Coastal Tin Mining and Marine Pollution in Thailand

Article

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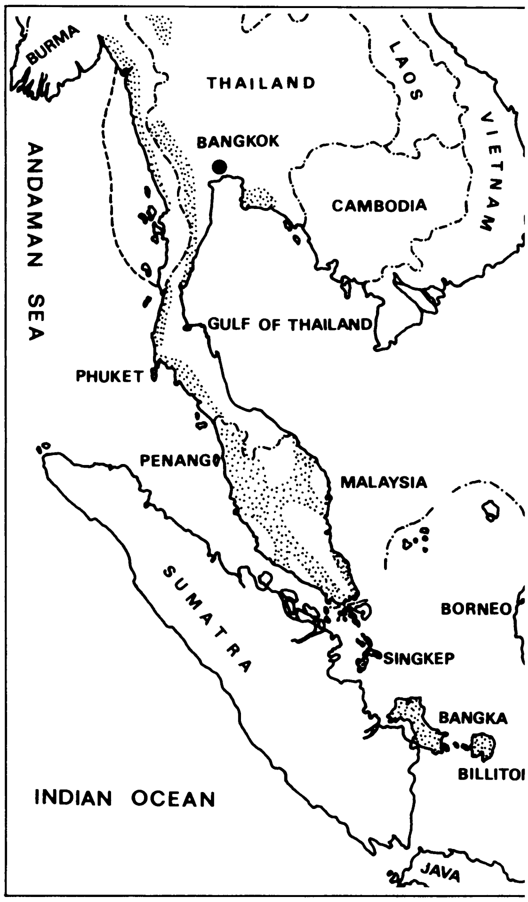


Figure 1. Distribution of tin belts in Southeast Asia. Tin deposits indicated by stippled area.

Tin ore is one of the major export commodities of Indonesia, Malaysia and Thailand. Tin mining is carried out extensively both on land and in coastal waters. Dredging has taken place along the west coast of Thailand and in the tin islands off the east coast of Sumatra, Indonesia. Marine pollution as a result of tin mining has become of concern within the last decade. Apart from direct physical destruction of the environment, pollution is mainly caused by suspended mine tailings, which increase the turbidity of coastal waters as well as smothering sessile benthic organisms in near-shore areas. The ecosystems of the coral reefs are particularly sensitive to the effects of suspended sediment. Reefs in the vicinity of dredging activities are damaged by smothering as well as by the increase in turbidity. However, some reefs partially recover following natural removal of sediment by the turbulent water movement that occurs during the monsoon season. Effects on benthic macrofauna and primary productivity remain localized. Thus, the scale of mining activity is the main factor determining the impact of tin wastes on open-water ecosystems.

INTRODUCTION

Southeast Asia is the major tin-producing region in the world. Malaysia, Indonesia and Thailand have been the major tin producers in the area. Together with other major tin-producing countries outside this region; e.g. Bolivia, Australia, Nigeria and Zaire, they produce about 93 percent of world tin supplies (1). Table 1 shows the tin concentrate production in selected countries of the Asian and Pacific region for 1981–1984.

Geographically, the major Southeast Asian tin belt extends for nearly 3000 kilometers, from northern Burma through peninsula Thailand and western Malaysia to the tin islands (Singkep, Bangka and Billiton) off the east coast of Sumatra (Figure 1) (2). This region has been mined for tin for more than 100 years, major exploitation taking place in the secondary deposits on land. In Thailand and Indonesia, coastal mining of alluvial deposits in near-shore areas began in the early twentieth century.

Mining in coastal waters has been carried out off Bangka and Belitung Islands in Indonesia and along the Andaman Sea coast of Thailand. Rich deposits have been reported from areas along the coast of Malacca and Perak, Malaysia (2). However, no large-scale mining activity has been reported for these areas since the 1960s. With the depletion of land-based deposits, exploration for tin in coastal waters has increased significantly, and in the 1980s has become the major source of tin production for both countries. The increase in coastal mining has resulted in public concern with regard to effects on the environment; this is especially true in Thailand.

