

HabitatSpace – to visualize/analyze climate change effects in 3-D

Tiffany Vance, NOAA/NMFS/AFSC
David Stuebe, Applied Science Associates
Scott Cross, NOAA/NESDIS/NCDDC
Sharon Mesick, NOAA/NESDIS/NCDDC

Abstract

Societal impacts consider the possible impacts of climate change on human societies. While these are critical, non-human organisms are also affected by climate change. This talk describes tools created to delineate oceanic habitats – especially pelagic habitats – in support of ecosystem-based management and marine spatial planning. These tools can be used to explore the impacts of climate change on marine organisms and ecosystems. HabitatSpace provides analysis and visualization in a GIS-based tool that uses UCAR's Integrated Data Viewer (IDV) for volumetric visualizations. While visualization tools provide appealing pictures of complicated data, they can also be coupled with geographic information systems to provide advanced analyses. New tools for the representation of multidimensional data allow users to visualize and interact with datasets such as three-dimensional output from particle tracking models. These tools can also be used to analyze conductivity-temperature-depth (CTD) data, which is the oceanographic analog to atmospheric sounding data.

Background

Looking at changes in essential fish habitats (EFH) is analogous to studies of the societal impacts of climate change. Essential fish habitat means “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity” (Magnuson-Stevens Act, 16 U.S.C. 1801 et seq). For the purpose of interpreting the definition of essential fish habitat: “Waters include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; substrate includes sediment, hard bottom, structures underlying the waters, and associated biological communities; necessary means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and spawning, breeding, feeding, or growth to maturity covers a species' full life cycle” (EFH Interim Final Rule, 62 FR 66531).

Climate change can alter the location, size, and shape of EFH. Societal changes such as increased fishing, changes in diet, and population migration can affect fishing pressure on habitats and the use of habitats by non-fishing activities. As these factors interact, it is increasingly important to be able to rapidly delineate and analyze habitats. Changes in circulation patterns or the timing of spawning can cause fish larvae to experience different habitats. Particle tracking models can be used to explore the paths that larvae might take under different modeled circulation regimes.

Project goals

GIS-based tools are used to delineate EFH (Cochrane et al., 2003; Friedlander et al., 2007; Whitmire et al., 2007). These tools work very well for the characterization of benthic EFH, but are less usable to identifying pelagic EFH. Work so far in the Gulf of Alaska and the Bering Sea has concentrated on the effects of trawling on the ocean floor, with emphasis on the path created by the dragging of nets and the recovery of the area after trawling ends (Thrush and Drayton, 2002). While this is important for preserving benthic species, it is of limited applicability to pelagic larvae and fish, or the larval stages of benthic fish. Larval and pelagic fish experience habitat as a 4-D entity. For this reason, extending habitat analysis to these lifestages and species requires exploring ways to define and analyze environmental variables in 3- and 4- D. To extend the strengths of 2.5-dimensional EFH to 3- and 4-dimensions, we need to be able to make many of the same calculations in 3-D that are currently made in 2-D. For example, being able to analyze 3-D data about the marine environment to create volumes and calculating the intersection of volumes. If larval fish prefer temperatures 5 to 8 °C and depths below the turbulent surface layers, but above 50m depth, scientists want to calculate the intersection of the two volumes defined by these criteria. As temperature history, not just temperature at a given moment, affect development, they want to integrate *in situ* temperature data with model output to create a temperature time series for the habitat and the larvae in it. We also need to provide this functionality in the GIS environment familiar to researchers.

HabitatSpace routines allow us to calculate oceanographic parameters such as the mixed layer depth, integrate datasets, display the trajectories of larval fish based upon model data, and visualize the results in 3- and 4-D views. Other routines calculate the intersection of the trajectories with planar features. NetCDF files are read and written as a native format in ArcGIS and slices of the data in x, y, z, and t can be displayed. These types of functionality can then be applied to EFH analyses.

As a part of the project, ASA developed a web-based tool that calculates particle trajectories utilizing external Regional Ocean Modeling System (ROMS) circulation fields hosted by THREDDS servers. The web-based tool, LarvaMap, leverages distributed computing and open standards to simulate passive long-term and large-scale larval fish transport. LarvaMap can be used to investigate how changing current regimes affect the habitats experienced by larvae. It can also be used to compare trajectories for a particular year with “climatologies” of larval paths.

