SECONDARY PRODUCTION ESTIMATES FROM BENTHIC BIOMASS: ASSESSING COASTAL EUTROPHICATION

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Abstract

As local, regional, and global concerns over coastal eutrophication increase, there is a greater urgency to obtain measures on this condition. Increased benthic biomass has been considered a symptom of eutrophication. While recognizing that cohort analyses provide the most rigorous measures of secondary production, biomass estimates with appropriate conversions and caveats can be used to generate informative first approximations. Regular sampling of biomass from a large scale, long-term, monitoring program of a major ocean outfall on the San Pedro Shelf, California has presented the opportunity to assess eutrophication through estimates of secondary benthic production.

This account focused on two stations representing an outfall (Station 0) and a reference site (Station C) 6 km west and upcoast of the outfall. Production estimates were based on 260 bottom samples per station, distributed over four seasons (winter, spring, summer, fall), and thirteen years (1985-1997). Macrobenthic production at Stations 0 and C over the thirteenyear period was estimated to be 35.3 g/M^2 /yr and 37.4 g/M^2 /yr, respectively. Different taxa dominated production at the two stations. Polychaete and molluscan production at Station 0 was 2 and 2.5 times higher, respectively, than that at Station C. In contrast, echinoderm and crustacean production at Station C was 2 and 2.5 times higher than that at Station 0. When San Pedro production figures were compared to elsewhere, they were well within the range of estimates from other shelf areas and estuaries. Local production figures did not support concerns about increased biomass associated with eutrophication and underlined the value of applying readily obtainable biomass data to compute production estimates in the absence of cohort analysis.

1. Introduction

Eutrophication in the coastal zone has been projected as a major problem for the millennium and beyond (Rosenberg 1985; Goldberg 1995). Eutrophication refers to a condition in freshwater, estuarine, and coastal habitats wherein microscopic and macroscopic plants grow rapidly due to an influx or surplus of nutrients. Rapid plant growth carries with it a whole host of symptoms that individually or collectively seriously alter water quality for indigent organisms and/or represent a risk to public health. While recognizing that eutrophication can be caused by natural processes (Valiela et al. 1997), Rosenberg (1985) clearly projected a major role for anthropogenic influences in the coastal scenario. Among several symptoms of eutrophication, increased biomass of infaunal and epifaunal macroi nverteb rates has been recognized. This condition has received great attention in the Baltic Sea and northern seas (Pearson and Rosenberg 1978; Arntz 1981; Cederwall and Elmgren 1980, 1990; Josefson 1990; Holte and Oug 1996; Oug 1998).

Assuming that increased benthic biomass is a definitive symptom of eutrophication how do local values reported herein support or refute this condition? To address this question we took advantage of regular sampling of benthic biomass from a large scale, long-term monitoring

program of a major ocean outfall on the San Pedro Shelf, California (Diener, et. al, 1995).
Emissions from ocean outfalls represent a source of particulate carbon and nitrogen to marine ecosystems and have been included as contributors to or causes of eutrophication. We assessed eutrophication by converting benthic biomass to estimates of secondary production. The latter is a more functional process than biomass or standing crop.

Secondary production is the generation of new biomass over time by non-photosynthetic organisms requiring organic substrate inputs.
Population dynamics studies require high frequency sampling, intensive laboratory treatment measuring ash-free dry weight (AFDW), and cohort analysis for production estimates. Since this process is laborious and costly, production studies are not as commonly pursued as their potential value would suggest for assessing community function. Production studies based on cohort analyses provide the most rigorous data (Nichols 1975; Price and Warwick 1980; Howe et al. 1988; Wilbur and Clarke 1998). Lappalainen and Kangas (1975) determined the relationship between wet weight biomass-dry weight and dry weight-AFDW for common littoral macrofauna in the northern Baltic Sea. When growth and mortality patterns or age composition (cohort analysis) are not determined, the empirically derived quotient of production rate (P) over annual population biomass ($\bar{B}$) has been used to estimate the production of animal populations from biomass data (Robertson 1979; Banse and Mosher 1980; Steimle 1985; Hood 1993; Wilber and Clarke 1998). In addition to focusing on secondary ›roduction as a measure of eutrophication, we also :howed how readily available biomass data can ›e used in such analyses. The hypothesis tested ere is that there is no significant relationship etween secondary production and an ocean utfall.

