Benthic macrofauna productivity enhancement by an artificial reef in Delaware Bay, USA

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To understand the potential enhancement value of a habitat-loss mitigation reef in Delaware Bay, especially as a source of food for fishery resources, the secondary productivity of the reef epifauna and nearby sand infauna was estimated and compared. The mean production of natural sand infauna was estimated at between 215 and 249 kcal m⁻² yr⁻¹, while that of the epifauna on the reef surfaces was between 3990 and 9555 kcal m⁻² yr⁻¹. With the 36 m² footprint of a reef unit as a basis for comparison, the 407 m² of reef unit surface covering that footprint produced 1.62–3.89 x 10⁶ kcal yr⁻¹ of epifauna compared with 7.74–8.96 x 10³ kcal yr⁻¹ per footprint area for the adjacent sand infauna. There was, however, substantial annual variability in the productivity of the epifauna, based on the recruitment success of Mytilus edulis.

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Introduction

Artificial reefs are used to enhance or restore habitats or biological resources (Stone et al., 1991; Jensen, 1997). Questions persist, however, about the ecological function of these habitats (Bohnsack and Sutherland, 1985; Polovina, 1991; Steimle and Meier, 1997). One especially vexing question is whether these habitats enhance biological productivity and, if so, to what degree (Polovina, 1991; Leevis et al., 1997). Recent considerations of the use of artificial habitats to mitigate habitat losses or to restore habitats and fisheries emphasize the need for estimates of productivity as a key habitat enhancement, replacement, or restoration parameter (Bohnsack and Sutherland, 1985). One approach to addressing the productivity issue is by examining how epifauna (epibenthic and epibiotic organisms) colonizing reef habitats enhance the availability of benthic invertebrate prey to fishery resources compared to typical infauna (endo-benthic organisms) of the soft sediments in an area (Steimle and Ogren, 1982; Bohnsack et al., 1991; Leevis et al., 1997). Biomass and productivity estimates for reef epifauna integrate a number of ecological alterations created by this type of habitat on a relatively flat estuarine bottom. These include changes in water flow and turbulence patterns that can bring more plankton to the bottom waters and promote recycling of benthic nutrients, which are local productivity factors (Marshall, 1967). Despite their importance, few productivity studies have been undertaken and these have considered mostly fish or harvestable shellfish populations, or were preliminary in nature (McDonald, 1978). Some studies of natural reefs suggest that reef habitats are more productive than sandy bottoms, but these studies are mostly for warm-temperate or tropical waters (Hopkinson et al., 1991), although there are some studies in temperate waters (Leevis et al., 1997).

Concrete reef units were deployed in lower Delaware Bay to mitigate subtidal habitat loss in the upper estuary. The development of the reef’s epibenthic community, and its use as prey, has been reported (Foster et al., 1995; Steimle et al., 1995). Here, biomass data are used to estimate secondary productivity of epifauna that colonized these reef units. This estimate of productivity
is compared with production estimates of the natural, off-reef infauna that is typical of the area to estimate degree of enhancement.

Materials and methods

The reef units, site, and benthic collection methods were described in Foster et al. (1994). Briefly, 16 concrete units were deployed in lower Delaware Bay in the summer of 1989. The fine-sand reef site is 11–15 m deep and in well-mixed, polyhaline waters, with a temperature range of 1–26°C. Each unit was composed of tiered, concrete panels forming a complex, open structure covering a 36 m² footprint of seabed to a height of about 2.7 m. Each unit had ~407 m² of surface area available for epibenthic colonization.

A specially designed, diver-held, stainless-steel sampler was used to collect 0.05 m² reef-surface samples for epibenthic colonization. The fine-sand reef site is 11–15 m deep and consideration taken to diver safety in a turbid estuary.

Some epifaunal species, such as red beard sponge, stone coral, barnacles, and various bryozoans and hydroids, were strongly bonded to the concrete surface or epibiotically to living mussel shells. This created a problem in obtaining a sample without including some concrete substratum or missing basal parts of organisms, such as barnacles, that remained on the surfaces (Gili and Hughes, 1995). Because of this difficulty, only the presence or absence of these taxa was noted. Although total biomass could obviously be underestimated, this was assumed to have little effect on forage value estimates, as few fish were found to feed on these taxa, and then perhaps only incidentally with other prey. In processing the near-reef infaunal and reef epifaunal samples, the specific blot-dried biomass of only the most visually dominant or fish-forage important species was individually determined because of logistic limitations. Total biomass of all other taxa was determined only for larger groups (e.g. miscellaneous, other molluscs, decapod crustaceans).

