Optimal Effort Controls for the Multispecies Groundfish Complex in New England

Daniel S. Holland[1] and Jean-Jacques Maguire
School for Marine Science and Technology, University of Massachusetts Dartmouth

Abstract: It is rarely possible or desirable to maintain a constant target fishing mortality rate for each individual stock in a multispecies fishery. Preventing overfishing of all stocks at all times will often be in conflict with attainment of optimal yield for the fishery. This paper presents a retrospective analysis and future projections of harvests and revenues for the Northeast Multispecies groundfish fishery under alternative control rules on nominal fishing effort. An age structured model of the ten primary groundfish stocks is used to project stock size and harvests by stock. Revenues are projected using ex-vessel price models estimated for each species and market category. Overall nominal effort is assumed to be perfectly controlled. However, stock and age specific catchability coefficients, which transform nominal effort into fishing mortality, are allowed to vary across cohorts and over time reflecting the historically observed variation in those parameters. Various static levels of nominal effort are compared with controls that maintain biomass weighted fishing mortality at or below threshold levels for all stocks in all years. The thresholds used are the current overfishing definitions for these stocks which, in most cases are the levels believed to correspond with maximum sustainable yield. Results show that strict controls on effort designed to prevent overfishing on individual stocks provides significantly lower and more variable revenues than constant effort levels designed to maximize revenues for the overall complex. Trade-offs between economic and biological risks are discussed in light of these modeling results.

Keywords: Multispecies, bioeconomic model, Georges Bank, Gulf of Maine, groundfish

INTRODUCTION

The Northeast multispecies groundfish fishery prosecuted on Georges Bank, in the Gulf of Maine and Southern New England is currently in a rebuilding state after the collapse of several principal stocks in the early 1990s (NDSDWG 2001). Following the collapse, a variety of management measures were implemented to promote the recovery of the depleted stocks. These include a moratorium on entry, substantial reductions in the number of days individuals can fish, large year-round and seasonal area closures, and increases in mesh sizes (NEFMC 1996). These measures resulted in significant reductions in fishing mortality on all stocks and most are rebuilding (NDSDWG 2001). Despite the recovery trend of the fishery, significant additional reductions in nominal fishing effort may still required. Legal mandates embodied in the Magnuson-Stevens Fishery Conservation and Management Act require managers to end overfishing on individual stocks and rebuild overfished stocks. Reductions in fishing effort are required if fishing mortality exceeds a threshold (F_{msy} for most stocks) or if stock biomass falls below a threshold. While fishing mortality is now acceptable or nearly so for several stocks, it is not for others, and spawning stock biomass (SSB) remains well below targets for several stocks (NDSDWG 2001).

Overfishing definitions for each stock are closely related to the fishing mortality expected to produce maximum sustainable yield (WGRBR 2002). However, because only the nominal effort applied to the entire complex is directly managed, it is difficult to maintain fishing mortality at overfishing thresholds for all stocks simultaneously. Eliminating overfishing on all stocks may require reducing fishing mortality far below targets for some stocks, thereby reducing revenues for the overall complex. Alternatively, setting fishing effort to maximize sustainable revenues for the overall complex will almost certainly result in overfishing of some stocks in some years. Although this conundrum, requiring balancing of economic and biological risks, has long been recognized (e.g., Larkin 1977), we continue to address it in an ad-hoc fashion rather than develop an explicit framework for assessing the necessary trade-offs.

This paper employs a type of retrospective analysis to assess alternative control rules on fishing effort for the overall Northeast multispecies groundfish fishery. Various static levels of nominal effort are compared with controls that keep fishing mortality at or below thresholds for all stocks. Simulations are also run with nominal effort set separately for each stock to maintain F_{msy} for each stocks. While the means to tune relative fishing mortality across stocks is limited in reality, this scenario provides a benchmark to compare outcomes from more feasible management scenarios. Trade-offs between economic and biological risks are discussed in light of these modeling results.

This analysis complements an earlier study by Overholtz et al. (1995) which simulated effort controls on a subset of these stocks, but did not consider the annual and interstock variation in fishing mortality and ramifications for eliminating overfishing on individual stocks. It also differs from the Overholtz et al. analysis in that it looks at what could have occurred in the past and uses observed recruitment rather than predicting recruitment using a parametric stock-recruitment function.

METHODS

A bioeconomic model is used to simulate stocks sizes, harvests and revenues from 1982 to 1997[2] assuming the observed recruitment and relative catchability of stocks (as estimated by VPA)[3], but allowing for alternative levels of nominal fishing effort. The analysis employs age-structured models of ten New England groundfish stocks. These include the Georges Bank cod (*Gadus morhua*), haddock (*Melanogramus aeglefinus*), winter flounder (*Pleuronectes americanus*) and yellowtail flounder (*Pleuronectes ferrugineus*) stocks, the Gulf of Maine cod stock, the Southern New England winter flounder and yellowtail flounder stocks, the Cape Cod yellowtail flounder stock and the Gulf of Maine/Georges Bank witch flounder (*Gyptocephalus cynoglossus*) and American plaice (*Hippoglossoides platessoides*) stocks. For all stocks other than Cape Cod yellowtail flounder, the model is initialized with the 1982 numbers at age from the published virtual population analysis (VPA) based assessments for each stock. The Cape Cod yellowtail stock is modeled only from 1985 forward since the assessment for that stock only goes back to 1985. The number of age-one fish in all years modeled corresponds with the observed recruitment reported in the stock assessments. For age two and above, the number of individuals N of stock i and age j in year t is endogenous to the model:

