

PRIMARY PRODUCTION ENHANCEMENT BY OCEANIC SEAMOUNTS¹

Daniel Pauly

Sea Around Us, Institute for the Oceans and Fisheries, University of British Columbia, Vancouver,
Canada
d.pauly@oceans.ubc.ca

ABSTRACT

Oceanic seamounts are known to have a rich endemic fauna and high biomasses of fish and invertebrates, sustained by a primary production that they locally enhance and by secondary production, which the seamount animals capture from passing currents. There has been much debate about the relative contribution of these two sources of food for seamount animals. Here, a method is presented for detecting the primary production signature of seamounts from remote sensing data. The results suggest the occurrence of a strong enhancement of primary production for seamounts reaching close to the surface, which, however, quickly tapers with depth.

INTRODUCTION

Various mechanisms have been advanced to explain how generally conical seamounts, located in the path of marine currents, would generate an upwelling-like transfer of deep, nutrient rich water toward the surface, and thus increase local primary production (Dower *et al.* 1992; Bakun 1996). While such local upwelling allows patches of high primary production to be detected, using field sampling over certain well-studied seamounts (Peláez and McGowan 1986; Dower *et al.* 1992; Comeau *et al.* 1995; Mouriño *et al.* 2001), a general procedure for remotely sensing the enhanced pigment signature of seamounts has been lacking so far. This is not surprising, as visual examination of large-scale satellite imagery does not display anything resembling the distribution patterns of known seamounts. Thus, it might be inferred that satellite imagery, perhaps because of random variations at various scales, cannot detect seamount signatures (Peláez and McGowan 1986). However, it is shown here that this is not the case, and that satellite imagery does contain the primary production signature of seamounts.

MATERIAL AND METHODS

Definition and identification of seamounts

In the absence of a global registry of seamounts and of standards upon which such registry could be based, a mid-resolution bathymetric map (NOAA/NGDC 2001) was used to identify seamounts, using two techniques (Kitchingman and Lai 2004; Kitchingman *et al.* 2007):

The first technique was the identification of a subset of the seamounts of the world via the application to a map distributed by NOAA of the flow direction and sink algorithms that are part of ESRI's ArcGIS software, and the standard deviation of the depth estimates in a three by three block including and adjacent to the cell being examined. Seamounts differ from other areas of the sea floor in that there is a steep change in depth as they reach toward the surface, and they can thus be identified by the high standard deviation of depth estimates in their area of occurrence, compared to nearby areas of sea floor. About 30,314 'steep structures' (likely seamounts) were identified using this method and a threshold of a 300 m standard deviation in depth.

The other technique started from the tip of every identified steep structure identified by the first, but then scanned depths around each, along eight radii of 90 km each, at 45° intervals, and recording the lowest and

. Cite as Pauly D. (2017) Primary production enhancement by oceanic seamounts. Pp 91 – 94. In Pauly D., Hood L., and Stergiou K.I. (eds.) Belated contributions on the biology of fish, fisheries and features of their ecosystems. Fisheries Centre Research Reports 25(1). Institute for the Oceans and Fisheries, University of British Columbia

¹ This contribution was originally submitted to a high impact journal, but rejected due to one of three reviewers suggesting that it suffered from a "crucial flaw", although we thought that it didn't (see the Appendix for details). The paper was not re-submitted, nor submitted elsewhere, and the co-authors lost interest. It is now included here, in shortened form, under the name of its original first author, who still thinks that it presented a good idea, as also stated in the other two reviews originally received.

highest depths over a distance of 90 km (10 pixels near the Equator, more at high latitude). A steep structure was considered a seamount if three conditions were met: (i) Each and all of the eight radii include depths differing by at least 300 m; (ii) If two radii include depths between 300 and 1000 m, the shallowest point is closer to the peak than to the deepest point, and the two radii form an angle of less than 135°; and (iii) At least five of the eight radii around a peak include depths with a difference of at least 1000 m, and the shallowest point is closer to the peak than to the deepest point. Jointly, these three conditions eliminated the ridges formed by lines of adjacent seamounts, and the 15,962 seamounts thus identified can be considered well isolated from each other. Of these, 14,287 overlapped with the 'steep structures' identified by the first approach, i.e., could be considered to be well defined, despite the low resolution of the bathymetric map used.

