NAFO Sci. Coun. Studies, 16: 133–135

Stability and Sustainability of Harvesting Strategies in a Modeled Fishery

R. Mohn
Marine Fish Division, Department of Fisheries and Oceans
Bedford Institute of Oceanography, P. O. Box 1006
Dartmouth, Nova Scotia, Canada B2Y 4A2

Abstract

Fishermen have been asking for quotas that are fixed over a period of years to "stabilize" the fishery. The practice in most Canadian groundfish stocks is to annually reassess the resource, apply a target fishing mortality and update the quota. This should allow the industry to follow booms in the resource and similarly to protect it during busts. There appears to be a sort of trade-off between stability, in the sense of constant quotas over a period of time, and optimizing the catch annually. The term stability is also misleading. If constant quotas are in effect while the resource is varying, then effort will have to vary to meet the quota. Fixing one aspect of the fishery (catch, effort or escapement) means that the others will vary. In general, stability with respect to one of these elements means variation in the others. The question is then which sorts of variability are the least disruptive to the industry.

To study these, a traditional age-structured catch projection model is expanded to include coarse economic considerations and quota setting. It also uses a stock-recruitment function with an environmental effect, which may be periodic or random, superimposed. The economic factors are costs of fishing and the effect of fleet revenue on fleet capacity. The model emphasizes the feedback control nature of an exploited resource. In general, a feedback control system has a reference target level, a process, an output and a sensor to compare the output with the target. The output is measured and compared to the target. Biological density dependent feedback is explicitly included in the model with a stock-recruit function. Economic feedback control is via the capacity of the fleet which depends upon profits. Finally, formal feedback controls are set by the management process. The three feedback loops of this model are at work simultaneously. The fishery is a common element of all three control loops. It is the intersection of the fleet and biological loops and the input for the management loop.

The model was based on Div. 4VX cod where 15 years of ages were included, and the fitted stock-recruitment curve was mildly domed. Recruitment was mediated by an environmental signal which is random (log-normal) with a range of approximately an order of magnitude and a coefficient of variation of 40%. Catch was modeled with Baranov's catch equation and selectivity taken from a recent assessment. Fleet capacity was defined as the potential effort that the fleet may exert. The actual effort exerted in a year was the lesser of the capacity and effort limits imposed by the management regime (if any). Three types of management regimes were used with the model: (i) target fishing mortality, (ii) target catch, and (iii) target escapement. Results using target escapement strategies were not reported as in general they were much less stable than the other two types. The target fishing mortality was mediated through a catch level as is the practice for many Canadian groundfish fisheries. The profit was defined for the fleet with a fixed cost of $25,000 and a variable cost of $65,000 per boat and a labour cost of 40% of the gross revenue. Capacity responded to profits by going up or down by a maximum of 5% per year. The capacity responded weakly to the profit with a sigmoid function with a standard deviation of a 10% profit rate. (That is a 10% profit would cause a 3.4% increase in capacity, a 20% profit, a 4.8% increase, etc.) One should note that this represents a negative feedback in that more boats will tend to have lower profit rates which decreases capacity and the system will stabilize. Neither opportunity costs nor net present values (discounted future returns) were considered in these calculations.

Results were presented in the form of equilibrium plots, sensitivity analysis, risk analysis and power spectra. The equilibrium plots form a link to traditional analyses such as yield-per-recruit and stock-recruit relationships. The sensitivity plots help reveal the interconnectedness of the modeled system. Risk analysis emphasizes the repercussions of various harvesting strategies and helps define overfishing. Feedback control systems tend to oscillate with a natural or resonant frequency and spectral analysis are an accepted tool for the investigation of oscillating systems.

Results from the fishery model, when the feedback controls are not operating, are analogous to a standard yield and biomass-per-recuit calculation. It is a production model with the recruitment constrained to a fixed level. $F_{0.1}$ and F_{max} are approximately 0.2 and 0.4 respectively which agrees with accepted values. The maximum profit point is about midway between $F_{0.1}$ and F_{max}. When only the biological feedback control is operant the biomass does not vary as much as when it was unregulated, as expected. $F_{0.1}$ and F_{max} are greatly increased from the traditional values to approximately 0.6 and 0.9 respectively.

When only the economic feedback control was active the biological variables were not affected. Moreover, the effort level which produced the maximum profit was not appreciably affected, although the average profits over the entire range of Fs were higher because the fleet fished less when it was uneconomic to do so. When both biological and economic feedback control were operating, the maximum profit point was at an F of about 0.6, much higher than $F_{0.1}$ or F_{max} from a traditional yield-per-recruit analysis.

Sensitivity analysis showed that profits were the most sensitive variable of those tested. For example, a 10% increase in the natural mortality shows a 30% negative effect on profits. The sensitivity to a 10% increase in the target F of 0.2 was a 5% increase in profits while it has only about a 2% negative impact on the biomass. This suggested that $F_{0.1}$ is too conservative.

Risk analysis with constant catch strategies showed that high levels (compared to $F_{0.1}$ or F_{max}) of effort were required to induce stock collapse, above twice F_{max}. Annual catch and effort values for a hybrid strategy, when the TAC was updated only every 5 years, showed less stability in profits than either constant catch or constant effort strategies. Even at a relatively low effort, which corresponded to an F of 0.4, a large scatter is seen in both catch and effort. Locking the TAC for 5-year periods destabilized the feedback control. An overestimated TAC for one 5-year period was followed by an underestimate for the next. Using the geometric mean recruitment for the first three age-classes was seen to stabilize the excursions, particularly in catch.

The addition of feedback controls into fishery models was seen to dramatically affect management strategies. Biological feedbacks have been included in production models for many years. They have less commonly been combined with economic and management controls. The choice of model had an effect of at least similar magnitude to the precision of the model parameters. This situation may be thought of an analog to an accuracy *versus* precision situation. Doubling the precision of a traditional yield-per-recruit model will not help if biological control of recruitment and growth are important factors and are not incorporated.

The constant catch strategy was least disruptive in terms of annual variation in profits. A hybrid strategy where catch is constant for 5 years and then re-assessed to a target F showed a higher variation in catch/effort than either pure catch or effort strategies, especially at higher Fs. The results suggest that such a method would perform much better if it incorporated some damping. For example, a weighted average of the new TAC estimate and the old one. Damping may also be included by using the average recruitment when estimating TACs.

These results were not meant to be definitive. Rather, they are meant to engender more interest in the development of models which incorporate as much biological and economic information as possible. Even if such factors cannot be completely defined, estimates can be derived to demonstrate the magnitude of potential impacts and in which directions biases might be expected.