Habitat Suitability Modeling using the Kostylev Approach in Support of Fisheries Management - Extended Abstract

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Introduction
The suitability of benthic marine habitats for biota is dependent largely upon hydrography (e.g. temperature, currents, stratification) and surficial geology (e.g. substrate type). Recognizing this relationship, researchers in Canada developed a broad-scale modeling approach using primarily hydrographic data. The model output is in the form of maps, which characterize habitats in terms of their “scope for growth” for biota as well as mechanical “disturbance”. This approach was based on papers by Southwood (1977, 1988) and has become known as the Kostylev Approach (Kostylev 2004, 2005), named after the principle developer.

In the USA, the Magnuson-Stevens Fisheries Conservation and Management Reauthorization Act requires the conservation of habitat essential for fisheries sustainability. The Act states, “One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats. Habitat considerations should receive increased attention for the conservation and management of fishery resources of the United States.” The Act requires the designation of Essential Fish Habitat (EFH) and establishment of management actions to conserve EFH.

Since the Kostylev Approach is a cost-effective method for the broad-scale characterization of marine habitats, it has the potential to be a readily available regional fisheries management tool. In order to test the usefulness of the approach for the potential designation of EFH and other management purposes, we applied the Kostylev approach to data collected in the Gulf of Maine.

Methods
A spatial database for the following fields within the Gulf of Maine was created:
(1) median grain size estimated from USGS database (Sediment Database, Branch of Atlantic Marine Ecology 2000);
(2) mean bottom stress estimated from Lynch and Naime (1993) and Naime et al. (1994);
(3) peak orbital wave velocity estimated by A. Drozdowski (unpublished data);
(a) primary productivity unpublished Sea WiFS analysis from Jay 0 ’Reilly;
(b) mixed layer depth estimated from Lynch and Naime (1993) and Naime et al. (1994)
(c) mean bottom temperature estimated from Naime et al. (1994);
(d) mean bottom salinity estimated from Naime et al. (1994);
(e) interseasonal bottom temperature estimated from Naime et al. (1994);
(f) interseasonal bottom salinity estimated from Naime et al. (1994).

All of the fields are interpolated with finite element mesh of Lynch and Naime (1993). This domain covers the Gulf of Maine in its entirety and features length scales ranging from 10 km to 500 m.

This database is used to compute the adversity and disturbance axes for the Gulf of Maine as in Kostylev (2004, 2005). The categorization of benthic habitat by disturbance and adversity (= the inverse of the scope for growth) is an idea whose theory was developed by Southwood (1977, 1988). In theory the disturbance axis is a measure of the rate of physical change in the environment. The adversity axis is inversely related to the maximum growth rate the environment can support. Together the adversity and disturbance axes form a habitat template which classifies the environment as a function of position.

In Kostylev's work the disturbance axis is assumed to be purely a function of the physical regime at the sea floor (items (1), (2) and (3) above), and is proportional to the probability of suspension of a sediment particle. The bottom shear stress is used as a proxy for the disturbance axis. The disturbance index is estimated taking into account the following factors: (1) median grain size, (2) current speed and (3) orbital wave velocity. Median grain size influences bottom shear stress through a roughness height and corresponding quadratic drag coefficient. Current speed and orbital wave velocity influence disturbance quadratically.

The adversity axis is a rough representation of unsuitability of the benthic environment to growth. The adversity axis is computed as follows:

Each field (a)-(f) is linearly rescaled based on the minimum and maximum values over the domain to create fields (a*)-(f*), each ranging from 0 to 1 across the domain. For fields positively correlated with adversity (temperature variability, salinity variability, salinity):

\[ a^* = \frac{a - \text{min}(a)}{\text{max}(a) - \text{min}(a)} \]

and for fields negatively correlated with adversity (temperature, chlorophyll a, mixed layer depth):

\[ a^* = 1 - \frac{a - \text{min}(a)}{\text{max}(a) - \text{min}(a)} \]
**Findings and Discussion**

Model results for disturbance (Fig. 1a) and adversity (Fig. 1b) show distinct patterns for the Gulf of Maine.

These findings can be mathematically combined and visualized in one map (Fig. 2 a).

Figure 1. Results from the Kostylev Approach for disturbance (a) and adversity (b) for benthic habitats in the Gulf of Maine. X-axis is latitude, and Y-axis is longitude in degrees. The color scale indicates relative values. Georges Bank (approx 41.5 degrees N, 68 degrees W) is characterized by large mechanical disturbance and small adversity (large scope for growth).

Figure 2. Adversity and disturbance can be presented together (a) using a habitat template matrix to map habitat types according to these two properties. The resultant habitat map can be overlain with other features such as abundance of managed fish species (b). X-axis is latitude, and Y-axis is longitude in degrees.
The map of these habitat properties – disturbance and adversity – were compared with the
distribution of managed fish species (Fig. 2b). For example, the distribution of cod was
clearly associated with areas of relatively high scope for growth. Similar comparisons for
several other species were performed and the habitat map often was correlated with species
abundance and distribution.

The type of habitat, as modeled with the Kostylev Approach, associated with fish abundance
can be presented by dividing the habitat template (as shown in Figs 2 a + b) into a matrix and
counting the number of “hits” in each cell (Fig. 3).

![Figure 3. The association of habitat types with fish abundance for 11 managed fish
species in NE USA. The adversity and disturbance axes are the same as shown in the
habitat template of Figs. 2 a + b; the template is divided into a 20 x 20 matrix. All
individuals caught in a tow in a single cell are counted. To correct for the differential
sampling rate of certain habitat types the total number of individuals found in a cell is
divided by the number of tows taken in that cell producing a histogram of mean number
of individuals per tow within a particular habitat bin.]

Assuming that the correlation between habitat type and fish abundance is reflective of the
importance of habitats for stock success, these findings can indicate to fisheries manager the
types of habitats important for sustainability of fisheries for a managed species. Further,
habitat-type hotspots, i.e. areas of importance for multiple species, may be identified with this
approach.
Conclusion
Using data collected by the NOAA Northeast Fisheries Science Center and other sources, the Kostylev Approach can be used to produce a habitat map of the Gulf of Maine. The habitat types, with which individual managed fish species are associated, can be readily identified. It is suggested that this approach may be a useful tool for fisheries managers. In the USA, this approach may help to designate Essential Fish Habitat, as prescribed in the Magnuson-Stevens Act. Further, habitats important for multiple species can easily be identified and may be useful for other management actions such as the designation of Marine Protected Areas.

References