BULLETIN OF MARINE SCIENCE, 38(1): 19–24, 1986

WATER PUMPING AND PARTICULATE RESUSPENSION BY CALLIANASSIDS (CRUSTACEA: THALASSINIDEA) AT ENEWETAK AND BIKINI ATOLLS, MARSHALL ISLANDS

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ABSTRACT

Water pumping activities of callianassids at depths of 18 m resuspended fine sediments in ejected water. Water volumes pumped daily averaged 1,120 ml at Enewetak and 2,250 ml at Bikini per mound, the difference perhaps attributable to difficulties with the collectors. Water volumes as great as 3,450 ml were produced daily. The suspended sediment load of water pumped through burrow systems averaged 3.1–3.3 times that found in controls taken 10 cm above the sediment surface. Material resuspended through callianassid pumping had generally higher gross alpha plus beta activity per unit weight than controls.

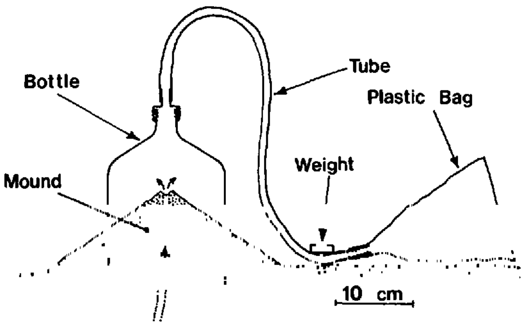
The high densities of burrows and lengthy residence times of deep lagoon water imply callianassids make a major contribution to total suspended particulates and radionuclides.

The dominant role of callianassid ghost shrimps in bioturbation of sediments in many shallow-water tropical areas is becoming increasingly well known. Recent papers by Roberts et al. (1982), Suchanek (1983), Suchanek and Colin (this volume), and Suchanek et al. (this volume), plus work by Tudhope (pers. comm.) have documented some activities of these crustaceans in the western Atlantic, central Pacific and Great Barrier Reef. Most work has concerned their densities, sediment overturn activities, and influences on community structure. The amount of water pumped and the ability of pumping activity to suspend sediment has not been previously examined.

The nature of callianassid mounds at Enewetak is documented in detail elsewhere in this volume (Suchanek and Colin; Suchanek et al.). At intervals of at least a few minutes, water and sediment are expelled by the pumping action of callianassids from the apices of the conical mounds. The flow of water produced is sufficiently strong to carry sediment particles over 2–3 mm in diameter out of the burrow system and deposit them as part of the conical mound. The mound grows with subsequent bursts of pumping with its slope essentially at the angle of repose. In addition to the larger sediment which is deposited almost immediately on the slope of the mound, some finer-grained material is carried into the water column to a height of at least several cm by the near-vertical stream of water issuing from the mound apex. A portion of this material carried into the water is only temporarily suspended, but the finer fraction will become suspended for some time.

MATERIALS AND METHODS

Pumped water and suspended particulates were collected from callianassid mounds using a device which enclosed the upper portion of the mound (Fig. 1). Collectors were constructed by removing the bottom from 4-liter plastic bottles. These bottles, without screwtop lids, were placed over an active callianassid mound and gently pushed into the sediment several centimeters until a positive seal against water flow was obtained around the lower edge. Hence, pumping of water from the mound would produce an equal displacement of water at the bottle opening. The rim of the bottle is sufficiently large in diameter (15 cm) that the central vertical tunnel of the mound is not disturbed by bottle emplacement. The water displaced as the bottle is pressed into the sediment exits the upper opening easily without disturbing the sediment. When done properly, no visible suspension of sediment occurs in the water inside the bottle.



