Pesticides in tropical marine environments: Assessing their fate

Projects using nuclear techniques in Mexico and other countries investigate the effects of pesticides on aquatic ecosystems

by F.P. Carvalho and R.J. Hance

While forecasts of economic and population trends are notoriously contentious, it seems to be fairly widely accepted that there will be approximately 11 000 million people to feed in the year 2050, which is about twice as many as there were in 1990. Simultaneously the stock of agricultural land will diminish as a consequence of urbanization, erosion, and desertification. It has been predicted that the arable area per person, which was 0.3 hectares in 1981 will decline to 0.22 hectares in 2000 and 0.13 hectares in 2050.

There seems little doubt that pesticides will remain an essential component of many agricultural systems. Although it is estimated that insect pests alone still destroy about one-third of the world's crops, yields would probably decline by a further 30% to 75% without crop protection chemicals. It is hardly surprising therefore that worldwide pesticide usage is on the order of 5 million tons per year with a value of US $26 billion.

Undoubtedly agrochemicals will be used in more refined ways as increasing use is made of the various biological and cultural strategies but it is difficult to envisage their disappearance. Whether the current range of materials and uses will continue is less certain as far as developed countries are concerned. *(See graphs, page 17.)* Those used in developing countries seem unlikely to change rapidly simply on grounds of cost.

Environmental and health concerns

Unlike may other chemicals regarded as environmental pollutants, pesticides are deliberately added to the environment and are devised to be lethal to some organism or other. The lack of specificity of some pesticides and their irresponsible use in certain regions have produced undesirable side effects.

The case of DDT was the first to bring widespread publicity to the effects of pesticides on non-target organisms. The major adverse effects of DDT and other organochlorine (OC) pesticides have been to reduce reproductive success in birds. DDT can reduce egg shell thickness in several species so that hatchability is reduced sufficiently to cause a decline in their populations. In contrast, the major effect of organophosphorus (OP) pesticides, and to a lesser extent carbamates, has been direct mortality. The mechanism of action of these insecticides is to inhibit acetylchlorinesterase activity which causes the disruption of nerve function and eventual death.

Whatever the mode of action, by destroying or significantly reducing the populations of some species, pesticides may alter the structure (species richness, biological density, and diversity) and functional activities of an ecosystem. A change of particular concern arises when predacious species are affected so that populations of their prey expand unchecked.

Although the environmental occurrence of these chemicals may be more frequent in areas of manufacturing and application, reports of significant concentrations of pesticide residues in almost every region have increased rapidly during the last few years. Traces of pesticides have been measured in the atmosphere, in rainwater, in surface and ground water, in soils, and in food. Due to the widespread use of pesticides, most human populations receive a chronic exposure to low concentrations of pesticides in food and water. The possible effects of the continuous exposure of humans are almost impossible to evaluate because the quantities are so small and the number of permutations and com-

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At left: IAEA-MEL marine scientists conducting experimental studies on the behaviour of pesticides in a tropical lagoon in Central America. *Below:* The abundance of fish in waters off the coast of Malpelo island near Colombia. *(Credits: IAEA-MEL; Aldo Brando, Bogotá.)*

binations of compounds is large. Because chronic effects in laboratory animals have been observed for some of these compounds, albeit at levels of exposure several orders of magnitude higher, there is some cause for anxiety.

Better environmental management

Although it is necessary to protect crops from diseases, insects, and weeds, mankind cannot survive with only domesticated plants and livestock. Biota in the natural environment number probably between 5-10 million species. They are involved in a variety of essential activities including recycling organic and inorganic materials, stabilization of soil, purification of water resources, maintaining energy flows in ecosystems, pollination of crops and natural vegetation, and stabilization of climate. Because of these activities, most, if not all, of these species are essential for the maintenance of environmental quality and for the survival of life on Earth. Misuse of agrochemicals can put many species at risk and so jeopardize the preservation of functional ecosystems. Furthermore, improper use of pesticides can even present a direct threat to public health, and thus a more disciplined use of these substances is called for urgently.

