Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S / **S C C S**

Canadian Science Advisory Secretariat / **Secrétariat canadien de consultation scientifique**

Proceedings Series 2007/034 / **Série des comptes rendus 2007/034**

Proceedings of the Assessment Framework for Northern Shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland

Compte rendu sur le cadre d'évaluation de la crevette nordique (*Pandalus borealis*) au large du Labrador et sur la côte nord est de Terre Neuve

May 28-30, 2007, St. John's, NL

Du 28 au 30 mai 2007, St. John's, T.-N.-L.

Meeting Chairperson
Dr. Noel Cadigan

Président de la réunion
Noel Cadigan, Ph.D.

Editor
Dr. Jerry Ennis

Rédacteur
Jerry Ennis, Ph.D.

Fisheries and Oceans Canada / Pêches et Océans Canada
Science Branch / Direction des sciences
PO Box 5667, 80 East White Hills Road
St. John's, NL, Canada A1C 5X1

November 2007 / **novembre 2007**

Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings include research recommendations, uncertainties, and the rationale for decisions made by the meeting. Proceedings also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

Avant-propos

Le présent compte rendu a pour but de documenter les principales activités et discussions qui ont eu lieu au cours de la réunion. Il contient des recommandations sur les recherches à effectuer, traite des incertitudes et expose les motifs ayant mené à la prise de décisions pendant la réunion. En outre, il fait état de données, d'analyses ou d'interprétations passées en revue et rejetées pour des raisons scientifiques, en donnant la raison du rejet. Bien que les interprétations et les opinions contenus dans le présent rapport puissent être inexacts ou propres à induire en erreur, ils sont quand même reproduits aussi fidèlement que possible afin de refléter les échanges tenus au cours de la réunion. Ainsi, aucune partie de ce rapport ne doit être considéré en tant que reflet des conclusions de la réunion, à moins d'indication précise en ce sens. De plus, un examen ultérieur de la question pourrait entraîner des changements aux conclusions, notamment si l'information supplémentaire pertinente, non disponible au moment de la réunion, est fournie par la suite. Finalement, dans les rares cas où des opinions divergentes sont exprimées officiellement, celles-ci sont également consignées dans les annexes du compte rendu.

Proceedings of the Assessment Framework for Northern Shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland

May 28-30, 2007, St. John's, NL

Meeting Chairperson
Dr. Noel Cadigan

Editor
Dr. Jerry Ennis

Compte rendu sur le cadre d'évaluation de la crevette nordique (*Pandalus borealis*) au large du Labrador et sur la côte nord est de Terre Neuve

Du 28 au 30 mai 2007, St. John's, T.-N.-L.

Président de la réunion
Noel Cadigan, Ph.D.

Rédacteur
Jerry Ennis, Ph.D.

Fisheries and Oceans Canada / Pêches et Océans Canada
Science Branch / Direction des sciences
PO Box 5667, 80 East White Hills Road
St. John's, NL, Canada A1C 5X1

November 2007

novembre 2007

ISSN 1701-1272 (Printed / Imprimé)

Published and available free from:
Une publication gratuite de :

Fisheries and Oceans Canada / Pêches et Océans Canada
Canadian Science Advisory Secretariat / Secrétariat canadien de consultation scientifique
200, rue Kent Street
Ottawa, Ontario
K1A 0E6

http://www.dfo-mpo.gc.ca/csas/

CSAS@DFO-MPO.GC.CA

Printed on recycled paper.
Imprimé sur papier recyclé.

Correct citation for this publication:
On doit citer cette publication comme suit :

DFO, 2007. Assessment Framework for Northern Shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland; 28-30 May 2007. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2007/034.

TABLE OF CONTENTS

SUMMARY

A meeting of the Newfoundland and Labrador Regional Advisory Process on Shellfish was held May 28-30, 2007 in St. John's. Its purpose was to review the assessment framework for Northern Shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland.

The meeting produced a substantially revised performance report spreadsheet to be used in the next shrimp assessment. The meeting could not define values for limit or precautionary reference points but it did outline a way to proceed towards defining these values.

This Proceedings Report provides summaries of presentations and the broad scope of discussion that took place. It also includes the decisions and conclusions reached by consensus and research recommendations made. No Science Advisory Report will be produced. However, all of the research material developed specifically for presentation at the meeting will be included in a CSAS Research Document.

SOMMAIRE

Une réunion du Processus consultatif régional de Terre-Neuve et du Labrador sur les mollusques et crustacés a eu lieu à St. John's du 28 au 30 mai 2007. Le but de cette réunion était d'examiner le cadre d'évaluation de la crevette nordique (Pandalus borealis) au large du Labrador et sur la côte nord est de Terre Neuve.

Cette réunion nous a permis de produire un rapport substantiellement révisé sur le rendement, présenté sous forme de tableur, qui sera utilisé au cours de la prochaine évaluation de la crevette. Les participants n'ont pu définir les valeurs des points de référence limites ou de précaution, mais ont présenté une solution pour faire progresser la définition de ces valeurs.

Le présent compte rendu contient des résumés des exposés et couvre les discussions qui ont été tenues. Il indique également les décisions qui ont été prises, les conclusions formulées après consensus et les recommandations proposées pour la recherche. Aucun avis scientifique ne sera produit. Par contre, tout le matériel de recherche élaboré expressément pour la réunion sera inclus dans un document de recherche du SCCS.

Introduction

A meeting of the Newfoundland and Labrador Regional Advisory Process on Shellfish was held May 28-30, 2007 in St. John's. Its purpose was to review the assessment framework for Northern Shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland. Terms of reference and lists of participants and presentations are provided in Appendices I through III, respectively.

Participation included personnel of DFO Science and Fisheries and Aquaculture Management Branches, and representatives from the fishing industry, FFAW, and the Provincial Department of Fisheries and Aquaculture. Open discussion and debate proceeded during and after each presentation.

This Proceedings Report provides summaries of presentations and the broad scope of discussion that took place. It also includes the decisions and conclusions reached by consensus and research recommendations made. No Science Advisory Report will be produced. However, all of the research material developed specifically for presentation at the meeting will be included in a CSAS Research Document.

Presentation and Discussion Summaries

1. An assessment framework for northern shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland (Dave Orr)

Summary

The traffic light approach was introduced as a means of tracking changes in stock and/ or environmental status. The following diverse set of nine performance report examples was presented to demonstrate that the Traffic Light approach has both broad application and support:

1) Gulf of St. Lawrence shrimp;
2) Eastern Nova Scotian shrimp;
3) Southern Gulf Snow crab;
4) Atlantic Herring – NL Region;
5) Climatic conditions as presented by the Atlantic Zonal Monitoring Program (AZMP);
6) Woods Hole Institute of Oceanography which includes a performance report in their tool kit;
7) Consumer Report;
8) Bedford Institute of Oceanography (BIO) which has included programs to create Traffic Light performance reports within the ACON visualization software. During 2001, BIO held workshops to develop this methodology.
9) Northern shrimp – NL Region. This workshop has been convened in order to evaluate and develop a Traffic Light framework performance report for the assessment of shrimp off Labrador and the northeastern coast of Newfoundland.

Each set of performance reports made use of their own metrics when determining within parameter changes in color. Snow crab researchers divided the data into three equal portions; color within the northern shrimp data was determined by whether it was above, within or below the 95% confidence intervals around the long term mean for that variable, while oceanographers made use of z transformed standard deviations around the long term mean. The Snow Crab and shrimp reports made use of three simple colors; red (concern), yellow (intermediate) and green (positive), while climatic data were presented on a color scale from dark blue for strong negative deviations to light blue and pink for minor deviations and dark red for strong positive deviations. Regardless of the metric used, trends within several parameters could be clearly presented on a single page. Through usage of the appropriate time lags, it was possible to produce a forecast. Such reports should not be limited to data poor situations; the method is equally suited when there are rich long term datasets and can include model output.

Biomass, abundance, age 2 abundance – the recruitment index, age 4 abundance, spawning stock biomass, commercial catch rates (CPUE) and the exploitation rate index (catch/ lower 95% confidence limit about the previous year's biomass estimate) were briefly described as the main indices used to determine stock status. The traffic light performance reports developed for the 2006 regional assessment (RAP) of Shrimp Fishing Area 6 (SFA 6) were presented. Weighting schemes for each parameter and associated scoring system developed for the 2006 assessment were presented (Figures 1 and 2).

The 2006 RAP concluded that the performance report system had utility but that a thorough review of the weighting and scoring methods had to be completed before the reports would be accepted as a part of the shrimp assessment framework. Therefore the present workshop was convened to complete this review and develop a framework that would be used in the next several shrimp stock assessments.

Discussion

Some of the biomass and abundance indices from the fall survey seem somewhat redundant. It was explained that the age 4 abundance index is made up of males that are about to become females. It can be used to predict female abundance the following year. The spawning stock index indicates the number of females that will be reproducing in the current year. It monitors changes in that component of the population and can be used to predict catch rates in the fishery the following year.

2. Northern Shrimp (*Pandalus borealis*) within Hawke Channel + 3K (SFA 6) and Hopedale+ Cartwright Channels (SFA 5) (Dave Orr)

Summary

Stock status of shrimp within Hawke Channel +3K (SFA 6) and Hopedale + Cartwright Channels (SFA 5) (Figure 3) was presented as background information for the workshop. Input variables for the present assessment and the traffic light spreadsheets from the 2006 RAP were reviewed.

Annual catches within SFA 6 increased from 11,000 t during 1994-96 to 72,600 t during the 2004 calendar year. The TAC for the 2005-06 management year was set at 77,932 t, of which 75,100 t were taken by March 31, 2006.

Spatial distribution of the SFA 6 fishery expanded between the mid 90's and 2000 remaining stable thereafter. The 2005 large (>500 t; LOA>100') vessel Catch Per Unit Effort (CPUE) remained at a high level, while the small vessel (<=500 t; LOA<=100') CPUE increased significantly during 2004 and remained at a high level during 2005. Biomass and abundance indices from autumn multi-species surveys increased over the 1997-2001 period. Both indices decreased slightly during 2002 but since then abundance remained high while biomass increased to the highest recorded level. The 2003 year class appeared weaker than average; however, the strong residual female biomass was expected to maintain the fishery over the short-term. Medium-term recruitment appeared positive due to the presence of a stronger than average 2004 year class. Female spawning stock indices increased from 182,000 t (22 billion animals) in 1997 to 404,000 t (55 billion animals) in 2005. The resource continued to be distributed over a broad area and exploitation rates have remained low with recent catches having no observable impact upon shrimp abundance and biomass.

Catches within SFA 5 increased from 7500 t in 1994-96 to 26,900 t by 2004. The TAC for the 2005-06 management year was set at 23,300 t and 22,900 t had been taken by the end of the fiscal year. Since 1996, CPUE has remained above the long-term average. Biomass and abundance indices have increased since 1998. Short term recruitment remains uncertain, because the autumn 2005 survey did not extend north of 2J. However, recruitment within Cartwright Channel appeared average. Longer term prospects were unknown. The resource continued to be distributed over a broad area with exploitation rate indices remaining low. Recent catches have had no observable impact on shrimp abundance and biomass.

Discussion

The weighting of indices along with a final score included in the 2006 assessment performance report spreadsheet were not used in the final assessment. It was recommended at the RAP that the weighting scheme be reviewed in this meeting. Issue was taken with the down-weighting of indices from the fishery, specifically the CPUE. It was explained that fishery catch rates are used in an assessment to indicate changes in stock size but in this case there is greater uncertainty compared to research survey catch rates. This is because at the current high abundance there are a number of other factors affecting catch rates in the fishery.

Survey data from 1995 and 1996 appeared anomalous and therefore were eliminated from various plots of fishery versus survey indices. Biomass was low in 1995 but much higher in 1996, possibly as a result of survey variability. Additionally the 1995 survey is more suspect because it was the first year that shrimp were included in the multi-species survey and sea-going staff for the most part had no prior experience with sampling for shrimp. The biological sampling details are considered good but the abundance/biomass indices are suspect for that year.

One figure shows two different relationships between SSB from the survey and CPUE in the fishery for different periods when abundance levels were substantially different - the linear fitting is probably inappropriate and likely obscuring the relationship.

1. Following further consideration of issues related to use of data from the 1995 and 1996 surveys, it was decided that abundance/biomass indices from the 1995 survey would be excluded from future analyses but detailed biological sampling information

from that survey would be used. The 1996 survey will be the starting point of the research vessel survey abundance/biomass series for shrimp.

From the perspective of a new assessment framework for shrimp, it would be useful to consider how the management units that have been used relate to stock units and whether assessment based on these management units is scientifically credible or whether it should be assessed as a single unit.

A genetics study found some localized differences within the Gulf of St. Lawrence but not enough difference over a very broad area of the NW Atlantic Canada to discriminate separate stocks.

Current management units originated when shrimp were primarily distributed in the deep channels off Labrador where the fishery started and developed. The major concentrations at that time were well defined and the old shrimp surveys starting in the late-1970s pretty well covered the distribution. But as abundance increased, distribution expanded to become approximately continuous over a very broad geographic area from north to south obscuring any separation between the management units. There is very limited knowledge about the stock unit as such and whether events in one SFA will impact another. North to south differences in biological characteristics probably reflects a cline rather than different stocks. In northern shrimp there also appears to be a very broad north to south dispersal of larvae which would probably eliminate any real separation into different stock units.

Only partial coverage of the current distribution is achieved by research surveys. Whether methods based on a well-surveyed area in the south can be applied to northern areas that are poorly surveyed is uncertain. Ideally, the whole distribution should be surveyed to the same degree.

2. It was concluded that there is no biological reason for present management units, however, assessment of these units will have to continue until there is a basis for doing otherwise. It should be made clear to managers, though, that there is no evidence of different stocks and the fishery in one management unit could impact the stock and fishery in another management unit.

This meeting will explore the possibility of developing a more scientifically rigorous framework for assessment of northern shrimp in the future. In the past, assessments have been based on a review of trends in various indices to make short term predictions of what to expect in the fishery during the following year. It is not a model-driven assessment. The various indices used are generally quantitative, but bringing them together has been qualitative. A traffic light spreadsheet has been used to summarize information from the different indices/indicators and provide an interpretation of stock status and a short-term forecast. Attempts are made to use environmental indices but, given lags, the time series tend to be too short for reliable prediction. Predator abundance trends are also used to make inferences about possible ecosystem impacts.

A simplistic ecosystem approach similar to the one applied to capelin years ago, that it is an important forage species and exploitation should be kept low, could be applied to shrimp which is currently thought to be an important forage species.

References

Orr, D., P.J. Veitch, and D.J. Sullivan. 2006. Northern shrimp (*Pandalus borealis*) off Baffin Island, Labrador and northeastern Newfoundland. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/042.

3. Using multiple fishery indicators in a traffic light plot (John F. Caddy)

Summary

A wide variety of uses for colour coding of indicators is emerging in fisheries and elsewhere. This presentation briefly touched upon fisheries with examples from the Atlantic, Black Sea, Gulf of Mexico and Gulf of St Lawrence. The utility of the Traffic Light method seems five-fold:

1) for simultaneously reviewing changes in the values of multiple indicators;
2) to formulate hypotheses on likely driving forces in multivariate situations;
3) to display indicator performance in relation to reference points;
4) to communicate complex information to non-technical audiences;
5) to formulate a fisheries control rule for management action using empirical indicators and semi-quantitative information.

The use of indicators and reference points for fisheries science and management has been emphasized since the UN Fish Stock Agreement in 1995, and limit reference points (LRPs) are the main tools for precautionary management. Limit reference points may be outputs from models, values of indicators when stocks were previously in serious decline, or may represent agreements between the parties/experts as to the indicator value which should prompt actions, such as the start of a recovery plan.

It may be useful to classify indicators into functional categories, and use them to monitor a fishery in terms of inputs, state variables, and outputs, with a broad range of indicators that include stock health, environment, and economic performance. Indicators may be grouped by the 'Characteristic' they measure, but ideally, each is derived from a different data source. Model-based indicators, empirical indicators, and system responses can be combined in a 'traffic-light' display system with the resultant management response based upon the number of key indicators which have changed colour. Statistical analysis and modelling should be carried out in parallel with a TL approach, and outputs can be incorporated into the TL. Recruitment indicators or age structured data can be lagged such that good and poor cohorts passing through the population are presented as vertical colour bands: this type of plot may also provide a rough forecast of future yields.

Stepwise decision rules for the inclusion of indicator variables were presented as follows:
1) Decide from prior considerations which 'Characteristics' of the fishery you wish to monitor (fishing pressure, biomass, environment, economics, etc) – then combine different indicators within a characteristic to obtain an overall index for that Characteristic.
2) Compile all time series indicators into a large matrix, and carry out a cluster analysis to judge similarity before combining indicators from apparently different characteristics into homogenous groups.

3) Plot smoothed time series for the indicator against smoothed series for the resource, after apply an appropriate lag period determined by inspection of time series or biological knowledge. Locate colour boundaries at inflexions in the plots.

In the North Atlantic, both east and west, (Figure 4) invertebrate landings have increased following declines in finfish stocks – does this demonstrate an ecological interaction or a shift in industry priorities? A release of trophic control by groundfish seems a more tenable hypothesis here than just climatic change or overfishing alone. However, the trends of landings of different finfish species (pelagic vs. demersal for example) show no obvious 'top down' sequence.

The TL approach can then be used in formulating conventional fisheries control laws, and in defining the interface between science advice and management decision-making through usage of a Consideration Matrix as suggested by the FRCC.

Discussion

The first step in a traffic light approach is a simple display of data. Initially, data from any long series such as landings with a wide range of indicator values is divided into 3 or 4 color bands each with a range of values.

A general questionnaire could contain a lot of positive responses while a stock is being fished unsustainably. A questionnaire can collect easy-to-get information that provides an overall evaluation of what is going on in the fishery; whether it is being properly managed and where management deficiencies may lie. Half of the questions relate to the stock and provide a basis for what might be happening with it. The scoring can provide an indication of whether things are improving over time.

Regardless of the time series considered, there must be a dynamic range which includes good and bad periods. In the case of northern shrimp, the surveys are fairly recent and coincide with a period when shrimp abundance has been increasing. Within such a short time series, boundaries for different colors in a traffic light approach for indices with limited range have to be justified and used in context.

<u>4. Towards a traffic light approach for Northern Shrimp that takes into account ecological interactions and environmental change</u> (John F. Caddy and Dave Orr)

Summary

Approximately 40 data sets of varying time length were considered for inclusion as potential indicators. The data sets were divided into 2 categories: long and short – the long series containing data (often less precise) longer than 15 years while the shorter data sets were more research validated but usually less than 10 yrs in duration. These 2 data sets were kept separate to avoid confounding. No attempt was made, *a priori*, to suggest mechanisms for the interaction of the shrimp stock with the variables in these data sets except to note hypotheses by previous workers.

