Time to act on endosulfan

The future of one of the world's most notorious pesticides is up for debate this autumn with scientific experts and farmworker advocates calling for a global ban. ***Dr Meriel Watts*** *of PAN Aotearoa New Zealand reviews the situation and presents the evidence for a ban.*

The organochlorine insecticide endosulfan is currently taking centre stage, alongside its cousin DDT, in global efforts to eliminate some of the worst pesticides. But whilst the use of DDT is now largely confined to vector control in Africa, endosulfan is still used on many crops in many countries – particularly cotton, soy, rice, tea, coffee and vegetables.

Such is the level of concern about this antiquated, highly toxic and persistent chemical, that it is banned in 55 countries (including all EU countries) and is being considered for global regulation under two different processes. Both these processes are strongly contested by endosulfan's manufacturers, especially those in India, and so-called scientific procedures have become highly charged politically, and their integrity endangered. This article outlines the regulatory concerns about endosulfan, the mounting evidence of the human and environmental impacts, and the scientific case for a global ban.

Increasing regulatory action

The PIC process

The countries which have signed up to the Rotterdam Convention have committed to cooperating and sharing responsibility in the international trade in hazardous chemicals. They have also committed to a legally binding Prior Informed Consent (PIC) procedure, which ensures that countries wishing to import a hazardous chemical listed under the Convention are pre-informed by the exporting country of any regulatory bans, and of the reasons for them. The importing country must give 'prior informed consent'.

The Chemical Review Committee of the Convention consists of technical experts from the signatory countries. It meets annually to consider evidence and make recommendations to the Conference of the Parties (CoP) on which chemicals should be included within the procedure. The CoP consists of representatives from the signatory governments who make the final decisions. However, the procedure for getting a chemical listed under PIC can be lengthy and politically charged.

In March 2007, the Chemical Review Committee of PIC agreed to recommend to the CoP that endosulfan be included in Annex III, the list of chemicals that have been banned or severely restricted. This recommendation was made on the basis of the notification of a ban by the Netherlands and severe restriction by Thailand[1].

The recommendation will be considered by the CoP in October of this year. However, the decision on endosulfan's final inclusion in Annex III is likely to be vigorously contested by India and, as decision-making is by consensus, such opposition threatens to block the whole PIC process.

The POPs process

The Stockholm Convention on Persistent Organic Pollutants (POPs) aims to protect human health and the environment by globally banning the production and use of persistent, bioaccumulative chemicals. Pesticides already listed under this convention include aldrin, endrin, dieldrin, chlordane, heptachlor, hexachlorobenzene, mirex, toxaphene, and DDT. It is likely that two other pesticides, chlordecone and lindane, will join these nine POP pesticides (as will a few industrial chemicals) after the POPs CoP4 (the fourth Conference of the Parties to the Stockholm Convention) in Geneva next year.

The European Union has nominated endosulfan to join them, but before it can do so the chemical must go through a lengthy process of assessment by the POPs Review Committee (POPRC). This process should finally start in October. However, as with PIC, endosulfan's inclusion is being strongly contested. India, China and Sierra Leone even tried to block its entry into the process for consideration in November last year at POPRC3. In the event endosulfan's entry was delayed one year for other reasons.

Action in the US

The United States Environmental Protection Agency (EPA) has been reviewing endosulfan for a number of years, but events are now unfolding rapidly. In November 2007 they released calculations showing that endosulfan cannot be used safely in the vast majority of scenarios for which it is currently approved, and that even with the best available technology and personal protective equipment, farmers applying endosulfan are exposed to unacceptably high levels. In May of this year more than 55 international scientists, health professionals and advocates signed a letter to the EPA asking for a ban. Then in July, a coalition of farmworkers, and health and environmental groups, including PAN North America, filed a lawsuit against the EPA to stop the continued use of endosulfan.

