Majalah Ilmu Kelautan, (2002), 25 (VII) : 23 - 26 *ISSN 0853 - 7291*

Bioturbation and Its Impact on the Sediments

Agus Indarjo*

Marine Sciences Department, Diponegoro University, Semarang, Indonesia

Abstrak

Aktifitas membuat lubang dari macrofauna dasar dipengaruhi oleh kondisi fisik dan komposisi kimia sediment, hal ini akan sangat penting untuk pertumbuhan mikroorganisme dan meioorganisme dan juga untuk mengaduk keseluruhan bahan organik. Di dalam sedimen bioturbasi akan dipengaruhi oleh kekuatan mengaduk, air dalam sedimen, kekasaran dasar. erosi velositas dan organisme lainnya

***Kata kunci :** Bioturbasi, makrofauna, meiofauna, mikrofauna dan bahan organik*

Abstract

Activities of burrowing benthic macrofauna are influenced by both the physical structure and the chemical composition of sediment. These factor, are very important for the growth of microorganisms and meioorganisms as well as the overall turnover of organic matter. Bioturbation within the sediment will influence the shear strength, water content, bed roughness, erosion velocity and other organisms

***Key word :** Bioturbation, macrofauna, meiofauna, mikrofauna dan organic matter*

Introduction

Benthic organisms, by their often remarkable behavior, are able to exert a profound impact on their environment. Manipulation of the sediment and bioirrigation by living organisms, together denominated bioturbation, may significantly affect the structure and properties of the sea bed and sometimes also the bottom water. Larger infauna species, ploughing through the sediment or living in (semi) permanent tubes and burrows are powerful bioturbators. Additionally, macrofouna and meiofauna organisms are known to modify the physical and chemical properties of sediment (Meadows and Tufail, 1986)

Bioturbation may affect the availability of organic matter for benthic community. The activities of burrowing benthic macrofouna are influenced by the physical structure and the chemical composition of sediment, which are very important for the growth of microorganisms and meioorganisms as well as the overall turnover of organic matter.. According to Jorgensen (1983) a substantial part of the organic matter produced in estuaries and coastal marine areas is decomposed in the sediment. Organic biopolymers will usually be mineralized by aerobic and anaerobic microbial sediment processes, the inorganic constituent are then released to the water column. This benthic recycling process is very important as a nutrient source for the benthic and the pelagic primary producers.

Impact of Bioturbation

Shear Strength

There are various field and laboratory methods for measuring shear strength, including the use of penetrating cones, vanes and shear boxes. In the shear box, shear strength is measured as the literal force needed to break a block of sediment into the parts under the vertically applied compressive load (Meadows and Meadows, 1991). When this is done at different vertical compressive loads, a positive linear relationship is obtained between compressive load (compressive stress). and shear strength (shear stress). This is termed as Coulomb's law. However, the shear box is not often used as a practical test of shear strength in the laboratory. The most common laboratory test to estimate shear strength is falling cone, which is the easiest test to use in a biological context (Meadows and Meadows, 1991). It is clear from Coulomb's law that shear strength will increase with the depth into the sediment, a fact which is well known in the engineering literature (Lambe and Whitman, 1979). This is due to the increasing overburden pressure of depth into the sediment which consolidates the sedimentary structure.

The mucopolysaccharide binding material used by many infanual invertebrate to construct the walls of their tubes (Meadows *et al.*, 1990) will introduce marked heterogenity into the sediment by locally increasing shear strength. Meadows and Tait (1985) recorded dramatic increases in shear strength caused

---

* Corresponding Author

Diterima / Received : 07-12-2001
Disetujui / Accepted : 21-01-2002

by burrow linings. In a sediment taken from depth of 20 cm it was measured 2.16 kNm^{-2}. In the same depth but in which there were many burrow linings, it haol different shear strength compared to single burrow lining (4,85 kNm^{-2}).

Small scale heterogeneity in shear strength also occurs in the intertidal zone, often caused by biological activity. For example algal mats considerably increase the shear strength of intertidal sediment (Tufail *et al.*, 1989) and this has been demonstrated in controlled laboratory experiments by Wood *et al.* (1990). Some of these ecological effect are, however, difficult to interpret. For example, Tufail *et al.* (1989) recorded a significant positive correlation between surface sediment shear strength and the abundance of Nereis diversicolor towards high tide which was to be expected if the burrow walls strengthened the sediment. However, they recorded an inverse correlation between the same two variables on the same beach towards low tide.

