WHEN, WHERE AND WHAT TO FISH? FISHERMEN'S BEHAVIOUR WHEN CHOOSING OPTIONAL SEASONAL PROFILES.

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ABSTRACT

Most fishermen are faced with several options in both long and short term planning of their activity. In this paper we study fishers short term decisions when different seasonal fishery options are available. This involves choices of spatial and temporal allocation of effort as well as use of varying fishing gears in order to obtain the planned target specie mix. In a heterogeneous fishing fleet the seasonal options may differ considerably from vessel to vessel, also depending on its home port. The paper presents a framework wherein the seasonal choices are understood on the basis of economically rational behaviour where expected marginal benefit of the different options are evaluated and the most profitable season chosen. A monthly model is developed to describe the marginal profitability of the various fishing opportunities based on Norwegian data. The impact management decisions may have on the chosen seasonal profile and the vessel profitability is then discussed on the basis of the presented seasonal model. In particular we study the impacts of different quota allocation regimes. A diverse fleet structure may be an efficient response on highly fluctuating and unpredictable fish resources, while fisheries regulations may have the effect of reducing the flexibility by which the fleet can respond to such changes.

INTRODUCTION

Humans in general make a vast number of decisions every day, but only a fraction of them involve active decision processes. When planning the activities of a medium sized firm, of which a number of people depend upon for their livelihood, it is reasonable to assume that more resources are devoted and that an analytic and rational decision process is employed.

Fishing vessels in general often have a number of options with tradeoffs between them available when planning their fishing activity. At the core, choices have to be made about where, when and what to fish given their resources and constraints in order to achieve the desired utility and economic return. Decisions are made at different timescales with an overall plan for the year and more detailed plans for each fishing season within the year and day-to-day decisions on the fishing grounds. Depending on the context the vessel is operating in, these may be highly complex problems involving many variables and high uncertainty.

Research question

The fishing pattern can vary considerably between individual vessels. This diversity may be due to several factors; different technical characteristics, knowledge, experience, other internal resources such as quotas or responses to the large uncertainty. But it may also be due to lack of explicit decision making processes. Software for assistance in planning and to calculate the economic implications of specific choices may not be available.

This study focuses on the large Norwegian groundfish trawlers with a research objective to describe the optimization problem facing a vessel manager and to develop a mathematical model for finding the optimum fishing pattern for a trawler. Although larger fishing companies have developed in-house

programs, senior representatives from these have expressing the need for assistance in such planning. The results from the model will be compared to the actual harvest pattern and discussed.

A number of studies have investigated fishing strategy choices. Lane [1] studied salmon freezer trollers using Markov decision process. Babcock and Pikitch [2] used a dynamic programming model to study target species assemblage in a multispecies trawl fishery at the US west coast. Choice of fishing location has been widely studied, and the methods are reviewed in van Putten *et al* [3]. Larkin and Sylvia [4] studied how intrinsic quality influenced the intraannual harvest schedule. To our knowledge, no studies have taken into account seasonal variability in catch rates.

Case fleet and fisheries

The case vessels employed in this paper is the Norwegian groundfish stern trawler fleet. Introduction of an ITQ regime has seen the fleet being reduced from about 100 in 2000 to about 40 vessels at present [5]. Their primary catch is cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and saithe (*Pollachius virens*). The vessel group's total catches in 2010 is shown in table I. Shrimp (*Pandalus borealis*) is also of some importance and other fish is generally caught as bycatch.

Table I Catches from Norwegian codfish trawlers in 2010

Specie	Quantity (tonnes live weight)
Cod	86,705
Saithe	89,737
Haddock	61,546
Shrimp	16,417
Redfish	7,456
Greenland halibut	3,734
Other	1,969

Cod, haddock and saithe are all managed by individual vessel quotas. Other species are generally caught as bycatch in these fisheries, some with individual quotas and some through a maximum allowed share in the primary fisheries. Most of the vessels have licenses for shrimp where the vessels are not restricted by quotas. The saithe and shrimp fisheries can be considered close to single-species fisheries. The catch composition in the cod and haddock fisheries can to a large extent be influenced by the skipper. This results in fisheries that range from single specie of cod through mixed fisheries to single specie haddock.

Their activity is primarily located to the Barents Sea and fishing banks in vicinity of the North-Norwegian coast. A large share of their saithe catches are taken in the North Sea. Most of the trawlers are equipped for freezing the catch onboard, and this is reflected in the landings where about 90% are frozen.

The fisheries the trawlers participate in exhibit large annual variation in important characteristics. This is common in high latitude areas where the sunlight and temperature varies strongly. Of particular importance to the trawler operations are catchability, sexual maturation and fillet yield. Eide *et al* [6] studied trawler logbook data and found that the cod catchability varied harmonically with time with a low at about 1/3 of the peak. For the coastal fleet, being far less mobile and thus more dependent on the fish migration pattern, the variations in catchability is even more pronounced [7].

