A brief summary of the New England Fishery Management Council’s Swept Area Seabed Impact (SASI) Model: A tool to estimate the impacts of fishing on Essential Fish Habitat

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires fishery management plans to minimize to the extent practicable the adverse effects of fishing on fish habitats. To meet this requirement, fishery managers would ideally be able to quantify such effects and visualize their distributions across space and time. The Swept Area Seabed Impact (SASI) model provides such a framework, enabling managers to better understand: (1) the nature of fishing gear impacts on benthic habitats, (2) the spatial distribution of benthic habitat vulnerability to particular fishing gears, and (3) the spatial and temporal distribution of realized adverse effects from fishing activities on benthic habitats. The model combines fishing effort data with substrate data and benthic boundary water flow estimates in a geo-referenced, GIS-compatible environment. Contact and vulnerability-adjusted area swept, a proxy for the degree of adverse effect, is calculated by conditioning a nominal area swept value, indexed across units of fishing effort and primary gear types, by the nature of the fishing gear impact, the susceptibility of benthic habitats likely to be impacted, and the time required for those habitats to return to their pre-impact functional value. SASI increases the utility of habitat science to fishery managers via the translation of susceptibility and recovery information into quantitative modifiers of swept area, and is currently being used in New England to inform both the design of fishery management alternatives to meet MSA requirements, and the anticipated impacts of these alternatives. The SASI model was developed by the New England Fishery Management Council’s (NEFMC) Habitat Plan Development Team.

Fishing effort estimation

In order to compare habitat impacts resulting from various types of fishing gears, all fishing effort in the SASI model is represented using a common area swept currency. The first step was to classify effort into nine major bottom-tending gear types: generic/groundfish trawls, shrimp trawls, squid trawls, raised footrope trawls, New Bedford-style scallop dredges, surf clam and ocean quahog hydraulic dredges, lobster and deep-sea red crab traps, bottom gill nets, and bottom longlines. These gear types are commonly used in areas designated as EFH for NEFMC-managed species, to target species managed by the NEFMC and/or Mid-Atlantic Fishery Management Council (MAFMC).

By gear type, assumptions were made regarding the angle of attack of each gear component in order to calculate a linear effective width for each gear component individually and then for the gear as a whole. This linear effective width is then multiplied by the length of the tow to generate nominal area swept. Next, assumptions about the contact of each gear component with the seabed are used to convert nominal area swept to contact-adjusted area swept. These contact indices are expressed as proportions, ranging from zero to one, such that contact adjusted area swept is always less than or equal to nominal area swept. A schematic of this calculation for trawl gears is shown in Figure 1. Although the area swept for each tow is
calculated separately, resulting contact adjusted area swept values in km² may be summed by trip, year, gear type, etc.

Figure 1 – Area swept schematic (top down view). The upper portion shows nominal area swept, and the lower portion shows contact adjusted area swept.

Depending on the types of questions you are trying to answer, you could generate fishing effort data layers that simulate even fishing pressure across the model domain, or you could generate data layers that more realistically reflect past fishing events or future projections. In either case, effort data would be used to parameterize the gear width and tow duration components of the area swept models. This type of information comes primarily from trips with at-sea observers. Other fishery-dependent information including the number of tows per trip, the number of trips per year, and the location of fishing, comes from the vessel trip report and vessel monitoring system databases. These data are temporally and spatially specific at various levels of resolution depending on the source.

Vulnerability Assessment

The purpose of the vulnerability assessment is to estimate the magnitude of the impacts that result from the physical interaction of fish habitats and fishing gears. The vulnerability information is then used to condition area swept via a series of susceptibility and recovery parameters. It is important to recognize that the vulnerability assessment only considers (a)
adverse (vs. positive) effects and (b) habitat associated with the seabed (vs. the seafloor and the water column). For ease in evaluating impacts, fish habitat was divided into components, geological and biological, which were further subdivided into features. Structural features identified include bedforms, biogenic burrows, sponges, macroalgae, etc. These may either provide shelter for managed species directly, or provide shelter for their prey. The geological and biological features are weighted equally during spatial implementation of the model, and are distinguished as being non-living and living, respectively. The vulnerability assessment uses a series of matrices to organize and present qualitative estimates of susceptibility and recovery for each feature by fishing gear type. While both components (geological, biological) are assumed to occur in every habitat type, the presence or absence of particular features is assumed to vary based on substrate type and natural disturbance (energy) regime. Thus, habitat types in the vulnerability assessment are distinguished by dominant substrate, level of natural disturbance, and the presence or absence of various features.

Figure 2 – Sample matrix for generic trawl gears in mud substrates.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Gear effects</th>
<th>Literature high</th>
<th>Literature low</th>
<th>S High</th>
<th>S Low</th>
<th>R High</th>
<th>R Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphipods, tube-dwelling</td>
<td>crushing</td>
<td>34, 113, 119, 228, 292, 334, 408, 409, 599, 658</td>
<td>89, 80, 97, 113, 149, 320, 575</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Anemones, cerianthid</td>
<td>breaking, crushing, dislodging, displacing</td>
<td>none</td>
<td>none</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Burrowing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogenic burrows</td>
<td>filling</td>
<td>334, 408, 409</td>
<td>101, 313, 333, 336, 407</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Biogenic depressions</td>
<td>filling</td>
<td>236, 408, 409</td>
<td>101, 247, 336</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Corals, sea pens</td>
<td>breaking, crushing, dislodging, displacing</td>
<td>none</td>
<td>101, 164</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Hydroids</td>
<td>breaking, crushing, dislodging, displacing</td>
<td>408, 409</td>
<td>368</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mollusks, epifaunal</td>
<td>breaking, crushing, dislodging, displacing</td>
<td>21, 34, 368, 408, 409</td>
<td>89, 203, 368</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bivalve, Modiolus modiolus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediments, unfeatured</td>
<td>resuspension, compression, geochem</td>
<td>88, 92, 211, 236, 330, 334, 406, 408, 409, 599</td>
<td>88, 211, 247, 277, 283, 313, 320, 333, 335, 336, 338, 372, 407, 414</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Susceptibility is a measure of the percentage by which a feature is reduced in functional value due to the impact of a particular fishing gear, and recovery is a measure of the amount of time it would take for the functional value of the diminished habitat feature to be restored following the cessation of impact. Recovery is evaluated separately for high and low energy environments. Both susceptibility and recovery are scored from 0-3. Values are assigned using knowledge of the fishing gears and habitat features combined with results from the scientific literature on gear impacts. To facilitate use of the literature in matrix evaluations, research relevant to regional habitats and fishing gears was summarized in a database. As an example, the otter trawl/mud matrix with its component features is shown in Figure 2, above. Both the literature review database and the matrix values can be updated as new information becomes available.
Model grid

