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IMPACT AND AMELIORATION OF SEDIMENT AND AGRO-CHEMICAL POLLUTION IN CARIBBEAN COASTAL WATERS

THE FATE OF AGRO-CHEMICALS IN THE LAND WATER INTERFACE, WITH REFERENCE TO JAMAICA AND THE WIDER CARIBBEAN

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EXECUTIVE SUMMARY

- By its very nature, the small island agro-ecosystem is prone to contamination by Agro-chemicals.

- Agrochemical pollution in Jamaica is largely non-point source in nature, hence it has been very difficult to measure and research.

- The mechanisms for movement of pesticides and other contaminants are largely physical and dependent on rainfall events.

- Water bodies such as bays and harbours are the major environmental sinks or final destination for pesticide residues.

- Most studies in Jamaica tended to focus on organochlorine and organophosphate based pesticides.

- Pesticide contamination has been detected in river and estuarine shrimp and is believed to potentially have a significant impact on the reproductive health of fish.

- Little or no studies in Jamaica have been conducted on bioaccumulation of pesticides up the food chain.

- Kingston Harbour and in Particular Hunt's Bay are contaminated with pesticides.

- There is however a paucity of baseline data on the concentration of nutrients and pesticides in the coastal waters around Jamaica.

- Increased use of fertilizer and pesticides over a twenty (20) year period is expected to result in increasing levels of contamination of the islands coastal waters.

ACRONYMS

2,4D	1-chloro-2-dichloro-1-(4-chlorophenyl)ethyl-benzene
CMS	Centre for Marine Sciences
CU	Copper Fungicide
DDE	Dichloro-ethenylidene
DDT	1-Chloro-trichloro-ethylidene
EP	Ethprofos
ES	Endosulfan
GP	Glycophosphate
LC_{50}	Lethal Concentration of dosage resulting in 50% mortality exposed test animals
LC_{95}	Lethal Concentration of dosage resulting in 95% mortality exposed test animals
LD_{50}	Lethal Dosage of dosage resulting in 50% mortality exposed test animals
LATEC	Least Acute Toxic Effect Concentration
LOEC	Lowest Observable Effect Concentration
LWI	Land water interface
NOEC	No Observable Effect Concentration
OC	Organo-Chlorine
OP	Organo-Phosphate
Ppb	Parts Per Billion
PROTEC	Pronounced Observable Toxic Effect Concentration
RADA	Rural Agricultural Development Authority
SMB	Skin/Muscle/Bone fraction
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
UWI	University of the West Indies

1   INTRODUCTION

The purpose of this document is to provide a review of the literature of studies conducted primarily in Jamaica relating to monitoring of Agro-chemicals in the environment. The review will include studies on the impact of Agro-chemicals at the land water interface as well as bio-accumulation, breakdown rates and transportation rates of these chemicals in the environment.

Documentation of agrochemical contamination of the Jamaican environment is not very extensive, and is in the main limited to studies which have been conducted fairly recently. Much of the studies have been related to the use of pesticides on crops such as coffee and banana as well as the use of pesticides on smaller holdings such as hillside vegetable farms. Studies conducted by the departments of Life Sciences, Agriculture and Chemistry of the University of the West Indies have provided most of the published information on this subject.

The fate of Agro-chemicals at the land-water interface in Jamaican waters has also received comparatively limited attention. However work has been conducted in Kingston Harbour as well as a few other agricultural drainage basins. These will be discussed in this document.   Studies   which   examined   the   breakdown,   bio-accumulation   and transportation rates of Agro-chemicals will also be examined.

2 BACKGROUND

Agriculture is the production of crops and livestock, and the pollutants associated with it include sediment, nutrients, pesticides, pathogens and solid waste. Agricultural pollution has been an issue for several decades within the Caribbean region, and the impact of agrochemical pollution has recently received increased attention. The management of the impact of agrochemical pollution is very important to small island states. This is due to the fact that because of the relatively small landmasses of Caribbean islands, the coastal and marine environments are generally no farther than 5 to 10 kilometres from agricultural and urban development. Therefore, agrochemical pollution poses a significant challenge to the protection of the coastal and marine environments of the Caribbean islands (UNEP, 1998), which includes near shore and open-water habitats that can be affected by land based agrochemical pollution. For the purpose of this literature review, the main focus will be on pesticide and nutrient pollution.

Jamaica is the third largest island in the Caribbean Sea (1,140,480ha). Over 60% of its land in comprised of white limestone, the rest is made up of metamorphic rocks and alluvium. The island is divided into 20 watersheds (Appendix 1) which are drained by 19 major rivers (Mansingh *et al.,* 1997))

As mentioned previously, the farming systems utilized in Jamaica are similar to those of other small islands in the region. The two main systems are:

> The export oriented plantation system, characterised by monocultures on fairly large estates and generally occupying the most fertile land (Gumbs, 1981). The local crops which fall into this category are sugar, bananas, coffee and citrus.

> and

> The subsistence-based agricultural system, which is typically smaller than the plantation system and developed on the more marginal agricultural lands which are often on very steep hillsides.

There are other forms of agriculture which may be applicable to either of the abovementioned farming systems. Animal husbandry and aquaculture activities can also contribute significantly to the pesticide and nutrient loading of the environment.

Agrochemical pollution can be in the form of point source as well as non-point source pollution. Point source pollution is any form of pollution from a confined and discrete conveyance such as a pipe, ditch, well, concentrated animal feeding operation or vessel (UNEP, 1996). Examples of point source agrochemical discharge include industrial discharges (e.g., discharges from sugar factories, rum distilleries), banana washing and packing activities, fish farms and chicken farms. Non-point sources of pollution emanate from unconfined or unchannelled sources including agricultural runoff, drainage or seepage, and atmospheric deposition. The pollutants are carried off the land by surface water or through groundwater flows.

The main characteristics of non-point source pollution include the following (Ongley, 1996):

- They respond to hydrological conditions

- They are not easily measured or controlled directly

- They focus on land and related management practices.

Agrochemical pollution is largely non-point source in nature, and hence presents a difficulty to researchers with respect to the collection and interpretation of data. However enough data exist for scientists and planners to formulate strategies for the monitoring and management of agrochemical pollution in Jamaica and other small island states.

3   REVIEW OF LITERATURE

3.1   The Nature of Pesticides

Structurally, modern pesticides belong to four different chemical groups, the organochlorines (e.g., DDT) which includes chlordane, toxaphene, hepachlor, lindane, telodrin, dieldrin and endosulfan, the organophosphates (e.g., malathion, diazinon, etc), the carbamates (e.g., Sevin or carbaryl) and the synthetic botanicals (e.g., Pyrethoids). Each group of chemicals differ significantly in its spectrum of toxicity to different insects, mode of action, persistence in the environment and toxicity to mammals and fish (Mansingh, 1987).

The most persistent group of insecticides are the organochlorines, and often the focal point for concentration of residues are water bodies. This means that residues could persist in natural water bodies for periods ranging from 2 weeks (heptachlor & endosulfan) to more than 1 month (DDT) (Eichelberger and Lichtenberg, 1971). This presents a real threat to aquatic ecosystems including the estuarine and marine environment in tropical regions.