Outcry in New Zealand

On the other side of the world, New Zealand's Environmental Risk Management Authority (ERMANZ), which is part way through a reassessment of endosulfan, is proposing that all uses should continue, including boom spraying of sports fields, cricket pitches, bowling greens and airport grass strips, to control earthworms – a use that appears peculiar to New Zealand.

ERMANZ's proposal caused an uproar, with two political parties (the Greens and the Maori Party) and a number of advocates and organisations, calling on the government to override it. The government has refused and public hearings on submissions are due to start in October.

Repeated sampling by PAN Aotearoa New Zealand and the Soil and Health Association consistently finds residues of endosulfan in tomatoes. Korea has for the second time rejected New Zealand beef because of endosulfan residues. Despite extensive investigations it is still not known how the beef became contaminated.

Exposure and impact

So why the concern about endosulfan? Quite simply it has all the worst characteristics of a pesticide rolled into one. It is highly toxic, persistent in the environment, and bioaccumulative in the food chain, including in humans, since we are at the top of both terrestrial and aquatic food chains. It is a broad spectrum pesticide, meaning that it is toxic to all insects, as well as to mammals, fish, birds, microorganisms, and it even causes damage to plants. Use of endosulfan has killed many hundreds of people, and condemned many thousands of others to chronic suffering.

Exposure to endosulfan

Exposure to endosulfan is widespread globally. Even where personal protective clothing is worn it is inadequate to protect against endo-

Endosulfan time bomb – Philippines ferry disaster

International action on endosulfan is taking place against the backdrop of what could prove to be a disaster of global proportions. In June a passenger ferry, Princess of the Stars, tragically sank off Sibuyan Island in the Philippines during a typhoon, with the loss of many lives. It was discovered that the ferry was also carrying 10 tonnes of endosulfan (along with other pesticides) destined for the Del Monte and Dole pineapple plantations.

Endosulfan was believed to have been banned in the Philippines, but apparently corporations were given an exemption until December of this year: it appears they were stocking up on the chemical before the exemption expired. One provincial government promptly banned the transport or use of endosulfan in its province, Bukidnon.

The endosulfan still lies at the bottom of the sea, awaiting salvage. Professor Romy Quijano of the Department of Pharmacology and Toxicology of the University of the Philippines described the situation as a 'time bomb'. There is no sign that any endosulfan has leaked yet, but if it does there would be 'massive global environmental pollution' according to Professor Quijano.

sulfan. Residues are commonly found in the body tissues of exposed agricultural workers.

Non-occupational exposure is also very common. In France endosulfan was found in the air inside 79% of homes in the Paris area, in some of them at levels higher than those found in greenhouses. At this stage (2006), endosulfan was still permitted for use in France on some fruit and vegetables, and its presence in homes appeared to result from drift and contaminated plant matter. It was also found on the hands of 20% of the general population sampled in Paris[2].

Residues in food are the greatest source of exposure. They occur commonly in fruit, vegetables, fish and other seafood, milk and dairy products, meat, seeds, nuts, spices, honey, olive oil, and even wine corks. As a result of this continual dietary exposure, endosulfan residues are commonly found in human placental tissue, umbilical cord blood and breast milk, and endosulfan is transferred to the foetus and newly-born infant[3-11]. Residues of endosulfan in breast milk in Bhopal, India in 2003 were 8.6 times the average daily intake levels recommended by the World Health Organisation[12]. The unborn foetus is exposed to this endocrine disrupting chemical at a time of exquisite vulnerability, and then re-exposed after birth through breast milk, with the potential for adverse effects on intellectual and physical development, and the onset of chronic diseases such as cancer later in life.

Human Poisonings

Poisonings have been reported in Benin, Colombia, Costa Rica, Cuba, Guatemala, India, Indonesia, Malaysia, Philippines, New Zealand, South Africa, Sri Lanka, Sudan, Turkey and USA. Endosulfan is regarded as one of the main causes of poisoning in many countries[13] including in Asia[14], Latin America[15] and West Africa[16].

