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Project Summary

Response of Benthic Ecosystems to Deep Ocean Sewage Outfalls in Hawaii: A Nutrient Cycling Approach to Biological Impact Assessment and Monitoring

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The full report describes the benthic nutrient budgets, metabolism, and community structure observed around two deep ocean sewage outfalls off Oahu, Hawaii. The overall effect of effluent on benthic and pelagic ecosystems off Oahu is insignificant—primarily as a result of effective dispersal and dilution. The results also indicate that a community function approach may, in some situations, be more efficient and effective than a community structure approach for ecosystem assessment and monitoring.

This Project Summary was developed by EPA's Environmental Research Laboratory, Narragansett, RI, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The intent of the research presented in the full report is to test the applicability of a new methodology to assess the response of the benthic community off Oahu, Hawaii, to sewage effluent discharged from two deep-ocean outfalls. A simple material flux approach was employed to measure delivery of sewage material to the sediment-water interface, storage of sewage material in the sediment, and metabolic recycling of effluent nutrients. The potential utility of the flux model is that the fate and effect of the sewage can be quantified in terms of total ecosystem function. For a material flux approach to constitute an improvement in the effectiveness and efficiency of practical ecosystem assessment and monitoring, it should provide more useful information than traditional monitoring strategies. In order to make such a comparison, a "standard" monitoring program based on identifying changes in infaunal community structure was conducted in conjunction with the benthic flux studies.

The Study Sites—Oahu Deep Ocean Sewage Outfalls

The Sand Island Wastewater Treatment facility currently treats domestic waste from residential areas, the Honolulu business district and the Waikiki resort area, and the concentrations of all priority pollutants fall below Federally acceptable standards. It provides advanced primary treatment for an average flow of 30.5 x 10^4 m^3 day^{-1} with an average suspended solids load of 40 mg l^{-1}. The wastewater treatment process consists of pre-screening, dissolved air flotation, clarification and final screening.

The Honouliuli (Barbers Point) wastewater facility and deep ocean outfall became operational in 1981. The service area for this system extends from Halawa to Barbers Point and consists primarily of residential communities with small local business centers. The two major municipal facilities that discharge into the Honouliuli system (Pearl Harbor and Waipahu) previously discharged directly into Pearl Harbor. Discharge from the Honouliuli outfall is approximately 6.5 x 10^4 m^3 day^{-1} with an average suspended solids concentration of 120 mg l^{-1} During the period of field study, the treatment plant facility was not operating. Influent was coarse-screened prior to discharge through the ocean outfall. Therefore, the effluent was essentially untreated raw sewage.

While the Sand Island Outfall has a definite seasonal variability, the hydraulic loading at Barbers Point is fairly consistent throughout the year.

The marine environments in the vicinity of both outfalls and the control site consist of a low-relief calcium carbonate sand bottom. Very few macro-benthic invertebrates or demersal and pelagic fish were observed in the outfall or control environments. The outfall pipes and armor rock provide areas of increased habitat complexity in otherwise barren areas. As a result, there are outfall-associated faunal communities with relatively high diversity and biomass.

The control station is located off Waikiki at a depth of 70 m in the region of Mamala Bay judged to be subjected to the least influence from discharge of both the sewage outfalls and Pearl Harbor. Bottom composition and current flow at the control site appeared similar to those of the outfall sites.

Conclusions

A set of relatively "standard theory" biogeochemical concepts and methodologies designed to quantify material fluxes of carbon, nitrogen and phosphorus was used to characterize functional ecosystem response to the Sand Island and Barbers Point (Honouliuli) deepwater sewage outfalls. Direct measurements of particulate flux indicate that only about 1% of the material reaches the sediment water interface; the remaining 99% is dispersed by currents.

Very little of the material that reaches the interface is incorporated into the sediment column. Vertical profiles of particulate organics show no concentration gradients in the upper 4 cm of sediment and only slight differences in concentrations between control and outfall sites. The organic material in the sediment appears to be the most recalcitrant portion of organic fallout. Lower C:N and C:P ratios of the sediment organics compared to particulate fallout indicate that long-term abiotic processes of adsorption and humification may cause sequestering of N and P in the sediment column.