Mansingh (1987) highlighted the fact that water bodies are the major environmental sinks or the final destination for pesticide residues. This paper also stated that of immediate concern to Jamaica is the impact of residues on aquatic fauna, birds, livestock and humans. Fish and shrimp are extremely susceptible to endosulfan which inhibits their respiratory, metabolic and reproductive physiology. Birds usually abandon their nests in treated plantations and forests. The residues affect their reproductive physiology resulting in thin shells and mortality among chicks.

The use of pesticides in Jamaica and elsewhere in the Caribbean has been mainly on manufacturers' recommendations (not specific to tropical or temperate climates) with the mortality of the pest as the only criterion for increasing the dose or frequency of application of the chemical. In 1980, 312 types of pesticides were imported to Jamaica. Of that number 186 were insecticides including the persistent ones such as dicofol, dieldrin, aldrin, grammexane and chlorodane. (Aldridge and Irons, 1981). Several dangerous weedicides such as paraquat are still extensively used across the region.

Pesticides are subject to various forms of chemical degradation such as photolysis, hydrolysis, oxidation and biochemical metabolism by plants, micro and macro-organisms. The rate of degradation depends on the chemical nature of pesticides and degradation agents (Hill and Wright, 1978)

Little information on pesticide residue is available in developing countries but there is a general belief that such resides are likely to persist more in temperate countries than warm tropical countries (Mansingh, 1987).

3.2   Pesticides in Aquatic Systems

Most of the scientific work published by the University of the West Indies, Mona has been conducted on the fate and impact of various organochlorine pesticides (OCs) on the environment.   Much of the research has tended to focus on organochlorine and

organophosphate (OPs) based pesticides and their impact on river systems within particular watersheds or drainage basins.

An island-wide survey of major rivers, springs, and wells was conducted by Witter *et al.* (1998), in order to determine the level of organochlorine and organophosphate pollution of these freshwater systems. Residues from water and sediment from 26 locations in 17 major rivers, 7 natural springs and 13 wells across Jamaica were collected and analysed. Insecticide residues were detected in 14 of the 17 major rivers, 4 of 7 natural springs and 8 of 13 wells and this is a reflection of the widespread use of pesticides in Jamaican watersheds and plains, and the transport or residues by leaching and run-off, which are aided by rainfall and massive soil erosion. The study confirmed the predominance of endosulfan residues in many of the rivers. Comparisons with previous studies showed that a significant reduction in concentration of insecticides such as DDT, DDE, aldrin, lindane and chlordane had occurred which suggests a reduction in the use of the formerly problematic pesticides.

Martin (1999) looked at insecticide residues in the rivers of two watersheds in Jamaica. The study looked at the Black River and Yallahs River watersheds, the types of crops grown and the amount of pesticides used. The study showed that the majority of the farms in the black river area were smaller than 4 hectares, the farms were either on steep slopes or gentle slopes and grew mostly yams, coffee, bananas, citrus and sugarcane. The most widely used pesticide was 2,4D used on sugarcane. The quantities ranged from 5.77 kg ha^{-1} annum^{-1}, in the Lower Black River and 4.17 kg ha^{-1} annum^{-1} in the Upper Black River. Endosulfan was applied to coffee at a rate of 0.39 kg ha^{-1} annum^{-1} in the Hector's River Valley and 0.0016 kg ha^{-1} annum^{-1} in the One Eye River Valley (Yallahs River Watershed). Diazinon and dieldrin were also used in the watersheds at a rate of 0.02 and 0.0077 kg ha^{-1} annum^{-1} in the One Eye River Valley and 0.0026 kg ha^{-1} annum^{-1} dieldrin in the Hector's River Valley.

The farms in the Yallah's River Valley were mostly small farms (<4ha) on steep slopes. Coffee was grown by the majority of farms thus endosulfan, copper fungicides and glyphosphate were the most heavily used pesticides. These chemicals were applied at a rate of 1.3 (ES), 4.98 (Cu),1.98 (GP) kg ha^{-1} annum^{-1} in the Upper Yallah's River Valley. Diazinon was also used in the watershed at a rate of 0.852 kg ha^{-1} annum^{-1} in the Upper YR Valley. Pesticide use in the Lower YR Valley was much lower, paraquat, dimethoate and copper were applied at rates of 0.36,0.27,0.62 kg ha^{-1} annum^{-1} respectively.

The study showed that residues of α and β-endosulfan, sulphate, dieldrin and diazinon were present in the two watersheds. Levels of ES were generally higher during wet periods than dry periods and during spraying periods. Approximately 20% of samples from the Yallah's River and 11% from the Black River watersheds exceeded the USEPA maximum of 0.22 μg/L for the protection of aquatic life.

Robinson and Mansingh (1999) also looked at the effect and transport of OC and OP compounds from coffee plantations to the coastal waters of Eastern Jamaica. The study was conducted on the north eastern slopes of the Blue Mountains. The watershed is drained by dozens of seasonal streams and rivulets and a few small rivers which discharge into five major rivers - Driver's, Rio Grande, Swift, Spanish and Buff Bay. OC residues were detected in only Spanish and Swift Rivers and coastal waters, but not in Rio

Grande. Residues of OPs were not detected in any river or coastal samples while carbamates, pyrethroids, herbicides and fungicides were not determined. Both the α and β isomers and endosulfan sulphate were detected in 0-70% of the water and sediment and 0-60% of fauna samples collected from the Spanish and Swift rivers and the coast. Dieldrin residues were detected only once in the Spanish and Swift rivers. The mean range of α and β- endosulfan and endosulfan sulphate residues detected in the river and coastal fauna, and in water and sediment samples were often above the tolerance levels of many fish species.

Endosulfan sulphate is sequestered rapidly from the sediments by aquatic fauna, from the results of this study it was estimated that there was a five to twenty-five fold bioaccumulation of residues from the aquatic environment by shrimp and fish.

Martin *et al.* (1995) looked at organochlorine residues in surface waters and sediment of the Black River. Water and sediment samples were collected on 17 occasions between July 1989 and October 1992 and, from 16 locations along the Black River and analysed for the isomers of endosulfan (alpha and beta), its toxic metabolite (endosulfan sulphate) and dieldrin. Endosulfan was primarily used for in coffee cultivation and dieldrin used for the control of root weevils in citrus. The study showed that 33 water samples collected from the rivers of the watershed had more than 0.22 μg/L of endosulfan residues (EPA standard), but none were found to exceed the standard for human health (74 μg/L). 18 water and sediment samples exceeded the recommended dieldrin residues set by EPA for human health, however the levels did not exceed the 2.5 μg/L tolerance level for aquatic fauna. The frequency of detection of all residues was higher in the spraying season than at any other time of the year.

3.3 Pesticides and Shrimp

Henry (1985) examined the organochlorine residues in a Jamaican River and uptake elimination by the shrimp, *Microbrachium faustinum* de Sassure. Residues for some organochlorine insecticides used for crop protection in the Rio Cobre Basin were detected in water, sediments and shrimp fauna of the adjacent Rio Cobre. The greatest amount of residues recovered were DDE in water, shrimp and sediment samples. Lindane and endosulfan residues were recovered only from sediment and shrimp samples. The pattern of pesticide input in this study reflected the contamination via run-off from nearby large estates, and not form small farms on hills. The small farms were largely responsible for erosion problems in the basin.