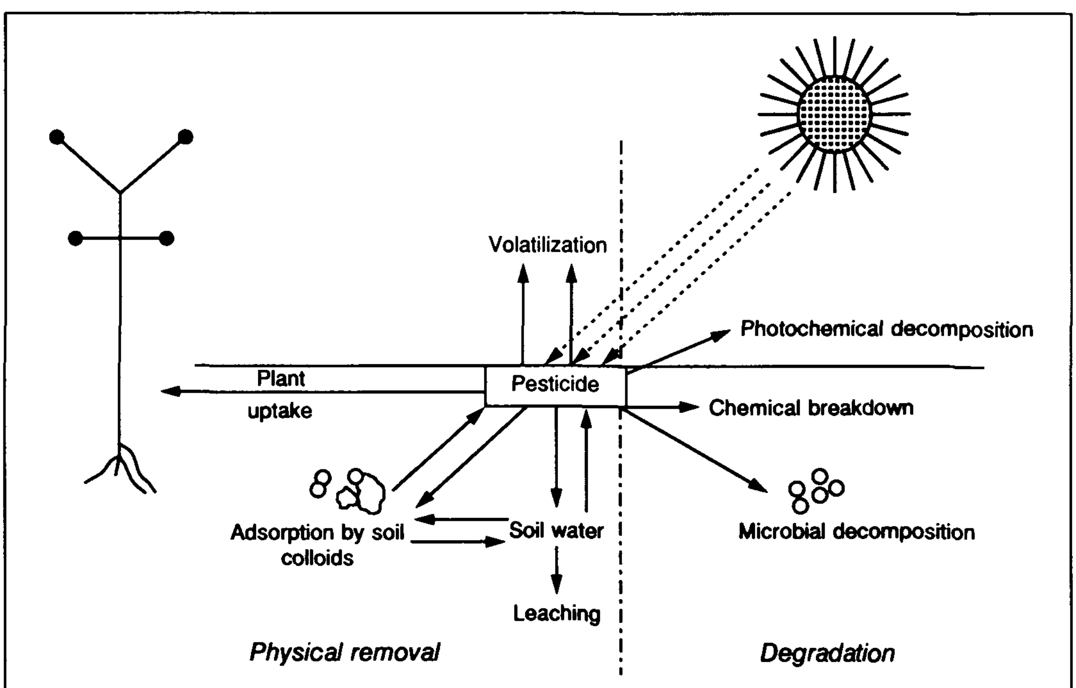
Acute poisoning of humans, except for suicides, is largely confined to rural workers and mostly results from exposure while mixing or applying pesticides. An estimate from the World Health Organization (WHO) puts the number of such occupational poisonings at one million per year of which 20 000 are fatal. These can largely be avoided by better compliance with safe handling recommendations, which requires better information and professional education programmes together with pressure on employers. Most countries now have legislation in place, or pending, in this regard. Such legislation also usually includes provision for the surveillance of pesticide residues in food and for the control of pesticide usage in agriculture.

Control of use not only should ensure the safety of food but also the environmental spread of pesticide residues. Unfortunately, many developing countries lack the resources to enforce pesticide related laws so these aims, however admirable, have yet to be achieved everywhere. Many small holders, spurred by the improved yields of crops as a result of pesticide use, apply excessive quantities of these products in the fanciful expectation of even greater production. One consequence is that substantial quantities of pesticides reach rivers and hence the sea.

Pesticides in the marine environment

The first generation of pesticides introduced over 40 years ago included the organochlorine compounds (OC), such as DDT, dieldrin, and toxaphene. By later standards they are unacceptably persistent in the environment although at the time of their introduction this property was considered an advantage. There has therefore

Processes acting on organic chemicals in the environment



been a shift away from these compounds, and their use is not permitted, or is severely restricted, in many countries.

The organophosphorus compounds (OP), like parathion, malathion, chlorpyrifos, together with the carbamate and pyrethroid compounds, have gradually replaced the OC pesticides. About 100 OP compounds are commercially available.

In general, OP pesticides are more toxic to mammals and invertebrates than OCs but are less persistent in the environment. However, each substance has a particular behaviour. Though it is known that environmental persistence depends upon ambient conditions — such as light, humidity, acidity, and microbial activity, all of which can contribute to the breakdown of a compound — in many situations the exact roles of these factors and their interactions are not known. The effects of these substances on non-target organisms, their accumulation by biota or their transfer to the higher trophic levels of the food-chain are also known in a general way. But predictions for specific circumstances can be uncertain.

