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A Precautionary Approach to Assessment and Management of Shrimp Stocks in the Northwest Atlantic

by

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Abstract

At a recent meeting of the NAFO Scientific Council participants considered three example stocks for the application of precautionary methods, including one "data poor" stock i.e. shrimp (*P. borealis*) on Flemish Cap (NAFO Division 3M). For stocks such as 3M shrimp for which quantitative reference points, targets or limits could not be defined, Scientific Council endorsed the interim use of stock specific checklists which include multiple, qualitative indicators of resource status. This method, which is similar to the matrices used in Environmental Impact Assessment, uses the "Traffic Light" analogy because assessment results are categorized as "green", "yellow or "red", corresponding to favourable, uncertain or unfavourable stock conditions. Recent stock assessments for Atlantic Canadian shrimp stocks, including the Scotian Shelf, the Gulf of St. Lawrence and the Labrador-Newfoundland Shelf, were conducted using the Traffic Light/checklist approach and results were viewed positively by scientists (some), fisheries managers and industry. A major drawback of the method in its current form is that it does not link assessments to TACs or other management controls. Modeling results suggest that "Traffic Light" results could be linked to simple harvest control rules in a way that is consistent with shrimp stock dynamics and management requirements, creating an integrated management framework.

Introduction

Assessment and management for many *Pandalus borealis* stocks in the Northwest Atlantic can be surprisingly *ad hoc* in that there are few clearly stated management objectives, biological reference points or harvest rules. Notwithstanding theoretical considerations, past experience and socio-economic pressures which result in undefined limits inherent in the scientific\management “culture” of any particular fishery, each change in TAC is essentially an independent decision made after careful evaluation of the current situation. Assessments generally consist of monitoring population changes using catch rate series and/or scientific surveys. Samples from survey and commercial catches provide general information on population structure and recruitment, but population reconstructions and formal yield projections are rare, even when the information is available. In this system, significant changes in the monitored parameters simply serve as “warning lights” that a change in the TAC should be considered by management; however there is no formal link between the two processes. This approach appears to have been relatively successful - stock collapses are rare compared to the highly parameterized stock assessment models and management regimes used for many finfish stocks. This approach has evolved because:

1. technical problems have prevented development of quantitative assessment models, including uncertainties in ageing, difficulties in establishing year class strengths, highly selective fishing gears, large survey areas, etc.
2. stock recruitment relationships on which to base biological reference points can rarely be demonstrated.
3. recruitment is believed to be largely environmentally determined.
4. shrimp stocks are believed to be relatively resilient to overfishing.

Recent developments, including the adoption of the Precautionary Approach (PA) by many international fisheries organizations and increasing fishing pressure on many shrimp stocks, indicate that a more rigorous approach to shrimp stock assessment and management should be adopted. Assuming that the present assessment methodology is both adequate and “as good as it gets” under current constraints, its precautionary extension would be a clarification of the process triggering concern for stock health, and formalization of the actions taken. The nature of shrimp assessment data, including the uncertainties mentioned above, and the complexities of evaluating disparate and often conflicting data sources, imply a semi-quantitative approach similar to that of Environmental Impact Assessment (EIA) .

Caddy (1996) first proposed the use of EIA methods in fisheries, including an assessment-management regime in which Limit Reference Points (LRPs) determine if stock indicators are "red" or "green" (Caddy 1998). A pre-negotiated suite of management responses linked to an overall "Traffic Light" score become progressively more severe as the number of red lights increases.

A variation of Caddy's "Traffic Light" method which excludes the use of LRPs was later adopted by the North Atlantic Fisheries Organization (NAFO) as an interim Precautionary Approach to managing data poor stocks (NAFO 1998a). This method, here called a "performance report" is also used to assess domestic shrimp stocks in Atlantic Canada (Parsons et al 1999, Savard 1999). Its main drawback is that it does not link assessment results directly to management action. The purpose of this paper is a) to evaluate the method as applied to two shrimp stocks in the Northwest Atlantic and b) use a simulation model to determine if "Traffic Light" results can be linked to harvest rules which are consistent with shrimp population dynamics and the Precautionary Approach.

Methods

Shrimp stock assessment documents from the Gulf of St. Lawrence (Savard 1999) and the Newfoundland-Labrador shelf (Parsons et al 1999) provide background information and the basis for the performance reports.

