Estimated Return to Harvest due to the Maryland Department of Natural Resources Repletion Activities 1990-2006

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Introduction

To estimate the influence on oyster stocks of repletion efforts undertaken by the Maryland Department of Natural Resources (DNR), this analysis looks at the additional return to harvests correlated with the planting of seed oysters and dredged shell. These two activities, along with the collection and use of fresh shell and some oyster hatchery work, comprise Maryland's oyster repletion program. Seed oysters are taken from stock-abundant areas and placed on harvest bars higher in the Chesapeake Bay where stocks are sparse and natural spatfall is less frequent. Dredged shell is used to replace shell removed by harvests in both seed-producing areas and on harvest bars throughout the Bay. It is thought that these activities increase harvestable stocks of oysters. Thus, estimating the increase in harvest implied by repletion program activities will provide a related measurement of the overall increase in population and a direct measurement of the benefits to oystermen due to the DNR's program.

As in Cabraal and Wheaton (1981), oyster harvest in an area and time will be represented as a function of the amount of fishing effort, measured as the oystermen's reported man hours, and the level of oyster stock in an area and time. Formally:

$$harvest_{i,t} = h(E_{i,t}, S_{i,t}) \tag{1}$$

where effort is denoted as E, stock by S, area by i and time by t.[1] Using this representation of harvest to analyze DNR's seed and shell program results in the returns if effort were to remain constant and only stock size increased due to DNR's program. Effort does not remain constant with a change in the repletion program however, as the stock effect of repletion factors into harvesters' effort decisions. To account for this

[1] It is assumed that harvest is increasing and concave in both arguments.

change in effort, our estimation will look at the increase in harvest due both to the direct impact of the seed and shell and the indirect impact through effort.

This report proceeds by first providing an explanation for why a change in effort needs to be considered when examining the returns to DNR's repletion efforts. Then, the general harvest and effort equations are updated with proxies for the level of stock and, an estimation strategy is outlined. After reviewing the data, the results are presented. Our results suggest small positive impacts from the seed and shell programs but an overall negative total return given the investment cost of planting the seed and shell.

Model

DNR's repletion program's effect

Costs for oystermen are represented here generally as $C(E,S,\mathbf{w},\mathbf{x})$, where $\mathbf{w}$ represents input prices and inputs by $\mathbf{x}$. It is reasonable to assume that costs increase in harvest, wages and inputs.[2] Taking the national price of oysters, p, as fixed, the oysterman's decision for any area and time, where i designates area and t designates year, is to maximize profits choosing effort, represented as:[3]

$$\max_{E_{i,t},\,\mathbf{x}_{i,t}} \pi(p_t, \mathbf{w}_{i,t}, \mathbf{x}_{i,t}, S_{i,t}) = p_t \cdot h_{i,t}(E_{i,t}, S_{i,t}) - C(E_{i,t}, S_{i,t}, \mathbf{w}_{i,t}, \mathbf{x}_{i,t}) \quad (3)$$

where $h(\cdot)$ is the harvest described above. At equilibrium, each oysterman will choose effort and inputs such that the marginal return to effort, equal here to price multiplied by the marginal effect of effort on harvest, will be equal to the marginal cost of effort, or

[2] Convexity of cost in harvest is also assumed.
[3] Price can be considered exogenous as the National Resource Council 2004 study estimates that Chesapeake Bay harvests currently constitute about 3 percent of total US supply. Thus, the Chesapeake Bay oystermen are "price takers".

$C_E(\cdot)$.[4] The first order condition implies that optimal effort is a function of price, wages and stock:

$$E_{i,t}(p_t, \mathbf{w}_{i,t}, S_{i,t}).^{5} \tag{4}$$

Placing equation (4) into equation (1) results in a new representation of harvest to be considered when evaluating DNR's program:

$$harvest_{i,t} = h_{i,t}(E_{i,t}(p_t, \mathbf{w}_{i,t}, S_{i,t}), S_{i,t}), \tag{5}$$

with a change in harvest due to a change in stock of:

$$\frac{\partial h}{\partial S} = h_E(\cdot)E_S(\cdot) + h_S(\cdot) \tag{6}$$

Evaluating the effect on harvest of a change in stock due to the DNR program thus requires looking at the indirect effect through effort, $h_E(\cdot)E_S(\cdot)$, as well as the direct effect evaluated in Cabraal and Wheaton (1981), $h_S(\cdot)$.

Econometric Model

As the repletion program may influence both harvest and effort through the level of oyster stock, it is necessary to estimate both the level of harvest (5) and the level of effort (4). A precise measurement of oyster stock, *S*, is not available for use in the estimations below. Rather than attempt to imply a stock size using a method such as the Leslie and DeLury models, we chose to proxy for stock by using factors which are assumed to influence it.[6] Using proxy variables for stock allows us to incorporate DNR's seed and shell plantings into the model as the repletion program affects local oyster populations. Lagged measurements for salinity and dissolved oxygen (DO), a spat index

[4] From this point on, the analysis is restricted to the choice of effort as data on input choice is unavailable.
[5] The second order condition of $ph_{E,E}(\cdot)-C_{EE}(\cdot) \leq 0$ is satisfied given the assumption of convexity of cost and concavity of harvest, implying any solution to the first order condition is a maximum.
[6] See Barker (2005) for more on these models.

and catch per unit effort are also included as each is believed to influence oyster abundance.

DNR's seed oyster bushels often contain some market sized oysters and some smaller oysters, in addition to spat. Market sized oysters, or "markets", may have an affect on harvest in the year they are planted, "smalls" in the next year or later and spat are not expected to add to harvestable stocks for two to four years after planting. Shell serves as substrate upon which natural spat can set, and these plantings are not expected to have a harvest effect until three or four years after they are planted. Thus, seed and shell data lagged over three previous time periods are included in the estimation models as sh_{t-j}, for shell lagged j years, and $seed_{t-j}$, for seed lagged j years from the present time t.[7] Also, we include a natural spat count index (*n_spat*) lagged by three and four years to account for the natural regeneration of stock.[8]

To account for the impact of Dermo and MSX diseases, we have included salinity levels (*sal*) of the previous three years. There are two opposing effects on stock size from salinity. First, the parasite that causes Dermo disease, *Perkinsus marinus*, is known to be more prolific, and the MSX disease is found more commonly, in water with higher salinity.[9] The second effect of salinity on stock size is a positive growth effect. A continuous variable for salinity is used and a negative coefficient is expected, given the evidence of disease and reduction of stock since 1990.[10] We also include a measurement for *DO* for the previous three years to account for any effect that levels of *DO* may have

[7] Four year lags were used but not found to be statisticly significant nor affect the results.
[8] The natural spat index used comes from DNR's Fall Summary 2005 Report.
[9] A description of the salinity disease relationship can be found in: Appendix 1 of DNR's 2005 Summary Report and Jordan (2004).
[10] As a check to using continuous salinity levels in estimation, we also used dummy variables for cutoff levels of salinity of: high (*sal* >15 parts per thousand), medium (15> *sal* >11ppt) and low (11 ppt> *sal*) suggested in Christman et. al. (2005).

on oyster growth. Finally, we include the catch per unit effort *(CPUE*) of the previous year to proxy for the standing population size at the end of the previous year.

