Appendix A2: Simulation analysis of Patch model estimates

The Patch model (Rago et al. 1996) was tested using simulated data for ocean quahogs and surfclams using the R statistical programming language. The purpose of the simulations was to evaluate model performance under "nominal" conditions (i.e. under the conditions assumed in developing the model), effects of measurement error in position data, assumptions about the spatial distribution of clams, and the size of spatial grids assumed in tabulating position data prior to fitting the Patch model. The simulation analysis involved depicting depletion sites in terms of "cells" (generally 0.25 x 0.25 m) that were small relative to a commercial clam dredge (e.g. 3 m) and the grids that are used in fitting the Patch model (e.g. 6 m). Small cells were used to minimize approximations in simulating the process of a dredge catching clams. Conversion of commercial depletion study results to estimates of survey dredge efficiency was not considered here although it is an important topic for future simulation work.

In the context of the simulations, the most important differences among simulated depletion experiments were the number and spatial pattern of the depletion tows and the species involved. The simulated depletion experiments were based directly on the actual depletion experiments carried out prior to 2008 (17 depletion experiments for ocean quahogs and 22 for surfclams, Table A11-A12 in NEFSC 2008a and Table C13-C14 in NEFSC 2008b). All of the experiments were "commercial" depletion experiments carried out using commercial clam dredges of various widths. Dredge widths assumed in simulations were the same as in the actual experiments.

Simulated depletion study sites were bounded by a rectangle with sides running north-south and east-west (Fig. Sims-1). The simulated study sites were as small as possible with width and length in even multiples the cell size and with a buffer included around the edge of the site that was at least as wide as the dredge. Smaller cells make calculation of simulated catches more accurate but require more computer memory. A cell size of 0.25 m was used in most simulations unless a larger cell size (e.g. 0.5 m) was required to conserve computer memory.

Position data for simulations were the same as smoothed data actually used in the Patch model (NEFSC 2008a, b). There are differences in position data among real depletion experiments that affect accuracy of the actual data but these differences had no impact on simulation results. In particular, there were differences in recording interval, data recording method, and the instruments used to measure position (e.g. various GPS, and Loran-C devices). Similarly, there were differences between experiments in crew, vessels and dredge width, although differences in dredge width were incorporated into the simulations and the Patch model. In general, depletion experiments made during the same year were more similar than depletion experiments made in different years, as the same vessels, commercial dredge and crew were usually used for most or all experiments in any one year. The chief scientists' approach to choosing tow paths was similar for all experiments during any one year but generally changed over time.

In most simulations, surfclams and ocean quahogs were assumed to be distributed across the bottom of the experimental site according to a negative binomial distribution $NB(\mu,k)$ with parameter μ measuring the mean density and dispersion parameter k measuring contagion or "clumpiness". The dispersion parameter k is negatively correlated with variance, $\sigma^2 = \mu+\frac{\mu^2}{k}$. As $k\rightarrow\infty$, the negative binomial distribution approaches the Poisson distribution with mean and variance μ. The negative binomial distribution has a useful property (pointed out by Jiashen T.)

that is used in the simulations. In particular, if $X_i \sim NB(\mu, k)$ then $Y = x_1 + x_2 + x_3 + \ldots + x_n \sim NB(n\mu, nk)$.

We simulated the distribution of clams in depletion experiments using negative binomial distributions with parameters on a per unit area basis (Appendix Table 2-1). Ocean quahogs had a higher density and dispersion parameter (lower variance) than surfclams. The per unit area parameters were based on the median density and dispersion parameter estimates from the real depletion experiments for ocean quahogs and surfclams. For example, μ per unit area was the mean density estimate for all of the ocean quahog experiments. The per unit area dispersion parameter for ocean quahogs for experiment *j* was $k = \frac{k}{\overline{a}_j}$, where k was the median dispersion parameter for ocean quahog depletion experiments, and $\overline{a}_j$ was the mean area swept by all tows in the experiment. If the spatial cells used in the simulation were 0.25 x 0.25 = 0.0625 m^2, for example, then the negative binomial distribution used to populate the cells was $NB(0.0625\ \mu, 0.0625\ k)$.

