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Before and After *Silent Spring*: From Chemical Pesticides to Biological Control and Integrated Pest Management — Britain, 1945–1980

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The use of chemical pesticides increased considerably after World War II, and ecological damage was noticeable by the late 1940s. This paper outlines some ecological problems experienced during the post-war period in the UK, and in parts of what is now Malaysia. Also discussed is the government's response. Although Rachel Carson's book, *Silent Spring* (1962), was important in bringing the problems to a wider public, she was not alone in sounding the alarm. Pressure from the public and from British scientists led, among other things, to the founding of the Natural Environment Research Council in 1965. By the 1970s, environmentalism was an important movement, and funding for ecological and environmental research was forthcoming even during the economic recession. Some of the recipients were ecologists working at Imperial College London. Moved by the political climate, and by the evidence of ecological damage, they carried out research on the biological control of insect pests.

> Pest control is of course necessary and desirable, but it is an ecological matter, and cannot be entirely handed over to the chemist.
>
> Julian Huxley, preface to the UK edition of *Silent Spring* (1963)[1]

Introduction

Rachel Carson's brilliant 1962 polemic, *Silent Spring*, gave clear warning of the loss of highly cherished ecological systems and helped to raise public awareness of the

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consequences of pesticide use.[1] In his preface to the UK edition, Julian Huxley gave some local examples of ecological damage, such as the decline of a British butterfly, and of the cuckoo that fed on its caterpillars. Although new pesticides were saving lives in areas of the world where malaria and other insect-borne diseases were common, and their use was leading to increased agricultural yields worldwide, there were problems. The section "Before *Silent Spring*: The new insecticides and their problems" gives a brief synopsis of some of the problems, and of concerns raised from the late 1940s to the 1970s. Because of the benefits, the British government was slow to respond. However, as is briefly discussed in the section "Environmental politics, 1962–1972," a growing understanding of ecological damage fed into a growing environmental movement, and helped to change the social and political climate. Among those affected by the new outlook were many young scientists, some of whom were motivated to seek alternatives to chemical pesticides. The section "Towards biological control" focuses on a few such scientists, recipients of new funding for ecological and environmental science. Those to be discussed worked at the Silwood Park campus of Imperial College London during the 1970s, and were later recognised as leaders in their respective fields. While acknowledging, as did Carson, that chemicals are needed in modern agriculture, they developed methods of biological pest control, promoted sustainable agricultural practice, and stressed the importance of biodiversity.[2]

Pest control was already an active research area at Imperial College in the early twentieth century. The professor of applied entomology, Harold Maxwell Lefroy, appointed in 1912, sought chemical controls for orchard pests and for pests in stored grains.[3] One of his research students, James Munro, later also a professor at Imperial College, continued this line of work.[4] Under Munro, applied entomology at the college, especially in relation to pest control, expanded considerably. By the eve of World War II, Imperial College was a leading centre in entomology — not only in applied areas, but also in insect systematics, physiology, and ecology. In addition to insect pests in stored foods, there was much emphasis on tropical agricultural pests, especially those of major economic crops, such as cotton, tea, sugar, cocoa, coffee, tobacco, and rubber.[5]

[1] Rachel Carson, *Silent Spring* (Boston, Mass.: Houghton Mifflin, 1962; London: Hamish Hamilton, 1963). Pesticide was a new word, coined after World War II. It refers to a wide range of chemicals, including herbicides, insecticides, and fungicides (all older terms). The Duke of Edinburgh, who wanted people to take notice, distributed several advance copies of Carson's book, including one to Christopher Soames, minister of agriculture, fisheries and food (1960–1964).

[2] For the zoology and applied entomology department at Imperial College and for more on some of the scientists discussed in this paper, see Hannah Gay, *The History of Imperial College London, 1907–2007: Higher Education and Research in Science, Technology and Medicine* (London: Imperial College Press, 2007).

[3] Harold Maxwell Lefroy (1877–1925) worked earlier as an entomologist in the Department of Agriculture in the West Indies. In 1901, he was appointed Imperial Entomologist in India. Lefroy's success in eradicating the death watch beetle from the timbers of Westminster Hall led to his opening a small chemical plant in Hatton Garden for the production of "woodworm fluid." It was the start of the pest control company Rentokil. Although Lefroy was seeking less toxic fumigants than the arsenicals then still widely used, he was fatally poisoned by one of his own chemicals.

[4] James Watson Munro (1888–1968) worked in forest entomology before joining the staff at Imperial College.

[5] Many of Lefroy's and Munro's students found work in the British Empire. Before World War II, there were only two other major British university centres in applied entomology. At Cambridge University, the focus was mainly on domestic agricultural pests, and at the London School of Hygiene and Tropical Medicine the focus was on human disease agents and vectors.

There was also activity related to pest control in the chemistry department. In 1940, the professor of organic chemistry, Ian Heilbron, began research into a substitute for the natural product insecticide pyrethrum.[6] Some Imperial College chemists had earlier developed a spray form of pyrethrum that was widely used against insect pests in stored foods, but the war meant that supplies from Japan and Macedonia were cut off, and those still arriving from Kenya were seen as insufficient. Munro, too, wanted to find an alternative to pyrethrum, and, having heard of a Geigy product named Gesarol being tested at the Rothamsted Experimental Research Station, asked Heilbron whether he would be prepared to study it further. Gesarol contained dichlorodiphenyltrichloroethane (DDT). Heilbron and his students separated the DDT isomers by distillation and fractionation, and found that the active ingredient was the *p*,*p*′ isomer.[7] Heilbron and Munro then persuaded the government to make an arrangement with Geigy for DDT to be manufactured in Britain under licence. The tests carried out indicated that the toxicity of DDT in mammals was low.[8] This gave Heilbron and Munro the confidence to ask for it to be tested as an insecticide in areas where malaria was a serious problem. In this, they had the support of another Imperial College professor, the chemical engineer Alfred Egerton.[9] Like

[6] Pyrethrum is extracted from some species of the genus *Chrysanthemum*, plants long known to have insecticidal properties.

[7] Sir Isidor (Ian) M. Heilbron FRS (1886–1959) is best known for his contribution to the synthesis of vitamin A, manufactured by Hofmann La Roche from 1946. DDT is the acronym for dichlorodiphenyltrichloroethane, although that name is also a simplification and not strictly correct. Gesarol was patented by the Swiss chemist, P. H. Müller (1889–1965), in 1939. It was the culmination of his work, begun during World War I, to find a safe chemical control for the lice known to be vectors of the typhus organism, a serious scourge in army and prisoner-of-war camps. Müller was awarded the 1948 Nobel Prize for Medicine/Physiology. (DDT had been made in 1874 by the Austrian chemist Othmar Zeidler, but he was unaware of its insecticidal properties, which were discovered by Müller.) In 1945, Heilbron was awarded the Priestley Medal of the American Chemical Society in recognition of his DDT and other work. See A. H. Cook, "Ian Morris Heilbron," *Biographical Memoirs of Fellows of the Royal Society* 6 (1960): 65–85. See also I. M. Heilbron, "The Role of Chemistry in Combating Tropical Diseases," *Nature* 161 (1948): 956–60.

[8] DDT was seen as a new wonder chemical. Kenneth Mellanby recounts how human test subjects wore underpants that had been soaked in very dilute solutions of DDT, and how this not only immediately killed off body lice but also kept the volunteers free of lice for several weeks, despite attempts to reinfect them. See Kenneth Mellanby, *Pesticides and Pollution* (London: Collins, 1965), 120–22. Kenneth Mellanby (1908–1993) was an excellent scientist but also a controversialist, being outspoken both on environmental matters and in his enthusiasm for medical research with human test subjects. He witnessed the Nuremberg trials, and had a misplaced sympathy for some Nazi doctors who engaged in experiments with human subjects. He had no sympathy for the more egregious cases, but after the war the public was in no mood for fine distinctions. Mellanby organised a group of about forty conscientious objectors who submitted themselves to various experiments during the war. These included Mellanby's own successful experiments on control of the scabies mite. Mellanby's controversialism cost him the usual scientific awards. His 1965 book, *Pesticides and Pollution*, was a response to Carson. Later, he wrote *The DDT Story* (Farnham: The British Crop Protection Council, 1992), in which he argued that DDT should still be used as an indoor spray for malaria control, advice given by the WHO in 2006, when it reversed an earlier decision. The total ban on DDT in the USA from 1972 and in the UK from 1984 has been highly controversial. Some wish to see it brought back for the control of bed bugs, which were previously largely eradicated. See Paul Weindling, "Kenneth Mellanby," *Oxford Dictionary of National Biography* (Oxford: Oxford University Press, 2004).