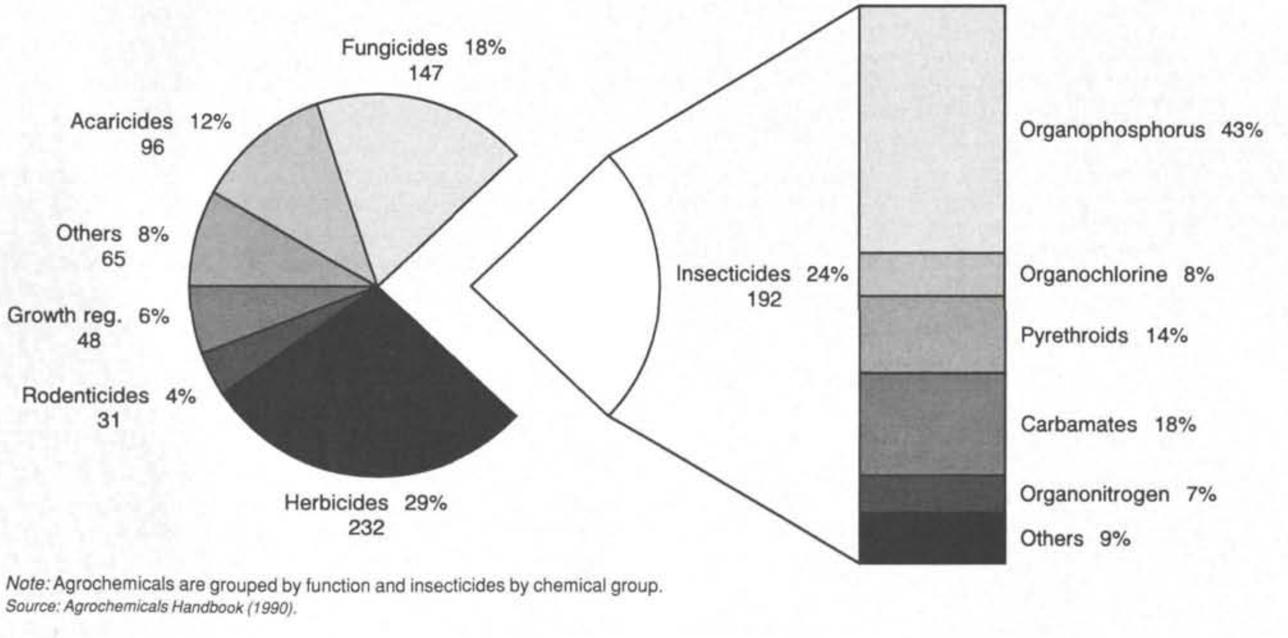
There is evidence that the OP compounds are sufficiently persistent to reach the marine environment at concentrations high enough to affect aquatic fauna and flora. They are toxic to invertebrates and vertebrate aquatic animals at very low concentrations (nanogram to microgram per liter levels). Shrimp and fish are particularly sensitive.

Data on the behaviour of pesticides in the tropical marine environment are very limited in comparison with information on the fate of pesticides in temperate regions. Preliminary surveys carried out by the IAEA's Marine Environment Laboratory (IAEA-MEL) in coastal lagoons in Central America indicate the presence of high concentrations of DDT and its metabolites in sediments and aquatic organisms. OP compounds, such as chlorpyrifos, were also found to be widespread contaminants in these lagoons.

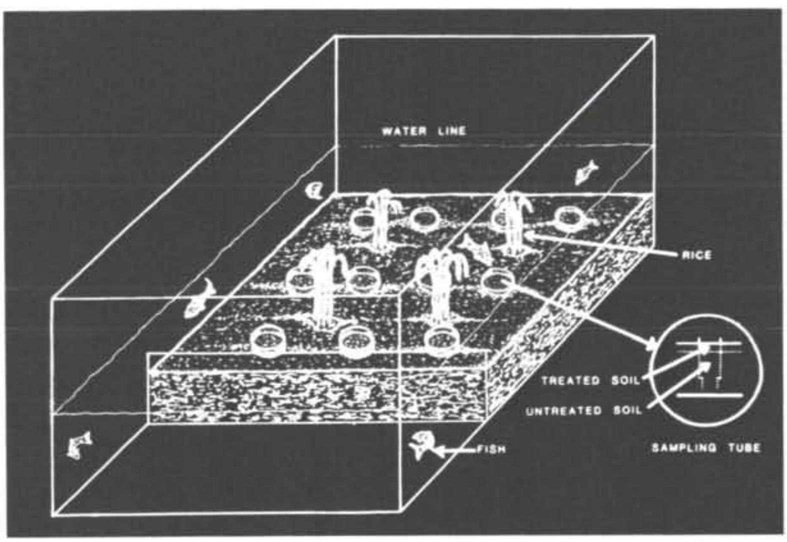
The presence of pesticides in coastal environments is not entirely unexpected since major agricultural areas are located in coastal plains and river valleys. However, OP compounds are generally considered to be of low persistence and thus their presence in lagoons is unexpected. However, occasionally massive fish and shrimp kills have been reported in estuarine and coastal lagoon ecosystems. Although the agents for this have not always been clearly identified, agrochemicals from adjacent agricultural fields have been suspected to be the lethal toxicants involved.