II. Materials and Methods

ıis account was based on benthic samples llected between 1985 and 1997 as a part of the Orange County Sanitation District's (District), permitted ocean monitoring program. Detailed field sampling materials and methods are provided in District (1995). From July 1985–April 1998, 53 benthic stations, located on the San Pedro Shelf, California, were sampled once a year during the summer (Fig. 1). These stations encompass about 65 km^2 and represent most of the habitat types found in the study area. Within these 53 stations, thirteen 60-m stations were also sampled quarterly (winter, spring, summer, fall). This sampling design reduces the effect of depth on biotic variables and provides seasonal data. Additionally, these stations are sited to test hypotheses related to outfall effects and reference stations at the nominal depth of discharge. Since the principal current direction at the discharge depth is towards the northwest (upcoast), Station 0 (~60 m from the outfall at Lat. 33° 34.67', Long. 118° 00.54') and Station C (~7 km from the outfall at Lat. 330 35.89, Long. 118° 03.80) were selected as the test and reference stations, respectively (Fig. 1).

Benthic samples were taken with a double yoked 0.1 M2 Van Veen grab and sieved on board through a 1.0 mm screen. The 1.0 mesh size is the conventional protocol used throughout the Southern California Bight (SCB) by regional, state and federal scientists (Word, et. al, 1980). After screening, samples were relaxed with 7% magnesium sulfate for 30 minutes samples, then initially preserved with 10% buffered formalin, and finally transferred to alcohol for permanent storage. Infaunal samples were sorted in the laboratory under dissection microscopes into five taxonomic groups: Echinodermata, Crustacea, Mollusca, Polychaeta, and Miscellaneous taxa (nemerteans, phoronids, platyhelminthes, etc.). Upon completion of the species identification and the enumeration of each sample the major taxonomic groups were blotted dry and weighed to the nearest 0.1 g wet weight. Measurements included molluscan shells, crab carapaces, ophiuroid discs and worm tubes.

Starting with mean wet weight biomass, data were corrected for reduction due to preservation, converted to dry weight, and then to AFDW, and