System architecture and software packages used

HabitatSpace extends the 2-D tools used for EFH to a suite of 3-D tools by integrating new and existing analysis routines into framework for 3-D GIS created in the GeoModeler project (Vance et al, 2007). GIS analyses are supported both by native ArcGIS functionality and by data loading and display routines using ArcEngine and ArcObjects (ESRI, 2010). These tools provide for the ingestion and display of shapefiles

System Architecture



Figure 1 HabitatSpace's architecture showing data sources, data ingestion, the server that stores the data, and the various types of analyses and output products available.

and netCDF datasets. HabitatSpace can map and analyze attributes via tools for the creation of interpolated surfaces and the calculation of areal statistics.

A plugin for Unidata's IDV (<http://www.unidata.ucar.edu/software/idv/>) is used for the display of surfaces and volumes. It is also used for the calculation of volumes based upon multiple criteria, such as water temperatures between 5 and 10 °C and salinities between 31 and 32.5 parts per thousand. The user interface to IDV has been simplified to make it easier for first-time users to rapidly perform analyses. The full functionality of IDV is still available for those more familiar with the package or those willing to learn a new visualization package. IDV is an OPeNDAP Common Data Model-enabled visualization client with a modular customizable interface which supports saving scenes. Java is used to connect modules and for visualizations. A .jar file is created to hold the customized version of IDV for the application. The file can be downloaded as an executable .jar file which launches IDV. Documentation on the use of the customized IDV is available within the IDV help menu.

Python is also used in HabitatSpace as a programming language as it is now a native scripting and programming language for ArcGIS and other GIS packages. Tools from the Python-based ArcGIS Statistics Toolbox are being use for 3-D statistical analyses. Some of the 2-D tools in the toolbox will be expanded to 3-D in future HabitatSpace

developments. HabitatSpace can use data stored locally and can also access a THREDDSS data server. The THREDDSS Data Server (TDS) provides an easy way to share netCDF files via OPeNDAP in a browse-able catalog. The catalog can be either local or remote depending upon file sizes and network capabilities. The ArcGIS tools in HabitatSpace can use either shapefiles or netCDF files. The IDV plugin uses primarily netCDF files, especially for remote files, but can also read shapefiles.

The LarvaMap application in HabitatSpace uses a Java-based larval transport (particle) model that access hydrodynamic data stored on NetCDF or served by THREDDSS and OPeNDAP servers. The model has ability to access distributed data that is CF-compliant. NCML is used to make non-CF data compliant. The tool allows for running particle-tracking models using ROMS and NCOM circulation models. It includes the ability to test performance of the model when it is installed on distributed servers (LambdaRail, cloud resources, etc.).



Figure 2 The LarvaMap interface showing the parameters that can be set and the map interface to determine larval release points or areas.

The front end of LarvaMap uses an Adobe Flex thin client with the OpenScales mapping Application Programming Interface (API), to provide an exploratory map interface, and access to the Environmental Data Server (EDS) and metocean Web Map Services (WMS) for contextual wind and current data. The user defines larval release parameters, including temporal extent, release duration, number of particles, and species type. Utilizing a Java-based distributed data retrieval and model processing backend, the larval transport model runs as a service, dynamically accessing oceanographic data from distributed THREDDSS servers. The output from LarvaMap can be displayed on the web client or the results can be read into ArcGIS for further analysis and display.