In the Gulf of St. Lawrence, commercial fishery catch and effort statistics are used to calculate catches numbers per units of effort (CPUE, NPUE). The data are standardised to account for changes in the fleets (changes in fishing power resulting from vessel changes and fleet renewal) and seasonal fishing patterns. Research surveys have been conducted in the Estuary and Gulf of St. Lawrence in August–September each year since 1990. The surveys use a stratified random design and are conducted from the Canadian research vessel *Alfred Needler*, equipped with a shrimp trawl. Results (biomass and abundance) are presented as relative indices, as the trawl used does not catch all the shrimp in the water column while passing over the seabed. However, since the survey is carried out in a standard manner from one year to the next and since it covers the geographic range of shrimp in the Estuary and the northern Gulf, the indices are considered to be reliable indicators of variations in shrimp abundance and biomass. Sizes of male and female shrimp in the catches are obtained from port sampling. Samples are adjusted upward to month and year for each SFA to derive a series of annual catch-at-length compositions. Sampling of survey catches provides data for constructing estimates of abundance at length and sex by area and year. Age composition from surveys and commercial data is inferred by identifying year classes within the composite distributions and tracking their development over time.

On the Newfoundland-Labrador Shelf trends in catch (tons) and effort (hours fished) from vessel log records are monitored for all areas and years. CPUE, expressed as kg per hour, is calculated by year for each SFA and used as an indicator of change in the fishable stock over time. The raw data (catch/effort) for each SFA are standardised by multiple regression as in the Gulf of St. Lawrence. Multispecies research trawl surveys have been conducted annually in the offshore area since 1995. These surveys employ a stratified-random sampling design that was developed for groundfish but use a lined, Campelen 1800 shrimp trawl as the sampling gear. In Hawke Channel + Div. 3K (SFA 6), survey coverage has been extensive in areas where shrimp are abundant and reliable estimates of the distribution as well as abundance/biomass indices have been obtained each year from 1995 to 1998. Farther north, coverage is not adequate (or the survey design is not appropriate) to address the patchy distribution of shrimp in these areas. Therefore, survey results from 1996 to 1998 for Hopedale + Cartwright (SFA 5) and 1996 and 1997 for Div. 2G (SFA 4) are less reliable for interpretation of trends in the resource and approximate level of exploitation. No surveys have been conducted in Div. 0B (SFA 2). Sizes of male and female shrimp in the catches are obtained from samples taken by observers on offshore vessels. Samples are adjusted upward to set, month and year for each SFA to derive a series of annual catch-at-length compositions. Age composition is inferred as in the Gulf of St. Lawrence.

A population model was developed to test the validity of the "Traffic Light" approach under data poor conditions as suggested in Caddy (1998) i.e. "Such a simple feed-back situation seems testable by simulation and could still be feasible in relatively data-poor conditions". Although Caddy suggested the use of fuzzy logic systems analysis, we felt that a relatively simple age-based model with a feedback mechanism i.e. a management response (setting a TAC) linked to parameters, here called indicators, measured with error, would be adequate to test the hypothesis that more poorly measured or understood indicators were better than fewer such indicators. This hypothesis examines the intuitive appeal or implied advantage of the "Traffic Light" approach i.e. that any one indicator is always associated with large variances and/or uncertainty as to what a change means relative to stock status, resulting in a high risk of failure of traditional assessment-management models (e.g. projections from VPA, production models) but that additional indicators, especially when obtained from independent observations, and when considered in total, will tend to reflect the true state of the stock. In addition we wanted to determine how the method would perform relative to a "traditional" shrimp stock management approach, in this case the setting of a TAC representing a fixed percentage of a measured spawning stock biomass.

The model assumes that the population at the start of the simulation is pristine, with recruits at age 1 and time 1 of 1000 million. Abundance at any age and time 1 can be derived from

$$N_{a,1} = N_{a-1,1} e^{-M_1}$$

Catch at age from age 2 is obtained from

$$C_{a,t} = N_{a-1,t-1} m_t S_a e^{-M_t/2}$$

Abundance for animals from age 2 which have experienced natural mortality and fishing is obtained by

$$N_{a,t} = [N_{a-1,t-1} e^{-M_t/2} - C_{a,t}] e^{-M_t/2}$$

Since few stock recruitment relationships have been demonstrated or described for *P. borealis*, the nature of this relationship and its effects were not considered - recruitment was simply linked to spawning stock through a hypothetical relationship which was identical for all simulation runs and included a process error (CVs of 60%). Surveys for spawning stock biomass and recruits were simulated by applying lognormal measurement errors to the actual abundances of spawners and recruits. Environmental/ecological indicators were represented by natural mortality, which was also assumed to be measurable with error, for example as the abundance of groundfish predators.