In the lab studies on the shrimp *Macrobrachium faustinum,* individuals showed acute toxicity symptoms of agitation, uncoordinated movement, hyperactivity, leaping (avoidance) and eventually death (Henry, 1985). Chronic symptoms of sluggishness leading to death were observed at concentrations of 1ppb of dieldrin. The major site for residue accumulation after 24 hr exposure to 0.01ppb dieldrin was the hepatopancreas, followed by gonads, gills, large claw, exoskeleton and muscle. Shrimp exposed to this level of dieldrin for 24 hrs were shown to eliminate 50% of the residues within 8 days after a return to uncontaminated water.

Lawrence (1985) examined organochlorine residues in Rio Cobre, Jamaica and the effect of dieldrin on the physiology of shrimps. In this study, shrimp, sediment and water

samples were collected on a monthly basis between July 1982 and August 1983 at three sites on the Rio Cobre and two of its tributaries. The water samples were analysed for pesticide residues, including DDE, dieldrin, α and β endosulfan (es). Residues were found in shrimp (ranging from trace-33.9 ppb DDE, trace-23.8 ppb dieldrin trace-1.37 ppb α-endosulfan). The sediment concentrations for all residues were considerably higher. Only dieldrin (6.17-270 ppb) was recovered from water samples. The sulfate derivatives of endosulfan are of particular concern to the ecology of Jamaica. They are very stable and have the ability to concentrate in organic sediments. The coastal mangrove community can become a sink for endosulfan phosphates. There was some evidence of bio-concentration of residue by shrimp. The effect of dieldrin on the active and resting phases of the shrimp was examined. Pesticide residues were observed to cause reduced mobility (increased resting phase) in shrimp. Ventilatory reversal rates, an index of respiratory stress, were 6.7 times higher than the control value.

Organochlorine residues in the rivers, sediment and shrimps of the Rio Cobre basin were monitored between 1982 and 1996 by the Pesticide and Pest Research Group (Mansingh *et al*, 2000). The detection of pesticide residues in shrimps, that were sampled in the four rivers ranged from 83 to 100% of per sample. The data revealed that the frequency of detection of endosulfan in shrimp has been increasing since 1989, however pesticides such as diazinon, dieldrin and lindane were not detected in shrimp sample from the Rio Cobre. This may be due to a gradual decrease in the use of these pesticides during the past fourteen years.

Effect of Pesticides on Fish

Walker (1997) examined the toxic effects of selected insecticides on Jamaican red hybrid *Tilapia nilotica*. The study looked at the No-Observable-Effect-Concentrations (NOECs) and Lowest-Observable-Effect Concentrations (LOECs) of isazofos, profenofos and diazinin for red hybrid tilapia, which were 0.15 (0.2 ppm); 0.5 (1.5-3.0 ppm) and 24-49.99 (50 ppm) respectively. LOECs caused typical organophosphorus poisoning symptoms ranging from darting, shuddering, uncoordinated movement to lethargy. The acute toxicity concentrations, as reflected by the 24hr LC_{50} and LC_{95}, were 0.36 and 46 ppm of isazofos, 4.69 and 17.23 ppm of profenofos and 71.65 and 120.81ppm of diazinon respectively.

When exposed for 1-72hr to a sub lethal concentration of 0.15ppm pf isazofos, the fish accumulated maximum residues of 68.21 ppm within 8 hrs. The concentration then significantly declined to 25.56 ppm over the next 16hrs. Similar exposures to a sublethal concentration of 17.6 ppm of diazinon resulted in significant and maximum accumulation after 4hrs of 56.61 ppm followed by rapid decline to 17.17 over the next 4 hrs.

Distribution of isazofos with the fish after 24hrs exposure to sublethal concentrations was maximal in the gut (50.47%) followed by gills (24.99%)>skin/muscle/bone fraction (SMB 16.1%)>gonads (8.44%). However, following the 24hr exposure to sublethal concentrations of diazinon, residues partitioned mainly into the SMB(60%)>gut>gills>gonads.

Williams and Chow (1993) carried out tests to establish the toxicity of endosulfan to the mangrove guppy *Gambusia puncticulata* Poey, a common fish in Jamaican mangrove

environments. Toxicity tests revealed that the 24hr LC_{50} for endosulfan in the mangrove guppy was 0.050 ppb, concentrations of 0.1ppb resulted in an instant reaction in the fish and 100% mortality within 1 hour.

The bioaccumulation of endosulfan by *Tilapia nilotica* was investigated by Robinson *et al.* (1997). The accumulation rate, elimination and metabolism of endosulfan by *Tilapia* was assessed. Fifteen fish were added to each tank and three fish removed from each tank at 1, 8, 24, 48 and 78 hrs after exposure to 0.0075 ppm endosulfan to determine the concentration of endosulfan in the tissue. Similarly 15 fish were exposed to 0.015ppm of endosulfan for 24 hrs after they were transferred to two fresh water aquaria for 2 min each for rinsing. They were then placed in a 20L aquarium with uncontaminated water to determine the rate of elimination of the insecticide. Three fish were removed immediately and thereafter, 1, 4, 8, 24, 48 and 72 hours after.

The fish tissue for analysis was blended with petroleum ether for residue analysis. The results of the experiment show that 95-100% of α-endosulfan and β-endosulfan were accumulated within an hour of exposure to the insecticide, with the maximum amount being accumulated after 4 hrs. The formation of endosulfan lactone and endosulfan sulphate (two metabolites of endosulfan) occurred within 1 and 4hrs of exposure to the insecticide.   Even with the production of metabolites, only 26-39% of the initial concentrations of α- and β-endosulfan were eliminated by the fish within 72 hrs after being placed in uncontaminated water.   The concentration of endosulfan sulfate increased steadily after they were introduced to the uncontaminated water. This indicates that the route of elimination of endosulfan is metabolism followed by excretion.

The order of partitioning of endosulfan in the fish was gonads>liver>gut>gills>skin/muscle/bone.   It is pertinent to note that endosulfan is accumulated in the tissues of *Tilapia* very rapidly but it is eliminated much more slowly. This, together with the fact that the endosulfan sulphate metabolite, which is just as toxic as the parent compound, is also produced and accumulated by the fish. This leads to the speculation that the extensive use of endosulfan in Jamaica is responsible for the reported decline in fish and shrimp populations in rivers.

The ecotoxicity of sub-lethal concentrations of endosulfan on Tilapia and its impact on the reproductive physiology of the fish was investigated by Williams *et al.* (1999). The 28 day sub-lethal toxicity of endosulfan to Tilapia (9-14 cm long: 20-40g) was assayed under static conditions in continually aerated glass aquaria containing 20L of dechlorinated water and 15 fish at 27-28 ^{0}C.   The fish were assayed with the following concentrations of endosulfan 0.0005, 0.0075, 0.008, 0.009 and 0.01, and were assayed in three replicates and repeated. Symptoms such as darting, shuddering, side-swimming and death were observed over time.   These observed results were categorised into different toxicity concentrations: the no-observable-toxic-effect-concentration (NOTEC), least-observable-toxic-effect-concentration (LOTEC), pronounced-observable-toxic-effect-concentration (PROTEC) and least-acute-toxic-effect-concentration (LATEC).

