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MARINE ENVIRONMENTAL IMPACT DUE TO MINING ACTIVITIES OF EL SALVADOR COPPER MINE, CHILE

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standing of the regulatory processes in natural communities. But in any case understanding and prediction are the ultimate, and indeed the only satisfactory, objectives of ecology so we are bound to progress towards them, however slowly. So to those whose remit lies in pollution or conservation—the two become indistinguishable—may I suggest that progress involving whole communities will come from again recognizing and capitalizing upon the opportunities afforded by those which are strongly biologically structured.

Accordingly I conclude with a dichotomous flow diagram depicting what I consider to be the logical progression of activities towards understanding, prediction and interpretation. For the sake of simplicity a pathway involving progressive physical changes (e.g. deposition of silt, organics) and their ecological consequences has been omitted, as have the parallel paths and/or imputs involving climatology, oceanography and laboratory experimentation implicit from Step 5 onwards. The assumption is made that communities which are not biologically structured are either not worth bothering about or cannot be monitored. I hope this assumption will provoke a response from those whose experience suggests otherwise as a further step in assessing the validity and practical value of this hypothesis.

REPORTS

Marine Environmental Impact due to Mining Activities of El Salvador Copper Mine, Chile

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Marine environmental impact as a result of copper mine tailing dumping in the sea is studied at Chañaral (North of Chile). These dumpings, from the copper mine El Salvador, have hindered harbour activities, caused geomorphological coastal modifications and affected seriously marine coastal ecosystems and recreational activities. At the old dumping site, Chañaral Bay (1938–1974), nearly 150 million tons of fine sediments were accumulated. Tailing discharges at the new dumping site, Caleta Palito, about 8 km north of Chañaral Bay are accumulating approximately at the rate of 25 000 tons of fine sediments per day, plus unknown quantities of chemicals (Cu, As, CN^-). From January 1975 to July 1976, this site has received over 13 million tons of sediments which has caused deterioration of the marine coastal environment, reduction in light penetration and high mortalities among marine invertebrates, fishes and algae.

The mining industry, specifically copper extraction and processing, plays an essential role in the Chilean economy. Most of the copper mines in Chile are located in the Southern Andes, in the arid-semi-arid region of the country. The three most important are: Chuquicamata at 2680 m above sea level (22° 19′ Lat. S.; 68° 56′ Long. W.). El Salvador at 2600 m above sea level (26° 15′ 33″ Lat. S.; 69° 34′ 15″ Long. W.) and El Teniente at 2113 m above sea level (34° 04′ Lat. S.; 70° 21′ Long. W.).

The environmental impact of metal mining activities has received world wide attention (Brown, 1968; Schmidt & Conn, 1969; Bell & Nancarrow, 1974; Bell *et al.*, 1975). The effects of such impact are already known and indices, regulations and pollution abatement measures have been presented (Nitta, 1967; FAO, 1971; Bell, 1976). Biological evaluations of marine organisms and ecosystems have disclosed ecological, physiological and biochemical alterations in species and communities affected by mining waste water, a result of both the inorganic and organic components contained in it (Connor, 1972; Brown & Newell, 1972; Thurberg *et al.*, 1973; Reish *et al.*, 1974; Bohn, 1975; Webb *et al.*, 1976).

In two of the copper mines, Chuquicamata and El Teniente, 'tailing' pollution control is obtained by the discharge of wastes into tailing ponds. Nevertheless, at El Salvador all untreated mining wastes are discharged through a semi-artificial canal directly to the shore. This paper deals with the marine environmental impact at the zone of Chañaral, Chile, as a result of ongoing mining activities at El Salvador and of mining activities in the past of Potrerillos Copper Mine, now exhausted.

Material and Methods

Observations and samplings were carried out during two surveys in the El Salvador-Chañaral area (Fig. 1a) in July 1975 and July 1976. As a basis for the study an

examination of the plant works, including the extractive process, plant processing of copper and molybdenum and the discharge canals, past and present, was made. The coastal area of Chañaral (Fig. 1b) was inspected from the Southern most part of Chañaral Bay to Puerto Pan de Azúcar, 24 km north of the bay (26° 09′ Lat. S.; 70° 45′ Long. W.).