Six stock indicators were used in the simulations, each of which was scored according to more or less arbitrary criteria as follows:

INDICATOR	CRITERIA	RESPECTIVE SCORES
Recruitment	<0.2, 0.2-0.5, >0.5 of virgin	1, 0, -1
Spawning Stock Biomass	>0.5 , 0.5 - 0.2, <0.2 of virgin	1, 0, -1
Environment	M is <0.5, 0.5 - 0.6, >0.6	1, 0, -1
Number of age classes	>4, 3-4, <3	1, 0, -1
Average age	<2.5, >3	-1, 0, -1
Sex ratio	<2, >4	-1, 0, -1

Average age and sex ratio were chosen to represent indicators whose meaning relative to stock health is ambiguous. For example, a change in sex ratio could signal both positive, negative (increasing or decreasing recruitment, increasing or decreasing survival of older animals) or unknown (rate of sex reversal) changes in the population structure. Despite their ambiguity, such indicators may still be useful if incorporated into the analysis in a "precautionary way" i.e. if the meaning of a change relative to the health of the stock is ambiguous, the precautionary approach would be to assume any change outside a given range signals instability and is bad. Consequently these indicators were scored as -1 if they fell outside a range, and 0 of they fell within it. During initial runs criteria were adjusted if necessary to give a reasonably large range of scores for all indicators for the 25 year simulations.

The annual "assessment" consisted of the arithmetic sum of the individual parameter scores. The feedback mechanism consisted of a simple harvest rule connecting the sum score from year t to the TAC for year t+1. The TAC was calculated as the percentage of the Spawning Stock Biomass determined from the harvest rule and the survey mean estimate of SSB. Rules for each of the four combinations of indicators compared were as follows, where the numbers indicate increases or decreases in the exploitation rate (i.e. percent of the measured SSB) from the previous year:

Score	1 indicator	2 indicators	3 indicators	6 (all) indicators
3 or >			+0.33	+0.33
2		+0.33	+0.165	+0.165
1	+0.33	+0.165	+0.11	+0.11
0	unchanged	unchanged	unchanged	unchanged
-1	close fishery	-0.33	-0.165	-0.165
-2		close fishery	-0.33	-0.33
-3 or <			close fishery	close fishery

Yields are presented as the mean of each 50 year simulation run. Risk was determined as the percentage of years in which the spawning stock declined below an arbitrary 10% of the virgin biomass in each run.

Results

Application to three shrimp stocks in the Northwest Atlantic

1. *Gulf of St. Lawrence*

<u>Background</u>

Landings of northern shrimp in the Estuary and Gulf of St. Lawrence have gradually increased since the fishery began in the mid-1960s. Landings rose from approximately 1000 to 7500 tons between the early and late 1970s, reaching over 15,000 tons by the late 1980s. Landings in 1998 amounted to more than 23,000 tons, a 40% increase over 1995 and a new high.

Shrimp harvesting in the Estuary and Gulf is controlled by a number of management measures, including TACs (total allowable catches) in the four management units or shrimp fishing areas (SFAs): Sept Îles (SFA 10), Anticosti (SFA 9), Esquiman (SFA 8) and Estuary (SFA 12). TACs have been taken in all areas since 1995. In 1998, there were 117 licences for shrimp. In 1997 and 1998, temporary allocations of shrimp were granted to fishers with groundfish licences. Other management tools include a minimum mesh size (40 mm) and, since 1993, the compulsory use of sorting grates, which significantly reduce groundfish bycatches. The shrimp fishery runs from April 1 to December 31.

1999 Assessment

The 1999 Gulf shrimp assessment used a "performance report" proposed by the Fisheries Resource Conservation Council (FRCC) to evaluate overall stock health (Brêthes 1998). An example of the method as used for the Sept Îles (SFA 10) fishery is given in Table 1. Indicators used in the assessment were grouped under three headings: fishing success, stock abundance and resource productivity. Most indices provided a positive outlook and reflected the current high biomass/abundance, large spawning stock and no increase in exploitation during the 1990's. The impact of observed spatial and temporal changes in fishing pattern was uncertain, as was the increase in Greenland halibut abundance with respect to predation mortality. The only "cause for concern" was the low numbers of small males encountered in the 1998 trawl survey that suggested low recruitment to the fishery. The overall assessment, based on a combination of all indices, concluded that the stock was in good condition in 1998 but, because of lower recruitment, could begin to decline in 1999. Therefore, stock status was somewhat uncertain in that it was not possible to quantify the future effect of reduced recruitment on either fishery performance or stock status.

A retrospective analysis was conducted for the Sept-Îles management unit to see if a series of annual performance reports reflected trends in stock status (Table 2). The analysis clearly shows "waves" of poor or strong year classes, their linkage between indicators over time, and how this was reflected in overall stock status.

2. Baffin Island, Labrador and northeastern Newfoundland

Background

Shrimp catches throughout the area extending from Div. 0A off eastern Baffin Island to Div. 3K off northeastern Newfoundland have increased from less than 3000 tons in 1977 to almost 80,000 tons in 1998. During the first decade, the fishery was confined to small areas within Div. 0A, 2H and 2J but expanded to southern Div. 2J and 3K beginning in 1987 and north to Div. 2G and 0B in 1988. The fishery is currently carried out over a vast geographic area, including grounds that were previously thought to be unproductive for shrimp.