In simulations and recent assessments, position data were assumed to track the center of the dredge. The assessment algorithm calculates catch assuming that all model grids are hit by the dredge if they intersect straight lines drawn between adjacent position observations. The simulation algorithm is potentially more accurate because it is based on smaller population cells and because the width of the dredge is included in calculating catch. The assessment and simulation algorithms both assume the clams in each grid and cell are mixed randomly prior to each tow.

The path of each tow in simulations was represented as a series of segments composed of rectangles and triangles centered on the straight lines between sequential position observations. The rectangle for each segment was as wide as the simulated dredge and as long as the distance between the position observations. Overlap of sequential rectangles and additional area swept when the dredge changed direction between segments were modeled as triangles and included in calculations (Appendix Figure A2-1).

The simulation was similar to an individual-based approach because catch from each population cell contacted by the dredge was determined by a random number for each resident clam and the assumed dredge efficiency. The simulation algorithm assumes that all of the clams in cells wholly within a rectangle are vulnerable to fishing. Rectangles partially covered by the dredge have a reduced probability *f* of capture, where *f* is the fraction of the cell covered by the dredge. Thus, the probability of capture for a clam in a cell contacted by the dredge is $p=ef$, where *e* is the assumed capture efficiency for the simulated dredge and f=1 for cells completely within the dredge path. To simulate the catch process, a uniform random number $r \sim U(0,1)$ was drawn for each clam in cells contacted by the simulated dredge. A clam was added to the catch and removed from the simulated population if $r \le p$. The number of clams in a population cell was always an integer greater than zero. All clams remaining in a cell after a dredge passed through were assumed to be randomly mixed and equally available for capture in a subsequent tow.

Procedures used to prepare data and fit the Patch model were basically the same as in the previous assessment NEFSC (2008a,b). The simulation software estimated transformed parameters log(*D*), logit(*e*) and logit(k/k_{max}) where k_{max}=15 is an upper bound on *k*. Rago et al. (1996) estimated arithmetic scale parameters. Following NEFSC (2006a,b) the Patch model parameter γ was omitted from the model. Rago et al. (2006) used γ to measure "indirect" effects on catches but the parameter has proven difficult to estimate in practice.

Software used for assessments determined intersections between tow lines and model grids by examining each individual interpolated position value, while the simulation used a geometric approach. However, this difference had little effect on results because the interpolation involves narrowly spaced points. Tests showed that simulation software and assessment software gave the same answers when applied to the same data.

Each simulation was run for each site using the actual tow paths recorded for each survey. A survey run involved calculating the number of clams caught by each tow in a survey, and supplying the patch model with the resulting catch totals and a matrix of the number of grid cells that were fished multiple times on successive tows (the hit matrix).

Scenarios and results

Simulation scenarios tested the affects of several variables on the patch model's ability to estimate parameters with known values. We tested three different grid sizes: grid size 1x was equal to the width of the dredge, 2x was equal to twice the width of the dredge and 3x was equal to three times the width of the dredge. We considered two spatial manipulations to the clam distribution over the site: "cross" and "parallel". Each moved 50% of the clams from one side of the site to the other, in a direction that was across the main trajectory of the tow paths or along it, respectively. This created an uneven spatial distribution of clams in the study site where the density on one side was approximately twice as high as on the other. Finally, we considered a position error by adding a sinusoidal error term to each recorded position in each tow. This was thought to mimic the error produced by a GPS unit placed high on a ship that is rolling in the waves.