Although oyster seasons differ somewhat depending on gear, the public season in Maryland generally runs from the beginning of October through the end of March. Allowing *t* to represent year "t", catch in October, November and December of year *t-1* is included with the harvest from January, February and March of *t*, to make up year *t'*s harvest. Seed and shell are planted in the spring and summer months of year *t* so would not influence year *t*'s harvest. Incorporating the above proxy variables for stock into our two general models of harvest and effort, the following two equations remain to be estimated:[11]

$$\begin{aligned} Effort_{i,t} = E_{i,t}(p_t,(S_{i,t}(sh_{i,t-1},sh_{i,t-2},sh_{i,t-3},seed_{i,t-1},seed_{i,t-2},seed_{i,t-3},n_spat_3, \\ n_spat_4,sal_{i,t-1},sal_{i,t-2},sal_{i,t-3},DO_{i,t-1},DO_{i,t-2},DO_{i,t-3},CPUE_{t-1}),E_{i,t-1}) \end{aligned} \quad (7)$$

$$\begin{aligned} Harvest_{i,t} = h_{i.t}(E_{i,t},S_{i,t}(sh_{i,t-1},sh_{i,t-2},sh_{i,t-3},seed_{i,t-1},seed_{i,t-2},seed_{i,t-3},n_spat_3, \\ n_spat_4,sal_{i,t-1},sal_{i,t-2},sal_{i,t-3},DO_{i,t-1},DO_{i,t-2},DO_{i,t-3},CPUE_{t-1})) \end{aligned} \quad (8)$$

Notice that a measure of lagged effort will be included in the regression of effort. Lagged effort and price are identifying instruments for effort in a test of the exogeneity of effort in the harvest equation.[12]

Within each year from 1990 through 2006, our data includes aggregate harvest for up to forty-four 3-digit National Oceanic and Atmospheric Administration (NOAA) area codes. Due to reporting errors in the data and the large number of zero observations for

[11] Wages and inputs have also been removed, we have an estimates on fixed costs but chose not to include them at this time to avoid introducing additional measurement error.
[12] See appendix for more details.

harvest and effort, the data is incomplete censored panel data. The data is estimated using separate pooled Tobit procedures which can be represented as:[13]

$$E_{it} = \max(0, z_{it}\beta + u_{it}) \qquad (9)$$

$$h_{it} = \max(0, x_{it}\beta + \varepsilon_{it}) \qquad (10)$$

where z_{it} and x_{it} are independent variables and ε_{it} and u_{it} are idiosyncratic error terms ($u_{it}|z_{it} \sim$ Normal $(0,\sigma_u^2)$, $\varepsilon_{it}|x_{it} \sim$ Normal $(0,\sigma_\varepsilon^2)$).[14] Independent variables include those mentioned above in equations (7) and (8). A maximum likelihood estimation procedure is used to estimate the resulting log likelihood function consisting of likelihoods for each observation, generically represented as:

$$\ln \ell_{i,t}(\theta) = 1[y_{i,t} = 0]\ln(1 - \Phi(\frac{x_{i,t}\beta}{\sigma})) + 1[y_{i,t} > 0]\{\ln \phi[\frac{(y_{i,t} - x_{i,t}\beta)}{\sigma}] - \ln \sigma\} \qquad (11)$$

where $\boldsymbol{\theta' = [\beta', \sigma]}$ is the transposed n-plus-one by one vector of parameters to be estimated, $\Phi(\cdot)$ and $\varphi(\cdot)$ are the standard normal cumulative and probability density functions respectively, and 1[*argument*] is an indicator function which equals one if the argument is true.

Data

An important caveat for this analysis is that harvest and effort data are fishery-dependent. They are generated by buyers of oysters who record harvest information for each transaction on a "buy-ticket", which is then compiled by DNR. These buy-tickets also form the basis for assessing a $1.00/bushel tax on oyster harvests. To the extent that tax-avoidance is a problem in the industry, harvests may therefore be under-estimated by

[13] The appendix contains the results from tests for fixed effects.
[14] See Wooldridge Chp 16 for a full discussion of the model. An assumption of strict exogeneity is not necessary for this model. Although estimated separately, the error terms for the two equations are conditionally distributed given the weak endogeneity of effort found during estimation (see Appendix).

these data. In addition, many oyster buyers may tend to note the origin of their oyster purchases with a bias toward local bars, due to a past policy of allocating repletion effort by harvest records. These are the data which the current management system produces however, and presumably, are used as a basis for management decisions.

Our data is organized at the 3-digit National Oceanic and Atmospheric Administration (NOAA) area code level.[15] Data on annual repletion efforts were obtained from the DNR shellfish program. These activities match with specific harvest and seed bars, which were located in NOAA three-digit area by way of a digital version of Gary Smith's 1997 report on Maryland's Historic Oyster Bottom. Harvest volumes and effort by gear type and year, reported by three-digit NOAA area codes were obtained from DNR's commercial fisheries database

Averages for DO and salinity data were calculated from the *Chesapeake Bay Program*.[16] After matching individual or multiple monitoring sites of the *Chesapeake Bay Program* with each NOAA area code by proximity, the monitoring site data was averaged over sites matched to an individual area if necessary and then averaged over the months outside harvest, from the beginning of April until the end of September, within a year.[17] This gave us an average DO and salinity amount for a majority of the areas that we had harvest data for.[18]

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[15] For estimation with this level of aggregation, we assume oystermen are homogenous within these areas, which we feel is reasonable. We have data further separated within area by gear type but the amount of observations is reduced greatly for some groups within this more disaggregated data.

[16] http://www.chesapeakebay.net/info/monprgms.cfm

[17] The effects of salinity are most pronounced during summer months when oysters spawn and when they grow the fastest (Ewart and Ford 1993). Low DO levels, which have the largest effect on oyster stock, occur during the summer months in the Chesapeake Bay (Jordan et. al. 1992).

[18] The full list of NOAA area codes used is: 5, 14, 25, 27, 39, 43, 47, 53, 55, 57, 60, 62, 72, 78, 82, 86, 88, 94, 96, 98, 99, 127, 129, 131, 137, 168, 174, 177, 192, 229, 231, 237, 268, 274, 277, 292, 331, 337, 368, 377, 437, 537 and 637.

Variables that only change with year include price and the natural spat index. The national price of oysters by weight used in the regressions came from NOAA. To evaluate the results, bushel price of oysters from the DNR was used. The index for natural spat was obtained from the 2005 Maryland Oyster Population Summary Status Report. Summary statistics for the main variables can be found in Table I. The total sample size is 681 observations for 43 NOAA areas over 17 years. This is an incomplete dataset due to some observations having positive harvest with zero effort, these observations were dropped along with the following year as the lagged catch per unit effort is then undefined.

Results

Comparing means

Before going over the regression results, it is worthwhile to look at a simple comparison of means for harvest across areas receiving and not receiving seed and shell. Table II reports the results for two-tailed t-tests for a variety of mean comparisons.[19] The first column indicates which group's mean is being compared to the mean of the remaining observations. For instance, "seeded only 1&2 yrs ago" implies that the mean harvest for areas that received seeding one and two years prior is compared to the mean harvest from all other areas.

The top six rows imply that the seed and shell planting have a positive affect on harvest in comparison to areas not receiving planting in the same year. The t-tests all reject the null hypothesis of equal means in favor of the seeded or shelled area mean being larger (one-tailed tests also support the seeded and shelled areas having a larger mean). The remaining fourteen rows separate the data into more specific area groups in

[19] The tests were run in Stata and allow for the two samples to have unequal variances.

an attempt to capture the timeline of the effect of seeding and shelling. These results are less supportive of individual planting groups having a larger mean harvest than the remaining sample as the majority of comparisons are not statistically significant.[20] This is not surprising as the groups formed are compared against all remaining areas. For example, the group formed by "seeded only one year ago" is compared against the mean of areas that include areas seeded one year ago so long as those areas were also seeded two years and/or three years ago. This creates a problem of creating comparisons which are not restrictive enough if one wants to see the advantage of seeding one year ago compared to not receiving seed one year ago.

To alleviate this problem of comparing means which are not restrictive enough, a third set of t-tests was investigated comparing the more specific groups of seed and shell plantings with groups that did not receive seed or shell in the same year(s). For instance, the "seeded only one year ago" group is now compared only to areas that did not receive seeding one year ago (whether the areas received seeding two or three years ago, along with one year ago, does not make the area acceptable to include). The results of these new t-tests given in Table III are more suggestive of a significant impact of seed and shell than the second set of t-tests. Specifically, five of the seven means for group categories for shelled areas and three of the seven seeded means are significantly different in the expected direction at the 10% level.[21] This preliminary analysis lends support to the DNR's repletion effort, but, further understanding the affect of the seed and shell

[20] Note that seeded only three years ago and shelled only three years ago are significant in the incorrect direction, implying that areas receiving planting three years prior have lower harvest. The perverse result for shell three years prior remains in the effort regressions run later.
[21] Seed only three years ago is significant but implies that receiving seed three years prior results in less harvest.

plantings requires accounting for other influences on harvest which follow in the regression analysis below.