[9] Sir Alfred Charles Glyn Egerton FRS (1886–1959). Heilbron was seconded to the Ministry of Production during the war, and chaired an interdepartmental committee on insecticides and insecticide development. Several laboratories, apart from his own at Imperial College, were involved. Some testing of spraying equipment was carried out at the Porton Down government establishment near Salisbury.

Heilbron, Egerton was a scientific advisor to the wartime cabinet. Aware of the problem of malaria infecting troops operating in tropical countries, he persuaded the government to support a trial. Munro was asked to set up a team to test DDT in British Guiana, where sugar cane workers were seriously affected by both malaria and yellow fever.[10] Spraying with DDT controlled the mosquito vectors of the agents of both these diseases to a degree never before witnessed, and without any immediately noticeable negative effects — although there was some concern over fish kills. Successful trials in British Guiana and elsewhere led to a huge increase in the manufacture of DDT.[11] The USA had its own research programme, and large quantities of DDT were manufactured there too. After the war, other chemical manufacturers began to compete, and new chlorohydrocarbon insecticides, such as aldrin and dieldrin manufactured by Shell, and heptachlor manufactured by ICI, entered the market. Organophosphate compounds soon followed.[12]

This paper will pick up the story at the point where problems with the new chemicals came to be recognised, especially in regard to agricultural usage and their effect on rural wildlife. The reaction by those in government and in the chemical industry to new ecological data will also be briefly discussed. The paper shows how support grew for what was termed integrated pest management (IPM), a three-pronged approach to pest control. It entailed a major reduction in the use of chemicals, a more targeted approach to their application, biological control, and encouragement for cultural change among farmers and horticulturalists.[13] The final chapter of Carson's book, entitled "The Other Road," had some suggestions as to how chemical usage could be reduced and perhaps eventually phased out. "We now stand where two roads diverge," she wrote. The road that she wanted people to travel led towards the sterilisation of insects by radiation, insect trapping by the use of pheromones, and the seeking of new insect pathogens. She mentioned biological control, but less favourably.[14] Pheromone research flourished, but biological control and IPM became the

[10] The college already had connections to British Guiana (now Guyana), as O. W. Richards (see below) and his wife Maud Norris had carried out research there before the war. The field team was led by C. B. Symes, who later became director of research for the Colonial Insecticide Committee. The spray used was a 5 per cent solution of DDT in kerosene. Kerosene was also used as the propellant for most pyrethrum sprays. After the war, spraying technology was much improved, largely because of work at the Colonial (later Overseas) Spraying Machinery Centre, at Silwood Park, Imperial College.

[11] Much post-war use of DDT was in Africa, to combat the insect vectors of malaria, sleeping sickness, and nagana. See Sabine Clarke, "Rethinking the Post-War Hegemony of DDT-insecticide Research and the British Colonial Empire," in *Environment, Health and History*, ed. V. Berridge and M. Gorsky (Basingstoke: Palgrave Macmillan, 2012).

[12] Wartime chemistry was also the source of this development. Organophosphate pesticides such as parathion were developed as a result of work on nerve gases, carried out first in Germany. For the history of some of this wartime chemistry, see Edmund Russell, *War and Nature: Fighting Humans and Insects with Chemistry* (Cambridge: Cambridge University Press, 2001).

[13] One of the first successes of this approach was the control of aphid pests on the forage crop lucerne (alfalfa) in California. See V. M. Stern, R. F. Smith, R. van den Bosch and K. S. Hagen, "The Integrated Control Concept," *Hilgardia* 29 (1959): 81–101. Cultural change in this context meant changing old routines such as planting times and crop rotations, and leaving some uncultivated areas close to fields.

[14] Carson may have had in mind classical biological control, which could account for her attitude. In classical biocontrol, some exotic species (i.e. a species new to the ecosystem) is introduced to control a pest. This can lead to problems should the introduced species run wild, or conflict with the conservation of native species. The term "biological control" was first used in H. S. Smith, "On Some Phases of Insect Control by the

most popular methods of pest control over the longer term, although they are now challenged by work on transgenic plants and animals.

Before *Silent Spring*: the new insecticides and their problems

The agricultural use of pesticides grew rapidly after the war, and farmworkers began handling chemicals without much knowledge of their toxicity and without proper protection. In the late 1940s, eight farmworkers died shortly after handling the herbicide 4,6-dinitro-orthocresol.[15] Because of this and other troubling incidents, the minister of agriculture, Sir Thomas Dugdale, set up a working party under Solly Zuckerman to study the use of chemicals in agriculture. The working party filed reports in 1951, 1953, and 1955.[16] The first of these dealt with the safety of farmworkers, the second with the risk to consumers of treated crops and contaminated animals, and the third with risks to ecosystems in rural areas surrounding farms. One consequence of the initial report was the Agriculture (Poisonous Substances) Act of 1952, but its measures were weak. One reason may have been that the accidental death and injury rates related to farm machinery and traditional work practices were far greater than the death and sickness rates attributed to chemicals. However, basic protective clothing for farmworkers handling chemicals was made mandatory, and some recording of the use of chemicals and some reporting of sickness were required. However, there was no thought of banning the new chemicals. Manufacturers were simply asked to participate in a voluntary precautionary information scheme. By the end of the decade, this scheme was falling apart in light of new data, which the manufacturers at first challenged. Some of these data were included in Zuckerman's third report, which moved the focus of the debate away from human health and towards ecological problems. The minister of agriculture was in a difficult position. On the one hand, it was clear that pesticides allowed for more intensive farming (through saving labour costs related to weeding and the destruction of insect pests) and for considerable increases in yields. This was true for both pastoral and arable agriculture. For example, sheep dipping with dieldrin needed only one application per year and, by

[14] *Continued*
Biological Method," *Journal of Economic Entomology* 12 (1919): 286–92. The idea, however, existed much earlier, and was discussed by Ilya Metchnikoff in the 1880s, when he proposed using a fungus to control the wheat cockchafer, and the use of bacterial agents for controlling some other pests. See Jeffrey C. Lord, "From Metchnikoff to Monsanto and Beyond: The Path of Microbial Control," *Journal of Invertebrate Pathology* 89 (2005): 19–29. I am indebted to Raf de Bont for telling me of this paper. One of the largest programmes in classical biocontrol took place in Africa during the 1970s and 1980s. See P. Neuenschwander and H. R. Herren, "Biological Control of the Cassava Mealybug, *Phenacoccus manihoti*, by the Exotic Parasitoid *Epidinocarsis lopezi* in Africa," in *Biological Control of Pests, Pathogens and Weeds: Developments and Prospects*, ed. R. K. S. Wood and M. J. Way, in *Philosophical Transactions of the Royal Society* B318 (1988): 319–32.

[15] P. L. Bidstrup and D. J. H. Payne, "Poisoning by Dinitro-orthocresol: Report of Eight Fatal Cases Occurring in Great Britain," *British Medical Journal* 2, no. 4722 (1951), 16–19. There had been earlier reports of birds, hares and rabbits dying from exposure to the same chemical. See also G. S. Wilson, "Farm Safety," *British Journal of Industrial Medicine* 23 (1966), 1–15, esp. 2–4.