This review on the effect of tin mining on the marine environment mainly discusses the physical pollution in the coastal environment that is caused by mine tailings. Problems of coastal dredging on the west coast of Thailand, especially Phuket Island, where a conflict of interests between tin dredging and other coastal-resource uses has led the government to conduct studies on the effects of dredging on coastal resources, are also discussed.

Table 1. Tin-concentrate (metal) production in selected countries in the Asian and Pacific region (1).

Country	1981	1982	1983	1984
Australia	12 267	12 126	9 275	9 300*
Burma	971	1 063	931	1 944
China	16 000*	–	–	–
Indonesia	35 268	33 800	26 554	23 220
Japan	564	529	599	480
Laos People's Democratic Republic	600*	–	–	–
Malaysia	59 938	52 342	41 367	41 307*
Thailand	31 474	26 207	19 942	21 958

* Estimated.

MINING METHODS AND EFFECTS ON THE ENVIRONMENT

Tin is mined in the form of cassiterite (SnO_2) from alluvial deposits on land and in coastal waters. Deposits on land are mined hydraulically using a gravel-pumping method. Dredging is carried out to recover mineral deposits from shallow waters and swamp areas.

Gravel Pumping

Gravel pumping involves liquefying unconsolidated deposits in an open pit with a high-pressure water-jet, after removing the top soil. The mixture is pumped to a slightly sloping sluice box. Tin ore and other heavy materials settle on the bottom of the sluice box and are prevented from flowing away by means of a row of baffles, while lighter materials are washed away as mine tailings. Tailings are fed into bunded areas and old mine pits where solids settle out and water is recycled or discharged into natural waterways. The environmental problems relating to land mining are

