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Swept Area Seabed Impact (SASI) Model Peer Review On Behalf of the New England Fisheries Management Council Providence, RI – February 15-17, 2011

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Executive Summary:

The Swept Area Seabed Impact (SASI) model is a method for spatially estimating the adverse effects of fishing on physical and biological features of seabed habitat. The model combines as inputs fishing effort data, seabed substrate and energy data, associations of biological habitat components with seabed substrate, and gear-specific habitat vulnerability parameters. It produces as outputs an index representing the adverse effect of fishing effort on seabed habitat features (Z). This index can be configured to represent equilibrium impacts simulated under constant effort assumptions (Z_{inf}), or to represent estimated impacts under historical distributions of fishing effort ($Z_{realized}$), or to represent estimated impacts under proposed distributions of fishing effort (Z_{net}); the latter can be compared with total net revenues within a grid cell averaged across years to create an estimated ratio of habitat impacts per dollar of net revenue (e). Estimates are typically provided at the resolution of a 100 km^2 grid scale for a geographical region that extends from 3 nm offshore to maximum depths that vary from 82 to 302 meters for different gear types from the Maine/Canada border to the North Carolina/South Carolina border and includes the Gulf of Maine, Georges Bank, the Mid-Atlantic Bight and the associated slope regions.

The Habitat Plan Development Team (PDT) developed this model over the years 2007 to 2010 at the request of the New England Fishery Management Council (the Council). This is considered to be Phase 2 of the EFH Omnibus Amendment 2. The model at various stages of development has been reviewed by the Council's Scientific and Statistical Committee (SSC). The SSC recommended that a formal peer review of the SASI model might benefit the process.

The Peer Review Committee (the Committee) met on February 15-17, 2011 to review the SASI model and supporting technical documentation that contains details of the SASI model as well as the two model extensions -- Local Indicators of Spatial Association (LISA) and the practicability analyses. The Committee appreciates the effort that went into the development of the SASI model and wishes to thank the PDT for their efforts in putting together an approach that can be used to promote discussion of the impacts of fishing activity on marine habitat.

In brief, the Committee believes that this model is a good first step in providing an objective mechanism for synthesizing many of the complex interactions that take place between fishing activity and bottom habitat. While the approach has its limitations, it may be fruitfully employed to explore potential impacts of spatially distributed fishing effort as specified by gear type. In particular, it can be used to facilitate discussion of the

seabed habitat impacts that alternative management strategies, which may alter the amount and/or distribution of effort over space, gears, and potentially time. While the model has been constructed to evaluate the spatial impact of fishing effort distributions on benthic habitat, any discussions of impact should also be considered in the broader context of other control mechanisms such as effort reduction, redistribution of effort in time, reallocation of effort by gear type, and modification of existing gear types.

The Committee anticipates and encourages the continued development and improvement of the SASI model to reduce uncertainty and improve model formulations, and to verify assumptions and input parameter values. The Council should work together with the developers of the model and the NMFS to foster this evolution. Adaptive management strategies coupled with good survey and other monitoring efforts would be useful to consider in this regard. The model can and should be used to identify and prioritize empirical research that will contribute most to improving the accuracy of the estimates of habitat impacts produced by the model.

Areas of particular concern to the Committee include:

- the assumption that impacts of fishing are additive and independent of the state of the habitat being fished or the quantity of effort already applied to the grid cell;
- the need for more in-depth understanding of the impacts that gear has on habitat and how this can influence recovery rates, particularly for high energy environments;
- the need for a better understanding of the impacts that different types of gear have on habitat;
- the need for better understanding of the behavioral responses of fishing fleets, particularly with regard to the redistribution of effort under alternative management scenarios;
- the need for better understanding of the link between the geological indexes used in the model relative to the systems and structures representing biological habitat in marine systems;
- the anticipated use of the model and its outputs beyond its current intended capabilities, despite the warnings and caveats provided by the PDT.