Increasing the grid size had a moderate effect on the performance of the patch model. The spatial manipulations had a more substantial effect, particularly in the case of the parallel permutation. Adding positional errors had no discernable effect on the performance of the patch model (Appendix Figures A2-2 and A2-3). Absolute relative median errors in density and efficiency showed the same general patterns (Appendix Tables 2-2). That is, a small affect of increasing the grid size, a moderate affect due to the spatial permutations in clam distribution and virtually no affect due to the inclusion of positional errors.

Discussion

The patch model performed well in the scenarios explored here. Performance was generally better for ocean quahogs than surfclams, but that may have been due to the inclusion of a few surveys that had particularly poor accuracy in the surfclam dataset. These generally resulted from surveys in which very few (< 10) tows were made. We can think of no other *a-priori* reason for differences in performance along species lines, unless there is an interaction between the starting parameter values for density and dispersion, and the patch models ability to estimate those parameters. We will continue to investigate this question in the next iteration of this study.

Increasing grid size tended to increase the magnitude of the error in the density and efficiency estimates from the patch model. The increase was slight and expected. The patch model assumes that each animal within a grid cell undergoes random redistribution after the fishing apparatus passes through. This assumption grows less realistic for clams as the grid cell size increases. Our simulation uses cells, rather than grids to place clams and then remove them as a result of fishing. Cells are small relative to grids and a random mixing of animals within a cell is probably closer to what occurs in nature. Thus the poor performance of the patch model at larger grid sizes is likely a reflection of the extent to which the assumption of random mixing fails to describe the underlying process for generating catches.

The patch model performed better when tows were taken across patches of clams rather than along them. This orientation would tend to provide tows with consistent catch sizes (if they were taken through equally un-fished grids), while tows taken parallel to the clam bed would provide more variable catches (high when taken through the clam patch and low when taken outside the patch).

Positional errors had nugatory effects on patch performance. This result was somewhat surprising and may be due to the fact that our error term was not random with respect to position, as the error was always zero at the start of a tow. Tows typically started at (approximately) the same place in a survey site and thus our error term may have had merely displaced the tow paths more or less uniformly, which would have little effect on the hit matrix and thus little effect on patch model performance. Additional work on this topic will be done in the next iteration of this study.

This analysis shows that the patch model will probably perform better when survey tows can be oriented across a patch of clams rather than along it. This result has limited practical value unless the dimensions of a clam patch can be described before a survey tow begins. There may be a way to do this using a camera, or set up tows, or it may be financially impractical. Investigation on this topic would be useful. It is also clear that more than 10 tows are required to achieve decent results using the patch model for these species. More work will be done to find an optimal sample size given certain starting conditions in the next iteration of this analysis.