Catches are controlled by TAC in all shrimp fishing areas within Canadian waters - Div.0B (SFA 2), Div. 2G (SFA 4), Hopedale + Cartwright Channels (SFA 5) and Hawke Channel + Div. 3K (SFA 6). TACs have been taken in all areas since 1995. Also, a TAC-controlled fishery for *Pandalus montagui* occurs east of Resolution Island (SFA 2, 3 and 4, west of 63^0 W). The number of licences for large, offshore vessels to fish shrimp in these areas increased from 11 in 1978 to 17 up to 1996. TAC increases in SFAs 5 and 6 in recent years resulted in the establishment of an additional fleet component for vessels less than 19.8 m. About 300 such vessels participated in the 1998 fishery, primarily in SFA 6. Other management measures include minimum mesh size (40 mm) and, since 1997, the compulsory use of sorting grates. The fishery is open from January 1 to December 31 in all areas but sea ice coverage defines the season in northern waters.

Management of the northern shrimp fishery by TAC aims to prevent over-exploitation of the shrimp resources. TACs in both the Gulf of St. Lawrence and the Newfoundland-Labrador Shelf are set conservatively and are closely monitored. Large increases in some TACs in 1997 and 1998 were based on new findings from multispecies research surveys initiated in 1995 which showed high abundance/biomass in these areas and low exploitation. Exploitation level was inferred by comparing nominal catch to the lower confidence interval (95%) of the biomass index. As indicated above, the index is believed to underestimate the actual biomass.

1999 Assessment

Assessment of northern shrimp in the Canadian northwest Atlantic in winter 1999 followed the approach used for the Gulf of St. Lawrence (i.e. observation, interpretation and evaluation of indices). An example of the method as applied to Hawke Channel + Div. 3K (SFA 6) is given in Table 3. Indices or indicators relevant to stock status were grouped under fishery data, research data and ancillary data. The first two groupings included the traditional data sources used in stock assessments whereas the last attempted to incorporate other factors that are believed to be important in determining the status of shrimp stocks but seldom find their way into the process. Most indices were evaluated positively (green lights) and there were no immediate concerns regarding either current status or future prospects (red lights). Two indices addressing recruitment were evaluated as uncertain (yellow lights): survey results indicated that the 1995 and 1996 year classes were weaker than those of 1993 and 1994 and warmer than average water temperatures from 1996 to 1998 could result in reduced recruitment to the fishery. The overall assessment, based on the combination of all indices, concluded that the current status was favourable with high biomass/abundance of male and female components. Future prospects were uncertain, however, given that the available data suggested a decline in recruitment.

Assessments were carried out for the other three SFAs using the same method and the results for all four areas are summarized in Table 4. The summary clearly showed how uncertainty in resource status increased from south to north. No evaluation was given where data were absent. In the example provided in Table 3, data from both the commercial fishery and research trawl surveys were reliable. The uncertainty about recruitment was two-fold: uncertainty that the recruitment index was reliable with such a short time series and uncertainty about how any realized reduced recruitment will impact overall stock status. In the Hopedale + Cartwright area (SFA 5), fishery data were considered reliable but research data were uncertain regarding trend because the survey design did not resolve the patchy distribution on shrimp in this area. A similar situation was evident in Div. 2G (SFA 4) with the additional observation that industry, itself, was uncertain about the stock distribution in this area. Div. 0B (SFA 2) lacked research trawl surveys and the fishery data were difficult to interpret because of the mixed-species fishery (*P. borealis/montagui*) in the main fishing area and the uncertainty about population structure and boundaries.

3. *simulation study*

Figure 1 shows a single run of 25 simulations, each consisting of a 50 year population trajectory. While yields and their associated risks vary significantly between runs, differences in yield between combinations of indicators within each run are relatively small, generally less then 2000 mt (Figure 1, top). Moreover, the risk associated with harvest rules using scores from all six indicators generally falls below the risk for other combinations of factors within each run (Figure 1, bottom). In Figure 2, the average yield, risk and yield per unit risk for 5 simulation runs are plotted for the six indicator combinations plus a management regime of constant exploitation calculated as 40% of the survey spawning stock biomass. The latter was chosen because a constant exploitation rate of 35% was used for Canadian stocks in the past until it was found that many stocks could sustain a higher rate without problems (Mohn et al 1992). Results show that runs using only 1 indicator to set the TAC resulted in the lowest, while the constant exploitation scenario produced the highest average yields, risks, and yields per unit risk. While runs with all six indicators produced lower yields than runs using 2 or three indicators or constant exploitation, the associated risks were also among the lowest observed. Fisheries managers may view the results from one indicator (s) as having acceptable levels of risk, but yields that are too low. Similarly, runs with 2 and 3 indicators or constant exploitation produce acceptable yields, but at risks that may be considered too high. Clearly the use of scores from all 6 indicators to set the TAC provided a "moderating" influence on the system and resulted in acceptable yields at low risk, a result that may be considered precautionary.