Terms of Reference:

1. **Is the SASI approach a reasonable way to estimate the magnitude and location of adverse effects of fishing on EFH, as required by the MSA? In particular, considering the availability of other tools used by Fishery Management Councils, is SASI -- without additional modification -- a valid approach to evaluate the adverse effects of fishing on EFH?**

   The SASI modeling approach is good at fulfilling its initial design objectives. Furthermore through its development, a greater potential has been realized for this model and the approach continues to evolve to meet growing expectations.

The model is quite sophisticated in terms of its characterization of the geophysical components of the system (substrate types, geological features, and energy levels). For now, these components can serve as a proxy for inferring the biological features of the benthic habitat. These features are the principal concern of managers with regard to minimizing the adverse impacts of fishing and other human activities on EFH. Other extensions and applications of the model detailed in the technical documentation, such as its application in exploring the practicability and economic consequences of alternative management actions, have been initiated recently and need further development. The model has been truly helpful in focusing thought on a multitude of issues regarding fishing effort and fish habitat and has provided an objective mechanism for synthesizing the complex array of data and interactions inherent in such systems. Perhaps not surprisingly, it does not answer all questions that one might have about impacts to the ecosystem and to the fishery (e.g. how fishing effort will realistically redistribute itself upon changes in management, or how total revenue might change in association with this).

The SASI model deals with many, but not all, of the key elements pertaining to EFH. For example, it provides a means of synthesizing the available peer reviewed literature about the effects of fishing on benthic habitat features. In this respect, the model is filling an information gap. However, it may not be useful to inform other important questions such as:

- What might happen to EFH in the water column as result of ghost gear, noise, and/or prey displacement?
- What is the effect of fishing on prey species such as pelagic fish like herring and benthic organisms like polychaetes?
- How can one fully or realistically characterize changes in fishing behavior?
- What approach might best be used to implement marine spatial planning?

Also, the SASI model may not be fully adequate for examining the impact of opening areas that have previously been closed because of the habitat types that might be expected to develop in such areas and how effort is likely to be applied in such areas. Furthermore, there may be areas that require special attention that are not captured by the domain-wide SASI model (e.g. Ammen Rock on Cashes Ledge). Such areas might be considered in addition to those specified by general model outputs. There are also text descriptions and maps of EFH that can be used to link together SASI and EFH designations (e.g. Amendment 2 Omnibus Phase I Document).

The SASI approach can be viewed as a flexible platform that can be used to inform decision making for EFH Omnibus Amendment 2 and that with further development can be expanded, improved and used later to answer a broader set of questions. It will serve very well as the focal point for a dialogue as to what would happen under alternative management scenarios. It offers a different insight from the approaches that other management councils have taken, but the model will not necessarily provide definitive answers to all questions. It should be viewed as a useful approach for exploring options.

Regarding the model's ability to assess the "magnitude" of a particular specification of fishing effort by area, there may be cumulative impacts incurred that are not adequately characterized.

Maps of gear specific vulnerability as derived in Phase 2 could be overlaid with the EFH component for all species and life stages as defined in Phase 1 to make comparisons of where impacts are likely to occur. For such an endeavor, it would be useful to have a flow diagram of how the Council might wish to use this model in conjunction with other pieces of information needed to inform decision making.

2. **Is the SASI approach, including the geostatistical and practicability analyses, a reasonable way to develop and analyze spatially-based management alternatives to minimize the adverse effects of fishing on EFH? In particular:**

    a. **Have uncertainties in SASI inputs and resulting limitations of SASI been appropriately characterized for the Committee, Council, and members of the public?**

The document that was provided was quite technical and it would be useful to make a more accessible executive summary of the approach available that provides a reasonable explanation of the method for the layman. Such a summarization may refer to the technical document, but would be directed towards a wider readership. The summary might include some simple examples of how the model works (although certain caveats would have to be provided with regard to the generality of such examples). It would be good to try to bridge the results coming from the quantitative analysis with an intuitive understanding that many have for the ecosystem.

