphasized.

(5) To aid in the exploration of environment-fish relationships and their possible use in assessment work, **it was recommended that case studies of one or more particular fish stocks be undertaken under the guidance of the FOC**.

(6) **It was recommended that regional working groups be developed to ensure that consideration of environmental information be an integral part of the assessment process**. This could occur through the Assessment Framework Working Groups, which should include oceanographers as part of the WGs.

(7) In some historical studies, plankton samples were collected and stored but not fully processed. These offer great potential for increasing our time series for plankton. **It was therefore recommended that efforts be made to ensure these samples are analysed to the fullest extent as possible.**

# Résumé


## Introduction

L'atelier était organisé conjointement par le Comité sur l'océanographie des pêches (COP) et le Programme de monitorage de la zone Atlantique (PMZA) de Pêches et Océans Canada et regroupait des biologistes responsables des évaluations ainsi que des océanographes. Les objectifs étaient de discuter comment l'évaluation des stocks pourrait bénéficiée d'information au niveau des écosystèmes et des données fournies par le PMZA en particulier, afin d'améliorer notre capacité de prévoir et de comprendre les causes des variations dans la distribution, l'abondance et la productivité des espèces de poissons et d'invertébrés. Le programme comprenait une première journée de présentations générales sur le PMZA, l'exercice d'évaluation des stocks, les liens entre l'environnement et les espèces dans la zone Atlantique et la contribution de deux chercheurs de l'extérieur : les Drs Keith Brander du CIEM (secrétariat du GLOBEC) et Brian Mackenzie de l'Institut Danois de la recherche sur les pêches. Au cours de la deuxième journée, les participants ont été séparés en trois groupes afin de discuter des besoins régionaux ou spécifiques aux différents stocks concernant l'information environnementale nécessaire aux évaluations et, aussi, des moyens pour encourager les échanges et la communication entre le PMZA, le COP et l'évaluation des stocks. La dernière journée, les discussions se sont poursuivies en session plénière et l'atelier a produit des recommandations sur la base de ces discussions.

## Présentations générales

Pierre Pépin (président du PMZA) a ouvert l'ordre des présentations par un exposé des buts, des activités et des produits du programme de monitorage. Cet exposé était suivi par une présentation sur la procédure d'évaluation des stocks et comment l'information environnementale pourrait être utilisée. L'évaluation des stocks peut être divisée en trois parties : (a) l'estimation de la taille du stock, (b) la prévision de la production et (c) chercher à comprendre les mécanismes responsables des fluctuations. L'information environnementale est susceptible d'être utile à chaque étape. L'environnement peut affecter le succès de capture et influencer l'estimation d'abondance (point 'a'), mais il a été suggéré que l'information environnementale serait surtout utile aux points 'b' et 'c', spécialement en se qui concerne la prédiction à long terme des stocks telle que, par exemple, pratiquée au CIEM. L'information environnementale serait particulièrement utile afin de suivre ou de détecter les changements de régimes dans l'écosystème. Actuellement, l'information environnementale est utilisée qualitativement pour un certain nombre de stocks mais il y a peu d'applications quantitatives dans l'évaluation des stocks. Il y aurait plusieurs raisons à cela. Premièrement, bien que des relations statistiques entre des variables environnementales et des paramètres de population ont dans certain cas été décrites, ces relations de nature exploratoires et corrélatives se sont souvent effondrées avec l'ajout de nouvelles données. Deuxièmement, les modèles quantitatifs d'évaluation des stocks ne permettent pas facilement l'intégration d'information auxiliaire (environnementale). Troisièmement, il n'y a pas de projections à moyen ou même à court terme des indices environnementaux. L'atelier a conclu qu'il est important de poursuivre la recherche dirigée vers la description des relations entre l'environnement et

l'évolution des populations et vers la compréhension des mécanismes impliqués. Il est aussi important d'examiner, quand cela est possible, l'importance relative de l'environnement par rapport à d'autres facteurs susceptibles d'affecter la population. Une approche systématique et un effort de collaboration soutenu intégrant monitorage et recherches spécifiques sur les mécanismes permettraient de progresser plus rapidement vers ces objectifs.

L'utilisation de modèles numériques a été également reconnue comme un outil utile pour définir les variables et les processus clés et pour fournir des indices environnementaux pour les évaluations de stocks. Les différents types de modèles seraient les modèles physique (hydrodynamique), bio-physique et l'assimilation de données. Les modèles couplant physique et biologie peuvent fournir de l'information sur les composantes majeures de la chaîne trophique : phytoplancton – zooplancton – invertébrés – poissons. Les modèles 'PZND' (phytoplancton – zooplancton – nutriments – détritus) sont utiles pour simuler les fonctions de base d'un écosystème. Les modèles de type 'IBM' (individual based models) sont utiles pour mieux comprendre l'effet de l'environnement sur la croissance, la survie, la dispersion, etc. des œufs et des larves de poissons et d'invertébrés. Un programme de monitorage (ex. PMZA) est nécessaire pour fournir les données essentielles au démarrage et à la validation des modèles.

L'atelier a aussi reconnu un besoin pour des initiatives favorisant les interactions entre les biologistes et les océanographes, entre échantillonneurs et utilisateurs de données, à l'intérieur de la zone Atlantique, afin de tester les hypothèses, générer de nouvelles hypothèses et identifier les besoins en information spécifique.

**Rapport sur les discussions des groupes**

Les participants de chacun des trois groupes (2 pour traiter de questions sur les espèces de poissons et 1 pour les invertébrés) ont été unanimes à déclarer que le monitorage de l'environnement marin est à la base de toutes études sur l'écologie des espèces. Présentement, le PMZA fourni une information générale sur les conditions océanographiques (physiques et biologiques) via le COP. Les indices spécifiques présentés via le COP sont jugés utiles et il est recommandé que cela continu. Dans certaines régions de la zone, des indices physiques particuliers pour un stock précis sont aussi présentés lors des évaluations régionales. L'atelier encourage le développement d'autres indices pour des stocks en particulier. Les indices biologiques sont moins souvent présentés lors des évaluations. Ceci est dû, en grande partie, au fait que les séries de données biologiques sont très courtes. Cependant, avec la continuation du PMZA, ces indices deviendront aussi utiles pour les évaluations.

L'importance des contributions au monitorage de programmes non inclus dans le PMZA (ex. les relevés de pêche scientifique) est peu connu des scientifiques responsables des évaluations. De plus, les participants ont exprimé le besoin d'une meilleure communication du mandat du PMZA et de l'étendu des activités de monitorage. Actuellement, ceci se fait via le site Internet du PMZA, les rapports aux SCCS, les présentations aux COP, etc.

Il est entendu que le COP devrait demeurer le forum principal pour la discussion des interactions entre l'environnement et l'évaluation des populations. Cependant, il a été également suggéré que les scientifiques responsables des stocks devraient examiner l'information environnementale (physique et biologique) et sont encouragés à chercher la collaboration des océanographes.

**Recommandations**

Lors de la session plénière, les recommandations suivantes ont été formulées sur la base des discussions de groupe :

(1) Des manques ont été identifiés dans les données présentement récoltées par le PZMA, soit : au niveau d'indices sur la production primaire et secondaire, le macro-zooplancton, le plancton gélatineux, les larves de poissons, le benthos, etc. et concernant certaines régions (détroit de Belle Isle, le sud de Terre-Neuve, etc.) et la zone côtière. **Il est recommandé que le PMZA étudie la possibilité et comment ces manques pourraient être incorporés au programme actuel**.

(2) L'information actuelle et plusieurs indices pourraient être utilisés pour produire des données particulières à certains stocks. Il a été jugé souhaitable que les données soient rendues accessibles aux utilisateurs (scientifiques responsables des évaluations) afin qu'ils puissent explorer et développer leurs propres indices. **Il est recommandé de développer un centre virtuel des données permettant un accès le plus large possible aux données.**

(3) Le site Internet du PMZA est considéré comme fort utile pour obtenir l'information et les indices mais des améliorations seraient aussi souhaitables afin de mieux aider les scientifiques responsables des évaluations dans leur tâche d'explorer les relations entre l'environnement et les espèces. **Il est recommandé que de l'information additionnelle concernant le mandat et l'étendu du PMZA, la méthodologie d'échantillonnage, des commentaires sur la qualité des données, etc. soit fournie sur le site Internet**.

(4) **Il est recommandé que la représentativité spatiale des stations du PMZA (l'échelle spatiale de la variabilité) soit analysée et présentée**. Cet exercice est déjà en cours, surtout au niveau des indices physiques, mais l'atelier a jugé cette question suffisamment importante pour formuler la recommandation surtout en ce qui concerne les indices biologiques.

(5) Afin d'aider le travail d'exploration des relations entre l'environnement et les espèces, et la possible intégration de l'information dans les évaluations, **il est recommandé que des cas d'espèces soient identifiés et étudiés sous les auspices du COP.**

(6) **Il est recommandé que des groupes de travail régionaux soient mis en place afin d'assurer que l'information environnementale est considérée lors du processus d'évaluation**. Dans la région des Maritimes et la région du Golfe, cela se ferait en

intégrant des océanographes au niveau des groupes de travail sur l'encadrement des évaluations déjà en place.

(7) Il existe des collections historiques de zooplancton qui n'ont jamais été pleinement analysées et qui offriraient un potentiel important pour augmenter la valeur des séries actuellement recueillies. **Il est recommandé que des efforts soient fait pour assurer l'analyse de ces échantillons**.

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# INTRODUCTION

## FOC and monitoring in the Atlantic Zone

The Fisheries Oceanography Committee (FOC) has the responsibility to contribute to the scientific basis for advice on fisheries problems influenced by meteorological, hydrographic, and biological processes. Assessments of exploited marine species based solely on intrinsic stock/population properties (e.g., number, size at age, mortality) provide short-term, year-to-year, predictions of abundance fluctuations of fish or shellfish stocks or populations. However, there is an increasing interest in, and the recognition of, the need to incorporate basic ecosystem information into the assessment process of exploited marine stocks. Among the advantages, there could be the possibility for longer-term forecasting of population trends and an increased capability to understand the impacts of environmental fluctuations on exploited populations. It is also the mandate of the FOC to discuss the application of oceanographic information to the analysis of the distribution and production patterns in the exploited stocks. Throughout the years, the FOC has been working to meet its obligations by holding various thematic sessions to discuss the role of oceanographic factors on the dynamic of the finfish and shellfish stocks at the Committee annual meetings and by creating ad hoc working groups.

The needs for monitoring of the physical and biological oceanographic variables in the Atlantic Zone were recognized early by the FOC and discussions on the implementation of a monitoring program can be traced back in time up to 1994. Subsequently, the Atlantic Zone Monitoring Program (AZMP) was initiated in the late 90's (see below) and the AZMP has now the responsibility for providing the FOC with the annual environmental (both physical and biological) overviews from which are presented the reports on the state of the oceanic environment.

Although it was implemented only recently, it was felt that there is now a need to evaluate the relevance of the data produced by the AZMP and to encourage the use of these data products, or additional products, in the estimation of the abundance and the investigations into the causes of variation in the abundance and the productivity of the marine resources in the Atlantic Zone.

## Workshop objectives

Monitoring programs of the oceanic environment, such as the AZMP, were implemented to build databases of basic oceanic properties (hydrographical, biological, and chemical) with the aim to describe, understand, and forecast the state of the marine environment. It was suggested that FOC should now discuss of the role of AZMP in the development of data products for the fisheries and on how to promote more interactions with fisheries scientists.

The workshop was co-sponsored by the FOC and the AZMP of the Department of Fisheries and Oceans (DFO). The steering committee included: Patrick. Ouellet (Chair, FOC

– Laurentian, IML), Pierre Pepin (Chair, AZMP – Atlantic, NWAFC), Ken. Drinkwater (Maritimes, BIO), and Doug Swain (Gulf, GFC). The general objective of the workshop was to discuss how stock assessment could benefit from ecosystem-level information and, in particular, to identify data products from the AZMP that could improve the capability of fisheries scientists in Atlantic Canada to foresee and to understand the causes of variation in the distribution, abundance, and productivity of fish and shellfish resources. The workshop combined formal presentations, overviews or case studies and round-table discussions. Specifically, the terms of reference for the workshop were defined as:

- Can we better account for some sources of uncertainty in current stock assessments by using environmental information; What are the major influences of the environment on fish/shellfish abundance estimates obtained from commercial catch data and/or research vessel surveys; How does the environment affect population processes? (e.g., growth, recruitment, egg production)
- What are the advantages and disadvantages of time series analysis versus event or regime shift analysis in determining the environment effects on fish stocks?
- How can environmental information be incorporated into fisheries assessment; How might environmental models be used in stock assessments?
- Review of current uses of oceanographic and ecosystem data products in stock assessments in Atlantic Canada and what additional generic and stock-specific indices can be derived from the data collected within the present AZMP.
- Are there stock/region-specific measurements that are important for assessment purposes that the AZMP could be collecting but is not?
- How can communication and co-operation between oceanographers and fisheries assessment scientists be improved?

**An overview of the AZMP (*Pierre Pepin*)**

The Atlantic Zone Monitoring Program was developed between 1996-98 in response to concerns that DFO needed to provide a thorough quantitative description of the ocean environment of the Northwest Atlantic that went beyond the past efforts that were largely restricted to details of the physical environment. Development of the program was based on practical constraints which guided the design of the observation network: (1) it is impracticable and too costly to provide zonal coverage of the physical climate with moorings; (2) with a limited sampling program variance in physical/chemical variables can be measured at seasonal and longer time scales; (3) hydrographic sections can provide broadscale assessment; and (4) large scale coherence in variability of planktonic organisms exists but significant short term fluctuations are also important.