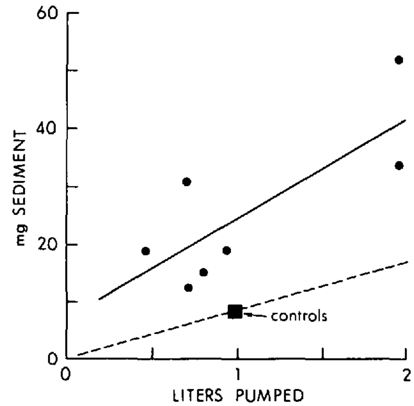


Figure 1. (Left) Diagrammatic representation of collector for effluent water from callianassid burrows. The plastic bottle is shown in section inserted over the callianassid mound.

Figure 2. (Right) Water volume pumped versus suspended sediment load for experimental and control samples at Runit Island, Enewetak Atoll, 21 m depth. All control samples fall within the indicated box (N = 8) while mound samples are plotted with regression line shown.

The emplaced bottles are left undisturbed for a few minutes, then a plastic hose ca. 1 m long attached to a screwtop fitting is installed on the bottle. Finally, an empty plastic bag for water collection is installed on the end of the tube and held in position near the substratum with a small lead weight.

After 24 h the bag is removed, tied shut, and replaced with another bag. The amount of settled sediment evolved during the previous 24 h is determined by comparing the increase in height of the sediment cone inside the bottle (visible through the translucent wall) with the level of sediment outside. One-liter control samples of water from 10 cm above the sediment bottom were taken for comparison of particulate load.

The collector bags were returned to the laboratory and their water volume measured using graduate cylinders. Particulates were removed by suction filtration on preweighed 0.45-μm millipore filters for both callianassid and control samples. Filters were dried for 24 h at 60°C, then weighed. Often only 300–400 ml of pumped water could be filtered without severe clogging on a single filter, requiring as many as seven filters for a single day's collection. All control samples required only one filter.

Gross alpha plus beta activities of the filtered particulate samples were determined by liquid scintillation counting using a Beckman LS-100 counter. The filters and particulate material were readily digested in the Aquasol R scintillation mixture; the resulting sample solutions were clear. Samples were counted at standard energy windows (^{3}H, ^{14}C, ^{32}P).

Water collected in the plastic bag did not directly represent the water pumped from the callianassid mound. Two factors cause (1) an overestimation of water volume pumped and 2) an underestimation of the concentration of particulates. The first is the volume of water in the collector displaced by evolved sediment. The second is the dilution of evolved water carrying a high sediment load by water present initially in the collector. At the beginning of an experiment, a volume of water (1–2 liters) is contained within each collector bottle. Water issuing from the mound mixes with this water as it is produced and the suspended sediment concentration of evolved water is reduced (assuming the pumped water contains a higher load). When 2–4 liters of water are collected after 24 h and 1–2 liters were present in the system initially, this can produce a 20–50% lower value for particulates in collected water (assuming complete mixing also) as compared to control water. The volume in the collector chamber occupied by water allows accommodation of mound sediment in this closed system as it is produced and provides a volume of water between the mound apex and the outlet to the collection bag where poorly suspended particles can settle before reaching the collection bag. The volume displaced by the sediment is small, only 5–10% of the volume of water pumped. Suspended sediment concentrations were corrected for these factors (initial water volume in collector versus pumped volume and volume of sediment evolved) before analysis.

Samples were collected from a typical callianassid-dominated sediment bottom at 21 m depth on the lagoon side of Runit Island, Enewetak. This was about 1,000 m lagoonward of a large central bunker (1310) on the island, the same area where McMurtry et al. (this volume) collected sediment cores. Samples from Bikini were collected at 18 m depth off Yomiyaran Island (two islands south of Bikini Island) near the eastern side of Bikini lagoon. This was also an area of callianassid-dominated