(1)

Following Overholtz et al. (1995), cohorts are tracked through age fifteen after which the survival rate is assumed to be zero. Total mortality for each cohort in each stock, $Z_{i,j,t}$, is the sum of fishing and natural mortality. Consistent with the VPA assessment for each stock, natural mortality is set at an instantaneous rate of 0.20 for all stocks except witch flounder which is 0.15. Cohort and species specific fishing mortality is calculated as:

(2)

where $F^{0}_{,i,j,t}$ are the age specific fishing mortalities reported in the VPA assessments for each stock and $E_{i,t}$ is a scalar used to multiply the matrix of fishing mortalities for each stock. The underlying assumption is that the fishermen's targeting and the resulting relative catchability of the different cohorts, and stocks would have remained the same regardless of nominal fishing effort. The relative catchability of different stocks after 1993 was heavily influenced by a complex and changing set of regulations, and thus confounds the assessment of simple effort controls. Consequently, the model employs the average relative catchability during the 1990-1993 period to transform nominal effort into fishing mortality for the 1994-1997 period.

Three alterative scenarios are investigated. The first assumes that nominal effort is held constant for the overall complex over the entire period such that $E_{i,t}$ is equal for all i and t. The relative mortality of each stock and cohort correspond directly with the VPA assessments of each stock. A full range of values for the effort scalar is investigated.

The second scenario assumes only overall nominal effort is controlled, but it is adjusted downward each year to the extent required to maintain fishing mortality at or below thresholds for all stocks. $E_{i,t}$ are constrained to be equal for all stocks in a given year but may vary over time. Consequently fishing morality for some stocks may be set well below thresholds in some or all years, but overfishing (according to legal definitions) does not occur for any stock. The controls on overfishing are based on fully recruited fishing mortality for all stocks except Georges Bank winter flounder for which the overfishing threshold is based on biomass weighted fishing mortality.

The third scenario adjusts the effort scalar for each stock in each year to achieve the target fishing mortality that corresponds with F_{msy}. As with the previous scenarios, the vector of partial recruitment for each stock corresponds with the VPA, but each $E_{i,t}$ is determined independently.

The Baranov catch equation is used to calculate catch as:

(3)

where $C_{i,j,t}$ is the catch in numbers from the *ith* stock and *jth* cohort. Harvest weight, $H_{i,j,t}$ from each cohort for each stock is calculated by multiplying numbers of individuals caught by their age specific weights, $W_{i,j,t}$ which are the observed catch-weights-at-age reported in the stock assessments for each stock.

(4)

Annual revenues for each stocks are calculated using projected catches and prices for each stock and cohort.

(5)

Where $P_{i,j,t}$ is the species and market category specific price associated with that stock and cohort. As described in the next section, these prices are determined endogenously by the model as function of annual projected catches aggregated by species and market category and a time trend. For the purpose of predicting and assigning prices, catches from different stocks of the same species and from different cohorts are grouped into the market category into which each cohort falls based on the average weight at age for that stock and the cull used by the Portland Fish Exchange (see table 1). Because the price models are estimated with prices adjusted to year 2000 values, the projected revenues from the model are in 2000 dollars.

To compare the present value of alternative management scenarios, revenues are discounted back to 1982 using a discount rate, *r*, of 0.04[4]:

(6)

where PVR is the present value (in 1982) of the revenue stream including the value of the residual stock. Different management policies leave different biomass of varying age structures at the end of the simulation policy, and it is important to consider the value of this residual stock. Thus, the value of the residual stock in 1997 is calculated, and added to the discounted revenue stream projections from the 1982-1997 period. The residual value is calculated by running the model forward with no added recruitment assuming the 1997 fishing mortality vector until the residual stock is depleted. Annual yields are multiplied by 1997 prices and discounted back to 1982.

(7)

1997 prices are used to estimate residual value since the harvest quantities in the residual yield projections are much lower that would be projected if the model continued to add recruits. This would tend to unduly inflate price projections. The assumption is made that prices in the final year of the simulation are indicative of prices that would be expected to prevail if the same harvest strategy were continued in subsequent years.

Price Models

Price models are estimated for each species and market category using data on landings and value of landings from the Northeast Fishery Science Center's commercial fisheries data for the years 1978 through 2000. Price models for four market categories of cod and two market categories of haddock are estimated as a system using a seemingly unrelated linear regression (SUR). Price models for four flatfish species are estimated as a separate (SUR) system. The flatfish system includes price equations for two market categories of yellowtail flounder, witch flounder and plaice and three categories of winter flounder (the largest is referred to as lemon sole).

The specifications used for the individual equations were linear-log (i.e. price per kilogram is regressed against the natural logs of the regressors). This allows for a non-linear demand curve without imposing constant elasticity. Value data is adjusted to year 2000 values using the US GDP deflator and, consequently, predicted prices are in 2000 dollars. In most cases, the natural log of real personal disposable income (RPDI) was used in place of an intercept. This effectively creates an intercept that shifts up over time capturing the positive time trend in real prices for most of the species. Landings quantities are in metric tons live weight. In some cases the "own" quantity variable with the highest predictive power is aggregate species landings while in other cases it is landings for that market category. In the case of cod prices most market categories are best predicted by landings of market size cod.