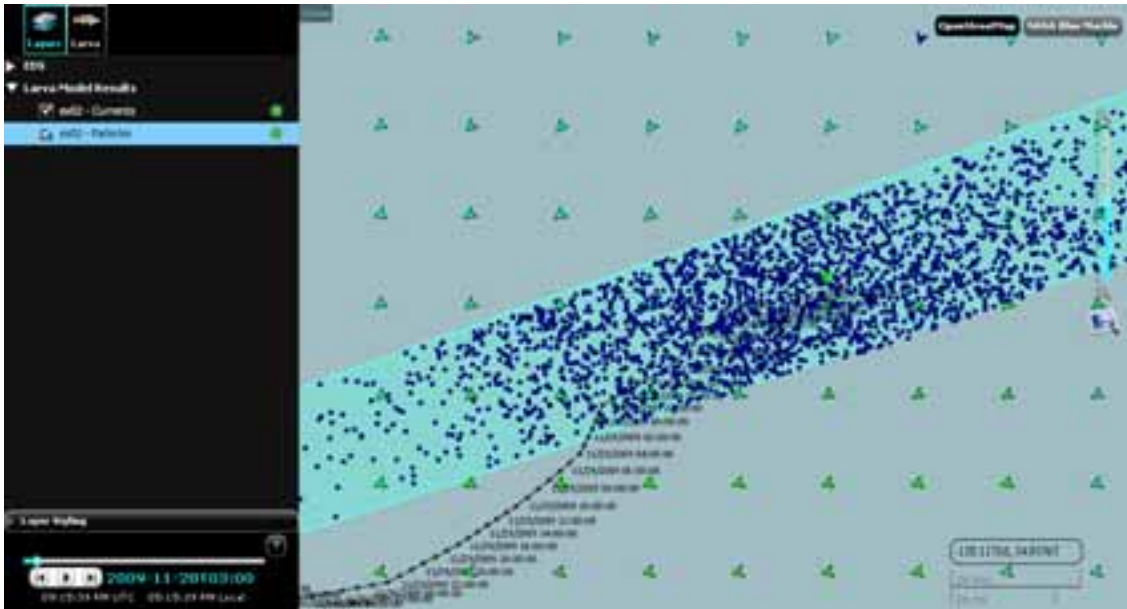


Figure 3. Output of LarvaMap shown in the web client. The green arrows show currents. The blue dots are the locations of particles and the path of a single particle is shown with the black line.

Prototype applications

While HabitatSpace is a prototype, it has been used for a number of research projects. In the first, it is used to compile and display data for a project on interannual variations in the patterns of growth rings in the otoliths (earbones) of walleye pollock. Walleye pollock are the target of the largest US fishery (by weight) and are used for human foods such as fishsticks and to make surimi. They are also an important forage fish for both larger fish and marine mammals in the Gulf of Alaska and the Bering Sea (Grebmeier et al., 2006; Kendall et al., 1996). Changes in the temperatures experienced by larval walleye pollock can affect the intensity of the rings seen on their otoliths (Dougherty et al., 2009). Figure 4 shows the data layers used for the project, including *in situ* water temperatures and salinities, bathymetric data, modeled ocean currents and water properties, fish catches, and meteorological parameters. These datasets are analyzed to look at interannual variations in the conditions seen by the larvae. *In situ* and modeled data are used to recreate the temperature history of larvae based on particle tracking models. HabitatSpace can be used to visualize and interpret the environment and to define potentially better habitats for the larvae. Figure 5 shows a three dimensional surface of a given temperature, with the surface colored based upon salinity. The image can be used to locate areas assumed to best support larval growth and survival.

