University of Portsmouth

Research paper 142

Modelling the effects of trade-offs between long and short term objectives in fisheries management

S Mardle and S Pascoe

Abstracted and Indexed in:
Aquatic Sciences and Fisheries Abstracts

Centre for the Economics and Management of Aquatic Resources (CEMARE), Department of Economics, University of Portsmouth, Locksway Road, Portsmouth PO4 8JF, United Kingdom.

ISSN 0966-792X

Modelling the effects of trade-offs between long and short term objectives in fisheries management

Running title:
Short vs. long term fisheries management

Summary

Fisheries management is typically a complex problem, from both an environmental and political perspective. The main source of conflict occurs between the need for stock conservation and the need for fishing community well-being, which is typically measured by employment and income levels. For most fisheries, overexploitation of the stock requires a reduction in the level of fishing activity. While this may lead to long term benefits (both conservation and economic), it also leads to a short term reduction in employment and regional incomes. In regions which are heavily dependent on fisheries, short term consequences of conservation efforts may be considerable. The relatively high degree of scientific uncertainty with respect to the status of the stocks and the relatively short lengths of political terms of office, generally give rise to the short run view taking the highest priority when defining policy objectives.

In this paper, a multi-objective model of the North Sea is developed that incorporates both long term and short term objectives. Optimal fleet sizes are estimated taking into consideration different preferences between the defined short and long term objectives. The subsequent results from the model give the short term and long term equilibrium status of the fishery incorporating the effects of the short term objectives.

As would be expected, an optimal fleet from a short term perspective is considerably larger than an optimal fleet from a long run perspective. Conversely, stock sizes and sustainable yields are considerably lower in the long term if a short term perspective is used in setting management policies. The model results highlight what is essentially a principal-agent problem, with the objectives of the policy makers not necessarily reflecting the objectives of society as a whole.

Key words: fisheries, multi-objective programming, short run, long run, North Sea.

Introduction

Fisheries management in the European Union (EU) is guided by the legislation of the Common Fisheries Policy (CFP) which itself derives from the Common Agricultural Policy (CAP). The objectives of the CAP (and thereby the CFP), as defined by article 39 of the Treaty of Rome, are to: increase production by promoting technical progress, ensure a fair standard of living for the agricultural community, stabilise markets, ensure availability of supplies, and ensure reasonable prices for consumers. In order to achieve these objectives with respect to fisheries, the CFP has four key areas: a common market organisation, a common structural policy, a resource conservation and management system, and an external policy concerned with agreements with countries outside the EU (Hatcher 1997).

The objectives of the resource conservation and management system, embodied in Article 2 of Regulation No. 3760/92, are "to protect and conserve available and accessible living marine aquatic resources, and to provide for rational exploitation on a sustainable basis, in appropriate economic and social conditions for the sector, taking into account of its implications for the marine ecosystem, and in particular taking into account of the needs of both producers and consumers".

Multiple objectives, as highly evident in the CFP, are typical of many fisheries management problems (Crutchfield 1973). The commonly declared objectives of such problems, as noted by Charles (1989), include resource conservation, food production, generation of economic wealth and reasonable incomes, maintain employment and sustain the community. The complexity of the natural fish resource and the diversity of interest groups involved dictate that a compromise between such objectives must be sought.

The major conflict for management occurs between the attempts to conserve the stocks and the desire for policy makers to satisfy the needs of the fishing community with respect to jobs and income. In most fisheries, attempts to reduce fishing pressure in order to conserve stocks is concomitant with a reduction in the number employed in fishing and reduced incomes in the short run. While the long run effects of these policies may be to increase regional incomes, the short term effects may be considered politically unacceptable, particularly in regions heavily dependent on fishing.

In a comparative example from public choice theory, Nordhaus (1975) developed a model that considered long run and short run inflationary pressures against employment. It was based on long and short run Phillips curves and iso-vote curves. An assumption of the model was that voters' expectations about future outcomes were based on current events. Voters' preferences were therefore based on the short run trade-offs between employment and inflation. Hence, Nordhaus was able to demonstrate that in a democratic economy, maximising votes results in a higher level of inflation in the long term.

A similar scenario exists in fisheries, with the trade-offs being between short and long term employment, profitability and stock size. Moves to reduce catch and subsequently employment are resisted by policy makers, as evidenced by the fact that TACs are evaluated yearly (Holden 1994) and often exceed the advice of the scientific advisors (ACFM 1996). From Nordhaus's (1975) model, it might be expected that vote maximisation would result in lower stock sizes in the long run and consequently lower levels of profit than otherwise might be achieved.

This is evidenced in the North Sea by the fact that it is significantly overfished. There is an obvious political reluctance to impose a policy resulting in a sizeable reduction in employment levels in areas where alternative employment opportunities are generally poor. However, biological advice suggests that a collapse of a species may occur unless action is taken to reduce fishing. Both of these outcomes affect fishing communities harshly, although the effects and likelihood of occurrence of a stock collapse on fishing communities is less certain than the effects of a reduction of fishing. Further, the effects of stock collapse, if any, are more likely to occur in the future whereas reducing fishing impinges on communities in the present.