The approach to implement the program consisted of developing a directed sampling program, which made use of existing activities as much as possible as well as developing additional strategies to fill gaps in time or space. The sampling elements consist of:

- Occupation of oceanographic sections in spring, summer and fall (as possible within individual regions);

- Biweekly occupation of fixed stations conditions permitting (e.g., ice in Gulf);
- Sampling of certain variables on multispecies surveys conducted in the various regions;
- Use of data collected from the Continuous Plankton Recorder "Z" (Iceland to St. John's) and "E" lines (St. John's to eastern U. S. via Scotian Shelf);
- Remote sensing of surface ocean colour and temperature (each pass, biweekly composites);
- Data of opportunity, related datasets (e.g., ice, meteorology, fish).

The variables collected as part of the field activities include:

- Chlorophyll – *in situ* at stations, sections and on some multispecies surveys (0 m and bottom); near-surface estimates from SeaWiFs remote sensing;
- Phytoplankton counts – from fixed stations and CPR;
- Zooplankton biomass and counts – vertical net hauls at fixed stations and sections; CPR; selected stations on multispecies surveys;
- Nutrients – fixed stations, sections, multispecies surveys (0 m and bottom);
- T, S, $O_2$, fluorescence, PAR at fixed stations, sections, multispecies surveys; SST estimated from NOAA remote sensing.

Field data have been collected since 1998, the CPR data start in the late 1950s or early 1960s with gaps from months to more than a decade, SeaWiFs began in September 1997, SST in October 1981, other data have been collected irregularly for the past century. All collections are based on standardized protocols across all regions as well as consistent analytical approaches to ensure comparable interpretation. The overall goal has been to characterize the seasonal and interannual variation in physical, chemical and biological oceanographic conditions throughout the Atlantic Zone.

For the physical variables, there exists extensive time series of information that allow researchers to investigate the short and long-term variations in the different components of the environment that provide a ready perspective of the changes taking place. In addition to time series, collections along standard transects provide a view of the spatial and temporal fluctuations in the physical environment. In some instances, there exists sufficient information to create time series of chemical and biological variables but the availability of such data decreases from the Scotian Shelf, to the Gulf and Estuary of the St. Lawrence and into Newfoundland. There is a suite of data products available on a routine basis, which aid in summarizing the overall changes in the marine ecosystem (e.g. integrated nutrient levels, mixed layer depth, characteristics of the vertical distribution of chlorophyll).

There are a number of elements that are not included as part of the routine activities of AZMP. These include benthos, other zooplankton (e.g. macrozooplankton, fish larvae), and nekton (e.g., large jellies, juvenile fish). Furthermore, there has been limited effort to develop models that describe or "fit" seasonal or regional variations in biogeochemical processes or zooplankton dynamics (e.g., stage-structured population models). Such efforts represent research projects at this stage and are not a routine element of the reports presented to various bodies. Finally, the FOC has started to put together a summary of recruitment trends based on regional assessments but this is not based on separate monitoring activities.

Reporting of the results of the AZMP is through the FOC (Res Docs, SSRs), an annual presentation to the Atlantic Science Directors, reports to NAFO, a dedicated website maintained by MEDS, an annual AZMP bulletin, regional website for SeaWiFs individual and biweekly composite imagery.

**A perspective on the use and application of environmental information in stock assessments (*Ghislain Chouinard*)**

There is often confusion about the meaning of stock assessment. The stock assessment process can be broken into three separate parts:

- Evaluation of stock size (how many fish?);
- Prediction of yield (how many can be fished and what are the impacts?);
- Understanding the mechanisms (what are the causes for the trends in population size?).

While some issues in evaluation of stock size may relate to environmental information, this information could potentially be more useful in addressing the last two parts.

Stock assessments aim at producing 'absolute' estimates of abundance. A quick review of the methods that can be used to obtain such estimates are presented. **Censuses** provide absolute estimates and can be conducted on some species (e.g., seals, salmonids with counting fence) but are normally not feasible for the vast majority of aquatic organisms. **Surveys** can provide near absolute estimates in cases where the catchability is high (e.g., snow crab in the southern Gulf) but normally provide relative estimates. **Tag/recapture experiments** can provide estimates of abundance but they are subject to many assumptions regarding the population stock structure, the fishery and natural mortality (M) as well as information relative to the tagging program (tag loss, tag reporting rates, etc). These are normally used to obtain point estimates in time. While environmental data are collected in these studies, they are generally not used quantitatively in the estimation.

Modeling is used to transform relative abundance indices into 'absolute' estimates. Production models (also called biomass dynamic models) use aggregate data and the concepts:

New biomass = old biomass + recruitment + growth - catch - natural mortality

or

Surplus production = new biomass - old biomass + catch

It is noted that the data requirements for the biomass dynamic models are generally lower than for more complex models. Because these analyses assume that there is a carrying capacity for the ecosystem, environmental influences, which may affect the carrying capacity, can be explicitly included in the analyses. This has been done for some stocks through the use of the CLIMPROD software.

Finally, absolute estimates of abundance can be calculated using dynamic pool models. These models track the fate of individual cohorts through time. These models usually require age-structured data of catch and abundance indices (research vessel survey or commercial CPUE series) as well as assumptions of natural mortality. There are several types of dynamic pool models: backward and forward virtual population analysis, delay-difference models, Bayesian VPAs, etc.

In the case of sequential population analysis (SPA), the basic population equation is used:

$$N_{a+1,\,t+1} = ((N_{a,\,t}\, e^{(-M/2)}) - C_{a,\,t}\,)\, e^{(-M/2)}$$

Knowing survivors, the catch over time and M, the underlying population can be re-constructed. However, survivors are unknown and need to be estimated. This is done by calibrating or 'tuning' the SPA with one or several abundance indices. Calibration is achieved by minimizing an objective function. Typically, this is the difference between the observed index and the predicted index assuming lognormal errors. Again although environmental data is usually collected during surveys or other studies related to the stock assessment process, currently, there is little direct application for such data in these models.

Although in general, there is little use for environmental data in the evaluation part of a stock assessment, there are some assumptions where environmental variables may be important: **How is survey catchability affected by environmental parameters? How is natural mortality affected by changes in environment?**

The second part of the stock assessment process - the prediction of yield - requires an estimate of the population, estimates of recruitment, average weights and natural mortality rates. Currently, environmental variables are generally not used in this process because there are few clear predictive relationships between the environment and these parameters on a stock-by-stock basis. Often, although one parameter has clearly been suggested, other parameters may also have an influence (e.g. effects of fishing), which clouds the issue. Once some relationships are uncovered and are well understood, they clearly could be used in these forward projections. There are a few considerations to note:

- Even if there are clear relationships involving environmental influences that can be incorporated, predictions will only be correct if the evaluation of stock status (the first part) is correct;
- Relationships with environmental variables have often been explored using correlation analysis. The approach can be useful but is also deficient because it

implies that the responses are linear which may not be the case. As well, spurious correlations are always possible;

- Predictions in the Canadian context are usually short-term (1-2 years) and the impact of changes in the environment may not be felt for several years. For example, the effect of environment on recruitment may not affect greatly the predictions if the recruited fish form only a small part of the catch.

Environmental variation is likely more important when examining longer-term predictions particularly if they imply changes in productivity regimes (regime-shifts). They would have important implications for exploitation reference points for the stocks. Again, the first requirement is to uncover the relationships between the environment and population characteristics and understand the mechanisms involved.

The use of environmental variables has largely focused on the third part of the process: understanding the mechanisms. There are many general mechanisms that have been identified. Some examples include:

- Temperature can affect reproductive potential, the timing of spawning and embryonic and larval development;
- Salinity can affect activation of spermatozoa and the transport of eggs (buoyancy) (e.g. Baltic Sea);
- Primary/secondary production and/or timing can affect survival (e.g. 4TVW haddock - Platt et al. 2002);
- Winds/currents can affect survival by transporting eggs/larvae into favorable or unfavorable habitats;
- Temperature can affect growth; clear when making comparisons between stocks, less important within stock;
- Some links between environmental parameters and M (e.g. temperature Lumby and Atkinson 1929).

Although all of these factors can be potentially important, some will be more important than others and some will not be important if the parameter in question varies little for the stock in question. **In summary, the most influential mechanisms need to be identified on a stock-by-stock basis**. Obviously, there is a need to examine variables that are relevant to the life history of the species under study. It is also important to consider the inter-relationships between environmental signals and population, as it is to define the scale.

To understand mechanisms, you need both short-term process studies (to test hypotheses or define process) and long-term monitoring (to help generate plausible hypotheses and further evaluate or test). Some of the next steps could be to systematically on a stock basis, define relevant AZMP products using biological knowledge of the species to explore potential relationships and form hypotheses. This could generate a rather long list and it may be necessary to re-visit or adjust (tweak) sampling strategies of AZMP. This would need to recognize the resource limitations of the program. Obviously, long-term monitoring needs to continue. The next steps would be to use process studies, meta-analyses and/or individual-based modeling to test hypotheses. Finally, the uncovered relationships could be incorporated in predictions using probability distribution of the parameter given current environmental conditions.

In summary, although environmental information is often used in a qualitative manner, there is little quantitative use of environmental data in stock assessments. This would be feasible once mechanisms are identified and understood. This can be done progressively but progress may be quicker if we adopt a systematic approach. Success in incorporating environmental data will require long-term monitoring (AZMP) and short-term studies to test hypotheses and a sustained collaborative effort. In all likelihood, it would require many years for each of the stocks.

Discussion:

*Discussion followed on the nature of the approach one needed to take in terms of incorporating environmental information into the stock assessment process. Some argued that before using environmental relationships the mechanism by which the environment operated needed to be established. This would provide some assurance that the relationship would hold up. Others suggested that if a strong empirical relationship was found that it should be used even if the exact mechanism was not known.*

**How might physical/biological models be used in stock assessments? (***Joel Chassé***)**

Numerical methods could be used to provide environmental information for stock assessments. These numerical methods include physical modeling, biophysical modeling and data assimilation. Physical environmental information could be obtained through hydrodynamic models as 3-D fields or derived indices. A modeling system of the Gulf of St Lawrence and Northeast Scotian Shelf is used to illustrate product examples that could be routinely outputted. The system is based on a 3-D numerical model of the ocean with a horizontal resolution of 4 to 1 km and 32 fixed levels in the vertical. The model is initialized with climatological temperature and salinity fields and it is forced by tides, fresh water runoff, mean transport at the boundaries and atmospheric forcing (wind, sea surface pressure and dynamically calculated heat fluxes). All the forcing to hindcast the circulation from 1948 to the present has been collected. The modeling system shows interesting skill by reproducing complex phenomenon like the Gaspé current, Anticosti Gyre, Nova Scotia current and the sea surface temperature seasonal cycle. The temperature and salinity fields could be outputted for any period of the year. Areas and volumes containing a given temperature range could be calculated and linked to indices of recruitment. The modeling approach is interesting in the sense that it could also provide the temporal evolution of the indices and serve as an interpolator between two different observed states of the system.

Biophysical information could be obtained by modeling the major components of the food web, i.e. phytoplankton, zooplankton, invertebrates and fishes. Phytoplankton Zooplankton Nutrients and Detritus (PZND) models are useful tools to simulate the lower trophic interactions of the food web. The primary production could be modeled with a twocompartment model, one for the small phytoplankton and one for the diatoms. The zooplankton could also be simplified with a two-box system for the micro-zooplankton and the meso-zooplankton. The model provides nutrient concentrations. The nutrient climatology has been derived for the Gulf of St. Lawrence (D. Brickman, BIO) and it is available for model initialization. Data from the AZMP program would be used with data assimilation techniques to generate updated nutrient fields for a given time.

Early life Stage (ELS) models and Individual Based Models (IBM) are used to better understand the effect of the environment of the growth, drift, mortality, survival and retention of eggs and larvae of fishes and invertebrates. Indices are derived from the properties of the clusters representing the eggs and larvae. The IBM for cod eggs and larvae in the southern Gulf of St. Lawrence is shown as an example. The IBM includes a tracking algorithm, growth, mortality, vertical migration and settlement modules. The spatial distribution of the recruitment could be calculated when all the larvae have matured or died and time series could be generated. One of the indices is the retention within a given area, i.e. the number of larvae that where present at the end divided by the initial number. The total survival is calculated by dividing the number of larvae that are still alive at the end of the simulation by the initial number. An indice of the drift is obtained by averaging the net displacement of all the larvae during the simulation. The possibilities for developing indices are almost endless and they could be generated for almost any species. IBMs could also be used to look at the connectivity of marine populations in terms of eggs and larvae drift. Understanding these links might have strong impact for the management of the resources. Brickman et al. (2000) had some success in predicting the recruitment of haddock on Browns Bank using a similar technique, but recent work indicated that the quality of the prediction is depending on the information (data) available for calibration of important parameters of the model such as mortality and temperature effects (growth rate).