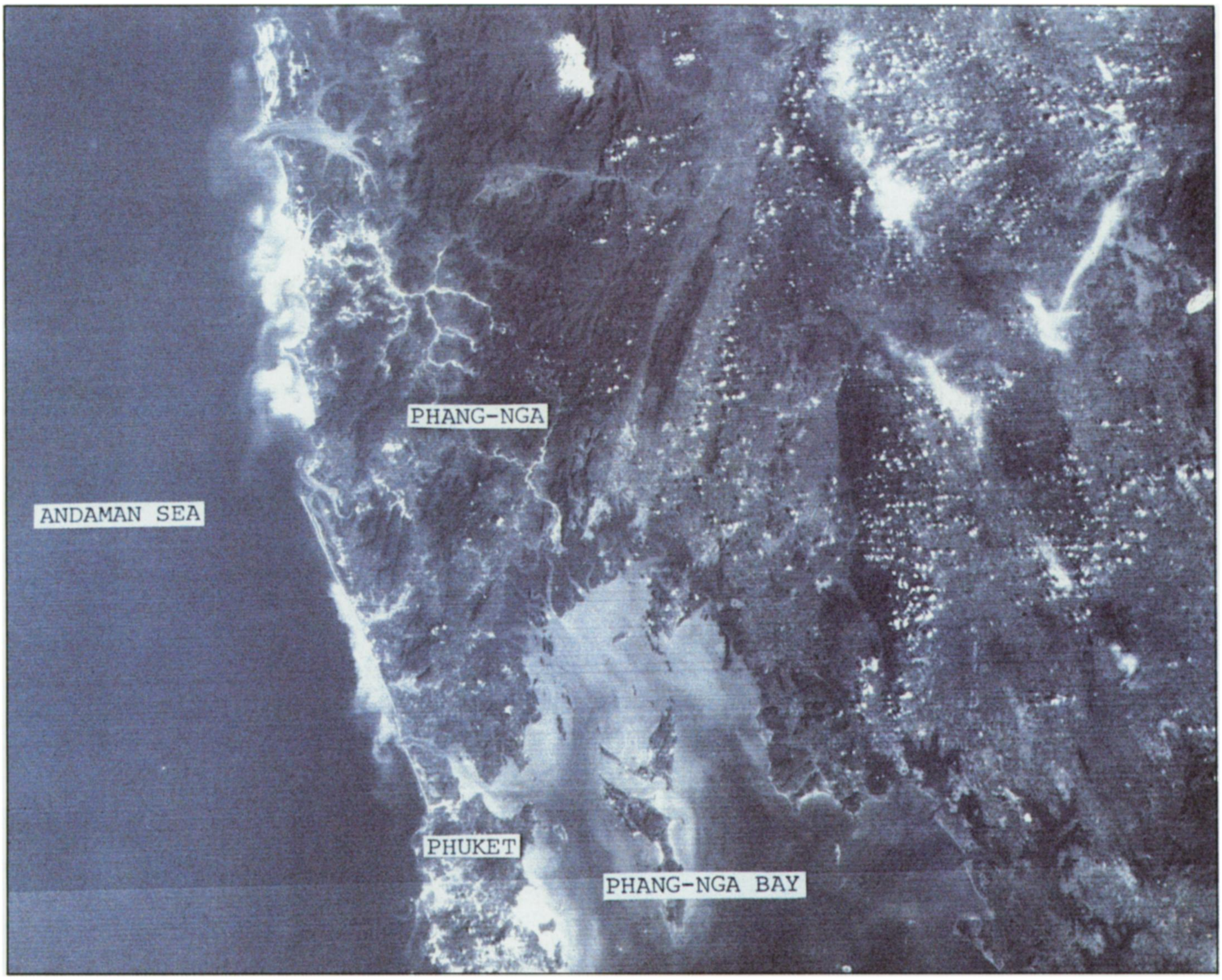


Figure 2. Landsat photo taken January 1979 showing Andaman Sea coast of Thailand. The sediment plumes were generated by intensive dredging activities within a depth of 20 meters along the Phang-nga coast. More limited plume distribution on northern parts of the west coast of Phuket Island was also detected. Suspended loads from land-based mines are visible as turbid streams (white lines on land) discharging into the coastal waters. Photo: NASA.

mainly physical damage of the mine area, and physical pollution (3, 4).

Since most mining areas were originally agricultural land or natural forests this mining method creates environmental problems, both during operations and after the mines are abandoned. Generally, once operations cease, a large pit, perhaps 15 meters deep, is left. Large piles of stones and gravel are scattered over a large area of uneven ground that is covered with fine and coarse sand. Because topsoils are removed during the mining process, the agricultural, reforestation and aesthetic value of the land decreases. Very few plants can survive and the areas affected are subject to severe erosion during the monsoon period. Runoff from areas that receive tailings, and occasionally failure of the embankments of retention ponds, result in streams of liquid waste that are rich in suspended materials. In intensive-mining areas this leads to highly turbid waters and deposition of sediments in waterways and coastal waters, especially in protected bays, as can be seen in Figure 2.

Because the cassiterite is recovered from unconsolidated deposits, potentially toxic heavy metals are seldom encountered (5). However, lead and arsenic occur in certain onshore-mining locations on peninsular Thailand. The occurrence of these heavy metals was seldom regarded as a problem until early 1988, when there were reports of arsenic contamination in the surface waters of one mining district in southern Thailand.

Dredging

Dredging is the method used to remove ore deposits from swamp areas and shallow waters of down to about 30 meters. The bucket dredge, adopted from canal and harbor dredges, was first used for tin mining in Phuket Bay, Thailand in 1907. Dredging entails removing sediment with a bucket ladder or suction pipe. The tin ore is separated from the sediment using the same gravitational methods as those used in land-based mining. Tailings are discharged directly from the rear of the dredge. The heavy fractions immediately sink to the bottom while fine particles form a turbid plume, which is dispersed in the vicinity of the dredge. Dispersion of the plume depends on the current regime. Eventually, the plume is diluted by the surrounding waters and settles out.

Bucket-dredging operations generate sediment plumes when dredging sediment from the bottom, when transporting the sediments up the ladder, and when discharging the tailings. These dredges can generate substantial quantities of suspended sediment. For example, the largest tin dredge in Indonesia could remove up to 700 000 cubic meters of sediment per month from depths of up to 45 meters (6). Bucket dredges cannot operate in rough weather, but in sheltered areas, may operate up to 300 days a year. Suction dredges are smaller, and require less capital investment. This type of dredge generates a sediment plume by releasing mine tailings to the surface waters. Both these types of dredge have their advantages for different types of deposits. A third type of dredge found along the Phang-nga coast of Thailand is the diver-guided suction boat. These were modified from fishing boats when exploitation of nearshore deposits in the area began, about 15 years ago. These small dredges operated in areas of rich deposits up to 18-meters deep.

