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Reduction of suspended particulates by mussels and other organisms in dolphin enclosures

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Abstract

Water clarity inside bottlenose dolphin (*Tursiops truncatus*) enclosures in San Diego Bay was greater than that outside the enclosures, in spite of fecal and urinary input by the dolphins. We investigated the possibility that this was due to common bay mussels, *Mytilus edulis*, that had colonized on the netting inside the dolphin enclosures. Using an estimated population of over 200 000 mussels and a range of published pumping rates, we calculated that the volume of water filtered by the mussels was equivalent to nearly 18.4 to 184 times the enclosure volume per day. The synergistic combination of available substratum, nutrient mixing, and the rich, natural microenvironment found in the dolphin enclosures enhanced the water quality of the immediate local environment by reducing the amount of particulate matter and algae in the water column. This resulted in greater clarity inside the mussel-encrusted enclosures. Similar substrata could be used by aquaculture operations for the treatment of natural waters used to house a variety of organisms from abalone to fin fish, either in small volume enclosures or in those with high density populations. Furthermore, mussel-encrusted netting might be employed to clear water overloaded with organic matter from sewage overflow, river runoff, fish farms, feedlot effluents, and other sources of organic pollution.

Introduction

Bottlenose dolphins, *Tursiops truncatus*, are housed in connected floating enclosures in San Diego Bay for the US Navy Marine Mammal Program. These enclosures are lined with 10 cm stretch mesh netting that allows free access to local fish and other small aquatic animals. The enclosure netting has proven to be an excellent substratum for some forms of algae, tunicates and mollusks, especially the common bay mussel, *Mytilus edulis*. Inside enclosures densely encrusted with mussels, the water is remarkably clear—it is often possible to see the bottom of the net 3 to 4 m below the surface of a mussel-encrusted enclosure, even when visibility is poor outside the enclosure or in an enclosure without encrusting mussels. We suspected this was similar to the observed increased water clarity of eutrophic lakes in the Netherlands where there are large populations of zebra mussels (*Dreissena polymorpha*) which have been shown to reduce the local algal biomass (as reported by Reeders & Bij de Vaate, 1990).

We have observed that it takes about 1 year for a new net in a *Tursiops* enclosure to become densely encrusted with *Mytilus edulis*, and the water inside this enclosure to become noticeably clear compared to outside the enclosure or in an adjoining, non-encrusted enclosure. Most of the mussels in these enclosures orient toward the inside of the enclosure where the resident *Tursiops* provide a rain of excreted urine and feces. Ridgway (1972) estimated that an average 178 kg *Tursiops* produces about 1.8 kg dry wt. of feces and 5.8 of urine per day.

We hypothesized that the water clarity inside the densely mussel-encrusted enclosure resulted from the mussels filtering the algae and particulate matter out of the water column. To quantify the degree of water clarity, we measured phytoplankton concentrations and suspended particulate densities both inside and outside a mussel-encrusted enclosure and in an enclosure that was not encrusted. We also estimated the density and size frequency of the encrusting mussel population. Finally, using a wide range of published pumping rates of *Mytilus*, we calculated the possible water volume filtered each day within the mussel-encrusted dolphin enclosure. We hoped the findings would support our hypothesis that within the mussel encrusted dolphin enclosures, the removal rate of particulate matter was greater than the introduction rate of particulate matter, which would explain the enhanced water clarity.

Materials and methods

Pen description
The netted dolphin enclosures were located at 32°42′N, 117°14′W; approximately 3.4 km from the mouth of San Diego Bay. The external measurements of the enclosures were 9.1 × 9.1 m. The untreated net on the inside of each measured enclosure was 7.3 × 7.3 × 2.45 m and was made of knotless nylon, with 10 cm stretch mesh (Marenovich Trawl Company P.O. Box 294 Beloxi, Mississippi 39533).

Enclosures were connected by gates to allow dolphins access to each other and to several other enclosures. Movement of the dolphins within and between the enclosures provided extensive mixing of the enclosed water and kept the particulate matter suspended and readily available to the filter-feeding mussels.

One enclosure, the calving pen, had an additional layer of smaller 4 cm mesh inside the larger mesh for added protection for small dolphin calves during the first 6 months of life. It was in this enclosure that we observed the clearest water and the heaviest density of mussels, perhaps due to the increased surface area provided by the smaller mesh. At the time the measurements were taken, the small mesh net had been in place for 2 years and mussels had been accumulating and growing on the net for this period of time.