Discussion

The performance report is a powerful visual tool that shows how the overal conclusion on the status of a stock is reached. It also shows the interdependance of indicators over time, for example, the abundance of males as an indicator of recruitment to the fishery is linked to the abundance of females, the survey biomass and commercial catch rates some years later. In Canada, the method has been accepted within two independent management regimes, both for the assessment process and the presentation of results to clients and stakeholders. Its appeal lies in its simplicity. All observations from the indicators considered in the process are described and interpreted in transparent terms and their strengths and weaknesses are evident. The format provides a mechanism for consensus building among scientists, fisheries managers and industry. It incorporates input from fishermen and environmental influences such as temperature and predation, despite their qualitative nature and usual exclusion from traditional approaches.

A clear weakness of the method is the interpretation of the 0, "uncertain" or "yellow light" category. In the performance reports given in this paper they do not represent "average" conditions. Uncertainty is defined as both uncertainty in the analysis of data (e.g. variance) and uncertainty in the interpretation of the observations (i.e. stock performance). Note that the "traffic light" analogy is one of convenience and does not strictly apply i.e. when real traffic lights turn yellow, red is inevitable. This may not necessarily be the case for the stock in question. Simply stated, the "yellow" category indicates a lack of information pertaining to any indicator or performance report summary. Under the Precautionary Approach, greater precaution should be applied in cases with greater uncertainty. This is rather circular logic, in that the ability to apply *more* precaution implies the ability to define and distinguish between the *more* and *less* precautious approach relative to the stock's reaction to fishing, an ability requiring greater certainty, or information. Moreover, it implies the ability to perceive and anticipate danger, which again requires information. The appearance of yellow lights in performance reports should serve as a warning to research managers that more information, and consequently more funding, is required in that area. The simulations were conducted under the premise that one cannot be more precautious with less information, consequently the yellow or uncertain category was not used - the 0 in the simulations represent an intermediate state between 1 and -1.

Simulation results show that increasing the number of indicators used to determine a total score and TAC reduces the risk associated with any particular yield and is more precautionary than an assessment-management regime using a single or limited number of indicators, or a fixed exploitation rate. In terms of practical application, the predetermined harvest rules used in this method are probably as important a precautionary attribute in that they reduce or elliminate management indecision. This is particularly important in a stock such as Pandalid shrimp where rapid population changes in combination with an *ad hoc* approach to setting TACs can result in critical delays in decreasing exploitation during population downturns.

The method offers other potential advantages over ‘traditional” fisheries management models including:

1. absence of empirically derived harvest parameters based on highly variable or limited data e.g. surplus production, stock-recruitment, projections from VPA, etc. which are used implicitly to set target yields.
2. a transparency of method and purpose which provides intellectual and political equality to all stakeholders and quantifies the decision making process.
3. a framework for bringing a variety of measurements, traditional stock assessment methods, anecdotal observations and political/economic considerations into management decisions.
4. an absence of scientific paradigms that require long periods of time or short catastrophic events to fall out of favour or falsify, or more insidiously, are impossible to falsify and therefor fall in the realm of metaphysics (Corkett 1997).

It is clear that both the performance report format itself and its linkage to the management response requires additional development. In its current form, the overall status of the resource in a performance report is a qualitative combination of all indicators without considering their precision and relative importance. Individual indicators could be weighted to reflect levels of uncertainty or potential impact. However, results to date suggest that performance reports can be linked to simple harvest control rules in a way that is consistent with shrimp stock dynamics and management requirements, creating an integrated management framework.

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Table 1. Performance report for Sept Îles (Shrimp Fishing Area 10) for 1999. Evaluations are + (green) positive, 0 (yellow) uncertain, or - (red) negative.