<u>Long series</u>: (including the total catch of shrimp within shrimp fishing area 6 (SFA 6), groundfish survey data series and longer environmental time series). The collapse of groundfish stocks and the rise in seal populations have been hypothesized by several

authors to have affected shrimp stocks, directly or indirectly, and these hypotheses cannot be ignored. Associated dramatic ecosystem and oceanographic changes have also been ongoing in the NW Atlantic, and these emerge from the longer data series despite the lack of precision of the shrimp data series, which for the purpose of this exercise was confined to total catch.

Short series: the standard survey data and biological analyses for *Pandalus borealis* in SFA 5 and SFA 6 suggest both interspecies and intraspecies interactions. However, while the short data series are more precise, they often lack dynamic range, with many starting after a period of dynamic ecosystem and environmental change. This limits the validity of conclusions drawn from these analyses until further annual data have been accumulated.

'Steady state' reference points derived from dynamic pool models are less convincing – in part because the exploitation rate on shrimp stocks has remained rather low, while changes in shrimp natural mortality may have been significant due to dramatic changes in abundance of key predator species.

Thus it was best to develop separate reference points from the interrelationships of shrimp research data sets (short series), and by comparing the longer commercial shrimp fishery series and biotic/abiotic variables. A forecasting procedure then becomes less one of tuning the overall effort to avoid overexploitation, than trying to account for interspecies interactions and environmental changes, and how they will affect future shrimp biomass. Thus the intent was to monitor the multispecies ecosystem and the fishery together, by focussing on pandalid shrimp and their predators.

Cluster analysis was used to identify linkages between shrimp landings and predictor variables (Figure 5; Table 1). It was assumed that shrimp catches are dominated by age 6 females and that the environment has a dominant impact upon shrimp within their first year of life; therefore environmental parameters were lagged by 6 years. Predation is limited by size of predator in relation to prey size; therefore it was assumed that most finfish are unable to eat shrimp older than 2 years of age, therefore the predator indices were lagged by 2 years. Seals are however thought to impact shrimp by eating cod which is the shrimp's main predator. This would not be dependent upon shrimp size or age therefore there was no lag between seal abundance and shrimp landings.

Colour coding was completed by plotting the smoothed resource series as if it were a function of a smoothed series of some biotic/abiotic data set. Inflexion points in the graph were used to identify and separate 'homogenous' conditions. One criterion for indicator selection was that running averages of landings plotted against biotic/abiotic variables, when compared at a biologically appropriate lag time, should show a consistent trend throughout the observed time series, without 'bending back'. This concept is illustrated below for three smoothed biotic series (Figure 6). SFA 6 shrimp catch plotted against cod and autumn redfish research CPUE data sets showed a fairly linear plot or shallow curve and were therefore chosen as traffic light indicators since one level of shrimp production corresponded to a relatively tight range of finfish CPUE data. Whereas the plot with Greenland halibut research cpue cycled back upon itself meaning that at least two values for the predator corresponded to the same shrimp catch and hence Greenland halibut research cpue could not be used as a reliable variable in further analysis.

Inflexion points were used in determining colour boundaries; while recognizing that the ideal situation where research investigations to support such choices did not always apply. Total shrimp catch when expressed as a 'function' of research vessel groundfish and seal abundance 2 yr earlier (assuming that finfish predator focus mainly on males) was low until finfish biomass had declined to low levels, when dramatic increases in shrimp catches occurred. While this does not confirm a functional relationship, it is interesting that the positive relationship between shrimp catch and harp seal abundance, despite occasional predation by seals on shrimps – may be because the dominant role of seals is to control abundance of those groundfish species, thought to be the dominant shrimp predators. Similarly, figure 7 objectively demarcates colour boundaries within abiotic environmental parameters. As noted, like other suppositions in this preliminary report, this should be regarded as a hypothesis, but suggests priority areas for further research.

Key time series showed an inflexion between periods when groundfish were abundant and shrimp landings low, and vice versa, and similarly, between high shrimp landings in warm periods and low landings during colder periods. Cut-off points were judged by eye to mark when a change over occurred – in this case, yellow was seen as a transitional state.

Through successive one year lags, abundances within each cohort were aligned, and by using the above approach of dividing abundance at age into three classes, it was possible to detect relative year class strength (Figure 8).

A similar approach to that proposed in Caddy *et al*. (2004) for forecasting *Chionocetes opilio* abundance is given in the following diagram, which should be viewed as <u>strictly preliminary.</u> The pie diagrams provide summations of the 4 variables for environmental variables (Figure 9). The tentative conclusion is that, if year class strength is the key factor and environmental conditions are valid indicators, continued good <u>landings seem possible</u> for the next few years..

The environmental variables were believed to mainly affect shrimp reproduction, and survival in the 1st yr of life. The pie diagrams average the colour of the 3 variables 'predicted' from 2007-2012 for partially recruited age groups. Although no exact annual forecasts are intended here, the figure suggests that the recent environmental conditions should support good recruitment, and therefore might lead to continued good landings over the next few years.

A range of values for M and Z for *Pandalus sp*. were found in the literature, which appears to show elsewhere that mortality is a function of relative predator abundance (Table 2).

If available, age structure is perhaps the best basis for a system of prediction, and is used in various cohort prediction methods; e.g., for finfish. One problem with such 'constant parameter' methods is that estimates of M vary widely, and some authors associate high M values with high predator abundance. In other words, where environment/ predator abundance changes radically over time, a 'constant natural mortality' cannot be guaranteed, and this is apparently the case for northern shrimp. The preliminary values for Z from abundance at age of cohorts in successive years in SFA 6 were determined as the log difference between abundance of ages 2-4 males in one year and abundances of ages 3-5 males in the succeeding year. Using this method, the Z values range between 0.23 and 0.49. Based upon the ratio of landings/survey biomass, F values were approximately 0.2. Therefore, M values for SFA 6 must be at the low end of the published range which extends from 0.25 - 2.0+. Figure 10, suggests that the reduction in predator abundance (moving from right to left on the diagram) led to a decline in shrimp M allowing a dramatic increase in shrimp recruitment/ abundance.

Thus, our problem with applying a standard shrimp assessment is that not only do we have fragmentary data on M, Z, but we suspect that these have both declined with declines in finfish predator populations.

A simple simulation for competing predators

Although we did not have quantitative data for evaluating seal and cod predation, an indicative simulation was attempted to look at the order of magnitude impacts of cod and seals upon trends in shrimp mortality, assuming fixed values at the start and end of runs based upon observed trends in shrimp predators: i.e., 100%-<5% for cod over the last 20 years, and 100% - >250% for seals over the same period (Figure 11). Interactions between seals, cod or other finfish species were not considered.

A simple conceptual simulation was considered using indicative data. A feeding rate of 15-20% body wt/ day and between 20-40% shrimp in the diet, was applied for seals feeding on shrimp, and somewhat higher rates for cod. For seals, this percentage was increased somewhat over the interval, assuming finfish food items became progressively scarcer. Shrimp recruitment was kept constant annually. This simulation suggests that although seals caused a slight increase in shrimp Z over the period, this was less important than the drop in M caused by much reduced cod (and other fish) predation. Although this simulation is simplistic and a wider range of input parameters could have been used, it is presumed that the main effect of the seal population increase was to keep cod biomass low.

The assumption underlying the above calculations may be summarised in the following figure, in which a coloured periphery indicates population increase over time, and a coloured centre, a decline (Figure 12).

Conclusions

Although any conclusions from this early analysis are tentative, this study points to the requirement for coordinated ecosystem and environmental analysis involving all major species in this northern ecosystem (including capelin - which since no data are available for this major forage species, has been connected by a dotted line to its supposed predators in the above tentative food web).

Discussion

Some of the relationships postulated need to be carefully scrutinized, but cannot be ignored indefinitely. The longest data series available is catch; which has been used as an index of abundance. Over much of the period this was just a developmental fishery that was tightly controlled. It expanded very rapidly over a very short period especially with the introduction of the small vessel (<=500t; length over all (LOA) <=100') fleet component and these changes soon occurred after the decline in predator abundance. Thus we recognize that the catch series can only be used in a very general way, but the slow accumulation of adequate time series of research data does not permit alternative approaches.

Current stock status is based on CPUE in the fishery and a number of indices derived from research survey data. Recruitment is the major factor in annual production, but how well it can be predicted from temperature or predator abundance is not clear. The catch is shown to be positively related to temperature within the year as well as to time series 6 years previously, even though work in the past has shown a positive effect of ice cover (i.e. low temperature) on future recruitment at a 6-year lag. There is better growth at higher temperature but the net effect of cold or warm conditions on production is something of a paradox. Prior to using any time series of environmental or ecological indicators, it is necessary to understand its effect. Any relationship with predator abundance is likely to be much longer term and associated with significant regime change. There are a number of problems associated with making predictions of recruitment to the fishable biomass from environmental/ ecological indicators. While there has been a regime change with a clear transition from a period with several predators to one with fewer, changes within the shrimp stock over the recent, shorter time period due to density-dependent effects have also occurred. There have been major fluctuations in abundance for all of the major species and interactions between them. Rather than focusing on a single species, an overall diagnostic of change in the fisheries ecosystem should be looked at before making a detailed assessment on any species.

The ecosystem has been in a relatively steady state over the last 10 years. In the context of a shrimp assessment, it is a good idea to continue studying the predator-prey situation; however, predators probably won't have an impact on shrimp until predator abundance significantly increases.

This work reconfirms the view that F is a minor component of total mortality. Around 40% of the biomass is 6 years and older which indicates that the stock is not fished very heavily.

The current status of the resource in SFA 6 is being adequately monitored by the survey. Several survey-based resource indicators, together with the exploitation rate index, and possibly some environmental indicators whose impacts are well understood, should provide all of the information needed to manage the stock in this management area in the short term.

An indicator has little value unless it is based on some scientific evaluation. Linear correlations should be a first step in trying to understand a cause-effect relationship. However, most environmental effects upon shrimp abundance appear to be non-linear.

The main purpose of stock assessment is to provide information allowing managers to make decisions that would ensure the shrimp stock is fished in a sustainable way while environmental conditions remain favorable. This requires some estimate of exploitation rate. If catch information were reliable and survey catchability were known, it would be possible to estimate exploitable rather than trawlable biomass from the survey, and target exploitation rates could be determined for the stock. This should provide managers with sufficient information to ensure that exploitation remained moderate. Nevertheless, some sort of forecasting would be required to determine sustainable target exploitation levels.

There has been progress in estimating mortality rates from age compositions and more could be done with existing data to demonstrate that F is quite low. The greatest potential danger to the stock may be density-dependent effects due to continued stock growth in the absence of predators. High shrimp abundance may also adversely affect recovery of groundfish stocks – there may be a density-dependent effect associated with shrimp predation on larval fish or their food supply. While there are advantages to under-exploiting, there are also advantages in keeping the stock within a moderate abundance range. There is the potential for example, that stocks may be at risk due to the effects of continued global warming. (*e.g.* high water temperatures were thought to cause the disappearance of *Pandalus borealis* disappeared from the Gulf of Maine during the 1960s-1970s).

Thus far, the focus of assessment work on shrimp has been very much on following short-term variations in shrimp populations; however, from time to time a focus on longer-term issues associated with the ecosystem and broader-scale environmental trends is important, and has been attempted here. We recognize however that some of the tentative results discussed in this report require further inputs and coordinated investigation from other species specialists.

5. Hopedale + Cartwright Channels (SFA 5) northern shrimp (*Pandalus borealis*): a case study illustrating the traffic light assessment framework (Dave Orr)

Summary

Forty four (44) long term (spanning at least 18 years) and twenty nine (29) shorter term environmental indices (spanning at least 5 years) were compiled with the intent of determining whether they could be used in performance reports to describe unstandardized SFA 5 commercial shrimp catch rates (Tables 3 and 4). Single trawl, no window data were included in the unstandardized catch rate model. The following stepwise methods were used to select variables that would be included in the performance report:

1. Multiple regression analyses were run using the Proc Reg procedure with forward selection set to accept variables with $P<0.05$ and the collin option used to test for multi-collinearity (SAS 9.1, 2003).
2. Correlation analysis was run iteratively on unique environmental data lagged 0 – 6 years. The lag with the highest absolute correlation coefficient was chosen as the appropriate lag to use in predicting catch rates.
3. A spreadsheet of environmental variables was created with the appropriate time lags. StatistiXL 1.7 (Roberts and Withers, 2007) was used to complete cluster analysis using the nearest neighbor method with Pearson Correlations as the distance/ similarity measure. Variables with high absolute Pearson Correlations were chosen for inclusion in the performance reports. It is important to note that extensive research must be conducted to ensure appropriate variables and their associated lags are chosen. Therefore this exercise was run to illustrate the methodology.
4. Unstandardized SFA 5 commercial CPUE and environmental variables were smoothed using a 3 year running average. CPUE was plotted against individual environmental variables. Inflexion points in the graphs indicated major changes in CPUE and objectively divided the environmental data into green (positive influence), yellow (intermediate) or red (concern) bands.
5. Each of the environmental datasets was color coded and combined into a performance report.
6. The environmental parameters were lagged. Each parameter was given equal weight and forecasts were provided by creating a pie chart of number of color coded cells within each year.

Multiple regression and correlation analyses indicated that predator abundance, ice cover and water temperature significantly influenced commercial shrimp catch rates. The correlations between the environment and SFA 5 commercial CPUE with various lags are presented in Figure 13. Figure 14 provides the cluster analysis of SFA 5 large vessel commercial CPUE with environmental parameters; while Figure 15 illustrates the usage of

inflexion points to color code each parameter. A performance report was created and when CPUE was lagged by 3 years against harp seal abundance and 2 years against cod research CPUE, periods of low commercial shrimp CPUE lined up with periods of low Harp seal abundance, cooler water and higher 2J3K Atlantic cod catch rates. This lag also provided a short term prediction that the fishery will be maintained over the short term (Figure 16).

Literature Cited

Roberts, A. and P. Withers. 2007. StatistisXL – Statistical Power for MS Excel. On-line available at: www.statistixl.com/default.aspx.

SAS, 2003. Version 9.1. Carey, South Carolina. USA.

Discussion

The gap in both the standardized and unstandardized CPUE time series from 1984 to 1989 is because all of the logbook data available for that period were weeded out in the process of selecting data for modeling. The gap was filled in by using the un-weeded, raw data because the cluster analysis program, StatistiXL 1.7 (Roberts and Withers, 2007), will not run if there are gaps in the time series.

The boundaries between red, yellow and green portions of the plots of indicators are determined by inflexions in the graph, which at times were chosen subjectively.

An indicator was chosen by way of a stepwise process starting with multiple regression to determine which variables have both significant and unique model influence followed by a test for multi-collinearity and then correlation analysis. No correction was applied for autocorrelation. For the cluster analysis, those correlations with the highest absolute coefficients were chosen and redundant variables of essentially the same characteristic were excluded. The coefficients in the correlation matrix are indices of similarity between two different variables included in the cluster analysis. Those with a high positive index indicate variables with a similar effect and those with a high negative index indicate ones with an opposite effect. Autocorrelation may be an issue.

Regression and correlation analyses were done independently to select indicators that would be included in the cluster analysis. Cluster analysis was used to select those indicators to be included in a traffic light spreadsheet.

Identifying cohorts in a year-class strength analysis is complicated by year effects and it is important to understand how these are removed. When there is a strong year effect there will be a problem estimating Zs because of the difficulty tracking cohorts.

Estimating Z based on cohorts is problematical. Retention in the survey gear increases up to age 4 and some age 4 males become females at age 5 – this results in an overestimate of Z using males only. Age 4 + age 5 males + females in one year divided by age 5 males + females the next accounts sex change resulting in lower Z estimates.

Limit Reference Points

The 3 x 3-panel grid with a range of environment/ecosystem conditions down the side and a range of stock conditions across the top is a useful starting point to develop a framework for shrimp assessment in the future (see Annex 3). In northern shrimp, the fishery is probably much less important than environmental/ecological conditions in regulating biomass and this general concept might be applicable. Defining boundaries for the various compartments will require further work but this might be a good approach. The northern shrimp stock is presently very healthy and environmental conditions appear to be quite favorable. Defining boundaries for that compartment is really the issue. This represents a limit reference point approach which is meant to aid future decision making. This will require a great deal of further work involving greater involvement of managers and stakeholders.

Rather than a multiple-indicator approach, a LRP based on a single indicator such as the exploitation rate index was also discussed. This would require a complete survey in each SFA. Using the lower 95% confidence interval for the biomass estimate may provide a conservative estimate of the exploitation rate, but not necessarily since the catchability in the survey trawl is unknown. This kind of approach has been used at NAFO where there is a shift towards managing on the basis of some rule that will keep the fishery out of trouble most of the time. It might not be possible to define a limit reference point but a target exploitation rate could be set. From an ecosystem perspective, shrimp are now a major component of the food chain and this supports the idea of a conservative exploitation level.

While such a simple approach is fine to include, there is insufficient confidence in a survey estimate to use it as the sole basis for management - everything available to assess the status of the stock should be considered. The traffic light (TL) approach is a very useful way of evaluating all indicators in a stock assessment. However, there is a distinction between an index and an indicator. An indicator lacks any kind of scientific validation and use of several indicators does not necessarily provide a better basis for scientific advice. Nevertheless, there is no reason why some quantitative index could not be the key part in a TL approach and weighted depending on its scientific validation along with a number of complimentary indicators.

Ecosystem considerations have to be included in any LRP evaluation. Northern shrimp is at an all-time high. It is not desirable to require that shrimp biomass must be maintained at a high level in the face of significant ecosystem shifts in order to have a fishery.

In quantitative fishery science, there are basically two approaches – one is estimation of stock size and risk assessment, the other is management strategy evaluation. The indicator-based approach is not widely used in situations where there is a reliable survey index and good catch information as well as age/size structure information, which is the situation we have for shrimp. There is a basis for a more quantitative approach rather than simply relying upon qualitative indicators.

There may be alternative analyses of various indicators that could be synthesized into a population model of current stock size and future productivity under different harvest levels over the short term. There could also be an operating model to evaluate management strategies using artificial simulation to test different limit reference points. Northern shrimp is not a really good candidate for this kind of modeling because there is no stock-recruitment relationship and the environmental/ecological factors that seem to be driving stock dynamics are poorly understood. Only when some environmental or ecological index can be used with confidence to predict stock condition will any serious LRP evaluation be possible and this is not likely in the short term. However, things are in good shape in this fishery at present and from that point of view it is a good candidate to put some sort of LRP or stopping rule in place based on some other approach before there has been a downturn when it will be more difficult. We need to define the combination of conditions or values of the various indicators to be used that would cause enough concern to tell managers they have to do something radically different. This is the B_{lim} sort of idea and would be a step towards developing a 3 x 3 panel (see Annex 3).