This description gives some insight into the complex decision problems facing the trawlers' managers. Observing the individual vessels' landing pattern, it becomes clear that the managers come to quite different solutions to these effort allocation problems. Figure 1 shows how the vessels distributed their

catches of cod, haddock and saithe in 2011. The unit of measurement is each vessel's monthly share of its own total catch of the specie in question. For cod the highest average landings are found in January with about 20% of the total cod catches. The lowest share is landed in March at just 2% of total catch. What is more interesting is that the variation between vessels is relatively high, in a single month a vessel may land from 0 while another may land 40% of its cod catches.

For haddock and saithe the variation between vessels is even more pronounced, but there is here a stronger seasonal signal as well. Haddock is mostly caught from April to September and saithe from February to September.
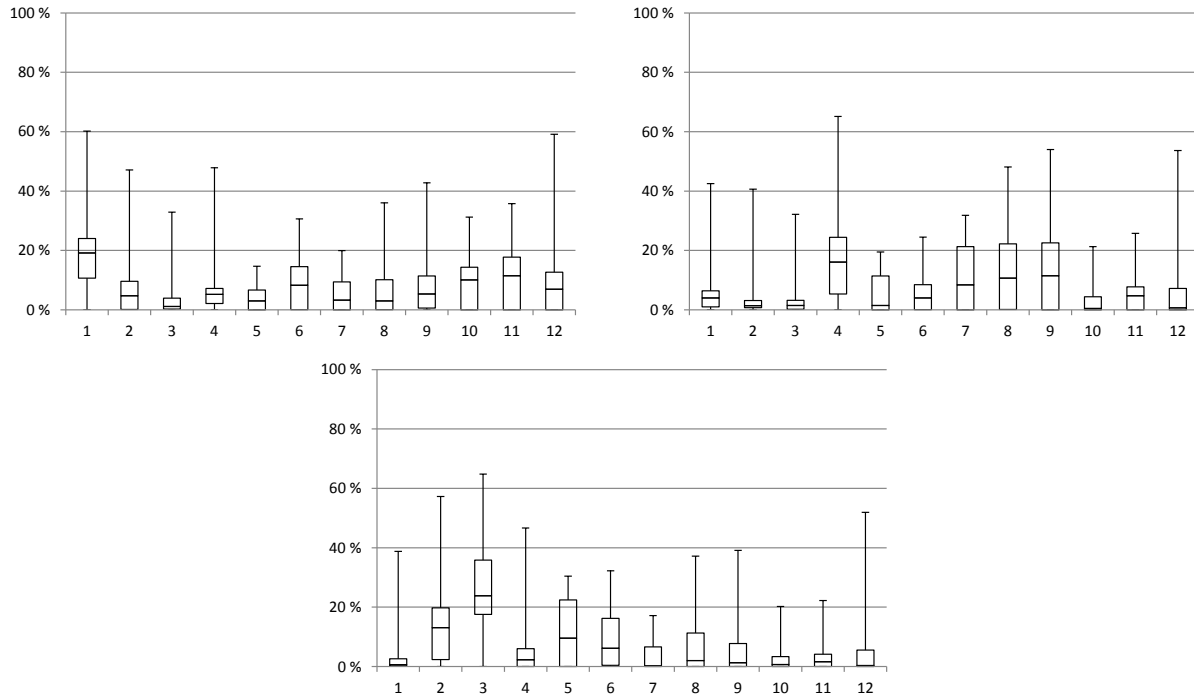

Figure 1 Box-plots of individual vessels share of the vessel's yearly catch of cod, haddock and saithe per month in 2011 (clockwise from upper left). Data from the Norwegian Directorate of Fisheries.

To further describe the variations between vessels in their harvesting pattern, we have divided their activities in five separate fisheries; the four top species caught and a "mixed" fishery. The first four is defined as when the specie in question account for more than ¾ of the monthly landings. The remaining observations are classified as mixed fisheries. The results are presented in table II. There is a clear pattern with cod in January, saithe from February to March, mixed from April to September and cod/mixed from October to December. Still, many vessels depart from this pattern and chose other harvesting patterns. To name a few deviations, some do not take part in saithe or shrimp fisheries, some catch all their cod and haddock through the mixed fishery and some are idle most of the year.