INDICATOR	*OBSERVATION*	*INTERPRETATION*	*EVALUATION*
FISHING SUCCESS			
Landings	40% increase in TACs and landings since 1995; TAC taken easily since 1995	Large biomass	+
Catch (number)	19% increase since 1995; decrease in males (12%), increase in females (62%)	High abundance; mean weight of catches has increased	+
Effort	40% reduction between 1994 and 1995; effort low and stable since 1995	High density	+
Seasonal pattern	High monthly CPUEs in 1998; CPUEs decline over season	High density; return to seasonal pattern of early 1980s	**0**
Spatial pattern	Effort reduced in southern part of Laurentian Channel; effort increased in western part of area	Change in distribution; geographic range may be shrinking	**0**
Stock distribution	Drop in densities in southern part of Laurentian Channel; increase in densities in western part of area	Change in distribution; geographic range may be shrinking	**0**
Industry perception	Good concentrations of shrimp in areas different from other years; few or no small shrimp	Densities still high, but change in distribution and low recruitment	**0**
STOCK ABUNDANCE			
Biomass index	Increasing since 1992–93; 1998 stable in relation to 1997; 1997 and 1998 values highest in series	Large biomass	+
CPUE	Increasing since 1992–93; 1998 value highest in series	High density	+
Abundance index	Increasing since 1992–93; 1998 stable in relation to 1997; 1997–98 values similar to that of 1990	High abundance	+
NPUE	Increasing since 1992–93; 1998 value highest in series	High density	+
RESOURCE PRODUCTIVITY			
Population structure	Age structure stable from year to year; growth gradient from east to west	No loss of female component; productivity lower in eastern part of Gulf	+
Size of males	Size of last mode of males smaller in 1998	Size at sex change will drop in 1999; females will be smaller	**0**
Size of females	Increasing since 1994; very big in 1998	Fewer individuals for same catch	+
Female abundance	Increasing since 1992–93; 1998 value highest in series	Large spawning stock	+
Male abundance	Abundance of all male components relatively stable in 1992–96, but fell in 1998 to average level	Average recruitment to spawning stock	**0**
Recruitment	Drop in male abundance to average level; very few small males in 1998 survey	Low recruitment to fishery	--
Predation	Cod and redfish abundance low, but increase in turbot	Predation pressure will rise	**0**
Exploitation rate	No increase with recent rise in catches; 1998 rates were same as those of early 1990s	Fishing mortality has not increased since early 1990s	+
ASSESSMENT			
All indicators combined	**Stock in very good condition in 1998, but could begin to decline in 1999 because of lower recruitment**		**0**

Table 2. Retrospective analysis (summary of performance reports) for Sept Îles area in the Gulf of St. Lawrence for 1990-1998.

YEAR	PREDATION	RECRUITMEN T	POPULATION ABUNDANCE	FISHING PATTERN	FISHERY PERFORMANC E	EXPLOITATIO N	
1990	--	--	+	+	+	+	0
1991	--	--	0	+	0	+	0
1992	0	--	--	0	--	--	--
1993	0	0	--	0	--	--	--
1994	+		0	0	0	0	0
1995	+	+	+	+	+	0	+
1996	+	+	+	+	+	0	+
1997	+	+	+	+	+	+	+
1998	0		+	0	+	+	0

Table 3. Performance report for Hawke Channel + Div. 3K (SFA 6) for 1999.

INDICATOR	***OBSERVATION***	***INTERPRETATION***	***EVALUATION***
FISHERY DATA			
CPUE - KG/HR	Increased for offshore fleet up to 1996 and has remained at a high level (> 2000 kg/hr). Inshore sector, including inexperienced fishers, had high catch rates when the fishery began in 1997.	Reflects an increase in the resource up to 1996, remaining at a high level since.	+
Spatial pattern	Eastward expansion in effort by offshore vessels in early 1990's.	Reflects the discovery of high concentrations of shrimp along the shelf slope during the exploratory fishery in 1992 and 1993. These areas previously were thought to be unproductive.	+
Temporal pattern	A winter-spring fishery for the offshore fleet and a summer-fall fishery for the inshore fleet.	Commercially viable concentrations of shrimp available throughout the year.	+
Male abundance	The abundant 1991 year class began to recruit in 1994 and produced higher catch rates in 1995 and 1996. The 1993 year class dominated in 1997 and 1998 but appears weaker than the 1991.	Good recruitment of year classes produced in the early 1990's resulted in high catch rates of males since 1995.	+
Female abundance	Catch rates of the female component increased from 1993 to 1996 and stabilized in 1997 and 1998.	Continued good recruitment since the mid 1980's is responsible for the increase in spawning stock throughout the 1990's. Spawning component remains healthy.	+
Sex inversion	The median size at sex change varied between 21 and 22 mm carapace length throughout the 1990's.	Stability in maturity schedules suggests that favourable sex ratios are being maintained within the population.	+
RESEARCH DATA			
Biomass/abundance index	The lower 95% confidence intervals for the biomass/abundance indices averaged about 400,000 tons/90 billion animals during the 1996 - 1998 period.	High biomass/abundance.	+
Spatial pattern	Widely distributed throughout the management area.	Wider distribution in the 1990's compared to the 1980's, reflecting higher stock size.	+
Recruitment (male age structure)	Survey abundance in 1996 and 97 was dominated by males of the 1993 and 1994 year classes. The 1994 year class dominated in 1998. The 1995 and 1996 year classes appear weaker.	Recruitment of males will likely decline, beginning in 1999 and continuing into the next millenium.	**0**
Spawning stock (females)	Relatively stable. Increase in 1998 survey due to small females, possibly part of the 1993 year class.	Female abundance should be maintained in the short term (1999 and 2000) by the continued recruitment of the 1993 and 1994 year classes..	+
ANCILLARY DATA			
Predation	Abundance of known predators such as cod, redfish, skate and American plaice remains low in the offshore areas.	Predation mortality remains low relative to periods of high predator abundance.	+
Environment	Warmer than average water from 1996 to 1998.	Could result in lower catch rates (reduced recruitment to the fishery) beginning in 1999 and continuing into the next millenium.	**0**
Industry perspectives	Catch rates were high in recent years with similar offshore catch rates in early 1999.	The resource is perceived to be healthy by both inshore and offshore sectors.	+
ASSESSMENT			
Exploitation rate	Ratio of nominal catch to survey biomass index (lower confidence intervals) has been less than 12% for the past 3 years.	Catchability of the survey gear is believed to be <1. Therefore, exploitation rate likely has been <12%.	+
Stock Status		Current status favourable with high biomass/abundance of male and females.	+
Future Prospects		Available information suggests a decline in recruitment for 2000+, so it is uncertain if the current TAC can be sustained	**0**