Endosulfan was used extensively for self-poisoning in Sri Lanka. Restrictions placed on it in 1998, together with restrictions placed on WHO Class 1 pesticides in 1995, resulted in 19,769 fewer suicides in 1996-2005 than in 1986-1995[17].

Some of the worst occupational poisonings have occurred in West Africa's cotton fields. Endosulfan had been removed from cotton growing there because of its high toxicity, but was re-introduced in 1998-1999 in Mali and Benin, and in 1999-2000 in Senegal, Cameroon and Burkina Faso, to control *Helicoverpa*, the cotton bollworm, which had become resistant to pyrethroids. Poisonings soon became apparent, particularly in Benin, where at least 37 people are known to have died from endosulfan during the 1999-2000 season, with an estimated total death toll of 70, and at least 90 people suffering illness[18]. The figures are considered a significant underestimation due to inadequate reporting. Food contamination also became a problem and was thought to be a major factor in Benin's 400 endosulfan poisonings over the period 2000-2003, of which 347 were fatal, and which accounted for 69% of all pesticide poisonings[19].

Involuntary 'bystander' exposure in Kerala, India, caused a high level of appalling chronic effects, in what is one of the very few examples where health impacts are so clearly linked to pesticides. The village of Kasargod experienced sustained exposure to endosulfan as a result of 20 years of aerial spraying of a nearby cashew nut plantation. Endosulfan was the only pesticide used. Twelve streams used by the villagers originated in the plantation and were subsequently found to have contaminated sediment and water throughout the year (that is outside the spray season), as a result of endosulfan's persistence in soil, and the soil being carried to the streams by storm runoff. Residues were still detected in the water and pond sediments 18 months after spraying ceased[20]. One sample contained endosulfan at 391 times the maximum permissible level[21]. The villagers were also directly exposed to spray drift and overspraying. Numerous congenital, reproductive, long-term neurological and other symptoms were experienced (see box). 197 cases were documented from just 123 households. Chronic morbidity was 70% higher than normal. There were observations of similar effects in animals too: cows giving birth to deformed calves, cows and chickens dying inexplicably, domestic animals with miscarriages, bleeding, infertility, stunting of growth and deformities, as well as fish kills and dwindling populations of honeybees, frogs, and birds[22,23,24]. Endosulfan has subsequently been banned in the State of Kerala and compensation paid to some of the victims and/or their families by the State[25]. The families of at least 135 victims who have died have received compensation. Yet India remains endosulfan's biggest proponent.

Health effects in Kerala

- congenital deformities of hands, feet and heart especially in females;
- other congenital deformities including child born with bladder outside body;
- endometriosis, early menarche, frequent menstrual disorders, male breast enlargement;
- delayed male sexual development (reduced pubic hair, testes and penis)
- reduced testosterone
- male sexual congenital deformities – undescended testicles, congenital hydrocele (swelling in scrotum)
- liver cancer, haematological cancers, brain tumours (neuroblastoma);
- congenital mental retardation, cerebral palsy, delayed mental and psychomotor development, learning disabilities, low IQ;
- psychiatric disturbances including suicide, epilepsy;
- frequent illness, skin diseases;
- ear, nose and throat problems;
- vision impairment and blindness.

The scientific case on health

The acute and chronic effects observed in people are supported by data from laboratory studies on animals and on human, animal and plant cells.

Acute effects

Absorption through the gastrointestinal tract is very rapid and efficient, with 90% absorbed in rats. Absorption through the skin is as high as 50% in rats[26]. The primary acute effect is on the central nervous system, as a result of endosulfan binding to GABA receptors in the brain[27], causing hyperexcitation and convulsions, and nervous system mediated effects on respiration and the heart. Death results from low levels of exposure. Female rats are 4-5 times more sensitive to the lethal effects of endosulfan than male rats, and a protein deficient diet caused a 20-fold increase in toxicity[28].