Table II Harvesting pattern for individual Norwegian trawlers per month in 2011

Vessel	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1		Sai	Mix	Shr	Mix	Cod	Mix	Sai	Shr	Mix	Mix	Mix
2	Cod	Cod		Mix	Cod	Cod	Mix	Had	Cod	Mix	Cod	
3	Cod	Sai	Sai	Mix		Cod	Mix	Mix	Had	Cod	Cod	Cod
4	Mix	Sai	Cod	Mix	Sai	Mix	Sai	Mix				
5	Cod	Mix	Sai	Mix	Mix	Mix	Had	Had	Mix	Mix	Cod	Mix
6	Cod	Mix	Sai	Mix	Mix	Mix	Had	Mix		Mix	Cod	Mix
7	Mix	Mix	Mix	Shr	Shr	Shr	Shr	Shr	Shr		Mix	Mix
8	Cod	Mix	Sai	Mix	Mix	Sai	Mix	Mix	Mix	Mix	Mix	
9	Cod	Cod	Sai	Mix	Mix	Mix	Mix	Mix	Mix	Cod	Cod	
10	Cod	Sai	Sai	Had	Mix	Mix	Mix		Mix		Cod	Mix
11	Cod	Sai	Sai	Shr		Mix		Shr	Shr		Mix	Mix
12	Cod	Sai	Sai	Mix	Mix	Mix		Mix		Cod	Cod	
13	Cod	Sai	Sai	Had	Sai	Sai	Sai	Mix	Mix	Cod	Sai	Sai
14	Cod	Sai	Sai	Mix	Mix	Mix		Mix	Mix		Cod	Mix
15	Cod	Mix	Sai	Mix	Cod	Mix		Mix	Cod	Mix		Mix
16		Sai	Sai	Sai	Sai	Mix		Sai	Sai	Mix	Sai	Sai
17	Cod		Sai	Mix	Sai	Mix	Had	Mix	Mix	Mix	Mix	Mix
18									Sai	Mix	Mix	Mix
19		Cod	Mix	Mix								
20	Cod	Sai	Sai	Had	Mix	Mix		Mix	Mix		Cod	Mix
21		Mix	Mix		Mix	Mix			Mix		Mix	Cod
22	Mix	Sai	Sai	Mix			Sai	Mix	Mix	Cod	Mix	
23	Cod	Mix	Sai	Mix	Mix	Mix	Sai	Had	Had	Mix	Mix	Cod
24	Cod						Mix	Mix	Had	Mix	Mix	Mix
25	Cod	Cod	Mix	Mix	Mix	Mix	Mix	Mix	Mix	Cod	Cod	
26	Cod	Cod										
27	Mix	Mix	Sai	Mix	Mix	Mix	Mix	Sai	Had	Cod		Mix
28	Cod	Mix	Mix		Shr	Sai	Shr	Had	Had	Mix	Mix	Mix
29	Cod	Cod	Mix	Mix	Mix	Mix	Mix	Mix	Had		Mix	Cod
30	Mix	Cod	Mix	Mix	Mix		Mix	Cod		Cod	Cod	Shr
31		Mix	Mix	Mix	Mix	Mix	Mix	Mix	Mix	Mix	Mix	Mix
32			Sai	Mix	Sai	Mix	Mix	Mix	Mix			
33	Cod	Sai	Sai	Mix	Mix	Mix	Mix	Mix	Mix	Cod	Mix	Sai
34	Cod	Sai	Sai	Had	Had	Sai	Sai	Mix	Mix	Cod		
35	Cod	Sai	Sai	Sai	Shr	Mix	Had	Had	Shr	Mix	Mix	Cod
36	Cod	Cod	Cod	Mix	Mix	Mix		Mix	Had	Mix	Mix	Cod
37	Cod	Mix	Mix	Had	Mix	Mix	Mix	Cod	Mix			
38	Cod	Cod	Mix	Mix	Mix	Mix	Mix	Had	Had	Cod	Mix	

MODEL AND DATA

This section describes the optimal control model and data that is developed and employed to analyze the research question. First a general overview of the model is given; next each element is described in more detail.

This study serves as a first stage analysis where the problem is described and a simplified deterministic model is developed. This will be enhanced and refined with better data and taking stochasticity into account in future studies. The model is developed in continuous time in the computer software Wolfram Mathematica v. 8. We have assumed a model vessel with a given cost structure. This vessel can participate in five separate fisheries. Each of the fisheries has a given catch and catch composition. Sales prices for each fish species are known. These data are utilized to calculate the marginal profit from participating in each fishery and search for the most profitable sequence of fisheries constrained by quotas in each fishery.

The model does not explicitly take into account the geographic location of the fishery and thus the costs of steaming to and from port and that this time is not available for fishing.

Fisheries and revenue

The trawlers have a number of fisheries options available. As mentioned, saithe and shrimp fisheries are conducted with little bycatch and can be considered single-specie fisheries. Cod and haddock can be caught in a mixed fishery, where the skipper by selecting fishing grounds and gear design to a degree can control the composition. This is illustrated in the four-dimensional plot in figure 3. The axes determine the relative share of the catch and the bubble size determines the quantity of cod. From the plot we can see that cod are caught in a mix with both saithe and haddock, but predominantly the latter as the bubbles are skewed towards the bottom in the plot. The composition varies from almost exclusively cod to high shares of haddock. This variability makes it difficult to model one or more "fisheries" for cod and haddock. For modeling purposes, we have implemented this through defining a "cod" fishery, a "haddock" fishery and a mixed fishery with a defined composition.

To estimate the catch associated with each fishery option, the Norwegian Directorate of Fisheries has supplied us data on each vessel's landings in 2009-11. The data contain landing date, quantity, value and specie. We first categorized each landing according to fisheries. Landings with more than ¾ of the catch consisting of one species were categorized as single specie fisheries. Landings with less than ¾ and more than 1/3 cod and haddock were categorized as "combi" fishery.

The difference between the landing date and the date of the previous landing was used to estimate tour length and calculate catch rate per day. The observations were sorted and averaged to obtain an estimate of catch rate per day for each fishery and month of the year. These observations were them used to estimate a continuous function for catch rates with functional form given in eq. 1 in order to capture the seasonal variations.