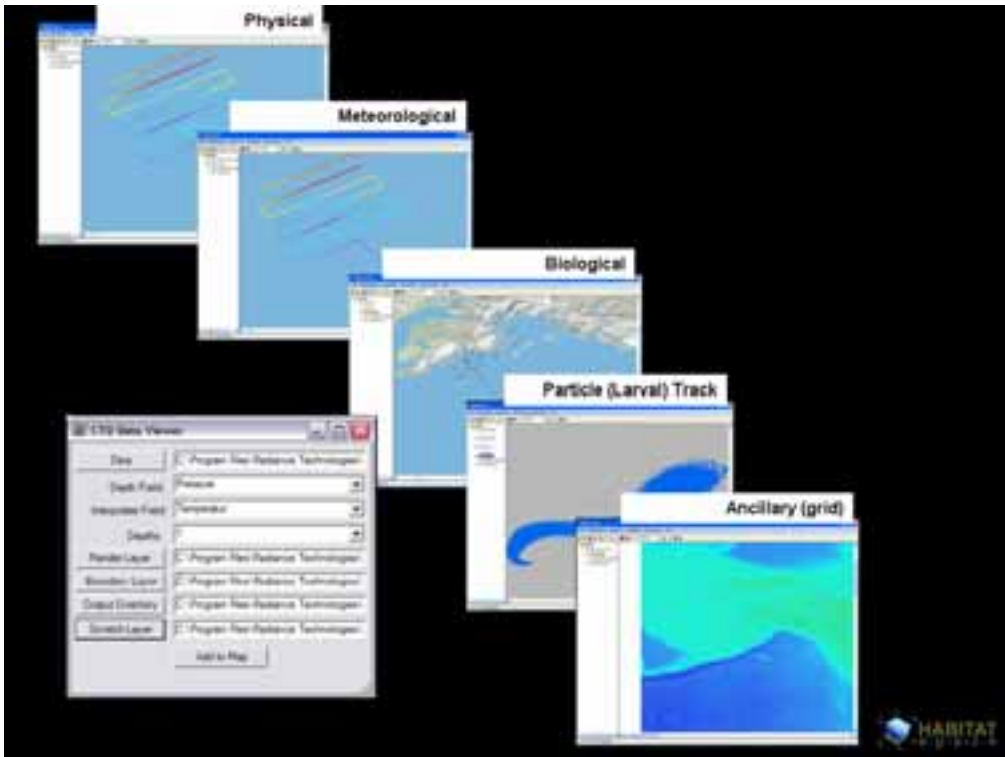


Figure 4 Data layers for use in walleye pollock studies using HabitatSpace. Datasets may be two- or three-dimensional.

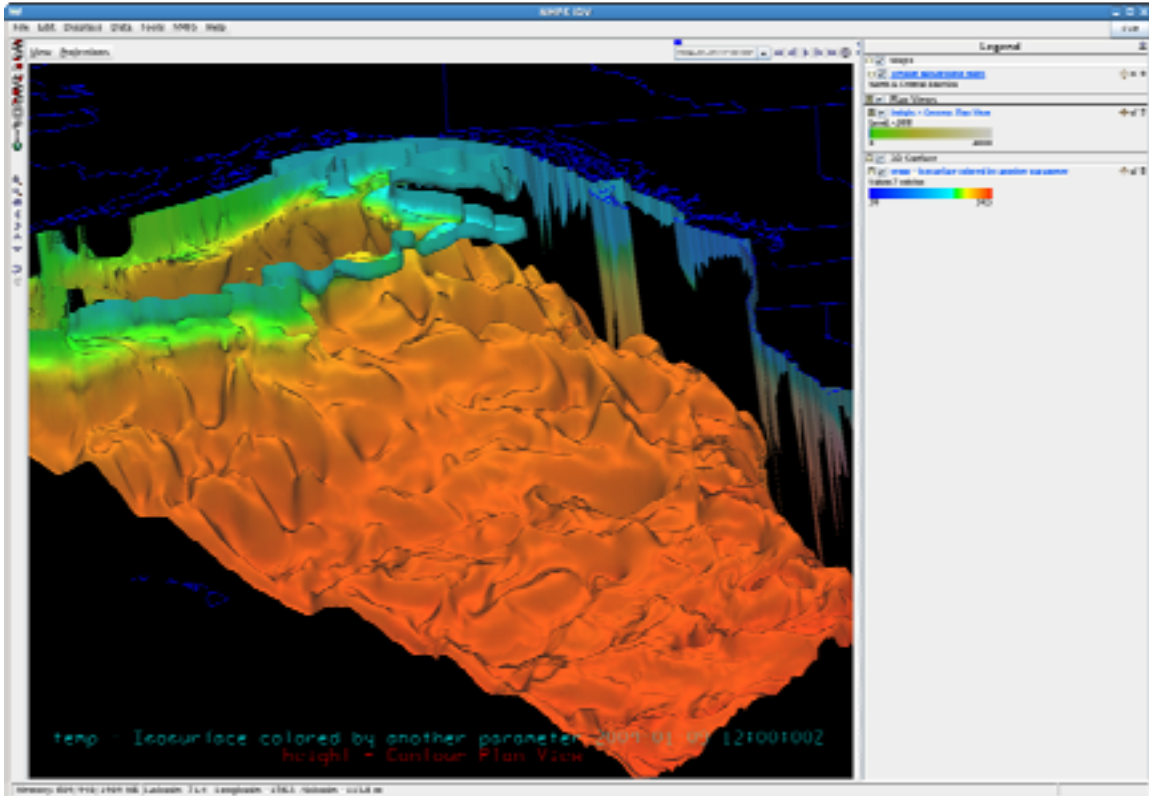


Figure 5 IDV used to color a surface of one parameter by the value of another parameter.

Surface shown is the depth of water of a constant temperature; the color shading is based upon salinity. The IDV plugin can also be used to define volumes. IDV can render volumes from gridded model data based on restriction criteria. The IDV project provided a set of tools to manipulate multiple restrictions applied to a single dataset. If a species is known to have limits to its survival, for example a tropical marine mammal such as a manatee that cannot survive in water temperatures below 63°F, the tool can be used to define the boundaries of acceptable habitats. If an area lies outside of these boundaries, it is not suitable for a marine protected area or other area to enhance the species' survival.