In this paper, a non-linear multi-objective model of the North Sea demersal fishery is used to investigate the 'optimal' levels of harvest from a short and long term perspective. As well as different time horizons, the model incorporates the multiple objectives of the EU Common Fisheries Policy (CFP). The model is used to estimate the potential losses in economic performance of the fishery from adopting a short term perspective.

The North Sea Fishery

The North Sea is the most important fishing region in the European Union (EU). In addition, it is one of the most intensely fished areas in the world. The North Sea contains a multi-species multi-gear fishery bordered by seven European countries: Belgium, Denmark, France, Germany, Netherlands, Norway and the UK. Each country relies greatly on the North Sea as a principle source of their most commonly required species of fish. The total value of the catch in 1994 was estimated to be about ECU 750 million (Mardle et al 1997). Thus, with so many people relying on the fishery, the management of the North Sea is a crucial and complex task.

The main species predominantly targeted for human consumption include cod, haddock, whiting, saithe, plaice, sole, nephrops and herring. The first seven of these are demersal (or groundfish) species, caught using beam trawl, otter trawl, nephrops trawl or seine nets. Herring is a pelagic species caught using a variety of different gear types.

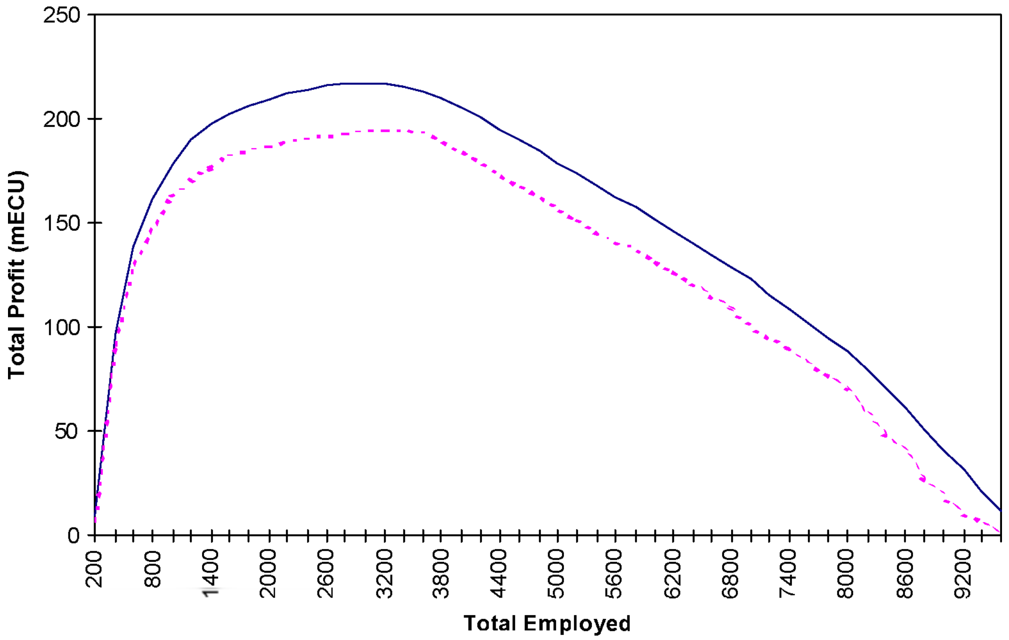
The stocks of the demersal species are considered to be below the level that produces the maximum sustainable yield (ACFM 1996). Further, cod, plaice and herring are currently considered to be at risk of collapse. Approximately 60% of the biomass of cod, haddock and whiting is removed each year, placing a great importance on recruitment. The EU currently imposes yearly total allowable catches (TAC) in order to curb fishing activity of these species. However, these TACs have generally been higher than those suggested by the scientific advisors (ACFM 1996).

Specific applications of bioeconomic models to the North Sea have been small in number. Kim (1983) developed a surplus production multispecies model of the demersal fishery to estimate the potential economic rent that could be achieved. Bjørndal and Conrad (1987) and Bjørndal (1988) developed a model of the North Sea herring fishery that included a fleet dynamics function. This allowed for changes in fleet size but not in fleet structure. Frost et al. (1993) developed two bioeconomic models of the North Sea fishery; a linear programming model and a larger simulation model to estimate levels of effort and catches. Dol (1996) developed a simulation model of the flatfish (sole and plaice) fishery in the North Sea, primarily for the Dutch beam trawl fleet.

Mardle et al (1997) developed a multi-objective long run equilibrium model which was used to estimate the optimal level of catch taking into consideration the multiple objectives of the CFP. The analysis looked at trade-offs between sustainable levels of employment, discarding and fishery profitability in a long run equilibrium setting. The analysis also looked at the effects of allowing trade in quota between countries, something which is currently not permitted under the CAP.

The trade-offs between potential long run profits (economic rent) and sustainable levels of employment estimated by Mardle et al (1997) are illustrated in Figure 1. The continuous and dotted lines represent quota trade and no trade within the fishery respectively. The trade-off curve was derived by estimating the maximum profits that can be achieved at different levels of employment. From figure 1, the maximum number of crew the fishery is able to sustain is about 9500, whilst the current employment level is estimated to be about double this amount. Hence, current effort levels cannot be sustained in the longer term, and the long run level of profits associated with the current level of effort will be negative. The maximum profit levels under each quota trade scenario are achieved at a low level of employment compared to the current situation. Higher levels of employment above the long run profit maximising level result in long run profits decreasing by about ECU 1 million for every 30 additional jobs.

