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Fisheries Impact Assessment – A Good, Bad and Ugly Approach  
to Precautionary Shrimp Stock Management

by

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**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 parameterised 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 organisations 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 formalisation 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). EIA methods offer 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. In 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 therefore fall in the realm of metaphysics and shamanism (Corkett, 1997).

An EIA of a shrimp stock, here termed a Fisheries Impact Assessment (FIA) can be considered more precautionary than the status quo when presented in the form of a simple checklist or matrix because it forces an evaluation that takes all available factors into account. Results which may involve complex individual measurements (temperature, biomass, recruitment), theoretical considerations (s-r), or anecdotal information (industry input) are each distilled down to a simple scale ranging from good to bad e.g. "red", "amber", and "green" can correspond to a decline, no change, or improvement in spawning stock biomass, environmental conditions, catch rates, etc. When considered as numbers e.g. -1, 0 and 1, scores for individual measurements can be summed into a single score, which carries the flavour of the current stock situation. In EIAs, while the best available information is used wherever possible, the accuracy of individual components are less important than the inclusion and consideration of ALL possible sources of information in the final synthesis. The overall assessment is believed to be reasonably sound, despite often-flawed individual components, an approach that is intuitively appealing to stock assessment biologists. However, EIA results are generally not used quantitatively e.g. a threshold score is not associated with approval or rejection of a development project, but rather as a guide for management decisions. In fisheries, an annual FIA will eventually result in a time series of scores that should reflect trends in stock dynamics. If this method is adopted, pressure from fisheries managers for hard numbers, including the amount of an increase or decrease in a TAC if the FIA is "good" or "bad", will inevitably lead to the question: can FIA scores be linked to simple "harvest rules" which are "more precautionary" than a more *ad hoc* approach of setting a TAC? This paper attempts to answer this question using a simple simulation model of a shrimp stock and fishery.

### Methods

FIA assessments were simulated using an age-based spreadsheet model of a shrimp population with the following properties:

1. Natural mortalities of 0.5 for ages 1-5 and 1.5 for age 6. All age 6 animals die after spawning.
2. All age 4 are mature males, all age 5-6 mature females.
3. Egg production of ages 5 and 6 based on average size and fecundity from literature.
4. Fishing mortality based on catch at age from commercial sampling (Scotian Shelf)
5. 2 recruitment thresholds, above first threshold ( $R_{r-s}$ ) recruitment is constant, below it is related to SSB; recruitment fails below a second threshold ( $R_{crash}$ ).
6. Change in environment simulated through change in natural mortality.

Among other things the model does not take into consideration:

1. Changes in catch composition or selectivity as abundance, age/size composition changes.
2. Changes in the ability of the fleet to catch the TAC due to decreasing abundance and catch rates.
3. Density dependant effects, e.g. changes in size at sex change, growth rates.
4. Uncertainty in monitoring results.
5. Random patterns of change in recruitment/environment.
6. Opposing influences of environmental (e.g. temperature effects on recruitment) and ecological (e.g. age specific natural mortality from predation).

The annual "assessments" considered 7 parameters including:

1. Recruitment (as determined by a pre-recruit survey at age 2)
2. Spawning stock biomass as determined from a research survey or CPUE
3. Population composition from survey and/or commercial catch sampling – the number of year-classes contributing at least 10% of the population
4. Predation mortality
5. Environmental conditions (e.g. temperature)
6. Average age of the population
7. Sex ratio.

Each parameter was assigned a value of  $-1$ ,  $0$  or  $1$  depending on whether it represented a decrease, no change, or increase in the health of the stock each year. Predation and environmental conditions were combined as one evaluation. Decreases and increases in average age were always scored  $-1$  and  $1$  respectively, although increases in age could signal recruitment failure under some situations. Changes in sex ratio were considered a destabilising factor and were scored  $-1$  if they changed significantly in either direction.