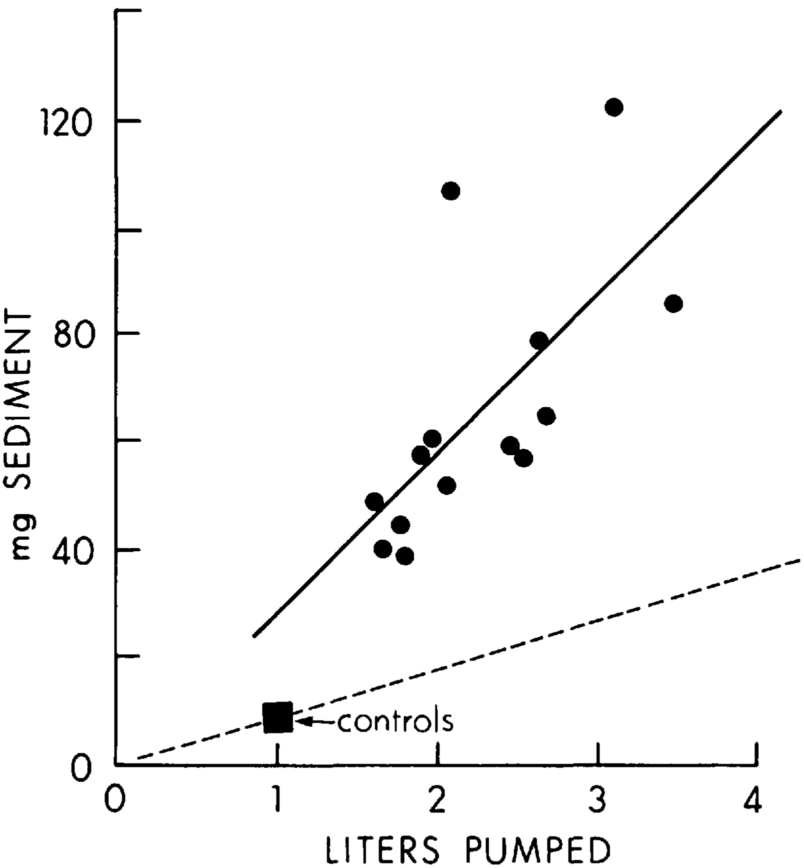


Figure 3. Water volume pumped versus suspended sediment load for experimental and control samples at Bikini Atoll, 18 m depth. All control samples fall within the indicated box (N = 12) while mound samples are plotted with regression line shown.

substratum. Scintillation counts were made only on Runit samples, since these were from an area of known moderate radiological contamination.

The collectors generally worked well. Some Runit samples were lost due to initial difficulties with hose connectors coming apart. Several Bikini samples were lost when large puffer fish bit holes in the plastic tubes. On occasion, a mound selected for collection was actually inactive, the bag containing very little or no water after 24 h. The few samples with no water or volumes less than about 0.5 liter were not considered in the analysis of particulates.

Results

Water Volume and Particulates.—The seven samples from Runit Island varied between 460 and 1,950 ml day^{-1} ($\bar{x}$ = 1,120 ml; SD = ±655). Some samples were lost when tubing connectors came apart while the collectors were deployed, possibly due to evolution of more water than the system could contain. Therefore, the Runit samples may underestimate mean pumping values.

The Bikini water volume data are perhaps more indicative of the norm since no samples were lost due to failed connections. The 14 samples ranged between 1,550 and 3,450 ml ($\bar{x}$ = 2,250 ml; SD = ±566). The only samples lost were due to fish biting the tubes.

All samples of water pumped from mounds had greater amounts of particulates than did water column samples. Per unit volume, the Enewetak samples averaged

Table 1. Callianassid effluent measurements (Enewetak lagoon off Runit Island 25–29 January 1982)

	Volume (ml)	Particulate wt (mg)	^{14}C energy window activity (cpm/g)*	^{32}P energy window activity (cpm/g)†
Callianassid mound collections				
1	2,040	35.5	(546 ± 14)	(635 ± 13)
2	485	7.1	138 ± 42	54 ± 37
3	675	12.6	79 ± 24	(273 ± 22)
4	840	9.1	135 ± 33	(288 ± 31)
5	735	7.4	130 ± 41	(118 ± 35)
6	2,060	26.3	(166 ± 20)	(373 ± 18)
7	1,000	11.6	(282 ± 28)	(519 ± 26)
Control collections				
1	1,070	6.4	150 ± 47	75 ± 38
2	1,065	7.2	61 ± 42	33 ± 36
3	1,075	7.2	32 ± 42	10 ± 35
4	1,075	8.2	26 ± 37	0 ± 30
5	1,000	8.6	47 ± 35	0 ± 29
6	1,000	8.3	60 ± 36	1 ± 30
7	1,000	7.8	69 ± 38	0 ± 32
8	1,000	8.3	111 ± 36	80 ± 31