[16] Lord Solly Zuckerman (1904–93) was later appointed chief scientific advisor to the Ministry of Defence and, in 1964, chief government scientist. Reports of the Working Party: *Toxic Chemicals in Agriculture* (London: HMSO, 1951); *Toxic Chemicals in Agriculture: Residues in Food* (London: HMSO, 1953); and *Toxic Chemicals in Agriculture: Risks to Wildlife* (London: HMSO, 1955).

lowering tick infestations, increased meat yields. And, while pesticides were not the exclusive factor, British wheat yields rose by about 25 per cent during the 1950s.[17] On the other hand, the returns on pesticide use were diminishing, and the ecological costs were becoming increasingly clear. Needless to say, the minister was lobbied from all sides.[18]

The scientific community was divided. All sorts of questions were raised; for example, was sheep dipping responsible for the presence of chlorohydrocarbons in human fat tissues? And if so, did that mean that sheep dipping with dieldrin should be abandoned? On these and other issues, some questioned the reliability of the data, some accepted the data but saw the deleterious effects as a price worth paying for increased agricultural productivity, and yet others pressed for safety above all else.[19] In my view, what tipped the balance against the manufacturers was not so much human safety. This was thought to be manageable: first, by providing suitable protection for farmworkers; and second, by monitoring residue levels in animal products. Given that toxicologists had claimed that the most persistent of the new chemicals, the chlorohydrocarbons, were not especially toxic in mammals, low levels were thought to be acceptable and achievable. What prompted their gradual withdrawal, not only in Britain, was the increasing recognition of serious ecological consequences in the countryside. Here, I will limit discussion to the agricultural use of the pesticides aldrin and dieldrin, and to some consequences of antimalaria spraying with DDT in two former British colonies that are now part of Malaysia.

Aldrin and dieldrin were first manufactured in the 1940s by the American company Julius Hyman. The company was taken over by Shell in 1952, after which the chemicals were also manufactured in the UK. They were sold as having a dual role: as antifungal seed dressings and as insecticides. However, it was soon noted that large numbers of seed-eating game birds were dying, notably wood pigeons, pheasants, and partridges. There was also evidence of increased deaths among raptors that preyed on the game birds, and among fish-eating birds. During the 1950s, the chairman of the British Field Sports Society was the Conservative MP for Salisbury, John Morrison. He was also chairman of the 22 Committee, and so an influential backbencher. Combatting the "poisoning of the countryside," as he saw it, became one of his causes, and he was an effective champion in the House of Commons.[20] In challenging

[17] Data on food production from the 1950s to the 1970s can be found in the *7th Report (Agriculture and Pollution) of the Royal Commission on Environmental Pollution* (London: HMSO, 1979). The report lists all of the principal pesticides used in Britain in the period 1950–1975, and claims that, by the 1970s, over 90 per cent of cereals, fruit trees and bushes, and vegetables were being treated. By then, over two hundred active ingredients were being marketed in about eight hundred approved formulations. The use of chlorohydrocarbons declined during the 1960s, but other insecticides replaced them. In the same period, there was a major increase in the use of herbicides.

[18] See John Sheail, *An Environmental History of Twentieth-Century Britain* (Basingstoke: Palgrave, 2002), 235–45, for a discussion of the response of the ministry to new data on pesticides during the 1950s and 1960s. See also John Sheail, *Pesticides and Nature Conservation: The British Experience, 1950–1975* (Oxford: Clarendon Press, 1985).

[19] See Sheail, *An Environmental History*, 235–45.

[20] The 22 Committee was founded in 1922 by a small group of backbench Conservative MPs who rebelled against coalition with the Liberal Party. Today, the committee is open to all Tory backbenchers. Morrison joined in a number of parliamentary debates on chemical usage in agriculture. See, for example, *HC Debates*: 28 July 1952, vol. 504, col. 85W; 4 May 1953, vol. 515, col. 11W; 9 February 1954, vol. 523, cols. 115–16W; and 23 June 1955, vol. 542, cols. 83–84W.

the use of the new pesticides, he had the support not only of members of the Field Sports Society, but also of the wider public. Veterinarians confirmed that the increased bird deaths were indeed due to chlorohydrocarbon insecticides, and that higher concentrations were found in the raptors that fed on the seed-eating birds than in the seed-eaters themselves.[21] But the question that the minister of agriculture wanted answered, before acting on the new information, was how many birds were dying. The ministry refused to perform its own census, insisting that the bodies demanding action, such as the Field Sports Society and the Nature Conservancy, provide better data.[22]

At that time, government resources were more focused on the human food supply, and troubling data were being collected there too. Chemists in both the Government Infestation Control Laboratory (under the Ministry of Agriculture) and the Laboratory of the Government Chemist found that rising levels of chlorohydrocarbons were showing up not only in lamb and mutton, but also in beef and milk. However, given the seemingly benign toxicological data, no steps were taken other than modifying the earlier notification scheme and attempting to have farmers apply lower volumes of the pesticides. Chemical manufacturers were asked to voluntarily notify the government of which products they were marketing, and what quantities were being sold and where. Compliance must have been poor, because, still in the 1970s, the chairman of the Royal Commission on Environmental Pollution, Sir Hans Kornberg, complained of poor marketing data.[23]

In 1959, under pressure in parliament, the minister of agriculture, John Hare, set up a research study group under Harold G. Sanders, his chief scientific advisor. According to John Sheail, Sanders was sceptical of the concerns of naturalists.[24] However, the research study group sought outside advice and invited formal submissions of evidence, prompting the British Ecological Society (BES) to submit its own evidence. Owain W. Richards, who drafted the submission, was head of the zoology and applied entomology department at Imperial College. The submission provided evidence of ecological damage, and identified eight areas needing further study. These included weed ecology, the long-term effects of insecticides on crops, the effects of insecticides on the flora and fauna of uncultivated land adjacent to farms, and the frequency of pesticide overuse by farmworkers — a serious and well-known problem at the time.[25] Members of the BES were not alone in fighting to maintain the integrity of the countryside. Although in many ways a human construct, the countryside had reached a relatively stable ecological state before the large-scale arrival of chemical pesticides and fertilisers. People had come to love it as it was.[26]

[21] Some raptors, such as the sparrow hawk and peregrine falcon, came close to extinction in Britain. With better pesticide control, they have made a comeback.

[22] Sheail, *An Environmental History*, 237–38.

[23] For testing, see: Sheail, *Pesticides*; and *7th Report of the Royal Commission on Environmental Pollution.*

[24] John Sheail, *Seventy-five Years in Ecology: The British Ecological Society* (Oxford: Blackwell, 1987), 206–7. Sheail was a member of the advisory board set up by the Ministry of Agriculture to advise on the issue of pesticides. Sanders was professor of agriculture at the University of Reading.

[25] See *7th Report of the Royal Commission on Environmental Pollution*, section 2.7. In some cases, it was claimed, concentrations over one million times greater than needed were being used.

[26] Relative stability was reflective of a dynamic equilibrium. The populations of various local plants and animals, although they fluctuated over time, had remained largely unchanged for a long period. The love of countryside and the fear of change because of a post-war "agricultural revolution" was well expressed by the sculptor Henry Moore in his foreword to Marion Shoard, *The Theft of the Countryside* (London: Temple Smith, 1980). He wrote "the English countryside has helped shape English character . . . the countryside which is so much part of our nation now stands in real danger of destruction."

The 1959 report of the Ministry of Agriculture's study group was one factor in the creation of the Natural Environment Research Council (NERC) under the Science and Technology Act of 1965.[27] The council was given the responsibility for supporting postgraduate courses and research in the earth sciences, ecology, and environmental science. A new source of funding became available for people with ecological and environmental interests. Courses opened up around the country, many of them interdisciplinary. They proved very popular, because many young people not only believed in environmental causes, but also sensed, rightly as it turned out, that there would be new environment-related job opportunities for biologists, chemists, engineers, sociologists, and economists.

Political discussion intensified during the 1960s. For a start, the spring of 1960 was exceptionally dry, which meant that more treated cereal seeds remained on the surface of the ground than usual, leading to many more bird deaths than earlier. There was a public outcry, and the Laboratory of the Government Chemist, experienced in examining sheep and cow carcases, moved to also examining those of birds. In response to the public outcry, the new minister of agriculture, fisheries and food, Christopher Soames, set up a chemical residues panel under the chairmanship of his chief scientific advisor (Harold Sanders), and an advisory committee on pesticides and toxic chemicals in the environment with Sir James Cook FRS, an eminent organic chemist and the vice-chancellor of the University of Exeter, as chairman. The residues panel strongly advised banning the use of aldrin, dieldrin, and heptachlor. ICI had already taken the decision to discontinue manufacturing heptachlor, and pressure was placed on Shell for the voluntary withdrawal of its products. The zoologist N. M. V. (Lord Victor) Rothschild FRS had just been appointed research director at Shell, and did his best to protect the company's interests.[28] This included lobbying his colleagues in the Royal Society in support of the pesticides' continued use, and in playing down their harmful consequences. Rothschild had some credibility as a long-term chairman of the Agricultural Research Council. He disputed the scientific evidence, but he was no ecologist.

