Applications of Earth Observations to Fisheries Management: An Analysis of Socioeconomic Benefits

Pelagic Habitat Analysis Module for Management of Marine Fisheries and Conservation

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Authors

- Lawrence Friedl, NASA Earth Science Division, NASA Headquarters, Washington, DC lfriedl@nasa.gov
- Dale Kiefer, System Science Applications, Pacific Palisades, CA kiefer@dornsife.usc.edu
- Woody Turner, NASA Earth Science Division, NASA Headquarters, Washington, DC woody.turner@nasa.gov
- Mark Hutson, Booz Allen Hamilton, Washington, DC, hutson_mark@bah.com
- David Wilson, Booz Allen Hamilton, Washington, DC, wilson_david@bah.com
- Maury Estes, USRA at NASA-Marshall, Huntsville, AL maury.g.estes@nasa.gov

Project Background

The loss and decline of fisheries can cause devastating economic and environmental impacts in countries and markets across the globe. In 2004 and 2007, the Applied Sciences Program initiated projects selected under open, competitive solicitations. One project, The Pelagic Habitat Analysis Module (PHAM), focused on improving assessments of fisheries stocks using satellite observations of parameters including: sea surface temperature, salinity, thermocline depth, currents, chlorophyll concentration, and frontal boundaries. Better knowledge of fish spawning (reproduction) and recruitment (growth to adulthood) leads to more robust estimates of fish population sizes and growth rates. Improved estimates enable international fisheries management organizations to formulate more informed policies for managing stable and productive fisheries, thereby mitigating the risks of stock collapse, extirpation (localized population extinction), and species extinction.

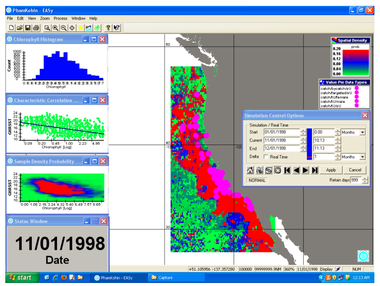
Using data from the United Nations Food & Agricultural Organization (FAO), the analytic team estimated the relative value of improved stock size estimates resulting from use of the Earth observations. This value is the sum of marginally higher catch rates (valued at market prices) and the costs avoided by preventing a stock collapse.

Paper Abstract

To estimate the immediate and potential future socioeconomic impacts of the Pelagic Habitat Analysis Module (PHAM) project supported by the NASA Applied Sciences Program, we modeled the reduced uncertainty of stock size estimates reasonably attributable to the project. Using assumptions derived from the fisheries management literature and data on the market size of certain fish species, the analytic team developed a framework for determining the differences in management policy associated with varying levels of stock size confidence, measured the resulting differences in allowable catches, and assessed the relative change in the likelihood of a stock collapse.

Using data from the United Nations Food & Agricultural Organization (FAO), the analytic team then estimated the relative value of the improved stock size estimates resulting from the addition of the Earth observations. This value is the sum of marginally higher catch rates (valued at market prices) and the costs avoided by preventing a stock collapse.

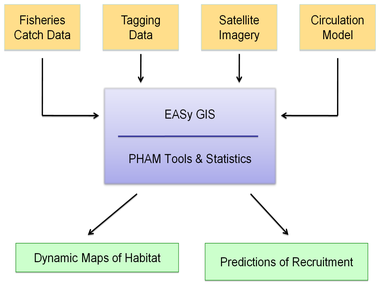
The Pelagic Habitat Analysis Module (PHAM) – NASA Data at Work



PHAM is a decision support system designed to aid both the management and conservation of marine fisheries. The software integrates data from fishery surveys, tagging studies of the movement of fish, and fleet reported catch and effort data, with satellite imagery and circulation models to define the habitat distribution of each species in terms of oceanographic variables. The project consisted of 2 case studies, the tuna fishery of the eastern tropical Pacific, which is managed by the Inter-American Tropical Tuna Commission (IATTC), and the monitoring of shark populations along the west coast of the United States by the Southwest Fisheries Science Center.

PHAM works within a GIS framework to integrate satellite imagery and ocean circulation models into the management of commercial and threatened pelagic species. We use this information to predict fish distributions, analyze population overlap among species, and inform models of population dynamics that are used for stock management.

PHAM resides within the EASy GIS tool, which provides a 4 dimensional (latitude, Longitude, depth, & time) home for the various data formats. Tools include EOF analysis of satellite imagery, data matching between environmental data and fisheries presence/count data, and statistical regression techniques for examining relationships between environmental conditions and species habitat. Analyses based on oceanic conditions detected from space and/or output from NASA's ECCO-2 global circulation model yield dynamic maps of predicted species density and recruitment of young fish to the adult population.