The invertebrates and fishes could be simulated using a spatio-temporal population dynamic model based on a diffusion-attraction equation:

$$\frac{\partial N}{\partial t} = D\left(\frac{\partial^2 N}{\partial x^2} + \frac{\partial^2 N}{\partial y^2}\right) - \frac{\partial}{\partial x}\left(\chi_o N \frac{\partial I}{\partial x}\right) - \frac{\partial}{\partial y}\left(\chi_o N \frac{\partial I}{\partial y}\right) - ZN + R$$

where $N$ is the abundance per unit area, $I$ is the habitat index, $D$ is the diffusion coefficient, $\chi_0$ is the attraction (advection) coefficient, $Z$ is the mortality rate and $R$ is the recruitment. This kind of equation has been used by Bertignac et al. (1998) to simulate the skipjack tuna concentration in the Pacific. The Advanced Fishery Management Information System (AFMIS) developed at Harvard University, uses a similar technique to forecast the cod catch per unit effort (CPUE) in the Gulf of Maine. The habitat index is hindcasted or forecasted by a hydrodynamic model of the ocean. This equation could be applied for the snow crab in the southern Gulf of St. Lawrence or to the cod stock on St. Pierre Bank where these stocks show some correlation with an habitat index based on temperature. Such application would have a great potential in helping to understand the long-term effects of the physical environment on invertebrate and fish stocks. Scenarios based on potential environmental (climate) changes could be carried out.

A monitoring program like the Atlantic Zonal Monitoring Program (AZMP) is a requirement for such a modeling approach. It provides information for model initialization and validation. Data assimilation is used to provide updated fields and precludes the model to drift away. Skill assessment is a necessary step in any modeling approach and it could be achieved only with sufficient data.

Discussion:

*Initial questions focused on the results from model drift simulations and what was used for the vertical distribution of the larvae in these cases. Vertical distribution data were derived from the historical literature and were set to remain constant over all years. This was acknowledged as a weak point in the modeling efforts and hence the need for improved vertical distribution data. The question was raised that if models with different dynamics produce similar results, how does one choose which model is best. It was suggested that this might be addressed through skill assessment methods but that at this early stage of model development (generally only one model is available) it has not been issue. It was suggested that multiple candidate hypotheses should be developed which various models could then address. Can the models address questions such as what impact the pelagic biomass would have on cod? It was felt that different models could be developed for different species and then linked together.*

**Marine Ecosystems in a changing world** (*Keith Brander ICES/GLOBEC*)

The title of the talk is intended to include more than one meaning. The first is the changing physical world. Our climate has always been changing but this is now at a faster tempo and with more direction than in the past. The second is the changing human world and the place that marine ecosystems occupy in the spectrum of human concerns. We (i.e. including scientists) create our view of the world and of our relationship to it. Social and political concern over marine ecosystems has increased greatly over the past decade. The talk will look at the consequences of both kinds of change for our study and understanding of marine ecosystems.

In relation to marine ecosystems, we should really all regard ourselves as outsiders - we lack direct experience of the sea. Our perceptions are formed by a different medium and a different scale from marine life. One of the ways to learn about changes in the marine ecosystem is by observing and analysing well studied components, particularly fish, and how they change their patterns of distribution, growth and behaviour. If fish do not respond appropriately to their changing environment they will fail to reproduce and will be replaced. In order to understand the dynamics of an ecosystem that we cannot observe directly or visit or experience in any meaningful way, we need to rely on the inhabitants to provide information on what is going on. Examples where fish have given us information about changes in the marine environment and ecosystem include the Peruvian anchoveta and the influence of El Nino and the 1881/82 tilefish kill off New England, which showed the episodic influence of the Labrador slope current as far south as Nantucket.

A series of questions (normative, analytical, strategic and operational) adapted from the IGBP Global Analysis, Integration and Modeling program provides a basis for considering the aims of marine ecosystem management and for designing and evaluating research on marine ecosystems within the same frame as other elements of earth system analysis. One or two of these questions will be considered in the light of current research.

Normative questions include:

- What kind of marine ecosystem do we want?
- What is the productive capacity under acceptable ethical and humanitarian standards?
- What equity principles should govern management?
- What are the general criteria for distinguishing non-sustainable and sustainable futures?

Strategic questions include

- What is the optimal mix of adaptation, mitigation and alteration which management should aim for?
- What is the optimal decomposition of the marine ecosystem into reserves and managed areas?
- What are the options and caveats for technological fixes like geoengineering and genetic modification?
- What is the structure of an effective and efficient system of institutions for the protection and exploitation of the marine environment?

Analytical questions include:

- What are the vital components of the marine ecosystem in view of operation and evolution?
- What are the major dynamic patterns, teleconnections and feedback loops?
- What are the critical elements (thresholds, bottlenecks, switches) in the marine ecosystem?
- What are the characteristic regimes and timescales of natural marine ecosystem variability?
- What are the anthropogenic disturbance regimes and teleperturbations that matter at the system level?
- Which are the vital components of the marine ecosystem that can actually be transformed by human action?
- Which are the most vulnerable regions under global change?
- How are abrupt and extreme events processed through nature-society interactions?

Some of the accumulating evidence for large-scale (pan Atlantic) dynamic patterns and teleconnections affecting copepod biodiversity and fish recruitment variability was presented later in the talk. Operational questions include:

- What are the principles for constructing representations of the marine ecosystem that aggregate away the details while retaining all systems-order items?
- What levels of complexity and resolution have to be achieved in marine ecosystem modeling?
- Is it possible to describe the marine ecosystem as a composition of weakly coupled components and regions, and to reconstruct the total system from these parts?

- Is there a consistent strategy for generating, processing and integrating relevant data sets?
- What are the best techniques for analyzing and possibly predicting irregular events?
- What are the most appropriate methodologies for integrating natural science and social science knowledge?

The levels of complexity and resolution required in marine ecosystem models of course depend on the kinds of question being addressed. A tabular comparison of 3D Ecosystem models of the North Sea showed the range of scales and processe which are included. There is little overlap between the list of ecosystem models with which biological oceanographers are familiar and those used by fisheries scientists. This is partly because they are developing such models for different purposes and partly because the groups do not communicate very much. More interaction and possibly convergence between them would probably benefit both groups.

A recent study of the ecological effects of the NAO shows how widespread (and teleconnected) the effects of such large-scale meteorological indices can be. The paper shows a range of direct and indirect effects on both terrestrial and marine life. Knowledge of large-scale effects of climate variability across the North Atlantic is not new however. Some classic work concerning the effects of climate change in the 1920's resulted in a number of publications that looked in particular at the effects on fish stocks at Greenland and over much of the North Atlantic.

Two consequences of environmental variability (linked to climate change) were presented. The first looked at the effect of the continuing increase in the NAO over the past three decades on management reference points (e.g. precautionary Spawning Stock Biomass) for cod. The stocks in the North Sea, Baltic, Irish Sea, Celtic Sea and West of Scotland all have reduced levels of recruitment at high NAO levels (possibly related to warmer temperatures). Reference points that fail to take this into account are in effect assuming that the environment is static (and like the average state over the whole period for which the stock have been assessed). The second example looked at changes in the abundance and distribution of various groups of copepods in the NE Atlantic, as sampled by the Continuous Plankton Recorder since 1966. There have been northward shifts in distribution of the common species by about $10^o$ of latitude over this period, with consequences for biodiversity and probably also for the structure and productivity of the ecosystems in which copepods play a major role.

Discussion:

*The question was raised whether we would be no worst off if we used very simple models, e.g., just using the same TAC as last year. This might be as good as what is being produced at present but it is dangerous if the stocks are near to critical point or edge (with fish stocks there appears to be many edges so such methods might be dangerous). Given limited resources, it was felt that putting more dollars into the existing process is not all that useful. It was suggested that one needed to know what the big picture (main objectives) is before determining what should be done. Some participants disagreed and suggested that one doesn't need to have the big picture in order to do things. They felt that the important* *question was whether the present process is good enough to protect the stock. But it was reiterated that knowledge of what direction we are headed was needed.*

*One important comment was that the future environment is likely to be different from the past. Nonetheless, it is important to incorporate environmental information into the assessment and certainly to consider basic information on the environment and to look at forecasts on a case-by-case basis. For example, forecasts of temperature in the Gulf of Maine could be useful for planning surveys.*

**Cod and Sprat recruitment processes in the Eastern Baltic Sea** (*Brian Mackenzie, DIFR*)

Two international and multi-disciplinary EU projects, CORE (1994-1998) and STORE (1999-2002), coordinated by The Institute of Marine Sciences, Germany, were conducted with the overall objective of understanding mechanisms of reproductive and recruitment success in cod and sprat, and incorporating this knowledge into new models of population dynamics. The more specific objectives were: (see ANNEX 1 for a complete description of the projects activities)

- Determine **stock-recruitment relationships** for Baltic cod and sprat in relation to environmental factors influencing production of viable spawn and survival of early life history stages.
- Improve **short-term predictions** by integrating recruitment estimates based on the present status of the stock and its biotic and abiotic environment.
- Develop predictive recruitment models for **medium-term stock forecasts** under different environmental and fishery scenarios.
- Estimate **biological management reference points** based on stock-recruitment and stock development simulation models, considering the precautionary approach for fisheries management.

The main environmental process that is presently known to affect cod recruitment is the concentration of oxygen at depths where eggs are neutrally buoyant. Oxygen concentrations in the deep layers of the Baltic decrease during periods between major inflows of oxygenated, saline water from the North Sea. The reduction in oxygen concentration is frequently sufficient to prevent cod eggs from hatching. Low salinity water also prevents successful fertilization of cod eggs. Oxygen concentrations and salinity therefore are important factors determining recruitment in this cod population. Therefore, hydrographic data can be used to derive indices of water volumes that allow successful egg fertilization and hatching. These indices can be estimated from single-station profiles at appropriate locations, grids of stations, and potentially via coupled physical-biological (NPZD-3D) oceanographic models.

The inflows of North Sea water that renew oxygen concentrations and increase salinities in deep layers of the Baltic depend on particular wind conditions and are therefore at least partly climatically dependent. Major inflows (i.e., those sufficiently strong to renew oxygen conditions in the eastern part of the Baltic) have been recorded from temperature-salinity monitoring by lightships and other instruments since 1897. During 1982 and 1993 there were no major inflows to the eastern Baltic, and this situation contributed to the rapid decline of the stock in the same time period. The stock is therefore sensitive to weather- and climate-driven inflows of North Sea water that allow successful egg fertilization and hatching.

There are other environmental processes that can significantly affect cod recruitment and these have been used in cod recruitment models. Sprat and herring are both important predators of cod eggs but their importance varies among years partly due to hydrographic conditions influencing relative predator-prey distributions. Process-based models of predation can be used to adjust egg production estimates used in recruitment models. Hydrographic transport and zooplankton abundances during the larval – pelagic 0-group phase also affect cod recruitment.

The project has contributed new data and knowledge to the Baltic fisheries assessment working group of ICES (e.g., updated data series for estimating spawners biomass and recruitment, improved data series and tuning procedures for MSVPA computations, advice regarding effect of oceanographic circulation on exchange with neighboring stocks and timing and location of closed areas on spawning success). New temperature influenced MSVPA estimates of sprat and herring mortality due to cod predation are implemented in the stock assessment. Environmental information (salinity-oxygen conditions in cod spawning areas) has also been used in consideration of the estimation of biological reference points for cod (ICES 1998). It is likely that additional contributions can be made in future (e. g., in the topics of spawners biomass and egg production estimation, and environmental impacts on short-term and medium – term projection scenarios of yield and stock development).

Discussion:

*A question was asked about the fact that there have been major changes in spawning cod distributions and to what extent the previous spawning regions are now not suitable or if this is part of an evolutionary process. It is suspected that anoxia is probably the major cause of the changes in cod spawning sites and this is a recent phenomenon, at least in the 1900s. Additionally, the substructure of the Baltic cod populations is presently being examined using genetics. Another question raised was about possible changes in growth patterns. But the Baltic studies did not focus on growth. Indeed, there are aging problems with two different institutions giving different results. There are growth data in individual countries but there is not wide coverage. These limited data do suggest that there is evidence for density dependent growth.*

**Additional submitted contributions - Summary**

Bob O'Boyle (Maritimes - BIO) pointed out that the 1996 *Oceans Act,* by the establishment of an ecosystem-based management (EBM) approach in Canada, has important implications for the scope of advisory information needed. Being an Atlantic-wide program, the challenge is to see if the AZMP (and the FOC) can or can be adapted to assist EBM, in the context of the projected Large Ocean Managements Areas (LOMA), by tracking coast-wide changes in the oceanic environments, specifically on three aspects: (1) diversity, (2) productivity, and (3) habitat quality. How (plankton) communities have changed over time – in relation to ocean processes – could be questions for the AZMP to consider. The AZMP was designed to monitor the basic levels of the ecosystem; its current focus is on oceanographic processes that affect plankton productivity at a regional level. A move towards monitoring effects at broader (coastal) scale could be considered. Evaluation of human impacts is a growing concern and although this is not the traditional area of the AZMP and the FOC, both may have a role in monitoring and assessing impacts of coastal and offshore activities.

The environment-fish interactions in the four regions of the Atlantic Zone were reviewed. Many examples can be found where the oceanographic environment appears associated with temporal changes in several stocks. These include effects on catchability, distribution, migration, growth, recruitment, etc. (see abstracts of Colbourne *et al*, Drinkwater, K. and Castonguay, M. presentations – ANNEX 1). However, the associations between individual environmental indices and a stock often break down when new information is considered, pointing to the complexity of the ecosystems and that functional relationships are most often not known. In addition, the uncertainty in the forecast is generally quite large limiting the value of possible projections. Currently, environmental information is not used or it is used only qualitatively in most stock assessments. Indeed, stock assessment is a formal analytical process and models in use typically do not allow users to include environmental information.