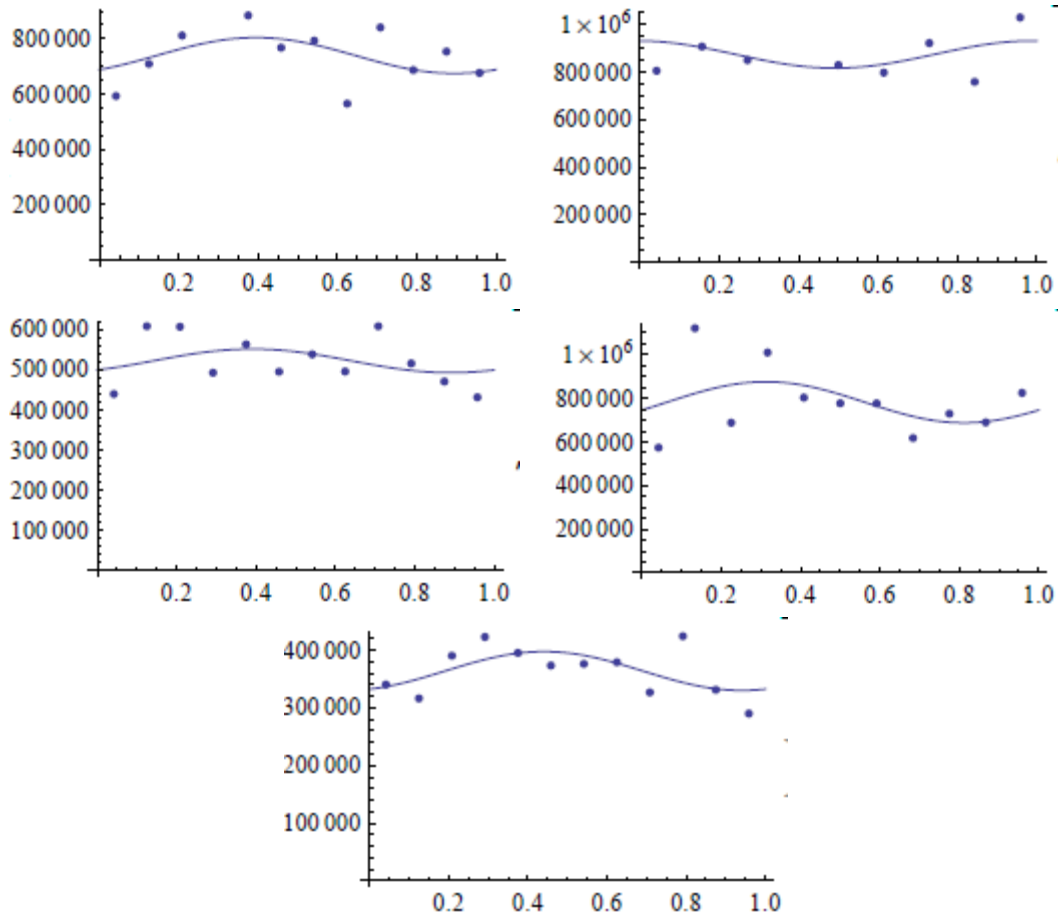$$Catch_{fm} = h - s \cdot \sin[(t - p) \cdot 2\pi], \qquad \text{(Eq.1)}$$

Figure 2 Modeled monthly catch rates (kg) for cod, haddock, saithe, combi and shrimp fisheries (successively from top left)

The results from the nonlinear regression are shown in fig. 2. The cod fishery is estimated to have a top in April/May at about 800 tonnes per month and bottom out in late October at 650 tonnes per month. The same general pattern, with a top in spring/summer and bottom in autumn/winter is found for saithe, combi and shrimp. Haddock has the opposite pattern, with low catch rates in summer and high during mid-winter.

Bycatch associated with each function was also estimated from data and the same harmonic functional form. Revenue is calculated by multiplying catches with sales prices. Average observed prices for each month are employed.

Costs

Only the variable costs of fishing are relevant for short-term decisions about where to allocate fishing effort. The Directorate of Fisheries carries out an annual profitability study of the Norwegian fishing fleet, sampling accounting figures from randomly selected vessels [8]. This does, however, not break down elements into variable and fixed costs. We have therefore assumed that sales fees, fuel and labour variable make up the variable costs and that there are no fixed elements in these items. Based on the survey results from 2010, fees make up 3% of revenue. Crewmembers are generally paid a percentage of revenues less other variable costs. There is also an element of fixed payments for officers, but this is small and disregarded here. Using data from the profitability survey for trawlers, we employ a crew share of 40% of revenues less fees and fuel costs.

Fuel costs are considerably more difficult to model, and a simplified approach is employed here. Fuel is primarily consumed associated with towing the trawl. Different species have different swimming speeds, and therefore require correspondingly different towing speeds and fuel consumption for the trawler. We have access to detailed fuel consumption figures from one trawler for one year. These observations form the basis for species-specific fuel cost-catch relationships. We have assumed that fuel use per day has both a fixed and variable component according to the following equations. Fuel price is assumed 5 NOK/l (about 0,8 USD/l). F is fuel consumption and H is daily harvest.