At Chañaral Bay, Puerto Pan de Azúcar and Caleta Palito (the latter is the present waste discharge site, 26° 15′ 6″ Lat. S.; 70° 39′ 24″ Long. W.) SCUBA was employed in order to determine sea bottom characteristics and sediment content. Sub-littoral organisms and communities were observed by means of the same technique. Three transects of 50 m^2 (5 $m \times 10$ m) were studied between depths of 2-8 m in both polluted and unpolluted zones found in the study area. The effort unit used during diving operations was 30 min./man per transect. Superficial temperature (Telethermometer YSI, model 42 SC) and light penetration (Secci disc, 25 cm diameter) were measured at several sites within a range of half a mile from the shore. Along the 24 km of shoreline the presence or absence of waste foam and the species and communities affected were registered. The dispersion of coloured contaminant from the waste discharge site was observed daily.

El Salvador mine is exploited by block caving techniques. After milling, minerals are concentrated by basic flotation. The copper sulphide concentrate (CuS; CuS_2) is transferred to the molybdenum concentration plant for the separation of molybdenum sulphide by differential flotation. The latter process requires the use of ANAMOL (arsenic and sodium sulphide), cyanide and lime as collectors of molybdenum sulphide and depressants of copper sulphide. The copper concentrate is sent through a pipe to the current refining plant of Potrerillos (previously a copper mine, 1938-1958).

In the overall mining and processing stages at El Salvador, 65 000 tons/day of water (2.5 tons of water per ton of raw material) are used. Water is obtained from Andean water resources. Excluding the water utilized at the molybdenum concentration plant, 40% of the water is recovered and recycled. The total waste water discharge reaches 39 000 tons per day (of which 850 tons are the output of the molybdenum plant). The content of suspended solids averages 25 000 tons per day. Tailing discharges from copper and molybdenum concentration plants are evacuated through a 25 km long canal which discharges at the locality of Llanta (Fig. 1a) into the bed of Rio Salado. At Llanta and Pueblo Hundido additional recovery of copper pyrite is performed by flotation.

Urban waste waters after treatment (El Salvador sewage treatment plant) are canalized 50-55 km downstream before meeting, at Pueblo Hundido, the tailing discharge stream (Rio Salado). From then on, a single stream carries both types of residues to the site of dumping in the coastal area of Chañaral. From 1938 to 1974 tailing and waste waters discharged directly into Chañaral beach (Fig. 1b). Since February 1975, a new canal collects discharges from Rio Salado, 8-10 km off Chañaral beach and carries them to a new dumping site at Caleta Palito.

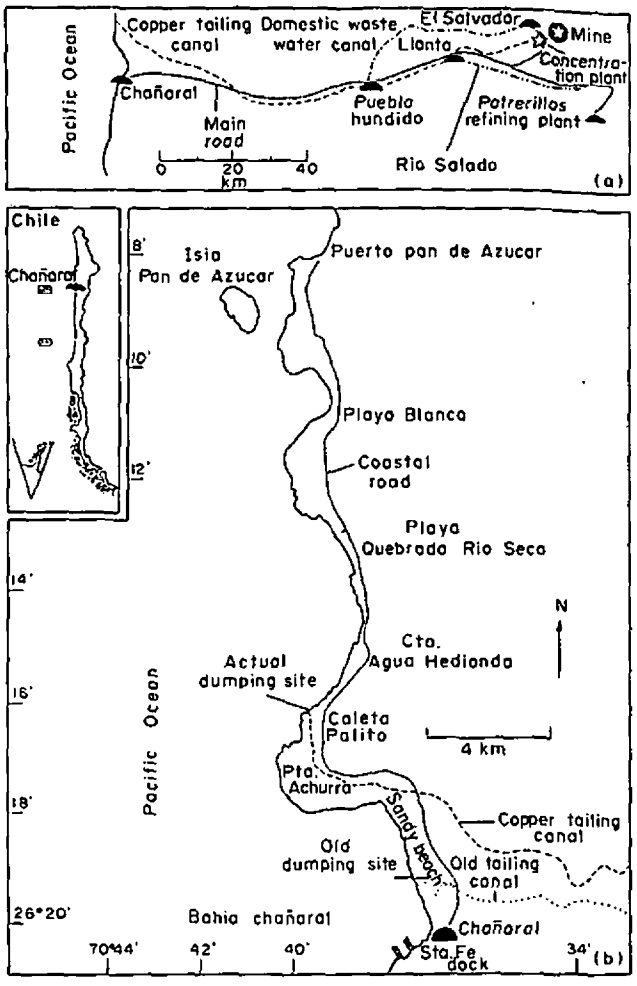

Fig. 1a Relative position of copper mine El Salvador and the city of Chañaral. Approximate position of tailing canals, domestic wastewater discharge and bed of Rio Salado are presented. (Taken partially from Behncke, 1976.)

Fig. 1b Shore line between Chañaral Bay and Puerto Pan de Azúcar, showing area of study and old and new dumping sites.