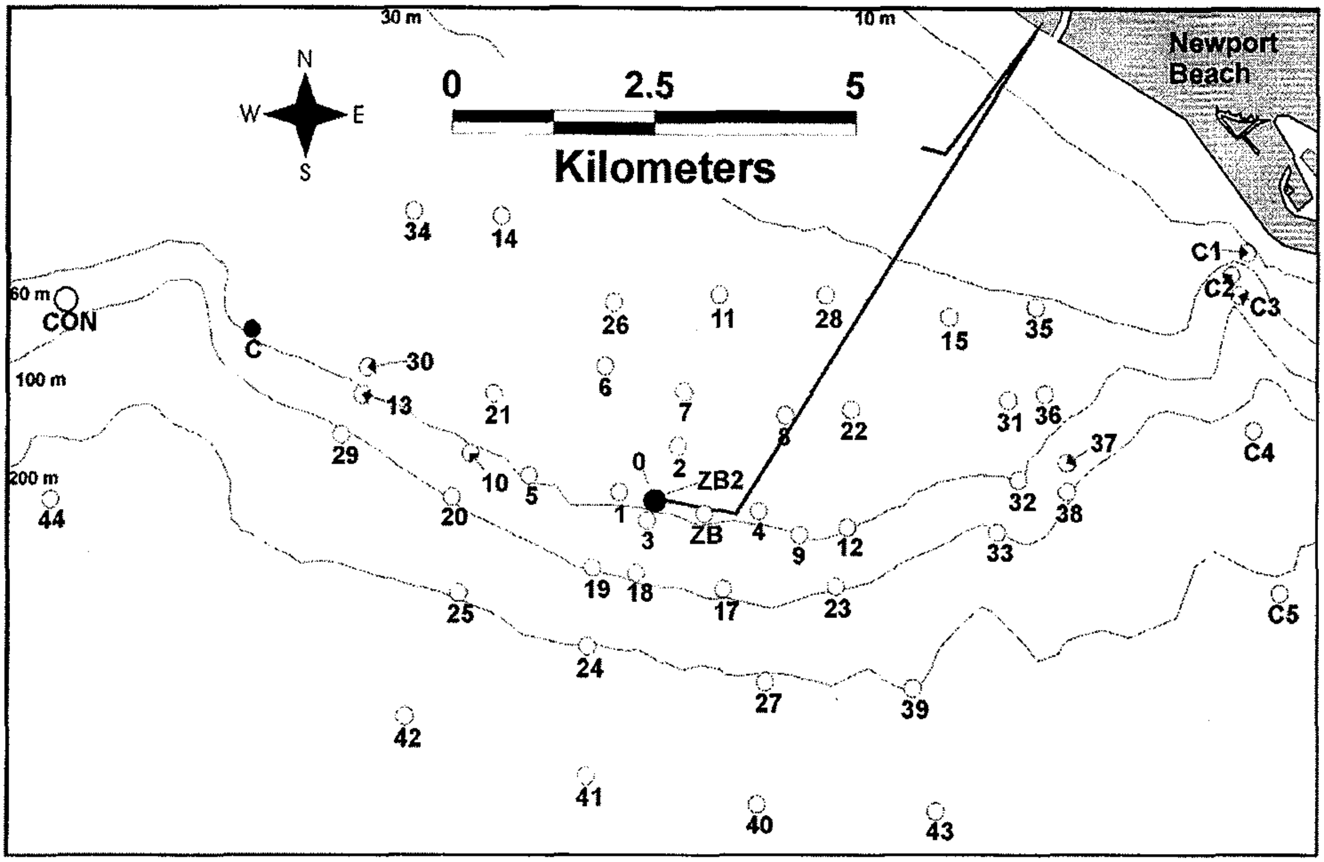

Fig. 1. District's benthic monitoring stations, San Pedro Shelf, California. Stations 0 and C in bold (•).

multiplied by $P:\overline{B}$ to yield estimates of secondary production (P). Corrections for preservation together with conversion rates were obtained from Lappalainen and Kangas (1975). From these authors we obtained conversion rates for species of bivalves, crustaceans, annelids and a few turbellarians, and applied them. Since there was no conversion data for echinoderms and AFDW for miscellaneous taxa, we applied values from molluscs and annelids, respectively, as the best approximations.

Application of $P:\overline{B}$ ratios follows the discussion and usage of Banse and Mosher (11980) and we used $P:\overline{B}$ ratios presented in Steimle (1985). Hood (1993) used similar assumptions and conversions for the SCB and Dauvin (1998) and Wilber and Clarke (1998) applied similar approaches to obtain estimates of secondary production in the Bay of Morlaix and in Galveston Bay, Texas, respectively.

III. Results

Mean biomass (g/0. 1 m^2) of major taxa at Station 0 and C is presented in Table 1. Different taxa dominated biomass at each station. Mean values for molluscs and polychaetes were 3 and 2 times higher, respectively, at, Station 0 compared to Station C (Table 1). In contrast mean values for crustaceans and echinoderms were 2 and 2.5 times higher, respectively, at Station C compared to Station 0. Echinoderms and molluscs had the highest standard deviations at both stations (Table 1).

Biomass was converted to estimates of secondary production for the entire period 19851997 (Table 2). Because similar correction and conversion factors were applied estimates of secondary production essentially reflected biomass patterns (Table 1). That is, production estimates for crustaceans and echinoderms

Table 1. Mean biomass (g/0.1 M^2) of major taxa on the San Pedro Shelf, California 1985-1997.