Figure 1: Total profit Vs total employment trade-off curve.



From the analyses of Mardle et al (1997) and ACFM (1996), reductions in employment in the fishery are likely to be inevitable. However, while the current levels of fishing may be unsustainable and result in long term losses, many sectors of the fleet are likely to be earning short term profits. The decision for policy makers, therefore, is whether short term higher levels of employment accompanied by short term profits outweigh lower levels of profits in the longer term for a given level of activity. This requires the trade-offs between long term and short term effects of different fishing levels to be modelled explicitly.

The Short Term/Long Term Multi-objective Model

Multi-objective programming (MOP) methods appear, from first impressions, to be a very useful approach for analysing fisheries problems, even though there are few examples reported in contrast to other comparable fields such as forestry, agriculture and water resource planning (Mardle and Pascoe 1997). Since 1977, only 36 papers have applied MOP techniques to fisheries (Mardle and Pascoe 1997). These include studies of the optimal resource allocation in the Scottish inshore fishery (Sandiford 1986) and the UK component of the English Channel fishery (Pascoe, Tamiz and Jones 1997); quota determination in the South African pelagic fishery (Stewart 1988), and an assessment of the coastal fishing fleet in Sri Lanka (Muthukude, Novak and Jolly 1991).

The model developed in this paper is based on the long run equilibrium goal programming (GP) model developed by Mardle et al (1997). Goal programming (GP) (see for example Ignizio and Cavalier 1994) was probably the first multi-objective programming technique to be developed (Charnes, Cooper and Ferguson 1955). GP has been applied effectively to many fields including fisheries, agriculture, water resource planning, forestry, and finance (Romero 1991). Such applicational studies generally develop linear models based on the paradigms of weighted GP (WGP) and lexicographic (or preemptive) GP (LGP), although non-linear GP, minmax GP, and fuzzy GP are among alternative variants (Tamiz, Jones and El-Darzi 1995).

The aim of the GP model is to minimise the sum of unwanted deviations (WGP achievement function (1)) from given target or goal values (goals (2)), using the Simonian concept of 'satisficing'. An optional set of hard constraints (3), in the traditional LP style, may also be included. The goals associate the relative objectives inherent in the model. The mathematical expression of the GP problem can be given by

$$\min\ z = \sum_{i=1}^{k} (u_i n_i + v_i p_i) \tag{1}$$

subject to,

$$f_i(\mathbf{x}) + n_i - p_i = b_i \qquad ,i = 1,\ldots,k \tag{2}$$

$$\mathbf{x} \in C_s \tag{3}$$

$$\mathbf{x},\mathbf{n},\mathbf{p} \geq 0 \tag{4}$$

where $f_i(\mathbf{x})$ is a typical objective function or goal (often linear), $\mathbf{x} \in R^n$ is the set of decision variables, $\mathbf{n},\mathbf{p} \in R^m$ are deviational variables, $\mathbf{u},\mathbf{v} \in R^m$ are the respective deviational variable predetermined weights. A mathematical representation of the complete non-linear goal programming model with variable and parameter descriptions is given in the Appendix.

The model includes the seven most important demersal species in the North Sea for human consumption; namely cod, haddock, whiting, saithe, plaice, sole and nephrops. It includes the North Sea's eight coastal states; Belgium, Denmark, England, France, Germany, the Netherlands, Norway and Scotland. And it takes account of the four associated major fishing methods or gear types; otter trawl, seine, beam trawl and nephrops trawl.

As the North Sea is a multi-species fishery by nature, the demersal species included interact with each other to a considerable degree. The increased stock of one species may displace another, some species consume others to some extent (ICES 1996a), and targeting certain species for catch may include a significant bycatch of unwanted species (Pascoe 1997). In the model, effort is applied to the fishery by the different fleets using the different gears. Associated with each gear type is a catchability coefficient for each species. Hence, bycatch is directly incorporated into the model through the catch equations. The predator/prey/competition features of the fishery were included using multispecies logistic growth models of the following form (equation (5)):

$$G_i = r_i B_i \left(1 - \frac{B_i}{\sum \beta_{s_i'} B_{s_i'} + K_i}) - \sum \alpha_{s_i} B_{s_i} \right) \quad (5)$$

where G_i is the growth of species i, r_i is the growth rate, K_i is the environmental carrying capacity (excluding the effects of the modelled prey species), B_i is the biomass, $s_i \in S_i$ is the set of predator species and similarly $s_i' \in S_i'$ is the set of prey species.