Water clarity
To quantify the degree of water clarity, both *in-situ* chlorophyll-*a* fluorescence and suspended solids were measured. Water was sampled using a continuous flow pump with the input port attached to an ECOS CTD. The pumped water flowed through three fluorometers aboard a boat (only two of the fluorometers were employed for this study, the third collected data for an unrelated study). The CTD was lowered by hand, inside and along the outside of the netted dolphin enclosures. For comparative purposes, inside and outside (outside measurements were collected both shoreside and channelside of the enclosure) measurements were made for the mussel-encrusted small mesh enclosure, the mussel-encrusted enclosure with the 10 cm stretch mesh and the enclosure with the 10 cm mesh net encrusted with algae and tunicates, but no mussels. Measurements were collected between 1000 and 1200 on 16 December, 1993.

The two Turner fluorescence radiometers measured chlorophyll-*a* fluorescence using excitation and emission filters as described by Strickland & Parsons (1968). These instruments had been calibrated the day before use.

Optical light transmission was measured using a Sea Tech 0.25 m beam transmissometer. The transmissometer was calibrated the day before using suspended sediment from San Diego Bay of known density.

Mussel abundance, size, and distribution on netting
To estimate the size and number of the mussels encrusting the enclosure net, a 0.31 m square section of the 4 cm mesh was cut equidistant (about 0.75 m) from the surface and from the lead line marking the lower lateral perimeter on each of the four sides of the enclosure net. These mesh samples supported mussel densities that appeared typical of the overall enclosure. All live mussels were removed from each sampled section and measured using digital calipers. There were very few dead mussels collected.

Calculations
To determine the potential filtration rate capacity of the encrusting mussel population, we used a broad range of possible pumping rates reported in the literature (Abel, 1976; Famme *et al*., 1986; Jørgensen *et al*., 1988; Kiørbe *et al*., 1981; Schulte, 1975), and our estimated density of live mussels in the entire enclosure.

Results and discussion

Light transmission
The clearest water was found on the inside of the enclosures. The enclosure with the clearest water was the mussel-encrusted enclosure with the small mesh (Table 1), showing a mean percent light transmission of 87%. That was followed by the mussel-encrusted enclosure with the larger mesh, with a mean percent light transmission of 81%. The least clear enclosure was the algal- and tunicate-encrusted enclosure with the larger mesh (76%). The water on the outside of the enclosure, both channelside and shoreside, had the least clear water of all as evidenced by the lowest mean percent light transmission, 73% and 72% respectively. Therefore, the water inside mussel-encrusted enclosures with the small mesh was 7% clearer than water in mussel-encrusted enclosures with the larger mesh, 12% clearer than water in algae- and tunicate-encrusted enclosures, and 15% clearer than the water outside the enclosures (Table 1).

*Chlorophyll-*a *concentration*
The lowest average algal concentrations were found in the two mussel-encrusted enclosures (Table 1). The lower measurement in the mussel-encrusted large mesh enclosure is probably due to the fact that dolphins were not present and therefore, excrement from the animals was not contributing to the amount of particulate matter in this enclosure. All data were analyzed using a standardized T-test, and differences were significant to $P \leq 0.05$. At the time

Table 1. Percent light transmission (%) and algal concentration (mg/m^3) in water inside and outside encrusted dolphin enclosures

	Median %; mg/m^3	Mean %; mg/m^3	Std dev %; mg/m^3	n
Inside enclosure:				
mussel-encrusted, w/small mesh (dolphins present)	87; 0.48	87; 0.43	0.81; 0.072	157
mussel-encrusted, w/large mesh (dolphins not present)	81; 0.41	81; 0.39	0.66; 0.048	155
algae- & tunacate-encrusted, w/large mesh (dolphins present)	74; 0.52	76; 0.52	0.86; 0.027	265
Outside enclosure:				
channelside	74; 0.55	73; 0.52	2.95; 0.063	517
shoreside	72; 0.56	72; 0.56	1.17; 0.014	414

the chlorophyll-*a* fluorescence of the bay water was measured, the bay had relatively moderate concentrations of chlorophyll-*a*, that is, circa 0.5 mg/m^3. During much of the year, the bay water exceeds 1.0 mg/m^3, at which time we suspect there would be a more striking difference between the clarity inside and outside the mussel-encrusted enclosures.