From 1990 to 1992, infauna samples were randomly collected by grab sampler from the reef site area and sieved through 0.5 mm mesh to characterize the benthic community (Steimle et al., 1995). These collections ended when the results were relatively consistent inter-annually and with infaunal data from previous studies in the area (Maurer et al., 1978). For the years 1993 and 1994, the mean of the available 1990–1992 infaunal survey data was used for estimating enhancement, as there is no reason to suspect that the infauna would have changed drastically during the unsurveyed years.

To determine which benthic taxa were important as forage for the local fishery resources and should be our specific focus, the stomach contents of 1229 fish collected on or near the reefs were examined (Foster et al., 1995). The most common reef fish examined were tautog (Tautoga onitis), toadfish (Opsanus tau), black sea bass (Centropristis striata), and scup (Stenotomus chrysops).

Secondary production was estimated by a two-step process. First, the preserved, wet-weight biomass of each prey species or major group of epifauna and infauna for each collection period was converted to its approximate energy (E; kcal g⁻¹) equivalence, based primarily on values for these or similar taxa available in Thayer et al. (1973) and Steimle and Terranova (1985). Secondly, appropriate, taxon-specific production to biomass ratios (P:B) from the literature were applied (Richards and Riley, 1967; Dame and Verbrugge, 1982; Steimle et al., 1990). Other P:B ratios, including blue mussel (M. edulis), were from a previous study in lower Delaware Bay (Howe and Leathem, 1984). To simplify calculations, E-values were multiplied by appropriate P:B ratios to create a factor (C) for converting wet weight biomass data (B, g m⁻²) to produce annual production estimates (kcal m⁻²; Tables 1 and 2). Based on Howe and Leathem (1984), two values were used for blue mussel P:B ratio because of its overwhelming dominance in most samples, with two cohorts usually evident: 2.2 representing a slower growing cohort of 1–2-year-olds; 6.2 representing a faster growing cohort of recruits. This resulted in a range of community production estimates to acknowledge the variable and dynamic nature of productivity for a community dominated by one or a few relatively short-lived species.

The production estimates are presented as means of two surveys within a year for both infauna and epifauna.

Results

Reef epifauna

The mean biomass of reef epifauna varied by several orders of magnitude, from about 10 to 25 000 g m⁻², with an overall mean over the 5-year period of approximately 8000 g m⁻² (Table 1). On average, 90% of the overall mean biomass was blue mussels and the high variability among years was the result of two “boom and bust” biomass cycles of the blue mussel population. A substantial recruitment boom occurred between August 1990 and June 1991, followed quickly by a bust, or
population depletion, a few months later (August 1991). This was followed in 1992 by another boom that was sustained until August 1993, and the population had another bust in 1994, when monitoring ended. Preliminary analysis of the apparent size structure of the mussel population in 1993 and 1994 indicated that only two length modes were present: a strong
\[ p_1 \]
10 mm mode in June representing new recruitment, which grew to
\[ p_1 \]
15 mm by August, and a weak second mode at
\[ p_1 \]
50 mm in both months.

The estimated mean annual production ranged from 3990 to 9555 kcal m\(^{-2}\) for the low and high mussel P:B ratio, respectively (Table 1). Again, 77–90% of the estimated production was blue mussels. The only other species contributing notably to the mean biomass (45 g m\(^{-2}\)) or production (242 kcal m\(^{-2}\) yr\(^{-1}\)) was the anemone (\textit{Metridium senile}) (Table 1), but in both cases this was less than 1% of the total.

### Infauna

The total infaunal biomass around the reef site ranged between about 40 and 400 g m\(^{-2}\) wet weight with a mean of 180 g m\(^{-2}\) (Table 2). Bivalve molluscs dominated the biomass of this community, including small clusters of mussels collected on the sand. The total sand community production estimates ranged between 120 and 260 kcal m\(^{-2}\) yr\(^{-1}\). The mean estimated infaunal production over all surveys was 215 and 249 kcal m\(^{-2}\) yr\(^{-1}\), for the low and high blue mussel P:B ratio, respectively.