Despite parsimonious specifications with only two or three regressors, the price equations are highly significant with R-squares ranging from 0.72 to 0.95. All regressors in all equations are significant at the 0.05 level and most at the 0.01 level. First order autocorrelation was present and corrected for in both systems of equations. The estimated equations used to predict prices in the simulations and summary statistics for them are given in the equations below. For each year of the simulation, the model calculates the aggregate catch quantities by species and market category according the stock and species specific market categorization. These quantities are used in the price equations listed below to generate prices by species and market category for that year. The predicted prices are then multiplied by the associated catch quantities to calculate annual revenues.

RESULTS

The results from the first scenario indicate that nominal effort corresponding to 40 percent of that actually applied during the 1982-1997 period would have maximized the present value of fishery revenues with a PVR of $2.05 billion (Figure 1). Discounted cumulative revenues for the 1982-1997 period are maximized at marginally higher effort level of 46 percent, but the larger residual stock at the end of the period makes a more conservative policy more valuable. Coincidentally, the undiscounted sum of cumulative revenues (including the value of the residual stock) is also maximized with 60 percent effort reduction. Relative to no effort reduction, a 60 percent cut in effort reduces revenue in only the first three years. By year three, revenues are 95 percent of those associated with no effort reduction, and annual revenues range from 3 to 36 percent higher in subsequent years (Figure 2). The PVR with a 60 percent cut in effort is 9 percent higher than the PVR with no effort reduction which equals $1.77 billion.

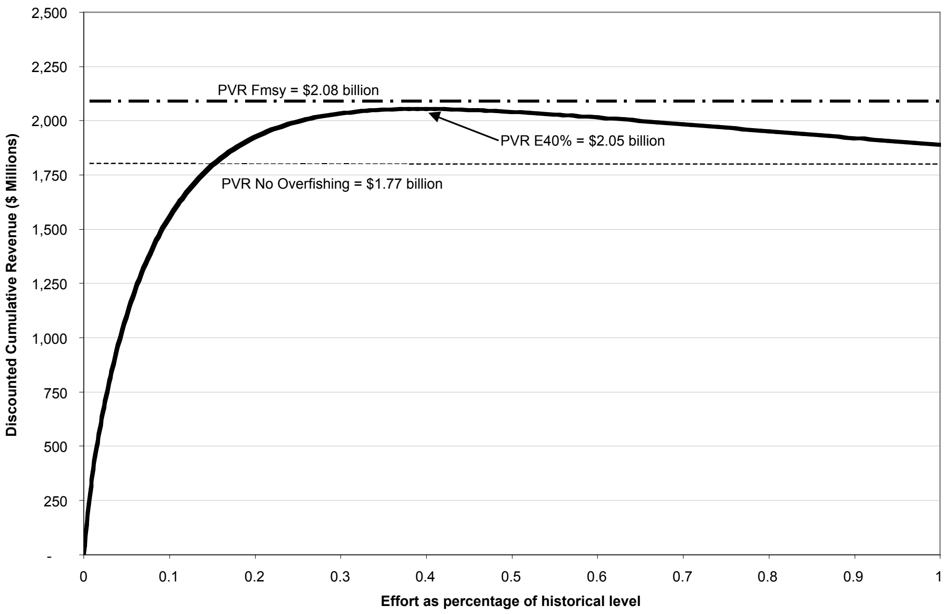

Fig. 1. Present value of revenues (PVR) for 1982-1997 plus the discounted value of the residual stock assuming alternative levels of nominal effort as a percentage of the historical level for scenario one (heavy black line) with static effort. PVR from scenario two with nominal effort adjusted each year to eliminate overfishing (thin dashed line). And PVR from scenario three with fishing mortality set at F_{msy} for all stocks in all years (alternating dashed-dotted line).

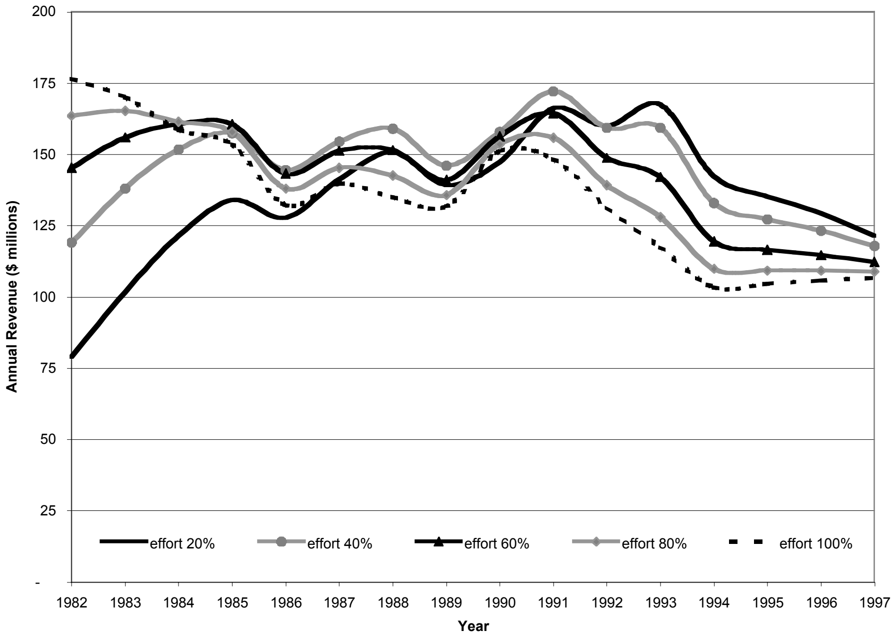

Fig. 2: Annual revenue for the 10 species complex given alternative levels of nominal effort held constant over time (scenario one).