Conclusion

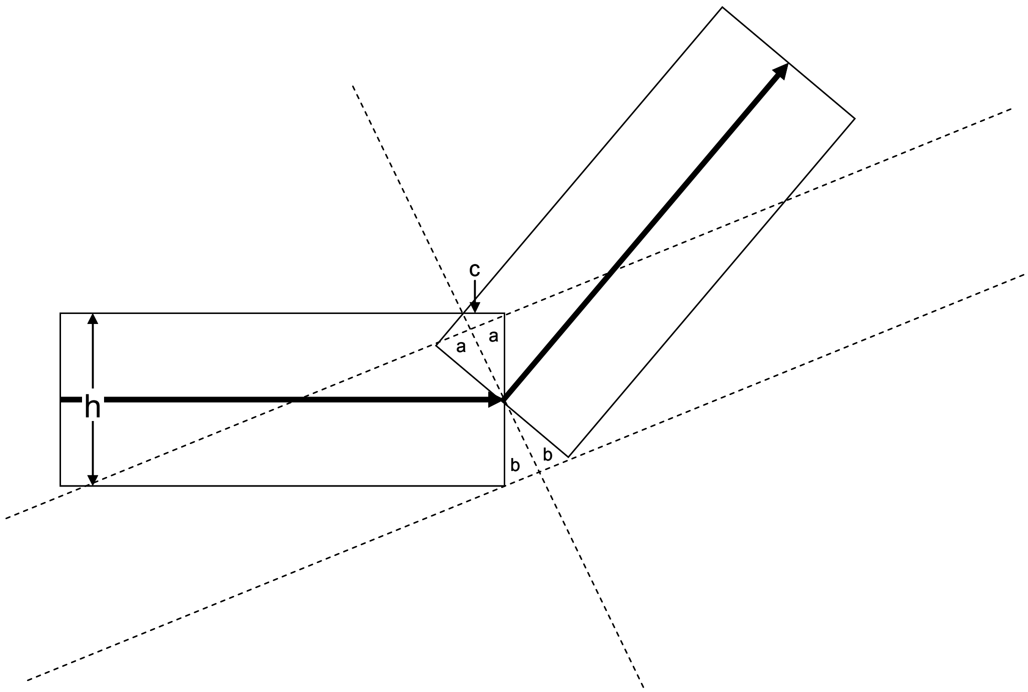
The patch model performed well under the conditions we tested in simulation. There are several interesting results that need to be investigated further and we intend to continue this work through a second iteration which will focus on developing a more realistic spatial distribution of clams and investigating the affects of tow order and orientation as well as finding an optimum number of tows given various starting conditions. We will also continue to examine the affects of positional errors. Thus far, we have found no reason to believe that the patch model is introducing