### Discussion

Although epifaunal studies have been reported for the region (Cory, 1967; Dean, 1977; Smedes, 1979), biomass estimates for mussel beds or hard-surface epifauna are generally not available for the western Atlantic. The range of values found on the reef units (0.01–24.9 kg m\(^{-2}\)) is similar to that found for European intertidal and subtidal mussel beds (0.22–19.34 kg m\(^{-2}\); Asmus, 1987), and mostly higher than for a deep rocky bottom, \textit{Sabellaria–Ophiothrix} dominated community (0.12 kg m\(^{-2}\), using a 5 × dry to
wet weight conversion; George and Warwick, 1985). Leewis and Waardenburg (1991) report that shipwrecks supported epifaunal AFDW biomasses between 40 g m$^{-2}$ (inshore pioneer hydroids) and 4100 g m$^{-2}$ (blue mussel community). Between 6.1 and 22.5 kg m$^{-2}$ wet weight of fouling community was also reported for ship hulls and on shallow surfaces of navigational aids near the mouths of various eastern North American harbours (Ayers, 1951; Maloney, 1958). Nixon et al. (1971), however, report a total biomass of 14.2 kg m$^{-2}$ dry weight (~75 kg wet weight) for a mussel bed in Narragansett Bay, Rhode Island.

Production estimates for reef or hard-surface epifauna are even scarcer than for biomass. The mean estimates for Delaware reef units, 3990 and 9555 kcal m$^{-2}$ yr$^{-1}$ (for low and high mussel P:B, respectively), are higher than the production estimates for some harvestable European mussel beds (2340 kcal m$^{-2}$ yr$^{-1}$; Asmus, 1987), and for an eastern Atlantic, deep rocky-bottom community (~106 kcal m$^{-2}$ yr$^{-1}$; George and Warwick, 1985). These estimates are similar to the fouling rates along the Western Atlantic (involving mostly mussels) of about 10–30 kg m$^{-2}$ yr$^{-1}$ (2000–6000 kcal m$^{-2}$ yr$^{-1}$ based on an energy equivalence of

### Table 2. Summary of sand-infauna biomass data (B, g m$^{-2}$ wet weight) for dominant taxa and estimated average production (kcal m$^{-2}$ yr$^{-1}$) by taxon based on taxon-specific conversion factors (cf. Table 1).

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</thead>
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<td></td>
<td>E P:B C</td>
<td>E P:B C</td>
<td>E P:B C</td>
<td>E P:B C</td>
<td>E P:B C</td>
<td></td>
</tr>
<tr>
<td>Mytilus edulis</td>
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<td>2.2</td>
<td>0.44</td>
<td>0.01</td>
<td>5.79</td>
<td>26.9</td>
</tr>
<tr>
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<td>6.2</td>
<td>1.20</td>
<td>0.01</td>
<td>5.79</td>
<td>26.9</td>
</tr>
<tr>
<td>Spisula solidissima</td>
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<td>0.2</td>
<td>1.6</td>
<td>0.32</td>
<td>0.30</td>
<td>0.57</td>
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<td>1.5</td>
<td>1.50</td>
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<td>0.35</td>
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<td>Nemertea</td>
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<td>1.0</td>
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<td></td>
<td></td>
<td>37.2</td>
<td>316</td>
<td>45.9</td>
<td>120</td>
<td>388</td>
<td>181</td>
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</table>

### Table 3. Comparison of the productivity of the footprint of the artificial reef (infauna; 36 m$^2$) in lower Delaware Bay and the reef itself (epifauna; 407 m$^2$) by year (P, kcal/footprint) for low (a) and high (b) blue mussel P:B, and the enhancement ratios calculated from these (R). The infaunal values for 1993 and 1994 use the mean from the previous surveys, and enhancement in parentheses is based on use of these mean values.