S. Smith (Maritimes – BIO) showed that no relation was found between bottom water temperature and scallop growth variations in the Bay of Fundy. However, there is a strong spatial pattern with area specific annual trends in weight-at-shell height data and similar trends can be observed in spatial and annual distributions of chlorophyll a data from satellite images, suggesting that a relationship should be explored.

Estimates and predictions of populations/stocks variables (abundance, recruitment, etc.) can be expressed as probability distributions and environmental effects can be seen as influences on these probability distributions. These distributions may not conform to know parametric theory, at least within the range of the sampled values, and Geoffrey Evans (NWAFC) presented a local, non-parametric method to estimate the form of a distribution from the observed data (see G. T. Evans, CSAS Res. Doc. 2000/120). An illustration of the method indicates that Northern cod recruitment is not related to salinity.

George Lilly (NWAFC) presented the current assessment of the consequences on aquatic resources of climate change in the Arctic Region (Arctic Climate Impact Assessment – ACIA). The exercise consists of using current scenarios of climate change from Atmosphere-Ocean General Circulation Models (GCM) to estimate impacts on marine species. However, there is a need for modeling that downscales the output from general climate models to the physical oceanography on scales that are more relevant to specific life stages of species off Labrador and Newfoundland. There is also need for more heuristic and predictive modeling of associations between physical oceanography and fisheries biology. Programs that involve iterative communication among oceanographers and biologists, and among data collectors and modelers, throughout the Atlantic Zone, will help to test old hypotheses, generate new hypotheses, and identify data requirements.

A primer on the oceanography of the Labrador/Newfoundland Shelf would help biologists to understand how finfish and crustaceans fit into their environment, and how changes in that environment might affect distribution, productivity of the stocks, and the success of the fisheries that exploit them. In addition, a discussion of the degree of confidence with which various properties and indices of the physical environment can be projected for various periods into the future would assist fisheries biologists in determining the extent to which it may be possible to use oceanographic data in projections.

Concerning new data products that might be useful, a climatology index that is specific to the Labrador Shelf might be more useful than the NAO index for those who wish to use such an index as an explanatory variable for various physical and biological phenomena. The Atlantic zone would benefit from bottom trawling in the north, surveys of small pelagics (including juvenile groundfish), and surveys of macrozooplankton (notably euphausiids and hyperiid amphipods). The cost of such surveys will be a consideration.

Discussion:

*The need for basic biological research for many species was acknowledged by the workshop and is essential to understand the coupling between the environment and fisheries. The practical question is how this might be achieved. One suggestion was to rethink the fisheries surveys and perhaps increase coverage in some areas and decrease it in others. Given that vessel time is limited this would amount to reducing the number of stations within strata and increase the number of strata. It was pointed out, however, that the number of stations within strata are chosen to reduce the uncertainty in the estimation errors of abundance so any changes to the surveys would have to have to be careful considered. Any change in surveys would require trade-offs and such a decision would have to be made based on prioritized objectives and all available information. Macrozooplankton is an important component of the ecosystem that is presently not well sampled. Samples could be obtained with little extra effort, e.g. using collection bags under the survey trawls. These are presently being employed successfully during some shrimp surveys.*

## BREAK-OUT GROUPS DISCUSSION

Following the first day presentations, the participants were divided on the basis of their specific current activities in three groups: two were to consider issues related to fishes and one group on invertebrate stocks/populations. Each break-out group was asked to discuss the following questions:

A) What environmental information or indices to you think are most important (effects on natural mortality, distribution, growth, production, recruitment, catchability, etc.) to assess the state (present and future) of finfish and invertebrate populations? These can be either stock specific index based upon personal knowledge or of a general nature.

B) What analysis or techniques should be carried out to elucidate the relationships between finfish or invertebrate stocks and the environment? Should there be a concerted effort to do this and if so, how and by whom (leave it to individual researchers, FOC, Regional Working Groups, etc.)?

C) Is there relevant environmental information important for fish and invertebrate stocks that is not currently being measured or made available from AZMP or other sources? If so, what recommendations would you make to correct the situation?

D) If the environmental information is or becomes available, how best can it be incorporated into the stock assessment process? Who should lead this work?

E) What recommendations would you make to increase exchanges and collaborations among people dealing with environmental issues and those involved with stock assessments?

Independently, all three break-out groups reached the same general conclusions: (1) the generic indices currently produced by AZMP are considered useful and that need to be continued, and (2) custom data products need to be developed by collaboration between oceanographers (e.g., AZMP, FOC) and assessment people. The report of each group discussions is presented in ANNEX 2, but here is a summary of the groups answer to the questions:

A) It was judged that the reviews of environment and fish interactions in the Atlantic Zone presented the previous day described adequately what information or indices are the most important. However, additional products could also be useful, such as:

- Indices of primary and secondary production;
- Benthos production;
- Data on macrozooplankton, gelatinous plankton, and ichthyoplankton;
- Advection/retention indices;
- Salinity;
- Oxygen and nutrients concentrations.

It was also recognized that some geographic areas are not well sampled by the current monitoring program:

- Near-shore zone;
- Strait of Belle Isle;
- Southern Newfoundland.

B) There was a consensus that the type of analysis strongly depend on the question or process investigated. Nonetheless, a common answer was that biophysical modeling should be more used. The improvement of drift models however, will require more information on vertical and horizontal distribution of plankton. Large signal to noise ratio is needed to detect environmental influences and retrospective analysis (time series – event analysis) were encouraged. A primer on oceanography and the description of the indices as well as information on the representativeness, quality, etc. are also needed. It was recognized that the development of relationships is an interactive process between oceanographers (producers) and fisheries scientists (users). It was also agreed upon that this should be a concerted effort thru FOC (session, WGs, etc.).

C) This question was partially answered in A) but here the emphasis was more on information from sources other that the AZMP. The participants identified the need for the monitoring of benthos and pelagic (nekton) surveys. In addition, it was argued that the analyses of past collections on zooplankton (e.g., Southern Gulf) and benthos from trawl surveys (NL, Maritimes) would be useful addition to current data series. The characterization of the physical habitat was also judged important in the case of invertebrate species.

D) It was clearly stated that FOC should remain the forum for these collaborations. The participation of oceanographers to the stock assessment working groups and assessment framework WG was seen as a first step. However, this is also the responsibility of assessment biologists to ask questions and to look for information and collaboration.

E) Creation of intra- and inter-regional working groups, under the auspice of FOC, to work on case studies or species and region specific questions was suggested.

## PLENARY SESSION - DISCUSSION

The chair of the AZMP began the discussion by stating that the AZMP has successfully established a field program during the last four years that has increased DFO's capacity to monitor changes in the hydrographic water properties and greatly expanded monitoring of the primary and secondary levels of production. Moreover, new environmental products or indices are being produced. Still, it is clear that there remain many gaps. Two such gaps identified during the workshop were the monitoring of macrozooplankton and the production of routine advection indices. It was acknowledged that there may have been communication problems in informing those involved in the assessment process about all of the AZMP activities and this will be addressed. In fact, specific elements of the AZMP will be re-evaluated to determine the most efficient program.

The idea of a "primer" on the physical oceanography of the Newfoundland region aimed towards biologists was supported by the workshop and it was suggested that this perhaps could be produced and published on the AZMP website. It could be a basic tutorial on circulation and hydrographic properties in the Northwest Atlantic as well as provide information on the biological oceanography. Also on the website, the objectives of monitoring within the AZMP should be stated. A discussion of how the value of time series is a function of record length, as discussed by K. Brander in regards to the CPR data, should be placed on the website and/or could be published in the AZMP Bulletin.

One of the objectives of the workshop, however, was to discuss how the information produced by the AZMP could be used, especially in support of the assessment process. There still questions remaining about the response of the fish stocks to changes in the environment and how the research into identifying these linkages should proceed. This should not be left up to the individual RAPS but should be a cooperative effort between assessment scientists and those in the FOC and the AZMP. Interactive tools such as a Virtual Data Center (VDC) would be an important step. G. Harrison (Maritimes – BIO) stated that the AZMP is just struggling in its efforts to stay on top of processing and making the data that are collected available in a timely fashion as well as producing generic indices from these data, not to mention the request to develop customized data products for individual fish species. One way to facilitate the latter is to allow the assessment scientists to work with the data themselves and for this the establishment of a VDC would be most useful. Some suggested that the VDC should include also more of the raw or processed data, for example the optimal estimated hydrographic data presently processed by the physical oceanographers, and some of the satellite data. Ideally, it would be best to enhance collaborations between AZMP, FOC and assessment scientists but there is problem with heavy workloads for those involved in each of these activities.

One of the take-home messages from the Baltic projects (B. MacKenzie – DIFR) was that the understanding of the system, including the role of the environment, was achieved only through extensive research. The workshop participants agreed that this is also required in eastern Canadian waters but under present fiscal restraints, the number of stocks assessed and present heavy workloads this will not be easily or soon achieved for any stock. It may be worthwhile, however, for the FOC to make assessment scientists and others in the community aware of what environment-fish research is presently being conducted (e.g. under the old SSF projects) and the results of such research.

L. Savard (Laurentian – IML) felt that the incorporation of environment into the assessment process would be best conducted within the FOC and that oceanographers should attend stock assessment meetings as part of this process. There is also a need to change the way assessments are usually done, for example by starting to ask routinely why things are changing and then try to explain them. That would be a first step to make significant advancement. This was considered a good point. However, the present purpose of the RAPs is to produce the number of fish that are available for exploitation and the exercise is not conducive to discussions on new ideas or methods. Therefore, this will need to be achieved before the RAP meetings. The Maritimes and Gulf regions are undertaking Structural Framework (Benchmark Assessment) meetings. These meetings are to examine assessment methods including how to incorporate new knowledge and should agree upon a method that would be adopted and used for the next 3 to 5 years. This has been done for some US-Canada straddling stocks and was very useful. Participation in these meetings by oceanographers will be essential to ensure that environmental information is discussed and to work on how it might be incorporated within the assessment framework. For this to work the oceanographers need to be informed in advance when such meetings will take place in order to prepare properly. It was noted that the Laurentian region has methodological meetings each fall where such discussion could take place.

A suggestion was made that regional multi-disciplinary groups could be formed to examine the environment-fish linkages and then report to the FOC. The FOC Chair felt that such regional groups could recommend to the FOC environmental questions or problems that they would like addressed. However, some wondered if the assessment biologists would use them if the environmental data were made available. This was acknowledged as a problem for reasons of workloads and in some cases interest but the regional working groups are one way to overcome this problem. Also, the FOC could undertake case studies, i.e. examine in detail a specific stock not only for possible environment-stock relationships but how these, if they are identified, might be used in the assessments. B. Mackenzie encouraged the FOC to undertake such case studies and to fully document the role of the environment. He also suggested that the results from the SGPRISM (ICES) be reviewed and perhaps use the same techniques to explore some Northwest Atlantic examples.

A short discussion of the FOC, its structure and the timing of its meeting was also held. Some assessment scientists wondered about if the scheduling of the FOC, which is now held in March, could be changed because of problems with availability of travel money at the end of the year and conflict with assessment meetings. K. Drinkwater noted that discussions on the timing of the FOC meeting have been held almost every year for the past five years or so. The late-March date allows enough time after the previous year for most of the environmental data from that year to be available. In terms of conflicts with assessment meetings, so many assessment meetings are now being held that it is almost impossible to select a time that does not conflict with one such meeting. It was also suggested that the FOC could split their theme sessions from the environmental assessment. If the theme sessions were held later in the year this might allow more scientists to attend. It was pointed out, however, that the theme sessions and environmental reviews are placed together in part to ensure that those involved in the reviews are not just talking to themselves. There were also suggestions of streamlining the environmental reviews, however, it was noted that the FOC is charged with reviewing these papers as part of the RAP process and so they cannot be streamlined too much. The Chair suggested that the FOC could look at holding mini-symposium or workshops on special topics and this could be discussed at the next FOC meeting. It was also suggested that the FOC needed to go beyond reporting on what was observed in the environment but also address what this might mean to fish stocks and to other levels of the food chain

**Workshop recommendations**

The Workshop steering committee meets after the meeting to draft the following recommendations on the basis of the discussions during the workshop.

(1) Several gaps were identified in the present AZMP collections. These included trophic levels (e.g., primary/secondary production indices, macrozooplankton, gelatinous plankton, fish larvae, benthos), remote geographic areas that are presently not covered (the Strait of Belle Isle, Southern Newfoundland), and the near-shore zone. **It was**

**recommended that the AZMP consider if or how these identified gaps might be incorporated into the AZMP.**

(2) Numerous climate indices could be used to produce customized data products for stock assessments. It was felt desirable to increase the availability of these data to the users (assessment biologists and fisheries scientists) in order that they could explore and develop their own data products. **It was recommended that a virtual data center be developed that would allow open access to as much of these data as possible**.

(3) The AZMP website was recognized as being helpful in accessing data and climate indices but it was felt that improvements could be made to further help the fisheries and assessment scientists in their task of exploring environmental relationships with fish stocks and fisheries. **It was recommended that additional information concerning background information on the AZMP (mandate, scope, etc.), procedures for data collection and processing, and on the data themselves (quality assurance, representativeness, and any caveats) be provided on the AZMP website.**

(4) **It was recommended that the spatial scales of variability of the data collected by AZMP and how this relates to their representativeness needs to be assessed by the AZMP**. While this process is already underway and nearing completion for some of the physical variables it was felt to be of significant enough importance, especially for biological variables, that it needed to be emphasized.