Nonlinear regression analysis was used to estimate the growth model parameters using ICES data between 1975 and 1995 (Mardle et al 1997). A summary of the predator-prey interactions between the species included in the model and the results of the regression analysis, with respect to R^2 and F test statistics, are shown in table 1. Note that the biomass of Norway Pouting which is a prey of four of the species is assumed constant, as this species is not explicitly incorporated into the model. Due to insufficient data, nephrops parameters were estimated on current levels of catch and effort. It should also be noted that the predator-prey relationships modelled are not intended to describe the interactions between the species completely, however for the data available for preliminary growth model analysis best approximations were taken.

Table 1: Species' interaction and test statistic results.

	Predator						
	Cod	Haddock	Whiting	Saithe	Plaice	Sole	Nephrops
Prey ↓	Whiting Pout	Pout	Pout	Whiting Pout			
R^2	0.211	0.334	0.451	0.282	0.308	0.434	n.a.
F	3.49	8.44	8.10	15.2	20.5	26.6	n.a.
	(5%)	(1%)	(1%)	(1%)	(1%)	(1%)	

n.a. not available

The model incorporates two catch curves. The long run catch effort relationship is the equilibrium catch curve. In equilibrium, the catch is equal to the growth of each species. The equilibrium level of biomass associated with each level of effort was estimated using the growth models identified in equation 5. In the short term, the catch can exceed the growth in the stock. The short term catch effort relationship is based on the estimated current biomass level, which is generally above the equilibrium biomass level given the current level of effort being expended in the fishery. Hence, the short term catch is considerably higher than the long term equilibrium catch given current effort levels.

The same level of effort (defined by the combination of boats in the 'optimal' fleet) was applied to both the long term and short term catch effort relationships. From these, the long term and short term level of catch and hence fishery profits could be determined with a given fleet size and structure. Employment is directly linked to the number of boats, so short term and long term employment are the same for a given fleet structure. A constraint in the model when defining the 'optimal' fleet was that long term profits must be at least non-negative. Persistent losses would force boats out of the fishery. Hence, the resultant solution is sustainable in the long term even if not 'optimal' in the long term. It was assumed that achieving a sustainable level of biomass and employment was an over-riding objective of management.

The parameters and data in the model are obtained for 1995 from a number of sources (Mardle et al 1997). Estimates are calculated using comparative data where directly unavailable. Prices (in ECUs per tonne of fish landed) were incorporated in the model as endogenous variables. Price flexibilities (Jaffry, Pascoe and Robinson 1997) were used to estimate the effects of changes in supply on price. The average price of each species in each country was taken and used as the base. Fixed costs and running costs of vessels, the number of boats present in the fishery and their respective days at sea were obtained from Concerted Action (1997). Crew wages were taken as a fixed proportion of the revenue, and gear selectivity was taken also from the North Sea simulation model of Frost et al. (1993). An optimisation was performed in order to estimate the importance of species to countries, as a scaling factor, by comparing derived catch to observed catch (ICES 1996b). All of the species incorporated in the model currently have yearly TACs assigned with historically proportional divisions to each country. However, in this model England and Scotland are treated independently, assigning the UK TAC according to the proportion of current boat numbers.

A key element of the analysis is the definitions of the goals to be achieved. Four key objectives were incorporated: maximise long term profit, maximise short term profit, maintain employment and minimise discarding. Initially, a single profit (or rent) maximising objective was introduced in order to establish the maximum profits that could be achieved in the fishery. The maximum level of long run profits were estimated to be approximately ECU 217 million, while the maximum short run profits were estimated to be about ECU 356 million. The employment target levels were taken to be the current level of employment defined by the existing fleet. A separate employment goal was estimated for each country. The discarding goal was represented by TAC over-achievement, where over-quota catch was included as a deviational variable in the achievement function. However, under-quota catch was not included in the achievement function. As long term and short term catch differed, long and short term discarding also differed. Separate deviational variables were modelled for each species in each time frame.

As each objective was measured in different units (i.e. million ECU, thousand tonnes, number employed), the deviational variables were normalised in the achievement function using the goal target value (percentage normalisation). Hence, the achievement function effectively incorporated the proportional deviations from the goal. Equal weightings were applied to the different key objectives: profits, employment and discarding. As a number of objectives had different levels (e.g. the employment goal was specified at the country level rather than the total fishery level), the weight of the main objective category was allocated equally across the sub-categories. Short term and long term weights were applied by multiplying the general category weight by the time horizon weight. Hence, the model could estimate the 'optimal' fleet from either a short term or long term perspective, or some combination of these by applying different time horizon weights.

Simulations and Results

The model was run under three scenarios. In the first, no weight was given to short run profitability. Hence it is equivalent to estimating the level of effort that maximises long run benefits[1] only. The second scenario considered both the long run and short run equally. Finally, the model was run with a zero weight on long run benefits. Hence it is equivalent to maximising short run benefits only, subject to the constraint that the long run level of profits cannot be negative for any fleet segment.

The results of the simulations are presented in Table 2. As would be expected, considering only long run benefits results in a substantially lower level of effort (expressed in terms of total crew employment) than if consideration is only given to maximising the level of benefits in the short term. Further, considerably larger short term annual profits can be achieved than in the long term, although the short term level of profitability is not sustainable. To maximise long term benefits, short term profits would be reduced by almost 50 per cent.