Modified fishing boats operate on the same principle as the larger suction dredge. With divers guiding the suction heads, they can collect from rich deposits selectively. However, the small size of their sluice boxes make them inefficient in separating ore from tailings. This leads to a substantial return of tin ore to the sea, making reworking by larger dredges uneconomical. The number of these small boats that are in operation is not known exactly, however, some estimates put their number at 6000 operating along the Phang-nga coast during the 1981 mining season. Because the weather is very rough during the Southwest Monsoon period (May–October), dredging activities can only be conducted in open waters during the calm Northeast Monsoon (November–April).

The sediment plumes from aggregations of small boats and from large dredges are detectable by satellite imagery (Figure 2). No study of the effects of these extensive dredging activities on the coastal environment has been carried out. However, the socioeconomic impact on the local communities has been quite substantial. Small-scale operations declined significantly after 1983 due to depletion of the deposits, and especially after the collapse of the tin market in 1985.

In the case of coastal dredging, the issues also concern the physical pollution caused by mine tailings, which, besides affecting marine organisms, also decreases the aesthetic value of the marine environment.

So far, there is no documentation on the toxic substances that may occur as a result of tin dredging. Higher heavy-metal concentrations (Cu, Zn, Fe and Sn) have been reported in sediment from the area close to the tin-smelting plant in Phuket. There were higher concentrations of these metals in bivalves; levels in corals were normal (7). For bivalves, the concentrations found were not lethal.

Bucket dredge operating in Phuket Bay at about 22-meters depth. This dredge has been in operation since the 1960s with a digging capacity of 320 000 $m^2 \cdot month^{-1}$. Only a very small fraction is retained as tin ore (about 0.3 $kg \cdot m^{-3}$ of sediment). The rest is discharged as mine tailings which create the turbid plume. Most of the discharge settles in the vicinity of the dredge while lighter particles, especially fine sand and silt clay components, are dispersed by tidal currents. Another dredge can be seen at the horizon. Photo: H. Chansang.

CONFLICT OF INTEREST BETWEEN TIN DREDGING AND OTHER COASTAL-RESOURCE USES

For the past 10 years, mining activities in the coastal waters of Thailand have created public concern. This concern is closely related to the effects on both the aesthetic value and the productivity of the coastal ecosystem. Public reaction often depends on the actual location of the dredging activities. Most concern arises from conflicts of interest in the utilization of coastal resources. Increasing tourism on Phuket Island has led to the development of tourist resorts along the west coast of Phuket, which are well known for their beautiful beaches, clear waters and underwater attractions. Major conflict issues are related to the effects of dredging on the coral reefs, and the increasing turbidity of coastal waters, which both affect the aesthetic value of the coastal environment

In addition, alterations to the scenery of the intertidal and subtidal zones are obvious to the naked eye. For example, the Phuket Bay shoreline has changed drastically since the early 1900s. This change was mainly due to a combination of tin dredging along the shoreline together with siltation from land-based mining. A canal drains the southeastern catchment area of Phuket Island, where major mining activity was concentrated during the last century. Increasing siltation led to the accretion of the shoreline and to increasing turbidity in the bay area. In some areas, dredging in the swamps or nearshore areas has led to conflict with local fishermen. Cockle-farmers complain that increasing sedimentation has made habitats unsuitable for rearing shellfish. Siltation of the navigation channels in shallow bays is yet another cause of conflict. The extent of the problem depends on the depth of the area affected as well as the hydrographic regime.

Bucket dredging within the 20-meter depth range in open bays along the Phuket coast shows no tendency to create obstruction or to alter the character of the sea floor.

EFFECTS OF TIN DREDGING ON LIVING COASTAL RESOURCES

The immediate physical effects of dredging are gross disturbance of the area and large quantities of suspended solids.These suspended solids affect biological resources in various ways. The most damaging effects are seen in sessile benthic organisms in shallow waters and the intertidal areas.

In Thailand, tin mining in mangrove swamps is located in Phang-nga, Phuket, and Ranong Provinces. Bucket dredges are commonly used for mining in the man-

Table 2. Physical and chemical properties of bottom sediment within a depth of one meter in a mangrove forest in Phang-nga Bay and forest areas six months and six years after dredging (8).