(5) To aid in the exploration of environment-fish relationships and their possible use in assessment work, **it was recommended that case studies of one or more particular fish stocks be undertaken under the guidance of the FOC**.

(6) **It was recommended that regional working groups be developed to ensure that consideration of environmental information be an integral part of the assessment process**. This could occur through the Assessment Framework Working Groups, which should include oceanographers as part of the WGs.

(7) In some historical studies, plankton samples were collected and stored but not fully processed. These offer great potential for increasing our time series for plankton. **It was therefore recommended that efforts be made to ensure these samples are analysed to the fullest extent as possible.**

# ANNEX 1

## Cod and Sprat Recruitment Processes in the Eastern Baltic Sea – Summary of CORE and STORE Projects for DFO Workshop on Atlantic Zone Monitoring Programme (AZMP) and Stock Assessment

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Recruitment processes of cod and sprat in the eastern Baltic Sea (ICES Subdivisions 25-32) have been studied as part of two EU projects, CORE (1994-1998) and STORE (1999-2002). The Institute of Marine Sciences, Germany, has coordinated the projects. The projects are international and multi-disciplinary, and have the overall objective of understanding mechanisms of reproductive and recruitment success in cod and sprat, and incorporating this knowledge into new models of population dynamics. The approach of the project is process-based; its specific objectives are:

- Determine **stock-recruitment relationships** for Baltic cod and sprat in relation to environmental factors influencing production of viable spawn and survival of early life history stages.
- Improve **short-term predictions** by integrating recruitment estimates based on the present status of the stock and its biotic and abiotic environment.
- Develop predictive recruitment models for **medium-term stock forecasts** under different environmental and fishery scenarios.
- Estimate **biological management reference points** based on stock-recruitment and stock development simulation models, considering the precautionary approach for fisheries management.

The projects had three main activities:

- Retrospective data compilation and analysis:
  -hydrography, plankton, fish biology;
- Process-based studies (field, lab) using modern equipment;
- Modelling component, including multi-species interactions and 3D physical-biological modelling

A full description of the project (workplan, project reports, dissemination lists) can be found on the Internet at the following address:

http://www.ifm.uni-kiel.de/fb/fb3/fi/research/projects/STORE/welcome.htm.

Project tasks addressed the following issues:

**-reproductive biology,** including

-spatial distribution of spawners;
-gonadal maturation, timing of spawning, recovery/development of historical data;
-fecundity, atresia;
-effects of pollutants (PCBs) on egg production and viability and female enzyme detoxification activities (EROD, AcHE);
-otolith-based growth models;
-relations between condition, food availability, abiotic factors and fecundity based on recovery and analysis of historical data;
-comparison of spawner biomass as reliable index of egg production, as estimated independently by egg surveys.

**-egg and larval ecology**, including

-field surveys of egg and larval production, horizontal and vertical distribution in relation to hydrographic variables;
-estimation of in situ egg mortality rates due to abiotic factors (oxygen, temperature, salinity) and predators (clupeids);
-laboratory studies of egg mortality and buoyancy in relation to female characteristics and abiotic variables (temperature, salinity, PCB contamination).

**-hydrographic-biological modelling**

-development of 3D circulation models coupled to egg and larval biology;
-evaluation of retention and dispersion of offspring from spawning areas for role in recruitment;
-estimation of survival rates during larval phase and comparison with independent estimates of survival (0-group recruits per late stage egg production);
-analysis of survivor characteristics at late 0-group stage (growth rates, hatch dates) relative to egg production seasonality and hydrographic processes during drift phase.

**-multi-species modelling**

-estimation of predator and prey spatial (horizontal, vertical) distributions relative to abiotic variables;
-predation on early life stages of cod and sprat by planktivorous fish;
-improvements to existing databases for application in MSVPA and MSFORE;
-performance of MSVPA runs on spatially disaggregated basis to generate time series of spawner biomass and recruitment for different spawning areas;
-incorporation of water temperature as forcing variable in feeding and digestion sub-model.

**-population modelling**

-development of stock (egg production)-recruitment models including effects of hydrographic and climate variables (temperature, salinity, oxygen, ice cover, NAO) predation, zooplankton abundance and larval drift;
-development of alternative modelling methods for the analysis of stock-recruitment relationships (e. g., Bayesian methods, GAM);
-demonstrate utility of new stock-recruitment models for stock assessment related activities such as short-term predictions, medium-term projections and estimation of biological reference points;
-conduct simulations of short term predictions and medium term projections for different scenarios of exploitation, species interactions and environmental (hydrographic-climate) forcing.

**Brief oceanographic context of the Baltic Sea**
(edited from MacKenzie et al. 2002)

The Baltic Sea is a semi-enclosed brackish-water body which is characterised by horizontal and vertical salinity gradients. The water exchange between the Baltic and the North Sea involves many processes and is complicated (Helcom 1996). Stratification in the Baltic Sea is controlled by occasional salt water intrusions and river runoff (Schinke and Matthäus 1998), both of which are climatically controlled (e. g., North Atlantic Oscillation: (Hänninen et al. 2000). In the interval between major inflow events, anoxic conditions can develop in the deep basins due to degradation of organic material. The aperiodic intrusions of the saline, well-oxygenated water from the North Sea and the Skagerrak can drastically change the hydrography of the Baltic Sea and even allow benthic settlement in the usually anoxic basins for short periods. Species diversity in the Baltic Sea is relatively low (Voipio 1981): many species are under permanent physiological stress because of the strong salinity and oxygen gradients in the geologically young Baltic.

The Baltic is influenced by large scale climatic variations in northern Europe. These are frequently associated with the North Atlantic Oscillation (Euroglobec 1998; Dickson et al. 2000) which affects river runoff, salinities (Hänninen et al. 2000) and winter thermal conditions in the Baltic Sea (Koslowski and Loewe 1994; Hinrichsen et al. 2002; MacKenzie and Köster 2002).

**Eutrophication**

Eutrophication was one of the major environmental changes in the Baltic during the 20$^{th}$ century (Elmgren 1989). Increased nutrient loading (e. g., due to agricultural use of fertilizers) has reduced water column visibility and the depth limit of macroalgae (Kautsky et al. 1986), and increased the occurrence and duration of hypoxia/anoxia (Elmgren 1989).

Eutrophication has also directly affected Baltic fish ecology, although true cause-effect relationships are difficult to resolve (Hansson 1985; Parmanne et al. 1994; Helcom 1996). This difficulty is due partly to the relatively short time series of eutrophication-related variables (e. g., chlorophyll, nutrients) and fish biomasses, and the complicated effects that eutrophication has on ecosystem structure and functioning (Hansson 1985; Helcom 1996). Eutrophication affects the diets of both demersal and pelagic fish species in the Baltic. For example, diets of demersal fish species in the eastern Baltic (ICES Subdivisions 25-32) and Kattegat change because hypoxia alters the infaunal species that are prey for demersal fish (Bagge et al. 1994; Pihl 1994) or cause fish to feed on pelagic prey or in shallower water (Bagge et al. 1994).

**Effects of environmental factors on cod recruitment**

The abundance of cod in the eastern Baltic depends partly on environmental conditions (Plikshs et al. 1993; Sparholt 1996; Jarre-Teichmann et al. 2000). The main environmental process that is presently known to affect cod recruitment is the concentration of oxygen at depths where eggs are neutrally buoyant. Unlike all other cod populations, cod eggs in the eastern Baltic are neutrally buoyant in deep water below a permanent halocline (Bagge et al. 1994; Nissling et al. 1994); cod eggs in areas outside the Baltic float near the surface (upper 20-30 m) where oxygen conditions are sufficiently high to enable normal development.

Oxygen concentrations in the deep layers of the Baltic decrease during periods between major inflows of oxygenated, saline water from the North Sea (Matthäus and Schinke 1999). The reduction in oxygen concentration is frequently sufficient to prevent cod eggs from hatching (Wieland et al. 1994). As a result the layer of water in the water column that allows cod eggs to hatch depends both on salinity (and therefore egg buoyancy; Nissling et al. 1994) and oxygen concentration. Low salinity water also prevents successful fertilization of cod eggs (Westin and Nissling 1991). Oxygen concentrations and salinity therefore are important factors determining recruitment in this cod population (Plikshs et al. 1993; Sparholt 1996; Jarre-Teichmann et al. 2000; Köster et al. 2001). Hydrographic data can therefore be used to derive indices of water volumes that allow successful egg fertilization and hatching. These indices can be estimated from single-station profiles at appropriate locations, grids of stations (MacKenzie et al. 2000), and potentially via coupled physical-biological (NPZD-3D) oceanographic models (Hansen et al. 2002).

The inflows of North Sea water that renew oxygen concentrations and increase salinities in deep layers of the Baltic depend on particular wind conditions and are therefore at least partly climatically dependent (Schinke and Matthäus 1998). Major inflows (i.e., those sufficiently strong to renew oxygen conditions in the eastern part of the Baltic) have been recorded from temperature-salinity monitoring by lightships and other instruments since 1897 (Schinke and Matthäus 1998). In the period 1897-1977, events occurred on average almost annually, but since 1977 inflow frequency has declined. During 1982 and 1993 there were no major inflows to the eastern Baltic, and this situation contributed to the rapid decline of the stock in the same time period. The stock is therefore sensitive to weather- and climate-driven inflows of North Sea water that allow successful egg fertilization and hatching.

There are other environmental processes which significantly affect cod recruitment and these have been used in cod recruitment models (Sparholt 1996; Köster et al. 2001).

Sprat and herring are both important predators of cod eggs but their importance varies among years partly due to hydrographic conditions influencing relative predator-prey distributions (Köster and Möllmann 2000). Process-based models of predation can be used to adjust egg production estimates used in recruitment models (Köster et al. 2001). Hydrographic transport and zooplankton abundances during the larval – pelagic 0-group phase also affect cod recruitment (Jarre-Teichmann et al. 2000; Köster et al. 2001).

In short, the following factors explain statistically significant variation in cod recruitment in the eastern Baltic Sea:

-egg production by the spawning stock, as estimated using interannual maturity, sex ratio and fecundity data
-salinity-oxygen conditions as represented by derived indices (e. g., "reproductive volume")
-egg predation by sprat and herring
-larval transport to coastal nursery areas and spatial-seasonal variations in zooplankton concentration

**Project contributions to stock assessment:**
**(based on Köster et al. 2002)**

The project has contributed new data and knowledge to the Baltic fisheries assessment working group of ICES (e.g., updated data series for estimating spawner biomass and recruitment, improved data series and tuning procedures for MSVPA computations, advice regarding effect of oceanographic circulation on exchange with neighboring stocks and timing and location of closed areas on spawning success). New temperature influenced MSVPA estimates of sprat and herring mortality due to cod predation are implemented in the stock assessment. Environmental information (salinity-oxygen conditions in cod spawning areas) has also been used in consideration of the estimation of biological reference points for cod (ICES 1998). It is likely that additional contributions can be made in future (e. g., in the topics of spawner biomass and egg production estimation, and environmental impacts on short-term and medium – term projection scenarios of yield and stock development).

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**AZMP and Ecosystem Based Management**

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Up until passage of Canada's Oceans Act in 1997, many of DFO's scientists had been primarily devoted to providing the information needs for the Fisheries Act through stock assessment and related research. The Oceans Act outlines the new requirement for establishment of an ecosystem-based management (EBM) approach in Canada, which significantly broadens the scope of advisory information needs. Such was recognized during the 2000-01 national review of the stock assessment program, which stated that the stock assessment program by 2010 'will have a broader horizon than what we currently term 'stock assessment' or 'fishery science'. It will involve the evaluation of populations, species and ecosystems.' There have been a number of initiatives over the last few years which have explored aspects of the EBM approach, including a workshop with the Maritimes fishing industry (Truro, 1999), an internal Maritimes DFO meeting (Sydney, 2000), a Maritimes Science workshop (BIO, 2001) and most notably a national workshop (Sidney, 2001) to define the objectives of EBM, organised by the national Working Group on Ecosystem Objectives (WGEO). The latter has led to illustrative (fall, 2002) and pilot projects (2003 – 2005) to investigate implementation of EBM on the Eastern Scotian Shelf. The work of the WGEO involves a number of themes, which could usefully be considered by the FOC and AZMP. It is expected that regions will continue to pursue work on how best to incorporate environmental relationships in stock assessment. The value added of the AZMP is an Atlantic – wide program that can consider processes on a coastal scale, something that fits well with the needs of EBM and that is not currently a feature of DFO programs.

Under EBM, analogous to the management units of fisheries management, consideration is being given to establishing a national system of Large Ocean Management Areas (LOMA), which would be based on biology, stakeholder requirements and current administrative boundaries. Within these, all ocean sectors would be governed by the same conceptual objectives but with operational objectives linked to these that would be specific to each ocean use sector. While the boundaries of some LOMAs have been defined (e.g. Eastern Scotian Shelf), it is planned to have a national system defined by 2003. **Over the longer term, the AZMP could assist EBM by tracking coast-wide changes in the physical, chemical and biological oceanography associated with these LOMAs**. This would further the efforts of the early 1990s ECNASAP project which studied changes in the demersal fish communities on the coast of North America and how these changed over time.