Meadows and Tait (1989) measured the surface shear strength of cores seeded with low, medium and high densities of the mud burrowing amphipod *Corophium volutator* and the polychaetae *N. diversicolor.* The burrows of both species significantly increased the shear strength of surface sedimemt, although this effect was more marked with *C. volutator. C. volutator* increased shear strength by 50% at medium density and 180% at high density. The figures for N. diversicolor were 39 % and 80 % respectively. Both species also decreased the water content at the surface of the sediment significantly, so the increase is shear strength was probably due to particle binding secretions on the burrow wall and by the reduction in water content and hence compaction of the sediment. If these result can be extrapolated to the field and if field seeding is a realistic possibility, there is potential for the stabilization of sediments by these and other species. It is very probable, for example, the byssus complexes of mytilid bivalves such as *Modiolus modiolus* and *Mytilus edulis* will be highly efficient in stabilizing muddy inshore sediments (Meadowsand Shand, 1989).

Water Content

The water content (W) of a sediment is the ratio of the weight of water (Ww) to the dry weight of the sediment (Ws)

$$W = \frac{Ww}{Ws} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Water content is also called moisture content (Smith, 1981). In an intertidal sand only a small proportion of the interstitial spaces will contain water and hence water content in the sediment will decrease as the ebb tide. Meadows and Meadows (1991) showed that the bivalve *Macoma balthica* will increase porosity of surficial sediments as it moves horizontally just below the sediment surface.

When water flows through a sediment, the sediment sometimes becomes unstable and unable to support any weight. This condition is called quicksand and can be extremely dangerous in the intertidal zone because large animals can sink into the sediment . The flow condition inducing quicksand are as follows. Water flows up through a sediment column of height (L) under a head of water (H) hence the hydraulic gradient is H/L. The sediment is stable when the intergranular pressure between the particles is greater than the pressure acting upwards through the sediment of the water flow induced by the head of water. When the intergranular pressure equals the upward pressure produced by the water flow the sediment becomes unstable and is then unable to bear any weight (Meadows and Meadows, 1991).

According to Hall (1994) the combined effects of burrowing and pellet production (with the consequent production of void space between pellets) would increase the bulk density and water content in the sediment . These impacts are much less obvious, or absent, in sand where a lack of sediment cohesion usually results in the collapse of feeding voids or other sediment structures. Intensely worked communities in fine muds typically contain > 60 % water and often over 70 %, whereas pioneer communities which tend to contain less efficient bioturbators typically have less than 60 % water (Rhoads and Boyer, 1984).

Bed Roughness

Bed roughness has an important influence on the erodibility of sediments because it offers a focus for the development of turbulence. Pits and depressions related to foraging activity, elevated structures from burrowing, animals tracking through the sediment and feeding activity are all likely to be important in this respect (Hall, 1994). Direct observation using the in situ flume show that biogenic features such as pits and mounds are indeed sites of initial erosion because they are the locations at which turbulence is first generated. Length scale of biogenic features range from metres to less than millimetres for the surface deposition of faecal pellets and, depending on the length scale, bed roughness can either increase or decrease as a consequence of bioturbation. Differences in roughness correlated to a large degree with animal size since very small individuals which rework the sediment surface are likely to smooth it out (Cullen, 1973) while larger epifaunal and infaunal taxa can generate marked topographic features by virtue of their burrowing and feeding activities. Dense polychaete or amphipod crustacean tube mats can often be found in disturbed habitats and such mats have been recorded to occupy several thousand square meters (Fager, 1964). Rhoads *et al.* (1978) give a field example of an apparent decrease in critical erosion velocity for muds in Central Long Inland Sound associated with the appearance of dense beds of the tube building polychaete *Owenia fusiformis*.

The effects of tube mats was considered in a study by Hall (1994) who examined the effects of changing the density of roughness elements on the velocity profile of the bed. At low densities, blocks acted as isolated roughness elements shedding turbulent vortices which dissipated much of their energy at the bed. In contrast at high densities, a skimming flow developed where maximum turbulent intensity occurred at the top of the roughness elements which protected the tube field within the bed from higher energy turbulence. Hall, (1994) showed that natural densities of tubes spanned the range from stabilization to destabilization. However, they suggested that prediction that a bed will be unstable on the basis of tube density criteria is compromised by the possible effects of mocrophytobenthos (diatoms) on sediment stability by binding them.