	Physical properties				Chemical properties							
	Composition			Soil	pH	organic	nitrogen	phosphorus	calcium	magnesium	chloride
	% sand	% silt	% clay	texture		matter %	%	ppm	ppm	ppm	ppm
Mangrove forest	43.3	47.4	9.3	loam	4.5	7.0	3.5	360	185	580	5784
Area six months after dredging	100	trace	trace	sand	4.9	0.6	0.03	347	24	25	425
Area six years after dredging	100	trace	trace	sand	7.2	0.6	0.03	373	24	33	791

Formerly mangrove swamp, this area has been mined since the 1930s. A dredge can be seen at the center of the picture. Dredging has left the area very uneven and in many parts the water depth now exceeds the limit for mangrove growth. Photo: H. Chansang.

grove-swamp areas. Dredging changes the structure and composition of sediments close to the mining sites.

Table 2 shows the sediment composition of a mangrove-forest area in Phang-nga Bay, and mangrove areas six months and six years after mining (8). Following a period of mining, organic matter and nutrients decrease drastically leaving the area unsuitable for recolonization by mangrove plants. For example, fifty-six percent of the sediment was lost when suspended solids were carried out of a mining area. Nutrient levels decreased by about 77 percent; varying from 4 to 96 percent. However, phophorous levels did not decrease. This was probably due to the acidity of the sediment, which binds the phosphate salts. After a period of six years, the sediment is still sandy and there have been only slight increases in nutrient content. Limited recolonization by vegetation occurred over the six years. It is estimated that a return to pre-dredging nutrient levels will require more than 20 years (8). Replanting of mangrove seedlings in mining areas has been attempted with limited success only (9).

In Phang-nga Bay, the major contribution of suspended silt load to the coastal waters comes from the land-based mines (Figure 2). The high sediment load (estimated to be over 800 000 tons per day) was carried downstream, silting up the waterways as well as being carried into the upper part of Phang-nga Bay. It also affected the abundance of plankton and the benthic population within the channels (8). In Ranong Province, suspended solids from tin mining have negative effects on cockle culture. A high cockle-mortality rate and changes in the sediment structure of culture beds together with a reduction in phytoplankton population have been reported (10).

The intensity of the effect of tin dredging depends on the distance downstream from the mining area (8, 10). A dredging capacity of about 100 000 cubic meters per month results in suspended solids still being found up to 4–6 kilometers downstream of the mining operation. Effects on areas close to the source as well as impact depend on the magnitude of the dredging activities.

In the open Bang Tao Bay, west coast of Phuket, where three dredges operated for five months a year, primary production in the water column declined because of the shading effect. This effect was most noticeable in the sediment plume area (11). The numbers of macrobenthic fauna were low at sites near the dredging area (12, 13, 14). High silt-clay concentrations, both in the water column and in sediment near the mining sites, were removed from the bay during the Southwest Monsoon season. The area was recolonized by pioneer species, dominated by polychaetes (10).

Results from the study in Phuket Bay indicate that abundance in terms of density as well as number of families of macrobenthic animals were comparable with undredged areas after seven years (15). As the effect on macrobenthic fauna was found to be local only, it was concluded that the effect of dredging in Bang Tao Bay, west coast of Phuket, was insignificant for the demersal fishery within the region.

EFFECTS OF TIN DREDGING ON CORAL REEFS

Coral reefs are known to be affected by siltation caused by dredging activities (16). Studies on the reefs of the northwest coast of Phuket Island have shown that sedimentation from dredging activities destroyed the reefs in the vicinity of the operations (17, 18). Figure 3 shows the effect of tin dredging on coral cover at Kamala Bay west coast of Phuket (18). The dredging began in January 1984, within about 1.5 kilometers of the monitoring station. Monitoring of coral cover by a photographic-transect method (17) was carried out prior to dredging in February 1981 and after in April 1984, the end of the dredging season. Effects on coral cover were severe. The most drastic effect was the smothering of corals, especially in the lower part of the reef slope; the upper slope was less affected. This effect could be due to the combination of physical disturbance by sedimentation and a reduction in light intensity, which is required to sustain growth at certain depths (19). During the Southwest Monsoon (May–October) partial recovery of the reef occurred as a result of water turbulence that removed sediment from the reef. Transparency on the reef varied between 2–6 meters secchi depth, depending on tides. The transparency in unaffected reef areas was about 8–11 meters secchi depth. Thus, the living-coral cover increased significantly in the lower slope in November 1984 and had to face the sediment load from dredging activity during November 1984 to April 1985. This prevented the reef from further recovery and decreased parts of the living-coral cover in the lower parts of the reef.