As stated above, the Sidney (2001) workshop outlined a hierarchy of objectives (conceptual to operational) for EBM, which addressed three main elements – diversity, productivity and habitat - all of which have potential implications for the work of the FOC and AZMP. Regarding diversity, how communities have changed over time and how these are related to ocean processes would be fruitful areas to consider. Previous work (ECNASAP) had focused on the demersal fish community, leaving open the possibility of expansion of this work to the plankton communities. This work could test Hubbell's (2001) recent neutral theory on biodiversity and biogeography. The latter also provides a theoretical basis for evaluating the impact of ecosystem fragmentation, either through natural or human processes, again an area of potential involvement of the AZMP. There is also a growing need to consider how benthic communities relate to their physical and chemical habitat. Finally, the soon to be enacted Species at Risk Act raises the specter of work to define critical habitat for species such as coral, whales, turtles, etc, an area to which the AZMP might be able to contribute.

Productivity processes have been the dominant focus of research by DFO scientists, with much of this on commercially targeted species. **There is a need to take a broader perspective of these processes. Plankton productivity is the base of the food chain and thus defines the carrying capacity of the ecosystem that it supports. How this changes with oceanography and thus climate is of some import**. How the various trophic levels exchange energy and how this is influenced by climate is also important. Consideration may be given to defining harvest limits by trophic level. So far, only a few regional efforts have considered trophic interactions using models such as ECOPATH and ECOSIM. As well, managers are increasingly seeking information and advice not only on the biological interactions but also on the technical ones as well e.g. bycatch of cod in the haddock fishery, yellowtail in the scallop fishery. How environment influences bycatch ratios is a potential area for monitoring and research. **Population productivity has been the traditional area of consideration by FOC and AZMP with recruitment, growth and mortality processes all under study. This should continue and indeed is the focus of other presentations at this workshop. However, many of these efforts have and will continue to be pursued at a regional level, without recourse to the AZMP. What the latter offers is a possibility to study these processes at a coastal scale through meta-analyses, as has been the modus operandi in the past. These efforts are encouraged**.

The third element of the Sidney (2001) objectives was habitat, with there being a growing need for research in this area in support of the evaluation of human impacts through oil and gas exploration, fishing, aquaculture and so on. For instance, SEAMAP is a program envisioned to map the bottom of Canada's coastal oceans. AZMP might have a role in this program. Certainly, the need for long-term time series of habitat and bottom community structure is becoming increasingly evident. **The same holds true for water column processes, a traditional area for the AZMP and FOC. With the call for programs on operational oceanography, there is a need for the review of the products of these programs, perhaps an activity that could be undertaken by the FOC. Finally, monitoring of the impact of coastal and offshore activities on water quality (e.g. contaminants) may need to be undertaken.**

Identification of indicators and reference points for monitoring purposes associated with the diversity, productivity and habitat objectives would need to be defined through 'unpacking' exercises, as described by the Sidney (2001) workshop and of which pilot exercises have been undertaken in the Maritimes region for the groundfish fishery, oil and gas, and aquaculture sectors. **How these indicators could be compiled into overviews of ecosystem status is an area that the FOC might consider for discussion. Thus far, approaches such as that of the Traffic Light and IBI have been considered. There may**

**be others. Finally, the AZMP has a useful role to play in data storage and dissemination, again given its coastal perspective**.

In summary, the needs of Ecosystem-based Management cross the many themes of diversity, productivity and habitat, which significantly expand the current vision of DFO Science. While regional efforts on aspects of these themes will continue, the AZMP is in a unique position to address research and management support questions at a coast-wide level. The challenge is thus to the AZMP as to whether it can adapt its activities to the new realities and opportunities created by the 1997 Canada Oceans Act.

## A review of environment-stock relationships for some fish and invertebrate species in the Northwest Atlantic

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Variations in the physical and biological oceanographic environment are thought to influence the abundance, and behaviour of many marine organisms and, hence, the management and operations of the fishing industry. The declining trend in temperature during the past three decades, or so, in the shelf waters off Newfoundland and Labrador likely contributed to the shift in the fishery from dominance by finfish up to the late 1980s to dominance by Crustacea since then. Therefore, the integration of environmental information into fishery resource stock assessments in a quantitative manner for management requirements is a pressing issue and one that is receiving increasing attention.

Trends in ocean climate and marine fisheries resources during the past several decades for the Newfoundland Region are reviewed. Also, preliminary efforts at stock predictions and forecasts are described together with attempts to incorporate environmental information into fish and invertebrate stock assessments.

In general, variations in the oceanographic environment appear to be associated with trends in production in several marine species as inferred from commercial fishery catch rates and stock assessment surveys. Some relationships indicate that environmental factors affect behaviour of species within year and are reflected in changes in their distribution and/or catchability. Others indicate that environment affects survival at early life history stages, particularly for crustacean populations, with implications for future recruitment to fisheries. The associations between individual environmental indices with measures of marine production however often break down as different physical and biological factors dominate suggesting complex ecosystem effects. This was particularly evident during the latter half of the 1990s as the ocean environment on the Newfoundland Shelf began to warm.

Statistical models, employed to explore relationships between invertebrate production and changes in the oceanographic environment in Newfoundland and Labrador waters, can be a valuable addition to a suite of indicators used to assess current status of and future prospects for important fisheries resources. However, the uncertainty in the forecasts is generally large and the functional relationships are not known.

Currently, within the Newfoundland Region, environmental information is used only qualitatively in most stock assessments. Some integration of environment-stock relationships within the Traffic Light framework has been achieved for certain shellfish assessments. The stock classification system for east and southeast Newfoundland herring, which is built on environmental stock-recruitment relationships, provides a rare example of full integration.

## Environment-Fish Interactions on the Scotian Shelf and in the Gulf of Maine

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The environment and its variability influence various life stages of most fish stocks. Several examples are provided from the Scotian Shelf and the Gulf of Maine including effects on distribution, migration, growth, recruitment and catchability. These include the range expansion of two cold water species, snow crabs and capelin, over the northeastern Scotian Shelf in response to cold conditions during the mid-1980s to the 1990s. The return date of Atlantic salmon each year to the LaHave River in Nova Scotia is shown to be related to the amount of ice near their overwintering grounds off Newfoundland and the Labrador Shelf. Greater amounts of ice delay the return. The differences in the mean size-at-age of cod stocks throughout the North Atlantic are linked to differences in the bottom temperatures they inhabit with larger cod associated with warmer temperatures. In addition, temperatures account for much of the year-to-year differences in growth rate of both cod and haddock on the Scotian Shelf and other cod stocks in the North Atlantic. Wind-induced temperature variability in the Baie des Chaleur in the Gulf of St. Lawrence and along the east and south coasts of Cape Breton Island is shown to affect the catchability of American lobster. Evidence suggests that the catchability effect increases with the amplitude of the temperature variability. Experiments suggest higher temperatures increase the walking activity of the lobster thereby increasing the likelihood that they will come into contact with the lobster traps. The recruitment of several ground fish species on the Scotian Shelf and the Gulf of Maine, including cod, haddock, pollock, yellowtail flounder and redfish have been linked to Gulf Stream warm-core ring activity. Fourteen of 17 groundfish stocks investigated showed a negative relationship with ring activity during the period when eggs and larvae are in the water. The hypothesis is that the rings entrain egg and larvae containing shelf water off the shelf. These are eventually lost to the population. Support for this hypothesis has been obtained from field studies off the Scotian Shelf where redfish larvae advected off the shelf were found to be in poorer condition than those that remained on the shelf. In general, years when many rings were close to the shelf during the egg and larval period always coincided with low recruitment whereas when there were few or no rings recruitment could be either high or low. Cod recruitment on the northeastern Scotian Shelf was also shown to be negatively related to the young stages (I-IV) of *Calanus finmarchicus* as measured by the continuous plankton recorder (CPR). Cause of this relationship is unclear but may be because the *C. finmarchicus* displaces other zooplankton that are fed upon by the cod.

Although these examples provide evidence of environmental influences on fish stocks, this information is generally not used in the assessment process. The exception is the link between ice and the run-time of salmon to the LaHave River. Based upon cumulative counts during the year, end-of-season estimates of the population of Atlantic salmon can be made as the season progresses, which provide valuable information to managers for adjusting in-river exploitation rates in order to meet conservation targets. End-of-season population estimates based on cumulative counts to a date are made as the season progresses using linear regression models with ice area. These have been used during the past 5 years for in-season forecasts with improved accuracy over previous in-season forecasts although there is a bias towards over estimating the final population numbers.

## Environment-fisheries interactions in the Gulf of St. Lawrence or how to enhance interactions between AZMP and fisheries.

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The purpose of this talk was to review, albeit incompletely, cases where the environment may influence the productivity of fisheries resources in the Gulf of St. Lawrence (GSL) and to propose new environmental monitoring deemed useful to fisheries in the Gulf. A clarification point was made at the outset that no material about incorporating environmental information into stock assessment would be presented as there was no example to report on this issue from work carried out in the Gulf. Stock assessment is a formal analytical process and models in use typically do not allow users to include environmental information.

The following seven topics were reviewed: (1) cold intermediate layer (CIL) / Snow crab productivity (Sainte-Marie et al.), (2) CIL / northern GSL cod distribution and growth (Dutil et al.), (3) environmental effects on southern GSL cod (Swain et al.), (4) krill abundance / fin whale dispersion (Harvey et al.), (5) CIL / hyperiid amphipod /cod diet (Harvey et al.), (6) RIVSUM/zooplankton/mackerel recruitment (Castonguay et al.). A common feature of three of these fisheries / environment associations involved fluctuations in the CIL, exemplifying the importance of this oceanographic feature in modulating productivity of Gulf resources, especially in the northern Gulf.

Three new environmental monitoring initiatives were then proposed. The first one involved enhancing the data products coming out of upcoming annual mackerel egg surveys, by way of analyzing routinely macrozooplankton (e.g., krill), merozooplankton (e.g., crab larvae) and mesozooplankton (primarily copepod species composition). The second initiative proposed aimed at putting in place a biological oceanography program on the annual northern Gulf groundfish/shrimp survey (nutrients, chlorophyll, and zooplankton). The last proposal involved implementing a monitoring program of the flow through the Strait of Belle Isles, as this flow exerts an important control of the northern Gulf CIL.

**AZMP and Stock Assessment: Bay of Fundy Scallops**

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The current population model used for scallops in scallop production area 1 and 4 of the Bay of Fundy is a delay-difference biomass dynamic model that assumes a constant growth rate over all years. We only have growth data from 1996 to the present but these data indicate that the constant growth rate assumption has been violated in the 2000 to 2002 period resulting in increased uncertainty for our biomass predictions for the following year(s). Monthly or more frequently collected temperature data for the Bay of Fundy are available from the Prince 5 sampling station near St. Andrews New Brunswick from 1924. These data and bottom temperature data collected during the annual scallop survey were analysed to see if they helped explain trends observed in the meat weight-at-shell height data from 1996 to 2002. No relation was found. The analysis of the meat weight-at-shell height data did indicate very strong spatial patterns with area specific annual trends. Preliminary analysis of the spatial and annual trends of chlorophyl a data from satellites indicates similar trends, and further analysis of these data with the scallop growth data may be more promising.

**How does the environment affect the odds?**

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Given the Department's commitment to embracing variability (uncertainty, risk, caution), estimates and predictions will typically be expressed as probability distributions, and environmental effects, if they exist and affect assessment practice, will be expressed as influences on probability distributions. As a rule, there will be no trusted theory for the form either of the distribution or of the influence. This talk therefore presents local, non-parametric methods for estimating these forms from the data with as few theoretical commitments as possible. As an illustration, the putative effect of salinity on Northern cod recruitment is re-examined and found not to exist.

# Predicting the future of marine fish and fisheries off Labrador and eastern Newfoundland under scenarios of climate change; information and thoughts for the Arctic Climate Impact Assessment (ACIA)

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*Introduction*

The inspiration for this presentation was the work that Jim Carscadden and I are conducting on behalf of the Arctic Climate Impact Assessment (ACIA). During the process of synthesizing information regarding the influence of the physical environment upon the dynamics of the major commercial finfish and crustaceans off Labrador and eastern Newfoundland, we became acutely aware of the difficulty in distinguishing the effects of environmental variability from the effects of the fishery and interactions among species. The current presentation will draw attention to some of the problems that we encountered as we tried to determine what physical changes are anticipated over the next century and contemplated how the biota might respond to those changes.

I also wish to use this opportunity to present personal opinions on some things that could be done to make investigation of the Labrador/Newfoundland Shelf more informative, useful and enjoyable. I recognize that some of these things may not be possible during a period of financial shortfalls, but perhaps we should measure our progress against that which is scientifically possible, not just that which is currently affordable. My list includes a call for a primer on the oceanography of the region and a request for additional information regarding the extent to which oceanographic properties can be projected. I conclude with a few comments on monitoring.