Regression Results

Cobb-Douglas loglinear (log-log) forms were used for estimating the Tobit models described above.[22] Other than the coefficients for the area fixed effects, the estimated coefficients for the harvest regression are reported in column one of table IV, marginal effects are equivalent to the coefficients as the conditional density is one at the mean.[23] Estimated coefficients and marginal effects, evaluated at the mean, for the effort regression are reported in columns two and three of table IV. The harvest coefficients and effort marginal effects are interpreted as elasticities so that a one percent change in a given independent variable causes a percent change equal to the same variable's marginal effect in the dependent variable. Overall, the fit of the regressions, as measured by the alternative R-square, is quite strong at 0.9815 and 0.8066 for the harvest and effort regressions respectively.[24]

Looking first at the harvest regression, the only repletion effort that appears to have a possible effect is shell planted one year ago, which is significant at the 10% level. The coefficient for one year old shell is hard to explain and may be a spurious construct of the data, further, given the endogeneity of effort, the larger corrected standard errors could result in a loss of significance. Taking the means for the amount of shell used last

[22] The natural log of harvest and the natural log of effort followed a normal distribution more closely then the respective non-logged states, further the results of the estimate of transformation (λ) of box-cox estimations were close to zero. Zero was used in place of observations falling between zero and one, which resulted in changing only observations equal to zero.

[23] Results for the area fixed effects can be found in the Appendix. Note that the error term from the effort regression is included and significant at the 10% level. This implies that effort is endogenous, although weakly. As a result of the possible endogeneity, the coefficients are consistent but the reported standard errors are too small (Datt and Ravallion 1994).

[24] R^2s were calculated according to Wooldridge as corr(predicted independent variable, observed ind. var.).

year and harvest from table I, 29,760 bushels and 5,300 bushels respectively, and evaluating the shelled last year coefficient at these means results in a large negative rate of return. Specifically, at these means, the 1% increase in shell one year ago resulting in a .014% increase in harvest, is equivalent to 297 bushels of shell resulting in 0.74 bushels of additional harvested oysters. The average price for a bushel of oysters over the years in our sample is $21.42 while the average cost of planting a bushel of shell is $0.53. For shell one year ago, at the mean, this results in a return in harvest dollars from investment in seed two years ago of 10%, or $0.05 return on every bushel of shell from one year ago, which is reported in the harvest columns in table V.[25]

As table IV shows, the seed and shell program appears to have a much more significant relationship with the effort decision. The amount of seed from one and two years ago, along with shell from one year ago, have significant positive correlations with how much effort is expended in a given area, while the amount of shell from three years ago has a significant negative relationship with effort.[26] Significant positive impacts on effort from the prior year's seeding and shelling may be the result of increased stock due to seed and shell being placed in all of the top "spots" for oysters to grow, and oystermen determining where to place effort over the season. This rationale would be "ideal" in the sense that the results we find would then be useful in relating the impact of the repletion efforts on stock. There is an alternative rationale for the correlation however; oystermen may be placing effort based only on where they know seed and shell has been placed the past summer, regardless of the effect the planting has on stock levels. The results for the impact of seed on effort support both rationales; the positive impact of seed last year (last

[25] Rates of return are holding period returns and are not annualized.
[26] The regressions were run with another year of lagged seed and shell included, the results did not change.

summer) may influence oystermen to harvest in a particular area while positive influence from two years past could be the result of planted oysters growing to maturity. For the impact of shell, shell lagged one year is likely directing oystermen as there is no clear rationale for last year's shell to have an impact on stock. Currently, the significantly negative impact from the amount of shell planted three years ago is unexplainable.[27]

In order to evaluate the impact on harvest through effort, or the first part of equation (6), the coefficient on effort in the harvest regression is multiplied by the various marginal effects from the effort regression. For example, the marginal effect of .12 for the amount of seed from one year prior, implies a .12% increase in effort for a 1% increase in seed the previous year. Using the coefficient on effort from the harvest equation of 1.03, the resulting effect of seed one year prior on harvest is a .1236% increase in harvest for a 1% increase in seed one year prior. Using the means for the amount of seed and shell from table I, along with the price of a bushel of oysters, the cost of a bushel of shell, and the cost of a bushel of seed, $3.96, the rates of return for seed last year, seed two years ago, shell last year and shell three years ago are 52%, 26%, 50% and -37% respectively. Alternatively this can be considered as a return of, $2.05, $1.01, $0.27 and ($0.19), per bushel of increase in seed or shell respectively before consider the costs, which is reported in the effort columns of table V. Total return for the seed and shell program, through the indirect and direct effects, can be found by adding up the per period returns and netting out the costs for the repletion activity, these are -22% and -77% for seed and shell respectively.

[27] Using comparative statics, E_S will be non-negative so long as $C_{ES}(\cdot) \leq 0$ and $h_{ES}(\cdot) \geq 0$. It may be the case that as stock increases, wages for workers go up due to an increase in demand for labor.

Moving on to the remaining coefficients, various specifications for salinity were used in addition to the continuous variables for which the coefficients are reported, including dummy terms for high, medium and low levels of salinity and dummies for having two and three high level years in a row, however the estimates remained similar to those reported. From the coefficients and marginal effects in table IV, higher levels of salinities in the summer before harvest imply significantly lower harvest, which is congruous with a negative impact from disease spreading via high salinity. The much larger magnitude for the marginal effect of salinity in the effort regression is surprising. The coefficients for DO in the effort regression are also a bit surprising as DO could be expected to have a direct impact on harvest through stock size, not solely through effort, although there are no significant results in the harvest regression. Further, the comparatively large significantly positive coefficient on DO lagged one year and comparatively large negative coefficient on DO lagged three years provide contradicting statements on how DO affects a stock size, albeit over time. A reasonable explanation for this has not been determined.

The marginal effect of the natural spat index lagged four years is exactly as expected for both the effort and harvest regressions, positive and significant. This result compared with the seed lagged two years implies that natural spat may take a longer time to grow than the planted seed. It is surprising, however, that the coefficient on the index lagged three years is significantly negative for the effort regression. It remains unclear why a larger spat count would be correlated with lower levels of effort three years post spat sampling.

As expected, effort plays a large role in explaining harvest and a significantly positive relationship exists between last year's and this year's effort. Also, higher effort in a given location in the previous year implies larger effort in the current year. Given that area specific differences are accounted for by fixed effects, this lagged effort impact implies that certain "hot spot" areas do not receive higher effort every year throughout our sample. In other words, it appears that oystermen are at least returning to areas that they harvested heavily the previous year rather than returning to the same bed year after year. Price appears to have no affect on effort when accounting for area fixed effects. This may be due a lack of large variation in price over the years in our sample.

Finally, the coefficient on lagged catch per unit effort is also positive and significant in the harvest regression but not significant in the effort regression. The difference in significance supports the notion that lagged catch per unit effort is an indicator of remaining stock from the previous year. Intuitively, a higher remaining stock level from the prior year results in a larger harvest the following year without an obvious impact on the level of effort (higher stock levels imply "easier" harvesting: higher levels of harvest with the same amount of effort). The differing significance between regressions implies that excess stock from the previous year does not imply a higher expenditure of effort, only harvest.

Conclusion

The goal of this paper was to estimate the impact of the Department of Natural Resources seed and shell planting program on the Chesapeake Bay oyster stock by estimating the impact this program has on oyster harvest. Cabraal and Wheaton (1981) provided the basis for this study. This paper augmented Cabraal and Wheaton's study by

incorporating the effect of the stock level on harvest through effort along with the direct effect of stock level on harvest. Estimation involved the use of an incomplete panel data set with observations at the NOAA area code level. This level of disaggregation has not previously been used to estimate the effect of DNR's repletion efforts. Area effects were tested for and found to be significant. The exogeneity of effort was also tested for and rejected. The results suggest mainly negative monetary rates of return to harvest with the exception of that from seed planted one year ago.