At the end of the period (28 days), three fish from each replicate were removed and assayed. Whole body parts or gonads were cut into small parts and extracted with a chloroform-methanol mixture. The toxicity data suggest that 0.0025-0.05 ppm may be defined as NOTEC, the 0.008 ppm dose LOTEC, 0.009 ppm PROTEC .

The lipid content of the gonads changed significantly over the 28-day period when exposed to NOTEC, LOTEC, and PROTEC of endosulfan (19.5, 53.96, 67.5% respectively). The overall decrease in total lipid may indicate increased lipid hydrolysis to produce the energy required to overcome pesticide stress.

3.4 Pesticides and Coastal Pollution

In 1985, the first monitoring of pesticides in the marine environment found traces of endosulfans (0.3-0.4 ppb) and dieldrin (0.05 ppb) in water samples from Hunt's Bay and the Hellshire coasts of the Kingston Harbour (KH), a 50km^2 bay which receives its freshwater from the Rio Cobre.

The SENTAR report on the pollution of Kingston Harbour addressed the issue of pesticide contamination (Chapter 11). The report confirms that pesticidal contamination of the coastal waters of the Kingston Harbour had been suspected for quite some time. Residues of seven insecticides were detected in the water and sediments, two of these (endosulfan and diazinon) are widely used in Jamaica, and the others were banned pesticides. Residues detected in Hunt's Bay sediments were generally higher than those from the Inner Harbour or Port Royal, of which endosulfan was the most frequently detected pesticide.

Though endosulfan was the most widespread insecticide in the coastal waters, the fish and oyster contained only diazinon and aldrin residues. Endosulfan is readily hydrolysed in water to non-toxic diol but in soil it is degraded to the highly toxic endosulfan sulphate, which is readily bioaccumulated , particularly by mussels.

The report highlighted the need for further studies, including monitoring of pesticide residues in the coastal waters of Hunt's Bay and Port Royal, as well as investigations on the acute and chronic toxicity of residues to fauna during different periods of agricultural activity.

Mansingh and Wilson (1995) carried out a baseline study on the status of insecticidal pollution of the Kingston Harbour. The study was conducted on the organochlorine (OC) and organophosphorus (OP) residues in the Kingston Harbour in an attempt to assess the level of pesticide pollution within this system. The study showed that residues of six OC's (endosulfan, DDT, dieldrin, aldrin, endrin and lidane), of one OP (diazinon) and of one hydrocarbon were detected in water and sediment samples taken from stations within the harbour. The origin of most of the residues may be traced to the Rio Cobre, which is the only river entering the Kingston Harbour. The levels of endosulfan in the sediments and water of the harbour and in particular Hunt's Bay were very high and often exceeded the lethal exposure limits for various fish species.

The detection of high levels of pesticide residues can be attributed to the cultivation of bananas, citrus, coffee, sugar cane and vegetables concomitant with the heavy use of pesticides and fertilizer in the watershed. Weekly sampling of the Harbour for a month in July 1992 revealed the following maximum and mean residue levels in water (μg l^{-1}) and sediments (ng g^{-1} results in parentheses) respectively: α-endosulfan, 8.56 and 2.18 (1 and 0.52); β-endosulfan, 15.7 and 7.86 (0.76 and 0.4); endosulfan sulphate, 0.0003 and 0.0003 (0);DDT, 7 and 7 (0.04 and 0.35); dieldrin, 3.75 and 1.88 (0.001 and 0.001); aldrin,

0 (36.7 and 9.2); endrin, 0.93 and 0.26 (0.006 and 0.006); lindane, 0 (0.8 and 0.5); and diazinon, 0.1 and 0.05 (0.007 and 0.045). Oysters and fish were also contaminated with α-endosulfan, diazinon and aldrin. The insecticide residues detected in the harbour may have an effect on and are likely to be detected in various marine fauna within the harbour.

Further work in Hunt's Bay and Hellshire coasts confirmed the presence of chlorpyrifos and endosulfan (α and β) and endosulfan sulphate in both the water column and sediments. The concentration of residues in the sediment were markedly higher than those in the water column (Mansingh, 1996).

The potential for agrochemical pollution of the Kingston Harbour from terrestrial runoff from major freshwater inputs was addressed as far back as 1961 by Goodbody. While not dealing directly with the impacts of agrochemical pollution, the paper discussed the mass mortality of marine fauna in the Kingston Harbour and Port Royal mangroves after a massive rainfall event. In 1956 between the 12th and 15th of October, 214 mm of rain fell in 72 hours. This event resulted in the flooding of the harbour and its lagoons with massive amounts of fresh water; entering as river flow, as drainage from the mangrove swamps and as direct rainfall on the surface. Therefore there is a high possibility for the rapid introduction of pesticides into the harbour from the agricultural basins (such as the Rio Cobre), following a high rainfall event.

In Jamaica and the wider Caribbean there have been limited studies on the direct links between agrochemical pollution, reduction in coastal water quality and the degradation of coastal living resources (Rawlins *et al.,* 1998). There is a paucity of baseline data on the concentration of nutrients and pesticides in the coastal zone. The increase in use of agricultural fertilizers and pesticides over the last 20 years suggests a concomitant rise in their loads to the coastal waters. For example total fertiliser use in 1961, 1978 and 1995 was reported as 13,506, 15,962 and 27,000 (Million Tons) respectively. Pesticide imports over the same period were valued at US $1,098,000, $666,000, $8,500,000 respectively. The types of agricultural practices that persist in small island states such as Jamaica, would prove the aforementioned assumption correct. Mansingh *et al.* (1997) postulated that coastal ecosystems on small islands throughout the Caribbean are particularly prone to soil erosion and contamination by agricultural chemicals for the following reasons:

- steep hillsides with thin soil cover are tilled using poor agronomic practices, leading to soil erosion.

- there are many small holdings with mixed cropping which require a wide variety of pesticides.

- intense rainfall leaches nutrients and pesticides into streams

- agriculture occurs predominantly in the coastal zone.

With this in mind there is no doubt that an increase in the concentration of Agro-chemicals in the land water interface has occurred over time.

Aiken and Jupp (1985) reported on a fish kill in St. Thomas, Jamaica. Significant mortality of a particular type of fish called Pinchers (*Harengula jaguana*) was seen in nearshore

waters near Yallahs, Cow Bay and Grant's Pen. From the limited data that was collected, a number of probable causes of the fish kill were postulated. They were as follows;

- Various algae which are potentially toxic could have caused the fish kill;

- One or more unidentified viruses which are specific for Pinchers; and

- Organochlorides/organophosphates possibly from agricultural sources.

In their conclusions they emphasised that no one causative agent could have been determined, and there may well have been a number of factors acting together.

Studies by Robinson and Mansingh (1999) also confirmed the presence of endosulfan, dieldrin, and pp'-DDE (a breakdown product of DDT) in the coastal waters of Portland.