Biomass reference points relate to how future production is a function of current stock size. In a precautionary approach, B_{lim} is the biomass level at which severe recruitment overfishing will occur. But in this species future production is more dependent on environmental/ ecological factors than biomass. A biomass reference point is not likely on any logical grounds.

Currently F is a small proportion of Z so the fishery won't likely cause a decline in the stock, but there must be an upper level of Z, possibly related to environmental change, that would drive the stock down. Reliable estimates of Z might have potential as a limit reference point.

Depletion of the females that accumulate at the upper end of the size distribution could result in recruitment overfishing at some point. A limit based on the ratio of mature females to total males might be possible. Very simple simulation indicates that this kind of accumulation of females in a narrow size distribution means very little growth of females or low availability of males. If this group starts to disappear, it could signal a recruitment overfishing situation. The M/F ratio could provide a precautionary indicator. It is assumed that this group of females is made up of multiple year classes, therefore such an indicator could be confounded by strong variation in year-class strength as well as by annual variations in size at sex change. Northern shrimp are protandric hermaphrodites and the M/ F ratios are regulated by sex change strategies that vary with population density. Nevertheless, the M/ F ratio appears to be relatively stable and should be a fair approximation of Z until an estimate is available from a length-based analysis. If it were to become very low, along with decreasing biomass in the survey, it would be cause for serious concern. However, if a change in the M/ F ratio were detected, other indices would have to be examined as well in order to interpret its significance.

A distinction should be made between limit and precautionary reference points. Setting a limit reference point means that the situation is very serious and radical management action must be taken. A precautionary reference point, on the other hand, represents a warning to managers when a situation is becoming delicate and is likely to deteriorate unless remedial action is taken - that would happen long before a limit is reached. A precautionary reference point is usually more practical, realistic and easier to set. While this distinction is consistent with the Canadian interpretation of the precautionary approach, it is not possible at this time to provide values for any possible precautionary reference points.

Comparison of current values for indices with values from back in the early 1990s prior to the regime change offer a possibility for developing precautionary reference points that could be a basis for warning managers and industry if there is a shift back to the predator dominated ecosystem of the past. This could provide some rough idea of what B_{loss} might be, although it would require a regime shift to get back to that level. However, as pointed out during the workshop usage of such a reference assumes that all environmental conditions were at least as favourable as those of the early 1990's. Remedial measures should be taken before the stock declines to this level.

One reference point that could be readily computed is some % of female biomass; however, currently there isn't enough dynamic range in the survey indices to provide a reference point that could be defended. Anything that might be put forward is just a best guess. Shrimp has been in something of a steady state at a high biomass level throughout the period that survey indices are available. Until there is a significant shift that provides dynamic range, it will not be possible to define specific values for limit reference points.

There is concern with using the % female biomass from the survey estimate. Shrimp can change sex to offset any decline in females. A drop in this index would not be much of a concern unless the fishery was taking a large portion of the males as well as the females and the catch were a high proportion of the biomass. It could, however, be a serious concern if it coincided with a significant environmental change such as cold conditions that could affect growth of males or the transition to females.

It has been suggested that a female percentage below around 10% would be a point that the stock should not be allowed to go. Industry would be greatly concerned if the % females dropped to anything close to that level and they were catching mostly small males – this could be an industry based rule. It is going to be very difficult to define reference points that are scientifically defensible.

In a precautionary framework, the argument that a reference point is not scientifically defensible is unacceptable. The research required to provide fully defensible reference points is well beyond current capabilities.

There is no reason why practical limits cannot be defined or accepted even if they are arbitrary.

3. The meeting is unable to specify values for any limit or precautionary approach reference points based on biomass or mortality. Nevertheless, possible useful approaches to their development have been identified. In particular, estimates of Z from length-based analysis should be pursued, even though it is not clear at this time what a limit reference point for Z might be.

Review of old performance report spreadsheet

This review of indices currently used in the assessment of northern shrimp focused on the performance report from the 2006 SFA 6 assessment – a copy is provided as Annex I.

Abundance/Biomass – It was agreed for reasons considered previously that the 1995 survey would be excluded from the time series of abundance/biomass indices. There was a brief consideration of OgMap versus STRAP, which are two methods (and computer programs) used to produce survey indices. OgMap gets rid of the problem of negative confidence intervals. It has been accepted at NAFO shrimp meetings and will continue to be used for shrimp.

It was agreed that the time series of abundance/biomass indices (with confidence intervals) to show trends will be included in any new shrimp assessment framework.

SFA 5 is only partially covered by the fall survey in alternate years. An evaluation of the partial coverage indicates it is adequate for generating estimates for the whole of SFA 5, however, this might not hold up at lower levels of abundance. A partial survey means increased uncertainty. There should be a recommendation to survey 2H (i.e. all of SFA 5) annually.

Age 2 Abundance – This is a recruitment index based on the survey estimate and separation of length frequencies into age groups by modal analysis using MIX - the analysis works best for age 2. Recruitment to the shrimp fishery is based upon size, depending on the gear used, rather than age; therefore, it would be more appropriate to have a size-based recruitment index. Age 2 abundance is more an indicator of year-class strength than recruitment. Nevertheless, it is used as a predictor of recruitment 2 years later when males start entering the fishery as well as an indicator of year-class strength.

Age separation is useful for tracking year classes through sizes in the survey samples. The MIX analysis produces standard errors about the age group estimates. However, detailed biological knowledge is used to constrain how the analysis separates age groups rather than let it make one big year class of all sizes. This is very subjective and standard errors from the analysis are not very meaningful. The most reliable and useful part of the aging analysis is on the left-hand side of the frequencies. How well the analysis works varies between years and there are two sources of uncertainty – the survey itself as well as the MIX analysis. There should be realistic confidence intervals to indicate the uncertainty.

The last assessment included the 11.0 to 16.5 mm CL size range as an index of recruitment. However, if growth is changing there will be difficulty predicting recruitment based on size or ages.

Age 4 Biomass – This is far less certain as an index because shrimp start to become females at age 4. It might be possible to identify these new females using sternal spine characteristics and use that as a measure of new spawning stock rather than age 4's, however, it might not work for samples taken in the fall survey when most females are ovigerous.

4. It was agreed that age two abundance and age four biomass would not be used in the performance report until an evaluation demonstrated their reliability.

Aging using MIX is probably a more reliable indicator of year-class strength than a recruitment index. It also provides a way of tracking the progression of year classes through the population over time. However, if older ages cannot be separated reliably, mortality estimation will be affected.

Spawning Stock Biomass – This is the female biomass that is currently in the fishery. It is considered fully recruited to the survey and the fishing gears. Although there is no stock-recruitment relationship, this index should be kept. This is one index in which a decline could occur without seeing it at smaller sizes.

Instead of Abundance, Biomass and SSB, it was decided to include Fishable Biomass and Female Biomass as indices in the performance report.

Large vessel CPUE – Much data are excluded in the weeding process for selecting data to be modeled to get the standardized CPUE series. An effort should be made to maximize the amount of data to be included and possibly eliminate the problem of gaps in the time series.

Small vessel CPUE – Small vessels are a major component of the fishery in SFA 6 but a minor component in SFA 5. While there is extensive overlap, there are areas where only small vessels have fished. The small-vessel time series is shorter but still useful on its own.

CPUE in the fishery is affected by many factors, and how well it measures changes in stock size is uncertain. Fishing experience may be a factor contributing to greater stability in CPUE in later years. It has little value as an indicator of change in abundance when stock size is high. The fleet tends to concentrate on high-density areas and it only reflects density where the fleet is fishing. Change in CPUE at high stock size is measuring vagaries of fishing, not change in stock size. It will only detect large changes in stock size.

The plot of SSB in the fall survey against CPUE the following year shows two relationships for different periods and biomass levels. This suggests that catchability in the survey compared to catchability in the fishery has changed. The CPUE index should be evaluated by way of a more careful look at the standardization process and better comparisons with the survey.

It was agreed that both the large and small vessel CPUEs will be included in the performance report but with appropriate caveats.

Size at sex change – It was suggested this should be dropped because it is not possible at this time to determine the impact of decreased size at sex change when the number of females is increasing. Attempts to relate the decrease in size at sex change to the environment have concluded it is a density-dependent effect. However, its interpretation as an indicator of stock health is ambiguous.

5. There is no consensus on how to interpret change in size at sex change in shrimp populations and it was agreed to drop this index from the performance report.

Exploitation rate index – This is the ratio of nominal catch (as reported in logbooks and from the official quota report) to the lower 95% confidence interval of the survey biomass index. In years when survey reliability is very low, using the lower C.I. could be misleading. The biomass point estimate is a better measure. This will mean an index of exploitation rate much lower than the already low current estimate. Error bars would capture the range in the index estimate.

6. It was agreed that the exploitation rate index would be based on the survey biomass point estimate and include errors bars reflecting the 95% confidence intervals and included in the performance report with a clear explanation of the change.

Given the problems with aging using MIX analysis of size frequencies from the survey, it might be possible to estimate Z by separating out 1st –year and older females in biological samples from the fishery for months when females can be separated by sternal spines.

Alternatively, there are methods based on mean lengths of animals that are fully vulnerable to the sampling gear that are widely used.

7. It was agreed that an estimate of Z would be included in the performance report.

Environmental and ecological indicators – Many possible relationships between shrimp abundance and environmental or ecological variables have been considered. Correlations can be spurious, or the two variables related to a third, rather than by cause and effect. Correlation analysis is really only a first step in formulating a hypothesis and is not valid unless there is a scientific basis for the relationship. There is probably nothing among the various correlations examined so far that could be used at this time as an environmental/ecological indicator in the context of an assessment framework. Nevertheless, variables that come from ongoing monitoring and that hold the best possibility of a relationship will continue to be observed.

Environmental and ecological indicators should continue to be reported in some context. The removal of predators in a system could result in a trophic cascade, similar to the regime change that has occurred in this area. It should be emphasized in the context section of the next SAR that for this species, change in abundance is largely driven by environmental and ecological factors rather than the fishery.

8. It was agreed that environmental and ecological indicators would continue to be monitored and reported in context but not included in the performance report.

The traffic light spreadsheet is probably a good way to display the main indices to be included in the next assessment. However, integrating across the various categories of indices is difficult. Some form of integration may be desirable for indices that measure the same stock characteristic.

There are many concerns with weighting indices. It is sometimes unclear whether weighting indicates quality of an index, or uncertainty about its interpretation, or its relative value compared to others. Weighting can also be quite subjective. It might be useful to rank the value of different indices of the same stock characteristic but not as a way of integrating across all indices to obtain a final score. Scoring is an attempt to quantify stock status.

Alternatively, indicators can be synthesized into a succinct statement about stock status, as has been the practice, rather than weighted and scored.

Weighting and scoring is an attempt to avoid situations that arise when using color coding in which one really important index is out-weighed by several others of a different color but much less importance. Color coding tends to weight indicators equally. Use of color coding to evaluate each index or indicator can be subjective and confusing. It should be used only for the stock status evaluation at the bottom of the performance report. What an indicator means could be included in the interpretation part of the spreadsheet.

9. It was agreed that the following indices/indicators would be included in the performance report and organized into categories as follows:

Production
Survey fishable biomass
Survey female biomass
Large vessel CPUE
Small vessel CPUE

Recruitment
Recruitment index (11.0 – 16.5 mm C.L. males)

Fishery
Exploitation rate index
Z
Industry Perspective

Stock Status
Current Outlook
Future Prospects

A draft of the proposed new performance report spreadsheet was presented for further review of content, in particular the issues of weighting and color-coding of indices.

An evaluation for survey indices will require going back to the earlier shrimp surveys for a period of lower abundance to avoid evaluation based only on surveys from the recent period of high abundance. The time series of other indices should be examined as well to get as much range in values as possible. CPUE evaluation should relate to changes in survey biomass. It might not be useful as an indicator of change in stock size at the current high level. Both the survey and the fishery are being conducted over a very broad area.

There are no rules as such for color coding an index/indicator evaluation in current practice. It is sometimes difficult but once consensus on interpretation of an index is reached at RAP, the appropriate color evaluation should be obvious and a working rule could be to leave it to consensus at the RAP. However, interpretation and evaluation of an index should consider its dynamic range.

When there is a series of different colors for the various indices/indicators, it can be very difficult to decide on the appropriate color for overall stock status evaluation. The decision can be very subjective and will depend on consensus at RAP. A conclusion on stock status has to be justified by the indices and their interpretation. Color coding is convenient for getting a take-home message at a glance and it should come at the bottom of the spreadsheet where stock status is evaluated.

It was decided that weighting and color evaluation of indices/ indicators will not be included in the performance report spreadsheet. Any uncertainty regarding quality of an index or its interpretation will be reflected in the interpretation column of the report. Red (negative), yellow (intermediate) and green (positive) will be used only to provide an evaluation for each of the two Stock Status indicators (current outlook and future prospects), as defined at the bottom of the spreadsheet, and uncertainty of stock status interpretation will be indicated by white.

A copy of the new performance report spreadsheet is provided as Annex II.

Summary of Conclusions

1. Abundance/biomass indices from the 1995 survey will be excluded from future analyses but detailed biological sampling information from that survey can be used. The 1996 survey will be the starting point of the research vessel survey abundance/biomass series for shrimp.

2. There is no biological reason for the present management units, however, assessment for these units will continue until there is a basis for doing otherwise. It should be made clear to managers that there is no evidence of different stocks and the fishery in one management unit could impact another.

3. The meeting was unable to specify values for any limit or precautionary approach reference points based on biomass or mortality. Nevertheless, possible useful approaches to their development were identified. In particular, estimates of Z from length-based analysis should be pursued, even though it was not clear at the meeting what a limit reference point for Z might be.

4. Age two abundance and age four biomass will not be used in the performance report until an evaluation demonstrated their reliability.

5. There was no consensus on how to interpret change in size at sex change in shrimp populations and it was agreed to drop this index from the performance report.

6. The exploitation rate index will be based on the survey biomass point estimate and include errors bars reflecting the 95% confidence intervals and included in the performance report with a clear explanation of the change.

7. An estimate of Z will be included in the performance report.

8. Environmental and ecological indicators will continue to be monitored and reported in the SAR context but not included in the performance report. It should be emphasized in the context section that for this stock, change in abundance is largely driven by environmental and ecological factors rather than the fishery.

9. It was agreed that the following indices/indicators will be included in the performance report and organized into categories as follows:

    a. Production
        i. Survey fishable biomass
        ii. Survey female biomass
        iii. Large vessel CPUE
        iv. Small vessel CPUE
    b. Recruitment
        i. Recruitment index (11.0 – 16.5 mm C.L. males)
    c. Fishery
        i. Exploitation rate index

ii. Z
iii. Industry Perspective

d. Stock Status
   i. Current Outlook
   ii. Future Prospects

Research Recommendations from 2006 RAP

SFA 6

1. Figure 10. As the size of shrimp has declined, there was an incentive for more search time to find more shrimp and that would have affected the CPUE. The ability of vessels to find aggregations and fish may result in CPUE not being an indicator of abundance. If the numbers of good aggregations are decreasing search time may increase thus affecting CPUE. An index of search time that is independent of fishing time should be determined. This should be added as a research recommendation. It is something to be considered for in the future. There are fewer great aggregations. Caution must be noted with regards to eliminating all the poor tows (small shrimp or low catch). Is there a way to tease search time out of the logbook information?

2. The survey has a fixed number of cells, but what Fig. 11 is measuring is the concentration of shrimp with in the cells. Figure 11 is a way to interpret the CPUE. It is a descriptor for the catch rate. The recommendation is to find away to combine figure 11 and CPUE. i.e. accounting for spatial changes in the fishery when computing CPUE.

3. Pertaining to Table 11, Figure 24: Are we clear regarding the point at which it would turn yellow. Negative. We do not have that answer. i.e. the point at which we will be in the danger zone. An F limit reference point needs to be determined (B. Chapman/G. Evans). This may be a task for the northern shrimp working group. Are these the proper indices? To identify limit reference points is the research recommendation. If the ecosystem approach is the way the Dept. is going than we also have to be aware of shrimp as a prey species. This is to be taken as an illustration as it is a work it progress. Identifying limit reference points will take time and they will not be ready for the 2007 assessment.

4. The approach of trying to summarize all the indices is good. If summarizing as a traffic light lets have a workshop to look at the weightings. A review of the application of the traffic light approach to shrimp is required before we present it at a RAP again. This may be handled by the framework approach. The recommendation is that this stock have a framework meeting in the very near future. Perhaps, this should be one of the first stocks to undergo a framework approach.

SFA 4

1. A comparison of multi-species RV surveys in 2G (about 60 sets) in the late 1990s to review what the distribution and abundance indices are like (B. Brodie). These surveys go up to 1999. For the July-August 2005 RV survey (Tables 21 and 22) there were 79 sets in 2G. To what extent should we be guided by commercial observations that suggest that there is no shrimp in these areas? The caution here is that commercially areas with small shrimp are avoided. A subdivision of some of the larger strata may wish to be considered to optimize the design. The recommendation is for a stratification and allocation scheme.

Research Recommendations from this meeting

1. Evaluate the time series of standardized and unstandardized CPUEs for SFA 5 to explain the inconsistencies in differences between the two, and determine whether it may be possible to model the data without leaving gaps in the time series.

2. Undertake to improve upon the use of modal analysis to separate age groups for tracking cohorts and estimating mortality. This should include simulation testing.

3. Explore a better method of aging and validate reliability of age 2 as an early indicator of year-class strength.

4. Validate a recruitment index based on the 11.5 to 16.0 mm size group for the next assessment.

5. Undertake an evaluation of the standardization process to ensure the CPUE series reflect stock size.

6. Investigate the estimation of Z using length-based methodologies and other approaches.

Appendix I: Terms of Reference

Assessment Framework for Northern Shrimp (*Pandalus borealis*)
off Labrador and the northeastern coast of Newfoundland

The Fluvarium
Nagle's Place
St. John's, Newfoundland and Labrador
28-30 May 2007

Meeting Chairperson: Dr. Noel Cadigan, Research Scientist, Groundfish Section, Aquatic Resources Division, Science Branch, DFO, NL Region.

TERMS OF REFERENCE

Background

Northern shrimp have been harvested off Labrador since the late 1970's and off the northeastern coast of Newfoundland since the late 1980's. Stock harvest advice is provided through the Regional Advisory Process (RAP). The most recent stock assessment was summarized in a series of Traffic Light Performance Indicator Reports. The Traffic Light approach was introduced by Caddy (1996) and adapted for shrimp by Koeller *et al.* (2000). However, critics felt that a weighting scheme for assessment indices and the determination of overall stock status required further development. Therefore, this meeting is being convened to review indices used in the current assessment, develop a weighting scheme for each, and determine objective means of evaluating overall stock status.