The technical document itself could be made more rigorous and complete in its description of the model. Many comments were provided during the meeting by both the Committee and others in attendance. There should be a thorough and complete specification of the model using equations in Section 8.1. In particular, the basic difference model might be simplified to avoid the multiplication and division of Z and Z should be adequately defined in a clear and consistent way (and be consistently reported as positive or negative in the document). This effort to make things clear and consistent should be carried through for all variables defined in the document and used in the model.

While we did not have access to the model code itself, and therefore cannot be certain of all of the potential behaviors of the model throughout its performance, it appears from the description that Equation 5 in Section 8.1 is not an accurate or complete mathematical description of how Z is calculated. The area swept term A_{ij} in Equation 5 should actually be the proportion of area swept for a particular gear in a particular area that is allocated to a specific habitat feature and the susceptibility term ω_{lt} should also be indexed by substrate, energy level and habitat type. The term associated with the decay rate should be based on area swept in prior years. It would be useful to include a formal description (with equations) of how area swept in Equation 5, denoted by the parameter A, is calculated – in other words, how total area swept in an grid cell is allocated across habitat types and habitat features within a grid cell. We suggest that a more accurate specification of Equation 5 may be as follows (though this should be verified by the authors):

$$Z_{t+1} = Z_t + \sum_{g=1}^{n}\sum_{i=1}^{9}\sum_{k=1}^{5}\sum_{l=1}^{2}\sum_{m=1}^{y}\left[-a_{g,i,k,l,m,t}\omega_{i,k,l,m} + \sum_{s=t-\tau}^{t}\lambda_{i,k,l,m}a_{g,i,k,l,m,s}\omega_{i,k,l,m}\right],$$

where Z_t is the total Z for the model domain (for all n areas indexed by g) at time t. The proportion of total area swept for a particular gear and allocated to a particular feature in a specific area, $a_{g,i,k,l,m,t}$, is calculated as

$$a_{g,i,k,l,m,t} = \frac{A_{g,i,t}}{\sum_{k=1}^{5}\sum_{l=1}^{2}\sum_{m=1}^{y} d_{g,k.l,m}}$$

where $d_{g,k,l,m}$ is a dummy variable that takes a value of 1 if that habitat feature, energy level, and substrate combination occurs in area g and zero otherwise.

It is also useful to think about the biological and economic impact derived from model predictions not only in the context of closing and opening areas, but also in terms of the impacts from other management options such as effort reduction, time closures, reallocation of effort among gears, and gear modification.

The modeling approach could have benefited from a more rigorous and thorough presentation of the uncertainty associated with model predictions. This is not a particularly easy task, but one that should be developed further. There are several ways that uncertainty can be expressed. One way is to provide some measure of uncertainty associated with model outputs as well as model inputs. These might be deduced using simple analytic methods or could potentially be derived using Monte Carlo or Bayesian MCMC techniques. While it is recognized that such measures might not fully represent the uncertainties associated with, for example, arbitrary model assumptions such as the collective decision making around the susceptibility scores, it would provide a first step in documenting the components of uncertainty and would help promote transparency in describing the limitations of the model. A second approach to characterizing uncertainty might be to provide sensitivity analyses reflecting the consequences to predictions of uncertainty in the parameters or assumptions. This approach would at least provide the bounds of what might be expected under alternative representations of the system, and could conceivably be communicated via a decision table that would provide the likely outcomes under alternative model formulations or assumptions. A third mechanism for communicating uncertainty is to provide qualitative descriptions of sources of uncertainty. The technical document currently does a reasonable job of this. However, such descriptions require scientists, managers and stakeholders to integrate such information on their own, which can be very challenging if not almost impossible to do.

b. Is the spatial scale of the model outputs (i.e. 100 km^2 grid) appropriate for fishery management applications? What ecological processes are missed by estimating adverse effects at a 100 km^2 grid resolution? What implications does this have for development of alternatives?