Table 4. Summary of performance reports for all shrimp fishing areas off Labrador-Newfoundland in 1999.

	HAWKE + 3K	HOPEDALE & CARTWRITE	Div. 2G	Div. 0B
FISHERY DATA				
CPUE - KG/HR	+	+	+	0
Spatial pattern	+	+	+	0
Temporal pattern	+	+		
Male abundance	+	+	+	0
Female abundance	+	+	+	0
Sex inversion	+	0	0	0
RESEARCH DATA				
Biomnass/abundance index	+	0	0	
Spatial pattern	+	0	0	
Recruitment (male age structure)	0	0	0	
Spawning stock (females	+	0	0	
ANCILLARY DATA				
Predation	+	+		
Environment	0	0		
Industry perspective	+	+	0	0
ASSESSMENT				
Exploitation rate	+	0	0	0
Stock Status 1999	+	0	0	0
Future Prospects 2000+	0	0	0	0

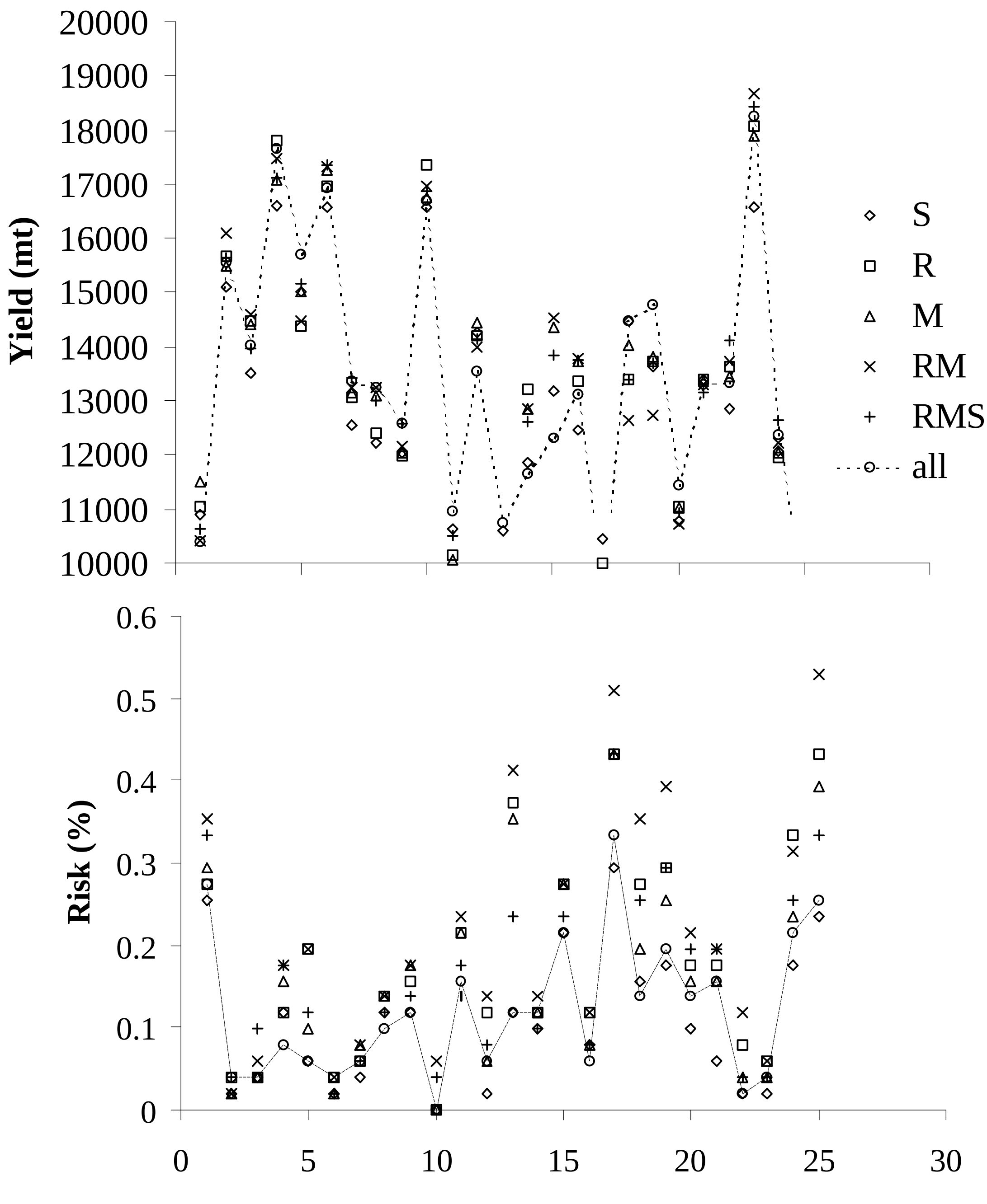