Objectives

The following objectives will guide meeting activities:

- *Review the current indices used in the assessment of shrimp off Labrador and the northeastern coast of Newfoundland.*

This review is expected to improve variables, possibly eliminating some while adding others, thereby enhancing application of the Traffic Light approach.

- *Explore means of weighting each variable used in the performance report.*

Not all variables have equal importance. For instance, trends in long term fishery independent biomass and recruitment indices are critical to overall status and could merit a higher score relative to trends in fishery dependent indices which are less reliable as stock indicators.

- *Develop an objective means of determining an overall stock status "score".*

The goal is to maximize objectivity in the assessment process; therefore, the meeting must strive to determine an objective scoring of overall stock status that can easily be interpreted for fishery management.

Additionally, the performance report must provide:

- A short term prediction of trends in future stock size; and

- A precautionary approach to northern shrimp management, with clear limit reference points.

Products

- CSAS Proceedings summarizing meeting discussions.
- CSAS Science Advisory Report outlining the agreed Traffic Light framework for assessment of Northern Shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland
- CSAS Research Documents

Participation

- DFO Science, Newfoundland and Labrador and other Regions
- DFO Fisheries and Aquaculture Management, Newfoundland and Labrador Region
- Industry
- Fish, Food and Allied Workers Union
- External Reviewers
- Provincial Department of Fisheries and Aquaculture

References

Caddy, J.F. 1996. A checklist for fisheries resource management issues seen from the perspective of the FAO Code of Conduct for Responsible Fisheries. FAO Fish. Circ., 917, 22p.

Koeller, P., L. Savard, D.G. Parsons and C. Fu. 2000. A precautionary approach to assessment and management of shrimp stocks in the Northwest Atlantic. J. Northw. Atl. Fish. Sci. Vol. 27: 235-246.

Appendix II: List of Participants

Assessment Framework for Northern Shrimp **28 – 30 May 2007** **Fluvarium, St. John's, NL**

Name	Affiliation	Mailing Address	E-mail	Phone/Fax
Bridger, Guy	FFAW/CAW			
Caddy, John	Consultant for DFO			
Cadigan, Noel	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	cadiganN@dfo-mpo.gc.ca	(709) 772-5028
Chidley, Gerard	G & D Fisheries			
Collins, Roanne	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	collinsR@dfo-mpo.gc.ca	(709) 772-5948
Dawe, Earl	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	daweE@dfo-mpo.gc.ca	(709) 772-2076
Dooley, Tom	Dept. Fisheries & Aquaculture, Province NL	PO Box 8700 St. John's NL A1B 4J6	tdooley@gov.nl.ca	(709) 729-0335
Ellis, Rick	Ocean Choice International	1315 Topsail Road PO Box 8274 Stn. A St. John's, NL A1B 3N4	rellis@oceanchoice.com	(709) 782-6244 (ph.) (709) 368-2260 (fax)
Ennis, Jerry	Rapporteur			
Glynn, Sherry	FFAW/CAW	PO Box 10 St. John's, NL A1C 5H5	sglynn@ffaw.nfld.net	(709) 576-7276 (ph.) (709) 576-1521 (fax)
Lilly, George	DFO Scientist emeritus	PO Box 5667 St. John's, NL A1C 5X1	lillyg@dfo-mpo.gc.ca	(709) 772-0568
Orr, Dave	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	orrd@dfo-mpo.gc.ca	(709) 772-7343

Name	Affiliation	Mailing Address	E-mail	Phone/Fax
Parsons, Don	DFO Scientist emeritus	PO Box 5667 St. John's, NL A1C 5X1		
Rashotte, Barry	DFO FAM	200 Kent St. Ottawa, ON	rashottb@dfo-mpo.gc.ca	(613) 990-0087
Shelton, Peter	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	sheltonp@dfo-mpo.gc.ca	(709) 772-2341
Sheppard, Bev	Harbour Grace Shrimp Co.	PO Box 580 Harbour Grace, NL A0A 2M0	bsheppard@hgsc.ca	(709) 596-8000 (ph.) (709) 596-8002 (fax)
Siferd, Tim	DFO Science	Central and Arctic Region FWI	siferdtd@dfo-mpo.gc.ca	(204) 984-4509
Skanes, Katherine	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	skanesk@dfo-mpo.gc.ca	(709) 772-8437
Stansbury, Don	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	stansburyd@dfo-mpo.gc.ca	(709) 772-0559
Sullivan, Darrin	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	sullivanda@dfo-mpo.gc.ca	(709) 772-4622
Wareham, Vonda	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	warehamv@dfo-mpo.gc.ca	(709) 772-2804
Wells, Nadine	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	wellsn@dfo-mpo.gc.ca	(709) 772-8892
Wheeler, John	DFO Science	PO Box 5667 St. John's, NL A1C 5X1	wheelerj@dfo-mpo.gc.ca	(709) 772-2005

Appendix III: List of Presentations

1. An assessment framework for northern shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland by Dave Orr

2. Northern Shrimp (*Pandalus borealis*) within Hawke Channel + 3K (SFA 6) and Hopedale+ Cartwright Channels by Dave Orr

3. Using multiple fishery indicators in a traffic light plot by John Caddy

4. Towards a traffic light approach for Northern Shrimp that takes into account ecological interactions and environmental change by John Caddy and Dave Orr

5. Hopedale + Cartwright Channels (SFA 5) northern shrimp (*Pandalus borealis*): a case study illustrating the traffic light assessment framework by Dave Orr

Appendix IV: Tables and Figures

Table1. Pearson correlation output from cluster analysis used to predict northern shrimp landings within SFA 6, 1988 – 2006. The highest absolute correlations are indicated with bold values. These parameters were selected for inclusion in the Traffic Light performance report.

Predictor variables	Lag (years)	Shrimp Catch
Harp seal abundance	0	**0.939**
Bottom temperature within SFA 6	6	**0.750**
Bottom salinity within SFA 6	6	**0.730**
SFA 6 area with water =>1^{o}C	6	**0.502**
SFA 6 area with water 2-3^{o}C	6	0.155
Stn 27 stratification index for Apr-Jun	6	-0.016
Greenland halibut research CPUE	2	-0.129
Redfish abundance index	2	-0.261
Cold Intermediate Layer index	6	-0.412
Area ice cover Apr-Jun	6	-0.418
SFA 6 area with water 0-1^{o}C	6	-0.426
Predator index	2	**-0.459**
Cod research CPUE	2	**-0.646**
Plaice biomass	2	**-0.676**

Table 2. A series of natural (M) and total instantaneous mortality (Z) values for northern shrimp, as found in the literature.

Z	M	Location	Age	Author		Comment
	0.25			Rinaldo (1976)		
0.6-1.4		Gulf of St. Lawrence		Frechette (1981)		
0.65		Alaska	3-4 years	Anderson (1978)		
0.66		Alaska	5-6 years	Anderson (1978)		
1.26		Alaska	6-7 years	Anderson (1978)		
.54-1.03	0.24 - 0.8	Gulf of St. Lawrence	3-4 years	Frechette and Labonte (1981)		
0.67	0.39	Gulf of St. Lawrence	2-3 years	Frechette and Labonte (1981)		
	0.2 - 0.3	Iceland		Skulladottir (1979)		
	0.5 - 1.0			ICES (1977)		
0.54 - 3.81		Alaska		Anderson (1991)	Pacific cod predation	
0.5-0.8		Gulf of St. Lawrence		Frechette and Parsons (1983)		
1.89-2.12		Norway		Hopkins and Nilsen (1990)		
1.46 - 6.21		Norway		Bergstrom (1997)		

Table 3: The long term environmental dataset collected as variables with potential usage in a northern shrimp assessment framework.

Index	**Years covered**	**Duration**
North Atlantic Oscillation (NAO) index on Jan. 15	1950 – 2006	57 years
Anomaly of the NAO index as measured in Iceland during February	1950 – 2006	57 years
Five year running average of the NAO index on Jan 15	1950 - 2005	56 years
Station 27 stratification index anomaly	1950 - 2005	56 years
Five year running average of the Stn 27 stratification index anomaly	1952 – 2003	52 years
Apr – June Stn 27 stratification index anomaly	1950 – 2006	57 years
Five year running average of the Apr – June Stn 27 stratification index anomaly	1952 – 2004	53 years
May Stn 27 stratification index anomaly	1984 – 2005	22 years
Five year running average of the May Stn 27 stratification index anomaly	1986 – 2003	18 years
Area occupied by ice (south of 55^{o}N) during Jan – Mar.	1969 – 2006	37 years
Area occupied by ice (south of 55^{o}N) during Apr – June	1969 – 2006	37 years
Bonavista Bay Cold Intermediate Layer (CIL) index	1950 – 2006	57 years
Bonavista Bay CIL anomaly	1950 – 2006	57 years
Flemish Cap CIL index	1951 – 2006	56 years
Flemish Cap CIL anomaly	1951 – 2006	56 years
White Bay CIL index	1977 – 2006	30 years
White Bay CIL anomaly	1977 – 2006	30 years
Seal Island CIL index	1950 - 2006	57 years
Seal Island CIL anomaly	1950 – 2006	57 years
NAFO div. 3L autumn area weighted bottom temperatures	1966 - 2006	41 years
NAFO div. 3L autumn area weighted bottom salinities	1966 – 2006	41 years
NAFO div. 3L spring area weighted bottom temperatures	1965 – 2006	42 years
NAFO div. 3L spring area weighted bottom salinities	1965 – 2006	42 years
Cartwright Channel autumn area weighted bottom temperatures	1965 – 2006	42 years
Cartwright Channel autumn area weighted bottom salinities	1965 – 2006	42 years
SFA 6 spring area weighted bottom temperatures	1965 – 2006	42 years
SFA 6 spring area weighted bottom salinities	1965 – 2006	42 years
Predator index (combination redfish, Greenland halibut, Atlantic cod, American plaice research catch indices normalized to the mean of each index)	1983 – 2004	22 years
Harp seal abundance index	1978 – 2006	29 years
Atlantic cod research CPUE (kg/tow)	1983 – 2005	23 years
Greenland halibut (30 – 70 cm tl) research CPUE (kg/tow)	1978 – 2005	28 years
Redfish biomass estimate (t)	1978 – 2006	29 years
Cartwright Channel area occupied by <0^{o}C water	1977 – 2006	30 years
Cartwright Channel area occupied by 0-1^{o}C water	1977 – 2006	30 years
Cartwright Channel area occupied by 1-2^{o}C water	1977 – 2006	30 years
Cartwright Channel area occupied by 2-3^{o}C water	1977 – 2006	30 years
Cartwright Channel area occupied by >3^{o}C water	1977 – 2006	30 years
Cartwright Channel area occupied by >1^{o}C water	1977 – 2006	30 years
SFA 6 area occupied by <0^{o}C water	1977 – 2006	30 years
SFA 6 area occupied by 0-1^{o}C water	1977 – 2006	30 years
SFA 6 area occupied by 1-2^{o}C water	1977 – 2006	30 years
SFA 6 area occupied by 2-3^{o}C water	1977 – 2006	30 years
SFA 6 area occupied by >3^{o}C water	1977 – 2006	30 years
SFA 6 area occupied by >1^{o}C water	1977 – 2006	30 years

Table 4: The short term environmental dataset collected as variables with potential usage in a northern shrimp assessment framework.

Index	Years covered	Duration
SFA 4 summer NO_3 at 0 – 50 m depths	1999 – 2003	5 years
SFA 4 summer NO_3 at > 50 m depth	1999 – 2003	5 years
SFA 4 summer chlorophyll$_a$ at surface	1999 – 2003	5 years
SFA 5 summer NO_3 at 0 – 50 m depths	1994 – 2006 (1995 missing)	12 years
SFA 5 summer NO_3 at > 50 m depth	1994 – 2006 (1995 missing)	12 years
SFA 5 summer chlorophyll$_a$ at surface	1994 – 2006 (1995 missing)	12 years
SFA 6 autumn NO_3 at 0 – 50 m depths	1993 – 2006 (1994 – 1998 missing)	9 years
SFA 6 autumn NO_3 at > 50 m depth	1993 – 2006 (1994 – 1998 missing)	9 years
SFA 6 autumn chlorophyll$_a$ at surface	1993 – 2006 (1994 – 1998 missing)	9 years
SFA 6 spring NO_3 at 0 – 50 m depths	1994 – 2006 (1995 missing)	12 years
SFA 6 spring NO_3 at > 50 m depth	1994 – 2006 (1995 missing)	12 years
SFA 6 spring chlorophyll$_a$ at surface	1994 – 2006 (1995 missing)	12 years
SFA 7 spring NO_3 at 0 – 50 m depths	1994 – 2006	13 years
SFA 7 spring NO_3 at > 50 m depth	1994 – 2006	13 years
SFA 7 spring chlorophyll$_a$ at surface	1994 – 2006	13 years
SFA 7 winter NO_3 at 0 – 50 m depths	1995 – 2006 (1996 – 1999 missing)	8 years
SFA 7 winter NO_3 at > 50 m depth	1995 – 2006 (1996 – 1999 missing)	8 years
SFA 7 winter chlorophyll$_a$ at surface	1995 – 2006 (1996 – 1999 missing)	8 years
Satellite remotely sensed spring bloom initiation time	1998 – 2005	8 years
SFA 6 Satellite remotely sensed spring bloom intensity	1998 – 2005	8 years
SFA 6 Satellite remotely sensed spring bloom timing	1998 – 2005	8 years
SFA 6 Satellite remotely sensed spring bloom duration	1998 – 2005	8 years
Continuous Plankton Recorder (CPR) decapoda counts 3LNO tracks Mar. – July	1991 – 2005	15 years
CPR decapoda counts 3LNO tracks Mar. – July	1991 – 2005	15 years
CPR euphausiacea counts 3LNO tracks Mar. – July	1991 – 2005	15 years
CPR copepoda counts 3LNO tracks Mar. – July	1991 – 2005	15 years
CPR nauplii counts 3LNO tracks Mar. – July	1991 – 2005	15 years
CPR diatoms counts 3LNO tracks Mar. – July		
CPR hyperiidae counts 3LNO tracks Mar. – July		

Newfoundland Region SSR – 2005 spreadsheet Northern Shrimp in Hawke Channel + 3K (SFA 6)

Index	Observation	Interpretation	Weight	Evaluation
Survey: Production				
Abundance	Minimum trawlable abundance increased from 60 billion in 95 increased to 140 billion in 01; remained high since.	Reflects an increase in the resource up to 01 and then remaining at a high level .	1	
Biomass	Minimum trawlable biomass increased from 232,000 t in 95 increased to 601,000 t in 05	Reflects an increase in the resource.	1	
Survey: Recruitment to fishery				
Age 2 Abundance	Increased from 15 billion in 98 to 40 billion in 01; remained ~ 30 billion over the period 02 – 04 dropped to 21 billion during 05	Good recruitment through 97 – 99 resulting in high 01-05 biomass/ abundance; anticipate 05 decrease will be reflected in short term decrease in age 4 biomass.	1	
Age 4 Biomass	Increased from 99,000 t in 95 to 300,000 t in 01; remaining at a high level since.	Reflects an increase and then stabilization in resource; anticipate a short term decrease due to 03 yr class which is weak compared to 97 – 02 yr classes	1	
Spawning Stock Biomass	The female stock index increased from an estimated 181,000 tons (22 billion animals) in 97 to 404,000 tons (55 billion) in 05. Presently broad size range of females.	Reflects a healthy resource.	1	
Fishery				
Fishery	Catches increased from 11,000 t in 94 – 96 to over 70,000 t by 04. With few exceptions, TACs were taken each year. Spatial distribution of the fishery expanded since the mid 90's. Mandatory use of sorting grates reduces groundfish bycatch. As well Hawke Channel and Funk Island Deep closed areas were established to protect snow crab.			
Large vessel CPUE	Increased from 1,000 kg/hr in 94 to 1,300 kg/hr in 95; has since been fluctuating without trend between 1,400 kg/hr and 1,800 kg/hr, presently within 95% cl; fishery has expanded spatially and temporally	Reflects a healthy resource	.25	
Small vessel CPUE	Fluctuating without trend between 330 kg/hr and 380 kg/hr until 03; since then increased to 470 kg/hr in 04 and 500 kg/hr in 05, presently above 95% cl; fishery expanding spatially	Reflects a healthy resource	.25	
Size at sex change	Decreased from 22.0 mm CL in 93 to 19.8 mm CL in 04; increased to 20.4 mm CL	Reduced size at maturity may imply increased mortality and reduced fecundity; however, high biomass should offset reduced individual fecundity.	.5	
Exploitation rate index	Ratios of nominal catch to survey biomass index (lower confidence intervals) remained between 10 – 14% since 98	Catchability of the survey gear is believed to be less than 1. Therefore, exploitation rate likely has been low.	.5	
Industry Perspective				

Current Prospects: Score = 3.25 remains positive from analyses of research survey and fishery data with current high biomass and abundance; resource covers a broad area

Future Prospects: During next 2 years may be a decrease in age 4 biomass as a result of the weak 03 year class. However, strong residual female biomass is expected to maintain fishery. 04 year class appears very strong as one year old shrimp.
Since 1995 temperatures have increased and this could impact growth, survival and sex change.

Figure 1: The traffic light performance report for the 2006 regional assessment of the status of shrimp within SFA 6.