*Arctic Climate Impact Assessment (ACIA)*

The ACIA is an assessment of the consequences of climate variability and change in the Arctic Region. Its purposes are to evaluate and synthesize knowledge on climate variability and climate change; to examine the possible impacts of such changes on the environment and its living resources; and to provide useful and reliable information to support policy-making processes (ACIA 2002). The study started in 2000. Its final report is due in late 2004. One chapter of that report will describe marine fisheries and the way that they might be impacted by climate change. At this time, there are sections on the Barents Sea, Iceland, Greenland, northeastern Canada, and the western and eastern Bering Sea. Each section contains a biological overview of the important species, a discussion of the economics of the fisheries, and a few thoughts regarding our ability to predict changes in individual species and the ecosystems in which they are embedded. Along the northeast coast of Canada the study area has been extended southward to the central Grand Bank (NAFO Division 3L) in order to encompass an environment and biota comparable to that considered by ACIA in the northeast Atlantic and around Iceland. This extension far to the south of other geographic areas is necessitated by the presence of the Labrador Current, which transports cold water southward from Davis Strait, the Canadian Archipelago and Hudson Bay. We invite colleagues from all disciplines to critique an early draft of the biological review (Lilly and Carscadden in prep.). This draft is available from the present author upon request.

The ACIA assessment builds upon two kinds of scenarios. First, it assumes a moderate scenario for emissions (greenhouse gasses and aerosols). This is the IPCC SRES B2 scenario (IPCC 2001). It then uses climate scenarios, based on this emissions scenario, from five Atmosphere-Ocean General Circulation Models (GCM's). The climate scenarios have a baseline of 1980-1999 and projections to 2099, with particular attention directed to 20-year time slices centred on 2020, 2050 and 2080. Projections from the five models disagree on the magnitude of changes and regional aspects of those changes, but they all project that warming will be greater in the Arctic than elsewhere and that warming will be greater in winter than in summer.

The GCM output includes surface air temperature. However, there is no projection of many of the variables that may be important to commercially important species and their predators and prey. One may wish to know, for instance, current strength, temperature and salinity at various locations and depths; the position, intensity and duration of fronts; ice extent and duration; and derived variables such as stratification. **There is a need, then, for downscaling from GCM output to the physical oceanography of shelf waters off Labrador and Newfoundland,** such as has been done for the Nordic Seas by Furevik et al. (2002).

As noted above, there is considerable spatial variability in the projected change in surface air temperature, both within and among models. In one model, the temperature change projected for the 2080 time period varies from an increase of about $10^0$ C off southeastern Baffin Island to a decrease of 2-$3^0$ C in both the central Labrador Sea and to the southeast of Newfoundland. Although we are advised not to be concerned about the details of model output, it does cause consternation when one ponders the response of a broadly distributed species that lives in waters underlying such a range in projected air temperature change.

While Siberia and western North America experienced warming during the last three decades of the $20^{th}$ century, the area of northeastern Canada and West Greenland experienced a cooling, particularly during the period 1965-1995. That is, the baseline period for the GCM projections was relatively cool in the Labrador/Newfoundland area, and we wondered if temperatures comparable to those projected for the $21^{st}$ century had been experienced during the relatively warm period in the middle of the $20^{th}$ century. To explore this we compared projected surface air temperature (averaged from the output of three GCM models for the region of Baffin Bay and the Labrador Sea) to air temperatures recorded at Nuuk and St. John's during the $20^{th}$ and early $19^{th}$ centuries. An increase in air temperature comparable to that projected for the Baffin Bay/Labrador Sea area by about the mid-$21^{st}$ century was seen in Nuuk during the late 1920s and 1930s. That warming led to extensions of cod, capelin and other species northward along the West Greenland coast and to a rejuvenation of the West

Greenland cod fishery (Vilhjálmsson 1997; Buch et al. 2002). In contrast, air temperatures at St. John's in the 1920s and 1930s were not substantially greater than the average during 1980-1999. (It must be noted that use of the 1980-1999 period as a baseline is somewhat awkward for the Labrador/Newfoundland area because of the considerable variability experienced during that period. In particular, the early 1990s were very cold whereas the late 1990s were very warm.) In any event, it is the area north of St. John's that is perhaps of greatest interest here. We are most curious as to whether changes in the marine biota comparable to those seen at West Greenland in the middle of the 20$^{th}$ century occurred off Labrador at about the same time. If they did not, they why? **There is a need for a search and synthesis of information on the marine biota of the Labrador Shelf and coast, going back at least to the latter part of the 19$^{th}$ century. A similar search and synthesis, if not already available, is required for air and sea temperatures for the Cartwright – Hamilton Bank area.** (Note that surface air temperature records at Cartwright go back only to the mid-1930s.)

During the present workshop, numerous examples were given of associations that have been demonstrated between some measure of environmental variability and some aspect of fish/crustacean biology or some aspect of a fishery. Correlation/regression analyses, of various degrees of sophistication, are important starting points for identifying such associations, but we need to move whenever possible toward understanding the mechanisms behind them. We also need to explore more thoroughly the residuals from such associations.

As is well understood, the past may not be a good key to the future, because circumstances change. This problem of non-stationarity may be looked at in a very literal way when one considers the influence of the North Atlantic Oscillation (NAO) on the environment and biota of the Labrador and Northeast Newfoundland Shelves. Many papers have drawn attention to the link between the positive phase of the NAO and intensified northwesterly winds, lower air temperatures, lower water temperatures and more extensive ice cover (e.g. Colbourne et al. 1994; Mann and Drinkwater 1994; Narayanan et al. 1995). However, there were years in the latter half of the 1990s when a strong positive NAO index did not lead to a cooling off Labrador and northeastern Newfoundland such as had been seen in the early 1970s, the early to mid-1980s, and the early 1990s. This was because the Icelandic Low had shifted somewhat to the east, and did not cause a flow of Arctic air over Labrador. There has been a tendency recently for many scientists to relate aspects of the physical and biotic environment to the NAO. **Perhaps it would help if a new climatological index could be developed for the Labrador Shelf area; one that incorporated both the strength of the Icelandic Low and its position relative to the shelf**. (On the other hand, perhaps the winds and air temperatures actually observed at Cartwright provide as much information as does an index such as the NAO.)

Our review of the many publications that discussed reasons for changes in the distribution and abundance of fish and crustaceans off Labrador and eastern Newfoundland revealed multiple hypotheses regarding almost every phenomenon (Lilly and Carscadden in prep). Some scientists regard fishing to be the sole cause of the collapse of Atlantic cod and most other commercially important groundfish, whereas others note that the collapses coincided with the decline in water temperature and increase in ice cover, and note various ways in which the change in environment might have contributed to the stock collapses. Some scientists even regard the collapse of non-commercial groundfish to be entirely the result of fishing (through by-catch). With respect to the surge in productivity of northern shrimp and snow crab, there is debate as to whether this was attributable to a release from predation pressure (from cod and other groundfish) or to a cooling of the environment that somehow improved recruitment in both shrimp and crabs. A combination of the two processes is highly likely. There is considerable uncertainty regarding status of capelin, and many of the changes that occurred in capelin biology during the early 1990s have not reversed, despite the warmer waters during the latter half of the 1990s. The distributions and relative abundances of the biotic components of the ecosystem off Labrador and eastern Newfoundland are currently substantially different from those in the past, even the past as recent as the mid-1980s. It seems very difficult to predict with any confidence whether the ecosystem will, during the next few years or decades, remain similar to its present condition, revert to a semblance of the past (even that of the mid-1980s), or change to something as yet unseen. With so much uncertainty about the response of individual species and the ecosystem as a whole, how can we confidently use the past to predict the future?

*A primer of the oceanography of the Labrador/Newfoundland Shelf*

Fisheries biologists, who are charged with providing information and advice on the biology and status of many species of invertebrates, fish and marine mammals, would benefit from a non-mathematical overview of the physical oceanography of shelf and upper slope waters off Labrador and eastern Newfoundland, an area dominated by the cold, southward flowing Labrador Current.

Physical oceanographers (e.g. Colbourne and Fitzpatrick 2002; Drinkwater and Petrie 2002) currently provide annual updates of numerous indices that provide metrics of monthly, seasonal or annual variability in various aspects of the environment. They also from time-to-time provide overviews of longer term variability, often in terms of decadal means (e.g. Colbourne 2002; Drinkwater 2002). The indices are useful in that they provide information about the magnitude of changes in the environment and metrics that can be used to test hypotheses. However, the fisheries biologist also needs to develop a feeling for how each organism makes a living within that physical environment – how the life history characteristics of the species/stock are tuned to the mean state and variability of the environment. The fisheries biologist also needs to determine how the species/stock might respond to and be affected by changes outside the norm. The fisheries biologist would be aided in these tasks by **a primer that provides both a description of the physical oceanography and a guide to the literature where technical details may be discovered**. Such a primer would assist the biologist in determining which of the currently available data sets and indices would be of relevance to any specific enquiry, and what additional data or indices would help to advance the enquiry.
Information that biologists might wish to find in such a primer include the following:

– A description, accompanied by 3-dimensional illustrations, of the average distribution of **water masses** in the Labrador Sea and adjacent shelf areas. This would include a discussion of the origin of these water masses.

- A 3-dimensional description of the mean **currents** in the area from Davis Strait to southern Newfoundland, including current positions and strengths. This would be accompanied by discussion of the causes and magnitude of variability in these currents at various temporal scales, from hours to decades.

- A description of the presence and strength of **gyres**, especially those around banks such as Belle Isle Bank and Funk Island Bank, and the existence of incursions of slope water onto the shelf, especially on the Northeast Newfoundland Shelf and southwestern Grand Bank.

- The **seasonal cycle** of warming and cooling, with a description of the downward progression of these processes at any given geographical point. (The sampling at Station 27 would presumably be the richest source of such information, but it would be helpful if there were also information from farther north, such as Hamilton Bank.) Of great interest here are the links between wind pressure fields, surface air temperature, water temperatures at various depths, and the extent and duration of sea ice.

- A discussion of the relative importance of **advection versus local events** in determining temperature and salinity at various selected geographical points. How important are events occurring off Greenland or in the Canadian Archipelago? Why is bottom water (at say 200 m) warmer during summer on the Labrador Shelf than it is on the northern Grand Bank? Why does the CIL cross-sectional area seem to have greater annual variability on the Seal Island line than on the Flemish Cap line?

- A discussion of processes that enhance **productivity**, including a description of areas where this happens. For example, what is the role of the Labrador Shelf saddles? Why is Hamilton Bank a hot spot? Why does the shelf break remain productive through most of the year?

*Projection of properties of the physical environment*

An overview of the most recent observations of climate and physical oceanography, accompanied by updates of certain regionally important indices, is now an accepted component of most (if not all) RAP meetings. While this information may give meeting participants some perception of what has been happening in the air and water, the information is seldom used directly, either to adjust an input to the assessment or to assist in making a projection. Part of the reason for this is that there are not many associations between environmental change and variables of interest to the assessment (fish biology or fishery behaviour) that are sufficiently robust to be used in a projection. However, in the majority of cases a relationship, even if well established, could not be used in a projection, because the presentation of environmental data does not include a projection of the state of important variables or indices for some period (say 1 year) into the future. If, for example, water temperature were known to influence growth rate, and temperature could be projected with some degree of confidence into the next year, then a predictive equation of growth rate on temperature could be used to project growth of individual cohorts over that time interval (assuming stationarity of the relationship). There is some evidence that the autocorrelative properties of water temperature time series can be used to look ahead one year (Shelton et al.

1999; Stein and Lloret 2001). What possibilities are there for using water properties observed upstream (e.g. off West Greenland, in the Canadian Arctic, or even on the northern Labrador Shelf) to project the properties of water to the south some time in the future? How predictable are large-scale climate patterns? **Perhaps the ability to project various physical properties and indices into the future could be explored and stated**, so that fisheries biologists would have a more thorough understanding of what opportunities there may be.

*Monitoring*

One of the questions we were asked to consider for this workshop is whether there are some important things that we could be monitoring but are not. Of course, the list of additional things that one might wish to monitor may be very long indeed. Here are a few considerations for a short list.

An argument can be made for basic **bottom-trawl surveying in the north**. There are important fishery resources there and much of the water of Atlantic Canada flows from there. At present, there are no bottom-trawl surveys in Divisions 0B and 2G, and Division 2H is monitored only every second year. Thus, we lack basic fishery-independent information on the near-bottom resources in these northern areas, and there is much less monitoring of temperature and salinity in this upstream area than there could be.

The biological monitoring under the AZMP is directed mainly toward primary productivity and zooplankton of interest to the study of fish larvae. For most species/stocks, there is no direct monitoring of any life history stage between the parent stock and some relatively late juvenile stage. That is, there is no monitoring of eggs, larvae, pelagic juveniles, or early stage demersal juveniles (for those species where these stages exist). It might be informative to monitor what is happening at intermediate stages in the life cycle, such as at the pelagic juvenile stage of groundfish. A **pelagic survey**, using for example an IYGPT trawl in conjunction with acoustics, would open a window into the nektonic portion of the ecosystem (Anderson 2001).

The AZMP does not include monitoring of **macrozooplankton**. Food habits studies have shown that euphausiids and hyperiid amphipods are important prey for "forage" species and the juveniles of many species of groundfish. In some geographic areas there is weak evidence, based largely on predator stomach examinations, that these macrozooplankton are not as available as they were in the past. In the absence of monitoring of these macrozooplankton, we are unable to address many bottom-up questions, such as whether the productivity of macrozooplanton is sufficient to support good growth and condition of commercially important species such as capelin and the juveniles of cod. Note that euphausiids have historically been important on Grand Bank in spring, and that hyperiids have been important north of Grand Bank during autumn.