In 1961, Shell voluntarily withdrew dieldrin as a treatment for cereal seeds sown in the spring (but not for autumn-sowed wheat, and not as an insecticide). The government, hesitant to impose a complete ban, stepped up precautionary measures and put in place some new procedures for educating farmers. Steps were taken to encourage an end to routine calendrical applications and for farmers to use chemical pesticides only when the densities of pests were such that yields were seriously threatened. When Cook's committee reported in 1964, it backed up the earlier panel, and strongly advised an end to the use of aldrin and dieldrin other than in exceptional circumstances. Soames then took more decisive action. The chemicals would no

[27] Sheail, *Seventy-five Years in Ecology*.

[28] Sheail has provided evidence of Soames's situation from papers held in the National Archives. Soames was under pressure from his under-secretary not to give in to pressure from Rothschild. He was also advised to get other government ministers on-side (which he did). See Sheail, *An Environmental History*, 236–45. Nathaniel Meyer Victor Rothschild FRS (1910–1990), third Baron Rothschild, was a Cambridge-educated zoologist who remained at the university as a research scientist (although engaged in war work) until just after the end of World War II. He joined the Labour Party after its general election victory in 1945, and was chairman of the Agricultural Research Council from 1948 to 1958. He joined Shell in 1961, and worked there until 1970.

longer be available for purchase by gardeners and horticulturalists, and their use in agriculture was to be severely restricted.[29]

Because of the various problems, there was support within the BES and other bodies for an experimental research station to be built next to the Monks Wood National Nature Reserve in Huntingdonshire. The government agreed to fund the station, to be run by the Nature Conservancy.[30] The medical entomologist and ecologist Kenneth Mellanby was appointed director. Work on wildlife toxicology began there in 1961 under Norman Moore.[31] Ecologists at Monks Wood, along with others worldwide, showed not only the direct consequences of pesticide use, but also how and why ecosystems were being severely damaged. They understood the need for agriculture to coexist with wild habitats, not only for the maintenance of biodiversity, but also to provide refuges for the natural control agents of agricultural pests.

Earlier, in 1948, ecologists and conservationists founded the International Union for the Conservation of Nature and Natural Resources (IUCN). At its first meeting in Fontainebleu, twenty-three countries joined as member states, and about two hundred organisations from sixty-four countries joined independently. The IUCN provided a forum where problems related to pesticides and ecology could be discussed. Its fifth meeting, held in Copenhagen in 1954, was on the effects of modern herbicides and insecticides on insect, mammal and bird populations.[32] In 1961, the IUCN established a committee on the ecological effects of chemical insect and weed control. Moore was the British representative on the committee and also its secretary. In 1963, he approached NATO for sponsorship of an advanced study institute on pesticides in the environment, and their effects on wildlife. The result was a two-week symposium held at Monks Wood in 1965.[33] All of the concerns expressed by Carson, including that of egg-shell thinning, can be found in the symposium proceedings, albeit expressed more dryly and technically.[34]

[29] *HC Debate* on "organochloro" pesticides, 24 March, 1964, vol. 692, cols. 244–52. The committee on pesticides and other toxic chemicals continued to meet, and came out with a further report in 1969, in which persistent chemicals remained the principal focus.

[30] The reserve had been set up by the Nature Conservancy in 1953 to protect an ancient woodland, principally of oak and ash. After the reform of county boundaries, and the decision to end Huntingdonshire's status as a county in 1974, it fell within the boundaries of Cambridgeshire.

[31] The station opened officially in 1963, but scientific work had begun there in 1961. It closed in 2008, and its scientific work was moved to another NERC site at Wallingford, in the Thames Valley. Norman W. Moore's memoir, *Bird of Time: The Science and Politics of Conservation — A Personal Account* (Cambridge: Cambridge University Press, 1987) tells much of the period under discussion in this paper. For pesticide use, see especially chapters 12–15. For Mellanby, see n. 8 above.

[32] *Effects of Modern Insecticides on Mammals, Birds and Insects* (Proceedings and Papers, IUCN, 1956). See also John L. George, "The Work of the IUCN's Committee on the Ecological Effects of Chemical Controls," in *Pesticides in the Environment and Their Effects on Wildlife*, ed. N. W. Moore (Proceedings of an Advanced Study Institute sponsored by the North Atlantic Treaty Organization, Monks Wood Experimental Station, England, 1–14 July, 1965) (Oxford: Blackwell, 1966), 287–90.

[33] Moore, *Pesticides in the Environment*. A theme running through these conference papers is increased understanding of the persistence and dispersal of both chlorohydrocarbon pesticides and organomercury fungicides in the environment. For example, evidence was presented of traces of these compounds in the tissues of arctic mammals. Moore introduced a dragonfly protection scheme under the auspices of the IUCN.

[34] Egg-shell thinning, established by comparing shells with those from earlier periods kept in museums, was a major public concern, and was seen as a principal factor in the population decrease of some bird species, notably raptors. The sparrow hawk still showed evidence of chlorohydrocarbons in its tissues in the late 1970s, despite a major decrease in the use of those chemicals during the previous decade. See *7th Report of the Royal Commission on Environmental Pollution*, 3.22.

Some of the early data on ecological problems came not as a result of pest control in agriculture but from malaria control. For example, World Health Organisation (WHO) teams working in North Borneo (now Sabah) and Sarawak conducted an indoor DDT spraying programme during the 1950s that had a number of interesting and serious ecological consequences. Malaria mosquitoes were effectively controlled, but there were problems. For example, many people living in homes with thatched roofs complained that, after the spraying, their roofs were eaten away by caterpillars. It turned out that a parasitic wasp that preyed on the caterpillars was especially vulnerable to DDT, leaving the caterpillar populations less controlled. It was also the case that many domestic cats died. They were poisoned not only because they cleaned their fur by licking it, but because they caught and ate small geckos that lived inside people's houses. The geckos preyed on insects. The cat deaths appeared to provide early evidence of DDT working its way up the food chain, and also that, at certain concentrations, DDT was harmful to mammals. The death of the wasps was a lesson in the loss of biological control. So, too, was the death of the cats, as the rodent population flourished. Replacement cats had to be trucked in to the most affected areas. In more remote areas, some were even parachuted in.[35] These ecological lessons were learned back in Britain and, added to the problems already discussed, helped to set the stage for further action.[36]

Environmental politics, 1962–1972

When Rachel Carson published *Silent Spring* in 1962, the ground was well prepared for its reception.[37] Other events, too, helped to raise people's awareness of

[35] There has been debate over the degree to which chlorohydrocarbons work their way up the food chain. See: Moore, *Pesticides in the Environment*, 181; F. Y. Cheng, "Deterioration of Thatch Roofs by Moth Larvae after House Spraying in the Course of Malaria Eradication," *Bulletin of the World Health Organization* 28 (1968): 136–37; and Patrick T. O'Shaughnessy, "Parachuting Cats and Crushed Eggs: The Controversy Over the Uses of DDT to Control Malaria," *American Journal of Public Health* 98 (2008): 1940–48. One source for this article was Gordon Conway, a scientist who worked in North Borneo in the early 1960s, and was there at the time of independence. Both Sarawak and North Borneo (renamed Sabah) became states of Malaysia. By the late 1960s, Conway (to be discussed further below) was a lecturer at Imperial College.

[36] There were many such lessons. DDT was used worldwide in orchards to control Codlin moths. It also killed their natural predators, some mites that also kept the red spider mite in check. Red spider mites became a major pest worldwide. See Moore, *Pesticides in the Environment*, 145. In the USA, attention was drawn to the environmental consequences of DDT usage after an attempt to control the bark beetle vectors of a fungus responsible for a major outbreak of Dutch Elm Disease during the 1950s.