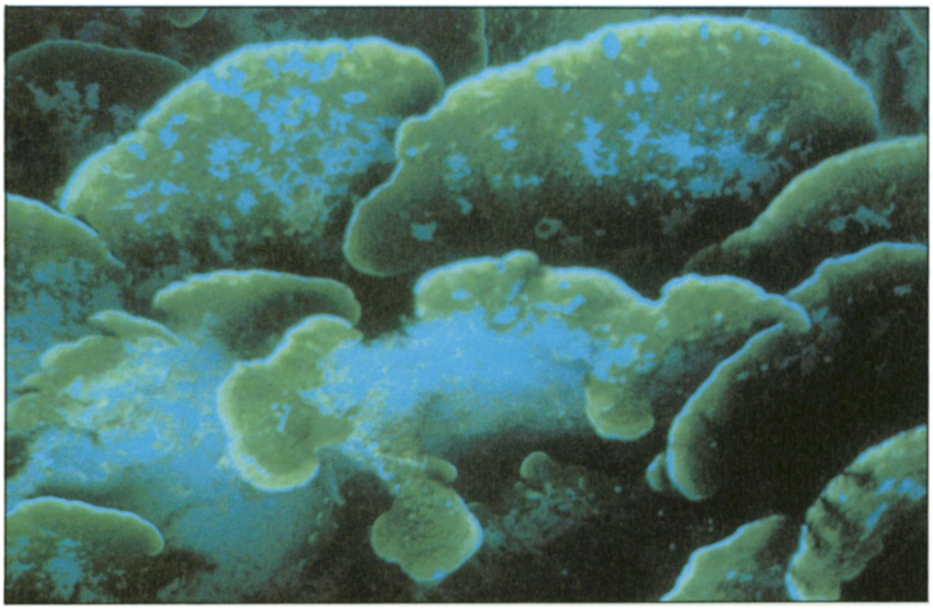
Dredging operations in Kamala Bay ceased after April 1985. Subsequent monitoring in November 1985 showed that water turbulence during the Southwest Monsoon of 1985 removed the sediment, but the coral had not recovered. Monitoring in May 1986 showed a decline in coral cover. This may due to several causes, besides those of sediment effects; e.g. Crown-of-Thorns starfish, *Acanthaster planci*, have been observed on the reef since November 1984.

Coral species have different degrees of tolerance to siltation (20). *Porites lutea*, the major reef builder of fringing reefs on the continent shorelines of Southeast Asia, can be covered by sediment for some time and still recover. Recovery depends upon the thickness of the sediment and its duration. *Montipora ramosa*, another common intertidal species, is also highly resistant to sedimentation. Morphologically, staghorn coral, *Acropora formosa* cannot be smothered by sediment. However, laboratory tests have shown that under the stress of increasing turbidity they die and only exposed bare calcium carbonate skeletons remain.

Besides the smothering of corals, measurement of oxygen production and utilization were also studied by Punrong and Chansang (20). At concentrations of suspended solids of 6 mg · L^{-1} and a sedimentation rate of 4 mg · cm^{-2} · day^{-1}, the respiration rate of *P. lutea* decreases. Higher concentrations of suspended solids and more rapid sedimentation rates decrease respiration rates further as well as affecting the rate of photosynthesis.

The study on the northwest coast of Phuket, during 1983 to 1986, indicated that dredging effects depend upon a number of contributory factors: distance from the dredges; hydrographic regime of the mining area, especially tidal current; and degree of reef exposure to wind and wave actions, especially during the Southwest Monsoon (18). As dredges operate on the west coast only during the dry season, water turbulence during the Southwest Monsoon tends to remove resuspended sediment from some reefs and from the bays. This contributes to various degrees of recovery of reefs as well as self-cleansing of coastal waters. It also shows that corals can regenerate once an optimal environment has been restored. After the dredge moved out the wind and wave action of several monsoon seasons removed the sediment cover providing hard substrates for coral larvae to settle on.