The spatial scale of the model is currently defined at a resolution of 100 km^2 grid cells because the VTR input data by gear type can currently only reasonably be disaggregated to that level. But in terms of implementation, users might be inclined to want to go to finer or coarser levels of resolution, and it is worthwhile discussing the consequences of what happens should one try to expand inferences to other scales. When one considers broader scale effects, one must recognize that the SASI model does not incorporate broader oceanographic features such as tidal currents or ocean ridges which can be important for fish aggregation and movement. On the smaller scale, one can envision small scale variation within a habitat that might be influenced by or interact with small scale variation in fishing effort. Such fine level impacts are not accounted for in the model. However, should finer level information become available (for example by making use of enhanced VMS data with more frequent polling times or other electronic monitoring equipment such as sensors that indicate when gear is deployed), then effort could be specified at a much finer scale allowing for a greater spatial resolution of the model. This, potentially, could enable the model to differentiate impacts at the scale of the specific individual disturbance (e.g. the real location of a tow).

While, in many instances trying to characterize impacts at a finer scale would make sense, the fishing effort data needed to fully characterize the impact is currently available only at coarser spatial scales, consequently we cannot make more informed inferences about these processes at present. If, in the future, such finer scale information does become available, then finer scale inferences could also be derived. Fine scale empirical data could be used to test the assumption that habitat impacts are additive and independent. This would allow the model to differentiate impacts based on the level of effort already applied to the specific area, allowing for decreasing (or even increasing) rates of marginal impact.

Is the 100 km^2 grid scale the appropriate size for management? The scale is convenient in providing some flexibility for managers. If there is habitat of significant value at a smaller scale, then an action can be taken restricting effort within the 100 km^2 cell. If there is an interest in providing some level of conservation at a broader scale, then stacking areas can be done as well. Obviously, one might identify specific tows that could occur within a single 100 km^2 grid that might or might not have an adverse impact locally within a cell (e.g. gear deployment might only happen in a less vulnerable area within the cell simply by choice of the fisher with the vulnerable habitat avoided), so care should be exercised in how these grids are interpreted and used. Note that it would be possible to allow for non-homogeneous distribution of effort across different habitat types within a grid cell without changing the spatial grid size of the model. This has already been implemented for hydraulic clam dredges based on the assumption that they cannot physically operate in some substrate types. In addition to eliminating certain habitats for specific gears completely and assuming their effort is applied in the residual area of the grid cell, it would also be possible to use some weighting scheme to allocate effort unevenly. Finding the appropriate information for other gear types to develop this weighting scheme would likely require significant additional effort.

It should be noted that, in addition to spatial scales, there are important temporal changes in the benthic environment that need to be considered in the application of the SASI model. The quality or usefulness of benthic habitats may change seasonally and at different times of the year may serve as important locations for spawning or for nurturing juvenile fish. The current spatial time step in the SASI model might be reexamined in the future to incorporate seasonal dynamics when the information at this time scale becomes available.

c. Are the practicability analyses appropriate to use for eliminating options at the alternatives development stage, or should they be reserved for a later stage when the impacts of various alternatives are being compared?

The habitat model is only now being exercised with the idea of how this might result in fleet impact in terms of practicability. There were two particular practicability explorations given in the document: 1) opening and closing areas and 2) relative differences of gear. The practicability analyses are not ready for use in their present form and in particular with regard to predicting impacts of opening and closing areas (particularly with reopening areas). With regard to the relative differences between gears, the analyses might be of greater utility particularly with regard to changes in effort level by gear type, subject to the caveats of the sensitivity analyses involving area swept assumptions. Some validation of area swept for fixed gears would be advisable as well.

Stylized examples were develop during the peer review by the Committee and the PDT representatives. These stylized examples that are now available are very informative in terms of how the calculations are done and how assumptions influence the results. They may not be generalizable in the sense that the simple example may show an impact that results from one area opening and another closing that may not in fact be found in a more complex characterization of the system. These stylized examples should not be proposed as a method for evaluating area closure changes. More work is needed to improve the predictive modeling of effort redistribution. Alternatively, the Council could make ad hoc assumptions about redistribution of effort and profit rates as a result of closure changes and use the model to explore the consequences of these assumptions.