<table>
<thead>
<tr>
<th>Period</th>
<th>Infauna P$_a$ × 10$^3$</th>
<th>Infauna P$_b$ × 10$^3$</th>
<th>Epifauna P$_a$ × 10$^3$</th>
<th>Epifauna P$_b$ × 10$^3$</th>
<th>Enhancement R$_a$</th>
<th>Enhancement R$_b$</th>
</tr>
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<tbody>
<tr>
<td>1993</td>
<td>(215)</td>
<td>(249)</td>
<td>4922</td>
<td>11 886</td>
<td>(23)</td>
<td>(48)</td>
</tr>
<tr>
<td>1994</td>
<td>(215)</td>
<td>(249)</td>
<td>258</td>
<td>273</td>
<td>(1.2)</td>
<td>(1.1)</td>
</tr>
<tr>
<td>Mean</td>
<td>215</td>
<td>249</td>
<td>3990</td>
<td>9 555</td>
<td>19</td>
<td>38</td>
</tr>
</tbody>
</table>
0.2 kcal g⁻¹ for mussels; Table 1) reported by Redfield and Deevey (1952).

Our results indicate there was a 1–2 orders of magnitude difference between productivity of reef epifauna and that of local infauna. The values for infaunal biomass (37–385 g m⁻² wet weight) are not exceptional, but similar to those reported in other estuaries of the Middle Atlantic Bight (Steimle and Caracciolo-Ward, 1989). The mean (182 g m⁻²) for all five surveys is more than double the mean for a March to September study of a nearby, but deeper and siltier site (75 g m⁻²; Howe and Leathem, 1984). No other biomass data are available for Delaware Bay, but the reef-site infaunal community seems to be typical of a large part of the lower Bay (Maurer et al., 1978). The estimated production (215 and 249 kcal m⁻² yr⁻¹ for low and high mussel P:B) is also similar to estimates of community production reported for other temperate, estuarine, or coastal, benthic infaunal communities (see Steimle, 1985).

The high profile, structurally complex artificial reef habitat usually supported up to 2 orders of magnitude (~20–100 fold) more secondary production per unit area than the natural seabed in the area (Table 3). However, enhancement was variable. Epifaunal data collected during the last sampling period, August 1994, compared with the mean infaunal data from previous years suggest that no net increase in community productivity might have occurred within the unit footprint because the enhancement factor has to be greater than 1.0 to compensate for the benthic infauna covered by the reef unit. When the production enhancement ratio falls below 11.3 (being the ratio of total reef surface area and reef footprint; 407 m²/36 m²), the reef community was likely not performing ecologically (in terms of providing potential food to higher trophic levels) as well as sand infauna community. This only occurred in 1994. This variability in enhancement also suggests how sensitive this reef epibenthic community may be to annual mussel recruitment variability (Smedes, 1979), and undoubtedly to unknown rates of predation. The blue mussel in Delaware Bay does not appear to survive much more than 2 years or is sloughed off by strong currents at larger sizes (Smedes, 1979; Seed and Suchanek, 1992), and thus there is no reservoir of older individuals to sustain high community biomass production levels over several years. Limitations on blue mussel persistence may be imposed by summer water temperatures >25°C, inadequate summer phytoplankton concentrations, genetics (Ince et al., 1980; Seed and Suchanek, 1992; Myrand and Gaudreault, 1995), or availability of suitable surface areas for larval settlement (Smedes, 1979).

Although variability in the productivity of different taxa associated with age structure and environmental factors may be large, artificial reefs apparently may enhance benthic secondary production per unit area in estuarine areas, such as lower Delaware Bay, by up to 2 or more orders of magnitude. This suggests that artificial reefs could have a role in habitat-loss mitigation efforts, when considered on a broader estuary ecosystem context, even though providing a clearly different habitat from what was available before. However, the question remains whether other estuarine communities have lost access to organic matter that is now being fixed by the reef epifauna or if energy that would have flushed out of the estuary to support coastal ecosystems is now being trapped. Also, as yet, insufficient data are available to adequately discuss and compare the trophodynamic importance of each habitat type relative to supporting fishery resources, or on the effects of predation on reef epifaunal abundance, community structure, and dynamics.

This study provides evidence of the habitat value of artificial reefs to enhance benthic productivity. This enhancement might be transferred to fish production, as reported by Bond et al. (1999). The variability in our biomass/production estimates supports the conclusion that long-term monitoring of artificial-reef communities are required until well after the initial, ephemeral colonization phase, when the community has reached some equilibrium with the environment in which it was deployed.

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References