The bathymetric data were available with a 2 minute resolution, while primary production data were available with 6 minute resolution only. Merging these datasets led to 12,977 large, well-defined seamounts being available at the 6 minute resolution-level used for this study. Coordinates and depths of the seamounts identified, along with a global map showing their distribution, are available elsewhere (Kitchingman and Lai 2004; Kitchingman *et al.* 2007).

Primary production

The primary production estimates used here were generated by the Inland and Marine Waters Unit, Institute for Environment and Sustainability, EU Joint Research Center, Ispra, Italy, and had a 6 minute resolution. They represented an annual average from November 1997 to December 1998, based on chlorophyll pigment concentration from SeaWiFS data and photosynthetically active radiation (see Appendix).

Seamounts for which no primary production value was available ($n = 39$), owing to gaps in the satellite coverage, were not considered. Each pixel covers an area of 81 km² and 'seamount pixels' were defined as those whose center was closest to tip of a seamount. 'Control pixels' were sampled at random from a circular band of 50 km inner and 100 km outer diameter around each seamount pixel. Values were rejected (with replacement) if they fell into a gap in the primary production map.

RESULTS AND DISCUSSION

Figure 1 shows that a consistent signal can be obtained by comparing the primary production estimated above known seamounts with that of control points selected at random from a radius of 50-100 km from each seamount. The two panels of Figure 1 thus illustrate the combined effects of depth and surface current velocity on primary production enhancement by seamounts. As might be seen, shallow seamounts exposed to currents of velocities above 5 m·s⁻¹ can locally increase primary production by more than 50%, with the effect fading within a radius of about 30-40 km around the tip of each seamount (Figure 1A). Conversely, shallow seamounts exposed to low current velocities generate less enrichment. Deep seamounts, whose tip reaches to less than 100 m, do not appear to enrich local productivity (Figure 1B).

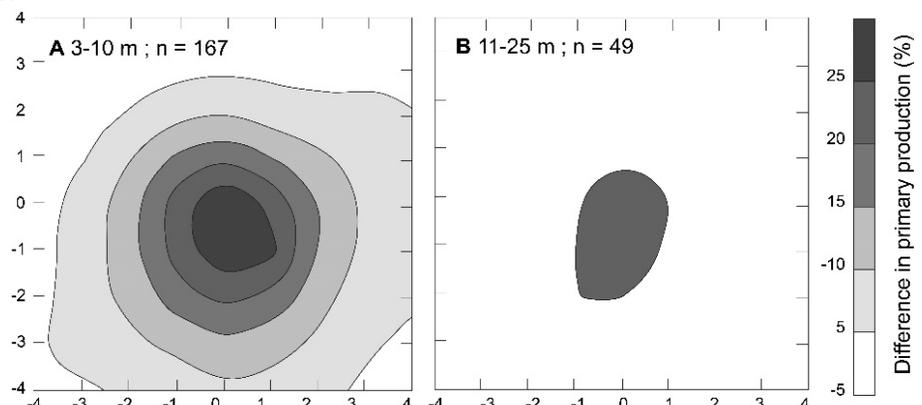


Figure 1. Mean primary production enhancement over 10,226 seamounts (relative to control points at 50-100 km) as a function of depth to the surface of the seamount peak, by square panels with sides of about 118 km. A. Shallow seamounts. B. Intermediate depth seamounts. Seamounts peaking at depths of less than 100 m do not enhance pigment visible through satellite imagery (see Figure 2), and are therefore not considered here.