Having some examples that demonstrate how the model works, how it may be used, and what consequences and biases there may be would prove very helpful. But, it needs to be very clear (especially with regard to the assumptions about the redistribution of effort and changes in catch rates) that the purpose of the examples is the exposition of the model structure and the consequences of critical assumptions rather than a methodology for evaluating spatially explicit management actions. As the methodology for characterizing effort distribution, catch rates and other behavioral and economic indicators improves then the use of the model to evaluate practicability scenarios will become more reliable.

3. **Existing gaps in data and theoretical understanding of habitat-related processes have been identified during model development.**

    a. **Review and evaluate research priorities that have been identified during the model development process.**

The research priorities and future work specified by the PDT seem reasonable. The Committee has decided to build on the PDT's original list.

Research Priorities:

A better understanding of the relationship between habitat and fish productivity is important. It is encouraging that the Council has focused some attention on this. The SASI model is playing an important role already in facilitating communication between the Council and NMFS on this issue. The needs of the SASI model, as articulated by the Council, could have a significant impact on research planning and implementation by the NEFSC and serve to help prioritize and develop new areas of research that are beyond the Center's current focus.

Susceptibility and recovery rates are currently based on the best available information from the literature and professional judgment. There is a need for a better understanding of how susceptibility to and recovery from trawling depend on the measures of 'energy' for each habitat. The question of what constitutes the degree of natural disturbance, for example, is inadequately understood to sufficiently define, in a quantitative sense, the relative importance of natural versus anthropogenic disturbances for habitat structure and stability.

The shapes of the vulnerability curves are also important, and researchers should try to explore whether the additivity and independence assumptions used in the model are reasonable. Is the marginal rate of habitat impacts really constant as it is assumed to be, or does it decline as additional effort is applied to the same area (e.g. the first cut is the deepest scenario). Also are there critical threshold levels beyond which more effort is catastrophic or causes irreversible change?

Recovery rates depend on both the area disturbed and the intensity of the disturbance. As with susceptibility, it is unlikely that the form of the recovery response is adequately understood to confidently state that a specified amount of trawling will have a specific recovery function.

Gear impact research could be expanded by NMFS, perhaps through cooperative studies, to explore some of these susceptibility and recovery issues. In the previous decade there was significant effort expended on reviewing the impacts of fishing gear on the benthos, but relatively little direct experimental work was carried out to better understand the dynamics, both immediate and longer term, of trawling on the seabed. This area of research should be revived and supported to better understand how benthic communities respond to varying degrees of trawling and to gain an appreciation of how anthropogenic disturbance compares to natural, storm driven, disruption of the benthic community and, ultimately, how these two types of disturbance relate to fishery productivity.

Geological data are used in the model as a proxy for habitat reflecting the fact that more geological information is available than biological (particularly with regard to benthic community structure). There is generally a lack of comprehensive data on benthos and benthic communities, and what does exist is more historical than recent in nature. It is often assumed that benthic communities remain constant over time and although this may be true in some environments it is certainly not a universal truth. Strong seasonal changes in the benthos will have a huge impact on fish utilization of an area, for example as spawning sites or as juvenile fish refuge. This dynamic is not currently incorporated in the SASI model due to lack of sufficient information. Biogenic habitat features may be more important than general geological features in influencing fish behavior and distribution so this kind of information needs to be generated and then incorporated into the model.

For fixed gear, the assumption is that the impact is minimal, especially in comparison to mobile trawl gear. However, this assumption needs to be investigated and quantified so that the SASI model does not underestimate the impact of fixed gear on benthic habitats.