The estimation results suggest that repletion efforts influence the level of harvest primarily through a change in effort. The direct influence of the repletion efforts on harvest are overstated in this report as standard errors corrected for endogeneity were not calculated. The corrected standard errors would be larger than those reported for the harvest regression and, thus, the reported coefficients for the harvest regression are less significant than reported. If repletion efforts were having a positive effect on stock, a positive relationship between some repletion activities and harvest would be expected. This is easily understood if one considers two areas with equal levels of effort, a higher stock level in one area would result with higher harvest levels and this would be picked up in the harvest regression if repletion efforts affected stock levels. Thus, the lack of a significant direct effect on harvest from repletion efforts may be an indicator of the repletion efforts having no significant effect on stock levels however, it is impossible to say for certain without an accurate stock estimate.

There are differing interpretations for why areas with more seed one and two years ago and more shell one year ago had higher effort. The effect from seed two years ago may be explained by the inclusion of oysters older than spat with the planted seed

and would then suggest that the repletion effort is increasing stock levels. The effect from shell and seed plantings done one year prior is more difficult to understand. One possible explanation for the effect of shell is that live oysters are being mixed in with the shell, however, after a discussion with DNR this is not likely to be the case. As given above, an alternative interpretation is that oystermen are following where the seed and shell is being placed in the summer and are oystering in those locations in the winter. This "directing" relationship is supported by the effort regression. As this "directing" relationship between repletion efforts and effort does not suggest an actual increase in stock motivating the placement of effort, the significant results found for seed and shell for one year prior do not directly point to a real increase in stock level from the repletion efforts. Unfortunately, with the data currently available, it is not possible to know for certain whether this result is indeed due to an increase in stock levels or whether the impacts of one year old seed and shell arise due to data issues.

Finally, the result of three year old shell having a significant negative impact on effort may imply a positive result for stock levels albeit with a negative result for returns to harvest. Associating a positive increase in stock level with a negative rate of return from harvest seems contrary to the goal of evaluating the repletion efforts, but, given the lack of accurate stock estimates, estimating returns to harvest seemed to be a natural secondary option to assessing the impact on stock level directly.

Our analysis has been constrained by the existing data and lack of accurate historical stock estimates. Although our results suggest a small stock effect, if any at all, from the DNR's repletion efforts, it is entirely possible that the repletion efforts are having a positive affect on stock levels but the existing data is not permitting an accurate

representation of the program's impact. Further effort in assessing stock levels and correctly reporting harvest and effort estimates would serve to facilitate future analysis of policy impacts, if such analysis is desired.

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Appendix

This appendix covers the regression results in more detail. Mainly, there is a concern that effort may be endogenous with harvest, the details and the results of an endogeneity test are reported here. Also, unobserved group specific error is a possibility in any panel data model and the test results for this are reported here as well. First, area specific effects are tested for in an effort equation used to test the endogeneity of effort. After effort is found to be exogenous, group effects are tested for in the harvest equation. Finally, one robustness check is done by transforming the continuous seed and shell variables into two sets of discrete dummy variables.

Endogeneity and Group Effects

The approach taken to test the endogeneity of effort in the harvest equation was first outlined in Smith and Blundell (1986) for continuous, possibly endogenous, variables and then generalized in Datt and Ravallion (1994) for censored, possibly endogenous, variables.[28] Testing for endogeneity requires estimation of the endogenous variable using the full set of repressors included in the main regression along with an instrument that identifies the equation. The estimated residuals that result from this "first stage" are then included in the main equation along with the possibly endogenous variable. From this full regression, the *t*-statistic provides an endogeneity test, where the null hypothesis of the coefficient equal to zero implies the variable is exogenous.

The instrument that was chosen for effort is effort lagged one year. As can be seen in table AI, the coefficient on $effort_{t-1}$ when *effort* is the dependent variable is statistically different from zero. The significance of the coefficient on $effort_{t-1}$ satisfies one condition of an instrument. The second condition, the exogeneity of $effort_{i,t-1}$ and $harvest_{i,t}$, or $cov(effort_{i,t-1}, \varepsilon_{i,t})=0$, is supported by the uncertain relationship between lagged effort and shocks in current harvest. A positive covariance may be expected as areas with low or no effort in the previous year may have unobservable characteristics that make that area poor with oysters and thus may imply lower or no shocks to harvest (a converse argument exists for high effort and good areas). Contrary to this positive covariance, an area with low effort the previous year may have large shocks in harvest

[28] Wooldridge summarizes the test procedures on pgs 530-531.

the following year due to a "rest period" on the stock (a converse argument exists for high effort followed by low shocks). The covariance relationship cannot be expected to be positive or negative generally, thus we feel that using lagged effort is a justified instrument.

Before estimating harvest and testing the exogeneity of effort, effort was estimated to calculate residuals to be used in the test. Table A1 has the results for the Tobit base regression, column one, and the Tobit regression with area fixed effects, column two, for effort. The Likelihood ratio result for group effects reported below these results imply that there are group effects in the effort regression. Unfortunately, testing for random effects is not possible as a random effects model requires an assumption of strict exogeneity. Strict exogeneity is not plausible here as the error in the current time period is likely correlated with variables of future time periods such as natural spat.[29] Given the results for group effects, these are included in the regression for effort.[30]

After calculating the residuals for the effort equation with fixed effects using:

$$\hat{y}_{i,t} = \Phi(\frac{x_{i,t}\hat{\beta}}{\hat{\sigma}}) \cdot x_{i,t}\hat{\beta} + \phi(\frac{x_{i,t}\hat{\beta}}{\hat{\sigma}}) \cdot \hat{\sigma},$$

the estimated residuals are included with effort in the main equation of harvest. Results for this altered main equation are reported for a base regression and a fixed effects regression in the first and second columns, respectively, of table A2. In both cases the coefficient on the estimated residual is significant at the 10% level suggesting effort may be endogenous.

The failure of the exogeneity of effort implies that the error terms in the harvest and effort regressions have a bivariate normal distribution, or:

$$(\varepsilon_{i,t}, u_{i,t}) \sim N_2\left[0,0,\sigma_\varepsilon^2,\sigma_u^2,\frac{\sigma_{\varepsilon u}}{\sigma_\varepsilon \sigma_u}\right].$$

Without estimating the effort and harvest equations by full maximum likelihood, the coefficients in the harvest regression which includes estimated residuals for the effort regression are consistent although standard errors are not asymptotically valid (Datt and

[29] A large harvest in year 1 could understandably reduce the appropriate natural spat count for year 4

[30] A check for normality was also done by running a probit model and comparing the probit coefficients against altered Tobit coefficients, there was not a great amount of difference thus normality appears to be a justifiable assumption.

Ravalion 1994). Corrected standard errors would be larger than the estimated standard errors reported here. Corrected standard errors and estimation by full maximum likelihood were not done for this report due to the time investment involved and the inexplicable results found in the effort regression pointing to errors in the data. These are both reasonable endeavors had the results been more reasonable in the effort regression.

After finding effort endogenous, group effects were tested for in the harvest equation. The result of the likelihood-ratio test found below the first and second columns of table A2 implies that the fixed effects model should be used.[31]

Dummy variable seed and shell plantings

In addition to the fixed effects model with continuous variables for shell and seed, dummy variables for shell and seed were also included as a robustness check, the results are found in columns three and four of table A1 and A2.[32] The specification marked I includes lagged seed and shell as continuous variables. Specifications II and III include lagged seed and shell as dummy variables depending on when the seed and shell was placed.[33] The dummy variables included are equivalent to those used to group areas in the t-tests. Note that the change to using dummy variables for seed and shell has little effect on the other coefficients in the regressions, suggesting that the coefficients other than those on seed and shell are robust to this change.