3.5   Fate of Pesticides in Tropical Environments

The use of pesticides in tropical and developing countries has increased rapidly over the past 25 years. In Jamaica, increased pesticide use has not been accompanied by a parallel growth in scientific data on the environmental fate of these pesticides in tropical agroecosystems (Singh *et al.,* 1991). Studies on the persistence, degradation, bioefficacy, transportation and fate of pesticides have been conducted by researchers.

Physicochemical studies on dieldrin and vamidothion were carried out under laboratory and field conditions, characteristic of tropical agro-ecosystems. Laboratory studies included measurement of spectral characteristics and rates of volatisation, hydrolysis, photolysis and leaching in soils. Field studies included measurement of dissipation rates of endosulfan and dieldrin in coffee and citrus plantations and vamidothion in coconut (Dasgupta *et al.,* 1996).

Volatility from E.C. formulations on glass surfaces 30^0C were in the order α-endosulfan>dieldrin>β-endosulfan, hydrolytic degradation rates of endosulfan at 300°C decreased with pH in the sequence pH 9.5 ($t_{1/2}$0.04 days)>pH 7.0 ($t_{1/2}$25 days)>pH 4.5 ($t_{1/2}$ $\approx$90days). Hydrolysis of dieldrin was insensitive to pH, over the same range $t_{1/2}$ $\approx$95 days. Photolysis rates using a mercury lamp were dieldrin ($t_{1/2}$ 2.5 hrs)>b-endosulfan ($t_{1/2}$ 3.5 hrs)>a-endosulfan ($t_{1/2}$ 20hrs) for hexane solutions and in aqueous solutions, dieldrin ($t_{1/2}$ 1.7hrs)> β-endosulfan ($t_{1/2}$ 33hrs)> α-endosulfan ($t_{1/2}$ 48hrs).

Photolysis rates in sunlight were in the same order. Over 90% of endosulfan and dieldrin was removed in the 0-5cm layer of soil when leached with up to 100cm water.

This study showed that the rates of hydrolysis of endosulfan are markedly pH dependent with apparent base catalysis, while dieldrin is resistant to hydrolysis between pH 4.5 to 9.5. It was found that vamidothion residues accumulate mostly in the water of immature coconuts after injection of the chemical into the trunk of the palm. A waiting period of about 3 months after injection might be required before these nuts can be safely consumed.

Both the field and laboratory observations show that although dieldrin will be much more persistent in the tropical environment than endosulfan, the major pathway of loss for both chemicals will be volatisation. Similar work conducted by Singh *et al.* (1991) also examined the dynamics of pesticides in tropical conditions. Kinetic studies on the degradation of dieldrin, and α and β endosulfan were carried out under laboratory conditions that simulated tropical conditions.

Anderson (1987) examined the bio-efficiency and perspective of insecticide in different types of Jamaican soils and their effect on soil fauna. The study examined the bioactivity of two organochlorine and six organophosphate insecticides on adult *Tribolium confusum* in 10 types of Jamaican soils. The study showed that the relative toxicity of insecticides varied in different soil types. Chlorpyrifos was the most toxic insecticide in all soil types. The study also showed that soil moisture content and temperature had a direct effect on toxicity of OPs and OCs to varying degrees and this was also dependent on soil type. The persistence of insecticides were dose dependent and revealed a decreasing order of carbaryl (Sevin©)>OCs>OPs.

Robinson (1997) looked at the fate, biological impact and management of ethoprofos and endosulfan residues in the Jamaican environment. Quantities of ethoprofos (EP) and endosulfan (ES) were leached with 1L of water through soil columns of different grades, Valda Gravelly Loam (VGL), Cuffy Gully Gravelly Sandy Loam (CGGSL), and Linstead Clay Loam (LCL). The leached quantities of EP and ES which were tested ranged between 67.0 - 81.5% and 2.9 and 9.1% respectively.

Surveys in 1990 and 1991 revealed insecticide contamination of Swift and Spanish rivers and their coastal waters. Residues of ES in water sediment and fauna ranged from 0.42-7.12 μg/L, 8.64-28.1 mg/g and 28.1-141mg/g respectively. A one time random sampling of 17 rivers, 7 natural springs and 13 wells revealed residues of ES in all but 3 rivers.

The conclusions of the study were that EP leached readily through soil, and its rate of leaching was 15 fold greater than ES. Organic matter exerted greater influence in the leaching of ES, while clay content exerted greater influence in the leaching of EP. The order of run off through different soil types was CGGSL<LCL<VGSL. Run off of the insecticide was directly proportional to the slope. An increase in slope from 15° to 25° resulted in up to 20% increase in run off. It was also found that natural vegetation on the slope reduced run off of ES and grass bands reduced the run off of EP and ES. Volatisation of ES from the soil was greater than that of EP. The rate of degradation of EP in soil was not significantly affected by the presence or absence of sunlight. However the degradation of ES was significantly faster in sunlight. The random survey showed that several of Jamaica's water resources (rivers, springs, wells) are contaminated by insecticides, endosulfan being one of the most frequently determined contaminant.

This study also looked at the effect of the pesticides in Tilapia, ES being more 271 times more toxic than EP. Bioconcentration of ES was much higher than EP and ethoprofos was eliminated much faster than ES from the body of the fish. Partitioning of the insecticides in the tissues of the fish were of the order gonads>liver>gut>gills>SMB.

More studies on the fate and transport of ethoprophos (Robinson *et al.,* 1999) showed that the hydrolytic half lives of ethoprophos in distilled, river, brackish and open sea water,

were 25, 133, 65 and 81 days respectively. Under laboratory conditions volatisation of the residues after 12 hours was 1.4-3.6, 2.3-4.5 and 6.5-20.2% from a sandy loam soil with 1, 10 and 20% moisture levels respectively. Photolysis in soil was considerably faster in direct sunlight ($T_{1/2}$ of 4.7 days) than in the shade ($T_{1/2}$ of 12.3 days). Microbial degradation of ethoprofos was also faster in unsterile soil than in sterile soil.

Studies on the persistence of pesticides in soil were also conducted by Gayle (1989), who investigated the bioefficacy and persistence of certain insecticides in three Jamaican soils. The bioactivity and persistence of 3 pyrethroids (decis, permethrin and phenothrin) and two organochlorines (dieldrin and chlordane) in three types of Jamaican soils, Chudleigh Clay Loam (CCL), Syndenhem Clay Loam (SCL), Marvelly Sandy Loam (MSL) at three different moisture levels (5, 10, 15%) were assayed with adult *Tribolium confusum*.

The results of the study showed that bioactivity of the pyrethroids was not much affected by soil water contents, however increased soil moisture enhanced the toxicity of the organochlorines. Under laboratory conditions the persistence of the insecticides as determined by LT_{50} for *T. confusum* depended upon soil type, moisture and concentration of insecticide. The insecticides were generally more persistent at a higher dose, lower moisture level and in clay loam rather than sandy loam.