Maximising long term benefits would also require catches of the main quotas species to be reduced in the short term relative to the level that maximises short term profits. In addition, the level of discarding was estimated to increase in the short term in order to maximise long run profits. In contrast, maximising short term benefits is likely to result in a substantially lower level of discarding.

Table 2: Simulation results.

	zero short run weights		equal weights		zero long run weight	
	short run	long run	short run	long run	short run	long run

[1] As the model is multi-objective, 'benefits' refers to all objectives being considered simultaneously. This results in a different 'optimal' fleet configuration than if only one objective, say profits, was considered.

Economic profits	144.1	197.8	228.7	157.1	280.2	0.0
Employment						
• Belgium	175.5		166.6		329.8	
• Denmark	447.7		1670.0		1670.0	
• England	609.5		577.2		659.1	
• France	483.4		452.0		547.8	
• Germany	353.3		395.6		459.1	
• Netherlands	992.7		810.9		1383.1	
• Norway	136.7		123.6		81.6	
• Scotland	425.4		400.9		651.4	
Landings						
• Cod	42.5	54.1	65.2	48.6	71.2	37.3
• Haddock	4.7	17.0	16.7	24.3	37.2	50.7
• Plaice	71.2	146.8	101.1	116.0	112.3	78.0
• Sole	18.5	28.5	25.5	30.0	34.3	27.2
• Whiting	29.0	19.3	30.5	11.0	36.2	0.0
• Saithe	25.2	58.5	40.0	64.7	44.0	61.8
• Nephrops	0.7	4.0	1.0	3.6	0.4	1.5
Discards						
• Cod	10.8	0.0	0.0	0.0	0.0	0.0
• Haddock	6.8	0.2	0.0	0.3	0.2	1.7
• Plaice	10.7	2.8	0.0	0.3	0.3	5.8
• Sole	2.2	0.2	0.0	0.2	0.4	0.4
• Whiting	0.1	3.2	2.9	2.4	1.8	0.0
• Saithe	16.7	28.4	4.4	25.5	4.6	33.4
• Nephrops	0.8	9.5	0.7	10.6	0.1	4.5

Hence, to achieve the maximum level of benefits in the North sea in the long run, effort levels and catch would need to decrease more than that required to achieve the maximum level of short run benefits. Short term profits was also estimated to be substantially lower and the level of discarding higher than the levels associated with maximising short term benefits. Given this, it is not surprising that fisheries managers prefer to take a short term perspective than a long term perspective, particularly as they may not be in the same position in the long term to glean the praise but will be there in the short term to receive the abuse. Fishers also may be reluctant to undertake considerable sacrifice in the short term in order to achieve long term benefits, particularly if there is no guarantee that they would reap the benefits as they may no longer be in the fishery when the stocks recover.

Changing the relative weights given to both the short run and long run by fisheries managers may result in a compromise that encompasses the best features of both scenarios with fewer costs. For example, giving equal weighting to both long and short run considerations results in an optimal level of employment, landings and discard levels that are closer to the short run optimal than those associated with the level of effort which produces the long run optimal level of profits (Table 2). The satisficing level of profits in both the short and long run are only 20 per cent lower than the respective level if each was optimised separately. This is less than the 50 per cent reduction in potential short term profits if long run benefits are maximised and the 100 per cent reduction in potential long run profits if short term benefits are maximised.

Given this, a compromise between short and long run objectives may result in an optimal solution that encapsulates the best features of both sets of objectives without imposing substantial costs in either the long or short term.

Discussion

The long term model (including short term effects) gives invaluable insight into the current status of the fishery. While it can be used to estimate the long term equilibrium operating levels of the fishery, it does not include a time scale with which this 'solution' may be achieved. Therefore, the long run model can give no direct information as to how this level of sustainability can be attained. If such a steady state is envisaged as the desired state for the fishery in the future, then short term goals and expectations for the fishery must be included in the analysis. The effects of management measures on the fishery can then be investigated in order to derive a path with which to achieve the goals evaluated in the multi-objective equilibrium model.

It is generally considered that the North Sea demersal fishery is overexploited, and stocks such as cod and plaice are currently thought to be well below biological safe limits. As would be expected with overexploitation, simply reducing employment (often assumed to be consistent with fishing effort) would not necessarily achieve the outcome simulated by the equilibrium model. Rationalisation of the fishery is not linked linearly to catch levels. Therefore, measures such as TACs are generally considered to force the reduction of catch. A reduction in profitability in the short term enforces rationalisation by those directly involved, as the opportunity cost of remaining in the fishery is greater than the potential benefits.

The actual level of profits in 1995 is not available, but short term profits undoubtedly exist in the fishery although the current level of fishing effort is considered to be unsustainable[2]. Therefore, in order for the main demersal North Sea species to survive, catch in the short term must be reduced. It is highlighted in the equilibrium models that the optimal fleet can catch at similar levels as limited by current quotas with far less employment.

It is acknowledged that it is beneficial to the EU to retain adequate stocks of demersal species in the North Sea, and not to wipe them out completely. This aim is declared in the objectives included in the CFP, Article 2 of Regulation No. 3760/92, are "to protect and conserve available and accessible living marine aquatic resources, and to provide for rational exploitation on a sustainable basis…". If stocks get to a critical level then fishing must be halted until the species has recovered sufficiently. This reality was reached with North Sea herring stocks in the 70s where fishing was not permitted for several years (Bjørndal 1988).