Systemic effects

The primary systemic targets are the liver and kidney, but endosulfan also causes haematological and respiratory effects. Observed effects include damage to the membrane of red blood cells at very low doses (1 µg/kg) that are 500-fold lower than the generally permissible level for residues in food, which is 0.5 mg/kg, and calcification of heart and arteries, aneurisms, cardiotoxicity through oedema and swelling of myocardial cells, and heart and circulatory failure[29,30,31]. Endosulfan is also toxic to both the adrenal gland and the pancreas[32], resulting in complex effects on blood glucose levels (both reducing and raising it). Endosulfan also causes oxidative stress[33], which is implicated in its neurotoxic effects[34,35], damage to the adrenal gland[36,37], and cancer[38].

Immune effects

Endosulfan is toxic to, and suppresses, the immune system, as well as promoting allergic responses. It induces the death of human Natural Killer T-cells, which are part of the immune system involved in tumour suppression[39], so endosulfan encourages the development of tumours. In the US the Agency for Toxic Substances and Disease Registry (ATSDR) concluded that humans may be at risk of adverse immune effects following exposure to endosulfan[40].

Endocrine disruption

Endosulfan is an endocrine disruptor in mammals, fish, birds and amphibians, affecting both male and female reproductive hormones. It chronically depresses testosterone levels in rats[41].

Studies on human cells indicate that endosulfan is oestrogenic at very low levels, interfering with levels of oestrogen receptors[42], and causing proliferation of human breast cancer cells[43,44,45], and oestrogen-sensitive ovarian cells[46]. It is also anti-androgenic[47,48,49], induces the activation and proliferation of progesterone receptors in human breast cancer cells[50,51], and it decreases the activity of progesterone[52,53]. Endosulfan is strongly implicated in increasing the risk of breast cancer[54], and may contribute to other oestrogen-dependent disorders such as cervical cancer and endometriosis[55,56].

Cancer

Evidence of the carcinogenicity of endosulfan is regarded as being inconclusive, and it has not been classified by the International Agency for Research on Cancer (IARC) as a carcinogen, leading some regulators to erroneously translate this uncertainty to mean that endosulfan does not cause cancer[57].

Some studies have found an increase in the total number of malignant tumours and pulmonary adenomas, and increases in the total number of carcinomas, hepatic carcinomas, and sarcomas in female rats, and lymphosarcomas in male rats[58].

Additionally, a number of studies have found endosulfan to have caused mutagenic and genotoxic effects in human lymphocytes and liver hepatoblastoma cells; in rat and mouse spermatogonial cells; in rat, mouse and hamster bone marrow; in rat foetal liver cells; in fruitfly; in fish gill, kidney and erythrocyte cells; in tadpoles; in oysters; in Chinese hamster ovarian cells; in bacterial systems (*Salmonella, E. coli and Saccharomyces*); in microalgae; and in the root tip cells of the wetland macrophyte *Bidens laevis* L[59-72].

There is also evidence that endosulfan is a tumour promoter causing a significant and dose-related increase in cancerous liver cells[73,74], possibly through its rapid inhibition of gap junctional intercellular communication (GJIC) in liver cells[75,76,77]. It inhibits apoptosis (programmed cell death), which could contribute to mutant cell survival, and therefore cancer, and it is increasingly being described as a potential carcinogen in humans[78].

Reproductive/developmental toxicity

Endosulfan has caused a number of adverse effects on male reproductive parameters in rats, with the effects being greater if exposure occurred during the developmental phase[79]. Endosulfan has also been found to reduce implantation in female mice, and to increase oestrus[80]. A study with human sperm *in vitro* showed that low concentrations of endosulfan (0.1nM) strongly inhibited the ability of sperm to fertilise ova[81].