Estuaries and coastal lagoons are especially rich and diverse ecosystems, and usually provide nursery grounds for coastal fish and, through the export of organic matter into the sea, are important in controlling productivity in coastal areas. These ecosystems also provide optimal conditions for the growth of molluscs (oysters, clam, mussels) shrimp and fish, and thus are themselves important fishery resources. In many tropical countries (Japan, Mexico, Viet Nam), coastal lagoons are used for farming shrimp and oysters and so are important economic assets. Therefore, the preservation of these lagoon ecosystems and

Distribution of agrochemicals in commercial use



Note: Agrochemicals are grouped by function and insecticides by chemical group.
Source: Agrochemicals Handbook (1990).



An open rice paddy is a difficult experimental environment, and scientists frequently use models — such as the one of a rice-fish ecosystem shown here — in isotope studies of pesticides.

the improvement of coastal management policies are matters of considerable urgency.

Knowledge of the fate of pesticides in an environment is essential for risk assessment and management decision-making. There is embarrassingly little information about the fate and behaviour of pesticides in terrestrial and marine tropical environments with which to assess their potential effects.

Nuclear techniques in pesticide studies

In the study of the environmental fate of pesticides, the use of carbon-14 labelled molecules has for some years provided an invaluable tool for research in both terrestrial and aquatic environments. They allow a compound to be followed in experimental systems and for the unambiguous identification and quantification of transformation products at very low concentrations. Because only the radioactive carbon is measured, for many purposes sample clean-up is less rigorous than that required by other techniques such as chromatography. Consequently, a large number of samples can be processed rapidly and measured with standard liquid scintillation equipment at low cost.

The programmes of the Agrochemicals and Residues Section of the Joint Division of the IAEA and Food and Agriculture Organization (FAO), and the Agrochemicals Unit at the IAEA's Seibersdorf Laboratories, have always been heavily committed to the use of these techniques for studies of the behaviour and fate of pesticides, which involves investigation of biological, physical, and chemical processes. Even the study of each process in isolated laboratory systems is made easier by the use of compounds labelled by carbon-14. For example, the kinetics of the distribution between solid (adsorbed) and liquid (in solution) phases in the soil — although it can be studied in the short-term with unlabelled compounds — really requires the use of carbon-14 labelling if the study lasts several days in order to check whether or not decomposition has taken place.

When attempting to obtain an overall picture of all processes, the use of isotopes is almost essential. Clearly one cannot use radiolabelled compounds in the open rice field. But in an enclosed model ecosystem, radioisotopes can be used safely to estimate the distribution and persistence of a pesticide under controlled conditions. This information cannot, of course, be directly extrapolated to the field but it does tell us which compounds to look for and where they are likely to be found in subsequent field monitoring studies.

In an ongoing research project carried out by the IAEA-MEL in collaboration with the Marine Station of the Universidad Nacional Autónoma de México in Mazatlán, the behaviour of pesticides in tropical lagoons has been studied with the help of such techniques. The results have shown that, once introduced in the simulated lagoon ecosystem, OP compounds such as chlorpyrifos distribute rapidly between water and suspended particulates. The fraction of the pesticide bound to particulates is stabilized and persists for a long time, whereas that in solution is rapidly degraded by hydrolysis and microbial metabolism. The pesticide bound by suspended matter and the sediment can be slowly released and become available to benthic organisms.

Results obtained in mesocosm experiments which simulate tropical lagoon conditions indicate that low concentrations of OP pesticides (at microgram per liter level) produce massive shrimp and fish kills. Moreover, the accumulation of pesticides in the internal tissues of molluscs, shrimp, and fish was shown to occur very rapidly (minutes to hours), and to attain concentrations three to four orders of magnitude higher than the pesticide concentrations in ambient waters. It is assumed that the expected fast degradation of OP pesticides by the action of the high ambient temperature, photolysis, and high microbial biomass in the tropical lagoon environment did not occur because binding by sedimentary particles and organic matter protected them.