[37] It is hard to document Carson's effect and legacy, but there is little doubt that it was considerable. For some American views on this, see: Lisa H. Sideris and Kathleen Dean Moore, eds., *Rachel Carson: Legacy and Challenge* (Albany: State University of New York Press, 2008); Thomas R. Dunlap, *Scientists, Citizens and Public Policy* (Princeton, N.J.: Princeton University Press, 1981); and Thomas R. Dunlap, ed., *DDT, Silent Spring and the Rise of Environmentalism* (Seattle: University of Washington Press, 2008). See also: Frank Graham Jr., *Since Silent Spring* (Boston, Mass.: Houghton Mifflin, 1970); and Dorothy Nelkin, "Ecologists and the Public Interest," *Hastings Center Report* 6 (1976): 38–44. Dunlap's 2008 book is a collection of excerpts from classic papers. The first, an essay by Stephen A. Forbes, "The Ecological Foundations of Applied Entomology," was originally published in 1915, and begins with the claim, "applied entomology is peculiarly an American subject," something that those working at Imperial College could well have challenged. H. M. Lefroy worked on insect pests of the cotton plant in the late nineteenth century, an area of research seen by Forbes as exclusively American. As to the later period, I have spoken to several British ecologists who began their careers in the late 1960s and early 1970s; all mentioned being inspired by Carson's book. For some other retrospective thoughts, see D. A. Christie and E. M. Tansey, eds., *Environmental Toxicology: The Legacy of Silent Spring*, Witness Seminars, vol. 19 (2004) (available at http://history.qmul.ac.uk/research/modbiomed/Publications). For more general coverage, see Samuel P. Hays, *A History of Environmental Politics Since 1945* (Pittsburgh, Penn.: University of Pittsburgh Press, 2000).

environmental problems. Indeed, the "long 1960s" was transformative not only in the ways in which people approached environmental matters, but also in their approach to science and technology more generally.[38] Another book that received much press coverage was *The Population Bomb* (1968) by the University of California biologist Paul Ehrlich. It portrayed a looming population crisis, and argued that both environmental conservation and limits to the earth's resources needed to be taken seriously.[39] In 1967, there was an environmental disaster along the Cornish coast caused by a major oil spill from the wreck of the tanker *Torrey Canyon*.[40] The public was upset not only by the oil pollution and loss of wildlife, but also by the overuse of dispersive detergent on the beaches. The incident was a tipping point for the environmental movement in Britain, and its spokespersons began to gain a greater political voice. In 1966, the Council of Europe declared that 1970 would be European Conservation Year. In early 1970, a conference was held in Strasbourg attended by officials from twenty countries, business leaders, scientists, and representatives of environmental groups. On 22 April 1970, the first Earth Day was celebrated in the USA. It saw the appearance of the highly successful Möbius strip recycling logo.[41]

In 1968, the Club of Rome was founded with the aim of bringing scientists and industrialists together to seek solutions to problems of the environment and conservation. Its first major publication, *Limits to Growth* (1972), was a work commissioned from scientists, including social scientists, at the Massachusetts Institute of Technology.[42] A computer model led them to predict the collapse of the industrial West by 2100 unless major steps were taken to conserve resources. One notable British resource being exploited in this period was North Sea oil and gas. Like the *Torrey Canyon* disaster, the new industry fed into the environmental debate in Britain. There was much concern over what drilling would mean for the ecology of the Scottish

[38] The "long 1960s" is Arthur Marwick's periodisation. See his *The Sixties: Cultural Revolution in Britain, France, Italy and the United States, c.1958–c.1974* (Oxford: Oxford University Press, 1998). For an interesting discussion of the period as it relates to science and technology, see Jon Agar, "What Happened in the Sixties?" *British Journal for the History of Science* 41 (2008): 567–600. Agar provides a synthesis of some of the principal secondary literature. He rightly sees *Silent Spring* as a text inspired by antinuclear activism, and that Carson saw parallels between radiation and pesticides.

[39] The "population crisis" was a topic of discussion throughout the 1950s and 1960s. It made the cover of *Time*, 11 January 1960. Another bestseller in this vein was William Paddock and Paul Paddock, *Famine 1975: America's Decision Who Will Survive?* (Boston, Mass.: Little, Brown, 1967). Garrett Hardin's influential paper, "The Tragedy of the Commons," *Science* 162 (1968): 1243–48, also focused on the population problem.

[40] This Liberian-registered tanker ran aground near Lands End on 18 March, 1967. It soon broke up, and its entire cargo of oil spilled out, much coming ashore. Although oil spills were not unusual, the scale of this one posed a problem for the government.

[41] US senator Gaylord Nelson was the political force behind the first Earth Day. Today, it is celebrated in over 150 countries. The recycling logo was designed by Gary Dean Anderson, an architecture student at the University of California at Los Angeles, who won a design competition sponsored by the Container Corporation of America, a major paper recycler.

[42] Donella H. Meadows, Dennis L. Meadows, Jørgen Randers and William W. Behrens III, *Limits to Growth* (New York: Universe Books, 1972). I mention only a few of the many books in this vein. Another popular one was Barry Commoner's *Science and Survival* (New York: Viking, 1966). Rachel Carson wrote the foreword to Ruth Harrison's *Animal Machines: The New Factory Farming Industry* (London: Vincent Stuart, 1964). The book raised public concern over factory farming, another issue with which the minister of agriculture had to deal. The furore over animal welfare, which parallels that over agricultural pest control and ecological loss, is well described by Abigail Woods in "Together Forever? The Past, Present and Future of Animal Health and Welfare," *Veterinary Times* 39 (2009): 8–9.

coastline and for offshore marine life. The 1970s saw the appearance of many fast-growing organisations, such as Friends of the Earth (founded in the USA in 1969; the UK branch was established in 1971) and Greenpeace (founded in Canada in 1971).[43] In Britain people, were also working on a range of domestic rural and marine conservation projects, such as protecting fenlands, conserving seal populations, and protecting Exmoor. The Wildlife and Countryside Act (1981) was an attempt to address concerns of that kind.

Among the many responses to environmental threat was the founding of the *Ecologist* by Edward (Teddy) Goldsmith in 1970. Goldsmith co-authored the document *Blueprint for Survival*, which took up the entire January 1972 issue of the *Ecologist*. It is a curious manifesto, both progressive and regressive in its radicalism. It is regressive in that it suggested the need to totally dismantle modern industrial society and move back to a simpler way of life. It is progressive in that it was a serious wake-up call, pointing to problems that governments needed to address, and arguing for the need to include ecological and environmental ideas in school curricula. Published later that year as a small book, *Blueprint* sold close to a million copies; its American edition had a supportive foreword by Paul Ehrlich. Goldsmith was also a founder of the Green Party of England and Wales.[44] *Blueprint* became, as intended by its authors, an unofficial manifesto for the United Nations Human Environment Conference held in Stockholm in 1972. The British government, too, acted in anticipation of the UN conference, and set up the Royal Commission on Environmental Pollution in 1970. For this they were strongly lobbied, especially by Eric Ashby, who was appointed the commission's first chairman.[45] The Stockholm conference, energetically chaired by Gro Harlem Brundtland, the future prime minister of Norway and future director of the WHO, was extremely important in helping to place the environment on the international political agenda.

The book *Only One Earth* (1972), also published for the UN conference, drew much attention. Its authors were the French biologist and environmentalist René Dubos and the British economist and advocate for the developing world Barbara Ward. Dubos coined the maxim "think globally, act locally" and used it in a speech given at the conference. The governments represented in Stockholm promised funding for environmental and ecological science, and, by and large, they delivered despite the

[43] For more on this and other such groups, see Philip Lowe and Jane Goyder, *Environmental Groups in Politics* (London: George Allen and Unwin, 1983). See also Richard Kimber and J. J. Richardson, eds., *Campaigning for the Environment* (London: Routledge and Kegan Paul, 1974). This essay collection captures the mood of the early 1970s.