$F_{cod,haddock,combi} = 0,05 \cdot H + 3692$, (Eq. 2)
$F_{saithe} = 0,075 \cdot H + 3838$, (Eq. 3)
$F_{shrimp} = 0,17 \cdot H + 6375$, (Eq. 4)

Quota restrictions

Catch for most species is restricted by quotas. Due to an ongoing ITQ-regime, these vary between vessels. Vessels can also be allowed to fish another vessel's quotas short-term, in case of mechanical problems, further aggravating differences between vessels. Table III presents the average, maximum and minimum catches for the vessels in 2011. There are relatively large differences for all species, especially for haddock, saithe and other species, where some vessels catch very little compared to the average and maximum catch. More than half the vessels do not participate in the shrimp fisheries. Based on the quotas of an example vessel, we set the quotas restricting the model vessel to 1 950, 1 250 and 1 450 for cod, haddock and saithe, respectively.

Table III Average, maximum and minimum catches per vessel 2011 (shrimp limited to participating vessels)

	Cod	Haddock	Saithe	Shrimp	Other
Average	2 700	1 915	1 697	1 099	293
Max	4 214	3 648	4 700	3 041	1 179
Min	912	37	47	238	6

Reward

Revenues are prices multiplied with catch. The prices employed here are actual monthly average prices obtained by the Norwegian trawlers in 2011 for catch frozen at sea illustrated in Fig. 3. Shrimp receive the highest prices and rose during 2011. Cod is valued at about 4 NOK/kg less and saithe and haddock about a further 3 NOK/kg less.
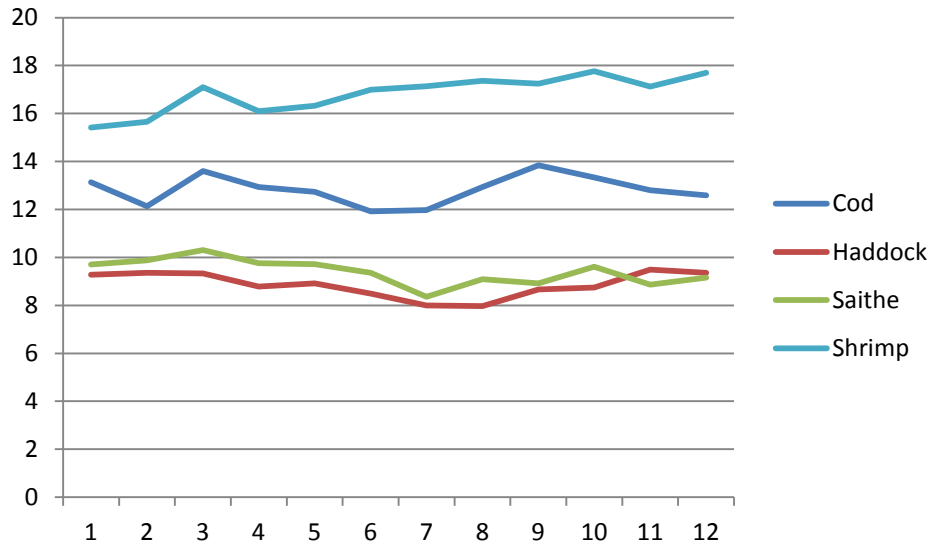
Figure 3 Monthly average prices (NOK/kg) for frozen catch employed in the model (Data: Norwegian Directorate of Fisheries)

RESULTS

Combining catch rates with costs and revenue information yields profit curves for each of the five fisheries options as shown in Fig. 4. The model shows relatively large differences in profitability within the year for most fisheries. For cod, marginal profit varies from 7 500 to 8 500. The differences are most notable for the haddock fisheries, varying from 6 400 to 9 000. These differences imply that how fishing effort is distributed over the year may have large influence on profits.

We also note that there are relatively large differences in profits between fisheries. Particularly saithe and shrimp fishing is clearly less profitable than the three other fisheries.

With no quota restricting vessel activities, a rational vessel plan would operate at the envelopment curve at all times. During the year, there are several shifts in which fisheries is more profitable. From January through February, haddock fisheries tops, followed by a short period of combi fishing. From about mid March to mid September, cod fishing is at the front followed by haddock fisheries for the rest of the year.
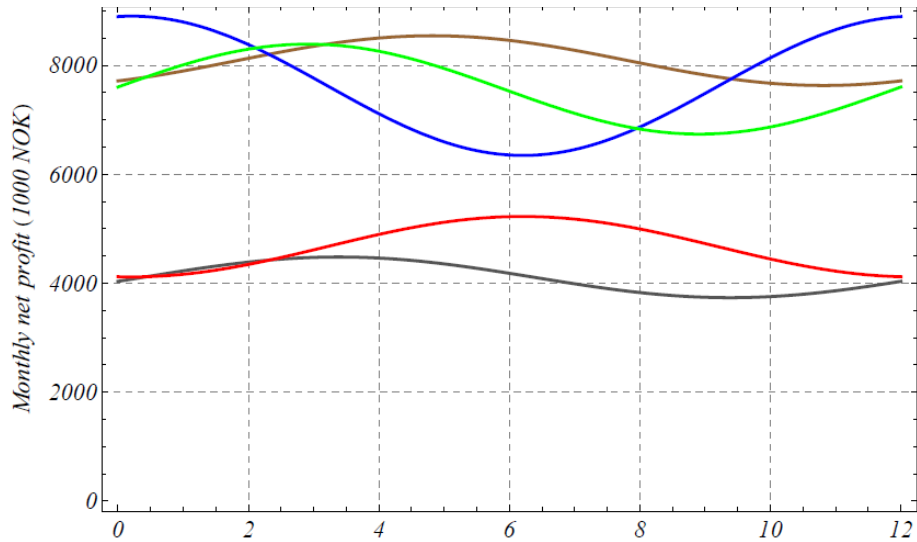
Figure 4 Modeled monthly profit from cod (brown), haddock (blue), saithe (gray), combi (green) and shrimp (red) fisheries