Incidentally, this is an example of a frequent feature of pesticide studies in that the result can be explained but could not have been predicted with confidence. In this case, adsorption (binding) reduced breakdown rates, presumably by reducing solution concentration of the pesticides and hence availability to microorganisms and photochemical reactions. However, it would be expected that the density of microorganisms near colloidal surfaces is greater than that in the surrounding solution. It is also known that some adsorption sites can catalyze degradation reactions. Both of these would increase degradation rates. There has been a large number of studies of the effect of adsorption on the persistence of pesticide in soils. In some cases, adsorption reduces degradation, in some cases it increases it, and in others it has no effect. It will be surprising if the same diversity does not occur in marine systems, since such observations can be explained on the basis of known mechanisms but they are not predictable with existing knowledge.

The outcome of the programme in Mexico highlights the need for further evaluation of contamination of tropical marine environments by pesticide residues. It is clear that, in order to assess the impact of pesticides in these ecosystems, we need to know more about their distribution, persistence, and fate, and of the factors which control the various processes.

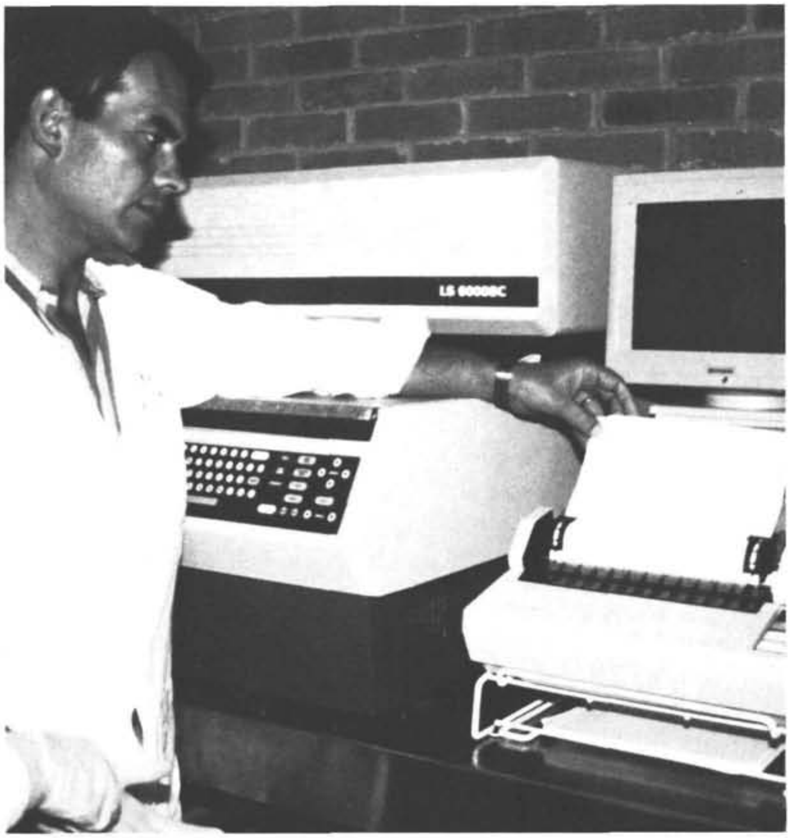
Future IAEA-supported research

To develop relevant studies, the IAEA is organizing a co-ordinated research programme (CRP) through its Laboratory at Monaco and the Joint FAO/IAEA Division. The CRP is entitled the Distribution, Fate, and Effects of Pesticides in Biota in the Tropical Environment; support has been offered by the Swedish International Development Agency (SIDA). It will concentrate on various aspects of the problem, including:

- a review of the current usage patterns of pesticides in selected study areas;
- the measurement of levels of residues in the marine environment;
- the breakdown and transformation of radiolabelled pesticides in model ecosystems, both marine and terrestrial;
- research on the partitioning of pesticide residues between different environmental compartments (water, sediments, suspended matter, biota, and atmosphere);
- micro-ecosystem experiments on the accumulation and effects of (radiolabelled) pesticides on fauna and flora of coastal regions; and
- modelling of the information generated and application to the development of the concept of "Integrated Coastal Zone Management".

The programme will include participants from about 15 Member States where pesticide research exists or is being developed. The results from this CRP should be instrumental in expanding the present knowledge of environmental contamination by pesticide residues in tropical coastal regions and in the assessment of the potential consequences.

Recommendations for improving the management of the sensitive ecosystems of tropical coastal areas will be formulated to help Member States implement practical measures to harmonize the interests of agriculture with the preservation of their aquatic resources. ❒



IAEA marine scientists provided training in radiotracer techniques to researchers in Mexico.
(Credit: IAEA-MEL)