* Activities determined by low-level liquid scintillation counting: ^{3}H energy window activity lost due to counter malfunction.
† Errors based on counting statistics (±1 standard deviation); values in parentheses are statistically significant from controls at 95% confidence level.

3.1 times and Bikini averaged 3.3 times the level in controls. There was a positive relationship between the amount of water pumped and total particulates (Figs. 2 and 3) but no significant change in the amount of particulates per volume as long as a volume of several hundred ml was produced.

Radionuclides.—The gross alpha plus beta activity results for the ^{14}C and ^{32}P energy windows are presented in Table 1. Unfortunately, ^{3}H window activities were lost due to a counter malfunction. Six out of nine callianassid particulate samples are higher than the controls in gross alpha plus beta activity in the ^{32}P energy window, whereas only three are higher in activity in the ^{14}C energy window (Table 1). These results are significant at the 95% confidence level. Studies of the radioisotopic composition of the lagoon sediments in this area indicate that most of the beta activity is attributable to ^{60}Co (McMurtry et al., this volume), and our experience with liquid scintillation counting indicates that most of this ^{60}Co activity occurs in the ^{14}C energy window. Although we cannot be certain without further radioisotopic work, the higher-energy activity in the ^{32}P window is suggestive of the alpha activity of transuranic isotopes that are concentrated in the near-surface layers of these sediments (McMurtry et al., this volume).

Total gross alpha plus beta activities of the callianassid particulates approach the levels measured in the surface sediment of the area, whereas the controls display total activities that are generally two to ten times lower than those of the surface sediment (McMurtry et al., this volume). Because of the ^{3}H energy window loss, these total activities are minimum values. The control particulates are at least ten times more active than particulates collected from the lagoon water in other locations (McMurtry and Schneider, in prep.). This activity may be the result of localized, contaminated sediment resuspension by either bottom currents or callianassid pumping.

There is a relationship between callianassid particulate activity and the volume of water pumped (Table 1). The reasons for this relationship are not clear. More vigorous pumping may tap more radioactive sediment layers at greater depth (McMurtry et al., this volume), or particulate activities at lower pumping rates may be indistinguishable from those in the ambient waters because of the nature of the sampling and the higher radioactivity of the suspended particulates in this area of the lagoon.

Discussion

Very few of the active processes capable of generating and moving particulate plutonium in the water column at Enewetak have been considered (Noshkin, 1980). He reported roughly similar amounts of Pu as "soluble" (less than 1 micrometer) and "particulate" phases in water at Enewetak (6–35 fCi per liter) (Noshkin, 1980).

The great majority of residual radionuclides at Enewetak is found in lagoon sediments. These are remobilized at a low rate to the water column, but the mechanisms are not well understood. There are several ways in which the sediment–water interface at water depths below several meters can be disturbed (Suchanek and Colin, this volume), but only a few mechanisms are known (such as callianassid shrimp and enteropneust activities) that involve rapid cycling of water or sediment from depths of 1–2 m or more in the sediment column (see Suchanek and Colin, this volume and Suchanek et al., this volume). The potential impacts of resuspended sediment and pumped water on radionuclide mobilization need to be assessed.