	Taxon									
	Crustacea		Echinodermata		Miscellaneous taxa		Mollusca		Polychaeta	
Year	C	0	C	0	C	0	C	0	C	0
1985	0.2	1.1	6.5	0.1	0.3	1.0	0.3	11.1	0.3	7.9
1986	0.3	0.7	5.8	3.7	0.3	0.4	6.6	5.7	6.6	5.6
1987	1.2	0.8	4.9	2.8	0.6	0.3	0.9	3.6	0.9	2.7
1988	15.1	2.0	20.8	6.4	3.1	0.2	1.5	2.9	1.5	5.5
1989	0.4	0.6	5.3	2.2	0.4	0.4	0.5	2.3	0.5	3.6
1990	0.4	0.7	8.4	1.2	0.5	1.2	0.2	1.5	0.2	2.8
1991	0.3	0.4	8.0	2.0	0.5	0.1	0.8	1.5	0.8	2.6
1992	0.5	0.5	5.8	5.7	0.2	0.8	0.5	1.9	0.5	2.1
1993	0.2	0.3	4.5	7.4	0.1	0.2	0.6	2.0	0.6	2.3
1994	0.2	0.7	6.5	5.3	0.2	1.0	0.6	2.1	0.6	3.4
1995	0.4	1.4	4.8	2.4	0.5	0.4	0.2	3.4	0.2	5.2
1996	0.5	1.1	5.7	0.6	0.2	0.6	0.7	3.2	0.7	5.7
1997	1.2	1.1	4.1	0.3	0.1	0.4	0.7	4.5	0.7	2.5
Mean	1.6	0.9	7.0	3.1	0.5	0.5	1.1	3.5	2.0	4.0
SD	4.1	0.5	4.1	2.4	0.8	0.4	1.7	2.6	1.5	1.8

Table 2. Estimates of secondary production (g/M^2 /yr) of major taxa on the San Pedro Shelf, California 1985-1997.

	Biomass WW (g/m^2)		Biomass Corr. Pres.		DW		AFDW		$P:\bar{B}$		P (g/m^2/yr)	
Taxon	C	0	C	0	C	0	C	0	C	0	C	0
Crustacea	16.1	8.7	15.3	8.3	10.1	5.3	2.6	1.4	3.9	3.9	10.3	5.5
Echinodermata	70.1	31	66.6	29.5	33.3	14.8	21.6	9.6	0.8	0.8	17.3	7.6
Miscellaneous taxa	5.4	5.3	5.1	5.0	4.1	4.0	0.7	0.7	0.9	0.9	0.6	0.6
Mollusca	10.9	35.4	10.4	33.6	5.2	16.8	3.4	10.9	0.6	0.6	2.0	5.5
Polychaeta	19.9	39.9	18.9	37.9	14.4	29.2	2.4	5.0	3.0	3.0	7.2	14.9
									Total:		37.4	35.3

Preserved material correction = 5% reduction; conversion from wet weight (WW) biomass to dry weight (DW) biomass - Crustacea = 34% reduction; *Echinodermata = 50% reduction, Miscellaneous taxa = 20% reduction, Mollusca = 50% reduction, Polychaeta = 23% reduction (Lappalainen and Kangas 1975).

Conversion from DW to Ash Free Dry Weight (AFDW) – Crustacea = 34% reduction, *Echinodermata = 35% reduction, *Miscellaneous taxa = 17% reduction, Mollusca = 35% reduction, Polychaeta = 17% reduction. *Not cited in Lappalainen and Kangas (1975) assume Echinodermata and Miscellaneous taxa similar to Mollusca and Polychaeta. $P:\bar{B}$. Production mean biomass ratio modified from Steimle (1985).

were higher at Station C than Station 0, and production for molluscs and polychaetes was higher at Station 0 (Table 2). Estimated total secondary production for the period 1985 through 1997 was 35.3 g/m^2 /yr at Station 0 and 37.4 g/m^2 /yr at Station C (Table 2). These data support the hypothesis that there was no significant relationship between secondary production and an ocean outfall.

IV. Discussion

A. Secondary Production

Since estimates of secondary production of macrobenthos are most rigorously pursued through cohort analysis (Nichols 1975; Price and Warwick 1980; Howe et al. 1988; Wilber and Clarke 1988), one of the more surprising results of this analysis using wet weight biomass was a plausible estimate of secondary production at both stations (Station 0 =35.3 g/m^2 /yr; Station C 37.4 g/m^2/yr) (Table 2). Because cohort analyses of AFDW are so laborious and time consuming indirect and approximate methods with wet weight biomass have been used in large scale, macrobenthic surveys (Steimle 1985; Hood 1993; Dauvin 1998; Wilber and Clarke 1998).