Although a 60 percent cut in effort maximizes present value of revenues for the overall complex, the changes in total harvest for the period modeled vary greatly across stocks. As Figure 3 shows, harvests from both cod stocks are increased relative to harvests at 100 percent effort. However, total harvest falls for several of the flounder stocks and Georges Bank haddock. Harvests from all stocks, other than haddock would have increased with more moderate effort reductions in the range of 20 to 30 percent. Since recruitment is exogenous in these simulations, gains in harvest result purely from increasing yield per recruit by reducing growth overfishing. Relatively greater reductions in effort would have been required to eliminate growth overfishing on the cod stocks and the Cape Cod yellowtail flounder stock than for the other stocks. Thus, given the fixed relative mortalities in scenario 1, maximizing revenue from the cod stocks required sacrificing harvests from several other stocks.

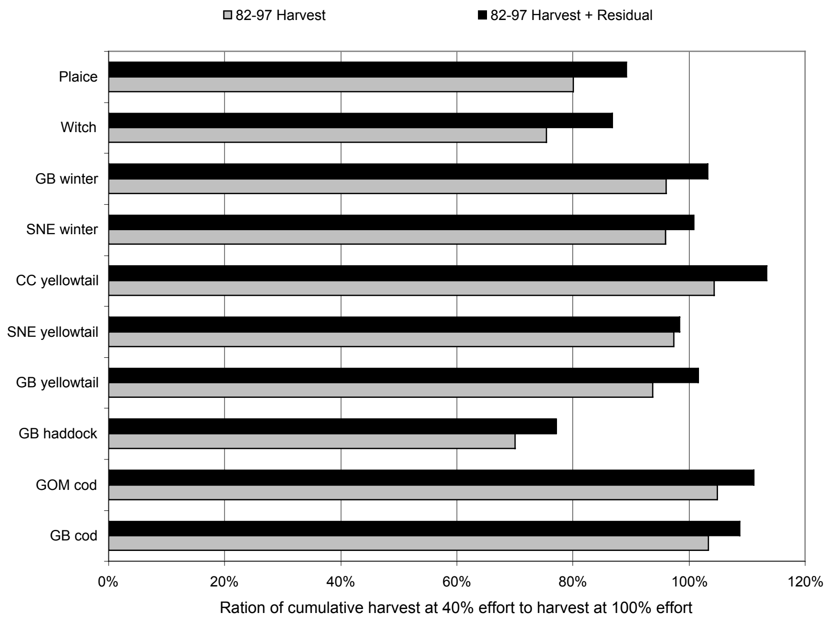

Fig. 3: Cumulative harvest at 40 percent effort as a percent of cumulative harvest with 100 percent effort from scenario one. Comparisons of cumulative harvests with and without inclusion of the residual harvest are shown.

It is informative to compare the potential revenues under simple controls on nominal effort (scenario one) to those achieved when effort is set independently for each stock (scenario three). It is unlikely that this could be achieved in practice, but the results provide a benchmark. The maximum PVR from scenario one is 98 percent of that achieved under scenario three when fishing mortality is at F_{msy} for all stocks in all years (Figure 1).

However, if it is not possible to adjust relative fishing mortality across stocks, strict adherence to overfishing guidelines (scenario two) would have required forgoing revenues to avoid overfishing. For any constant nominal effort, fishing mortality varies greatly both across stocks and over time. This results from a complex combination of factors including changes in age structure and relative availability of different stocks and targeting decisions of fishermen. When nominal effort is held constant at the rate that achieves maximum PVR, the fishing mortality for some stocks fluctuates above and below the overfishing threshold and results in chronic overfishing for many (Figure 4a,b). If only controls on nominal effort are available to managers (scenario 2), strict adherence to overfishing thresholds requires setting effort in any given year at from 7 to 21 percent of the observed effort levels. This results in a 14 percent drop in PVR (to \$1.77 billion) relative to the maximum achieved under scenario one (Figure 1) and results in high variability of nominal effort and revenues from one year to the next (Figure 5).