Exposure *in utero* has caused embryotoxic effects including increased resorptions and skeletal variations, decreased birth weight and length, and increased aggressive behaviour in newborn rats[82]. More recently, a study reported accumulation of cerebrospinal fluid in the brain, underdeveloped cerebrum, incomplete ossification of skull bones, and malformations of the liver, kidneys, ribs and renal pelvis[83].

Neurological effects

Endosulfan targets the prefrontal cortex of the brain, which is involved in cognitive tasks, selective attention, short-term working memory, response inhibition, behavioural flexibility, sexual and maternal behaviour, and depression[84]. There is evidence that it can cause behavioural effects such as aggression and increased time to learn tasks, even after exposure has ceased, as well as impaired learning and memory processes, extreme sensitivity to noise and light, and muscle spasms[85].

There is emerging evidence that exposure to endosulfan may increase the risk of Parkinson's disease. It alters the brain levels of the neurotransmitters dopamine, noradrenalin and serotonin[86]. Mice exposed to endosulfan from postnatal days 5 to 19 exhibited only insignificant changes in dopamine, acetylcholinesterase and alpha-synuclein levels; however when re-exposed as adults, they showed significantly depleted dopamine, and increased levels of alpha-synuclein[87]. The loss of dopamine and the accumulation of alpha-synuclein are both associated with Parkinson's disease.

The scientific case on the environment

Ecotoxicity

Endosulfan is extremely toxic to fish, especially juveniles. It is also very toxic to amphibia and reptiles, shrimps and prawns, aquatic snails and plants, coral reef organisms, and other invertebrates[88,89,90]. Concentrations of endosulfan found in many rivers, particularly after rainfall events carrying runoff into rivers, greatly exceed levels known to cause toxicity, and its use results in the disruption of the aquatic food chain[91], as well as in massive fish kills in the USA[92,93], Sudan and Senegal[94]. Endosulfan has been implicated in the decline of frog populations in California, possibly by depressing acetylcholinesterase activity in tadpoles[95]. Many incidents of wildlife deaths have been reported, especially in Africa[96,97]. Congenital deformities, miscarriages, infertility, stunting of growth, and dwindling populations have also been reported[98-104].

Endosulfan is highly toxic to birds, bees, earthworms and a wide range of beneficial insects that are vital to IPM programmes[105-111]. It significantly reduces the development of the 'entomopathogenic' fungus, *Verticillium lecanii* (Zimm.) — a fungus used in some IPM programmes to kill insect pests such as aphids, thrips and whitefly[112].

Endosulfan is toxic to beneficial soil micro-organisms such as actinomycetes[113]. These are bacteria that play a vital role in replenishing the supply of nutrients in the soil through decomposition of organic matter and the formation of humus. They also help non-leguminous plants to fix nitrogen. Endosulfan is toxic to mites and springtails, tiny insects that are key to maintaining soil fertility and to mixing the organic and mineral components of soil[114].

Environmental Fate

Endosulfan is semi-volatile. It evaporates from the surface of soil and plants after application. Field studies in Australia have found 70% of endosulfan is lost from cotton fields through volatilisation[115,116]. The atmospheric half-life of endosulfan varies with temperature, and has been measured as ranging from 12 hours to 38 years, the latter in the Canadian Arctic[117,118,119].

Following evaporation, endosulfan can undergo long-range atmospheric transport, depositing out of the air in the cold regions of the world. It has been consistently measured in air all over the world, including in remote locations in the Arctic, high mountain areas in Asia (Himalayas), Europe, and North America, as well as in tropical mountains in Costa Rica, at levels higher than most other POPs[120].

Endosulfan residues have been found in biota and in environmental media at locations far distant from where it has been released – in both the Arctic[121,122,123] and Antarctic[124]. It has been found in grasses on Mt Everest[125] and in spruce needles of the Central Himalayan region[126], in lichen and conifers in the Canadian Rockies, and the western national parks of the USA[127,128].