Assessments and management proceeded as follows: Fishing was started at a TAC representing 30% of the spawning biomass. Exploitation rates of between 30-40% were used widely in Canada as targets in the past, but fell out of favour when some fisheries exceeded set limits without apparent negative affects (Mohn *et al.*, 1992). It was assumed that the simulated population could sustain some higher level of exploitation, to be determined by increasing the TAC (as a percentage of the perceived spawning stock biomass) gradually if monitoring and assessment results warranted. The FIA "score", simply representing the sum of the individual scores, were arbitrarily scaled to the exploitation rate/TAC increase or decrease using a precautionary approach where "experimental" increases were relatively modest compared to rapid mitigative decreases to prevent stock collapse and a destabilised population structure as follows:

SCORE	INCREASE/DECREASE
$>0$	$+33\%r$
$0$	$0$
$-1$ to $-2$	$-25\%$
$-2$ to $-4$	$-50\%$
$<-4$	$-100\%$

Thus the "good", no change, and "bad" scores of individual FIA components were rendered precautionary by limiting the overall score and resulting management actions to "good", "bad" and "ugly" choices.

Since trends in a low information fishery tend to be recognised and are acted upon only after a number of years, increases or decreases in exploitation rates were applied only every 3 years, and were based on the 3 year average FIA score.

## Results

Figure 1 represents the simulated population during a 50 year period without fishing, including a period of stable environmental conditions and high biomass, a period with deteriorating environmental/ecological conditions simulated by increasing natural mortality and reflected in decreasing recruitment and spawning stock biomass, and a subsequent period of recovery. The magnitude of change in biomass is similar to those observed on the Scotian Shelf in the absence of significant fishing pressure.

Figure 2 simulates a fishery with very limited information and precaution. In Fig. 2A fishing is conducted with a constant, high exploitation rate of 60% of the spawning stock. The population stabilises during stable environmental conditions and constant recruitment, but fishing brings SSB below  $R_{s-r}$  during the period of poor environmental conditions and eventually below  $R_{crash}$ , with extinction by 2025. In Fig. 2B a lower constant exploitation rate of 30% results in substantially lower catches over the period of the fishery, but the end result is the same, extinction during poor environmental conditions, only 4 years later (2029). In Fig. 2C very high initial exploitation rates result in rapid deterioration into a recruitment fishery. Exploitation rates during periods of increased recruitment are then limited to half of those during the high biomass period. Total catches are slightly less than the high exploitation scenario of Fig. 2A.

Figure 3 simulates a fishery with precautionary harvest control rules based on FIA scores and annual assessments from full annual monitoring. In Fig. 3A favourable assessments during the high biomass period raise exploitation rates to very high levels just prior to the environmental downturn. The decrease during the unfavourable period is not rapid enough to prevent recruitment failure in a number of year-classes. Increases after the downturn are premature and exacerbate the problem. Total catches are slightly less than the scenario depicted in Fig. 2C. In Fig. 3B a ceiling exploitation rate results in a more rapid decrease during the environmental downturn,

avoiding  $R_{\text{crash}}$ . Exploitation rate is increased to initial levels only after the stock has returned to levels associated with the previous period of stability. The population remains stable throughout the period and catches are the highest of the scenarios presented.

The simulation shown in Fig. 3C represents a more realistic, cyclical model of change in natural mortality/environment. Monitoring detects the initial decrease and application of the harvest rules results in a fishing moratorium and avoidance of extinction. Increases during the subsequent period of improving environmental conditions appear to result in a stable population, but decreases during the next environmental decline are not fast enough to avoid extinction.

### Discussion

The model generally behaves in ways, which are characteristic of shrimp populations and how they are thought to respond to fishing, including resilience to high levels of exploitation, and rapid responses to change in environmental conditions and fishing mortality. Unfortunately, much of what is known about shrimp population dynamics comes from models. Notwithstanding this circular validation, the crudeness of the model, the assumption of a stock-recruitment relationship and the arbitrary nature of its parameters, etc., the simulations do provide some insight into the problems of coupling FIA results to harvest control rules. Some observations:

1. Any rules set on a relatively new resource would necessarily be arbitrary, or based on experience with other stocks. In the absence of a time series of effort and abundance that covered periods of favourable and unfavourable environmental conditions, the levels of increase and decrease may be unduly influenced by socio-economic considerations.
2. The arbitrary rules set on the simulated stock were not precautionary enough to prevent destabilisation or collapse of the population; i.e. more rapid decreases and slower increases and/or ceilings on exploitation rates were necessary. In the real world, such large changes are probably unrealistic. Still, it suggests that flexibility to rapid increases and decreases in exploitation rates may be a key element of a precautionary management scheme for shrimp.
3. In the real world a 3-year period before management action is probably a minimum to establish a convincing trend in a low information fishery with high variability of abundance estimates. In the simulations this was too slow to prevent destabilisation or collapse in some situations. This implies that accurate annual abundance estimates and decisive management actions are required during critical times. An *ad hoc* approach to setting quotas and changing current exploitation levels in combination with poor data is inherently indecisive. The institution of a simple set of rules similar to those used in the simulation will, at least, counter such indecision and therefor is more precautionary than the FIA alone.
4. A clear definition of overfishing is required in this system, i.e. what is the FIA trying to avoid? Prevention of a destabilising population structure and a fishery based on a limited number of good recruiting year-classes may be one option. This implies a much reduced level of fishing if environmental conditions alone have resulted in a recruitment fishery.
5. The model used in this paper is probably more sensitive to exploitation than a real shrimp population by ignoring, among others, density dependant and spatial effect responses by the population and the fishing fleet. The actions/rules needed to avoid stock collapse or year-class failure are probably more extreme than would actually be required. More sophisticated modelling may well result in more reasonable precautionary control rules.
6. In an assessment and management regime based on harvest rules linked to FIA scores it is not possible to be "more precautionary" with less information. More caution implies the ability to recognise danger (i.e. good monitoring) and the ability to avoid it (i.e. knowledge of how the stock will react to fishing and suitable control of the fishery).

### References

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- MOHN, R. K., D. G. PARSONS, and L. SAVARD. 1992. Report of Canadian Atlantic Scientific advisory Committee, Invertebrates and Marine Plants Subcommittee, Shrimp Management Alternatives, December 5-8, 1989, Ottawa, Canada. *Can. Tech. Rep. Fish. Aquat. Sci.*, **1884**. 30 p.

