Vessel Efficiency in the Northwest Atlantic Sea Scallop Fishery

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Abstract

In June, 1999, a portion of the Georges Bank fishing grounds (Closed Area II) that had been closed to protect depleted groundfish stocks was opened to US commercial sea scallopers to harvest sea scallop beds that had grown substantially. Vessels that participated in the exemption fishery were each allowed a maximum of three trips in Closed Area II. A trip was limited to 10,000 pounds of scallop meats per trip and charged 10 days at sea from a vessel's 1999 days-at-sea allotment. The fishery was further controlled by a 9.4 million pounds scallop total allowable catch (TAC) and a 853,000 pound yellowtail flounder bycatch TAC (an overfished finfish stock). By mid-November, the exemption fishery was terminated because the allowable bycatch of yellowtail had been taken. By this time, 187 out of 276 permitted vessels had made more than 644 trips to Closed Area II, harvesting a total of 6.0 million pounds of scallop meats worth more than $36 million (ex-vessel). This study compares the technical efficiency of limited access scallop vessels which participated in the Closed Area II fishery with those which did not participate. We used Data Envelopment Analysis (DEA) and trip level data to decompose efficiency measures for trips which took place both in and out of Closed Area II. Explicit measures for sea scallop biomass are included in the models to determine how biomass affected the DEA measures.

I. Introduction.

Closed fishing areas have become an increasingly popular fishery management tool to reduce fishing mortality on key species, to protect marine mammals, preserve biodiversity and to protect essential fish habitat. Often, closing an area to protect one species or species assemblage can have unintended consequences on other fishing industry sectors by restricting their ability to fish in key areas. The Georges Bank Atlantic sea scallop fishery is one example where this has occurred.

In December 1994, the Secretary of Commerce closed three large areas on Georges Bank in order to rebuild depleted stocks of Atlantic cod, haddock and yellowtail flounder. These areas were closed to all fishing gear capable of catching groundfish, including scallop dredges. By 1999, sea scallop biomass in the closed areas had increased 20 times from the 1994 levels (NEFSC 2001).

The sea scallop industry was granted limited access to Closed Area II (figure 1) on Georges Bank, beginning June 15, 1999. Restrictions were placed on vessels that chose to participate in the Georges Bank sea scallop exempted fishery program. First, only vessels using scallop dredge gear were allowed in the program. Secondly, vessels were limited to a maximum of three trips in Closed Area II of 10,000 pounds per trip, or 11,000 pounds per trip with an observer, with an overall Closed Area II scallop catch quota of 9.4 million pounds. Thirdly, a total allowable by-catch limit was established for yellowtail flounder of 853,165 pounds, which if attained, would terminate the exempted fishery program. Lastly, each sea scallop vessel making a trip in Closed Area II would be charged 10 days at sea from its yearly fishing time allocation, or the actual fishing days used during its closed area trip, whichever is greater.

The 1999 exempted fishery program was terminated in November when the yellowtail flounder bycatch limit was reached. By then, 187 out of a possible 276 limited access sea scallop vessels had participated in the program, but only 64% of the total scallop quota had been landed. The program again operated in 2000, but only 80 vessels participated in Closed Area 2, possibly due to an increase in scallop abundance in the general open areas. Additionally, vessels may have participated in 1999 for strategic purposes to ensure that the program was successful and would be offered again in the future.

This paper evaluates the efficiency of vessels participating in the 1999 sea scallop exempted fishery program to determine if they were less (or more) efficient than non-participating vessels. Additionally, we investigated how sea scallop biomass and yellowtail bycatch impacted the efficiency of sea scallop vessels. Because a minimum of 10 days at sea was charged for each trip to Closed Area 2, concern was raised that efficient vessels were being discouraged from participating because they could catch an equivalent amount of scallops with less effort outside the closed areas. The 10 days at sea charge may have had unintended distributive effects that penalized efficient vessels.