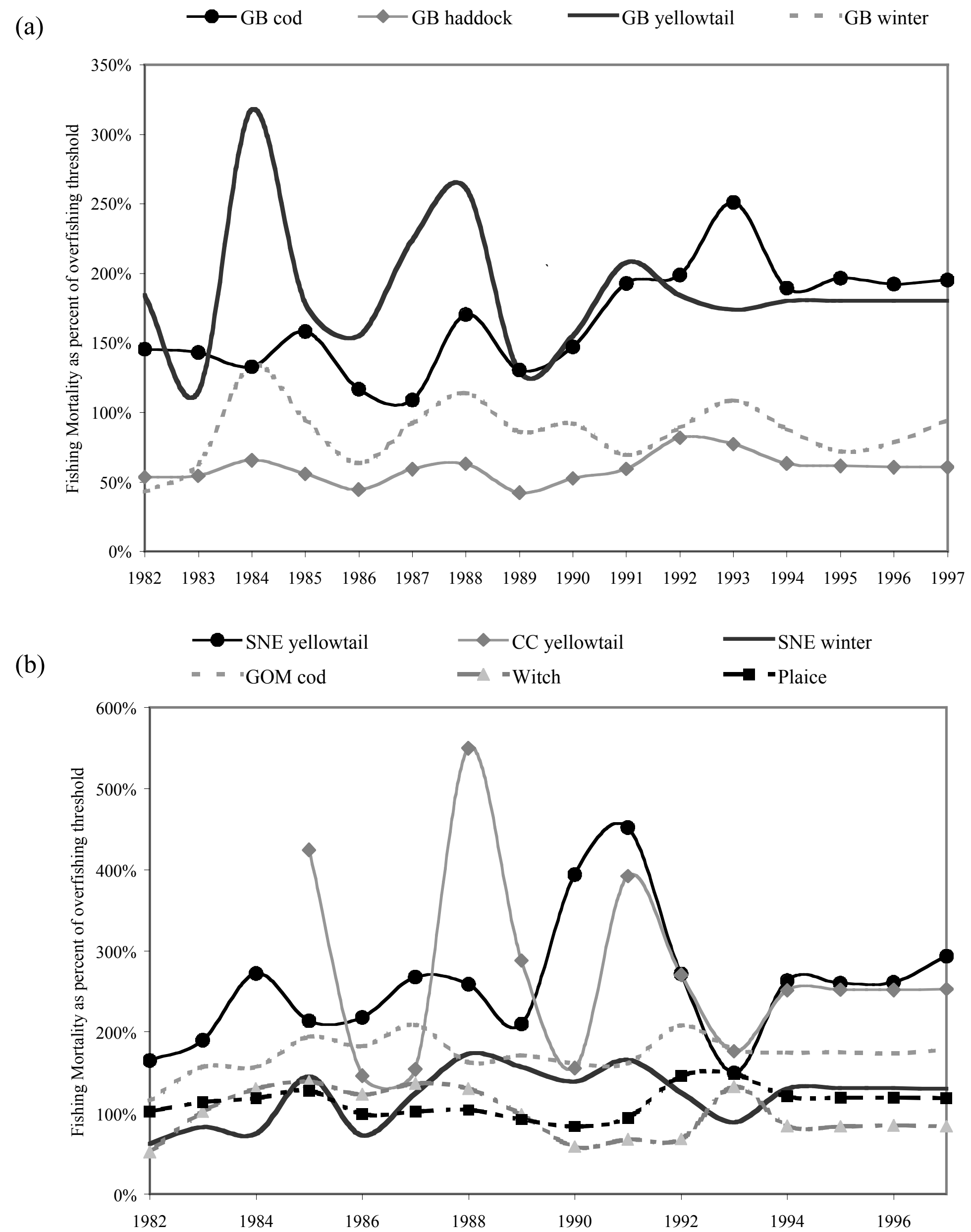

Fig. 4: Fishing mortality as a percentage of the overfishing threshold given a 60 percent cut in nominal effort (scenario two).

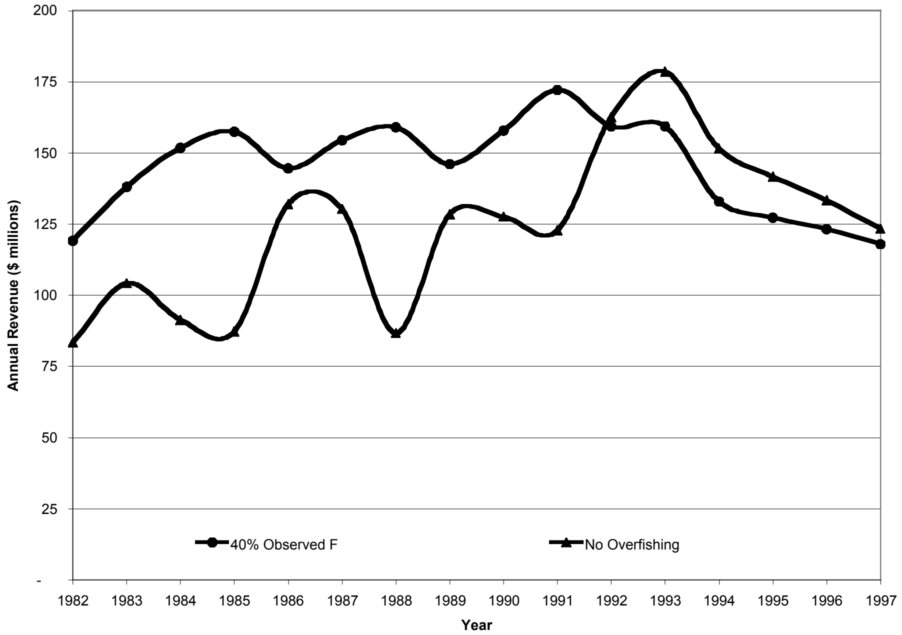

Fig. 5: Comparison of (a) annual revenue and (b) annual nominal effort for scenario one with 40 percent of observed effort and for scenario two with effort adjusted in each year to eliminate overfishing.