The optimizing routine is utilizing the capacity of constrained optimization built into the Mathematica software. The model's control variable is the type of fishery, searching for local profit maximums of varying sequences of fisheries, assuming none, one or several occurrences of the five possible fisheries. The optimizing routine is constrained by the quotas of cod, haddock and saithe, and takes into account varying bycatch within each fishery over the year.

The results from the optimization are shown in Fig. 5, obtaining a contribution to fixed costs of 43.2 million NOK. The model suggests the vessel should do haddock fisheries in December and January, switch to cod fishing in late January before utilizing shrimp from mid-March to early December.
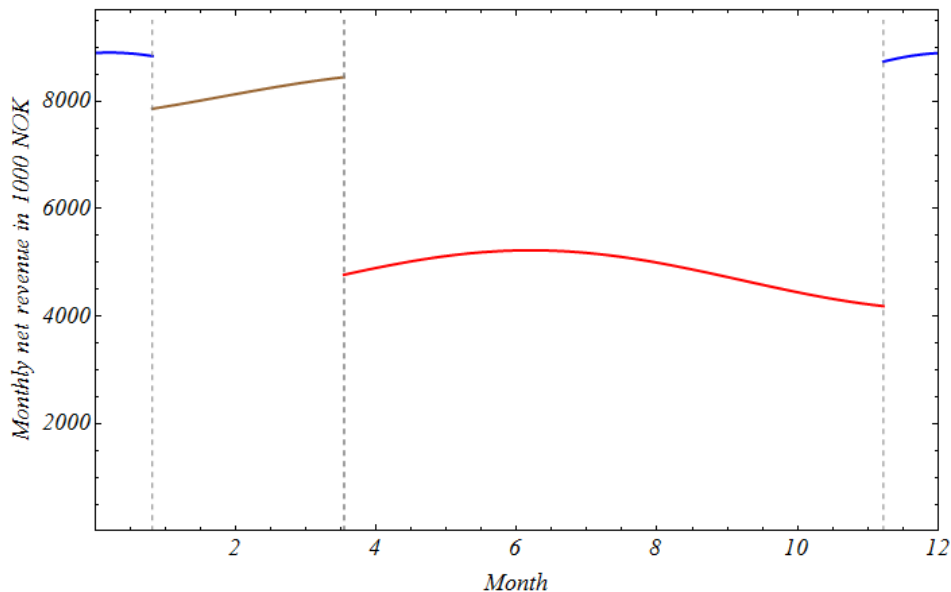

Figure 5 Profit maximizing selection of fisheries and sequence

Table IV compares the vessel's total catch and quota by specie. The cod and haddock quotas are fully utilized, while the saithe quota is marginally exploited with only 194 out of 1.450 tons fished. Based on

the marginal profit curves, this was expected, as the saithe only showed higher profits than shrimp a small period in February. The little saithe that is caught is caught as bycatch in the cod and haddock fisheries.

Table IV Catch, quotas and contribution for the modeled vessel

	Catch	Quota	Profit (1,000 NOK)
Cod	2,000	2,000	14,457
Haddock	1,250	1,250	6,763
Saithe	194	1,450	
Shrimp	2,843	No quota	22,000
Total	6,267		43,220

DISCUSSION

Our model predicts a fishing pattern chronologically composed of a short haddock season, a medium cod season, a long shrimp season and a short haddock season finishing off the year. Although there is large variation between the actual vessels' observed fishing patterns, the predicted pattern differs considerably from the observations. Relatively few vessels undertook long shrimping seasons and few had haddock seasons. Those that did fish haddock generally placed this towards the middle of the year. Cod was usually done in January, as opposed to the modeled February to April. During this time, most of the observed trawlers undertook saithe fisheries, a fishery that is not represented in the modeled pattern.

The model is a simplification of the highly complex decision problems facing actual fishermen, making restrictive assumptions and leaving variables out of the model. A number of factors can have influence on the results and can contribute to explaining the differences, particularly model assumptions and suboptimal decisions by the operators.

The model assumes full information about catch rates. As the observed catch rates showed large variations, this is an obvious shortcoming that is explicitly modeled in other effort allocation studies such as Lane [1] and Babcock and Pickitch [2]. With information about the true catch rates coming from the first tows, a skipper would have new information and could change the decision about where and what to fish. We did not have explicit haul data to calculate catch rates, but approximated this through data from landing forms stating date and landed quantity. This may underestimate trip length and hence catch rates. The landings are often a combination of various fisheries, yielding further uncertainty about catch rates.