As the dummy variables are a discretized representation of a continuous variable, there is no direct comparison to the rates of return reported in the main body of this report, however, marginal effects for the dummy variables can be roughly calculated as a percent change in the dependent variable given that dummy variable being equal to one.[34] The marginal effects are reported for significant results in table A3. The percentage increases are relative to the harvest and effort of areas that never receive seed or shell, 3,294 bushels of harvest and 2,659 man hours respectively. Although comparable rates

[31] The assumption of normality was checked as in the effort case and the assumption was found to be justifiable.
[32] The regression was also run including seed lagged 4 years which had no significant effect.
[33] Specifications which included both dummy variables and continuous variables were run but no seed or shell resulted with a significant coefficient.
[34] There is some bias in this interpretation. See Jan van Garderen and Shah (2002) for a discussion. An estimate in Kennedy (1981) is suggested as percentage = 100 $(\exp\{\beta_D - \frac{1}{2} V(\beta_D)\} - 1)$ - which was used to calculate the estimated values here.

of return are not available, note that the significant effects for seed and shell are similar to those found for continuous variables. For example, the positive effect for harvest and effort is again on shell lagged one year, shell lagged three years again has a significantly negative impact on effort, and seeding of various lags have positive impacts on effort.

Comparative Static

Under the assumptions made so far, harvest is increasing in both effort and stock. Using the first order conditions of profit maximization, the derivative of effort with respect to stock, $E_S(\cdot)$, is found implicitly to be:

$$\frac{\partial E(\cdot)}{\partial S} = \frac{C_{ES}(\cdot) - ph_{ES}(\cdot)}{ph_{EE}(\cdot) - C_{EE}(\cdot)}$$

The sign of $E_S(\cdot)$ will be non-negative so long as the cross partial derivative of cost with respect to effort and stock is non-positive, or $C_{ES}(\cdot) \leq 0$, $h_{ES}(\cdot) \geq 0$and the cross partial derivative of harvest with respect to effort and stock is non-negative, or $h_{ES}(\cdot) \geq 0$.[35] Both of these additional assumptions are reasonable. The assumption on harvest implies that the return to harvest from an extra unit of effort increases when stock increases. The assumption on costs implies that it becomes no more expensive to increase effort when the level of stock increases.

[35] An assumption of either cost being strictly convex with respect to effort, harvest being strictly concave with respect to effort or both is needed to guarantee the existence of a solution.

Table I

Variable	Obs	Mean		Std. Dev.	Min	Max
Harvest	681	5300.411	Bushels (Bshls)	11402.11	0	92297.91
seed t-1	681	6921.718	Bshls	18838.28	0	200945
seed t-2	681	8203.495	Bshls	21205.65	0	200945
seed t-3	681	8808.515	Bshls	21318.6	0	200945
shell t-1	681	29759.56	Bshls	102088.8	0	1122907
shell t-2	681	33140.94	Bshls	113533.7	0	1122907
shell t-3	681	34467.59	Bshls	112625.4	0	1122907
D(seed t-1)	681	0.35536		0.478974	0	1
D(seed t-2)	681	0.377386		0.485089	0	1
D(seed t-3)	681	0.399413		0.490138	0	1
D(shell t-1)	681	0.19677		0.397849	0	1
D(shell t-2)	681	0.201175		0.401173	0	1
D(shell t-13)	681	0.220264		0.41473	0	1
D(seed yr t-1)	681	0.058737		0.235305	0	1
D(seed yr t-2)	681	0.041116		0.198705	0	1
D(seed yr t-3)	681	0.079295		0.270398	0	1
D(seed yrs t-2&3)	681	0.076358		0.265766	0	1
D(seed yrs t-1&3)	681	0.036711		0.188189	0	1
D(seed yrs t-1&2)	681	0.052863		0.223925	0	1
D(seed yrs t-1,2&3)	681	0.207049		0.405488	0	1
D(shell yr t-1)	681	0.076358		0.265766	0	1
D(shell yr t-2)	681	0.066079		0.248603	0	1
D(shell yr t-3)	681	0.091043		0.287881	0	1
D(shell yrs t-2&3)	681	0.039648		0.195273	0	1
D(shell yrs t-1&3)	681	0.024963		0.156128	0	1
D(shell yrs t-1&2)	681	0.030837		0.173003	0	1
D(shell yrs t-1,2&3)	681	0.064611		0.246019	0	1
sal t-1	681	10.45445	Parts per Thousand (PPT)	4.515998	0	20.43914
salt t-2	681	10.66007	PPT	4.550786	0	20.43914
sal t-3	681	10.8964	PPT	4.566757	0	20.43914
DO t-1	681	6.516038	mg/L	0.916711	3.968656	9.572677
DO t-2	681	6.524978	mg/L	0.900227	3.968656	9.339583
DO t-3	681	6.535522	mg/L	0.886243	3.968656	8.908571
N_spat t-3	681	45.67841	Number per Bshl	76.69612	2	276.7
N_spat t-4	681	50.43847	Number per Bshl	76.38643	2	276.7
Price	681	3.599896		0.625337	2.395174	4.912825
Effort	681	4278.173	Man Hours (MHs)	9230.109	0	92591
CPUE t-1	681	1.860464	Bshls/MHs	7.001207	0	121.7575

D(expression) indicates a dummy variable =1 if expression is true

Table II

Harvest means for areas	*Observations*	*Mean (bshls)*	*Std Dev*	*Mean (bshls) of Remaining Sample*	*T-test Ho: mean = mean*	*P*
Seeded one year ago	242	**10094.01**	15673.96	**2657.925**	-7.0197	0
Seeded two years ago	257	**9327.913**	14551.11	**2859.212**	-6.5436	0
Seeded three years ago	272	**8591.065**	14105.29	**3112.005**	-5.7476	0
Shelled one year ago	134	**11692.54**	17231.36	**3734.516**	-5.1838	0
Shelled two years ago	137	**11143.43**	18235.45	**3828.914**	-4.5773	0
Shelled three years ago	150	**8210.928**	15123.77	**4478.231**	-2.8527	0.0048
Seeded only one year ago	40	**6313.807**	15646.77	**5237.172**	-0.4285	0.6705
Seeded only two years ago	28	**3886.293**	8283.913	**5361.047**	0.9053	0.3722
Seeded only three years ago	54	**1712.445**	5348.497	**5609.422**	4.5022	0
Seeded only 1&2 yrs ago	36	**5301.284**	10277.01	**5300.362**	-0.0005	0.9996
Seeded only 2&3 yrs ago	52	**4710.489**	7861.046	**5349.18**	0.539	0.5916
Seeded only 1&3 yrs ago	25	**5867.454**	8842.38	**5278.801**	-0.3226	0.7494
Seeded all of 1-3 past yrs	141	**13139.47**	17099.12	**3253.544**	-6.6663	0
Shelled only one year ago	52	**7164.694**	11349.08	**5146.289**	-1.2321	0.2227
Shelled only two years ago	45	**6572.322**	9749.928	**5210.417**	-0.894	0.3754
Shelled only three years ago	62	**3188.201**	6683.645	**5511.973**	2.3921	0.0186
Shelled only 1&2 yrs ago	21	**16626.21**	25157.8	**4940.044**	-2.1228	0.0463
Shelled only 2&3 yrs ago	27	**6995.762**	19022.51	**5230.419**	-0.4789	0.6359
Shelled only 1&3 yrs ago	17	**8954.423**	10690.45	**5206.859**	-1.4247	0.1724
Shelled all of 1-3 past yrs	44	**15746.82**	19293.71	**4578.838**	-3.8025	0.0004

Table III

HARVEST	*Obs.*	*Mean (bshls)*	*Std Dev*	*Mean (bshls) of comparison Sample*	*Obs. of Comparison Sample*	*T-test Ho: mean = mean*	*P*
Seeded only one year ago	40	**6313.807**	15646.77	**2657.925**	439	-1.465	0.1507
Seeded only two years ago	28	**3886.293**	8283.913	**2859.212**	424	-0.6365	0.5292
Seeded only three years ago	54	**1712.445**	5348.497	**3112.005**	409	1.6645	0.0994
Seeded only 1&2 yrs ago	36	**5301.284**	10277.01	**2264.812**	359	-1.738	0.0903
Seeded only 2&3 yrs ago	52	**4710.489**	7861.046	**2820.718**	345	-1.6034	0.1134
Seeded only 1&3 yrs ago	25	**5867.454**	8842.38	**2490.725**	333	-1.8677	0.073
Seeded all of 1-3 past yrs	141	**13139.47**	17099.12	**2362.608**	305	-7.2305	0
Shelled only one year ago	52	**7164.694**	11349.08	**3734.516**	547	-2.12	0.0384
Shelled only two years ago	45	**6572.322**	9749.928	**3828.914**	544	-1.8335	0.0728
Shelled only three years ago	62	**3188.201**	6683.645	**4478.231**	531	1.354	0.1789
Shelled only 1&2 yrs ago	21	**16626.21**	25157.8	**3280.295**	475	-2.426	0.0248
Shelled only 2&3 yrs ago	27	**6995.762**	19022.51	**3726.958**	465	-0.888	0.3825
Shelled only 1&3 yrs ago	17	**8954.423**	10690.45	**3616.214**	458	-2.0375	0.0578
Shelled all of 1-3 past yrs	44	**15746.82**	19293.71	**3294.12**	413	-4.2445	0.0001