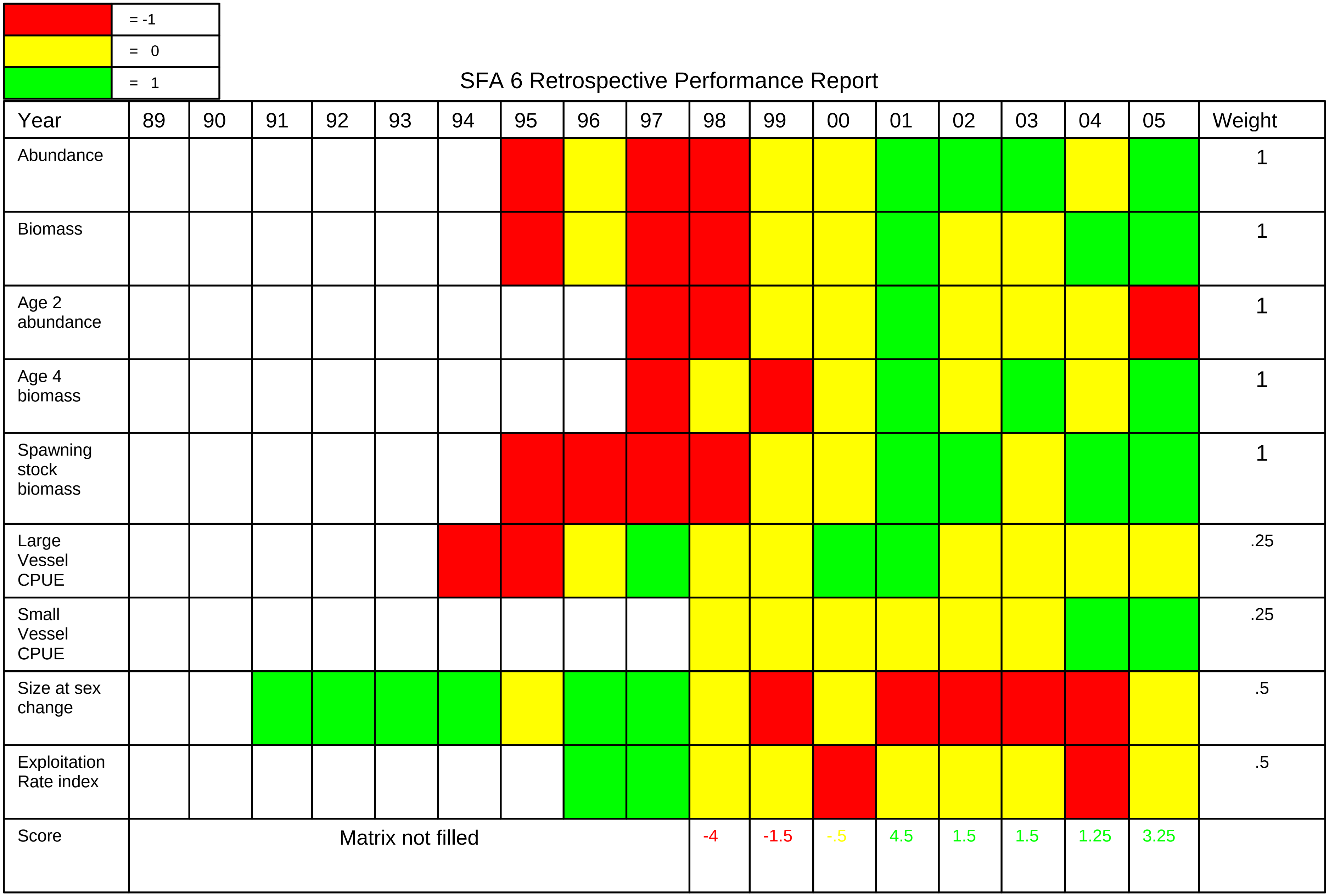


Figure 2: A retrospective performance report for SFA 6 shrimp.

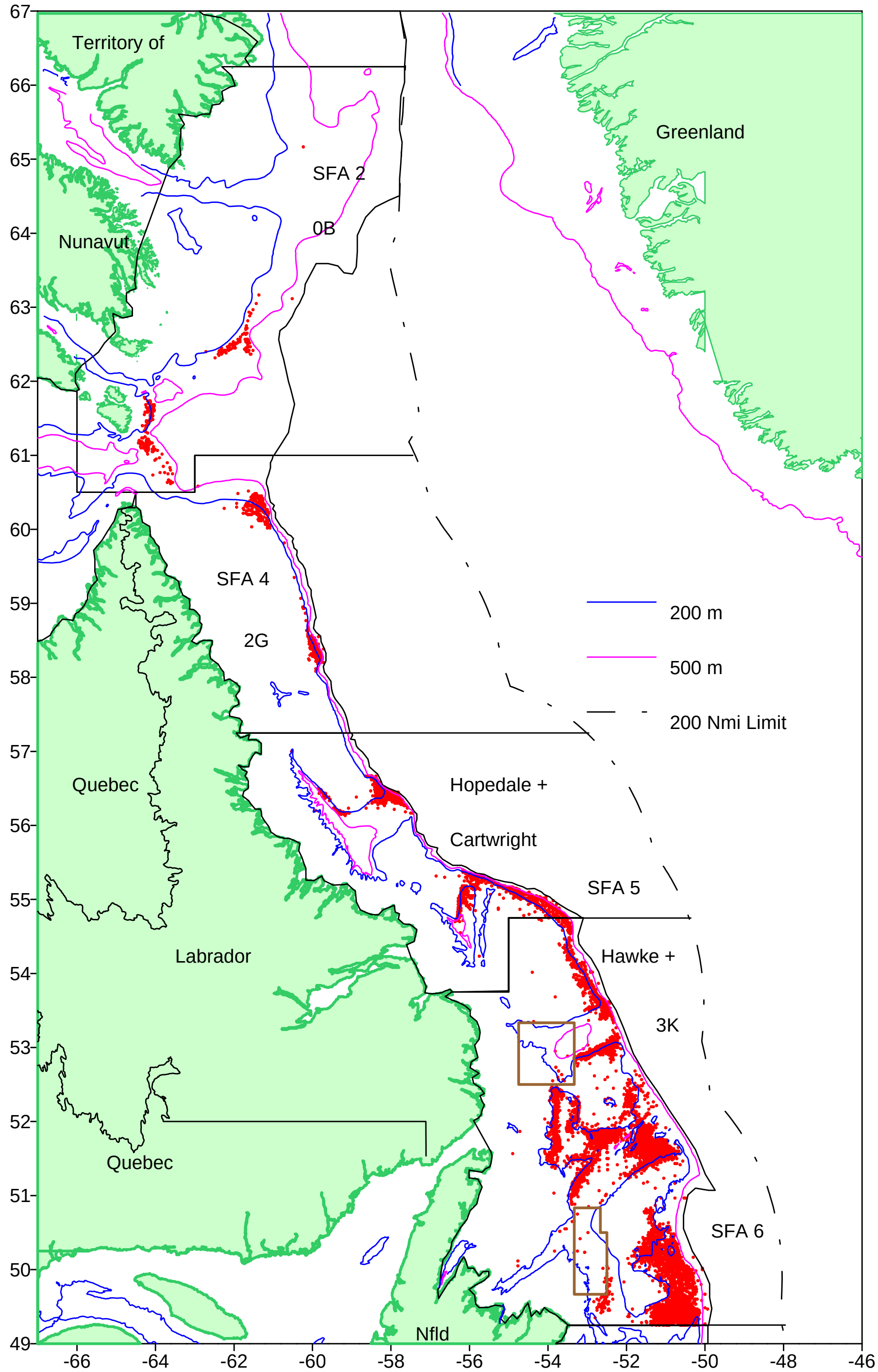


Figure 3. Locations of the Shrimp Fishing Areas (SFA's) with an overlay of 2005 shrimp fishing positions.

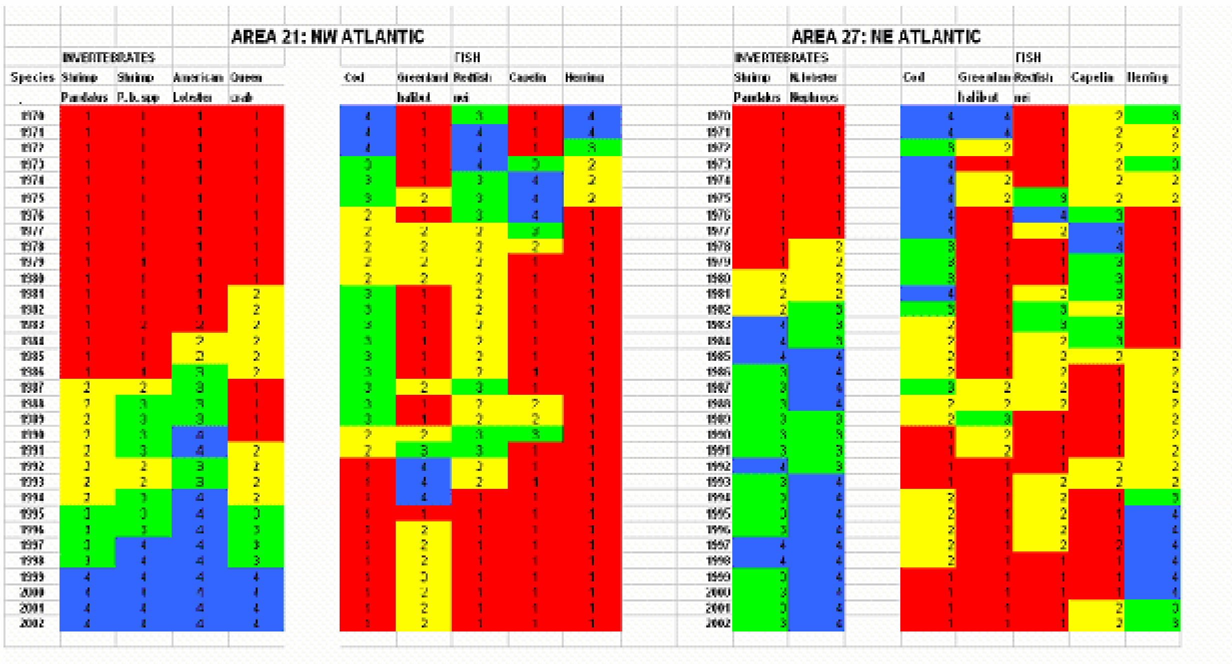


Figure 4: Traffic light plots for landing trends in NW and NE Atlantic – Invertebrates versus finfish (FAO data).

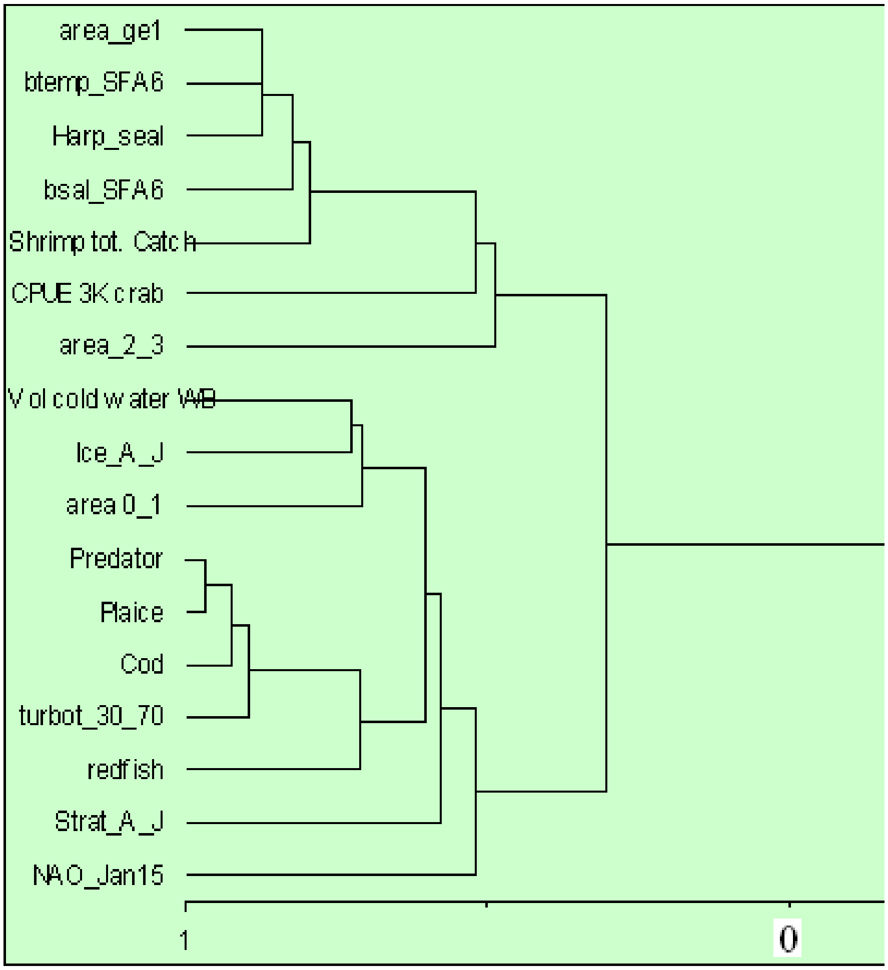


Figure 5 Example of cluster analysis used to identify linkages between the total SFA 6 shrimp landings and various environmental parameters. The environmental variables were first identified through multiple regression analysis prior to cluster analysis. Cluster analysis was completed using StatistiXL 1.7 (Roberts and Withers, 2007) using the nearest neighbour method with Pearson correlations as the distance/similarity measure.

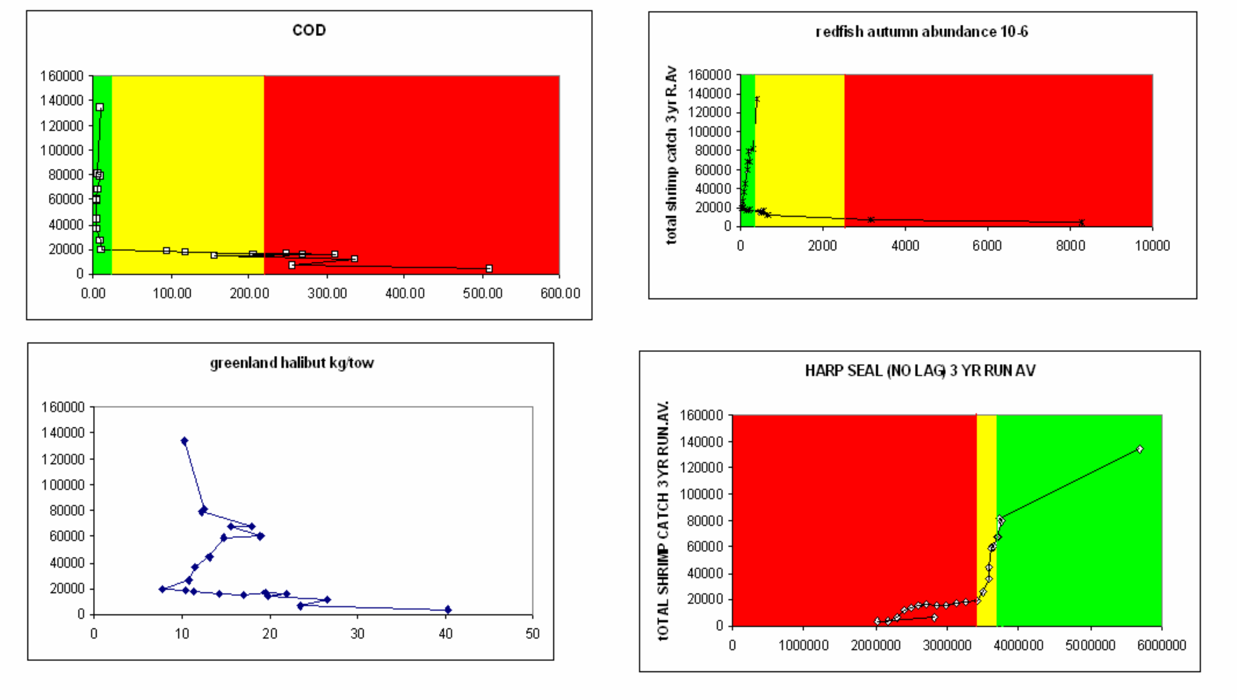
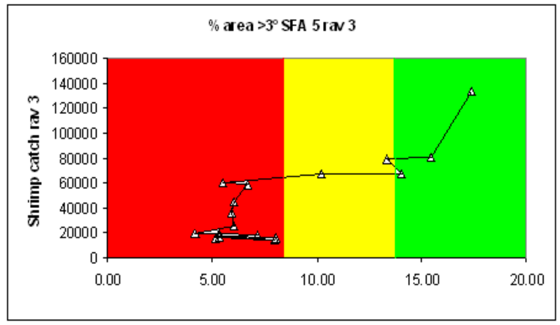
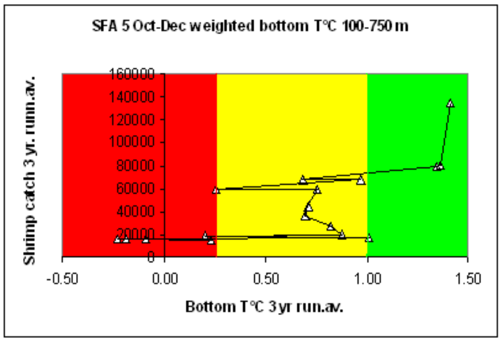


Figure 6. Plots of SFA 6 shrimp landings versus finfish (predator) and harp seal research survey indices. Dependent and independent values were smoothed using a three year running average. Inflexion points were used to objectively identify major shifts in landings. These inflexion points were therefore used as boundaries between green (positive), yellow (intermediate) and red (concern) areas. Please note that the plot using Greenland halibut research cpue cycled back upon itself meaning that at least two values for the predator corresponded to the same shrimp catch and hence Greenland halibut research cpue could not be used as a reliable variable in further analysis.

Running averages of shrimp catch all areas against selected temperature data series





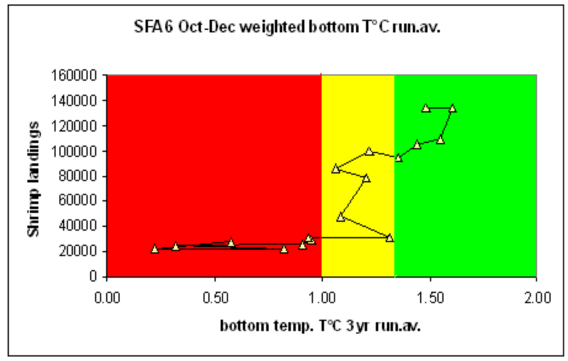


Figure 7. Plots of SFA 6 shrimp landings versus abiotic indices. Dependent and independent values were smoothed using a three year running average. Inflexion points were used to objectively identify major shifts in landings.

	Age 0	Age 1	Age 2	Age 3	Age 4	Year sampled
1991					5,152	1995
1992				8,165	17,706	1996
1993			31,726	34,707	18,377	1997
1994		7,463	35,239	32,248	32,166	1998
1995	2	3,414	20,300	25,396	22,250	1999
1996	88	2,405	10,195	19,937	18,969	2000
1997	45	9,759	37,261	34,801	35,896	2001
1998	8	10,298	35,164	33,243	21,454	2002
1999	1	8,295	36,487	43,072	31,314	2003
2000	0	3,171	21,900	25,587	17,650	2004
2001	12	7,937	31,128	30,320	18,057	2005
2002	9	10,760	37,543	40,105		
2003	72	4,130	21,266			
2004	41	15,906				
2005	37					

Figure 8. SFA 6 abundance at age data (1995-2005) illustrating that periods of strong year classes appear as yellow and green horizontal bands (1997 – 1999) while period of weak year classes appear as red bands (1995 and 1996). In this case, the boundaries were established by ranking abundance at age from lowest to highest and dividing the data into thirds..

- Bottom temp SFA6 (raw data) – first row
- Bottom temp SFA6 (3 year run av.) – second row
- Bottom salinity SFA6 (raw data) – third row
- Bottom salinity SFA6 (3 year run. av.) – fourth row

(The bottom row is total shrimp catch (3 year run. av.).