The catch rate "data" were regressed to form a seasonal pattern. For some fisheries, the fit was less good, and it is likely that the true seasonal pattern had not been modeled. The model assumes that the fishermen cannot influence the catch composition beyond the selection of the five defined fisheries. The observations on individual landings as illustrated in fig. 6 suggests that the skippers can target a number of catch compositions.
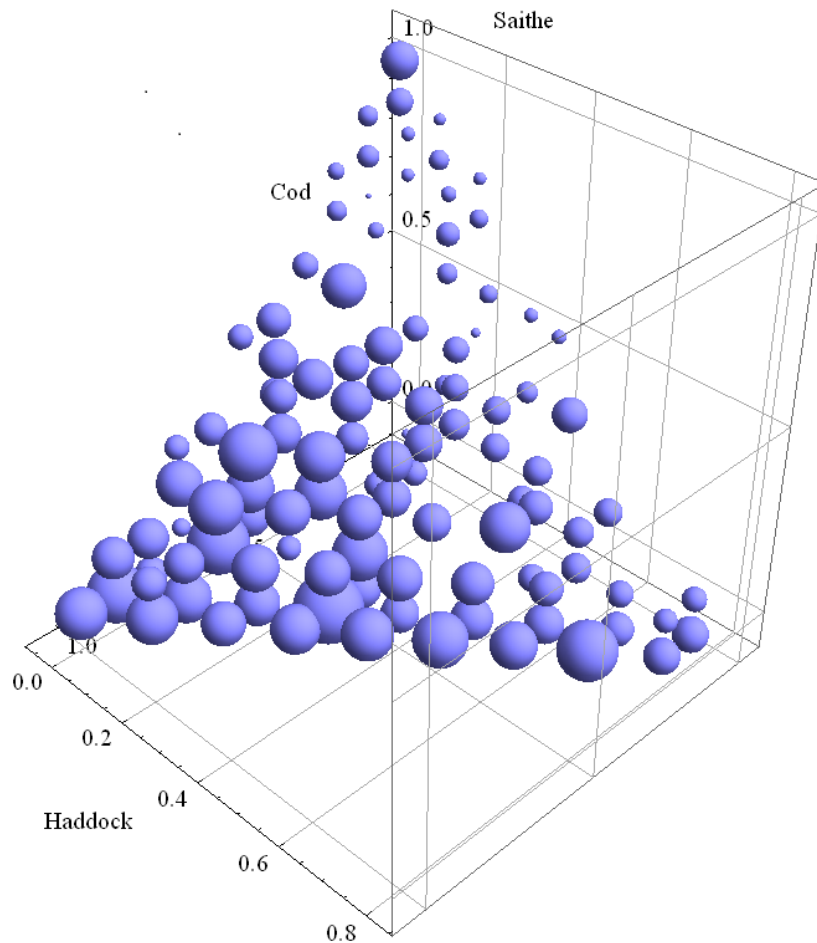
Figure 6 Cod catches (size of bubbles) distributed according to share of cod, haddock and saithe in landings 2011.

Although the uncertainties associated with catch rates are likely the largest, differences among the vessels in technical and organizational characteristics also play a major role. Different size, engine capacity, cargo holds, fish finding and processing equipment can render a vessel unsuited for certain areas or fisheries. As an example many vessels do not have equipment for processing shrimp installed as shrimp prices have recently risen after a long period with low prices and profitability. Some of the vessels are owned by vertically integrated companies and may have a fishing pattern that is influenced by downstream firms [8].A prime difference among vessels is found in their quota portfolio. Some vessels hold higher quotas than others, and this will have a major impact on their harvesting pattern. Higher quota for the model vessel will likely lead to reduced shrimping season and expanded haddock and cod seasons.

The model also implements quite simplified cost function, represented only by fuel, fees and labor costs. The fuel costs may be misrepresented, as we do not have good information on the causal relationship between catch and fuel consumption. Total fuel costs for a year is comparable with observations of fuel costs, but the division between fisheries and catchability is uncertain. With high catchability, the trawler's processing capacity may be limiting, and it may not need to operate the trawl continuously, reducing the fixed element in the cost function.

We may also have disregarded other variable cost elements that may vary with fisheries. The maintenance cost of fishing gear is an example of such an item. If a fishery is taking place on rocky bottom and another on mud, the cost is likely to differ. We have not included any opportunity costs associated with fishing as these vessels have very few alternative uses today.

Spatial aspects are only indirectly included in the model through the data on catch rates. A more detailed modeling of these could influence the results as some fisheries occur further from port than others, thus reducing available fishing time and increasing fuel costs. Supply and demand is also assumed to be as in 2011. If all vessels were following the predicted pattern, it is likely that this would have influence on prices.