In a second project, scientists are looking at the early life history of Greenland halibut in the Bering Sea (Blood et al., 2009). While there was a commercial fishery for Greenland halibut in the eastern Bering Sea, catches have declined greatly since the 1970s. While they are well studied in the Atlantic, less is known of their life history patterns in the Pacific and Bering Sea. The fish live on the seafloor but their eggs and larvae reside in the water column. Hydrographic models and data from moorings and drifters are being

Bering Canyon Trajectory

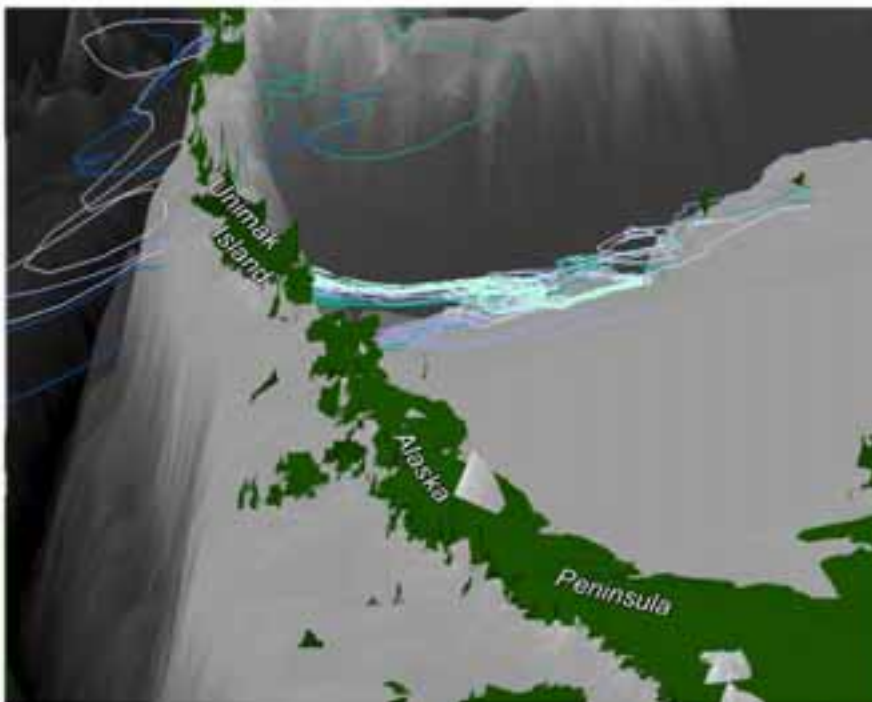


Figure 6 Trajectories of Greenland halibut larvae based upon a particle-tracking model. Figure created by Zachary Winters-Staszak.

used to study the dispersal and habitats of these early life history stages. Figure 6 shows a visualization of the path of larvae released at various depths in a particle-tracking model simulating larval dispersion. The locations are described in four dimensions (X, Y, Z and time). The model also calculates environmental parameters such as temperature and salinity for each particle location and these can be portrayed and analyzed. The ArcGIS