Ratios of stable isotopes of nitrogen indicate that near the outfall structures, there is a substantial sewage component to the surface sediment organic material. It also appears that naturally occurring organic material may originate predominantly from recycled benthic detritus emanating from the nearshore region, rather than pelagic (plankton) fallout.

In-situ benthic fluxes indicate that essentially all of the sewage-related particulate material that reaches the sediment-water interface is rapidly recycled to dissolved forms. This contrasts with the control area, where only about half of the particulate fallout is recycled. The difference appears to result from the highly labile character of the sewage particulates as compared to the relatively refractory "old" material fueling natural benthic processes.

Benthic fluxes are apparently caused primarily by aerobic metabolism. Ratios of N:P flux indicate that both nutrients are released back to the water column at similar rates in about the same ratio as sewage effluent

Although the magnitude of fluxes varies with site and time, metabolic processes are qualitatively consistent. Stoichiometry of O_2 uptake and dissolved nitrogen release indicates that respiration and nutrient regeneration are not closely coupled.

Pore-water profiles of NH_4^+, NO_3^- + NO_2^+, PO_4^{3-}, have concentration gradients in the top 1 to 2 cm of the sediment column that produce similar ionic diffusive fluxes across the interface at both outfall and control sites. These fluxes do not mirror the variations in measured net benthic flux that appear to be functions of the outfall influence. Ratios of net to diffusive flux greater than unity, as well as the lack of bioturbation and wave/current stirring, suggest that the changes in net flux are caused by rapid remineralization of effluent material at the sediment surface. Ratios of net to diffusive flux of near unity from the control sites indicate that most of the diagenetic activity is occurring within the sediment column when there is no anthropogenic input.

Most in-situ measured dissolved N flux is the result of NH_4^+ production from deamination and ammonification. Nitrate and nitrite flux is low and does not follow the major trends of other constituents, possibly because the rates of nitrification are too slow to reach steady-state within the experimental time.

Diffusive flux of PO_4^{3-} is greatly affected by sediment adsorption, causing net uptake at the control sites. However, surface metabolism appears to be relatively unaffected by this abiotic process and the effect is masked at the outfall sites.

At Barbers Point, benthic fluxes of dissolved nutrients in the vicinity of the diffuser are consistently higher than in control areas during both years of study, 1984 and 1985. Organic flocs of sewage origin were also observed on the sediment surface within 50 m of the Barbers Point diffuser.

At Sand Island, no organic flocs were observed. Benthic flux is greater than the control at Sand Island only during the sampling, coinciding with pulse inputs of elevated dissolved BOD from seasonal discharge of a pineapple cannery. The increased BOD apparently triggers the growth of microbial mats which fragment to provide a particulate nutrient source to the benthos. Therefore, only when raw sewage particles or secondary sources of particulate material (mats) reach the sediment-water interface is there an influence on benthic community function. In the present study this influence to the benthos is limited to within the *zone of initial dilution (ZID).*

Analysis of sediment macrofauna and meiofauna at Sand Island and Barbers Point indicates that beyond the ZID, no significant changes occur in community structure compared to the control. Within the ZID at Sand Island there are statistically significant decreases in diversity, number of species, and number of individuals but no significant changes in biomass. Within the ZID at Barbers Point, there is no significant change in diversity, species number, or number of individuals, but biomass is increased. These patterns do not typify ecosystem response to nutrient subsidy or eutrophication (i.e. decreased diversity and number of species, increased biomass and number of individuals).

While no clear-cut relationship exists between community structure and effluent input, a possible cause for the depressed community structure near the Sand Island diffuser is the absence of filter feeders, possibly owing to periodic pulses of bacterial mats. If this is the case, the inter-pulse interval may be too short to allow recolonization of the filter feeders.