Fig. 7 shows other local profit maxima reported by the model. In the first panel, the start of each fishery is done earlier in the year and the second has the cod season later in the year. The third panel replaces the haddock and some of the cod fishery with the combination fishery. The reduction in profits are relatively small for these alternatives, 0.2, 1.1 and 0.5 million NOK, respectively. This implies that the economic loss of selecting the wrong fisheries and sequence is relatively small.
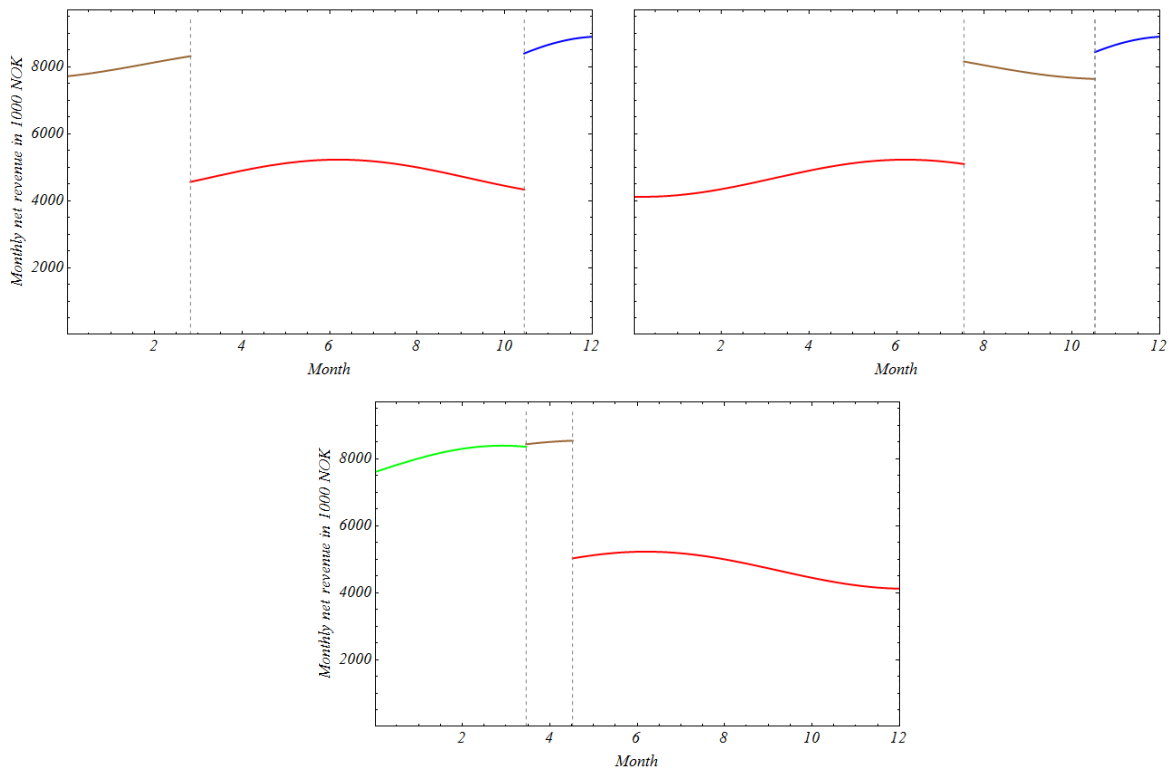

Figure 7 Other local profit maximizing fisheries sequences

REFERENCES

[1] Lane, D. 1989, A partially observable model of decision making by fishermen, *Operations Research*, 37(2), pp. 240-254.

[2] Babcock E. A. and E. K. Pikitch, 2000, A dynamic programming model of fishing strategy choice in a multispecies trawl fishery with trip limits, Canadian Journal of Fisheries and Aquatic Science, 57, pp. 357-370. Van Putten, I. E., S. Kulmala, O. Thebaud, N. Dowling, K. G. Harmon, T. Hutton and S. Pascoe, 2011. Theories and behavioural drivers underlying fleet dynamics models, *Fish and Fisheries*, 13(2), pp. 216-235.

[3] Larkin, S. L. and G. Sylvia, 1999, Intrinsic fish characteristics and intraseason production efficiency: A management-level bioeconomic analysis of a commercial fishery, American Journal of Agricultural Economics, 81(1), pp. 29-43.

[4] Larsen, T.A. and B. Dreyer, 2012, Norwegian codfish trawlers – structure and profitability (in Norwegian with English summary), Report 12/2012, Nofima, Tromsoe.

[5] Eide, A., F. Skjold, F. Olsen and O. Flaaten, 2003, Harvest functions: the Norwegian bottom trawl cod fisheries, *Marine Resource Economics*, 18, pp. 81-93.

[6] Flaaten, O., 1987, Seasonal catchability variations and production functions in the Lofoten fishery (in Norwegian), Report 7005/1-87, FORUT, Tromsoe.

[7] Directorate of Fisheries, 2011, Profitability survey of year-round operated fishing vessels (in Norwegian with English summary and tables), Directorate of Fisheries, Bergen.

[8] Hermansen, O., J. R. Isaksen and B. Dreyer, 2012, Challenging spatial and seasonal distribution of fish landings – experiences from vertically integrated trawlers and delivery obligations in Norway, *Marine Policy*, 36(1), pp. 206-213.