Erosion Velocity

The surface stability and erodibility of sediments can be assessed by their critical erosion velocity, which is the water velocity at which the sediment surface first begins to erode (Meadows and Tufail, 1986). It has curvilinear relation to particle size, and is higher for consolidated than unconsolidated sediments, especially at small particle sizes. For instance, a consolidated (cohesive) sediment of mean particle diameter 1 to 5 (m has a critical erosion velocity of about 250 to 500 cm/s^{-1} while the velocity for unconsolidated (non cohesive) sediment of the same particle size about 10 to 25 cm/s^{-1} (Meadows and Meadows, 1991).

Rhoads *et al.* (1978) collected sediment with a box cores at about 14 m depth in Central Long Island Sound USA, and then seeded it with the capitellid *Heteromastus filiformis*. Critical erosion velocity increased by about 80 % become stable within seven days. Rhoads and Young (1971) considered the holothurian *Molpodia oolitica*, which lives insubtidal muds of Cape Cod Bay USA, with its anterior end approximately 20 cm below the sediment surface. It produce a faecal mound of ingested particles at the sediment surface which in turn provide a relatively stable sediment for the settlement and subsequent growth of the polychaete Euchone incolor, the amphipod *Aegmina longicornis* and the bivalve *Thyasira gouldi*, all of which are suspension feeders. Rhoads and Young (1971) believe that the *Molpodia* mounds increase turbulence near the sea bed and this may account for the high level of turbidity presumably caused by erosion in areas where the species is abundant.

Meadows and Tufail (1986) designed a flume to test the critical erosion velocity of blocks of sediment containing *A. marina*. Like *Molpodia*, *A. marina* produces faecal mounds on the sediment surface. Critical erosion velocities for loose bed material and the general sediment surface were about 17 and 26 cm/s^{-1} respectively, but the casts of *A. marina*, although protruding from the sediment surface, had much higher critical erosion velocities, of about 44 cm/s^{-1}. Studies with artificial and natural faecal pellet implied that this high critical erosion velocity was caused by binding secretions produced by *A. marina* in the faecal coils (Meadows and Meadows, 1991).

Biological activity can also made the sediment surface destabilized. Hall (1994) showed that movement of the small mobile bivalve *Transenella tanilla* which produces tracks on the surface of sediments which can reduce the critical erosion velocity up to 20 %. Eckman *et al.* (1981) using wetted foundry sand showed that sediment erosion within clumps of tubes of living *Owenia fusiformis* occured at lower velocity than in areas such as clumps did not exist. Similar experiments by Luchenborh (1986) using the polychaete *Diopatra cuprea* led him to conclude that the lowering of critical erosion velocities in the presence of *D. cuprea* tubes is more likely to be caused by biologically mediated sedimentological changes, such as mucous binding and bioturbation, than by alternations of near bed flow caused by the hydrodynamic effects of the tubes.

Other Organisms

Of the physical disturbance processes, bioturbation is probably the one which has received most attention. In the intertidal, Reise (1985) showed that at high worm densities, the activities of *A. marina* disturbed the tube building spionid *Pygospio elegans* and reduced its numbers. Similarly, in field and laboratory experiments, Dewitt and Levinton (1985) showed that disturbance generated by the ploughing action of the mud snail Ilyanassa obsaleta led to emigration of the tube building amphipod *Microdentopus gryllatalpa*.

Other intertidal fauna for which the effects of bioturbation have been demontrated include the predatory Naticidae gastropod which plough trails through the sediment. Wiltse (1980) focused on *Polinices duplicatus* and conducted a year long caging experiment to examine the effects of both predation on mulluscs and disturbance to non-mollusc species. For both mollusc and non-mollusc species, community attributes such as diversity, evenness, the number of species and the diversity of total individuals, all decreased with increasing snail density.

Flint and Kalke (1986) studied the infaunal benthos of Corpus Christie Bay, Texas over a 3.5 years period and considered the effects of bioturbation by layer burrowing infauna such as *Enteropneusts, Ophiuroids* and *Echiurans.* They demonstrated that a marked change in the depth distribution and the species richness of the fauna was associated with the colonization of the area by the acorn worm *Enteropneust schizocardium.*

Conclusion

Bioturbation may affect the availability of organic matter for benthic community. Activities of burrowing benthic macrofauna influence both the physical structure and the chemical composition of sediment, factors that are very important for the growth of microorganisms and meioorganisms and thus also the overall turnover of organic matter. Impact of bioturbation in the sediment as shear strength, water content, bed roughness, erosion velocity and other organisms.