consistent bias, or unacceptably inaccurate estimates of survey density and efficiency into the stock assessment process.

Appendix Table 2-1. Summary of Patch model estimates from all ocean quahog and surfclam depletion experiments conducted during 1997-2005 (Table A11 in NEFSC 2008a; Table C14 in NEFSC 2008b). The negative binomial parameter k measures variance (higher values of k indicate less variability and *vice-versa*).

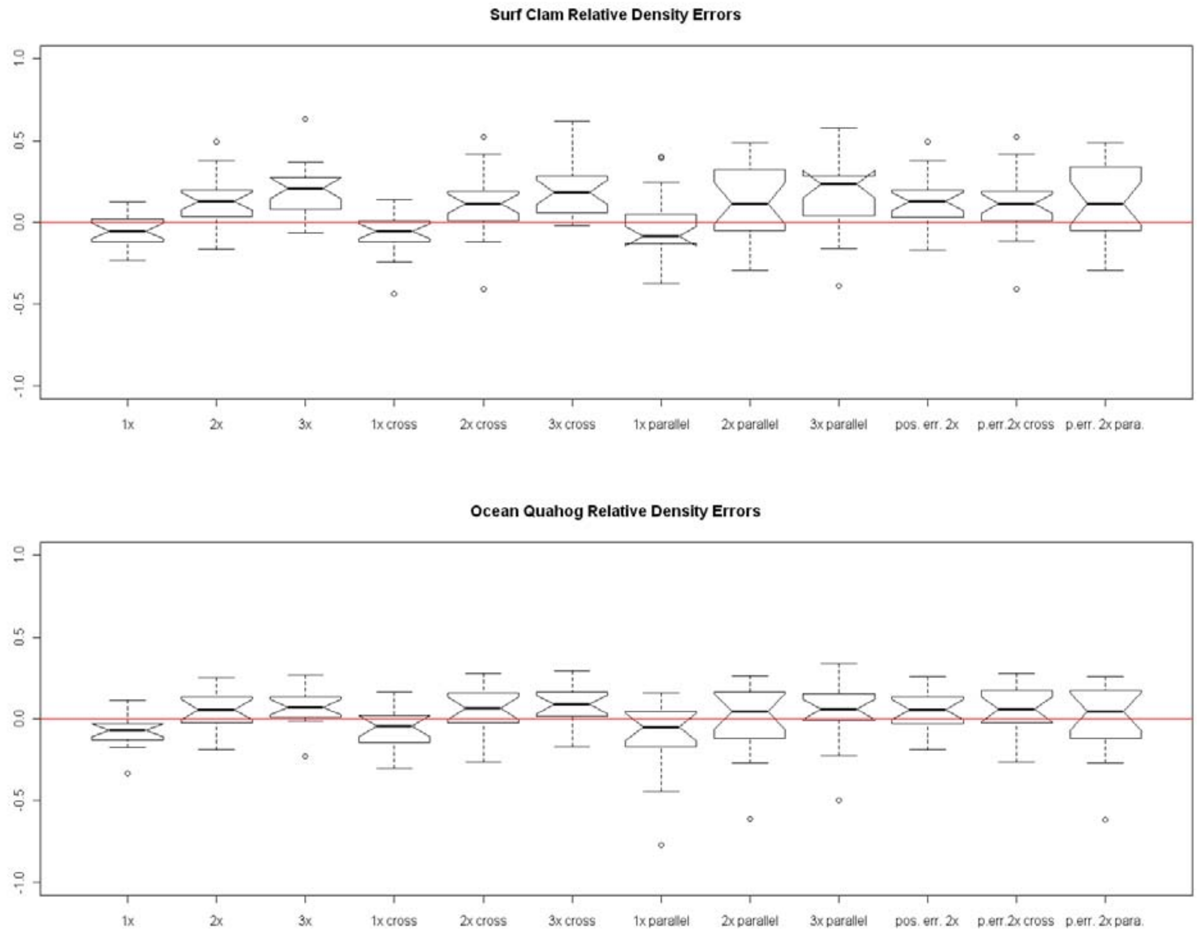
Species	N depletion experiments	Median density (D, n/m^2)	Median efficiency (e)	Median k for tows (k)
Ocean quahog	18	0.883	0.660	8.065
Surfclams	19	0.269	0.765	5.676