Results and Discussion

Tailing discharges impact on the marine environment in Chañaral area affect: harbour activities, geomorphological coastal features, marine ecosystems, marine resources extraction and recreational activities. Maritime activities at Chañaral Bay are mainly the shipment of copper (at Barquito, south of the bay), iron (Santa Fe dock) and fisheries at Muelle Fiscal and Muelle de Pescadores. From 1938 to 1974 the total tailing discharge at Chañaral Bay reached an estimated 150 million tons. Several reports (Mission du Laboratoire Central d'Hidraulique, France, 1962; Rubio, 1968, 1970; Corniquel, 1969) established a significant reduction in depth of the bay and damaging effects on the buoy (abrasion). Despite moving the tailing discharge from Chañaral Bay in 1975, it appears those fine non-consolidated sediments continue to interfere with normal harbour activities due to current and wave action induced shifting of accumulations inside the bay.

The above mentioned reports have also established the existence of significant geomorphological alterations along the coastline of Chañaral beach. Corniquel (1969)

TABLE 2
Superficial temperatures and light extinction at the areas studied (polluted and unpolluted) in connection with copper tailing discharges from mine El Salvador, Chile (13, 14/7/1975).

	Puerto Pan de Azúcar (*ca* 15 km north of actual dumping site) unpolluted	Caleta Agua Hedionda (*ca* 2 km north of actual dumping site) polluted	Caleta Palito (actual dumping site) very polluted	Punta Achurra (*ca* 2 km south of actual dumping site) polluted	Bahia Chañaral (*ca* 7 km south of actual dumping site) polluted
Superficial temperature (°C)	13.4–13.5	13.0	13.2	12.5	14.0
Light extinction (Secci disc) (m)	7–10	2	0.6	2	2

Table 2 shows readings of two physical parameters: superficial temperature and light penetration at different geographical points of the area studied. Extinction of light at 0.6 m of depth in Caleta Palito reflects the abundance of solid suspension matter produced by tailing discharges. It can be seen that maximum penetrability of light is observed at Puerto Pan de Azúcar (control area) and that other points near the actual dumping site (Caleta Agua Hedionda and Punta Achurra) show important reductions in penetrability. Low values of light penetrability at Chañaral Bay reflect suspended sediment drives from past accumulations and not due to actual discharging.

Although an exhaustive ecological impact study was not completed, we think the data presented reflects accurately the damage the inter- and subtidal marine communities have incurred. The future resources of Chañaral undoubtedly depend on the sea due to the presence of upwelling areas and the consequent biotic richness. Tailing dumpings in the area are putting in jeopardy such a future for the area. Furthermore, recreational maritime activities have been substantially affected. The sea resort of Agua Hedionda (Fig. 1b) has disappeared as a consequence of the establishment of the new dumping site at Caleta Palito.

We feel that more research should be carried out in the area in order to study the re-utilization of large masses of tailing or domestic waste waters, following the design of irrigation systems in such an arid zone. Tailing ponds in El Salvador should be implemented as soon as possible. In addition studies should be initiated for chemical contaminant analysis of waters (Cu, As, CN^-) and for presence of solids. Monitoring systems should be implemented and basic ecological studies developed in the polluted and still unpolluted areas of Chañaral.

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pointed out that between October 1962 and March 1969 the 4.5 km long Chañaral beach had expanded seaward 130 m in the north zone and 100 m in the south. The artificial expansion was a consequence of 'fines' tailing sedimentation deposited on the beach. Regarding impacts on marine ecosystems, two situations can be discussed: environmental impact at Chañaral Bay by dumping from 1938 to 1974, and the impact at Caleta Palito, current dumping site since 1975.

The millions of tons of 'fines' dumped at Chañaral Bay and adjacent beaches have seriously affected marine ecosystems. Surveys carried out in 1975 and 1976 showed conditions of total biological sterility regarding sandy beach macrofauna. None of the species described for unpolluted beaches of the area (Behnke, 1976) or other Chilean sandy beaches (Castilla, 1975; Castilla *et al.*, 1977) have been found in the course of such surveys. Results from dives in the Bay of Chañaral during July 1975, at 10–12 m depths, showed a layer of fine unconsolidated sediment accumulated to 2 m in depth. Benthonic communities are seriously affected by large scale sedimentation. Katz *et al.* (1966) has shown that unstable habitats interfere with the normal development of a benthonic community. No sandy or rocky benthonic community as such was observed during the dives in Chañaral Bay. Planktonic communities in the area are felt to be affected by permanent suspension of solids, a result of wave activity, currents and other oceanographic phenomena occurring in the bay. Suspended solids interferred with light penetration and our Secci disc measurements showed extinction of light penetrability at depths of 2–3 m in the bay.