Fig. 1. Yield and associated risk for 25 simulation runs, each consisting of a 50 year population trajectory. Symbols represent runs in which 1 (R, M or S), 2 (RM), 3 (RMS) and all indicators were used in the feedback consisting of simple harvest rules applied to a survey estimates of spawning stock. R - recruitment index from survey; M - measure of natural mortality; S- spawning stock biomass from survey.

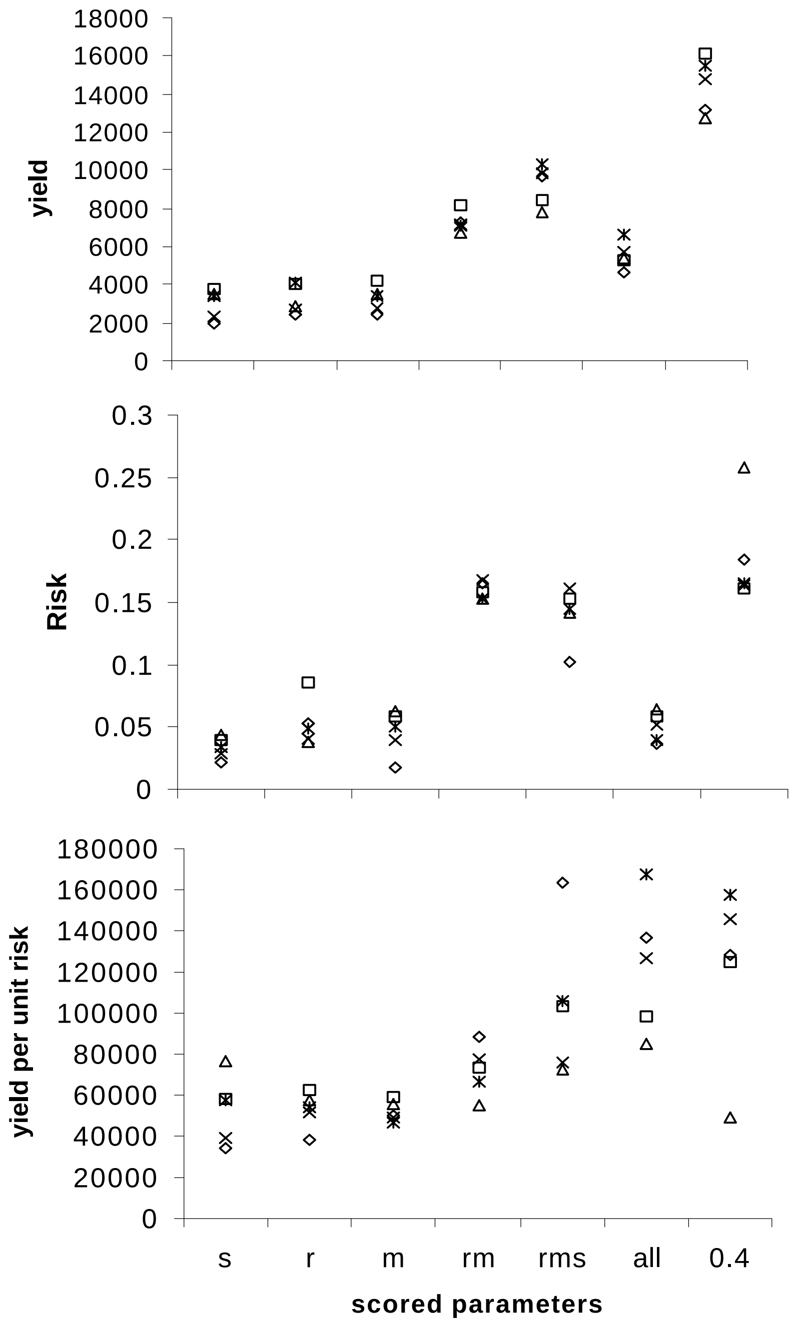

Fig. 2. Average yield, risk and yield per unit risk from 5 groups of 25 runs. Scored indicators on the x-axis are the same as per Figure 1 but include runs in which TACs represent a constant exploitation rate i.e. percentage of the measured spawning srock biomass (0.4).