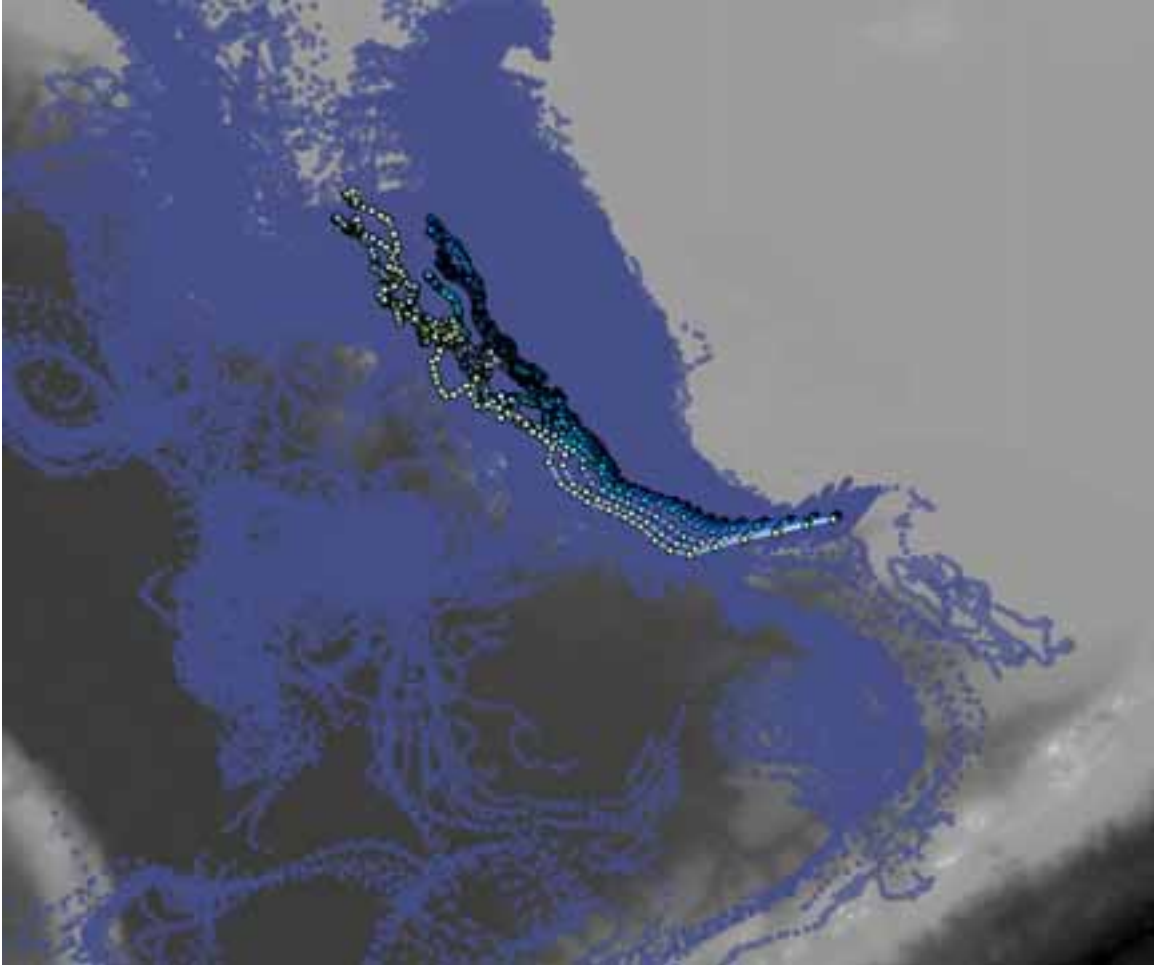


Figure 7 Paths of the mean center, by day, of clouds of larvae released at discrete depths. The lighter blue lines show larvae released at the surface while the progressively darker blue lines track larvae released at increasing depths.

statistical toolbox can be used to perform analyses such as calculating the mean center of the larval distribution for each day of the model run and plotting it along with associated variables such as water temperature. Figure 7 shows the path of the mean center of the larval “cloud” for each day. Each line shows the center for a group of larvae released at a single depth. Analyses such as these can show how the depth of spawning or hatching of the eggs might affect their eventual paths, and the habitats they encounter. Knowing the mean center of the distribution of a species, or of a life stage of a species, allows fisheries managers to fine-tune the location and timing of no-take and other regulatory areas. Rather than needing to limit access to the entire known range of a species, it may be possible to limit access to smaller areas that encompass the great majority of the spawning fish or the majority of the larvae.

Conclusions

Existing EFH efforts have proven the benefits of identifying areas of special concern for habitat protection. However, these efforts are limited in that they concentrate on 2-D benthic environments. As it becomes increasingly necessary to determine habitats of importance for pelagic species, tools to define these habitats will be needed. Current EFH work depends highly upon GIS-based analyses. As current GIS techniques do not provide 3-D equivalents to analyses such as the intersection of areas and buffering around an area of interest, new tools are needed. Since scientists are familiar with making these calculations in a GIS environment, it makes good sense to extend abilities of the GIS rather than developing an entirely new suite of tools. The use of HabitatSpace by two projects investigating the habitats of larval fish has shown the benefits of the tool. Scientists have been able to visualize various aspects of the habitat and to visualize and analyze the paths of larvae and the environmental conditions they encounter during the early stages of their life.