The model is currently based on a number of parameters from different sources, some of which may not be comparable. In a number of cases, parameters had to be estimated

[2] In 1996/97 UK gill netters operating in the North Sea were estimated on average to be earning rates of returns of about 18 per cent, beam trawlers about 11 per cent and otter trawlers about 10 per cent (SFIA 1998). With expected rates of return being in the order of 10 per cent (Pascoe, Robinson and Coglan 1997), these boats are generally breaking even or earning economic profits in the short term. However, this is at the expense of a decreasing biomass of the key species.

based on secondary information. As a consequence, the results presented in the paper are indicative rather than predictive.

These caveats notwithstanding, the model analyses demonstrates the political incentives to slow down effort reduction rather than attempt to achieve a long run optimal solution. From the model results, the political cost of moving to a long run optimal fleet is a loss in fishery short run annual profits of about ECU 136.1 million and reduction in employment of over 2000 compared with the optimal short run solution. The potential long run gain is less than ECU 200 million. However, this gain will not occur until some time in the future, by which time somebody else may be in office. Given this, the political discount rate is likely to be high, and the discounted future benefits of long term management are hence likely to be negligible while the short term costs high.

This is essentially a principle-agent problem. The key objective of the policy makers is to largely reduce conflict within the sector that they are managing. The objective of the industry is to maintain rather than reduce production and profitability. As future gains are uncertain and as these gains would only accrue to a subsector of the industry (the “survivors”), the future gains are not considered sufficient to affect the short term losses. From a broader societal perspective, however, this is a suboptimal view. An overexploited fishery results in resources not being used in the most efficient manner. This includes not just the biological resource, but all inputs applied to the fishery.

The model results also demonstrate that a compromise solution can exist that seems to encapsulate the best features of both the short term and long term optimums. Using a model such as that developed in this paper to examine trade-offs between multiple objectives may result in a better, more politically acceptable, solution from a multi-objective perspective.

One of the strengths of goal programming models is the ease with which alternative scenarios and decision maker preferences can be investigated. Straightforward weight modification on the objectives (or goals) provides a "what-if" scenario analysis framework, which should aid discussion of proposed policies. In the advanced model development environments available, such as GAMS (Brooke, Kendrick and Meerhaus 1988), simulation of the model over time can also be simply introduced.

The model also allows managers to better identify the costs associated with trade-offs between objectives. For example, the opportunity cost of maintaining employment can be estimated in terms of forgone fishery profits. This opportunity cost can be assessed against other costs that may be incurred in the economy if employment is reduced. In the long run, the potential for displaced labour to find alternative employment is likely to be high. Hence the cost associated with a policy of maintaining employment in some areas may be substantial.

Conclusions

In this paper, a model of the North Sea demersal fishery has been developed to examine the optimal fleet configuration from both a long and short term perspective. The model results highlight the political problems facing fisheries managers. Short term solutions can result in higher short term benefits and employment levels than long term solutions.

However, implementing short term solutions results in a considerable loss in terms of long term profitability. Using a model such as that developed in this paper, however, provides managers with a third alternative based on a compromise between long and short run objectives. Such a compromise may be more politically acceptable and hence lead to better (if not optimal) long term management.

Critics of the CFP have suggested that policy makers focus more on achieving short term objectives than longer term goals (Holden 1994). It is clear that fishery rehabilitation is a slow process and a long term aim is required. However due to the dynamic environment of fisheries, short term decisions and modification to yearly (or part-yearly) management schemes must be possible. The long run equilibrium model includes such short term objectives to give an overall view of the best achievable scenario. Long term trends can therefore be focused on by performing further simulations in order to aid the definition of short term policy.

Acknowledgements

The base model used in this research was developed as part of an EU funded research project (research contract FAIR-CT96-1814).

References

Advisory Committee on Fishery Management (ACFM) (1996). *Report of the ICES Advisory Committee on Fisheries Management, 1995.* Report No. 214, Copenhagen: International Council for the Exploitation of the Sea (ICES).

Bjørndal, T. (1988). The optimal management of North Sea herring. *Journal of Environmental Economics and Management*, 15(1), 9-29.

Bjørndal, T. and Conrad, J.M. (1987). The dynamics of an open access fishery. *Canadian Journal of Economics*, 20(1), 74-85.

Brooke, A.D., Kendrick, D. and Meerhaus, A. (1988). *GAMS: A User's Guide.* Scientific Press, California.

Charles, A.T. (1989). Bio-socio-economic fishery models: labour dynamics and multi-objective management. *Canadian Journal of Fisheries and Aquatic Science*, 46(8), 1313-1322.

Charnes, A., Cooper, W.W. and Ferguson, R. (1955). Optimal estimation of executive compensation by linear programming. *Management Science*, **1**, 138-151.

Concerted Action (1997). *Coordination of Research in Fishery Economics: Economic Performance of Selected Fleet Segments in the EU, 1996/2 Report.* Working Document 10, January. (EU project AIR CT94 1489).