Mussel population

Although other suspension feeders were sometimes present in the enclosures, for example bay anchovy (*Anchoa* sp.), it was apparent that mussels constituted by far the least varying and largest biomass of filtering macroorganisms. The mean length of the 1177 live mussels measured was 50.7 mm (std dev 12.2), with a range of 7.97 to 83.5 mm. The number of mussels on each side of the enclosure was calculated using the average density from sub-samples collected from the top and bottom of that side. The number of mussels on the bottom of the enclosure was calculated from the average of the four sub-samples from each quadrant. The total number of live mussels in the enclosure was estimated to be about 200 500.

Pumping and filtration rates of *Mytilus edulis* are affected by various factors including animal and gape size, algae density, particle characteristics, temperature, season, etc. (e.g. Bayne *et al*., 1993; Bernard & Noakes, 1990; Jones *et al*., 1992; Jørgensen *et al*., 1990; Redpath & Davenport, 1988; Schulte, 1975; Vismann, 1990; Winter, 1973). To estimate the possible daily volume of water filtered by the mussel population in the small mesh enclosure, we used two average pumping rates, 0.5 and 5.0 $L \bullet h^{-1} \bullet mussel^{-1}$, that represented wide range of published values (e.g. Abel, 1976; Famme *et al*., 1986; Jørgensen *et al*., 1988; Kiørbe *et al*., 1981; Schulte, 1975). Thus, with an estimated mussel population of approximately 200 500 individuals in an enclosure that contained 1.306×10^5 L of water, the estimated volume of water filtered by the mussels is equivalent to nearly 18.4 (@ 0.50 $L \bullet h^{-1} \bullet mussel^{-1}$) to 184 (@ 5.0 $L \bullet h^{-1} \bullet mussel^{-1}$) times the enclosure volume per day. Of course these calculations assume a closed system, which is not the case in this situation. In addition, we did not measure parameters such as nitrogen or phosphorus production by the dolphins or the uptake of the same by the mussels. However, the calculations do support our observation that within the mussel encrusted dolphin enclosures, the removal rate of particulate matter was greater than the introduction rate of particulate matter, with the result being greater water clarity.

The ability of mussels to reduce the density of suspended particulates in bodies of water has been documented (c.f. Riemann *et al*., 1988; Reeders & Bij de Vaate, 1990; Reeders, Bij de Vaate & Slim, 1989). In one study conducted in enclosures in a fjord in Denmark, phytoplankton biomass was reduced by 10 to 59% by adding *Mytilus edulis* (Riemann *et al*., 1988). In addition, it was found that the presence of planktivorous fish and nutrients in these enclosures resulted in an increase in the growth rate of the mussels (Riemann *et al*., 1988). Therefore, the addition of substrata that support increased settlement of *Mytilus* could be used to restore water quality to eutrophic bodies of water and to improve water clarity by reducing chlorophyll levels. The latter has been shown to be the primary effect of the presence of mussels (Riemann *et al*., 1988). In the Netherlands, water quality has been restored in eutrophic lakes by employing the zebra mussel, *Dreissena polymorpha* (Reeders & Bij de Vaate, 1990). However, *D. polymorpha* is considered to be a nuisance species in some locations (Griffiths *et al*., 1991) and there is concern that invading populations of *D. polymorpha* in non-native waters will provoke major changes which may have negative effects on shallow water ecosystems (Herbert *et al*., 1991).

We propose taking advantage of *Mytilus edulis* filtration capacity in its native habitat by enhancing the natural settlement of new populations by providing additional substrata. This species is considered to be a very important component in the energy flow of coastal ecosystems because of its biomass dominance (Kautsky, 1982*a*). In addition, the tolerance of *Mytilus* to reduced salinities (Kautsky, 1982*b*) should further enhance its usefulness in systems developed to clear water overloaded with organic matter from sewage overflow, river runoff, fish farms, feedlot effluents, and other sources of organic pollution.

Conclusion

Naturally occurring populations of the common bay mussel *Mytilus edulis*, living on netted substrata used for housing marine mammals can have a beneficial impact on the water quality of the immediate area. In a mussel-encrusted dolphin enclosure, the removal rate of particulate matter by a dense population of mussels can exceed the introduction rate of particulate matter. The result is greater water clarity within the enclosure compared to outside the enclosure. Similar substrata could be used by aquaculture operations for the treatment of natural waters used to house a variety of organisms from abalone to fin fish, either in small volume enclosures or in those with high density populations. Furthermore, mussel-encrusted netting might be employed to clear water overloaded with organic matter from sewage overflow, river runoff, fish farms, feedlot effluents, and other sources of organic pollution.

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