II. Methods

Technical efficiency can be measured from either an input or output orientation. A production plan is generally considered to be efficient if there is no way to produce a given level of output with fewer inputs (input orientation), or to produce more output (output orientation) with a given level of inputs (Varian, 1984). To estimate efficiency, we used Data Envelopment Analysis (DEA), and adopted an input oriented approach because scallop trips in the closed area were capped at 10,000 pounds (11,000 with an observer). Vessels fishing in the closed area were unable to expand output because of the trip limits. Although these limits do not apply to other areas, the need to be consistent across areas in our analysis made it necessary to use an input oriented model. F•re, Grosskopf and Lovell (1994), developed the following Data Envelopment Analysis (DEA) to model efficiency from an input orientation:

$$\min_{\lambda, z} \lambda \qquad (1)$$

s.t.

$$u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm}, m = 1,2,\ldots,M, \ (2)$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq \lambda x_{jn}, n = 1,2,\ldots,N, \ (3)$$

$$z_j \geq 0, j = 1,2,\ldots J. \ (4)$$

Where :

8 = efficiency score
u_{jm} = quantity of output m produced by firm j.
x_{jn} = quantity of input n used by firm j.
z_j = weights used in constructing the frontier.

The F•re, et al. model assumes constant returns to scale (CRS) and strong disposability of inputs, but with the addition of a constraint could be converted to a variable returns to scale (VRS, $\Sigma z_j = 1$), or non-increasing returns to scale (NRS, $\Sigma z_j <= 1$) model.

A technical efficiency (TE) score of 1.0 indicates that an observation is efficient, while a score of less than 1.0 indicates that (1) an observation is inefficient, and (2) the amount by which inputs need to be reduced for that observation to be considered efficient. For example, a score of 0.9 means that a firm should be using 10% less inputs (1-0.9) to produce the same output. Note that all inputs are reduced by the same proportion (radially), although there are ways to reduce inputs non radially using slacks (Ali, 1994), or by using the two-stage routine of Coelli (1996).

Because fishing vessels use both fixed and variable factors in their production process, the following modified model was used (F•re, Grosskopf and Lovell , 1994):

$$\min_{\lambda, z} \lambda \quad (5)$$

s.t.

$$u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm}, m = 1,2,\ldots,M, \quad (6)$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, n \in F_x \quad (7)$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq \lambda x_{jn}, n \in V_x \quad (8)$$

$$z_j \geq 0, j = 1,2,\ldots,J. \quad (9)$$

where F_x are the fixed inputs, and V_x are the variable inputs.

The technical efficiency measure estimated in equations 5-9 can be decomposed to determine whether an observation is scale efficient (SE). A scale efficient vessel is operating at a point of constant returns to scale, and its scale of production corresponds to what would occur from a long run competitive equilibrium (Kerstens, 1999). When TE-CRS is equal to TE-VRS, the observation is scale efficient, and the ratio of TE-CRS to TE-VRS (SE) is one. A ratio of less than one indicates that an observation is scale inefficient. If an observation is scale inefficient, the TE measure can be further decomposed to determine whether the observation is producing inefficiently small output in a region of increasing returns to scale, or an inefficiently large output in a region of decreasing returns to scale by comparing TE-CRS with TE-NRS. IF SE is less than one, and TE-CRS equals TE-NRS, input scale inefficiency is due to operating in a region of increasing returns to scale. When SE is less than one, and TE-CRS is less than TE-NRS, input scale inefficiency is due to operating in a region of decreasing returns to scale (F•re, Grosskopf and Lovell , 1994).

In the exempted fishery program, an overall yellowtail bycatch quota was implemented, which when reached would shut down the fishery. In essence, the flounder bycatch is viewed as being a "bad" output from a regulatory standpoint, and therefore needs to be treated differently than a standard output. Vessels which have large amounts of yellowtail bycatch need to have their efficiency scores reflect the fact that they are catching more flounder than other vessels. Although vessels can not exclude the flounder from their dredges before it comes on deck, they can avoid areas that they know have large concentrations of yellowtail flounder. Because yellowtail flounder by-catch can be viewed as a detrimental output from this fishery, it is treated as a variable input, and efficient vessels will be those that can contract both their conventional inputs, and their yellowtail flounder bycatch, conditional on their output. This is essentially the same approach used by Reinhard, Lovell and Thijssen (2000) when they examined the environmental efficiency of Dutch dairy farms with waste, such as surplus nitrogen, treated as an input. Treating undesirable outputs as an input is one of five methods analyzed by Scheel (2000) in his study of how to treat undesirable outputs in efficiency analysis.

