Session: Ecosystem Delineation and Production

Fishery Production Potential

Kimberly Hyde, Michael Fogarty, Robert Gamble & Kristin Kleisner

Summary

Fisheries production potential estimates are a function of the available production at different trophic levels, the transfer efficiencies across trophic groups, the proportion of production considered suitable for harvest, and the determination of sustainable exploitation levels. In this simplified food web approach, two pathways are recognized for the trophic transfer of primary production – direct grazing of microplankton, principally diatoms; and transfer of nano/picoplankton production through the microbial food web. While the fraction of nano/picoplankton production is often greater than microplankton production, direct grazing is a more efficient pathway. Advances in understanding transfer efficiencies and data available for global primary production allow for key improvements to production potential estimation methods. Here satellite remote sensing models of phytoplankton size classes are used to estimate size fractionated primary production. The fractions of microplankton and nano/picoplankton production are then traced through a simplified food web to determine the fisheries production potential of multiple trophic levels. The proposed ecosystem limiting reference level is set by the fraction of microplankton production. In the Northeast U.S. Continental Shelf (NES), annual primary production ranges from 260-320 $gCm^{-2}d^{-1}$, with approximately 24-28% derived from the microplankton component. This primary production results in an overall estimated potential yield of approximately 895,000 tonnes for the benthivore, planktivore and piscivore functional groups, assuming the exploitation rate is the same at all trophic levels. Alternative exploitation options can be defined that still meet the limiting ecosystem reference level.

Introduction

The energy-based fishery production potential of marine systems can be estimated by tracing the energetic pathways from primary production to fisheries yield. This bottom-up control of fish production has been demonstrated in many regions of the world ocean (Ware, 2000), however estimates of accessible global fish production potential are highly variable (Pauly 1996). Early estimates were based on total primary production, inferred ecological transfer efficiencies, and observed or assumed levels of the mean trophic level of the catch. Our modified approach uses satellite-derived estimates of size-fractionated primary production, improved estimates of ecological transfer efficiencies from a large number of energy flow networks models, and an expansion of the implicit food chain to a food-web model that includes discrete ecosystem components (including benthos, planktivores, benthivores and piscivores). Primary production was partitioned into microplankton (>20 µm) and nano-picoplankton (< 20 µm) production. The former includes diatoms and larger dinoflagellates while the latter includes smaller flagellates, autotrophic bacteria, *etc*. In this simplified food web (Figure 1), microplankton

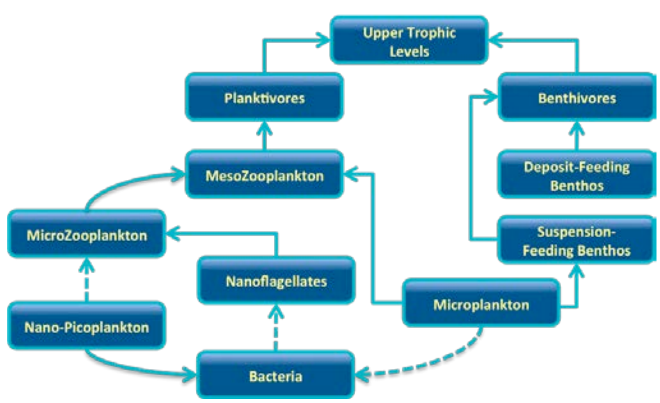

Figure 1. Simple model tracing production through the food web.

production is transferred directly to mesozooplankton and benthic components, while production from the smaller size classes is transferred through the microbial food web. The microbial pathway involves two or more trophic transfer steps before reaching mesozooplankton, which is the bridge to the higher trophic levels.

Materials and Methods

Annual estimates of primary production were calculated for the Sea-viewing Wide Field-of-View (SeaWiFS, 1998-2007) and Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua, 2008-2014) sensors using a modified version of the Vertically Generalized Productivity Model (VGPM) (Behrenfeld and Falkowski 1997). This modified VGPM model replaces the original temperature-dependent description of photosynthetic efficiencies with the exponential "Eppley" function (Eppley 1972) modified by Morel (1991). To estimate the proportion of primary production attributed to the microplankton population we first estimated the microplankton total chlorophyll *a* (i.e. biomass) fraction (Pan *et al.* 2011) and then used an empirical relationship based on more than 600 *in situ* measurements of size fractionated chlorophyll and primary production in the Northeast U.S. Continental Shelf (NES) LME (O'Reilly *et al.* 1987) to calculate percent of microplankton production.