Table IV

Number of observatinos	681			681		
Uncensored observations	537			538		
Obs. left censored, at zero	144			143		
	ln(Harvest)			**ln(Effort)**		
	Coeffcient			Coeffcient		ME
	(Standard Error)			(Standard Error)		
ln(seed t-1)	0.0035957			0.1239342	***	0.121613
	(0.012)			(0.032)		
ln(seed t-2)	0.0132257			0.0722865	**	0.070933
	(0.011)			(0.034)		
ln(seed t-3)	0.0058742			0.0219842		0.021572
	(0.011)			(0.033)		
ln(shell t-1)	0.0143318	*		0.0690441	***	0.067751
	(0.008)			(0.025)		
ln(shell t-2)	0.0034748			0.0365742		0.035889
	(0.008)			(0.026)		
ln(shell t-3)	-0.0097407			-0.058655	**	-0.05756
	(0.008)			(0.025)		
ln(sal t-1)	-0.5972005	***		-2.897731	***	-2.84346
	(0.19)			(0.541)		
ln(sal t-2)	-0.1849763			0.5034831		0.494053
	(0.19)			(0.599)		
ln(sal t-3)	0.0386124			-1.387492	**	-1.3615
	(0.212)			(0.678)		
ln(DO t-1)	-0.1282415			-2.93138	*	-2.87647
	(0.492)			(1.5)		
ln(DO t-2)	-0.1079611			0.7360927		0.722306
	(0.477)			(1.508)		
ln(DO t-3)	0.1789548			3.318691	**	3.256532
	(0.516)			(1.586)		
ln(n_spat t-3)	-0.0239553			-0.2173122	**	-0.21324
	(0.034)			(0.101)		
ln(n_spat t-4)	0.0939722	***		0.4288341	***	0.420802
	(0.033)			(0.1)		
ln(effort)	1.026648	***				
	(0.036)					
ln(effort t-1)				0.4230881	***	0.415164
				(0.045)		
ln(price)				-0.8655041		-0.84929
				(0.607)		
ln(CPUE t-1)	0.3145828	***		0.1631998		0.160143
	(0.058)			(0.186)		
uhat	0.0678285	*				
	(0.039)					
Constant	1.564659			8.554898		8.394664
	(1.887)			(5.85)		
sigma	0.7485978			2.448581		
R-sqrd	0.9815	a		0.8066	a	
Log Likelihood	-664.67811			-1368.8639		

*** Significant at the 1% level (two tailed)

** Significant at the 5% level (two tailed)

* Significant at the 10% level (two tailed)

a) R-squares calculated as corr(y, estimated y) per Wooldridge

b) NOAA area fixed effects included in regression, results in Appendix

Table V

	Increase in harvest per one bushel increase (Bshls)		Inc. in dollars from harvest per one bushel inc.		Per period return		Total return netting costs
Repletion effort	Harvest	Effort	Harvest	Effort	Harvest	Effort	
shell t-1	0.002553	0.012389	$ 0.05	$ 0.27	10%	50%	Shell: -77%
shell t-3		-0.009087		$ (0.19)		-37%	
seed t-1		0.095609		$ 2.05		52%	Seed: -22%
seed t-2		0.047052		$ 1.01		26%	
Avg. cost of seed/bu	$ 3.96						
Avg. cost of shell/bu	$ 0.53						
Avg. price of oysters/bu	$ 21.42						

Table A1

Number of obs	681		681		681		681	
Uncensored	538		538		538		538	
Left censored	143		143		143		143	
	ln(Effort)							
	BASE		*Fixed Area Effects*					
			I		II		III	
	Coeffcient (Standard Error)	[a]	Coeffcient (Standard Error)		Coeffcient (Standard Error)		Coeffcient (Standard Error)	
ln(seed t-1)	0.0968731 (0.03)	***	0.1239342 (0.032)	***				
ln(seed t-2)	0.0500711 (0.039)		0.0722865 (0.034)	**				
ln(seed t-3)	0.0148168 (0.028)		0.0219842 (0.033)					
ln(shell t-1)	0.0772544 (0.021)	***	0.0690441 (0.025)	***				
ln(shell t-2)	0.0511222 (0.021)	**	0.0365742 (0.026)					
ln(shell t-3)	-0.0515347 (0.024)	**	-0.058655 (0.025)	**				
D(seed yr t-1)					1.361865 (0.464)	***		
D(seed yr t-2)					0.3647905 (0.548)			
D(seed yr t-3)					0.0572025 (0.423)			
D(seed yrs t-2&3)					0.8418611 (0.458)	*		
D(seed yrs t-1&3)					0.9361004 (0.607)			
D(seed yrs t-1&2)					1.463553 (0.515)	***		
D(seed yrs t-1,2&3)					2.039552 (0.498)	***		
D(shell yr t-1)					1.022743 (0.391)	***		
D(shell yr t-2)					0.6488027 (0.418)			
D(shell yr t-3)					-0.6805116 (0.371)	*		
D(shell yrs t-2&3)					-0.077264 (0.541)			
D(shell yrs t-1&3)					0.4469812 (0.674)			
D(shell yrs t-1&2)					0.7741529 (0.603)			
D(shell yrs t-1,2&3)					0.2545448 (0.512)			
D(seed t-1)							1.156684 (0.282)	***
D(seed t-2)							0.590743 (0.295)	**
D(seed t-3)							0.1783493 (0.292)	

D(shell t-1)							0.7592727	***
							(0.283)	
D(shell t-2)							0.3812004	
							(0.287)	
D(shell t-3)							-0.687556	**
							(0.285)	
ln(sal t-1)	-1.928237	***	-2.897731	***	-2.864884	***	-2.844986	***
	(0.598)		(0.541)		(0.543)		(0.54)	
ln(sal t-2)	1.986047	***	0.5034831		0.6155054		0.5794892	
	(0.575)		(0.599)		(0.599)		(0.598)	
ln(sal t-3)	0.3871576		-1.387492	**	-1.399858	**	-1.350319	**
	(0.577)		(0.678)		(0.679)		(0.678)	
ln(DO t-1)	-2.521518		-2.93138	*	-2.93865	*	-2.850006	*
	(1.57)		(1.5)		(1.502)		(1.497)	
ln(DO t-2)	0.5891928		0.7360927		0.8175405		0.8429204	
	(1.726)		(1.508)		(1.52)		(1.505)	
ln(DO t-3)	2.886518	*	3.318691	**	3.360256	**	3.356885	**
	(1.639)		(1.586)		(1.591)		(1.585)	
ln(n_spat t-3)	-0.170033		-0.2173122	**	-0.213963	**	-0.2116414	**
	(0.111)		(0.101)		(0.104)		(0.101)	
ln(n_spat t-4)	0.3560953	***	0.4288341	***	0.4271457	***	0.4377413	***
	(0.08)		(0.1)		(0.1)		(0.1)	
ln(effort)	-2.011037	***	-0.8655041		-0.684025		-0.7696785	
	(0.523)		(0.607)		(0.61)		(0.606)	
uhat	0.7269032	***	0.4230881	***	0.4263637	***	0.4271796	***
	(0.033)		(0.045)		(0.045)		(0.045)	
ln(CPUE t-1)	-0.0445421		0.1631998		0.1655722		0.1690393	
	(0.163)		(0.186)		(0.188)		(0.186)	
Noaa Area 14			-11.13932	***	-10.84952	***	-10.79777	***
			(2.896)		(2.893)		(2.888)	
Noaa Area 25			0.3213573		0.6909324		0.8894108	
			(1.599)		(1.57)		(1.551)	
Noaa Area 27			1.886397		2.137765	*	2.341669	**
			(1.234)		(1.213)		(1.194)	
Noaa Area 39			3.00312	***	3.161746	***	3.086737	***
			(1.139)		(1.137)		(1.134)	
Noaa Area 43			1.437361		1.321735		1.455123	
			(1.031)		(1.042)		(1.031)	
Noaa Area 47			1.929238	**	1.890195	*	1.970037	**
			(0.97)		(0.974)		(0.969)	
Noaa Area 53			3.266913	***	3.425672	***	3.382065	***
			(1.154)		(1.155)		(1.151)	
Noaa Area 55			-3.521067	**	-3.415752	**	-3.365694	**
			(1.403)		(1.402)		(1.399)	
Noaa Area 57			2.806648	***	2.78917	***	2.823291	***
			(1.008)		(1.009)		(1.008)	
Noaa Area 60			2.284417	**	2.422492	**	2.381939	**
			(1.112)		(1.115)		(1.11)	
Noaa Area 62			-3.032044		-2.883926		-2.677948	
			(2.07)		(2.061)		(2.05)	
Noaa Area 72			1.396557		1.344847		1.367187	
			(0.98)		(0.981)		(0.98)	
Noaa Area 78			2.662112	**	2.6039	**	2.62498	**
			(1.066)		(1.081)		(1.067)	
Noaa Area 82			-0.3770508		-0.3820659		-0.3448529	
			(1.242)		(1.25)		(1.241)	
Noaa Area 86			0.9167896		0.8411773		0.89254	
			(1.049)		(1.051)		(1.049)	