Crutchfield, J.A. (1973). Economic and political objectives in fishery management. *Transactions of the American Fisheries Society*, 102(2), 481-491.

Dol, W. (1996). Flatfish 2.0a: a spatial bioeconomic simulation model for plaice and sole. *Proceedings of the VIIth Annual Conference of the European Association of Fisheries Economics (1995)*, Ed. CEMARE, University of Portsmouth, UK.

Frost, H., Rodgers, P., Valatin, G., Allard, M-O, Lantz, F. and Vestergaard, N. (1993). *A Bioeconomic Model of the North Sea Multispecies Multiple Gears Fishery.* Vol. 1-3, South Jutland University Press, Esbjerg.

Hatcher, A. (1997). Producers' organisations and devolved fisheries management in the United Kingdom: collective and individual quota systems. *Marine Policy*, 21(6), 519-533.

Holden, M. (1994). *The Common Fisheries Policy: Origin, Evolution and Future.* Fishing News Books, Great Britain.

Ignizio, J.P. and Cavalier, T.M. (1994). Linear Programming. Prentice-Hall, USA.

International Council for the Exploration of the Sea (ICES) (1996a). *Report of the Multispecies Assessment Working Group.* ICES CM 1996/Assess: 3.

International Council for the Exploration of the Sea (ICES) (1996b). *Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak.* ICES CM 1996/Assess: 8.

Jaffry, S., Pascoe, S. and Robinson, C. (1997). Long run price flexibilities for high valued species in the UK: a cointegration systems approach. *CEMARE Research Paper*, P111, University of Portsmouth, UK, 12pp.

Kim, C. (1983). Optimal management of multi-species North Sea fishery resources.

Weltwirtschaftliches Archiv - Review of World Economics, Band 119, 138-151.

Mardle, S. and Pascoe, S. (1997). A review of multi-objective programming applications in fisheries. *CEMARE Research Paper*, P117, University of Portsmouth, UK, 23pp.

Mardle, S., Pascoe, S., Tamiz, M. and Jones, D.F. (1997). Resource allocation in the North Sea fishery: a goal programming approach. *CEMARE Research Paper*, P119, University of Portsmouth, UK, 22pp.

Muthukude, P., Novak, J.L. and Jolly, C. (1991). A goal programming evaluation of fisheries development plans for Sri Lanka's coastal fishing fleet, 1988-1991. *Fisheries Research*, 12, 325-339.

Nordhaus, W. (1975). The political business cycle. *Review of Economic Studies*, 42, 169-90.

Pascoe, S. (1997). *Bycatch management and the economics of discarding*. FAO Fisheries Technical Paper, FAO, Rome (in press).

Pascoe, S., Robinson, C. and Coglan, L. (1997). Economic and Financial Performance of the UK English Channel Fishery. *CEMARE Report No. 44*, University of Portsmouth, UK

Pascoe, S., Tamiz, M. and Jones, D.F. (1997). Multi-objective modelling of the UK fisheries of the English Channel. *CEMARE Research Paper*, P113, University of Portsmouth, UK, 14pp.

Romero, C. (1991). *Handbook of Critical Issues in Goal Programming*. Pergamon Press.

Sandiford F. (1986). An analysis of multi-objective decision making for the Scottish inshore fishery. *Journal of Agricultural Economics*, 37(2), 207-219.

Seafish Industry Authority (SFIA) (1998). *Fishermen's Handbook: costs and earnings of the United Kingdom fishing vessel fleet, 1996/97*. Seafish Industry Authority, Edinburgh.

Stewart T.J. (1988). Experience with prototype multicriteria decision support systems for pelagic fish quota determination. *Naval Research Logistics*, 35, 719-731.

Tamiz, M., Jones, D.F. and El-Darzi, E. 1995. A review of goal programming and its applications. *Annals of Operations Research* 58: 39-53.

Appendix

Mathematical Representation of the Model

$$\min\ z = w_{L1}\frac{npL}{Max\Pr ofL} + w_{L2}\sum_j \frac{ne_j + pe_j}{TB_j} + w_{L3}\sum_i \frac{pdL_i}{sTAC_i} + w_{L4}\sum_j\sum_i \frac{ntL_{ji} + ptL_{ji}}{TAC_{ji}} +$$

$$w_{S1}\frac{npS}{Max\Pr ofS} + w_{S2}\sum_j \frac{ne_j + pe_j}{TB_j} + w_{S3}\sum_i \frac{pdS_i}{sTAC_i} + w_{S4}\sum_j\sum_i \frac{ntS_{ji} + ptS_{ji}}{TAC_{ji}}$$

subject to,

$$\sum_j\sum_k fprofL_{jk} + npL - ppL = Max\Pr ofL$$

$$\sum_j\sum_k fprofS_{jk} + npS - ppS = Max\Pr ofS$$

$$\sum_k Emp_{jk} boats_{jk} + ne_j + pe_j = \sum_k Emp_{jk} NB_{jk} \qquad ,\forall j$$

$$\sum_j\sum_k (catchL_{jki} - landL_{jki}) + ndL_i - pdL_i = 0 \qquad ,\forall i$$