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
btemp_SFA6					0.58	0.78	0.10	1.68	0.87	1.05	1.98	1.78	1.96	1.48
Btemp Run. Av (3 yr)					0.58	0.49	0.85	0.88	1.20	1.30	1.60	1.91	1.74	1.70
bsal_SFA6					33.74	33.85	33.66	33.93	33.94	33.59	34.21	34.07	34.23	34.19
Bsal Run. Av (3 yr)					33.74	33.75	33.82	33.85	33.82	33.91	33.96	34.17	34.16	34.21
Shrimp tota	1350.00	2050.00	3000.00	3000.00	5600.00	5600.00	4301.00	7565.00	9180.00	11050.00	11050.00	11050.00	23100.00	46200.00

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
btemp_SFA6	1.66	1.71	2.00	2.37	2.33	2.28	2.48	2.18	2.53	1.98	2.81	2.89	2.77	2.09
Btemp Run. Av (3 yr)	1.62	1.79	2.03	2.23	2.33	2.36	2.31	2.40	2.23	2.44	2.56	2.82	2.58	2.09
bsal_SFA6	34.23	34.17	34.18	34.19	34.23	34.24	34.18	34.24	34.22	33.89	34.17	34.30	34.26	34.16
Bsal Run. Av (3 yr)	34.19	34.19	34.18	34.20	34.22	34.22	34.22	34.21	34.12	34.09	34.12	34.25	34.24	34.16
Shrimp tota	58632.00	61632.00	61632.00	61632.00	85585.00	77932.00	78044.00	77417.00						

Figure 9. A traffic light performance report using environmental parameters to predict future shrimp landings in SFA

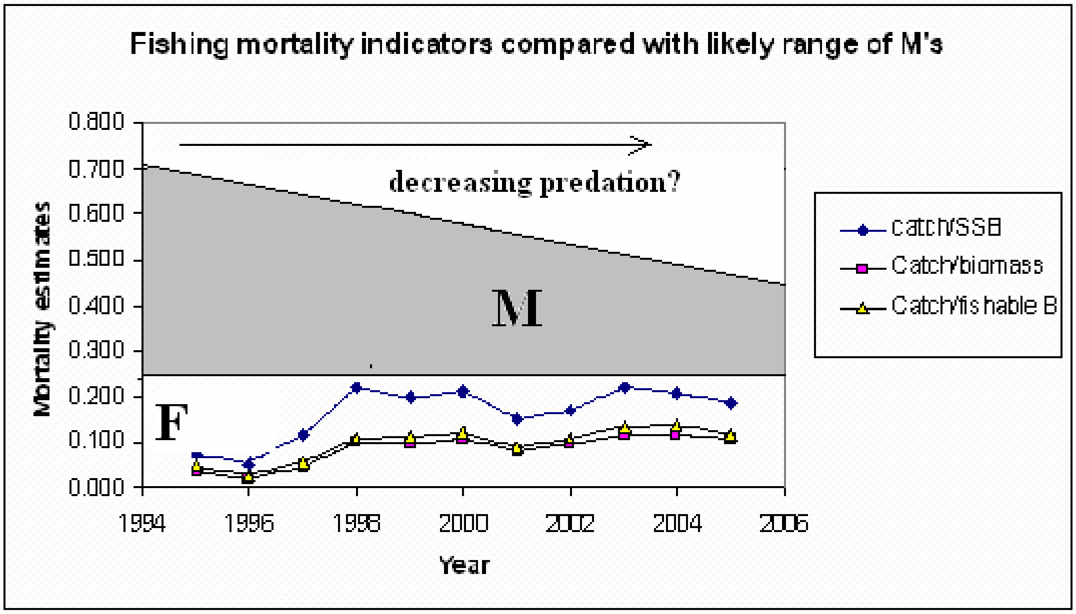


Figure 10. Changes in natural mortality (M) for SFA 6 shrimp hypothesized as predation pressure decreases over time.

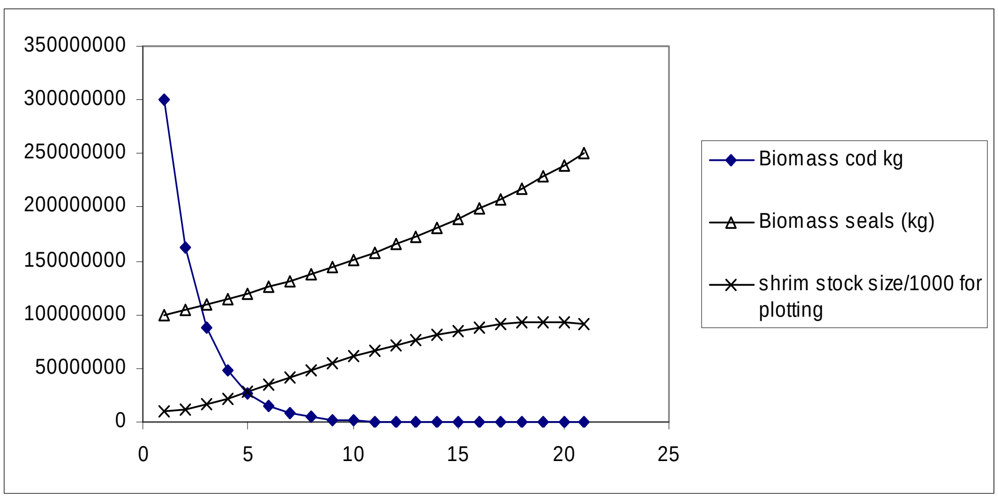


Figure 11. Simulated changes in SFA 6 shrimp stock size as cod and seal biomass changed over time.

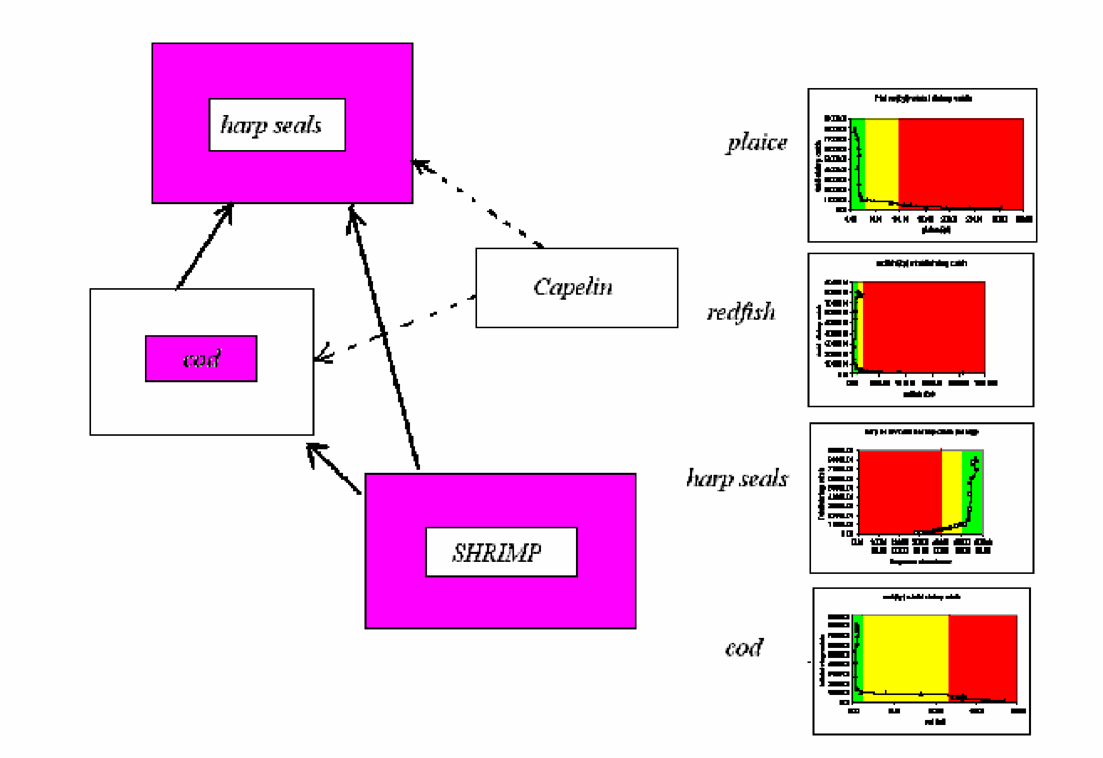


Figure 12. A conceptual model illustrating the increase of SFA 6 shrimp and seal biomass with the decline in cod stocks (left), and smoothed plots of predator abundance against shrimp biomass values (right).

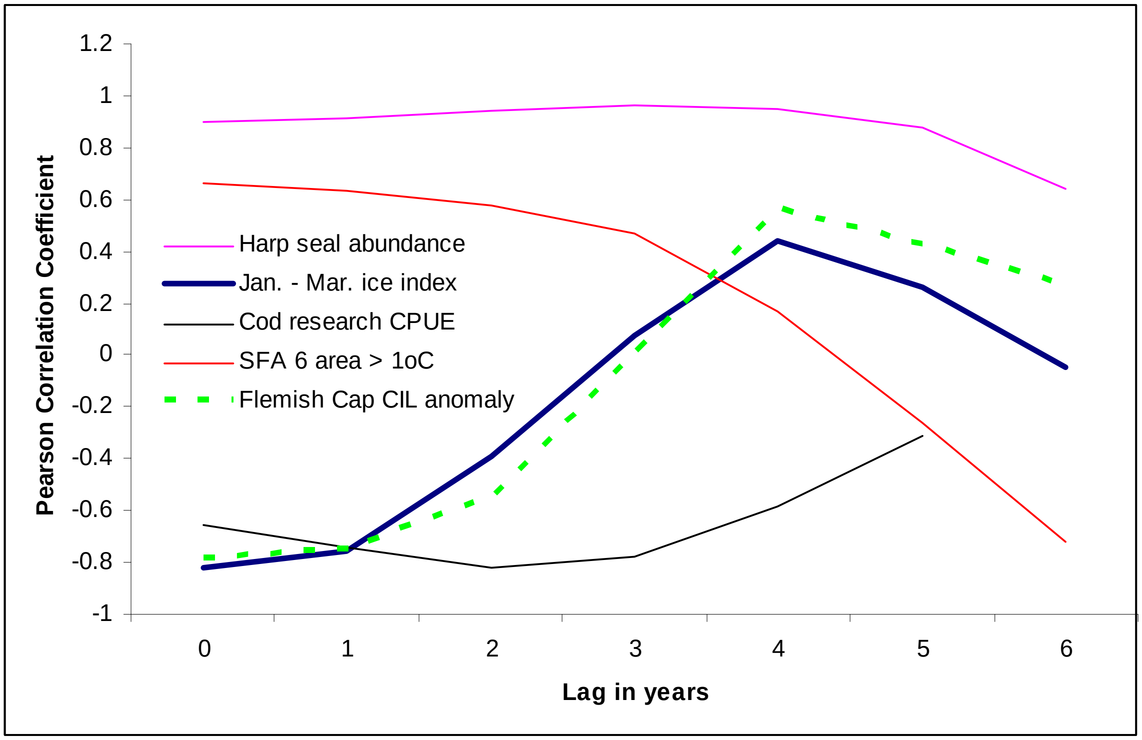
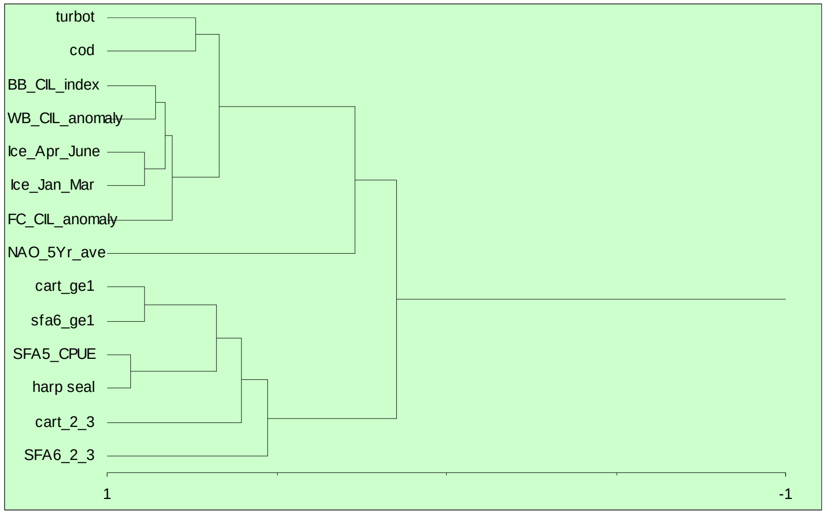


Figure 13: Pearson Correlation coefficients for environmental parameters used to describe SFA 5 commercial shrimp catch rates. The maximum absolute coefficient for each parameter provided the appropriate lag.



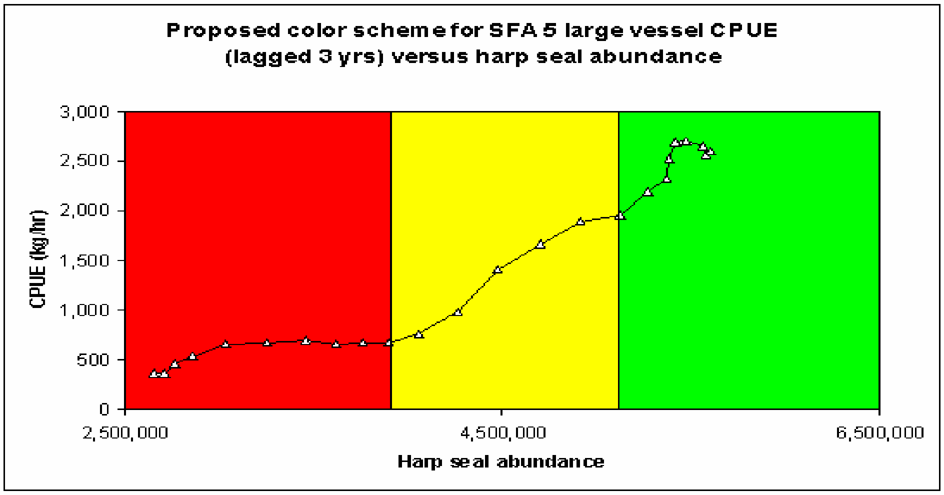
r coefficients from Pearson correlation approach to cluster analysis (21 year time series compared)

other variables	Lag	**Large vessel CPUE**
Harp seal abundance	3	**0.930**
SFA 6 % area ge 1°C	0	**0.660**
Cartwright Channel % area ge 1°C	0	**0.613**
Cartwright Channel % area 2-3°C	0	**0.427**
SFA 6 % area 2-3°C	4	0.313
NAO 5 yr. average	3	-0.010
Bonavista Bay CIL index	0	**-0.645**
Greenland halibut research CPUE	4	**-0.646**
Apr. - Jun. ice index	0	**-0.665**
White Bay CIL anomaly	0	**-0.704**
Flemish Cap CIL anomaly	0	**-0.766**
Cod research CPUE	2	**-0.789**
Jan. - Mar. ice index	0	**-0.802**

Variables used in the performance report:

Harp seal abundance	3 yr. lag
Jan. – Mar. ice index	0 yr. lag
Cod research CPUE	2 yr. lag
SFA 6 % area ge 1°C	0 yr. lag
Flemish Cap CIL anomaly	0 yr. lag

Figure 14: Cluster analysis of SFA 5 large vessel CPUE with environmental parameters chosen through stepwise linear regression and correlation analysis.



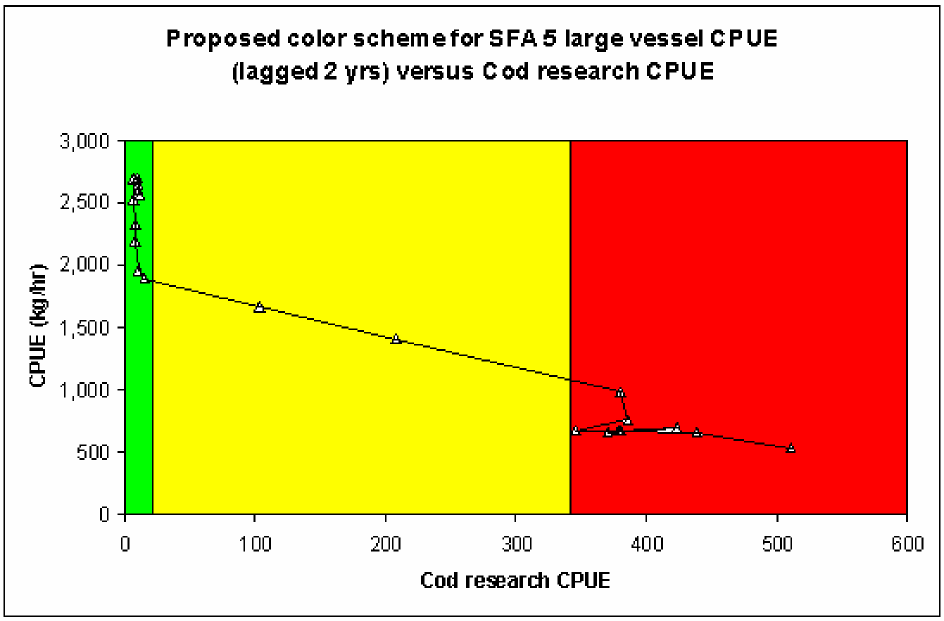
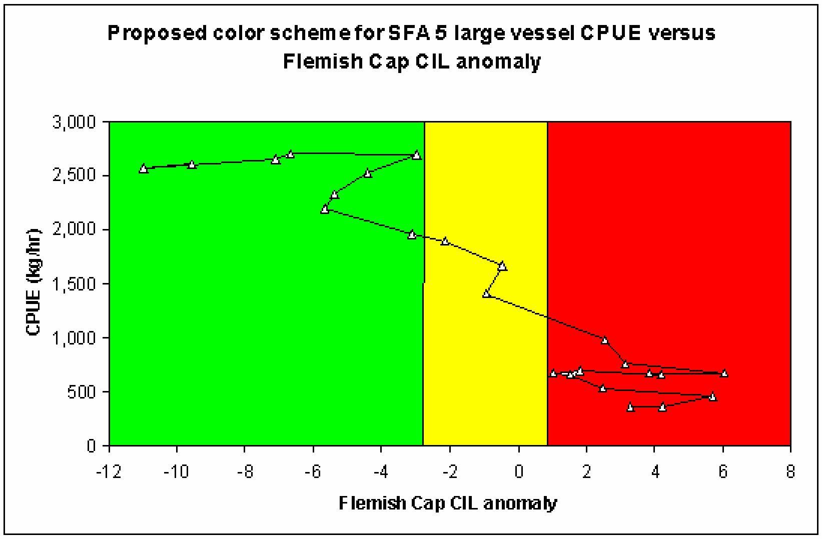


Figure 15: Usage of inflexion points to objectively determine good (green), intermediate (yellow) and concern (red) periods for various environmental parameters.