III. Data

Sea Scallop and yellowtail flounder catch data by location and trip were obtained from mandatory vessel logbook reports submitted to the National Marine Fisheries Service. Fixed inputs were vessel length and gross tonnage. Variable inputs included crew size, days-at-sea, vessel horsepower, and yellowtail flounder bycatch. Landings and input usage for each vessel was aggregated into eight distinct management areas. These areas were defined as south of Closed Area II (SCA), DelMarVa (DMV), CA II, Hudson Canyon (HC), northeast Georges Bank (NEGB), New York Bight (NYB), South Channel (SC), southeast edge of Georges Bank (SEGB). Sea scallop biomass estimates were derived from fishery independent surveys (NEFMC 2000), and were converted to pounds of meat per square mile in each area. Because many vessels make multiple trips to a given area in a given month, landings and variable inputs were averaged by month for each area. A moving average for each area was then constructed using the monthly data, and then averaged over the entire year. This was done to account for stock depletion effects during the year and resulted in each vessel having one record per area fished.

IV. Results

There were a total of 649 observations based on 208 vessels fishing in eight areas, including Closed Area II, during 1999. There was little difference in the physical characteristics of vessels fishing in Closed Area II and vessels fishing in other areas (Table 1). Catch rates of scallops in the closed areas (expressed as pounds per day absent) were about 77% higher than outside the closed area (Table 1). Vessels fishing in the exempted area program also had a higher yellowtail flounder bycatch, and on average, used fewer days at sea. Trip landings from the closed area were only slightly higher on average, but this was due to the trip limit that was imposed on the vessels.

The average efficiency score for participants in the exempted fishery program in all areas was 0.59 for the CRS model, and 0.75 for the VRS model (Table 2). For participants fishing in open areas, the average score was 0.57 under the CRS model, and 0.74 under the VRS model. Non-participants averaged 0.53 with a CRS model, and 0.77 with a VRS model. Under the VRS model, both participants and non-participants fishing in the NEGB area were all considered efficient with scores of 1.0.

There was early concern that the 10 day minimum charge against a vessel's days at sea allocation would discourage more efficient vessels from participating. During the 1999 program, there were a large number of scallop vessels which participated, and many may have been doing so for strategic reasons. To test whether there was any difference in the efficiency of vessels which participated in the Closed Area II fishery and those that did not, a non-parametric Kruskal-Wallis test (Freund and Walpole, 1980) was performed separately for each area. It was necessary to use a non-parametric test because the data are bounded above at 1.0. The SEGB and SC areas were excluded from the analysis because there were too few non-participants in those areas. A significant difference between participants and non-participants scores was only detected in area 5 (Table 3), under assumptions of constant returns to scale. These results do not support the hypothesis that more efficient vessels chose not to participate in the exempted fishery.

Vessels participating in the exempted fishery program were able to expend less effort harvesting scallops because of the high density of scallops in Closed Area II. Because biomass had a large influence on the catch rates of these vessels, we also ran the model without biomass included. Results show that under the CRS model, there is little difference between the TE scores with or without biomass included as a variable input (Table 4). However, this does not hold using a VRS model. Based on the Kruskal-Wallis test, there were significant differences found in 5 of the 8 areas with a VRS model when biomass was excluded as a variable input (Table 5). There was a particularly large difference in the NEGB area between efficiency scores when biomass was excluded (Table 4). Vessels in this area were landing trips which were larger than those from the closed area on a biomass which was a quarter of that in closed area II. Further investigation is needed to determine if the biomass measure was accurate, whether a finer spatial scale was needed for the area estimate, or whether vessel trip records had an accurate area location recorded. Whatever the case may be, this shows that under the VRS model, biomass influenced the position of the frontier.