Callianassid mounds are the most conspicuous bioturbational features of Marshall Island atoll lagoons, and significant quantities of water are cycled through these burrow systems (for information on burrow morphology see Suchanek et al., this volume). The occurrence of callianassid mounds throughout the Enewetak lagoon at all depths below about 10 m has been documented by Colin (this volume) and Suchanek et al. (this volume). Suchanek et al. (this volume) reported increasing density of "large" callianassid mounds (>5 cm diameter) with increasing depth. Considering the distribution of depths within the lagoon, it is estimated, for purposes of discussion, that there is 1.0 large mound per m^2 of soft substratum from 15–30 m depth and 2.5 per m^2 for depths below 30 m. Colin (this volume) reported the deep lagoon (below 30 m) consisted of approximately 85% soft substratum. The Enewetak lagoon comprises about 930 km^2, of which 80% (744 km^2) is deeper than 30 m and an additional 7% (65 km^2) lies between 15 and 30 m depth (Emery et al., 1954). Therefore, the total area of lagoon below 15 m depth equals 809 km^2, of which 85% is soft substratum. Using the density estimates for mounds, there are an estimated 1.5×10^9 large callianassid mounds in the Enewetak lagoon. If an average of 50 mg of fine sediment per mound is put into suspension daily (using an intermediate figure for the Bikini-Enewetak data), this would be about 7.5×10^4 kg per day for the entire Enewetak lagoon. The sediment injected into near bottom waters probably does not move much vertically except when near bottom water is brought upward by the general lagoon circulation (Atkinson et al., 1981). The deepest parts of the lagoon are characterized by a slow circulation, and residence times for water in such areas are probably in excess of the approximate 40-day mean residence time for lagoon water as a whole (Atkinson et al., 1981). It is perhaps a valid assumption that water immediately above the sediment surface stays near that surface for periods of many days while undergoing slow horizontal drift. Surface wind driven flow, mid-depth return flow and a slow deep circulation shown by Atkinson et al. (1981) support such an assumption, and, with the exception of coral pinnacles which would disturb horizontal flow, there is no physical mechanism which could produce significant vertical circulation in the deep lagoon. Indeed, a distinct increase in turbidity in the last few meters before reaching bottom is commonly observed while descending to the lagoon bottom. If a figure of 2 m is accepted as the normal limits of daily vertical circulation of deep lagoon water, then callianassid mounds inject about 0.05 $mg \cdot liter^{-1} \cdot day^{-1}$ of suspended sediment into this water volume. A lagoon residence time of 100 days, probably not an unreasonably high figure for deep lagoon water, would produce about 5 $mg \cdot liter^{-1}$ suspended sediment injected into the water, a figure close to the 6–11 $mg \cdot liter^{-1}$ particulates found in control water samples.

The question of how long suspended particulates might remain in suspension cannot be answered at present. Those that settle to the bottom have an excellent chance of being resuspended again through the activities of callianassids or other bioturbators. A system of fine particulates either in suspension in the water column or waiting to be put into suspension could be thought to exist. They are probably lost to the system only when lagoon water exits the atoll to the open North Pacific.

The effect of circulating water through sediment layers a meter or more below the sediment surface is not known, but considering the results of Waslenchuk et al. (1983) for Bermudian callianassids, it could be important in consideration of remobilization of radionuclides buried deep in the sediment. Waslenchuk et al. (1983) found that irrigation of the burrow system by the ghost shrimp provided a mechanism for injecting pore water constituents into the water column, and that in the case of reduced arsenic, burrow irrigation may be partially responsible for the maintenance of observed arsenic species disequilibria in coastal waters. The potential for radionuclide transport from pore water to the water column by callianassids is great and deserves attention in the future.

Acknowledgments

We would like to thank the staff of the Mid-Pacific Research Laboratory for their help in the field work, particularly L. J. Bell, L. Boucher, S. Johnson and J. Harrison. Operation of the Mid-Pacific Research Laboratory was provided under contract from the United States Department of Energy to the University of Hawaii. Operations at Bikini were carried out from the R/V Liktanur II, K. Coberley, captain, and we would like to thank the crew for their cooperation. Operation of the R/V Liktanur II was also provided by the U.S. Department of Energy.

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Date Accepted: August 26, 1985.

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