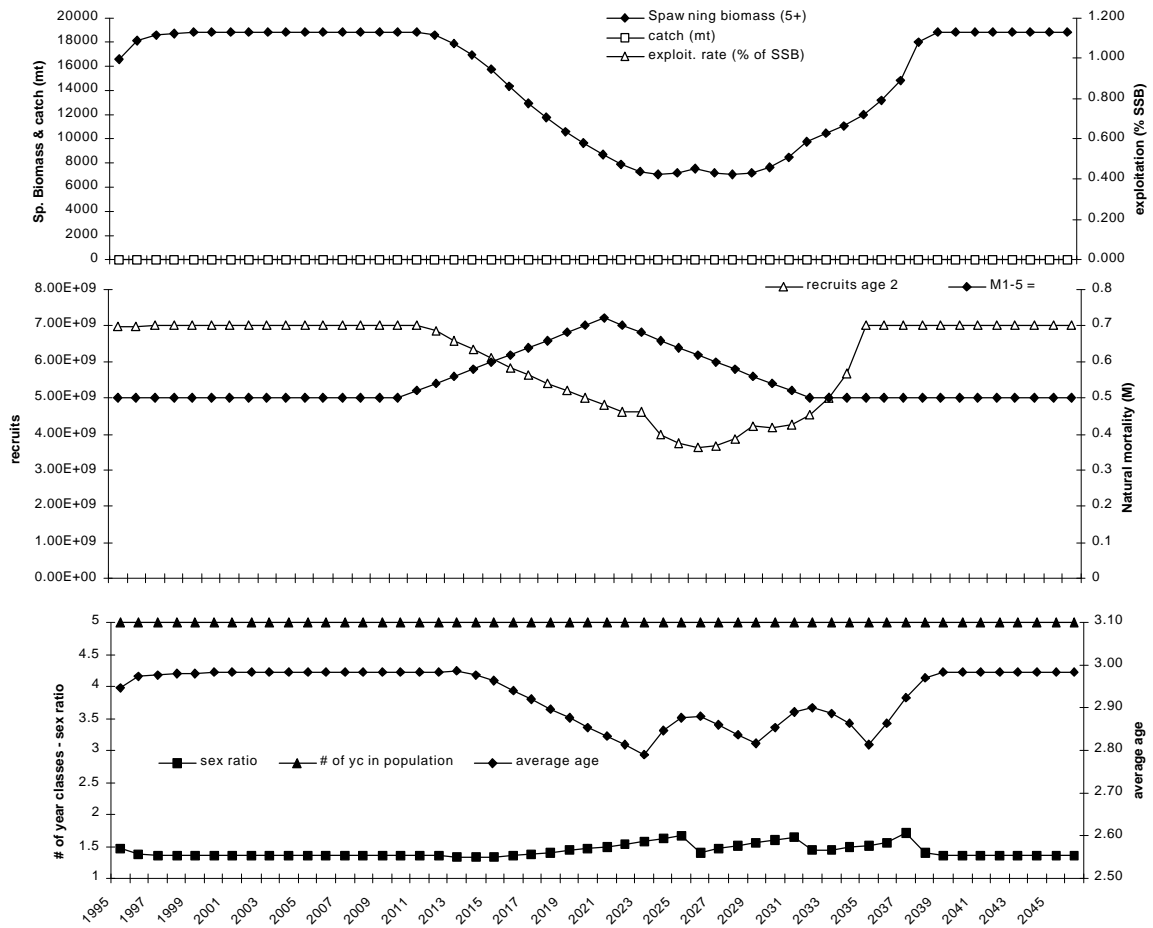


Fig. 1. Model results with no fishing

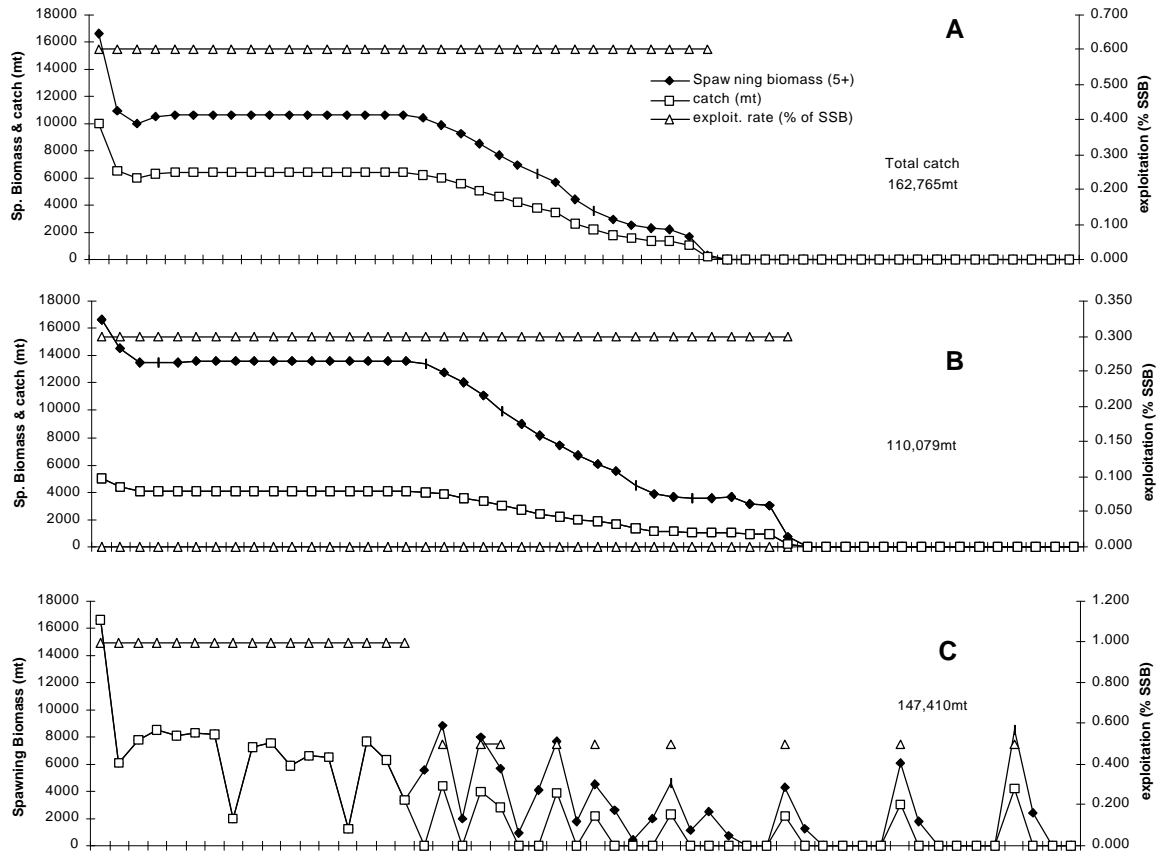


Fig. 2. Fishing without applying precautionary harvest rules.