In the future, LarvaMap will be used to evaluate how distributed services-based systems can be used to improve computationally intensive science projects. The LarvaMap system will be deployed on one or more cloud computing architectures. LarvaMap is a good application to test both the computing aspects of the cloud and the storage and transport of large datasets needed to run models. In addition to deploying the system in the cloud, future developments include additional inputs for defining species and adding in larval fish behaviors, such as vertical migration.

Acknowledgements and disclaimers

Funding for this project was provided by the High Performance Computing and Communications (HPCC) project of the NOAA Office of the Chief Information Officer. For more details, please see <http://nwweb.nwn.noaa.gov/hpcc/nwg/>. Additional support for this research was provided by the NOAA Fisheries-Oceanography Coordinated Investigations (FOCI). This research is contribution EcoFOCI-nnnn to NOAA's Ecosystems & Fisheries Oceanography Coordinated Investigations. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies. Mention of software products does not imply endorsement of these products

References

Blood, D.M., J.T. Duffy-Anderson, A.C. Matarese. D. Sohn, P.J. Stabeno, W. Cheng. 2009. Early Life History of Greenland Halibut (*Reinhardtius hippoglossoides*) in the Eastern Bering Sea Based on Recent Field Studies (2007-2009): Spawning, Distribution, and Physical Processes Affecting Drift and Dispersal, Larval Fish 33rd Annual Conference, Portland, OR, July 2009.

Cochrane, G.R., N.M. Nasby, J.A. Reid, B. Waltenberger, K.M. Lee, 2003. Nearshore Benthic Habitat GIS for the Channel Islands National Marine Sanctuary and Southern California State Fisheries Reserves Volume 1, U.S. Geological Survey Open-file Report 03-85, <http://geopubs.wr.usgs.gov/openfile/of03-85/>.

Dougherty, A.B., K. Bailey, T.C. Vance. 2009. Geographic Comparison of Growth and Hatch Dates of Age-0 Walleye Pollock (*Theragra chalcogramma*) in the Gulf of Alaska. International Otolith Symposium (4th), Monterey, CA, Aug 2009. URL: ftp://ftp.afsc.noaa.gov/posters/pDougherty02_pollock-go.pdf

Friedlander A.M., E.K. Brown, M.E. Monaco. 2007. Coupling Ecology and GIS to Evaluate Efficiency of Marine Protected Areas in Hawaii. *Ecological Applications* 17(3), p. 715-730.

Grebmeier, J.M., J.E. Overland, S.E. Moore, E.V. Farley, E.C. Carmack, L.W. Cooper, K.E. Frey, J.H. Helle, F.A. McLaughlin, S.L. McNutt. 2006. A Major Ecosystem Shift in the Northern Bering Sea. *Science* 311 (5766), 1461-1464.

Kendall A.W., J.D. Schumacher, S. Kim. 1996. Walleye Pollock Recruitment in Shelikof Strait: Applied Fisheries Oceanography. *Fisheries Oceanography* 5:4-18.

Thrush, S.F. and P.K. Dayton. 2002. Disturbance to Marine Benthic Habitats by Trawling and Dredging: Implications for Marine Biodiversity. *Annual Review of Ecology and Systematics*, 33, p. 449-473.

Vance, T.C., N. Merati, S.M. Mesick, C.W. Moore, D.J. Wright. 2007. GeoModeler: tightly linking spatially explicit models and data with a GIS for analysis and geovisualization. Proceedings of the 15th Annual ACM International Symposium on Advances in Geographic Information Systems, November 7-9, 2007, Seattle, Washington.

Whitmire, C.E., R.W. Embley, W.W. Wakefield, S.G. Merle, B.N. Tissot. 2007, A quantitative approach for using multibeam sonar data to map benthic habitats, in Todd, B.J., and Greene, H.G., eds., Mapping the Seafloor for Habitat Characterization: Geological Association of Canada, Special Paper 47, p. 111-126.

Software

ESRI, 2010. ArcEngine and ArcObjects. <http://resources.esri.com/arcgisengine/>, viewed 6/4/2010.

HabitatSpace IDV jar file - <http://www.asascience.com/software/downloads/>

Contact author:

Tiffany C. Vance
NOAA/NMFS/AFSC, 7600 Sand Point Way NE
Seattle, WA, USA
tel. 01.206.536.6767
email tiffany.c.vance@noaa.gov