Noaa Area 88		-1.488175		-1.488306		-1.440687	
		(1.557)		(1.556)		(1.551)	
Noaa Area 94		-3.085549	**	-3.012365	**	-3.001758	**
		(1.274)		(1.272)		(1.273)	
Noaa Area 96		-2.092879		-1.939819		-1.948775	
		(1.544)		(1.55)		(1.536)	
Noaa Area 98		-0.3725654		-0.3456473		-0.3381945	
		(0.992)		(0.989)		(0.992)	
Noaa Area 99		0.875531		0.9162243		0.9494393	
		(1.07)		(1.071)		(1.067)	
Noaa Area 127		-1.008398		-0.9466951		-0.9179148	
		(1.209)		(1.206)		(1.207)	
Noaa Area 129		4.500551	***	4.527292	***	4.567793	***
		(1.376)		(1.374)		(1.375)	
Noaa Area 131		1.787254		2.018126		1.925327	
		(1.318)		(1.315)		(1.31)	
Noaa Area 137		0.7948913		0.9687022		0.8830233	
		(1.05)		(1.053)		(1.05)	
Noaa Area 168		0.1750289		0.2096628		0.1964168	
		(1.072)		(1.084)		(1.069)	
Noaa Area 174		-0.311953		-0.3388883		-0.2785118	
		(1.216)		(1.224)		(1.213)	
Noaa Area 177		-0.0308167		-0.0413462		0.0508979	
		(1.126)		(1.131)		(1.124)	
Noaa Area 192		3.27544	***	3.350335	***	3.340789	***
		(1.054)		(1.051)		(1.053)	
Noaa Area 229		3.024378	***	2.97911	***	3.094732	***
		(1.066)		(1.068)		(1.064)	
Noaa Area 231		1.190869		1.468066		1.720514	
		(1.4)		(1.372)		(1.353)	
Noaa Area 237		0.6739548		0.8592796		0.8832586	
		(1.266)		(1.263)		(1.254)	
Noaa Area 268		-0.1684669		-0.1599783		-0.107466	
		(1.27)		(1.273)		(1.267)	
Noaa Area 274		1.814276		1.891217		2.068344	
		(1.307)		(1.296)		(1.281)	
Noaa Area 277		-1.085858		-1.044858		-0.9357666	
		(1.342)		(1.333)		(1.327)	
Noaa Area 292		3.383208	***	3.25889	***	3.38958	***
		(0.972)		(0.981)		(0.973)	
Noaa Area 331		-7.52112	**	-7.22231	**	-7.15027	**
		(3.18)		(3.184)		(3.171)	
Noaa Area 337		-6.95708	**	-6.550273	**	-6.305816	*
		(3.286)		(3.274)		(3.257)	
Noaa Area 368		-8.756042		-8.545066	***	-8.366838	***
		(3.118)		(3.112)		(3.1)	
Noaa Area 377		-6.120923	***	-5.931027	***	-5.830929	***
		(2.244)		(2.249)		(2.232)	
Noaa Area 437		2.751105	***	2.764169	***	2.765815	***
		(1.002)		(1)		(1.002)	
Noaa Area 537		2.314126	**	2.49451	**	2.407516	**
		(1.029)		(1.039)		(1.027)	
Noaa Area 637		1.230165		1.408856		1.299655	
		(1.036)		(1.047)		(1.039)	
Constant	-0.4615719	8.554898		7.725148		7.478553	
	(2.607)	(5.85)		(5.84)		(5.807)	
sigma	2.701899	2.448581		2.440423		2.447739	

R-sqrd	0.7633 [b]	0.8066 [b]	0.8083 [b]	0.8068 [b]
Log Likelihood	-1431.5686	-1367.6323	-1365.4343	-1367.2388
Likelihood ratio test: Chi-Square(42)	127.8726 ***			

*** Significant at the 1% level (two tailed)
** Significant at the 5% level (two tailed)
* Significant at the 10% level (two tailed)
a) Reported standard errors are robust, clustered by area to accont for serial correlation
b) R-squares calculated as corr(y, estimated y) per Wooldridge

Table A2

Number of obs	681	681	681	681
Uncensored	537	537	537	537
Left censored	144	144	144	144
		ln(Harvest)		
	BASE		*Fixed Area Effects*	
		I	II	III
	Coeffcient (Standard Error) [a]	Coeffcient (Standard Error)	Coeffcient (Standard Error)	Coeffcient (Standard Error)
ln(seed t-1)	0.0028963	0.0035957		
	(0.014)	(0.012)		
ln(seed t-2)	0.0132221	0.0132257		
	(0.01)	(0.011)		
ln(seed t-3)	0.0047894	0.0058742		
	(0.01)	(0.011)		
ln(shell t-1)	0.0123135 *	0.0143318 *		
	(0.007)	(0.008)		
ln(shell t-2)	0.0034977	0.0034748		
	(0.007)	(0.008)		
ln(shell t-3)	-0.0116314	-0.0097407		
	(0.008)	(0.008)		
D(seed yr t-1)			0.1190827	
			(0.158)	
D(seed yr t-2)			0.0272794	
			(0.176)	
D(seed yr t-3)			-0.0100571	
			(0.136)	
D(seed yrs t-2&3)			0.2175371	
			(0.151)	
D(seed yrs t-1&3)			0.0298256	
			(0.197)	
D(seed yrs t-1&2)			0.0302304	
			(0.176)	
D(seed yrs t-1,2&3)			0.2132845	
			(0.189)	
D(shell yr t-1)			0.2478133 *	
			(0.128)	
D(shell yr t-2)			0.0717068	
			(0.133)	