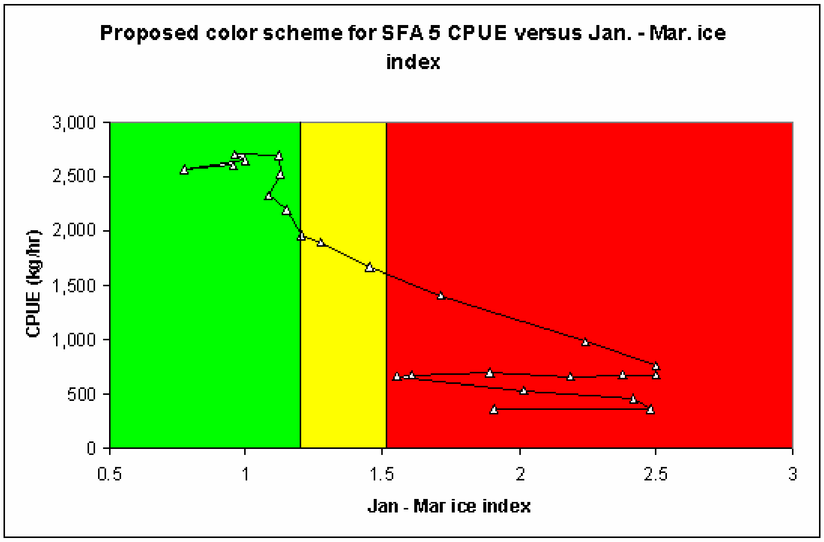


Figure 15. (Continued): Usage of inflexion points to objectively determine good (green), intermediate (yellow) and concern (red) periods for various environmental parameters.

Independent variables:

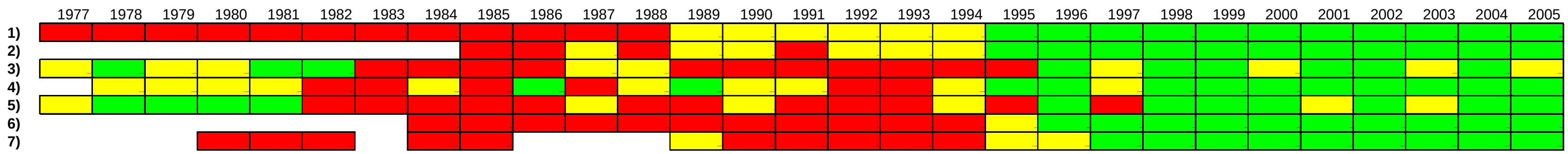
1) Harp seal abundance
2) Cod research CPUE (num/tow)
3) Jan. - Mar. ice index
4) SFA 6 % area ge 1^{o}C water
5) Flemish Cap CIL anomaly

Each independent variable receives a weight = 1

Dependent variables:

6) analysis SFA 5 large vessel shrimp CPUE (kg/hr) dataset
7) Model SFA 5 large vessel shrimp CPUE (kg/hr)

Non lagged



When CPUE is lagged 3 yrs against harp seal and 2 yrs against cod abundances, periods of low shrimp CPUE line up with periods of low Harp seal abundance, cooler water and higher 2J3K Atlantic cod abundance. This lag also provides a short term prediction.

Lagged

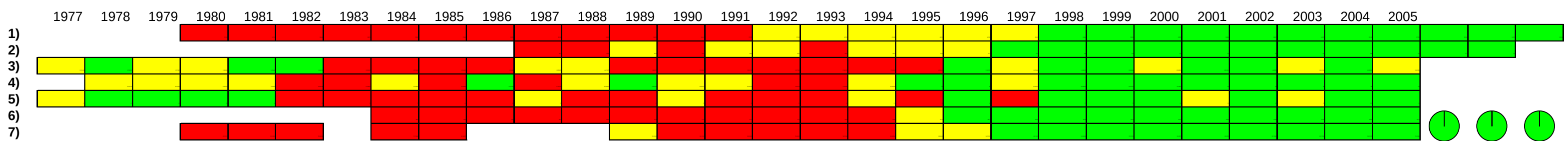


Figure 16: Comparison between lagged and non lagged SFA 5 large vessel CPUE performance reports. Once the appropriate lags are made, vertical bands of green, yellow and red become more obvious indicating periods of positive, intermediate and negative influence on shrimp production as well as allowing short term predictions.

Annex 1: Old Performance Report Spreadsheet

Newfoundland Region SSR – 2005 spreadsheet Northern Shrimp in Hawke Channel + 3K (SFA 6)

Index	Observation	Interpretation	Weight	Evaluation
Survey: Production				
Abundance	Minimum trawlable abundance increased from 60 billion in 95 increased to 140 billion in 01; remained high since.	Reflects an increase in the resource up to 01 and then remaining at a high level .	1	
Biomass	Minimum trawlable biomass increased from 232,000 t in 95 increased to 601,000 t in 05	Reflects an increase in the resource.	1	
Survey: Recruitment to fishery				
Age 2 Abundance	Increased from 15 billion in 98 to 40 billion in 01; remained ~ 30 billion over the period 02 – 04 dropped to 21 billion during 05	Good recruitment through 97 – 99 resulting in high 01-05 biomass/ abundance; anticipate 05 decrease will be reflected in short term decrease in age 4 biomass.	1	
Age 4 Biomass	Increased from 99,000 t in 95 to 300,000 t in 01; remaining at a high level since.	Reflects an increase and then stabilization in resource; anticipate a short term decrease due to 03 yr class which is weak compared to 97 – 02 yr classes	1	
Spawning Stock Biomass	The female stock index increased from an estimated 181,000 tons (22 billion animals) in 97 to 404,000 tons (55 billion) in 05. Presently broad size range of females.	Reflects a healthy resource.	1	
Fishery				
Fishery	Catches increased from 11,000 t in 94 – 96 to over 70,000 t by 04. With few exceptions, TACs were taken each year. Spatial distribution of the fishery expanded since the mid 90's. Mandatory use of sorting grates reduces groundfish bycatch. As well Hawke Channel and Funk Island Deep closed areas were established to protect snow crab.			
Large vessel CPUE	Increased from 1,000 kg/hr in 94 to 1,300 kg/hr in 95; has since been fluctuating without trend between 1,400 kg/hr and 1,800 kg/hr, presently within 95% cl; fishery has expanded spatially and temporally	Reflects a healthy resource	.25	
Small vessel CPUE	Fluctuating without trend between 330 kg/hr and 380 kg/hr until 03; since then increased to 470 kg/hr in 04 and 500 kg/hr in 05, presently above 95% cl; fishery expanding spatially	Reflects a healthy resource	.25	
Size at sex change	Decreased from 22.0 mm CL in 93 to 19.8 mm CL in 04; increased to 20.4 mm CL	Reduced size at maturity may imply increased mortality and reduced fecundity; however, high biomass should offset reduced individual fecundity.	.5	
Exploitation rate index	Ratios of nominal catch to survey biomass index (lower confidence intervals) remained between 10 – 14% since 98	Catchability of the survey gear is believed to be less than 1. Therefore, exploitation rate likely has been low.	.5	
Industry Perspective				

Current Prospects: Score = 4.25 remains positive from analyses of research survey and fishery data with current high biomass and abundance; resource covers a broad area

Future Prospects: During next 2 years may be a decrease in age 4 biomass as a result of the weak 03 year class. However, strong residual female biomass is expected to maintain fishery. 04 year class appears very strong as one year old shrimp.

Since 1995 temperatures have increased and this could impact growth, survival and sex change.

Abundance of known predators (e.g. cod and Greenland halibut) remains low in the offshore areas while the abundance of harp seals has been increasing. While there is uncertainty as to the impact of predation, it is assumed to be low compared to times of high predator numbers.

Annex 2: New Performance Report Spreadsheet

Performance report for Northern Shrimp (*Pandalus borealis*)

Index	Observation	Interpretation
	Production	
Survey fishable biomass		
Survey female biomass		
Large vessel CPUE		
Small vessel CPUE		
	Recruitment	
Recruitment index (11 – 16.5 mm C.L. males)		
	Fishery	
Exploitation rate index		
Z		
Industry Perspectives		

	Stock Status	Evaluation
Current Outlook		
Future Prospects		

Status Definitions	
	Concern for Current Status or Prospect
	Intermediate
	Positive Evaluation
	Uncertainty of interpretation

Annex 3: Comments by J.F. Caddy on the traffic light analysis for Northern shrimp

General

A change in perspective over the last few years has occurred in marine fisheries: people are now taking a look at a broader set of environmental/economic/ecosystem data than before, and a broader focus on ecosystem inter-ractions is now being promoted.

- Stock assessments in the 1980s generally worked with data series of a limited number of types (Biomass, catch rates, sizes and ages), fitting them into mathematical models, and judging the state of exploitation.
- Such approaches are still valid, but we now know that ecosystem effects occur, as well as socio-economic and environmental impacts.
- Managers are becoming more comfortable monitoring a wider range of variables and displaying them together, so judgements can be backed up by a traffic light system displaying the data sets, and not just model output under restricted assumptions.
- Monitoring fisheries nowadays looks at a broader range of indicators, including ecosystem factors, environment, and economic performance.

My terms of reference for this short consultancy was to suggest a forecasting approach for shrimp production based on the TL approach, and propose a management framework for using a TL approach in shrimp management. A methodology was developed and a series of analyses were conducted, but this exercise could not be completed in the available time before the meeting.

Some 40 time series of data were provided, mainly oceanographic information and groundfish standard catch rates from surveys. The first approach was to exclude those data series where there was no evidence that these variables tracked close to monotonically, those data sets which monitor shrimp stock status. Although this was not considered optimal by the meeting (since landings do not necessarily reflect abundance), the same approach is recommended using either commercial or research vessel catch rates as used by David Orr for SA 5. The following procedure is recommended with these alternative data sets.

Data sets were divided into 2 categories: long and short – the long series containing data (often less precise) longer than 15 years: the other data less than 10 yrs. Separate TL approaches were attempted for the two data sets. The long series contains imprecise fisheries information; the short data series have the defect of not fully covering the impressive ecological changes that occurred at the end of the last century.

The importance of documenting multispecies interactions is now being promoted. This approach requires a search for time series that represent the main components in figure 17.

Fig. 1. Some first-order biological interactions directly affecting the managed population that could usefully be monitored in a multispecies fishery and (outside the box) several second-order factors affecting productivity.

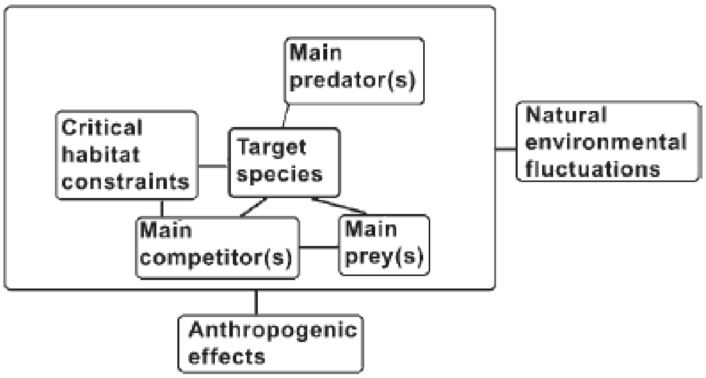


Figure 17. A conceptual model of first order interactions that directly affect a stock being managed are presented inside the large box while several second order factors affecting stock productivity are outside the box.

<u>Some useful terminology</u>:

1) Monitoring biological, environmental or economic time series results in an **indicator**.
2) **Groups of indicators** that measure similar processes are referred to as ‘**characteristics’ or ‘indices’.**
3) **Reference** points are values of indicators believed to represent important changes to the fishery system.

Indicators may be incorporated into a ‘basket’ of monitoring measures, but it is ideal if each is derived from a different data source. It may be useful to classify indicators into functional categories called ‘Characteristics’. An alternative approach is to consider functional characteristics such as in the figure 18.

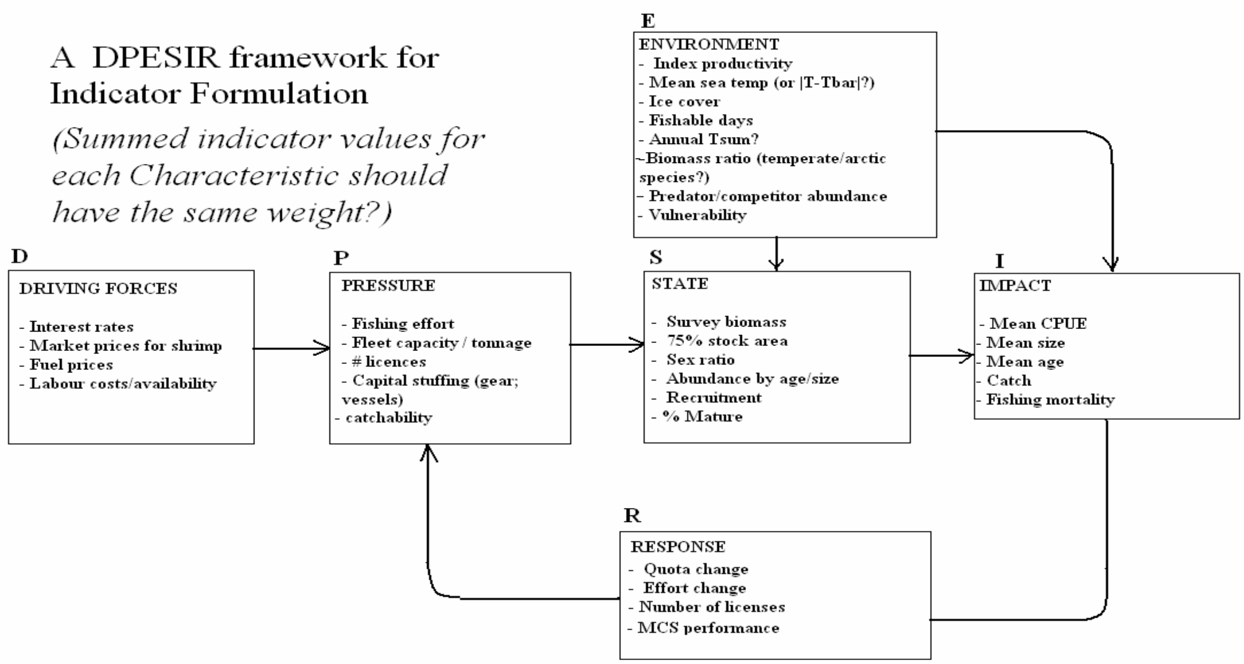


Figure 18. A conceptual framework for indicator formulation.

Both model-based, empirical indicators, and questionaire responses can be combined in a ‘traffic-light’ information display system to monitor what is happening in the fishery..

- A tally of green, yellow and red indicators can help evaluate the likelihood of changes ongoing, and could be the basis for decision rules.
- Statistical analysis and modelling can be carried out in parallel, and outputs incorporated into the TL approach.

In trying to envisage which variables should be monitored in a N. shrimp TL system, I went through papers in the last symposium (Orr, (ed). 2006), and **counted** mentions of relevant variables, and **underlined** observed or hypothesized interrelationships between them (Figure 19):

Two main approaches have been used in assigning indicators to a TL:

1) Decide from prior considerations which ‘Characteristics’ of the fishery you want to monitor (fishing pressure, biomass, environment, economics, etc) – then combine different indicators within a characteristic to get an overall index for that characteristic;

2) Assemble all of the indicators in a large matrix, and carry out a cluster analysis, principal component analysis, or other method of judging similarity, and see which indicators seem to measure the same trends – combine indicators from apparently different characteristics into homogenous groups.

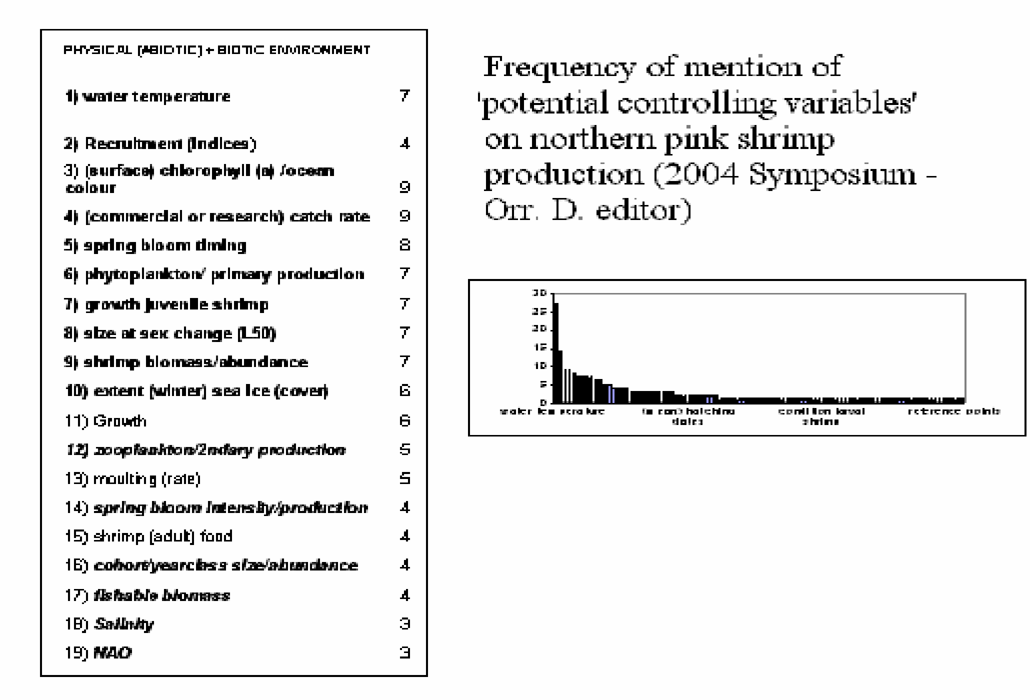


Figure 19. Frequency of mention, within (Orr , ed. 2006), of environmental variables that may control the production of northern shrimp (*Pandalus borealis*).

Defining precautionary and limit reference points.

Essentially, a Limit Reference Point corresponds to the value of indicator that constitutes a serious risk to the stock, and calls for immediate management action.
Precautionary Reference Points reflect the evaluation by experts that the fishery is moving in a direction where a risk to the stock will arise if the current trend is continued. At this point, at least a review of the situation is recommended.