The increased variation in revenues under the no overfishing policy is important from an economic viewpoint. Variation in revenues is undesirable from a socio-economic standpoint since it increases financial risk and, assuming decreasing marginal utility of income, lowers utility for fishers. Given a downward sloping demand curve, variation in catches also provides lower total revenues from a given total catch than would the be realized with a more even distribution of catches over time. The coefficient of variation (CV)[5] of annual revenues from scenario two (CV =0.224) is nearly twice that of for scenario one with 40 percent effort (CV=0.115). Thus the conservative management strategy designed to reduce biological risk by strict adherence to overfishing definitions can be seen to significantly increase economic risk.

While it would have been possible to eliminate overfishing on all stocks with relatively moderate reductions in revenues it might not have been feasible to rebuild stocks to the target biomass. When effort is restricted to below overfishing thresholds in all years (scenario two), SSB for most stocks remains well below targets in 1997 (Figure 6). Three stocks remain below 50 percent of the target (Southern New England Yellowtail at 13 percent; Georges Bank Yellowtail and haddock at 31 percent and 24 percent respectively). It is notable that, even with a complete cessation of fishing, the SSB of Georges Bank haddock and Georges Bank yellowtail flounder do not rebuild to MSY within the 16 year span modeled due to insufficient recruitment. Haddock SSB reaches only 30 percent of the target by 1997.

The accuracy of the model projections is difficult to assess not least because it is unclear whether the projected changes in relative stocks sizes would have significantly altered targeting behavior and relative catch rates and higher stock sizes might have produced higher recruitment. The simulations are non stochastic and utilize the point estimates of recruitment, fishing mortality and catch weights from the published VPA analyses. The prices used are also the point estimates of predictions from the price models. While there is clearly uncertainty in the estimates of recruitment, fishing mortality, and prices, it is not feasible to model the uncertainty in the overall revenue stream from the multispecies system in a meaningful way because the covariance of error across different input variables, such as recruitment and fishing mortality rates, and endogenous model predictions, such as prices, is not known. Given these caveats, the results should be viewed as exemplary of what might have taken place rather than accurate predictions of what would have taken place under an effort reduction program. The relative differences between scenarios may be more informative than the nominal results.

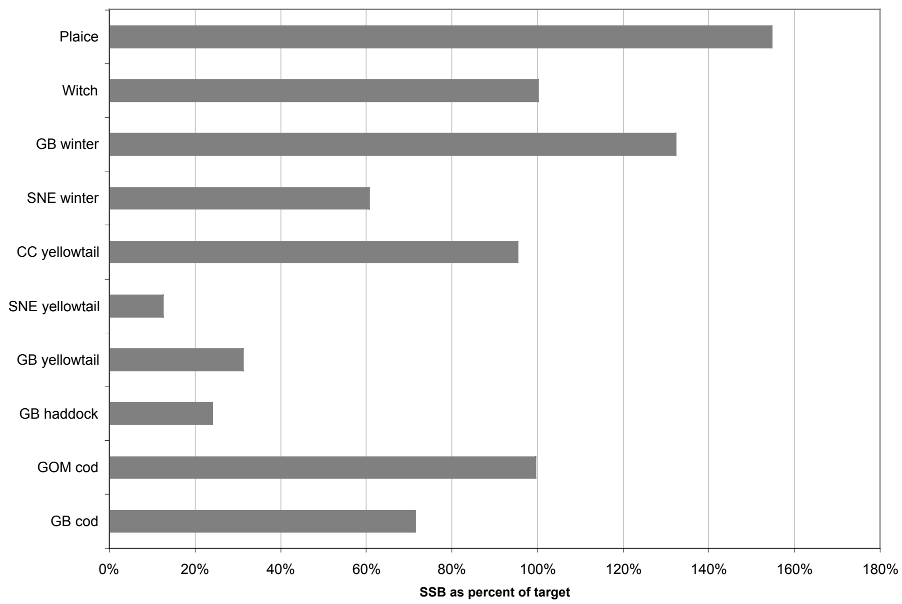

Fig. 6: Spawning stock biomass (SSB) in 1997 as a percentage of target biomass given nominal effort reductions to eliminate all overfishing (scenario two) for Georges Bank cod, haddock, yellowtail flounder and winter flounder[6], Witch flounder, American Plaice, Gulf of Maine Cod, Cape Cod Yellowtail flounder and Southern New England yellowtail flounder and winter flounder.

DISCUSSION

An unambiguous result from this analysis is that very substantial reductions in fishing effort in the 1980s and early 1990s would have significantly increased the value of the fishery even if the resulting increase in SSB had not led to increased recruitment. With a sixty percent reduction in nominal effort starting in 1982, annual revenues would have dipped below those actually realized for only the first three years and would have remained well above the observed revenues thereafter. The 9 percent increase in PVR associated with a 60 percent effort reduction would have been further augmented by a substantial reduction in harvest costs. The total days at sea for groundfish trips averaged around 93,000 during the 1982 to 1993 period, which would suggest a optimal level of around 37,000 days[7]. It is estimated that over 60,000 days were fished in 2001 and another 90,000 were allocated but not used. Thus, even with elimination of the latent effort associated with the unused days, this study suggests that further effort reductions might be required to optimize revenue for the complex.

A present value revenue curve for different levels of nominal effort was shown in Figure 1. Like a yield-per-recruit curve, it is relatively flat in the vicinity of the maximum so that a reduction in nominal effort results in a proportionately smaller reduction in value in the vicinity of maximum value. Since cost would be expected to fall along with nominal effort, maximum present value of net revenues (PVNR) would likely be achieved with effort well below that which maximizes the present value of gross revenues. Due to the lack of cost data, the effort that would maximize the PVNR was not explicitly modeled; however, an objective of maximizing PVNR would clearly dictate a more conservative strategy than that which maximizes PVR.