It has also been consistently measured in precipitation: in snow in the Canadian Arctic[129] and US national parks[130], as well as in ice in the Italian Alps[131] and Antarctica[132], and in rain in Asia[133], Africa[134], Europe[135], North America[136], and Latin America[137]. Residues of endosulfan in the Caribbean are believed to have resulted from deposition in dust carried from the African Sahara/Sahel region[138].

Levels of endosulfan have continued to increase in the Arctic, in beluga whales[139] and in air[140] at the same time as the levels of most POPs have declined. Similar increases have been observed in the freshwater fish char; residues were 2.2 times higher in 2002 than they were in 1992[141].

Persistence

Endosulfan is persistent, with a half-life in water of up to six months under anaerobic conditions[142], and a half-life in soil under aerobic conditions of up to six years[143].

Residual levels in the soil where cotton crops are grown in Australia and India can be higher at the beginning of the season than at the beginning of the previous season, indicating a continual build-up in the soil[144,145,146].

Endosulfan's persistence has resulted in it becoming a ubiquitous global contaminant of soil, sediment, fresh and marine waters, aquatic and terrestrial biota including plants, and human food.

Bioaccumulation

Endosulfan bioaccumulates in the environment and in humans. The European Union regards a chemical as being bioaccumulative if it has a bioconcentration factor (BCF) of more than 2,000: the range estimated by the US EPA[147] for endosulfan is 1000-3000, with a BCF of more than 11,000 recorded for one species of fish[148].

Additionally, endosulfan has an even greater potential to bioaccumulate in terrestrial species than in aquatic species, because of its high log KOA (octanol-air partition coefficient), which is more significant to air-breathing animals than the log Kow (octanol-water partition coefficient) used to predict bioaccumulation in aquatic species. Estimated biomagnification factors for herbivorous and carnivorous terrestrial species range from 2.5 to 39.8[149,150].

Countries that have banned endosulfan

Bahrain, Belize, Benin, Burkina Faso, Cambodia, Cap-Vert, Colombia, Cote d'Ivoire, European Union (27 countries), Gambia, Guinea Bissau, Jordan, Kuwait, Malaysia, Mali, Mauritania, Niger, Nigeria, Norway, Oman, Qatar, Saudi Arabia, Senegal, Singapore, Sri Lanka, St Lucia, Syria, Thad, United Arab Emirates

Countries that have restricted endosulfan

Australia, Bangladesh, Canada, Honduras, Iceland, Indonesia, Iran, Japan, Korea, Madagascar, Panama, Philippines, Russia, Thailand, USA

Countries reassessing endosulfan

Brazil, Canada, New Zealand, Uruguay, USA, Venezuela

Countries manufacturing endosulfan

China, Germany, India, Israel

Monitoring data have shown increasing concentrations of endosulfan in beluga whales[151], and in freshwater char[152]. There is evidence of bioaccumulation in fish in Argentina, with a biomagnification factor greater than that for DDT and most other POPs[153]. There is evidence of bioconcentration in plants too: in bulrushes with a bioconcentration factor higher than that for DDT[154], in grasses[155], and in conifer needles – where endosulfan levels in two-year old needles were three times higher than those in one-year old needles[156]. There is evidence of bioaccumulation resulting from maternal transfer of endosulfan in elephant seals in Antarctica, where significantly higher relative proportions were found in the pups than in the adults[157].

Conclusion

In conclusion, there is a wealth of evidence that endosulfan is highly toxic to all species, is persistent and bioaccumulative. It has caused widespread poisonings and suffering and is a serious environmental contaminant. So it is not surprising that there is a concerted global effort being made to rid the world of this truly nasty pesticide. There are plenty of alternative ways of managing the pests against which it is used – after all, 55 countries have found they can manage without it[158]. Will time be called on endosulfan or will vested interests prevail?

Dr Meriel Watts is Coordinator of PAN Aotearoa New Zealand and a scientist with PAN Asia and the Pacific, merielwatts@xtra.co.uk

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