For most indicator time series we know which direction the indicator should move to be favourable/ unfavourable for the species or its biomass/harvest, but we may not have reference points. Colour boundaries (r/ y; y/ g) can be defined by inflexions in the X-Y plot of the shrimp data series against the data series being considered. Quite a high proportion of the environmental and finfish data series tested showed a transition between two different ‘regimes’: an issue that needs further research attention. The colour boundaries may be based on research information, or be based on inflexions in the plots of the shrimp time series against the potential indicator. For such plots, 3 year running averages were used for smoothing and appropriate lags were introduced. For descriptive purposes, it may be useful to divide up either the observed range of the data, (or better, the feasible range of the variable) into 3 or 4 colour bands. Whether variable increases result in increased shrimp productivity will determine whether variable trends will be green, yellow or red.

Establishing a lag between two data series should either come from a knowledge of critical life history periods, or from lagged correlation analysis or by cluster analysis of a range of lagged data. Visual inspection of colour coded time series can often judge if a series is lagged correctly against the shrimp data series by comparing the relative position of colour bands.

Indicators of mortality, predation and environments

A summary of mortality estimates for *Pandalus sp* populations shows that these vary significantly, especially in relation to predator abundance. There seems to be indirect evidence that the decline in M due to predator depletion was one factor in the growth of shrimp biomasses which probably occurred in conjunction with changing marine environments.

Dramatic ecosystem and oceanographic changes are ongoing in the NW Atlantic. My conclusion from looking at the data on fishing mortality rate (Y/ biomass indicators) and total mortality rates (Z) from age structure, is that both the natural mortality rate (M) and the fishing mortality rate (F) on the stock are relatively low for a short-lived species, and are in the low end of the range judged by published estimates.

Natural and total mortality estimates from the literature show a high variability for shrimp M – evidently it is dependent on predation, mainly by fish. We can reasonably suppose that M has declined from higher values such as 0.6+ to lower values of 0.2+ with the decline in bottom fish predators. Can we demonstrate this effect?

A relatively high proportion of the stock of the order of 40% is formed of mature females (Age 6+) which confirms that overall mortality is low and spawning stock depletion is not currently a major problem. (in fact, the proportion of mature females in the stock is suggested as an easily-obtained indicator for fishing mortality).

This suggests that the key issue for a forecasting procedure is less one of tuning the effort to avoid overexploitation, but more that of trying to account for interspecies interactions and environmental changes that affect future shrimp biomass as a rough forecast of likely good, average or poor fishing conditions in the future year(s) –the forecasting procedure will of course have to consider fishing mortality rates (tracked by Y/ B ratios) but the conclusion of this short study is that predator control and environment are the key factors currently determining shrimp abundance, and not primarily fishing mortality, and that any monitoring/ forecasting system has to reflect this.

The reason given for the wide range of M values by most authors in the above table is a consequence of finfish (gadoid) predation at high predator abundance, or low abundance of predators and hence low M. In the case of the stocks considered here, the low value of Y/ B ratios supports a low exploitation rate and this tends to be confirmed by the high proportion of adult females (Age 6) in the biomass. A simple cohort simulation shows that we are only likely to get such a high % of mature females if both natural and fishing mortalities are low, and this was demonstrated by a simple cohort simulation using a range of M and F values (Table 5). Two examples of outputs are shown below, with a hypothetical set of indicators based on survival ratio of mature females/total biomass – this ratio is believed to be a useful precautionary index of state of exploitation.

Table 5 A series of natural (M) and total instantaneous mortality (Z) values for northern shrimp, as found in the literature.

Z	M	location	Age	author	comment
	0.25			Rinaldo (1976)	
0.6-1.4		G.StL		Frechette(1981)	
0.65			3-4	anderson(1978)	
0.66			5-6	"	
1.26			6-7	"	
.54-1.03	0.24 - .8	G.StL	3-4	Frechette and Labonte (1981)	
0.67	0.39	"	2-3	"	
	.2 - .3			Skulladottir (1979)	
	.5 - 1.0			ICES 1977	
.545-3.813		Alaska		Anderson (1991)	intense predation by Pacific cod
0.5-0.8		G StL		Frechette and Parsons (1983)	
1.89-2.12		Norway?		Hopkins and Nilsen (1990)	
1.46-6.21		"		Bergstrom (1997)	

M	XXXX	X		X	X						
Z		XXX	XXXX	X	X	X	X			X	XX
	0.2	**0.4**	**0.6**	**0.8**	**1**	**1.2**	**1.4**	**1.6**	**1.8**	**2**	**>2**

PERCENT FEMALE BIOMASS IN SURVEYS

M constant = 0.25						
F	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
% Female B	**48**	**41.3**	**34.9**	**28.9**	**23.5**	**18.8**
M constant = 0.5						
F	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
% Female B	**31.8**	**26**	**21**	**16.7**	**13**	**10**

:

PERCENT FEMALE BIOMASS IN SURVEYS

M constant = 0.25						
F	0.1	0.2	0.3	0.4	0.5	0.6
% Female B	48	41.3	34.9	28.9	23.5	18.8
M constant = 0.5						
F	0.1	0.2	0.3	0.4	0.5	0.6
% Female B	31.8	26	21	16.7	13	10

When you compare the P. borealis values for M from the literature with the order of magnitude of F suggested by the Y/B ratio, you can't help concluding that the M for SA 6 is currently very low, and this may account for much of the stock expansion of shrimp (plus a lesser effect of a warming trend):

Figure 20 suggests that possibly F < M. The Z values suggested for Area 6 from the age composition are Z = 0.23-0.49. The fishing mortality indicators from Y/B are probably overestimates and are around F = 0.2. From this, we can deduce M is at or below M = 0.2, which is low for a shrimp stock judging from the table 5, but consistent with the disappearance of key predator abundances.

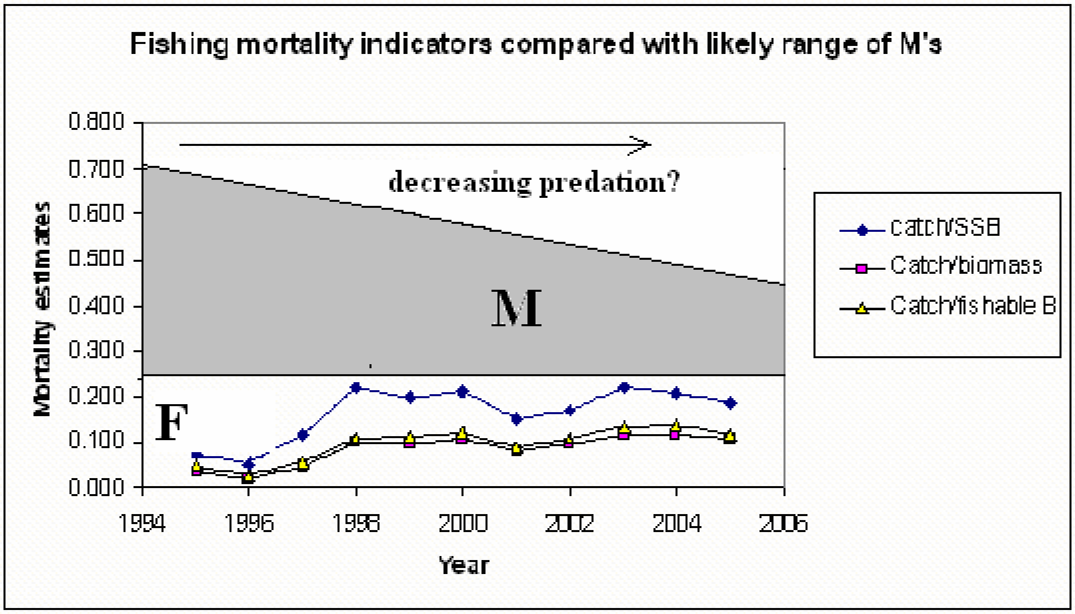


Figure 20. Changes in natural mortality (M) for SFA 6 shrimp as predation pressure decreases over time.

Some ideas on possible precautionary and limit reference points.

The following tables are suggestions as to possible precautionary reference points for a number of variables, and in a few cases an idea as to where the Limit Reference Point might lie, based on past experience and estimates. Since it seems unlikely that a model framework will be developed that incorporates dynamic ecosystem change, including shrimp, my conclusion is that reference points will be precautionary – depending to a large extent on the considered opinion of a group of experts. The context for such an analysis include:

- data and analyses from this species and this fishery and experience from related fisheries
- the fact that a return to conditions in the earlier period of cod abundance and lower temperatures are to a certain extent known, means that the indicator values at that time provide precautionary reference points for shrimp.

Table 6. Some safe working limits for the shrimp fishery based on analyses to date

Indicator / Typical current value	Precautionary RP	LRP	Comments
Z =M+F / 0.39	**Zpr = 0.6?**	**Z_{LIM}= 0.8?**	**M as well as F may change – Z is a measure that reflects both changes in F and M**
F' = Y/B / 0.2? F= 0.39 – 0.2? ~ 0.2?	**F_{PR} = 0.4?**	**F_{LIM} = 0.6?**	**Quotas should be set such that (Yt+1)/Bt < Flim?**
% Female B of total (SURVEY) / 30-40%?	**PB_{PR} = 0.3?**	**PB_{LIM} = 0.1?**	**A sharp drop in %female may precede a reproductive decline?**
T°1 (Pick a Temp° time series linked to cod cpue?)	**$T°_{PR}$ set at $T°_{1990}$ levels?**		**Assumes that a return to cold conditions will be unfavourable**
B_{COD} or $CPUE_{COD}$	**COD_{PR} = cod biomass at 1980's or early 1990 level?**		**Assumes cod is a key predator - when recovers will reduce shrimp biomass?**
BIOMASS SHRIMP (or of other indicators?)	**$[B_{t-1}–B_t)/B_{t-1}]$ >0.3**		**This type of reference point measures SURPRISES: e.g., Situations when population parameters change abruptly for the worse since the previous year. If there is a drop in 1 yr of > 30%, a precautionary warning is issued to industry?**

Mesh size selection

When we look at the commercial catch samples, it is probable that they underestimate the abundance of younger ages. i.e., we probably should adjust commercial catch rates-by-age by a selection curve before deducing relative numbers at age from commercial catches. (This is less important for the research survey data which uses fine mesh liners). In absence of a similar study here, a study by Labonte and Frechette (1978) in the Gulf suggested the following selection at size situation (Figure 21):

Selectivity at age:

age	size	prop.
1	10.1 m	0.015
2	14.5 m	0.121
3	17.4 m	0.37
4	19.7 m	0.61
4	20 f	0.665
5	21 f	0.762
6	22.8f	0.87

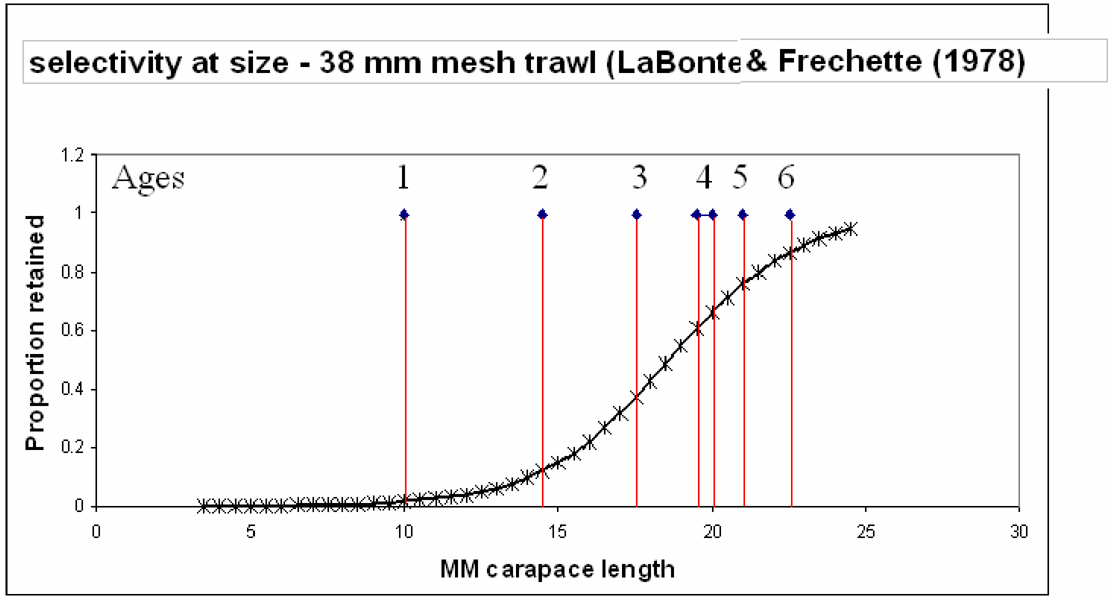


Figure 21. An example of a shrimp catch curve using data from (LaBonte and Frechette, 1978).

Getting a better idea of selectivity emerges as a useful research priority, and would allow catch size frequencies to be analysed for Z from catch curve analysis on the corrected log size frequencies (see FISAT software).

Lagging time series

The appropriate lag period can be determined from a knowledge of life history, by lagged correlation plots, or by cluster analysis of lagged time series (Figure 22). The plots did not generally show a high sensitivity to small changes in the lag applied.

One approach to examining possible lags is to repeat a correlation analysis for different lags, to find a possible peak (for +ve indicators) or a trough (for negative indicators).

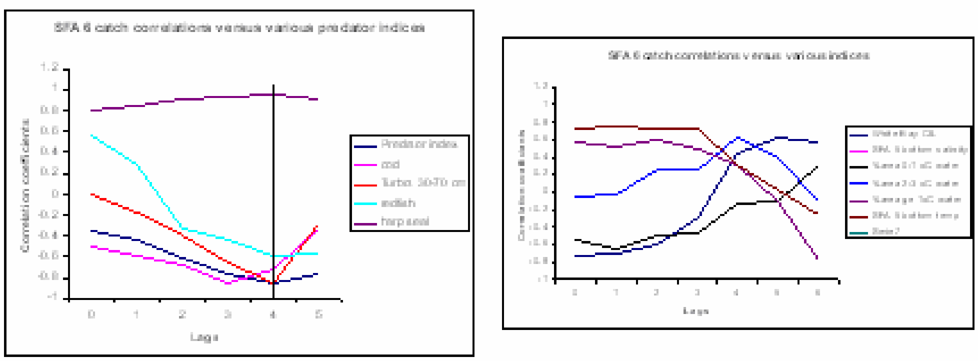


Figure 22.

Lagging abundance data backwards for 4-6 yr for commercial sizes is necessary prior to comparing adult shrimp series against environmental data (a 2 yr lag was used for comparisons with predators).
These lags should be verified where possible by supplementary data.

The use of TL data in management

Trends in key ecosystem indicators should ideally be provided to management in a clear way to help them in decision making and to summarize factors believed to be influencing the fishery and resource in discussing the standard indicators.

The interface between science advice and management decision-making should be clear cut. A Consideration Matrix is one option once suggested by the FRCC as an interface between scientists and managers. Scientists should place the stock in the appropriate ‘box’ each year, and managers should generally follow, with limited discretion, the rule specified in each ‘box’ (Figure 23).

INDICATORS OF ENVIRONMENT AND ECOSYSTEM	STOCK CONDITION (based on annual surveys)		
	HEALTHY STOCK CONDITION	BIOMASS BELOW Bpr	BIOMASS BELOW Blim
habitat/environmental conditions satisfactory	May increase capacity	maintain capacity constant	Close the fishery in this subarea
Evidence of deteriorating productivity	maintain capacity constant	Seek to reduce capacity or days fished	Close the fishery in this subarea
Habitat/ environmental conditions unsatisfactory	Seek to reduce capacity or days fished	Close the fishery in this subarea	Close the fishery in this subarea

Figure 23. A preliminary matrix that may be used in establishing harvest control rules.

Methological notes:

Mortality and relative age class strength

Sillimans method (described in Ricker 1954) is one way of estimating an overall mortality. $Z = \ln(N_t + \ldots + N_{t+n-1}) - \ln(N_{t+1} + \ldots + N_{t+n})$ for each row in the above lagged matrix of numbers at age (Figure 24).

Another output from the lagged age composition data shown here is to use each row (corresponding to a single cohort) to obtain relative cohort strength. This might be obtained simply by adding numbers for the same cohort/row for all ages in the above lagged figure, but this estimate will be heavily influenced by the abundance of age 3 shrimp. To allow the other age groups to contribute to the estimate while retaining the differences between cohorts, each age group is weighted by dividing by the relative abundance obtained from the sums of numbers at age after these have been converted to relative numbers by dividing all series by Age 1 abundance. These age-specific relative numbers are then mutiplied by the numbers in the matrix before adding numbers at age for a cohort horizontally to get an estimate of relative abundance that takes the contribution of all ages in a cohort into account (Figure 24).

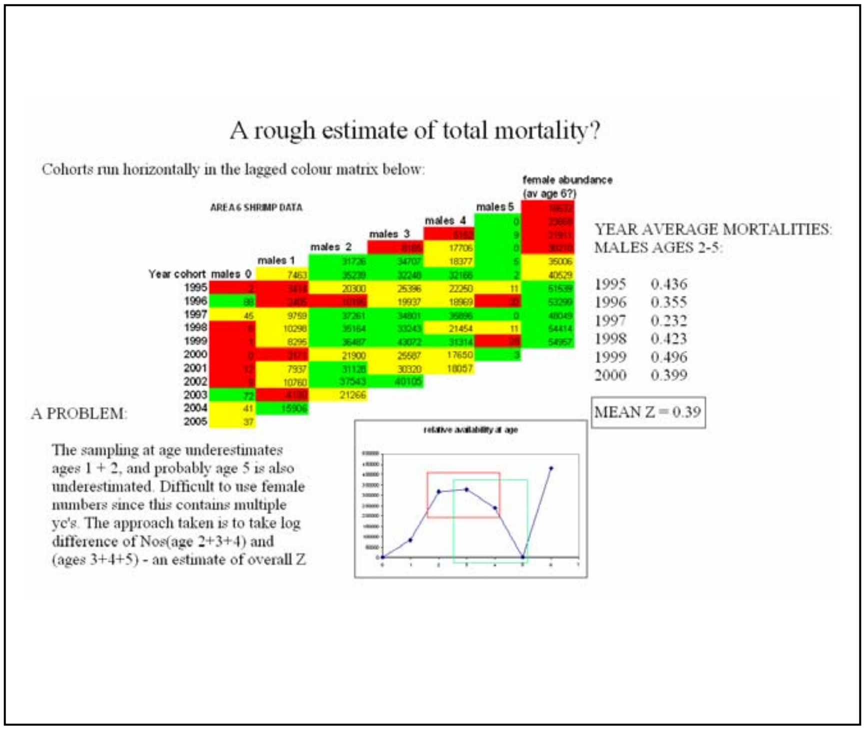


Figure 24. Mortality and relative cohort strength from shrimp population demographics. Please note that this example does not make use of SFA 6 shrimp abundance at age estimates.