Figure 2 shows the relative difference in primary production between seamount pixel and their controls for 12,848 seamounts with distance from the sea surface ranging from 1 to 5,600 m. As might be seen, only shallow seamounts, reaching to about 100 m of the surface, generate surface pigmentation increases that are detected by the SeaWiFS satellite sensors. It cannot be excluded that deep primary production is enhanced by deeper seamounts, but this would imply a form of primary production not considered in the algorithm commonly used

to turn observed surface pigment concentrations into estimates of primary production². The approach used here can be also be straightforwardly extended to atolls and islands small enough to function as net nutrient importer (Polis and Hurd 1996), i.e., those whose surrounding waters are enriched solely by the island mass effect. The results presented here also suggest, if indirectly, that the high biomasses of fish and other organisms reported from various seamounts rely largely on drifting zooplankton and marine snow (Koslow 1997), rather than on local primary production. This emphasizes the need to protect from destructive fishing methods the deep coral and other sessile organisms which, jointly with seamount fishes such as orange roughy (*Hoplostethus atlanticus*), capture the drifting organisms that fuel seamount ecosystems, and also provide the shelter required by juvenile seamount fishes.

ACKNOWLEDGEMENTS

This is a contribution of the *Sea Around Us*, mainly funded by the Pew Charitable Trusts at the time the work was undertaken. The work was based on a global map of (large) seamount developed by Adrian Kitchingman and

Sherman Lai of the *Sea Around Us*. The original submission also included, as co-authors, Reg Watson, Telmo Morato, and Villy Christensen, who had discussed the results with the (first) author, and Nicolas Hoepffner, EU JRC, who had supplied the SeaWiFS production estimates.

REFERENCES

- Bakun, A. 1996. Patterns in the Oceans: Ocean Processes and Marine Poulation Dynamics. California Sea Grant College System, National Oceanic and Atmospheric Administration in cooperation with Centro de Investigaciones Biologicas del Noroeste, La Jolla and La Paz.
- Comeau, L.A., A.F. Vezina, M. Bourgeois and S.K. Juniper. 1995. Relationship between phytoplankton production and the physical structure of the water column near Cobb seamount, northeast Pacific. *Deep-Sea Research, Part a - Oceanographic Research Papers* 142: 993-1095.
- Dower, J., H. Freeland and S.K. Juniper. 1992. A strong biological response to oceanic flow past Cobb Seamount. *Deep-Sea Research, Part a - Oceanographic Research Papers* 39: 1139-1145.
- Kitchingman, A. and S. Lai. 2004. Seamount biodiversity and fisheries. pp. 7-12 In T. Morato and D. Pauly (eds.) *Seamounts: Biodiversity and fisheries*. Fisheries Centre Research Report 12 (5). University of British Columbia, Vancouver.
- Kitchingman, A., Lai, S., Morato, T. and D. Pauly. 2007. How many seamounts are there and where are they located? Chapter 2, pp. 26-40 In: .J. Pitcher, T. Morato, P. Hart, M. Clark, N. Haggan and R. Santo (eds.), *Seamounts: Ecology Fisheries and Conservation*. Blackwell Fish and Aquatic Resources Series. 12, Oxford, U.K.
- Koslow, J.A. 1997. Seamounts and the ecology of deep-sea fisheries. *American Scientist* 85: 168-176.