Comparative studies were conducted in Trinidad and Tobago by Deonarine (1980) on the biomagnification of chlorinated hydrocarbons in the Caroni mangrove swamp. The study looked at the trophic structure of the Reeds area of the Caroni Swamp. In addition, it attempted to determine if there was any evidence of food chain concentration of chlorinated hydrocarbon residues in the environment. The results showed that the presence of chlorinated hydrocarbon contaminants such as Arochlor 1254, dieldrin, heptachlor epoxide, DDT and its metabolites and endrin was confirmed within the study area. The study was however unable to clearly demonstrate a bioaccumulation effect of pesticides in the food chain. While a clear increase from detritivores to carnivores could not be shown, there were higher concentrations of chlorinated hydrocarbons detected in herbivores and omnivorous organisms such as *Callinectes rapidus*, (Blue crab) *Tilapia mossambica* and *Mugil carema*. (Mullet) These elevated concentrations however were not demonstrated in their food which included algae and/or detritus. It was also found that residues were not found to be concentrated in carnivores such as *Arius* spp (Catfish), *Centropomus* spp (Common Snook) and *Batrachoides urinamensis*. (Toadfish).

While there has been limited work on the fate of Agro-chemicals in the land water interface in Jamaica, extensive work has been conducted on the fate of pesticides and other Agro-chemicals in soil and rivers. The effect of Agro-chemicals on aquatic organisms and land based pests have also been studied, primarily by the Pest and Pesticide Research Group at the University of the West Indies. For example an extensive monitoring programme of four main rivers of the Hope River watershed. Monitoring revealed the presence of endosulfan in 29-57, 40-60 and 9-55% of the samples in 1989, 1990 and 1991 respectively. Diazinon was detected in 14-29, 0-10 and 0- 9% and dieldrin 0 -14, 0- 46 and 9- 46% of samples in the same years. In many cases the levels were found to be above the LC_{50} values for several aquatic fauna (Mansingh *et al.*, 1995).

3.6 Non Point Agricultural Nutrient Pollution

Non-point agrochemical pollution of the coastal environment is usually in the form of nutrient loads from fertilizer use as well as improperly treated sewage. The input from major rivers and agricultural drainage basins along the coast of the island is responsible for much of the eutrophication of the coastal waters. Typically the loads of nutrients discharged from arable lands are an order of magnitude greater than those discharged from pristine forested areas. When the nutrient assimilation capacity of receiving water bodies is exceeded, what results is the deterioration of the water quality. This takes the form of algal blooms, reduction in water clarity and reductions in dissolved oxygen concentrations (Rawlins *et al.,* 1998).

It is often difficult however to separate the nutrients derived from agricultural and sewage sources. Research conducted at Hellshire Bay identified three principal sources of nutrients: Kingston Harbour storm gullies, agriculture and (sewage) contaminated groundwater (Goodbody, 1989).

One approach to assessing nutrient loads of agricultural origin is to compare the amount of fertiliser imports into the island over time. The trends are then used to make inferences on the average annual use of these fertilisers, and its relationship to the level of coastal eutrophication (Rawlins *et al.*, 1998).

Much of the studies on the effect of nutrients on coastal water quality, have not focussed on input from agricultural activities. The studies conducted in Kingston Harbour (Wade, 1976; Webber, 1994; Goodbody, 1999; Green, 1999; Clarke, 2000) on nutrient effects did not attempt to isolate agrochemical nutrients from general non-point inputs to the Harbour. Likewise, studies in Discovery Bay have tended to group all forms of possible nutrient inputs, namely sewage without attempting to isolate agrochemical pollution (D'Elia *et al.,* 1981; Ramsay and Greenaway, 1997; Campbell, 2000). There have been a limited number of studies on point source nutrient loading from agriculture.

4 CONCLUSIONS AND RECOMMENDATIONS

The review of the literature with respect to the fate of chemicals in the Jamaican environment has provided some insight into the level of understanding of this issue. Particularly in light of the fact that Jamaica is a small island state, water bodies are the major environmental sinks or final destination for pesticide residues. For Jamaica the major water bodies of concern are: major rivers, wetlands and coastal waters. The studies also suggest that agrochemical contamination of the environment is likely to occur in Jamaica because of: its geology (thin soil cover), topography (steep hillsides), poor agronomic practices and unique rainfall pattern (distinct rainy seasons). All these factors contribute to heavy pesticide and sediment loading of the rivers and coastal waters of the country. There is however a paucity of information and research on pesticide impacts in tropical environments.

Agro-chemical (mainly pesticide) contamination of soil is directly related to the usage rates in the field. As a result the literature reviewed showed that instances of significant soil contamination could be related to intensive farming systems, such as coffee, sugar and banana plantations. Where large acreages were subject to sustained agrochemical use for extended periods of time (over 30 years etc), there was likely to be evidence of pesticide contamination in the soil.

There is a paucity of information related to transportation mechanisms and rates of agro-chemicals in the Jamaican environment. The movement of pesticides from source to sink is closely linked to rainfall and related erosion of topsoil. Thus the mechanisms for movement of pesticides and other contaminants are largely physical and dependent on rainfall events.

Agro-chemicals, in particular pesticides are subject to various forms of chemical degradation such as photolysis, hydrolysis, oxidation and biochemical metabolism by plants, micro and macro organisms. The rate of degradation depends on the nature of the chemical. The dissipation rates of residues in tropical conditions, determined from half-life rates for endosulfan were calculated in distilled, closed sea, open sea and river waters (Mansingh *et al.*, 1997). The literature on degradation of endosulfan and other pesticides showed that the degradation rates of pesticides are often increased by a combination of hydrolysis and phyotolysis. Degradation of pesticide residues in soils appears to be largely dependent on the action of sunlight. The concentration of pesticide residues detected in the coastal waters of the island is influenced by the level of dissipation and degradation of these agro-chemicals, i.e. from source to sink.

Studies on bioaccumulation rates were also reviewed, however most of the literature focussed on bioaccumulation in test species such as cultured freshwater fish (*Tilapia nilotica*). There were studies on pesticide residues in shrimp and mangrove fish (guppies). The impacts of pesticides on these aquatic organisms were also investigated and the studies show that the test animals behaviour, physiology and reproductive functions are all significantly affected by pesticide impacts. The studies suggest that pesticides are partitioned in the body of the fish in a particular way. Highest levels will often be detected in the gonads, then next the liver, gut, gills, and finally in the skin/muscle/bone of the test organisms. Therefore pesticide contamination may have an important impact on reproductive health of organisms in the coastal waters.

Of the literature reviewed, there were no studies on bioaccumulation of pesticides up the food chain. For example, zooplankton to shrimp to fish to birds (or humans). It appears that studies in this area are needed. Additional focus is also needed on the chronic toxicity of residues to aquatic fauna during different periods of agricultural activity.

As outlined within the document, not much work has been done with respect to linking the impact of agro-chemicals in the environment on the coastal waters of Jamaica. A few studies speak to the decline in coastal water quality from agricultural impacts, however most tended to be focussed on nutrient pollution ie misuse of fertilizers and disposal of animal wastes. However some data exists on pesticide impacts in polluted bays such as Hunt's Bay, within the Kingston Harbour. This bay is the end point for the large Rio Cobre watershed as well as it receives some terrestrial runoff from sections of the Kingston.

Much of the data on pesticides in the coastal waters of Jamaica would have been generated from studies conducted within Hunt's Bay. Sparse information exists for other areas around the island and this underscores the need for further work in this area.