[44] Edward R. D. Goldsmith (1928–2009) was the older brother of the financier Sir James Goldsmith. Goldsmith's basically conservative political ideas were to put him at odds with some co-founders of the Green movement in Britain. The origin of the use of the term "green" to describe environmental movements is obscure. The first political Green Party was founded in Tasmania, but "green" ideas were everywhere, and several Green Parties sprang up at roughly the same time. The one in England was founded in 1973. At first called the People Party, it went through several name changes before becoming the Green Party of England and Wales in 1985.

[45] Lord Eric Ashby (1904–1993) began his distinguished academic career as a botany student and then lecturer at Imperial College. He ended it as Master of Clare College Cambridge and as vice-chancellor of the university. The Royal Commission on Environmental Pollution produced many important research papers, including some on pesticides in agriculture. Despite its forty-year record of providing good advice, the commission was closed by the Cameron government in April 2011.

recession.[46] Academic ecologists, including those to be discussed below, were among the beneficiaries. The conference also led to the founding of two new bodies in 1973. One was the UN Environment Programme (UNEP), with headquarters in Nairobi.[47] The other was the International Institute for Environment and Development (IIED), with headquarters in London. Barbara Ward was its first director. She encouraged a number of projects in the developing world, including ones related to problems caused by the use of chemicals in agriculture.[48]

Another outcome of growing ecological concerns worldwide was the growth of the science of ecotoxicology. In 1979, the Society of Environmental Toxicology and Chemistry was established. It was an international body with plenty to occupy its agendas. New disasters, such as the nuclear accidents at Chernobyl and Three Mile Island, and the Exxon Valdez oil spill in Alaska, provided much for scientists to think about. Despite increasing awareness, problems with chemical contamination continue. According to Helmut van Emden and David Peakall, writing in 1996, about sixty thousand to seventy thousand chemicals were then still in regular use, yet toxicological data for humans and for wildlife were available for only a small fraction of the three thousand chemicals that made up 90 per cent of usage.[49] The situation today is unlikely to be very different.

Towards biological control

Without the public awareness of environmental problems, and the consequent political response, the expansion of ecological work in the 1960s and 1970s would not have occurred in the way that it did. Those at Imperial College's Silwood Park Field Station, already a major centre in applied entomology, tapped into the new political

[46] The economic recession gathered momentum after the 1973 Yom Kippur War, and a temporary oil embargo against the USA. The embargo was followed by a major jump in the price of oil imposed by OPEC (Organization of Petroleum Exporting Countries), which was unhappy with President Nixon's 1971 decision to sever the link between gold and the US dollar. The result was a huge inflation in oil prices that lasted until well after the Iranian Revolution of 1979. The consequences for university funding were dire but, because of the rise of environmentalism, ecological science went relatively unscathed.

[47] About £20 million went to founding the UNEP. Its first director was the Canadian businessman Maurice Strong, the behind-the-scenes force and secretary-general of the 1972 UN conference. He later chaired the 1992 UN Conference on Environment and Development held in Rio de Janeiro, and was a moving force behind the Kyoto Protocol. Strong was a senior advisor to Kofi Annan, and is involved also with Mikhail Gorbachev's Green Cross International. Brundtland later chaired the World Commission on Environment and Development and authored its influential report, *Our Common Future* (Oxford: Oxford University Press, 1987).

[48] The economist Barbara M. Ward (Baroness Jackson of Lodsworth) (1914–1981), a major advocate for the developing world, was president of the IIED from 1973 to 1980. The IIED was funded by industry and by development funders such as the World Bank. The connection between the environment and development was made at a 1968 conference; see M. Tagi Farvar and John P. Milton, eds., *The Careless Technology: Conference on Ecological Aspects of International Development* (Garden City, N.Y.: Natural History Press, 1972). Attending were major figures such as the biologist and environmentalist Barry Commoner, the economist Kenneth Boulding, and the ecologist and conservationist Frank Fraser Darling. Gordon Conway, whose work will be discussed below, also gave a paper.

[49] Helmut F. van Emden and David Peakall, *Beyond Silent Spring: Integrated Pest Management and Chemical Safety* (London: Chapman and Hall, 1996), x. H. F. van Emden, a former student of T. R. E. Southwood at Imperial College, is an emeritus professor of horticulture and professor of applied entomology at the University of Reading. The website of the UK Pesticide Residues Committee includes much interesting data on food safety.

reality and became well funded as a result.[50] Work on insect ecology expanded during O. W. Richards's tenure as head of the department of zoology and applied entomology.[51] It was to do so even more under his successor, T. R. E. (Dick) Southwood.[52] As a junior staff member, Southwood was already interested in biological control. His first research project at Silwood was carried out together with a more senior member of the staff, Walter Jepson. Funded by the Agricultural Research Council, they studied the frit fly, *Oscinella frit*, a cereal pest that was attacking oat crops. It turned out that frit fly populations were regulated in part by parasitic mites that preyed on frit fly larvae. Chemical pesticides were preferentially killing off the mite population and so destroying that form of natural control.[53] Interestingly, Jepson, a reader at the college, left to join the agricultural chemicals division of American Cyanamid. But for Southwood, the work led in the direction of research into plant–insect communities and biological control. When, in 1968, Southwood gave his inaugural lecture as professor, Jepson was a little critical. There was much to admire about Southwood and the lecture, he wrote, but when he "launches into the realm of pest management, he seems at times to be succumbing to the elbow jogging influence of the Carsonites, the integrationists and the conservationists."[54] Jepson belonged to a generation that had developed a range of chemical pesticides, and he had joined the chemical industry. He was defensive. But Southwood had sensitive political antennae; he understood the growing public concern over the environment, a concern that he shared. Not only did he join the public debate, but he recognised that universities needed to respond. Under his leadership, research at Silwood Park moved further towards the ecological and environmental sciences.

Southwood also made some good political moves. In 1969, following the publication of Ehrlich's book, he was invited to address the Parliamentary and Scientific Committee on the topic of overpopulation.[55] Three years later, along with 136 others, including Julian Huxley, Frank Fraser Darling, and Peter Medawar, he signed a letter to *The Times* in support of the *Blueprint for Survival* document.[56] In his department, he was supportive both of those seeking more effective chemical pesticides and of

[50] The field station, now known as the Silwood Park Campus, occupies about 250 acres near Ascot, Berkshire.

[51] Owain Westmacott Richards FRS (1901–1984).

[52] Sir Thomas Richard Edmund (Dick) Southwood FRS (1931–2005) was educated at Imperial College. He carried out doctoral research on some cereal insect pests under C. B. Williams at the Rothamsted Experimental Station. Richards appointed him to the staff in 1955, and he became head of department in 1967. Southwood moved to Oxford University when appointed to the Linacre Chair of Zoology in 1979. In 1989, he was appointed vice-chancellor of the university.

[53] They began this research project in 1955, and published several papers. See, for example, T. R. E. Southwood and W. F. Jepson, "Studies on the Populations of *Oscinella frit* L. (Dipt: Chloropidae) in the Oat Crop," *Journal of Animal Ecology* 31 (1962): 481–95.

[54] Comments by W. P. Jepson, dated 18 October, 1969. Bodleian Library, *Southwood Papers*, B14. By "integrationists," Jepson meant those promoting integrated pest management.

[55] Bodleian Library, Southwood Papers, E. 58; see notes and correspondence on "man's population," 1969–70. Southwood was a pessimist, and claimed that there is "only a 50/50 chance of the world surviving the dangers of overpopulation" (Imperial College London, *Topic*, 11 June 1979). MS E.72 is a paper titled "The Principles of Population Estimates," given at the WHO Conference on Vector Ecology, December 1971.

[56] Bodleian Library, Southwood Papers, B16; *The Times*, 25 January 1972, 15. Southwood, the instigator, was the first to sign, followed by two other Imperial College zoologists, J. S. Kennedy and Gordon Conway. Conway will be discussed further below.

those seeking biological control methods. He also supported work on the control of human disease vectors, and he promoted Michael Way's integrated approach to pest management. Way, an early IPM enthusiast, was carrying out research on the biological control of aphids.[57] He was also director of the Overseas Spraying Machinery Centre located at Silwood.[58] Much research funding came from the Colonial (later Commonwealth) Office and from a number of tropical agricultural industries, such as tea, rubber, and, especially, cotton. Research carried out at Silwood into IPM served both domestic and overseas needs. Commonwealth connections became even stronger in the 1980s with the relocation of both the Commonwealth Agricultural Bureaux and the Commonwealth Institute of Biological Control to Silwood.[59] But even before they arrived, scientists at Silwood were collaborating with people working at both these bodies. There was much collective research, and advice was given to people in countries around the world on pest management and sustainable agriculture.