Regeneration of corals is also possible when some remnants of live tissues from large colonies survive the smothering effects. These remnants have significantly increased coral coverage after the removal of the sediment from some reefs. However, reefs in the area that are protected from Southwest-Monsoon turbulence have less chance of recovery due to an annual increase in sediment accumulation. This situation stresses the importance of water-mass movement in the reef vicinity. This movement of water transports suspended sediment from dredges to reefs during the dry season and removes resuspended sediment during the rainy season.



Sediment from tin dredging settles on *Montipora aequituberculata* at 12-meters depth on the west coast of Phuket. Photo: H. Chansang.

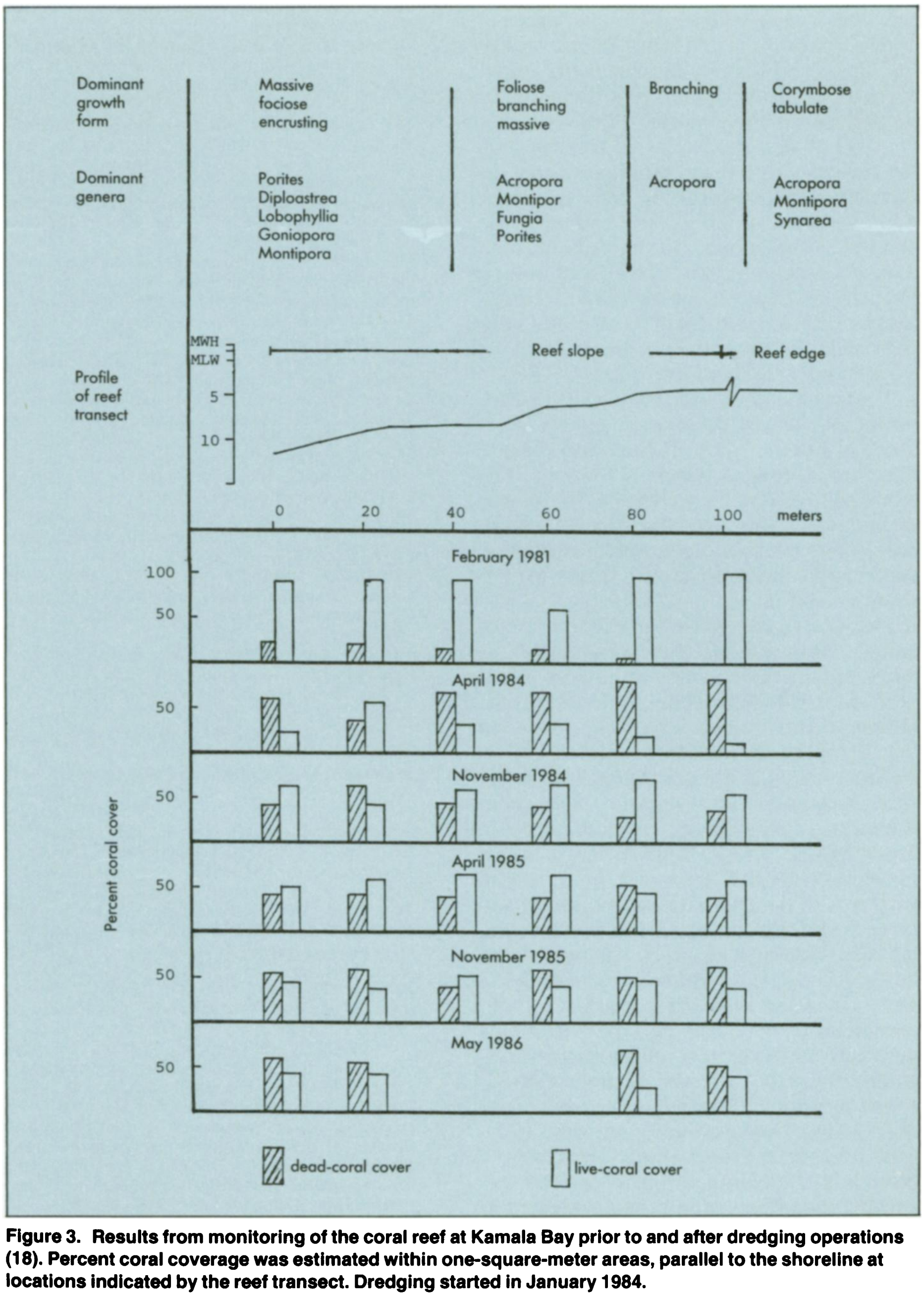


Figure 3. Results from monitoring of the coral reef at Kamala Bay prior to and after dredging operations (18). Percent coral coverage was estimated within one-square-meter areas, parallel to the shoreline at locations indicated by the reef transect. Dredging started in January 1984.

TIN MINING—THE PRESENT SITUATION

Since 1980, the decline in demand for tin, due to technological innovation as well as to the increasing market share of aluminum and plastics, has led to an oversupply of tin on the world market. To contain the tin surplus, the International Tin Council maintained its price support while tightening export control on the member countries according to the International Tin Agreement. This severely affected the economies of the tin-producing developing countries. The measure was to some extent offset by rising production in countries other than the producing member countries and by an increase in illegal trade in tin. Thus, in October 1985, the Council dissolved the price support, a decision that led to the collapse of the international tin market. Most tin mines ceased to operate and workers were made redundant.

The present tin price is about one half of the price in 1985 and only a few mines are in operation, including offshore dredges. It has been predicted that the situation of the tin-mining industry has already reached a bottom level and that it will in the future show some improvement. However, it is not anticipated that the value of tin will reach the pre-1985 level. Market demand is the key factor in determining the recovery of the tin-mining industry. In such an event, with the dredges available, shallow-water mining will remain the choice, as the secondary deposits on land have been depleted and the cost of mining the primary deposits remains high. Turbidity and siltation will again be issues of concern once the tin-mining industry recovers from the ill effects of oversupply.