References

Cullen, D. 1973. Bioturbation of superficial marine sediments by interstitial meiobenthos. *Nature.* London. 242 : 323 - 324.

De witt, T.H. and Leviston, J.S. 1985. Disturbance, emigration and refuges : how the mud anail, *Hyanassa obsoleta* (Say), affects the habitat distribution of an epifaunal amphipod, *Microdeutopus gryllotalpa* (Costa). *J. Expr. Mar. Biol. Ecol.* 92 : 97 - 111.

Fager, E.W. 1964. Marine sediments : effects of to a tube-building polychaete. *Science*: 143 : 356 - 359.

Hall, S.J. 1994. Physical disturbance and marine benthic communities : life in unconsolidated sediments. *Oceanogr. Mar. Biol*: an *Ann Rev.* 32 : 179 - 239.

Jorgensen, B.B. 1983. Processes at the sediment-water interface. In the major biogeochemical cycles and their interactions : 477 - 509.)Eds Bolin, B and Cook, R.B). John Wiley and Sons, Chichester. (SCOPE (*Scient. Comm. Probl. Environ.*) 21).

Lambe, T.W and Whitman, R.V. 1979. Soil mechanics. (Standard edn). Wiley and Sons, New York.

Luckenbach, M.W. 1986. Sediment stability around animal tubes : the roles of hydrodynamic processes and biotic activity. *Limnol. Oceanogr.* 31 : 779 - 787.

Meadows, P.S. and Tufail, A. 1986. Bioturbation, microbial activity and sediment properties in an estuarine ecosystem. *Proc. R. Soc. Edinb.* (B) 90 : 129 - 142.

Meadows, P.S. and Meadows, A. 1991. The geotechnical and geochemical implications of bioturbation in marine sedimentary ecosystem. *Symp. Zool. Soc.* London. 63 : 157 - 181.

Meadows, P.S. Tait, J. and Hussain, S.A. 1990. Effects of estuarine infauna on sediment stability and particle sedimentation. *Hydrobiologia.* 190 : 263 - 266.

Meadows, P.S. and Tait, J. 1985. Bioturbation, geotechnics and microbiology at the sediment-water interface in deep-sea sediments. In *Proc. of the nineteenth European mar. biol. symp*: 191 - 199. (Ed. Gibbs, P.E.). Cambridge University Press, Cambridge.

Meadows, P.S. and Tait, J. 1989. Modification of sediment permeability and shear strength by two burrowing invertebrates. *Mar. Biol. Berl.* 101 : 75 - 82.

Meadows, P.S. and Shand, P. 1989. Experimental analysis of byssus thread production by *Mytilus edulis and Modiolus modiolus* in sediments. *Mar. Biol. Berl.* 219 - 226.

Reise, K. 1985. Tidal Flat Ecology. An experimental approach to species interaction. Spinger Verlag. Berlin, Heidelberg, New York, Tokyo.

Rhoads, D.C. and Boyer, L.F. 1984. The effects of marine benthos on physical properties of sediments : a succession perspective in animal sediment relations. New York. *Plenum Press.* p, 3 - 52.

Rhoads, D.C., Yingst, J.Y. and Ullman, W.J. 1978. Seafloor stability in central Long Island Sound. Part I. temporal changes in erodibility of fine grained sediment. New York. *Academic Press.* P, 221 - 44.

Rhoads, D.C. and Young, D.K. 1971. Animal sediment relations in Cape Cod Bay. Massachusetts II. Reworking by *Mo;padia oolitica* (Holothuroidea). *Mar. Biol.* 11 : 255 - 61.

Tufail, A., Meadows, P.S. and McLaughlin, P. 1989. Meso- and micro-scale heterogeneity in benthic community structure and the sedimentary environment on an intertidal muddy-sand beach. Scientia mar. 53 : 319 - 327.

Wiltse, W. I. 1980. Effects of *Polinices duplicatus* (Gastropoda : Naticidae) on infaunal community structure at Barnstable Harbour, Massachusetts, USA. *Mar. Biol.* 56 : 301 - 10.

Wood, D.M.., Meadows, P.S. and Tufail, A. 1990. Biological strengthening of marine sediments. In microbiology in Civil engineering. Proceedings of the federation of European microbiological societies symposium held at Cranfield Institute of Technology, UK, 3 - 5 September 1990 : 306 - 316 (Ed. Howsam, P). *E and F N Spon*, London.