Due to the embankment at Chañaral Bay, tailing waste discharge was transferred to Caleta Palito in 1975. The new dumping site is the starting point of a sandy and rocky littoral zone which extends north with biologically rich marine intertidal and sublittoral communities. The pollution impact produced by solids sedimentation and chemical action (not yet exhaustively investigated) has substantially altered the littoral ecosystem. Massive fish and mollusc mortalities were reported at the new dumping site (February 1975) by local inhabitants a few days after the initiation of the discharging process. In July 1975 and July 1976 we detected massive mortality of organisms in the intertidal and subtidal areas. The species affected were: the starfish, *Stichaster striatus*; the limpet, *Collisella spp.*; the key-hole limpet, *Fisurella spp.*; the sea urchin, *Tetrapigus niger*; the crabs, *Hemigrapsus crenulatus* and *Homolaspis plana*; the 'loco', *Concholepas concholepas* and the fishes, *Sicyases sanguineus* and *Aphos porosus*, as well as several species of littoral algae.

Throughout the whole survey at Caleta Palitó we observed greenish slicks spreading over hundreds of metres of coast following the course of the predominant winds between Punta Achurra and Quebrada Rio Seco (Fig. 1b). The rocky and sandy areas near the new dumping site appeared covered by tailing residues which appeared detrimental to coastal communities. Furthermore, as predicted by the 1962 report of the Mission du Laboratoire Central d'Hydraulique, France, we observed that the Chañaral Bay is still being affected by the tailing discharges from Caleta Palito. This is due to the effect of local coastal seawater currents and to the constant change of winds in the area.

At Quebrada Río Seco, 8 km north from Caleta Palito we detected tailing residues in July 1976. Pyrite is easily detected for its tendency to float with water movements; consequently pyrite-sediments on rocks and sand have a peculiar 'pyrite-green' colour.

Up to July 1976, 13 million tons of solids had accumulated on the new dumping area. Our diving observations showed that due to the accumulation of these sediments the reduction of depths in the Caleta Palito area (from coastal line to 500–600 m offshore) ranged from 10–5 m. Therefore, major geomorphological coastal changes are currently in process at Caleta Palito.

Table 1 shows the main species of fishes, invertebrates and algae at the control rocky area of Puerto Pan de Azúcar (Fig. 1b), 15 km north of the dumping site. In July 1975 this area appeared free from the pollution effect of tailing discharges. Though low visibility from suspended solids (50–60 cm) impeded fish observations at Caleta Palito, examinations of macroinvertebrates and algae were reliable.

Results in Table 1 show that at the Pan de Azúcar area organic diversity and density of marine organism are high. According to our observations (in the intertidal and subtidal) we conclude that chemical pollution and sediment accumulation hinder the development of benthic invertebrates, algae and fish at the Caleta Palito area.

TABLE 1

Marine organisms observed utilizing SCUBA (July 1975) in rocky seabed areas in Puerto Pan de Azúcar (control area) and Caleta Palito (tailing dumping site).
Diving time at Puerto Pan de Azúcar 60 min., depths 2–8 m.
Diving time at Caleta Palito 30 min., depths 3–6 m.

Species observed	Common names	Number of organisms: Puerto Pan de Azúcar 50 m² (mean two replicates)	Number of organisms: Caleta Palito 50 m²
Fishes			
Cheilodactylus antonii	'bilagay'	9	?
Aplodactylus punctatus	'jerguilla'	33	?
Mugiloides chilensis	'rollizo'	25	?
Doydixodon laevifrons	'bauco'	65	?
Isacia conceptionis	'cavinza'	125	?
Paralichthys adspersus	'lenguado'	1	?
Invertebrates			
Stichaster striatus	'estrella común'	200	None
Meyenaster gelatinosus	'estrella júpiter'	4	None
Patiria chilensis	'estrella roja'	P	None
Concholepas concholepas	'loco'	225	None
Fisurella spp.	'lapa'	P	None
Collisella spp.	'lapa'	P	None
Achantopleura echinata	'chitón'	P	None
Homalaspis plana	'jaiba mora'	2	None
Cancer plebejus	'jaiba reina'	4	None
Balanus psittacus	'picoroco'	N	None
Tetrapigus niger	'erizo negro'	N	None
Pyura chilensis	'piure'	N	None
Sea anemones	'actinias'	N	None
Algae			
Lessonia nigrescens	'chascón'	P	None

N = numerous; P = present; ? = observations impeded.