The problem of marine pollution can, probably, be regarded as insignificant if dredges move further offshore and explore deposits in deeper waters. However, this will require new innovations in mining techniques. Although this may be technologically feasible, economic justification will remain the determining factor for executing such plans.

Measures to decrease the distribution of turbid plumes have been suggested to minimize the effects of tin mining on coastal resources. These include releasing mine tailings at the bottom of the sea, instead of the current practice of surface release (21). Nonetheless, it is still questionable whether such measures would prevent damage to the coral reefs that are in the vicinity of dredging operations. Knowledge of water movement in the area will be a useful yardstick in determining the minimum distance a dredge can approach the protecting reef. The most practical solution would be to determine whether tin or corals are more desirable at specific locations under specific circumstances. Any decision must take into account several factors and include all parties affected. Proper coastal-zone land-use planning is needed. Undoubtedly, socioeconomic pressure is always one of the important factors to be considered. It is hoped that knowledge regarding the effects of mining on coral reefs and other coastal resources will be used in guiding decision-makers in choices and alternatives.

CONCLUSIONS

Within the last decade there has been a substantial increase in knowledge about the effects of tin-mining pollution in coastal waters. This knowledge has been useful in identifying the real issues. It can be concluded that the mining impact is significant in intertidal and shallow-water areas and that turbidity and suspended solids are the main causes of the damage. The effects are localized and depend upon the scale of operations. The nearshore sessile benthic organisms such as mangrove fauna and corals are severely affected by mining activities. For corals, recovery is possible if sediment is removed and the conditions for coral growth are restored. Macrobenthic fauna on the seabed are also destroyed, but would recover after cessation of mining. Primary production around the suspended-solids plume decreases. However, despite effects on the foodweb chain, for both demersal and pelagic fish, a significant impact on commercial fisheries has not yet been observed. This could be due to the fact that the effects are confined to limited areas.

It is possible that the impact of mining activities can be alleviated if future operations are carried out further offshore so that the effects will not reach sensitive targets along the coast. To determine the mining zone, an understanding of water-mass movement nearshore is needed. Meanwhile, with the limited capability of existing dredges, the problem of effects, caused by increases in suspended solids and turbidity will remain.

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