The magnitude of the cost reduction that would result from such a large effort reduction coincident with dramatic increase in catch rates is uncertain and would depend on a variety of factors. Effort reduction in the form of a reduction in fleet size would have resulted in a substantially greater reduction in costs than reductions in fishing by all vessels due to savings in fixed costs. However, even a cut in nominal effort implemented with a fleet size reduction would probably not yield a proportional reduction in cost since some costs (including crew) would be affected by the increased volume of fish handled per day fished. Nevertheless, it is instructive to consider the potential magnitude of such a cost reduction relative to the increase in revenues gained with the effort reduction. A vessel cost simulator developed by Lallemand and Gates (1998) suggests that an average trawler[8] fishing 200 days of the year in 1993 would have incurred costs (including fixed costs and the opportunity costs of labor for crew and captain) equal to over 90 percent of its gross revenues. If this ratio held true for the fleet as a whole, a sixty percent cut effort might result in cost savings up to six times the magnitude of revenue gains.

A primary objective of this analysis was to compare alternative control rules on fishing effort. The differences in results under alternative control rules are moderate relative to those resulting from effort reduction, but they are instructive nevertheless. In single-species fisheries, maintaining a precautionary fishing mortality such as $F_{0.1}$ generally results in relatively modest reductions in annual harvests and may actually increase net profits relative to F_{msy} since harvest costs are reduced[9]. However, maintaining precautionary or threshold fishing effort for individual stocks in a multispecies fishery may lead to significant reductions in overall revenues and increase variability of revenues if it is not possible to tune catches of individual stocks. Attempting to maintain SSB in the vicinity of SSB_{msy} for each individual stock is even more problematic due to large fluctuations in recruitment that may be largely independent of fishing pressure.

This retrospective analysis of the Northeast multispecies groundfish fishery demonstrates the dilemma managers must face in balancing biological risks and economic concerns. Strict application of current control rules on individual stocks might have significantly lowered total revenue for the overall complex during the period studied and would have increased its annual variation. It is quite possible that a more conservative strategy might have resulted in higher recruitment for otherwise overfished stocks thereby offsetting losses from over constraining fishing on some stocks. The answer to that question depends on the relative importance of stock size and environmental factors in determining recruitment and deserves further study.

The Northeast multispecies groundfish fishery has been rebuilding from a depleted state for the last several years (NESDWG 2001). Nominal effort and fishing mortality have been reduced significantly. Effort is still be above targets for some stocks (Brodziak 2002), and over capacity and latent effort continue to threaten the biological and economic viability of the fishery. However, strict application of control rules regarding overfishing and biomass thresholds would have and will likely continue to require reductions in effort beyond what is economically optimal unless better ways can be found to shift effort from weaker to stronger stocks. This is exemplified by the biological advice provided by Northeast Fishery Science Center staff in June 2002. This advice calculates the reductions in fishing mortality from 2001 levels necessary to rebuild stocks and eliminate overfishing. Substantial reductions are required for some stocks (e.g., reductions of 94 percent for Cape Cod yellowtail flounder, 78 percent for Gulf of Maine cod, and 65 percent for Georges Bank cod), but mortality on several important stocks could be increased (e.g., increases of 11 percent for Georges Bank haddock and 16 percent for Georges Bank yellowtail flounder) (Brodziak 2002). It may not possible, and perhaps not desirable to try to tune fishing mortality on every stock. Furthermore, it may not be possible to achieve biomass targets for all stocks simultaneously due to biological interactions between stocks or cohorts (e.g., predator prey relationships or cannibalism).

The tools currently used to tune relative catches across stocks (i.e., closed areas and trip limits) are ineffective and inefficient. Trips limits cause regulatory discards, and closed areas, which are designed primarily to reduce efficiency rather than protect habitat or juvenile populations, have increased the cost of taking a given total catch (Holland 2000). It is debatable whether stock specific total quotas would improve the situation since individual fishers would not have incentives to shift targeting behavior until they were exceeded. Individual quotas (IQs) might provide the appropriate incentives to shift effort to less heavily fished stocks, but new IQ programs are not currently allowed under US law and are unpopular with the fishing industry in the Northeast. Even with proper economic and regulatory incentives the feasibility of tuning relative catches across stocks is unclear due to the spatial overlap and commingling of stocks. It is unrealistic to expect to maintain biomass at or above targets for all stocks at all times without significant reductions in revenues. It may be more appropriate to design control rules and harvest strategies for the overall groundfish complex. It may also be necessary to broaden the scope of harvest control rules to account for the larger system of biologically interdependent fisheries, and dynamic control rules may be advisable (Collie and Gislason 2001).

ACKNOWLEDGEMENTS

Funding for this research was provided by the Massachusetts Fishery Recovery Commission. I am grateful to Brian Rothschild, Steve Correia, Ralph Mayo and an anonymous referee for providing constructive advice but any remaining errors are mine alone.

REFERENCES

Brown, R.W., Burnett, J.M., Begg, G.A., and Cadrin, S.X. 2001. Assessment of the Georges Bank Winter Flounder Stock, 1982-1997. *Northeast Fish. Sci. Cent. Ref. Doc.* 00-16.