Macrofauna ($\geq$ 0.5 mm) may serve to accurately characterize the benthic fauna at the Oahu outfall sites as long as the sample size and number of replicates is adequate.

The Oahu outfalls are ideal for comparing community structure and function as environmental management tools, because no obvious changes occur in either the physical or the macrofaunal environments. If large aggregations of indicator species, such as *Capitella capitella*, were present in the vicinity of the Oahu outfalls, community structure analyses would have been adequate to recognize biological impact. On the other hand, if organic deposition near the outfalls caused the formation of an anaerobic sediment layer, such a change in the benthic community function would serve to identify ecosystem impact.

The nutrient cycling approach, utilizing direct measures of fluxes into and out of the benthic boundary zone, is verified as a viable and sensitive approach to quantifying the potential for environmental stress at relatively low levels of anthropogenic influence. Although the influence also results in discernable alterations to infaunal community structure, what causes the alterations and what they indicate about the effect of the sewage discharge on ecosystems remain unclear.

From an environmental management standpoint, the effects of the sewage outfalls upon benthic and pelagic ecosystems are insignificant. However, the augmentation to benthic flux is substantial enough to change the characteristics of metabolic function of the benthic boundary zone from that typical of the deep sea to that of estuaries or coastal seas.

In addition, the benthic function analysis indicates that even in open ocean outfalls, primary treatment of effluent is preferred to raw effluent discharge. Even with primary treatment highly labile dissolved organics may alter environmental quality.

At present, the rationale of biological assessment and monitoring is based solely on the identifying changes in specific community parameters within specific areas of the environment relative to the input source; hence, the emphasis on fauna inventories. However, broadening the view of assessment and monitoring to include total ecosystem response, as well as the input functions that cause the response, appears to yield much more potentially useful information for evaluating the performance of outfall discharge systems.

Because the methods are available to determine subtle changes in community function, it is possible to identify ecosystem changes at levels of stress below the threshold necessary for changes in community structure to become discernable. Hence, analysis of community function may be a more practical method of assessment and monitoring.

The levels of technology and capital investment required for metabolic flux analyses are considerably more advanced than those required for community structure analyses. In the case of the Oahu outfalls man hours were approximately equal for the two approaches, but results of community structure analyses were rather ambiguous and did relatively little to address the cause-effect relationships of sewage effluent on a small segment of the marine ecosystem. Community function analyses, on the other hand, resulted in a clear descriptive and statistical picture of impacts on the entire benthic community.

In addition, following the initial investment (and provided submersible capabilities are available) the equipment and analytical facilities required to conduct future "community function" programs are relatively basic and inexpensive. Because the data generated by functional analyses are available almost instantaneously, regardless of the number of replicates, there is no delay in seeing results, as is often the case when large numbers of benthic samples are collected. Therefore, for long-term repetitive monitoring programs, the community function approach may be a cost-effective alternative to the community structure approach.

Recommendations

The results of this study indicate that simple biogeochemical balances of material fluxes from the benthos in the vicinity of domestic sewage discharges provides an effective and efficient method of characterizing environmental impact. However, although the functional approach has been demonstrated to be useful for characterizing small changes under conditions of marginal stress, it would be valuable to apply the techniques to discharge situations with substantial environmental degradation.

While deployment of an assessment and monitoring program based on benthic community function is best handled at deep ocean sites with the use of research submersibles, all of the necessary techniques can be conducted from surface-operated equipment. However, the availability of a research submersible improves the capabilities of the program, and appears to be one of the more beneficial uses of undersea technology. It is recommended that when submersible time is available for assessment and monitoring programs, a share of the time be designated to perform some form of functional assessment of ecosystem response.

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The complete report, entitled "Response of Benthic Ecosystems to Deep Ocean Sewage Outfalls in Hawaii: A Nutrient Cycling Approach to Biological Impact Assessment and Monitoring," (Order No. PB 87-165 205/AS; Cost: $18.95, subject to change) will be available only from:
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