$$\sum_j\sum_k (catchS_{jki} - landS_{jki}) + ndS_i - pdS_i = 0 \qquad ,\forall i$$

$$\sum_k landL_{jki} + ntL_{ji} - ptL_{ji} = TShare_{ji} ntac_i \qquad ,\forall i, j$$

$$\sum_k landS_{jki} + ntS_{ji} - ptS_{ji} = TAC_{ji} \qquad ,\forall i, j$$

$$ntac_i \geq \sum_j\sum_k landL_{jki} \qquad ,\forall i$$

$$ntac_i \leq \sum_j\sum_k catchL_{jki} \qquad ,\forall i$$

$$days_{jk} \leq SeaDays_{jk}\,\mathrm{boats}_{\mathrm{jk}} \qquad ,\forall j, k$$

$$catchL_{jki} = (Select_{ik} Scale_{ji}) days_{jk} bio_i \qquad ,\forall j, k, i$$

$$catchS_{jki} = (Select_{ik} Scale_{ji}) days_{jk} Biomass_i \qquad ,\forall j, k, i$$

$$f_i = \sum_j\sum_k (Select_{ik} Scale_{ji}) days_{jk} \qquad ,\forall i$$

$$bio_c = (0.651 bio_w + 0.310 BioPout + 77.302)(1 - f_c / 0.508)$$

$$bio_h = (0.245 BioPout + 578.76)(1 - f_c / 0.819)$$

$$bio_w = (1.378 BioPout + 88.59)(1 - f_c / 0.079) + 0.002 bio_c + 0.239 bio_s$$

$$bio_s = (0.130 BioPout + 1018.84)(1 - f_c / 0.405)$$

$$bio_{so} = 224.94(1 - f_c / 0.538)$$

$$bio_{pl} = 1680.03(1 - f_c / 0.375)$$

$$bio_{ne} = 300(1 - f_c / 0.2)$$

$$price*_{ji} = AvP_{ji}\left(1 - \left(PF_{ji}\frac{\sum_k (land*_{jki}) - TAC_{ji}}{TAC_{ji}}\right)\right) \qquad ,\forall j, i$$

$$frev^*_{jk} = \sum_i price^*_{ji}\, land^*_{jki} \quad ,\forall j,k$$

$$f\cos t^*_{jk} = FC_{jk} boats_{jk} + VC_{jk} days_{jk} + WV_{jk} frev^*_{jk} \quad ,\forall j,k$$

$$fprof^*_{jk} = frev^*_{jk} - f\cos t^*_{jk} \quad ,\forall j,k$$

$$land^*_{jki} \le catch^*_{jki} \quad ,\forall j,k,i$$

$$\sum_i land^*_{jki} \le 0.4 boats_{jk} \quad ,\forall j,k$$

Note: The * in the price and cost equations denotes the fact that the equation is required for the short term variable and the long term variable.

Indices

i	Species; cod, haddock, whiting, saithe, plaice, sole and nephrops.
j	Country; Belgium, Denmark, England, France, Germany, Netherlands, Norway and Scotland.
k	Gear type; otter trawl, seine, beam trawl and nephrops trawl.

Variables

$fprof_{jk}$	Profit (mECU).
$frev_{jk}$	Revenue (mECU).
$fcost_{jk}$	Costs (mECU).
$price_{ji}$	Price ('000 ECU).
$catch_{jki}$	Catch ('000 tonnes).
$land_{jki}$	Landings ('000 tonnes).
$days_{jk}$	Number of days fished ('000 days).
$boats_{jk}$	Number of boats.
f_i	The fishing mortality, i.e. catchability ′ effort.
bio_i	Species biomass ('000 tonnes).
$ntac_i$	Total allowable catch ('000 tonnes).
np (pp)	Negative (positive) deviation from the economic rent goal.
ne_j (pe_j)	Negative (positive) deviation from the nbr employed goal.
nd_i (pd_i)	Negative (positive) deviation from the discard goal.
nt_{ji} (pt_{ji})	Negative (positive) deviation from the TAC goal.

Data

w_l	Achievement function weight for l^{th} goal (l=1,…,5).
$MaxProf$	Maximum profit achievable in the fishery (mECU).
TAC_{ji}	Total allowable catch ('000 tonnes).
$sTAC_i$	Total allowable catch by species ('000 tonnes).
$TShare_{ji}$	Current TAC share per country by species.
NB_{jk}	Current number of boats.
TB_j	Total number of boats by country.
Emp_{jk}	Current employment.
AvP_i	Average UK price in 1995 ('000 ECU).
PF_{ji}	Price flexibility coefficient.
FC_{jk}	Fixed cost per boat ('000 ECU).
VC_{jk}	Variable cost per day ('000 ECU).
WC_{jk}	Wages as a percentage of revenue.
$Select_{ik}$	Gear selectivity coefficient.
$Scale_{ji}$	Relative efficiency index.

$SeaDays_{jk}$	Estimated maximum number of days fishing per vessel.
$BioPout$	Constant for the biomass of Norway pouting (‘000 tonnes).
$Biomass_i$	Estimated species biomass in 1995 (‘000 tonnes).