Excluding yellowatil flounder by-catch from the model resulted in little difference in efficiency scores using either a CRS or VRS model (Table 6). There was no significant difference (.05 level, 1 d.f.) between scores in any area based on the Kruskal-Wallis test when yellowtail flounder bycatch was excluded.

The TE scores were further decomposed to examine scale efficiency. Because the model calculates efficiency with respect to a sub-vector of variable inputs, scale efficiency is being measured in relation to the variable factors. That is, given the fixed factors, is the vessel operating at the most productive scale size for the variable inputs? If not, is the vessel operating in a region of increasing or decreasing returns to scale for the variable inputs? Overall, 20 observations were considered to be scale efficient, and four of these were from the closed area. For the 629 observations which were not scale efficient, all were producing an inefficiently small output in a region of increasing returns to scale. This indicates that they were producing too little output, and if they increased variable input usage, output would increase proportionately more than their inputs increase. Given that the variable inputs were horsepower, crew size, days at sea, biomass and yellowtail flounder bycatch, these results are consistent with expectations about how fishing vessels operate. However, because vessels use both steam time and search time during their trip, it may be difficult for vessels to reach a point of scale efficiency. Regulations limiting crew size are also likely to keep vessels operating in a region of increasing returns to scale. Additionally, vessels fishing in Closed Area 2 were subject to a trip limit, which constrained their ability to produce enough scallops to be deemed scale efficient.

V. Summary and Conclusions

The technical efficiency of U.S. Atlantic sea scallop vessels fishing in the northwest Atlantic was measured to determine if regulations governing access to Georges Bank Closed Area 2 discouraged more efficient vessels from participating in the exempted fisheries program. Results indicated that there was no difference between the efficiency scores of participants and non-participants in all but one area outside the closed area. However, with such a large number of participants, there were very few non-participants for comparison. There may have been a large number of participants because industry wanted to see the program succeed so it would be available in future years. Unfortunately, at the time this study was completed, year 2000 data were not available to see if these results held.

Scallop biomass was much higher in the closed area than in other areas. The inclusion of biomass had no effect on the individual efficiency scores using a CRS model, but did have an impact using a VRS model. Further investigation is needed to determine if biomass estimates on a finer scale would improve the models, since vessels can easily target areas of high abundance. Although, the biomass level was generally fixed for each area, there is likely to be considerable variation of scallop density within each area. Additionally, there may be a temporal aspect which is not being accounted for because fishery independent surveys are only conducted once per year. There needs to be further research conducted to fully understand the role of biomass in frontier estimation.

Minimizing regulatory bycatch is an important concern in many fisheries worldwide. Efficiency measures need to reflect the fact that bycatch can be environmentally detrimental, and the efficiency scores need to be adjusted accordingly. In this analysis, yellowtail flounder bycatch was considered an input, not an output. However, we found no significant difference in efficiency scores when yellowtail flounder was removed from the model using under either constant or variable returns to scale. Further work is needed to see whether this result holds in other years and for other fisheries.

Efficiency scores were further decomposed to determine how many observations were scale efficient, and for those that were not, how many were operating in an area of increasing or decreasing returns to scale. Only 20, out of 649 observations were determined to be scale efficient, and those that weren't were operating in a region of increasing returns to scale. Scale inefficiencies are not something that can be easily adjusted in the short-run, but instead may require adjustments in capital stock. However, in the absence of property rights, regulations affecting how vessels are allowed to operate and limits on allowable catch will always affect the ability of vessels to reach optimal scale.

It was unfortunate that at the time of this study, year 2000 data were not available because they could provide important information to managers concerning the impact of the minimum days at sea charge for access to the scallop closed area. There is a great deal of further work which could be done to evaluate the efficiency of scallop vessels, and we view this work as a first step. For example, the scores could be decomposed further to answer questions concerning input congestion. This could lead to information which would help managers evaluate areas to open in a rotational area management strategy. Additional work could also be conducted with parametric techniques to provide confidence intervals for the efficiency scores. Finally, cost data could be incorporated to examine allocative efficiency. Unfortunately, cost data are often lacking for a majority of fishing vessels.