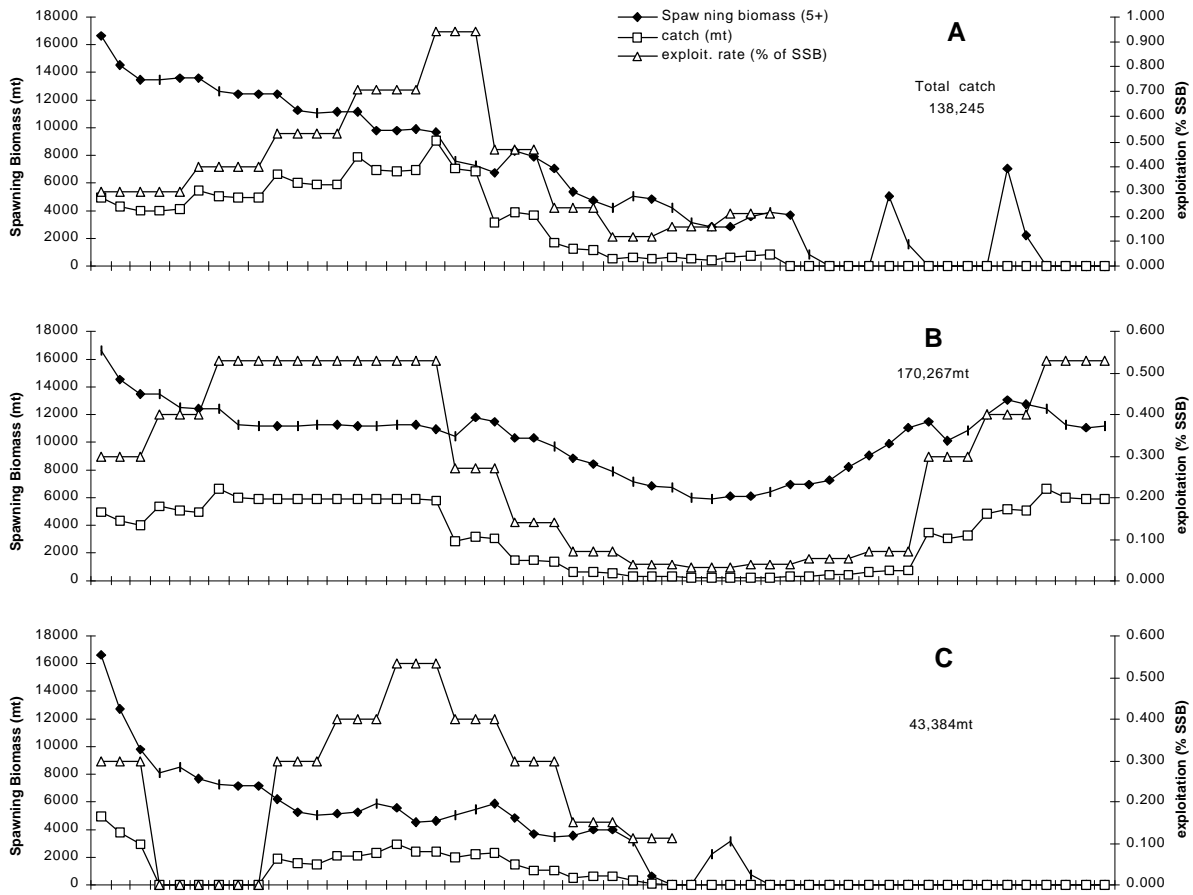


Fig. 3. Fishing with harvest control rules linked to Fisheries Impact Assessment, including A. rules only; B. rules plus ceiling on exploitation rate, after decline return to initial exploitation rate only after SSB recovers to previous levels, and C. cyclical environmental changes.