To be useful for spatially explicit management strategies, SASI outputs must be spatially referenced. A substrate-based model grid was developed to provide a surface on which to combine area swept fishing effort data and vulnerability information. Two sources of substrate data, usSEABED and University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) video survey, were used to generate the grid. Across both data sets, substrates were classed based on particle size (using the Wentworth scale) into mud, sand, granule/pebble, cobble, and boulder. An unstructured grid was generated from the raw substrate data using a Voronoi tessellation procedure. Depending on the arrangement of samples in space, the grid cells vary in shape and may be larger or smaller, as shown below. As new substrate data becomes available, it can be added to the model and the grid can be updated. Next, each of these grid cells was classified as having a high or low natural disturbance (energy) regime using critical shear stress and depth-based criteria. Finally, a 100 km² grid was overlaid on the unstructured grid, and the substrate composition of each 100 km² grid cell was calculated based on the attributes of the typically smaller unstructured cells as shown in the rightmost panel of Figure 3.

Figure 3 – The model grids. From left: Energy, with low energy in blue and high in red; Substrate, showing mud (green), sand (light green), granule-pebble (yellow), cobble (orange), and boulder (red); structured grid for fishing effort data, with 100 km² cells.
Combining fishing effort, feature vulnerability, and spatial grids

The various model components, including fishing effort, the various grids, and habitat feature vulnerability, are combined as described in Figure 4.

Figure 4 – SASI model flowchart

In mathematical terms, swept area seabed impact, or \( Z \), can be represented using the following simple equation, where \( A \) represents the area swept and \( \Omega \) represents vulnerability. The static, non-indexed version of the basic model for \( Z \) is:

\[
Z = A \omega ,
\]  

(1)

where \( A \) represents the nominal area swept by one unit of fishing effort and \( \omega \) represents susceptibility, which in this case is a quality adjustment based on the vulnerability of habitats to fishing gears. Here, the \( A \) parameter is calculated as:

\[
A = (w \chi) d ,
\]  

(2)
where \( w \) is the linear effective width of the fishing gear and \( \chi \) is a constant representing the degree of bottom contact a particular fishing gear component may have. The variable \( d \) is the distance traveled in one unit of fishing effort. Indexing this model across all units of fishing effort \((j)\) by nine fishing gear types \((i)\) and a matrix of habitat types determined by combinations of five substrates \((k)\), two energy environments \((l)\) and 27 individual habitat features \((m)\) provides us with:

\[
Z = \sum_{i=1}^{9} \sum_{j=1}^{n} \sum_{k=1}^{5} \sum_{l=1}^{2} \sum_{m=1}^{27} \left[ A_{i,j} \omega_{k,j,m} \right].
\]

However, the vulnerability of habitats to units of fishing effort is estimated in the Vulnerability Assessment using both a susceptibility and recovery value. Incorporating the recovery vector requires re-writing the model as a discrete difference equation. Let the basic equation be

\[
Z_{t+1} = Z_t \left[ 1 + (X_t - Y_t) \right],
\]

where \( X \) is the positive effect of one time unit (year) of habitat recovery, and \( Y \) is the adverse effect of one time unit of fishing activity. The positive effect term \( X \) is the proportion of total adverse effect, \( Z \), that recovers within a given time step, estimated as a linear decay model:

\[
X_t = \frac{\lambda (A \omega)_{t_0} |A\Delta t}}{Z_t}.
\]

The parameter \( \lambda \) represents the decay rate and is calculated as \( 1/\tau \) where \( \tau \) is the total number of time steps over which the adverse effects of fishing will decay. \( t_0 \) is the initial time unit that the affect enters the model and \( \Delta t \) is the contemporary time step, such that \( \Delta t = t - t_0 \) where \( t \) is the year for which the calculation is being made. The adverse effect term \( Y \) is the proportion of \( Z \) that is introduced into the model at time \( t \):

\[
Y_t = \frac{(A \omega)_t}{Z_t}.
\]

Indexing this dynamic model across all units of fishing effort \((j)\) by nine fishing gear types \((i)\) and a matrix of habitat types determined by combinations of five substrates \((k)\), two energy environments \((l)\) and 27 individual habitat features \((m)\) leaves us with:

\[
Z_{t+1} = Z_t + \sum_{i=1}^{9} \sum_{j=1}^{n} \sum_{k=1}^{5} \sum_{l=1}^{2} \sum_{m=1}^{27} \left[ \lambda (A_{i,j} \omega_{k,j,l} \Delta t) - (A_{i,j} \omega_{k,j,l})_t \right].
\]
For more information about the SASI model or the EFH Omnibus Amendment, visit the habitat section of [www.nefmc.org](http://www.nefmc.org), or contact:

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