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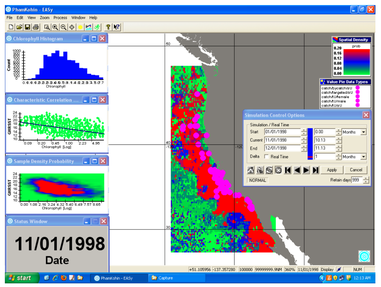

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Methodology

Fisheries Managers Must Balance Short-term Profits with Sustainability of the Fishery

- Uncertainty over stock size or recruitment rate (population growth) can complicate determining the appropriate catch rate and lead to a sub-optimal quota
- Setting fishery quotas too low can be costly to market participants
  - Individual fishermen are unable to maximize their profits, resulting in lower revenue for the fishermen and higher prices for consumers
- Setting fishery quotas too high leads to overfishing
  - This can result in closing the fishery in future years, or even outright stock collapse and complete loss of future profits

By Reducing Uncertainty, NASA Data Allow for More Optimal Fisheries Management

- A more accurate estimate of population size can raise quota and reduce risk to threatened species. These benefits can be quantified and valued using the following formula:

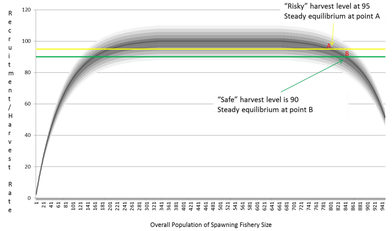
$$Value = \sum_{t=1}^{\infty} \delta^t \Delta Y_t * P_t + \Delta p(x) \sum_{t=1}^{\infty} \delta^t Y_t * P_t$$

Where Y_t is the value of the total harvest in catch year t, P_t is the market price of the catch in year t, ΔY_t is the change in the optimal catch rate, δ is the discount factor, and$\Delta p(x)$is the change in probability of a fisheries closure or stock collapse based on more optimal management

- This equation reflects that the optimal risk-averse catch rate may increase, while there is a simultaneous reduction in the future probability of fisheries closure or stock collapse due to overfishing

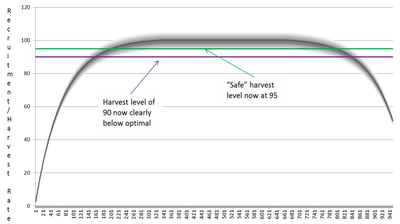
Dynamics of Fisheries Management

Higher catch rates under uncertainty can threaten stock stability



- The figure to the left charts a hypothetical fishery recruitment rate relative to population level under uncertainty (grey line); the sigmoidal shape and flat "top" is derived from PHAM data.
  - The uncertainty associated with population curve includes both stock size uncertainty & potential adverse environmental shocks
- Fisheries managers must set the sustainable harvest quantity for each season based on the size and recruitment rate of the fishery stock; this involves setting the vertical catch line:
  - Risk averse managers wanting 95% confidence of avoiding stock collapse would set the "safe" line at a rate of 90 (green line)
- The yellow line, set at a rate of 95, represents a 68% probability of avoiding collapse

Reducing uncertainty around original estimate raises the optimal "Safe" catch rate



- The figure on the bottom left shows how a reduction of uncertainty around the original "true" line can raise the catch rate without increasing the probability of stock collapse
- Reducing uncertainty (variance) around the estimates of population by ½ has provided a more optimal catch rate:
  - Risk averse managers wanting 95% confidence in avoiding stock collapse would raise the "safe" catch to 95 (green line)
  - The previously "safe" catch rate of 90 (purple line) is now clearly sub-optimal, restricting harvest size and reducing supply

Modeling Results & Current Users

Estimated Savings from 17% Reduced Stock Size Uncertainty

Atlantic Bluefin	Pacific Bluefin	Yellowfin
• 10-year market value of $125mm • Threat reduced from 50% to 41% • $21mm NPV* in Savings	• 10-year market value of $17.8mm • Threat reduced from 10% to 8% • $3.1mm NPV	• 10-year market value of $1.8mm • Threat reduced from 1% to 0.8% • $0.3mm NPV

*Net Present Value

- One of the primary results of the paper was an estimate of the 10-year value from reduced uncertainty in three fisheries markets
- The calculations assumed a 17% reduction in stock-size uncertainty, which impacted the likelihood of stock collapse for three species at various risk levels of collapse
- The estimated value of the risk-reduction was equal to the change in collapse probability times the present discounted value of the market over the next 10-years
- The market value was determined using Fishstat J data over the previous decade.

Further Findings From This Project

Large correlation between environmental conditions and recruitment rate

- Significant reduction in shape uncertainty and size of recruitment curve of several species and populations

Greater understanding of how environmental shocks will influence spawning population and location over the next few years

- Reduction in resources used in fishing through improved models of location (SeaStar, Roffers)

NASA Remote Sensing Data is Playing a Significant Role in Fisheries Management

Key Stakeholders in fisheries management using model outputs

- Inter-American Tropical Tuna Commission*
- Northwest Atlantic Fisheries Organization*
- Center for Studies and Development for Fisheries
- Central Institute of Fisheries Technology
- Southwest Fisheries Science Center
- East China Sea Fisheries Institute
- Secretariat of the Pacific Community
- Several Academic institutions

*Fisheries Manager

Several Readily Available NASA Data Products Are Used in Research Process

Data Sources Used in PHAM	
SeaWiFS Chlorophyll*	MODIS Chlorophyll*
MODIS Sea Surface Temperature*	GHRSST#
AVHRR Sea Surface Temperature#	AVISO Sea Surface Heights
NASA JPL Frontal Probability*	ETOPO Bathymetry
NOAA CoastWatch Frontal Probability	QuickSCAT SeaWinds*

*** Indicates NASA data product**
 # Indicates a user of NASA data, either as part of the data analysis or as a calibration reference