D(shell yr t-3)					-0.1187978			
					(0.118)			
D(shell yrs t-2&3)					-0.0172361			
					(0.167)			
D(shell yrs t-1&3)					0.0756867			
					(0.215)			
D(shell yrs t-1&2)					0.0674672			
					(0.189)			
D(shell yrs t-1,2&3)					0.0663556			
					(0.16)			
D(seed t-1)							0.0387665	
							(0.103)	
D(seed t-2)							0.0996333	
							(0.098)	
D(seed t-3)							0.0668374	
							(0.094)	
D(shell t-1)							0.1680661	*
							(0.094)	
D(shell t-2)							0.0294374	
							(0.09)	
D(shell t-13)							-0.1142778	
							(0.091)	
ln(sal t-1)	-0.3794305	***	-0.5972005	***	-0.5872344	***	-0.5890433	***
	(0.13)		(0.19)		(0.189)		(0.188)	
ln(sal t-2)	0.0744156		-0.1849763		-0.1786042		-0.1831361	
	(0.159)		(0.19)		(0.191)		(0.19)	
ln(sal t-3)	0.3423635	*	0.0386124		0.0517805		0.0501564	
	(0.178)		(0.212)		(0.211)		(0.21)	
ln(DO t-1)	-0.1795463		-0.1282415		-0.1209831		-0.1171288	
	(0.467)		(0.492)		(0.491)		(0.488)	
ln(DO t-2)	-0.1171578		-0.1079611		-0.0827225		-0.0887286	
	(0.486)		(0.477)		(0.481)		(0.476)	
ln(DO t-3)	0.2753166		0.1789548		0.1722576		0.1766264	
	(0.374)		(0.516)		(0.52)		(0.516)	
ln(n_spat t-3)	-0.0257379		-0.0239553		-0.0169866		-0.0220417	
	(0.029)		(0.034)		(0.035)		(0.034)	
ln(n_spat t-4)	0.0674656	**	0.0939722	***	0.0910902	***	0.0939539	***
	(0.03)		(0.033)		(0.033)		(0.033)	
ln(effort)	1.047658	***	1.026648	***	1.026568	***	1.027314	***
	(0.017)		(0.036)		(0.037)		(0.036)	
uhat	0.0483092	*	0.0678285	*	0.0678285	*	0.0673911	*
	(0.025)		(0.039)		(0.039)		(0.039)	
ln(CPUE t-1)	0.4272116	***	0.3145828	***	0.3189314	***	0.3156141	***
	(0.104)		(0.058)		(0.059)		(0.058)	
Noaa Area 14			-2.552687	***	-2.490132	**	-2.509491	***
			(0.981)		(0.971)		(0.968)	
Noaa Area 25			-0.487868		-0.4408297		-0.4305645	
			(0.499)		(0.491)		(0.485)	
Noaa Area 27			0.0927874		0.1164019		0.1375919	
			(0.397)		(0.394)		(0.39)	

Noaa Area 39	-0.4126869		-0.37272		-0.4053285	
	(0.387)		(0.39)		(0.386)	
Noaa Area 43	0.1367627		0.1178407		0.1361648	
	(0.331)		(0.335)		(0.332)	
Noaa Area 47	0.0459935		0.0326366		0.0495858	
	(0.317)		(0.319)		(0.317)	
Noaa Area 53	-0.2087987		-0.1833222		-0.1992372	
	(0.394)		(0.399)		(0.395)	
Noaa Area 55	-0.2812384		-0.2606787		-0.2621649	
	(0.456)		(0.452)		(0.451)	
Noaa Area 57	-0.3063199		-0.3086337		-0.3062906	
	(0.339)		(0.34)		(0.339)	
Noaa Area 60	-0.5852654		-0.5493492		-0.576398	
	(0.364)		(0.368)		(0.365)	
Noaa Area 62	-1.297186	**	-1.261953	**	-1.260201	**
	(0.645)		(0.638)		(0.633)	
Noaa Area 72	0.2907469		0.2813134		0.2859711	
	(0.317)		(0.317)		(0.316)	
Noaa Area 78	-0.5121344		-0.5164118		-0.5186884	
	(0.363)		(0.368)		(0.363)	
Noaa Area 82	-0.6104507		-0.6030668		-0.6079616	
	(0.392)		(0.395)		(0.391)	
Noaa Area 86	-0.4132959		-0.4174229		-0.4165109	
	(0.347)		(0.348)		(0.347)	
Noaa Area 88	-0.4347719		-0.4158673		-0.4294786	
	(0.497)		(0.495)		(0.493)	
Noaa Area 94	-0.5681118		-0.553346		-0.556943	
	(0.418)		(0.416)		(0.416)	
Noaa Area 96	-0.7236295		-0.6853533		-0.7079739	
	(0.487)		(0.486)		(0.481)	
Noaa Area 98	-0.297317		-0.2903187		-0.2931628	
	(0.328)		(0.327)		(0.327)	
Noaa Area 99	-0.1726949		-0.157641		-0.1656186	
	(0.343)		(0.344)		(0.342)	
Noaa Area 127	-0.511423		-0.4940861		-0.499485	
	(0.396)		(0.394)		(0.394)	
Noaa Area 129	0.395462		0.4022049		0.4022005	
	(0.472)		(0.474)		(0.473)	
Noaa Area 131	-0.3878469		-0.3370501		-0.3734141	
	(0.423)		(0.426)		(0.421)	
Noaa Area 137	0.0477201		0.0749378		0.054749	
	(0.334)		(0.336)		(0.335)	
Noaa Area 168	-0.4922466		-0.476218		-0.4910752	
	(0.348)		(0.351)		(0.347)	
Noaa Area 174	-1.075831	***	-1.076712	***	-1.0726	***
	(0.396)		(0.399)		(0.395)	
Noaa Area 177	-0.4208209		-0.4211355		-0.4097525	
	(0.372)		(0.373)		(0.371)	
Noaa Area 192	-0.0255951		-0.0130835		-0.0181594	
	(0.366)		(0.367)		(0.366)	

Noaa Area 229			-0.0917876		-0.0976442		-0.084607	
			(0.356)		(0.358)		(0.357)	
Noaa Area 231			-0.2440777		-0.2151104		-0.1929052	
			(0.444)		(0.437)		(0.433)	
Noaa Area 237			0.155393		0.1866599		0.1758221	
			(0.398)		(0.399)		(0.395)	
Noaa Area 268			-0.1577265		-0.1462411		-0.1507129	
			(0.405)		(0.405)		(0.403)	
Noaa Area 274			-0.606392		-0.5972997		-0.5834899	
			(0.42)		(0.418)		(0.415)	
Noaa Area 277			-0.1070766		-0.1028508		-0.0938985	
			(0.434)		(0.429)		(0.426)	
Noaa Area 292			-0.1511699		-0.1622898		-0.153713	
			(0.346)		(0.347)		(0.346)	
Noaa Area 331			-2.016834	**	-1.941804	*	-1.970231	**
			(1.006)		(1.001)		(0.994)	
Noaa Area 337			-1.725694		-1.648806		-1.651205	
			(1.036)		(1.021)		(1.013)	
Noaa Area 368			-2.263972	**	-2.202037	**	-2.216146	**
			(1.018)		(1.005)		(0.999)	
Noaa Area 377			-1.315597	*	-1.2637	*	-1.278326	*
			(0.738)		(0.732)		(0.725)	
Noaa Area 437			-0.3104493		-0.3045247		-0.3093307	
			(0.348)		(0.349)		(0.348)	
Noaa Area 537			-0.571066	*	-0.545517		-0.5638246	
			(0.344)		(0.351)		(0.345)	
Noaa Area 637			-0.5999041	*	-0.5661214	*	-0.5954205	*
			(0.338)		(0.343)		(0.339)	
Constant	-0.7991285		1.564659		1.422439		1.443375	
	(0.793)		(1.887)		(1.872)		(1.857)	
sigma	0.7961766		0.748113		0.7463095		0.7479411	
R-sqrd	0.9787	b	0.9814	b	0.9815	b	0.9814	b
Log Likelihood	-700.65857		-664.07427		-662.82162		-663.95644	
Likelihood ratio test: Chi-Square(42)	73.1686	***						

*** Significant at the 1% level (two tailed)

** Significant at the 5% level (two tailed)

* Significant at the 10% level (two tailed)

a) Reported standard errors are robust, grouping by area to accont for serial correlation

b) R-squares calculated as corr(y, estimated y) per Wooldridge

Table A3

% Change in harvest and effort given change from no repletion to positive repletion		
Repletion effort	Harvest ME	Effort ME
D(shell yr t-1)	17.78%	112.73%
D(shell yr t-3)		-49.93%
D(shell t-1)	27.08%	175.81%
D(shell t-3)		-49.71%
D(seed yr t-1)		285.52%
D(seed yrs t-2&3)		129.44%
D(seed yrs t-1&2)		325.49%
D(seed yrs t-1,2&3)		655.09%
D(seed t-1)		216.24%
D(seed t-2)		79.67%