Appendix Table 2-2. Absolute estimated relative density for surfclams and ocean Quahogs, by simulation type. An absolute estimated relative density of zero would represent perfect replication of the "true" parameter values used to populate the simulated survey site.

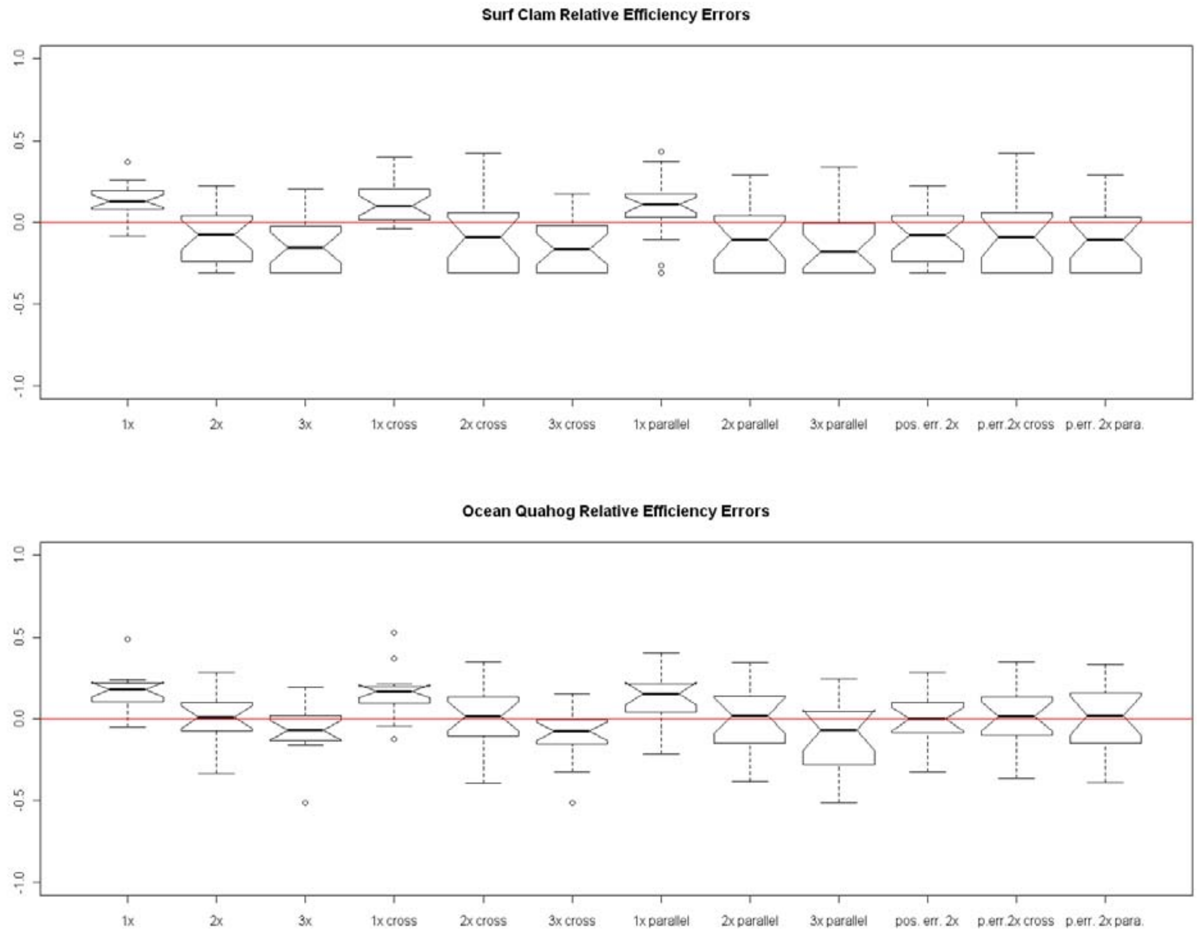
	Surf Clam	Ocean Quahog
Permutation	Absolute Relative Median Dens. Error	Absolute Relative Median Dens. Error
Grid size = dredge width	0.0703	0.0929
Grid size = 2*dredge width	0.1446	0.0873
Grid size = 3*dredge width	0.2105	0.0914
cross 1x	0.0707	0.0944
cross 2x	0.1325	0.1352
cross 3x	0.1842	0.1415
parallel 1x	0.1095	0.1402
parallel 2x	0.1832	0.1585
parallel 3x	0.2489	0.1543
position errors 2x	0.1446	0.0890
position errors 2x + cross	0.1319	0.1262
position errors 2x + parallel	0.1829	0.1605



Appendix Figure A2-1. Mathematical representation of the area swept by a simulated dredge between three position observations (heads and tails of dark arrows). The dark arrows are the center of the dredge. The large rectangles with are as wide as the drege (*h*). The areas of the triangles marked *a* and *b* where the dredge pivots cancel. The area swept is the area of the large rectangles, less the area of the triangles marked c. The additional area in the arc that can be drawn between the lower vertices of the two triangles marked b is ignored. Clams are caught with probability equal to dredge efficiency if their spatial cell intersects the rectangles and triangles that mark the simulated dredge path/.



Appendix Figure A2-2. Estimated relative density for surfclams and ocean Quahogs, by simulation type. The boxes are drawn from the first quartile to the third quartile and centered on the median. The whiskers are drawn to 1.5 times the inter-quartile (first to third quartile) distance. An estimated relative density of zero would represent perfect replication of the "true" parameter values used to populate the simulated survey site.



Appendix Figure A2-3. Estimated relative efficiency for surfclams and ocean Quahogs, by simulation type. The boxes are drawn from the first quartile to the third quartile and centered on the median. The whiskers are drawn to 1.5 times the inter-quartile (first to third quartile) distance. An estimated relative efficiency of zero would represent perfect replication of the "true" parameter values used to populate the simulated survey site.