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Table 1. Characteristics of Sea Scallop Vessels -1999

	All Open Areas	Closed Area II
Number of Vessels	208	184
Average Length (ft)	83.6	83.7
Average Gross Registered Tonnage	163.0	161.4
Average Horsepower	864.3	863.8
Average Days Absent Per Trip	7.9	6.9
Average Crew Size	6.0	6.4
Average Scallop Pounds per trip	6,208	9,576
Average Yellowtail By-Catch per trip	18.6	149.2
Average Catch Rate of Scallops	786	1388
Average Catch Rate of Yellowtail Flounder	2.4	21.6

Table 2. Efficiency scores for Participants and Non-Participants using a Constant Returns to Scale (CRS) and a Variable Returns to Scale (VRS) model

	CRS		VRS	
	Participants	Non Participants	Participants	Non Participants
SCA	0.69	0.77	0.72	0.81
DMV	0.52	0.51	0.66	0.66
CA II	0.75		0.78	
HC	0.46	0.47	0.54	0.58
NEGB	0.60	0.35	1.00	1.00
NYB	0.50	0.48	0.69	0.71
SC	0.62	0.55	0.80	0.86
SEGB	0.60	0.57	0.80	0.76
All Open Areas	0.57	0.53	0.74	0.77
All Areas	0.59		0.75	

Table 3. Results of the Kruskal-Wallis Test for Differences

Between Participants and Non-Participants by Area

Area	Chi-square Statistic	Degrees of Freedom	Significant .05 level ? (Yes or No)
CRS Model			
SCA	0.8	1	No
DMV	0.02	1	No
HC	0.46	1	No
NEGB	6.36	1	Yes
NYB	0.02	1	No
VRS Model			
SCA	0.94	1	No
DMV	0.09	1	No
HC	0.55	1	No
NEGB	0	1	No
NYB	1.04	1	No

Table 4. Efficiency Scores with and without biomass included as a variable input

	Model Type					
	CRS		VRS		Biomass (1,000 lbs of meat per square mile)	Average Landings (Pounds per trip)
	Biomass	No Biomass	Biomass	No Biomass		
SCA	0.70	0.70	0.73	0.73	16.8	9,631
DMV	0.54	0.51	0.66	0.59	7.5	8,973
CA II	0.75	0.75	0.78	0.78	16.0	9,670
HC	0.48	0.47	0.54	0.54	31.4	7,665
NEGB	0.58	0.57	1.00	0.64	4.3	10,384
NYB	0.50	0.49	0.69	0.57	6.6	8,777
SC	0.61	0.60	0.81	0.64	5.6	11,439
SEGB	0.60	0.59	0.79	0.62	5.6	11,323

Table 5. Results of the Kruskal-Wallis test comparing efficiency
scores of a VRS model with and without biomass included

Area	Chi-Square	D.F.	Significant at .05 Level? Yes or No
SCA	0	1	No
DMV	7.05	1	Yes
CA II	0	1	No
HC	0	1	No
NEGB	126.9	1	Yes
NYB	59.3	1	Yes
SC	27.9	1	Yes
SEGB	14.15	1	Yes

Table 6. Efficiency scores with and without yellowtail flounder (YT)

by-catch included as a variable input

	Model Type				
	CRS		VRS		YT Bycatch (Pounds per
Area	YT	No YT	YT	No YT	Day at Sea)
SCA	0.70	0.67	0.73	0.71	190
DMV	0.52	0.51	0.66	0.65	0
CA II	0.75	0.73	0.78	0.76	150
HC	0.47	0.45	0.54	0.53	10
NEGB	0.59	0.56	1.00	1.00	34
NYB	0.50	0.48	0.69	0.69	30
SC	0.61	0.59	0.81	0.79	30
SEGB	0.60	0.58	0.79	0.79	30

Figure 1. Georges Bank Closed Areas