RADA or other selected organisations should compile all nationally available research on the fate of agro-chemicals in the environment, including studies on the impacts of pesticides on drinking water, terrestrial environments and marine and freshwater environments and share information to enhance local programmes as well as identify gaps of where further research is needed.

Capacity and financial resources in organisations such as CEHI and UWI, should be investigated to see what is feasible in terms of further research. Given limited capacity and resources, effectively targeted research activities and long term monitoring programmes need to be established and sustainable financing mechanisms need to be sought to fund research institutions and laboratories (i.e. through chemical companies or other organisations).

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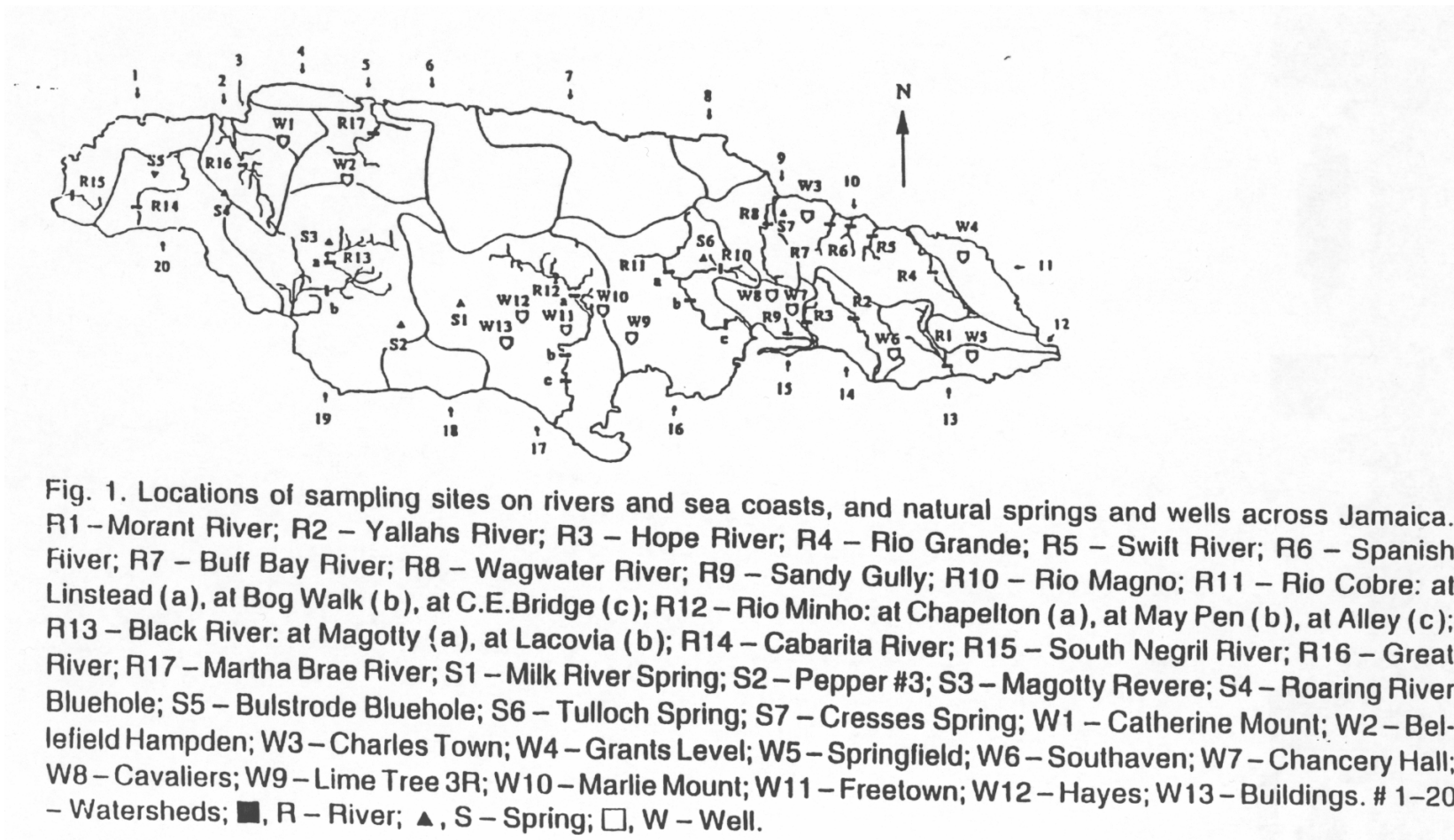
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6 APPENDICES

6.1 Appendix 1: Map of watersheds across the island of Jamaica. Adapted from Mansingh *et al.* (1997).

Fig. 1. Locations of sampling sites on rivers and sea coasts, and natural springs and wells across Jamaica. R1 – Morant River; R2 – Yallahs River; R3 – Hope River; R4 – Rio Grande; R5 – Swift River; R6 – Spanish River; R7 – Buff Bay River; R8 – Wagwater River; R9 – Sandy Gully; R10 – Rio Magno; R11 – Rio Cobre: at Linstead (a), at Bog Walk (b), at C.E.Bridge (c); R12 – Rio Minho: at Chapelton (a), at May Pen (b), at Alley (c); R13 – Black River: at Magotty (a), at Lacovia (b); R14 – Cabarita River; R15 – South Negril River; R16 – Great River; R17 – Martha Brae River; S1 – Milk River Spring; S2 – Pepper #3; S3 – Magotty Revere; S4 – Roaring River Bluehole; S5 – Bulstrode Bluehole; S6 – Tulloch Spring; S7 – Cresses Spring; W1 – Catherine Mount; W2 – Belfield Hampden; W3 – Charles Town; W4 – Grants Level; W5 – Springfield; W6 – Southaven; W7 – Chancery Hall; W8 – Cavaliers; W9 – Lime Tree 3R; W10 – Marlie Mount; W11 – Freetown; W12 – Hayes; W13 – Buildings. # 1–20 – Watersheds; ■, R – River; ▲, S – Spring; □, W – Well.

6.2 Appendix 2: Usage of insecticides in the Rio Cobre Basin up to 1989. Adapted from Mansingh *et al.* (1999).

TABLE I

Usage of insecticides in the Rio Cobre basin up to 1989

Insecticide	Target	Usage
DDT	All crops	1948 to 1960s quite regularly; abandoned since the mid-1970s
Chlordane	Sugarcane	1948 to 1960s against termites
	Citrus	1948 to mid 1950s, soil treatment against root weevils
	Coffee	Irregular since 1979, on fallen berries against berry borer
Dieldrin	Sugarcane	1948–1950s against termites and citrus, coffee scales
	All crops	Since 1948 against root weevils
	Citrus	1955–1990
Aldrin	Citrus	In place of dieldrin against citrus root weevils
Endrin	Citrus and sugarcane	As above
Endosulfan	Coffee	Since 1979, against berry borer
	Vegetables	Since 1979, fairly regularly
Heptachlor	Coffee	1948–1975, against leafminer
Lindane	Many crops	Whenever needed
	Cattle	2–4 weekly cycle against ticks regularly between 1948 and 1960, irregular thereafter
Kelthane	Citrus	Foliar sprays against mites and flies, 1948–1975
	Cattle	Irregularly since 1948 against ticks
Endosulfan	Coffee	Since 1979, against berry borer
	Vegetables	Since 1979, fairly regularly
Coumaphos	Cattle	Regularly since 1950s against ticks
Diazinon	All crops	Foliar sprays, regularly since the early 1950s
	Cattle	2–4 weekly cycle against ticks
Malathion	All crops and cattle	As above
Chlorpyrifos	Banana, coffee	Since 1987, plastic sleeves coated with the insecticides used by banana farmers
Actellic	Vegetable	Since 1987
Dimethoate	All crops	Foliar sprays, regularly since the early 1950s
Mocap	Banana	Regularly since 1948

6.3 Appendix 3: Insecticides contamination in coastal water and sediment samples in Kingston Harbour and Hunt's Bay. Adapted from Mansingh and Wilson, 1995.