Trophic transfer efficiencies were derived from published Ecopath with Ecosim (EwE) models for temperate-boreal systems. The characterization of transfer efficiencies between discrete trophic levels based on these EwE models followed the approach of Ulanowicz (1995). Rather than assume or assign tropic transfer efficiencies at different levels of the food web, we used the model estimates to define probability distributions characterizing transfer probabilities at each step in the food web (Fogarty *et al.* 2016).

The fisheries production potential model was implemented in JAGS (Just Another Gibbs Sampler) and employed a Gibbs Markov Chain Monte Carlo sampler. For each run, 10,000 iterations were used (with the first 1000 burn-in runs discarded).

Results

Total mean annual primary production varied from approximately 260 to 320 gC m^{-2} yr^{-1} and on average, microplankton were responsible for roughly 24-28% of the total annual production (Figure 2). This primary production yields nearly 900,000 tonnes of fisheries production potential. These estimates can be used in concert with observed catch data to estimate ecosystem exploitation rates for major ecosystem components including benthos, benthivores, planktivores and piscivores (Fogarty *et al.* 2016)

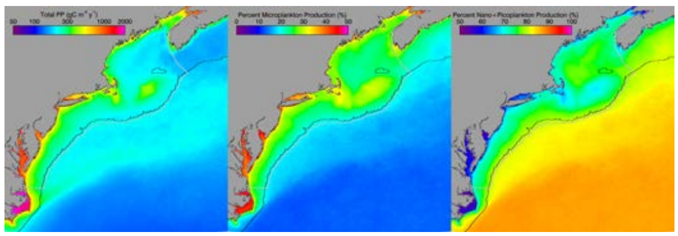

Figure 2. Total annual primary production, percent microplankton production and percent nano/picoplankton production.

References

Behrenfeld, M. J., and Falkowski, P. G. 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnology and Oceanography, 42: 1-20.

Eppley, R. W. 1972. Temperature and phytoplankton growth in the sea. Fishery Bulletin, 70: 1063-1085.

Fogarty, M. J., Rosenberg, A. A., Cooper, A. B., Dickey-Collas, M., Fulton, E. A., Gutiérrez, N. L., Hyde, K. J. W., *et al.* 2016. Fishery production potential of large marine ecosystems: A prototype analysis. Environmental Development, 17, Supplement 1: 211-219.

Morel, A. 1991. Light and marine photosynthesis: a spectral model with geochemical and climatological implications. Progress In Oceanography, 96: 263-306.

O'Reilly, J. E., Evans-Zetlin, C., and Busch, D. A. 1987. Primary Production. *In* Georges Bank, pp. 220-233. Ed. by R. H. Backus. MIT Press, Cambridge, MA.

Pan, X., Mannino, A., Marshall, H. G., Filippino, K. C., and Mulholland, M. R. 2011. Remote sensing of phytoplankton community composition along the northeast coast of the United States. Remote Sensing of Environment, 115: 3731-3747.

Pauly, D. 1996. One hundred million tonnes of fish, and fisheries research. Fisheries Research, 25: 25-38.

Ulanowicz, R. E. 1995. Ecosystem trophic foundation: Lindeman exonerate. *In* Complex Ecology: The Part-Whole Relation in Ecosystems, pp. 549-560. Ed. by B. C. Patten, and S. E. Jorgensen. Prentice-Hall, Engle-wood Cliffs, NJ.

Ware, D. M. 2000. Aquatic ecosystems: Properties and Models. *In* Fisheries Oceanography: An Integrative Approach to Fisheries and Ecology and Management. Ed. by P. J. Harrison, and T. R. Parsons. Blackwell Science, Oxford.