Behavioral responses of the fleet and fishing effort to changes in management should also be considered. If a reliable spatially-explicit bioeconomic model were available for these fisheries, then a habitat impact simulation could be run in conjunction with that and the relative impacts on the fishery and habitat could be better quantified and quantified simultaneously. There is a growing literature on fishing location choice, and with new research developing in this area, better characterizations of the bioeconomics in this region could be developed in conjunction with the SASI model. In addition to a better characterization of behavioral responses, other components could be developed to supplement the model including habitat characterization and responses, resource productivity in each area, and cost-benefit trade-offs of different management actions. The Council has tasked the SSC with exploring how the Council could manage under an EBFM system. If SASI becomes available as one the tools used by the Council, priority should be given to carefully examining how SASI will fit into the broader EBFM approach.

The SASI model, coupled with bioeconomic modeling could also inform alternative management strategies for achieving habitat protection goals in addition to spatial closures. These strategies could include incentive-based approaches (e.g., taxes and subsidies) and market-based approaches (e.g., habitat use rights). Both of these approaches might lead to industry-driven innovation in gear development that minimizes impact on habitat.

b. Review and evaluate updates to the structure of the model that could be made in the future, given additional data or understanding of habitat-related processes.

The developers of the SASI model made the decision to track habitat impacts as a decaying function almost like the production and persistence of a pollutant rather than to attempt to model the impacts of effort on the state of the habitat. This contrasts with the approach taken by the developers of a somewhat similar model developed by the Alaska Fishery Science Center which tracked a virtual habitat state. The advantage of tracking the habitat state is that it allows for differentiation of habitat impacts based on the state of the habitat. The Alaskan model assumed that the absolute impacts of fishing on habitat and the recovery of habitat depended on the state of habitat in the area impacted. Habitat impacts and the habitat stock are modeled as analogous to the effects of fishing mortality and growth of a fish stock. The weakness of this approach is that there is insufficient empirical information to document the true state of the habitat at some point in time (i.e., starting conditions), and the true shape of the habitat impacts function is not well understood or parameterized. The Alaskan analysis took the additional step of hypothesizing a relationship between the state of the habitat stock and the productivity of the fishery and used the state of the fishery relative to the modeled habitat stock to infer whether fishing impacts on habitat were more than minimal. An independent peer review of the model determined that there was insufficient empirical support for these relationships between habitat and fishery productivity to enable this determination.

The failure of the Alaskan model and methodology for evaluating habitat impacts was cited by the SASI developers as a reason for not modeling a habitat state variable and only tracking a "stock" of habitat impacts. It appears, however, that the primary issue that reviewers had with the Alaskan model was not the way that the habitat stock was modeled but the inferred relationship between habitat and fish productivity. While New England would suffer from the same lack of knowledge about that relationship, and a lack of knowledge about the functional relationship between fishing effort and the state of habitat, it still might be useful to track a virtual habitat in the SASI model. This would enable the model to, at least as a sensitivity analysis, allow the rate of habitat impacts to be a function of previous fishing and the virtual habitat state.

Conclusions and Recommendations

The SASI modeling approach is a good first step in providing an objective mechanism for synthesizing many of the complex interactions that take place between fishing activity and bottom habitat. Although the approach has its limitations, it appears that it can be fruitfully employed to explore potential spatial impacts of fishing effort by gear type. It is an objective mechanism for characterizing for discussion the impacts that alternative management strategies have on seabed habitat. While the model has been constructed to evaluate the spatial impact of fishing effort distributions on benthic habitat, any discussions of impact should also be considered in the broader context of other control mechanisms such as effort reduction, redistribution of effort in time, reallocation of effort by gear type, and modification of existing gear types.

Although the SASI model itself provides useful information for fishery managers and stakeholders, the practicability analyses presented in the document are not ready for use in their present form and in particular with regard to predicting impacts of opening and closing areas (particularly with reopening areas).

It is recommended that continued evolution and development of the approach be encouraged. In particular, the areas of biogenic characterization of the habitat, model refinement to include representative functional responses and uncertainty, and expanded characterizations of economic, behavioral and social consequences should all be further developed and explored.