Production estimates from other studies are presented in Table 3. Based on wet weight biomass data from the SCB Hood (1993) estimated that benthic productivity was 62.5 kcal/ m^2/yr^{-1}. Using Hood's (1993) assumptions and conversion rates we estimated energy values of 90.2 kcal/m^2/yr for Station 0 and 91.8 kcal/m^2/yr for Station C (Table 3).

Production from Stations 0 and C were very similar to those reported from the Bristol Channel, England, off the coast of Delaware, and in several estuaries. Even with reservations about using wet weight biomass in monitoring protocols (Tetra Tech 1985; Bergen et al. 1998); problems with preservation fixatives, blotting procedures, conversion factors (Lappalainen and Kangas 1975); assumptions using $P:\overline{B}$ ratios (Banse and Mosher 1980); and $P:\overline{B}$ ratios from other geographic areas (Steimle 1985), the production estimatesprovided by cohort analysis.

Table 3. Representative production estimates from continental shelf and estuarine areas.

Continental Shelf	Kcal/m^2/yr	g/m^2/yr
Northumberland, England		1.7
Bristol Channel, England	103	34.1
Delaware, USA		30
Station 0 (this study)	90.2	35.3
Station C (this study)	91.8	37.4
SCB*	62.5	
Estuaries		
Asko-Landsort, Sweden		7.6
Gullmar Fjord, Sweden		26.5
Carmathen Bay, England		25.8
Swansea, England		14.2
Ythan Estuary, Scotland		108
Grvelingen Estuary, Scotland		57.4
Eastern Canada		6.5-21.2
Long Island Sound		21.25
Delaware Bay		46.5
Sources: Steimle (1985), Maurer, et al. (1992), *Hood (1993)		

However, these estimates should be tested through cohort analyses. We do not argue for replacing secondary production estimates based on cohort analyses with indirect less accurate and indiscriminate application of $P : \overline{B}$ ratios (Chesney 1985). We do encourage using data (wet weight biomass) from existing protocols to maximum advantage (Wilber and Clarke 1998).

B. Eutrophication

Cederwall and Elmgren (1980, 1990) asserted that eutrophication with associated increased biomass is a major process affecting the entire Baltic Sea and is not restricted to coastal areas. Arntz (1981) focused on the relationship between biomass and the pycnocline in Kiel Bay (western Baltic). He concluded that future eutrophication might have increasing destructive effects. Josefson (1990) stated that the correlation between benthic biomass and land runoff from western Sweden was in accordance with an eutrophication hypothesis. Holte and Oug (1996) studied softbottom macrofauna to assess enrichment effects from discharges of municipal sewage and fish factory effluents in the Norwegian Sea. Even though effluent discharges increased from 1983 to 1992, faunal changes did not provide evidence of an increased bioenhancement of the area during the period.

Assuming that increased biomass is an accurate symptom of eutrophication how do the values reported herein support or reject this condition? The only biomass values in the SCB that may have been symptomatic of eutrophication occurred off the Palos Verdes Peninsula (Stull 1995). Biomass exceeded 2000 g/m^2 at some Palos Verdes stations during 1972 and 1977. However, these high values were due to unusually large populations of the echiuran *L. pelodes* (Stull et al. 1986; Stull 1995). An irony of this situation was that although the echiuran provided biomass measurements presumably characteristic of eutrophication, its burrowing behavior and associated irrigation of burrows coincidentally reduced sediment contaminant concentrations for the same area (Stull 1995). As the echiuran year class phenomenon receded, sediment contaminant concentrations regained their former stature prior to the *L. pelodes* explosion. Moreover, when biomass from Palos Verdes was plotted latitudinally compared to other national and global measurements, mean Palos Verdes biomass fell within latitudinal ranges (Maurer and Haydock 1990). For the San Pedro Shelf biomass values and estimates of secondary production are not symptomatic of eutrophication, any increases in biomass probably represent bioenhancement of selected species from organic enrichment (Maurer et al. 1993 a, b).

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VI. References

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