Although classical biocontrol continued, it was the restoration of natural biological control that became the most important aim of IPM, and it remains important today. But how to conserve and increase natural enemies? Many methods were tried, including reducing chemical usage, avoiding monoculture, removing crop debris, and educating farmers to allow their agricultural plots to be surrounded by wild areas so that the natural enemies of pests could thrive. Research on the mass production of local (nonexotic) predators and parasites was another approach. For example, a parasitic wasp was bred in large numbers and successfully introduced into Asia, where it helped to control the diamondback moth, a major pest of cabbage plants. Spraying technology was improved so as to protect operators and to deliver pesticides more effectively with lower concentrations. Small-scale (knapsack) sprayers were developed for use in the developing world.[60]

The British government responded well to the 1972 Stockholm conference and to public pressure.[61] During the recession following the OPEC crisis, ecology and environmental science were two of the few areas where universities could grow. As a result, when Southwood became head of department, he was able to bring several young ecologists to work at Silwood. The first was Gordon Conway, a future co-signatory of the *Blueprint* document.[62] On gaining his BSc from the University College of Wales at Bangor in 1959, Conway joined the colonial service and, after

[57] See, for example, M. J. Way, G. Murdie and D. J. Galley, "Experiments on the Integration of Chemical and Biological Control of Aphids on Brussels Sprouts," *Annals of Applied Biology* 63 (1969): 459–75. See also M. J. Way, "The Natural Environment and Integrated Methods of Pest Control," in Moore, *Pesticides in the Environment*, 29–32. Way had studied the pesticidal properties of DDT at Oxford in the early 1940s, work paralleling that being carried out at Rothamsted.

[58] Today, after a few name changes, the unit is known as the International Pesticide Application Research Centre (IPARC). Way succeeded Southwood as director of the Silwood Park campus in 1979. A later director of the IPARC was Graham A. Matthews, a specialist in the integrated control of cotton pests, who carried out work in Malawi. See G. A. Matthews, "Pesticide Research at Silwood Park," *Antenna* 21 (1997): 108–15.

[59] For these bodies and their work, see Gay, *The History of Imperial College London*, 223 passim.

[60] For these various developments, see Matthews, "Pesticide Research at Silwood Park."

[61] Solly Zuckerman, chief scientific advisor to the government until 1971, attended the conference and was keen to see its recommendations acted on.

[62] Conway was appointed before the 1972 conference, but other appointees were to follow.

additional training in tropical agriculture, began working on cocoa plantations in North Borneo, soon to become Sabah. Unlike the earlier WHO team, which tried to eradicate malaria, Conway had learned about biological control at university and was able put it to the test. Young cocoa plantations were located in jungle clearings, and the cocoa trees were seriously defoliated by insect pests. The farmers responded with heavy spraying. Conway persuaded them to stop, and to allow natural control to take over. Two major pests soon came under the control of parasitic wasps. Another pest was controlled by removal of some nearby trees that were its natural hosts. Chemical spraying did not stop altogether, but IPM allowed the natural control agents to survive, the trees to recover, and the cocoa crop to increase.[63] After his work in Sabah, Conway enrolled at the University of California (Davis), where he carried out research for a PhD under Kenneth Watt, a specialist in North American forest pests. Conway also took some temporary work with the Ford Foundation that entailed travelling to several Asian countries with the foundation's Gordon Harrison to determine what types of sustainable agricultural project should be supported.[64] Conway must have impressed Harrison, because, on gaining his doctorate, he was awarded a grant of $500,000 by the foundation to set up a research unit in environmental management and sustainable agriculture. The result was the Environmental Resources Management Research Unit at Silwood, where Conway introduced some of Watt's system ideas. A press release stated that members of the unit would apply "computer simulation and system analysis methods to the study of natural resources, especially [in relation] to pest management." Also stated was the hope that the unit would encourage overseas students to come to Silwood, and to make use of the college's considerable resources in tropical agriculture.[65] In 1976, with funding from the Ministry of Environment, the college set up the Centre for Environmental Technology. It offered a wide range of MSc courses. Conway was appointed director, and soon received a further research grant from the ministry (£450,000, a huge sum in those cash-strapped times).[66]

Southwood also appointed several other young ecologists. One was Michael Hassell, an Oxford DPhil who had spent a postdoctoral year with a leading American

[63] Some of this work is discussed in Gordon Conway, *The Doubly Green Revolution: Food for All in the Twenty-first Century* (Ithaca, N.Y.: Cornell University Press, 1998); see esp. 205–6 passim.

[64] Gordon Harrison, a Harvard University history graduate, was responsible for organising the funding of the Ford Foundation's many agricultural projects, and for research grants to universities. He is the author of *Earthkeeping* (Boston, Mass.: Houghton-Mifflin, 1971), an excellent and very prescient book on environmental matters, and *Mosquitoes, Malaria and Man* (New York: Dutton, 1978), written while visiting Imperial College.

[65] Report in *IC News*, 31 October, 1969 (copy available at the Imperial College London archives).

[66] Funding for the new centre was helped by the fact that the college rector, Brian Flowers, was chairman of the Royal Commission on Environmental Pollution and understood the political situation. During the 1980s, while on leave from the college, Conway worked on a major sustainable agriculture project in Southeast Asia under the auspices of the IIED (see above). In 1988, he became a full-time employee of the Ford Foundation. As the head of its New Delhi office, he directed programmes in sustainable agriculture in India, Sri Lanka, Nepal, and Bhutan. He was president of the Rockefeller Foundation (1998–2005), returning to a professorship in international development at Imperial College and as chief scientific advisor to the minister for international development. One of Conway's books connects directly to the concerns of Carson: Gordon Conway and Jules Pretty, *Unwelcome Harvest: Agriculture and Pollution* (London: Earthscan, 1991).

biological control scientist, C. B. (Ben) Huffaker, at the University of California at Berkeley. Hassell told me that, like Conway, he was influenced by Carson's book. He, too, wanted to gain a clearer understanding of pest–predator systems, but he cannot be described as an applied entomologist in the manner of Way or Conway. His special interest is in insect parasitoids. About 10 per cent of insects are parasitoids. Mainly fly, ant, wasp or bee species, they deposit their eggs in the larvae of other insects. The parasitoid larvae feed on, and usually kill, their hosts. They are excellent natural control agents, and so a good understanding of their population biology is important to applied work.

Hassell, Conway and other "pure" and "applied" entomologists were to learn much from Robert May, who first visited Silwood in 1971.[67] Southwood recognised that May, although new to ecology, had some theoretical ideas that they could all profit from. He invited May to return each summer as a visiting professor, something May did until moving permanently to England in 1988. May's population biology models had great heuristic power that helped many, including Hassell in his work with prey–predator (host–parasitoid) systems.[68] As stabilising pests at a low level was the biocontrol scientists' goal, much of the theorising was directed at this complex problem. More generally, May's models brought out the fragility of ecosystems, and the fact that stability in nature was something maintained by complex dynamic interactions. A collection of papers given at a 1988 conference held at the Royal Society captures well the work of the previous fifteen years, much of it carried out at Silwood.[69]

Another scientist who began working at Silwood in the early 1970s is Michael Crawley, a herbivory specialist. Working with him in the mid-1970s was a postdoctoral fellow, Richard Brown. Brown left to work for ICI at Jeallot's Hill, Bracknell (now run by Syngenta and, next to the noncommercial Rothamsted, the UK's largest agricultural research site). There he became part, and later the leader, of an ICI team working on the global impact of insecticides. This connection with ICI resulted in Crawley leading one of the teams in the Planned Release of Selected and

[67] Robert M. May (Lord May of Oxford) is an Australian with a PhD in theoretical physics from the University of Sydney. May began thinking about ecological modelling during a sabbatical leave in 1971–1972. He found common ground with Southwood and others working at Silwood. He was also much influenced by Robert MacArthur, a professor at Princeton University. Shortly after MacArthur's premature death in 1972, May was appointed to a chair in the zoology department at Princeton. In 1988, he moved to the UK and took up a Royal Society research chair held jointly at Imperial College London and Oxford University. May was appointed chief government scientist in 1995, and was elected president of the Royal Society in 2000.