TABLE 1

Summary of data on insecticide residues detected in coastal water and sediment samples from all the sampling stations of Kingston Harbour during July–August 1992.

Insecticide	Sample	Frequency*	Residues in water (μg l^{-1}) and in sediments (ng g^{-1})	
			Range	Mean
α-Endosulphan	Water	5	0.118–8.56	2.18
	Sediment	2	0.003–1.0	0.52
β-Endosulphan	Water	2	0.01–15.7	7.86
	Sediment	3	0.006–0.76	0.38
Endosulphan SO$_4$	Water	1	0.0003	0.0003
	Sediment	0	BDL†	BDL
p,p'-DDT	Water	1	7.02	7.02
	Sediment	3	0.03–0.04	0.035
Dieldrin	Water	2	0.014–3.75	1.88
	Sediment	1	0.001	0.001
Aldrin	Water	0	BDL	BDL
	Sediment	4	0.002–36.7	9.18
Endrin	Water	4	0.012–0.9	0.26
	Sediment	1	0.006	0.006
Lindane	Water	0	BDL	BDL
	Sediment	3	0.003–0.77	0.514
HCB	Water	0	BDL	BDL
	Sediment	1	1.01	1.01
Diazinon	Water	2	0.0003–0.1	0.05
	Sediment	2	0.002–0.007	0.0046

*Five samples each of water and sediments collected at weekly intervals for 4 weeks from five sampling stations, and two samples each from two stations collected 1 month apart (a total of 24 samples each of water and sediments).
†BDL, Below detection level.

TABLE 2

Residues of insecticides detected in water and sediments of three sampling locations in the Hunt's Bay area of Kingston Harbour during July–August 1992.

Insecticide	Sample	Frequency*	Residues in water (μg l^{-1}) and in sediments (ng g^{-1})	
			Range	Mean
α-Endosulphan	Water	2	0.12	0.12
	Sediment	1	0.003	0.003
β-Endosulphan	Water	1	15.7	15.7
	Sediment	1	0.006	0.006
Endosulphan SO$_4$	Water	1	0.0003	0.0003
	Sediment	0	BDL†	BDL
p,p'-DDT	Water	1	7.02	7.02
	Sediment	1	0.031	0.031
Dieldrin	Water	1	3.75	3.75
	Sediment	0	BDL	BDL
Aldrin	Water	0	BDL	BDL
	Sediment	1	0.005	0.005
Endrin	Water	3	0.012–0.93	0.33
	Sediment	0	BDL	BDL
Lindane	Water	0	BDL	BDL
	Sediment	1	0.77	0.77
Diazinon	Water	1	0.1	0.1
	Sediment	0	–	–

*One sample of water and sediments collected from each of the three stations (Nos 43, 47 and 48) on 7–9, 14 and 29 July and 11 August 1992 (a total of 12 samples each of water and sediments).
†BDL, Below detection level.

TABLE 3

Insecticide residues detected in water and sediment of two sampling locations in the Port Royal area of Kingston Harbour during July–August 1992.

Insecticide	Sample	Frequency*	Residues in water ($\mu g\, l^{-1}$) and in sediments ($ng\, g^{-1}$)	
			Range	Mean
α-Endosulphan	Water	2	0.63–1.47	1.05
	Sediment	1	1.043	1.043
β-Endosulphan	Water	1	0.01	0.01
	Sediment	1	0.02	0.02
Endosulphan SO$_4$	Water	0	BDL†	BDL
	Sediment	0	BDL	BDL
p,p'-DDT	Water	0	BDL	BDL
	Sediment	1	0.04	0.04
Dieldrin	Water	1	0.014	0.014
	Sediment	1	0.001	0.001
Aldrin	Water	0	BDL	BDL
	Sediment	2	0.002–0.007	0.0045
Endrin	Water	0	BDL	BDL
	Sediment	1	0.006	0.006
Lindane	Water	0	BDL	BDL
	Sediment	2	0.003–0.77	0.387
Diazinon	Water	0	BDL	BDL
	Sediment	2	0.002–0.0072	0.0046

*One sample of water and sediments collected from each of the two stations (Nos 35 and 37) on 6–9, 14–17 and 28 July and 10 August 1992 (a total of eight samples each of water and sediments).
†BDL, Below detection level.

6.4 Appendix 4: Pesticide contamination in Spanish River, Swift River, and the coastal waters of Portland. Adapted from Robinson and Mansingh (1999).

Table III

Insecticide PCB[a] residues detected in water, sediments and fauna of Spanish and Swift rivers and sea coast of Portland, Jamaica, between October 1991 and December 1992

Insecticide	River/ Sea Cost	Sample	Frequency[b]	Residues in water (µg/l) and sediment and fauna (ng/g)	
				Range	Mean
α-Endosulfan	Spanish	Water	3	0.245–6.25	2.70 ± 1.286
		Sediment	1	–	3.81 ± 0.151
		Fauna	5	10.3–21.5	15.9 ± 1.608
	Swift	Water	2	1.00–2.11	1.56 ± 0.425
		Sediment	4	0.777–94.3	24.3 ± 16.44
		Fauna	4	4.01–16.1	9.05 ± 1.862
	Coast	Water	3	0.349–0.420	0.40 ± 0.024
		Sediment	2	1.09–2.44	1.77 ± 0.675
		Fauna	3	68.5–110.6	86.1 ± 12.63
β-Endosulfan	Spanish	Water	3	0.03–2.40	1.22 ± 0.484
		Sediment	0	0	0
		Fauna	4	3.40–16.3	8.13 ± 1.991
	Swift	Water	3	0.80–3.19	1.92 ± 0.489
		Sediment	2	0.30–1.2	0.75 ± 0.318
		Fauna	4	2.40–28.8	11.1 ± 4.320
	Coast	Water	0	0	0
		Sediment	1	–	6.14 ± 0.30
		Fauna	4	4.31–53.7	30.9 ± 15.96
Endosulfan sulphate	Spanish	Water	2	0.09–0.143	0.12 ± 0.019
		Sediment	4	1.52–11.6	4.83 ± 1.624
		Fauna	6	3.80–21.2	10.21 ± 2.021
	Swift	Water	5	0.029–6.90	3.64 ± 0.954
		Sediment	6	0.011–4.94	3.05 ± 0.564
		Fauna	6	1.20–6.5	7.91 ± 1.291