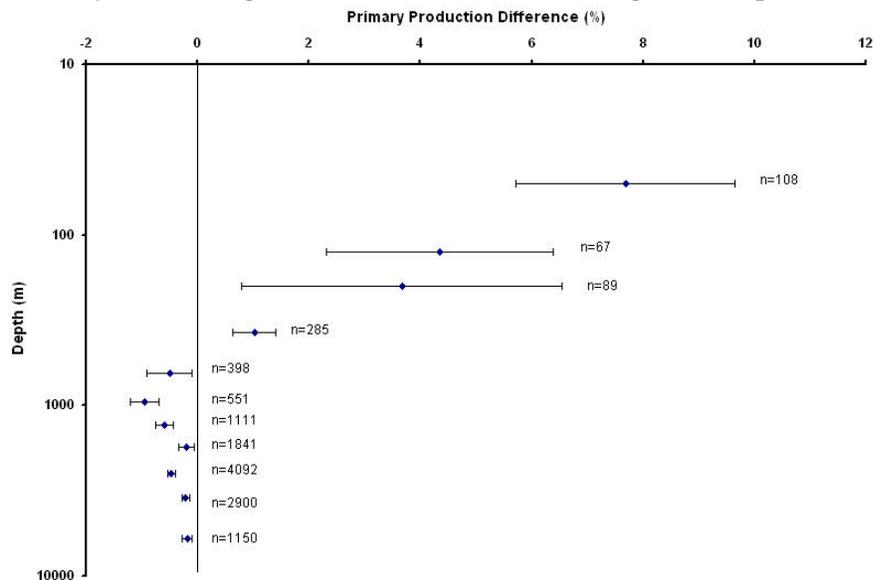


Figure 2. Primary production difference (means +/- 1 s.e.) above seamounts of various depths as evaluated by reference to control points at distances of 50-100 km. Overall, 12,848 large (>1000 m) conical oceanic seamounts for which primary production pixels were available are included here.

² The “crucial flaw” alleged by one of the 3 reviewers of the original version of this contribution thought that the primary production estimates over shallow seamounts were inflated due to the ‘shadows’ of (i.e., the reflection from) the seamounts themselves. Such ‘shadow’, however, would not generate the pattern documented in Figure 1. Moreover, the text stated that the algorithm used for inferring primary production for sea surface colors took care of reflection from the seafloor, and hence also from shallow seamounts. However, you can’t really argue with anonymous reviewers, even when they are clearly wrong.

- Mouriño, B., E. Fernandez, P. Serret, D. Harbour, B.Sinha and R. Pingree. 2001. Variability and seasonality of physical and biological fields at the Great Meteor Tablemount (subtropical NE Atlantic). *Oceanologica Acta* 24: 167-185.
- NOAA/NGDC. 2001. ETOPO₂ global 2' elevations CD-ROM. NOAA National Geophysical Data Center.
- Peláez, J. and J.A. McGowan. 1986. Phytoplankton pigment patterns in the California current as determined by satellite. *Limnology and Oceanography* 31: 927-950.
- Polis, G.A. and S.D. Hurd. 1996. Linking marine and terrestrial food webs: allocthonous input from the oceans supports high secondary production on small islands and coastal land communities. *The American Naturalist* 147: 396-423.

APPENDIX

Remarks from Nicolas Hoepfner, Joint Research Center, Ispra, Italy, from an email sent to the author on April 22, 2005.

The situation with respect to shallow waters is as follows:

Within the NASA processing chain for SeaWiifs (i.e., SeaDAS), a routine can be activated to flag out waters shallower than 30 m (with reference to bathymetry database ETOPO 2). However, the standard level 3 chlorophyll products from NASA that we used to derive primary production maps do not include this flag because, in many cases, the first optical depth sensed by the satellite is still significantly shallower than the bottom depth (in other words, the bottom reflectance would have little effect on the surface chlorophyll). Exceptions occur in areas combining shallow and clear waters, e.g., around The Bahamas where the 'surface chlorophyll values' from NASA are indeed the reflection from the bottom. In that particular case, the chlorophyll data and, thus, the [primary production] data are likely to be not reliable.

In other cases, where chlorophyll can be assumed to be reasonable, the effect of shallow waters (seamounts or coastal waters) on the depth-integrated primary production should be studied on a case by case basis, because it depends on the biogeographical province that includes the seamount area and the dataset used for that province. Basically, the model estimates integrated primary production from surface down to the 0.1% light level. Let's now suppose that a seamount is included in a larger province where the representative chlorophyll profile has been established with a rather low chlorophyll values in the upper layer (indexed from satellite) and a deep chlorophyll maximum at 80 m. If the seamount is at 30 m and the satellite-derived surface chlorophyll signature over the seamount does not differ very much from that surrounding the seamount, the primary production estimate will use a similar chlorophyll profile but the integration will stop at 30 m. The resulting effect would be a tendency to obtain lower integrated production over the seamount when compared to primary production in the surrounding waters.

But again the magnitude of this artificial effect should really be studied case-by-case because, even with subsurface or deep chlorophyll maximum, the model is giving most of the primary production in the upper layer (e.g. 100% to 10% light level). This is confirmed by field measurements. Therefore, the bias on integrated primary production should not be too bad.