Brown, R.W., and Munroe, N.J. 2000. Stock Assessment of the Georges Bank Haddock Stock, 1931-1999. *Northeast Fish. Sci. Cent. Ref. Doc.* 00-12.

Brodziak, J.K.T. 2002. Personal communication. June 4, 2002.

Cadrin, S.X., King, J., and L.E. Suslowicz. 1999. Status of the Cape Cod Yellowtail Flounder Stock for 1998. *Northeast Fish. Sci. Cent. Ref. Doc.* 99-04
Cadrin, S.X., Neilson, J.D., Gavaris, S., and Perley, P. 2000. Assessment of the Georges Bank Yellowtail Flounder Stock for 2000. *Northeast Fish. Sci. Cent. Ref. Doc.* 00-10.
Collie, J.S., and Gislason, H. 2001. Biological reference points for fish stocks in a multispecies context. Can. J. Fish. Aquat. Sci. 58:2167-2176.
Harley, S. J., Meyers, R.A., and Dunn, A. 2001. Is catch-per-unit-effort proportional to abundance? Fish. Aquat. Sci. 58:1760-1772.
Holland, D.S. 2000. A bioeconomic model of marine sanctuaries on Georges Bank. Can. J. Fish. Aquat. Sci. 57:1307-1319
Lallemand, P., and Gates, J.M. 1998. Otter Trawler Simulator. University of Rhode Island, Department of Environmental and Natural Resource Economics.
Larkin, P.A. 1977. An epitaph for the concept of maximum sustainable yield. Trans. Am. Fish. Soc. 106:1-11.
Mayo, R.K., Thunberg, E.M., Wigley, S.E., and Cadrin, S.X. 2002. The 2001 assessment of the Gulf of Maine Atlantic cod stock. *Northeast Fish. Sci. Cent. Ref. Doc.* 02-02.
New England Fishery Management Council (NEFMC). 1996. Final amendment #7 to the Northeast multispecies fishery management plan, Appendix 10. February 7, 1996.
Northeast Regional Stock Assessment Workshop (NRSAW). 1998. Report of the 28th Northeast Regional Stock Assessment Workshop (28th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. *Northeast Fish. Sci. Cent. Ref. Doc.* CRD 98-15
Northeast Regional Stock Assessment Workshop (NRSAW). 1999. Report of the 28th Northeast Regional Stock Assessment Workshop (28th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. *Northeast Fish. Sci. Cent. Ref. Doc.* CRD 99-08
Northern Demersal and Southern Demersal Working Groups (NDSDWG). 2001. Assessment of 19 Northeast groundfish stocks through 2000: a report to the New England Fishery Management Council's Multi-Species Monitoring Committee. *Northeast Fish. Sci. Cent. Ref. Doc.* 01-20.
O'Brien, L., and Munroe, N.J., 2001. Assessment of the Georges Bank Atlantic cod stock for 2001. *Northeast Fish. Sci. Cent. Ref. Doc.* 01-10.
O'Brien, L., and Esteves, C. 2001. Update Assessment of American Plaice in the Gulf of Maine - Georges Bank region for 2000. *Northeast Fish. Sci. Cent. Ref. Doc.* 01-02.
Overholtz, W.J., Edwards, S.F. and Brodziak, J.K.T. 1995. Effort control in the New England groundfish fishery: a bioeconomic perspective. Can. J. Fish. Aquat. Sci. 52: 1944-1957.
Wigley, S.E., Brodziak, J.K.T. and Cadrin, S.X.. 1999. Assessment of the Witch Flounder Stock in Subareas 5 and 6 for 1999. *Northeast Fish. Sci. Cent. Ref. Doc.* 99-16.
Working Group on Re-Evaluation of Biological Reference Points for New England Groundfish (WGRBR). 2002. Re-evaluation of biological reference points for New England groundfish. *Northeast Fish. Sci. Cent. Ref. Doc.* 02-04.

---

[1] Corresponding author. D.S. Holland. School For Marine Science and Technology, University of Massachusetts Dartmouth, 706 S. Rodney French Blvd., New Bedford, MA 02744, USA; Tel: 508 910 6355; Fax: 508 910 6371; email: dholland@umassd.edu
[2] Assessments are not available beyond 1997 for several stocks, thus it is not possible to model the entire complex of stocks as a system beyond that point and simulations are curtailed there.
[3] Data for the simulations was derived from published VPA assessments conducted by the Northeast Fisheries Science Center. The references for the individuals assessments used are listed in the references.
[4] A higher discount rate of 7 percent has been used in previous policy analyses for this fishery (NEFMC 1996). However, following Overholtz et al (1999), a 4 percent discount rate is used since inflation was already removed from projected prices by estimating price models with deflated prices.
[5] CV in this case is not a measure of uncertainty of model outcomes, but rather of variation in revenues over time.
[6] The target is in terms of total biomass for Georges Bank winter flounder.
[7] This is a very rough estimate since the average fishing power of the fleet has almost certainly changed as a result of aging of vessels, technical innovations and changes in the composition of the fleet, and because the estimate of days fished prior to 1994 are based on voluntary reporting which may significantly underrepresented the actual days fished.
[8] We consider a 12 year old trawler based in New Bedford, 75 feet long, 120 gross tons with 600 horsepower.
[9] Losses of net national benefit may, however, occur due to a loss of consumer surplus as demonstrated by Overholtz et al (1995) in their modeling of this fishery.