*Summary*

Programs designed to explore the possible consequences of climate change can provide a forum in which climatologists, physical oceanographers, biological oceanographers and fisheries biologists can address a wide variety of questions over a range of temporal and spatial scales. There does appear to be a need for modeling that downscales the output from climate models to the physical oceanography on scales that are significant to specific life stages of individual species. Although not discussed above, there is also need for more heuristic and predictive modeling of associations between physical oceanography and fisheries biology. Programs that involve iterative communication among oceanographers and biologists, and among data collectors and modelers, throughout the Atlantic Zone, will help to test old hypotheses, generate new hypotheses, and identify data requirements.

A primer on the oceanography of the Labrador/Newfoundland Shelf would help biologists understand how finfish and crustaceans fit into their environment, and how changes in that environment might affect distribution and productivity of the stocks and the success of the fisheries that exploit them.

A discussion of the degree of confidence with which various properties and indices of the physical environment can be projected for various periods into the future would assist fisheries biologists in determining the extent to which it may be possible to use oceanographic data in projections.

A climatology index that is specific to the Labrador Shelf might be more useful than the NAO index for those who wish to use such an index as an explanatory variable for various physical and biological phenomena.

The Atlantic zone would benefit from bottom-trawling in the north, surveys of small pelagics (including juvenile groundfish), and surveys of macrozooplankton (notably euphausiids and hyperiid amphipods). The cost of such surveys will be a consideration.

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## ANNEX 2

### Group fishes-1 report

Develop of tools to allow users to explore the development of environmental indices that can be customized to address their stock or species-specific issues: automate the production process of indices already produced by AZMP?

- *Proposed pilot project*: to develop an interface that allows the production of several standard temperature products to be produced automatically based on time and space constraints specified by user (e.g. area of a given temperature range at a given depth or bottom)
- Other variables to be developed over time include salinity, advection/retention indices, $O_2$, nutrients, biological (the latter being dependent on implementation of BIOCHEM).

Development of a web-based "Primer" that includes a user's guide for specific environmental indices that incorporates:

- Information about quality assurance;
- Representativeness;
- Caveats about unpublished analyses, etc.

Make all indices widely available:

- Recognizes that not all elements are refined or perfect (developmental products with necessary caveats);
- Development of processing strongly iterative between producers (AZMP) and users.

New products:

- Primary and secondary production;
- Assess methods to provide data on macro- and ichthyoplankton;
- Develop advection/retention indices based on diagnostic circulation models:
- Southwest NS haddock;
- Southern Gulf snow crab and cod;
- NF/Lab shelf snow crab and *Calanus.*

**Group fishes-2 report**

Currently, AZMP provides a broad overview of physical and biological oceanographic conditions. However, this is dependent on input from many other programs not funded by AZMP's core budget (e.g., the multispecies trawl surveys). Some concerns are expressed about communication: e.g., the scope and mandate of AZMP not well known among assessment scientists. There is also a need to improve communication to stock assessment personnel to increase awareness of how AZMP communicates what it does – AZMP website, CSAS status reports presented and reviewed at FOC, CSAS Res Docs, annual bulletin highlighting important environmental events.

There was a call for specific examples of where environmental data has been successfully applied. One of the best examples is the Baltic case described by Dr. Brian MacKenzie. This example emphasized the intense research effort and high level of resources required to achieve this.

Concerning the need to incorporate environmental data in stock assessment: the group considers that there is little need in terms of estimate of current level of abundance or biomass. But this is needed to forecast and the importance increases with time-scale of the forecast. It is essential for long-term forecasts and to predict responses to climate change etc. Also management response to current biomass level needs to consider environmental conditions – different response when in high productivity state versus low productivity state.

A) Based upon personal knowledge of specific finfish or invertebrate stocks/populations, what environmental information or indices do you think are most important (effects on natural mortality, distribution, growth, production, recruitment, catchability, etc.) to assess the state (present and future) of the populations?

- **General consensus that the generic indices are considered useful and need to be continued**. The physical indices are presented at stock assessment meetings and provide a useful overview of environmental conditions. Biological indices are generally not routinely at present because these time series have just started but data projects for biology will soon be presented routinely.
- In many cases, **custom data products are presented in the general overviews at RAPs, tailored to the species groups being considered**.
- **An example of stock-specific indices was presented for 4T** cod but it was generally felt that stock-specific indices or custom data products couldn't be addressed at this meeting. Need a larger body of people to address this. **These custom data products need to be developed by collaboration between oceanographers and assessment biologists**. Venues for this collaboration are discussed below.

B) What analysis or techniques should be carried out to elucidate the relationships between finfish or invertebrate stocks and the environment? Should there be a concerted effort to do this and if so, how and by whom (leave it to individual researchers, FOC, Regional Working Groups, etc.)?

E) What recommendations would you make to increase exchanges and collaborations among people dealing with environmental issues and those involved with stock assessments?

- Need to simultaneously test as many plausible hypotheses as possible to reduce likelihood that apparent relationships are spurious or uncover relations obscured by confounding;
- Retrospective time series analyses or event analysis (i.e. large signal to noise ratio in environment or fish)?
- Need to use both. Difficult to apply based on these extreme events. Success will likely depend on large signals;
- **Suggest more emphasis on application of biophysical modeling**. These haven't been used much in annual overviews or implemented in AZMP. Models could be used to provide information on currents, retention etc, environmental properties that are difficult to measure by conventional means. Also will identify where additional information is needed. **Modeling more advanced for the physics, but not well developed for biological components**. The effective use of these models may require a re-evaluation by AZMP of its data collection and products. For example, **information on the vertical and horizontal distribution of organisms is required for the biological components.** Even given vertical distributions at a point in time, need rules for change (vertical migration etc);
- **The Baltic example demonstrates the need for intense research efforts to establish and validate relationships between environmental indices and fish population dynamics/assessment parameters before these can be used in stock assessment**;
- Research on other factors also needed to validate apparent relationships (e.g., stomach contents to validate relationships between zooplankton and larvae);
- On the other hand, another view was that the best we can do at this stage may be to describe how environment affects the probability distributions of fish stock variables such as recruitment success without understanding mechanisms;
- Suggested that need to look at relationships between environment and community structure/general ecosystem characteristics in addition to just a single species approach;
- **There already has been a concerted effort thru FOC working groups, theme sessions and individual research initiatives. But this varies regionally and by species group. There's a need to target people for the theme sessions and working groups**;
- **There's a need for greater involvement of oceanographers in regional assessment working groups, RAPs. Recommend that oceanographers should be involved in Assessment Framework WG meetings to incorporate environmental data into the framework as it's being developed**. Workloads and project management are issues here. Currently both assessment scientists and AZMP scientists are working at full capacity. Management will have to consider the resource (human and monetary) requirements of increased interaction.

C) Is there relevant environmental information important for specific fish and invertebrate stocks that is not currently being measured or made available from AZMP or other sources? If so, what recommendations would you make to correct the situation?

- We recognize two issues: (1) are the appropriate data being collected but the custom data products lacking, or (2) are their important environment/ecosystem properties not being measured? The first is tractable, and enhanced interaction between AZMP and assessment biologists will identify the data products that AZMP can produce or provide the data for. A number of components that aren't being monitored were identified in the presentations and discussion. **These include macrozooplankton, benthos, gelatinous zooplankton, and satellite altimetry. Some of these have significant resource implications (e.g. benthos), others may be tractable to add (gelatinous zooplankton, satellite altimetry)**;
- We noted a number of region-specific gaps in AZMP data collection;
- **NGSL Strait of Belle Isle; south coast of NF**. Each of these have significant resource implications for AZMP;
- Have the scales of variability and representativeness of the fixed stations been addressed in the design of AZMP? AZMP is conscious of this issue and is currently evaluating its sampling design in relation to scales of variability. Emphasis is on documenting scales of plankton variability.

D) If the environmental information is or becomes available, how best can it be incorporated into the stock assessment process? Who should lead this work?

- **Through participation of oceanographers in the stock assessment WGs and assessment framework WGs. This will need to be led by these WGs**.

**Group invertebrates report**

It is felt strongly that monitoring the environment is the basis of all ecological studies on marine species

A)

- We need to improve the understanding of mechanisms or processes involved in the production of a marine species (recruitment, growth, mortality);
- But based on what we know, we think that monitoring production at lower trophic levels (primary production, secondary production including macrozooplankton, and benthos production) is very important. We feel that a good characterization of the habitat / environment is crucial especially in a changing environment;
- The coverage of the nearshore should be improved (e.g. for lobster and rock crab in shallow waters);
- We recognize that specific requirements for certain species might not be achievable within AZMP (e.g. scallop beds).

B)

- It depends on the process being studied: recruitment fluctuations, growth or mortality (as multispecies interactions). Simulation studies could identify the important processes and variables to be measured;
- Should be done by working groups, inter-regional (to take advantage of all available expertise) to address specific issues. The approach could be based on case studies (for example, the environmental influence on shrimp growth, the impact of winds on settlement and recruitment of lobster, thermal habitat of snow crab).

C)

- It is felt that processing samples that have been collected over the years should be a priority (e.g. plankton samples from the mackerel egg survey). To improve the monitoring of benthic component, the benthic organisms caught during the bottom trawl surveys should be sorted, counted and weighed by species;
- At predetermined stations, the collection of information on vertical plankton distribution should be done as it is important for modeling of early stage studies;
- Elements mentioned in number one are also relevant to question number 3;
- Because the substrate type is very important for benthic species as scallops, snow crab and lobster, benthic habitat should be characterized. In some areas, it has already been done (e.g. RoxAnn in eastern NFLD, geological surveys) but again, data should be processed.

D)

- It should be incorporated to explain the history of the stocks, to comment on the present status and to propose management or harvesting strategies that are adapted to the environment / production situation;
- The fishery biologists who are responsible for producing stock assessments should look for the information (environmental as well as biological) and seek collaborations to obtain the best results;
- FOC should be the forum to foster these collaborations.

E)

- Create regional multidisciplinary study groups;Increase participation to inter regional meetings such as FOC;
- Encourage oceanographers to attend stock assessment meetings.

## ANNEX 3 - Agenda

# Workshop on Strategies for Strengthening the Link between the Atlantic Zonal Monitoring Program (AZMP) and Stock Assessment

November 13 to 15, 2002
Crowne Plaza Hotel
Montreal, Québec

**Program/Agenda**

**Day 1: Overviews and general presentations**

| | |
|---|---|
| 8:30 – 8:45 | Opening: Introduction and Workshop Objectives (P. Ouellet) |
| 8:45 – 9:30 | Overview of AZMP activities and data products (*P. Pepin, B. Petrie*) |
| 9:30 – 10:15 | The use and applications of environmental information in stock assessments (*G. Chouinard*) |
| 10:15 – 10:30 | Break |
| 10:30 – 11:00 | An overview of reference points and ecosystem management: where environmental information fits in? (*B. O'Boyle*) |
| 11:00 – 11:30 | Environment-fishery interactions NF region (*E. Dawe and D. Parsons*) |
| 11:30 – 12:00 | Environment-fishery interactions SS/GOM (*K. Drinkwater*) |
| 12:00 – 13:00 | Lunch |
| 13:00 – 13:30 | Environment-fishery interactions in the Gulf of St. Lawrence (*M. Castonguay*) |
| 13:30 – 14:00 | How the environment affects the odds (*G. Evans*) |
| 14:00 – 14:30 | How might physical/biological models be used in stock assessments? (*J. Chassé*) |
| 14:30 – 15:00 | Fisheries Management in a Changing Environment (*K. Brander*) |
| 15:00 – 15:15 | Break |
| 15:15 – 16:00 | Environmental influences on cod in the Baltic |

| | |
|---|---|
| | (*B. MacKenzie*) |
| 16:00 – 16:30 | Scallop-environment interactions<br>(S. Smith – presented by *P. Koeller*) |
| 16:30 – 17:00 | Predicting the future of marine fish and fisheries off Labrador and eastern Newfoundland under scenarios of climate change; information and thoughts for the Arctic Climate Impact Assessment (ACIA) (*G. Lilly*) |

Formation of three working groups (2 fishes, 1 invertebrates) and questions and instructions for working group discussions

**Day 2: Working groups**

8:30 – 11:00 Working groups presentations and discussions

11:00 – 12:00 First summary (if necessary, re-alignment of the groups)

12:00 – 13:00 Lunch

13:00 – 17:00 Working groups presentations and discussions

**Day 3: Plenary**

8:30 – 12:00 General discussion, conclusions and recommendations

PM Closure

## List of participants

Bancroft, Doug (HQ-Ottawa)
Brander, Keith (ICES)
Bundy, Alida (Maritimes)
Castonguay, Martin (Laurentian)
Chassé, Joel (Maritimes)
Chouinard, Ghislain (Gulf)*
Dawe, Earl (NWAFC)
Drinkwater, Ken (Maritimes)
Duplessie, Daniel (Laurentian)
Evans, Geoff (NWAFC)
Harrison, Glen (Maritimes)
Harvey, Michel (Laurentian)
Koen-Alonso, Mariano (NWAFC)
Lilly, George (NWAFC)
MacKenzie, Brian (DIFR, Denmark)
Mitchell, Michel (Maritimes)
Morin, Bernard (Laurentian)
O`Boyle, Bob (Maritimes)
Ouellet, Patrick (Laurentian)
Parsons, Don (NWAFC)
Paul Fanning (Maritimes)
Pepin, Pierre (NWAFC)
Peter Koeller (Maritimes)
Petrie, Brian (Maritimes)
Plourde, Jacques (Laurentian)
Savard, Louise (Laurentian)
Swain, Doug (Gulf)
Therriault, J.-C. (Laurentian)