[68] These ideas on population modelling were brought together in Robert M. May, *Stability and Complexity in Model Ecosystems* (Princeton, N.J.: Princeton University Press, 1973; 3rd. ed. 2001).

[69] See R. K. S. Wood and M. J. Way, eds., *Biological Control of Pests, Pathogens and Weeds: Developments and Prospects*, in *Philosophical Transactions of the Royal Society* B318 (1988): 109–376. See especially R. M. May and M. P. Hassell, "Population Dynamics and Biological Control," 129–69. See also J. A. Pickett, "Integrating the Use of Beneficial Organisms with Chemical Crop Protection," 203–11. Pickett notes that new pyrethroids were beginning to replace organochlorine, organophosphate and carbamate insecticides during the 1980s. Another interesting paper is J. H. Lawton, "Biological Control of Bracken in Britain," 335–55. Lawton, too, was influenced by May's ideas. Bracken, a major weed that poisons livestock, is a reservoir for sheep ticks. Lawton was proposing classical biocontrol: the import of some herbivorous moths (from South Africa), and some gall-forming mites, to control the bracken. Lawton, then at the University of York, later moved to Silwood.

Manipulated Organisms (PROSAMO) project, which began in the late 1980s.[70] The project entailed a number of field experiments, lasting ten years, to determine what, if anything, followed from introducing transgenic plants into the environment. This was a new type of biological control. Some of the plants were given genetic material that gave them either insect-repelling or herbicide-resistant properties. Crawley's main conclusion was that there was no danger of transgenic plants running rampant and spreading dangerous genetic material to nearby weeds or other plants. (Some genetic transfer is bound to happen, as it does with nontransgenic plants.) It was the remit of other research teams to study the consequences for human and animal health.

Conway and others continued working with more traditional IPM. For example, during the 1980s, Conway began work in Southeast Asia, much of it in Thailand with rice farmers. There, he developed what he termed agroecosystem analysis.[71] Like many others, he understood that chemicals would have to remain part of the solution to the problem of pest control and the achievement of high agricultural yields worldwide. But, as Huxley had already noted in 1963, pest control is an ecological matter, and the use of chemicals has to be viewed in that context.

Some further, and concluding, comments

> He gave it for his opinion, that whoever could make two ears of corn, or two blades of grass to grow upon a spot of ground where only one grew before would deserve better of mankind and do more essential service to his country than the whole race of politicians put together.
>
> Jonathan Swift, *Gulliver's Travels; Voyage to Brobdingnag*, chap. 7

Today, we see things a little differently from Swift. We recognise the serious problems associated with intensive agriculture, problems that came to be understood by many scientists within a relatively short period following World War II. Public awareness followed soon after. The 1970s, as in so many other areas of cultural and political life, were especially transformative. It is interesting to consider why this was so. The proceedings of the 1972 UN Human Environment Conference give us some clues.[72]

[70] PROSAMO arose after much discussion. Already in the 1980s, people in both industry and government recognised the need for regulatory regimes for GM crops and for the use of GM microbial agents in agriculture. For a sociologist's take on the project, see Mario Moroso, "The Institutionalisation of GMOs: Institutional Dynamics in the GM Regulatory Debate in the UK, 1986–1993" (PhD Thesis, University of Exeter, 2008). Moroso claims that people working with industrial partners such as ICI, Unilever and Monsanto believed that GM crops were harmless, but that the research was necessary because industry needed to calm the fears of the public. A regulatory regime would provide both public reassurance and lay down the rules for industrial competition, something also desired by industry. It was, he claims, for these reasons rather than scientific discovery that PROSAMO was undertaken. It is not clear whether the academic scientists involved would agree that the scientific value was minimal, although many ecologists played down the dangers of GM crops even before much testing had taken place.

[71] Conway, *Doubly Green Revolution*. See also Gordon R. Conway, "Agroecosystem Analysis," *Agricultural Administration* 20 (1985): 31–55, for a discussion of this interdisciplinary approach as developed in Thailand.

[72] The papers are kept at the UN Sergio Viera de Mello Library in Nairobi. Much can be read on-line at http://www.unlibrary-nairobi.org/PDFs/UN_environment.pdf.

Providing safe and sufficient food for people around the globe was an international political goal and a central UN concern — and so it remains. One of the major post-war developments in agriculture was the so-called Green Revolution. It began with plant-breeding research in Mexico during the 1940s. The revolution's most notable figure was the plant pathologist, agronomist and, later, Nobel Peace Laureate, Norman Borlaug. Especially notable were his high-yield dwarf varieties of disease-resistant wheat suited to warm climates. They performed spectacularly well in Mexico and India. New rice varieties were also developed, mainly in India, and also grown successfully in Southeast Asia and the Philippines.[73] Only after time were problems with the new varieties recognised. Although they were disease-resistant, they were not pest-resistant.[74] Furthermore, the seeds were expensive, and the plants required not only pesticides but also artificial fertilisers and much irrigation to produce the high yields. Although the Green Revolution had made a significant contribution to the reduction of global hunger, in today's parlance it was not green. It proved too expensive for poor farmers and used too much water, and the heavy use of fertilisers and pesticides was damaging to local ecosystems and to the larger environment.[75]

During the 1960s, the environmental movement was viewed somewhat negatively by champions of the Green Revolution. By the 1970s, the tide had turned, and environmentalism had made it onto the agenda at the UN. It was a political force in many countries. Delegates to the 1972 conference took it seriously and, as a result, the UN placed much emphasis on agricultural research, on research into the biological control of pests and, more generally, on finding ways of avoiding the pitfalls of the earlier Green Revolution. The conference was a major catalyst in the move towards a more integrated approach to pest management.

This paper has outlined some events relating to pesticides, environmentalism and insect ecology that took place in Britain during the three decades following World War II. As has been shown, in the late 1940s there were already some serious domestic problems due to pesticide use. These related both to human health and to ecological damage. Similar problems, often far greater, were being experienced in countries of the British Empire. Although the post-war period saw an end to empire, much scientific research in Britain remained focused on tropical agriculture. Gordon Conway's work is a case in point. Generous funding, especially for projects in Africa and Southeast Asia, continued, despite the recession of the 1970s. Added to this was new funding for environmental and ecological research focused on British problems. Universities tend to follow the money and, after the founding of the NERC in 1965,

[73] A major figure in this development was M. S. Swaminathan, who also successfully introduced some of Borlaug's wheat varieties to India. He was the winner of the 1987 World Food Prize.

[74] Pest resistance was soon added to breeding programmes, and some progress has been made in this area since the 1980s. The Green Revolution was largely funded by the Rockefeller Foundation and public money. The more recent developments in GM food crops have been funded by corporations and entrepreneurial investors. On past evidence, we should expect some unintended consequences.

[75] For some of the problems with the Green Revolution, see Gordon R. Conway and Edward B. Barbier, "After the Green Revolution: Sustainable and Equitable Agricultural Development," *Futures* 20 (1988): 651–70. See also Conway, *Doubly Green Revolution*, 176.

and new research funding prompted by the 1972 conference, many new environmental science units opened up. The Imperial College Centre for Environmental Technology was one among many. Ecology, which before the war had been a fringe discipline, became more central to British science. Today, the government's chief scientific advisor, Sir John Beddington, is an ecologist who began his working life in the 1970s and who once headed the Imperial College centre. Another marker of ecology's new importance is a rise in the number of ecologists elected to the Royal Society. Between 1945 and 1977, only four ecologists were elected Fellows. In 1977, Richard Southwood and John Harper were elected, after which the doors opened for many more. Robert May, the theoretical ecologist invited to Silwood by Southwood in 1971, was elected in 1979. In 2000, he was elected president of the Royal Society. May is also a former chief scientific advisor to the government. Old institutions need to stay abreast of new trends and renew themselves, or they become anachronistic. During the 1970s, renewal meant the inclusion of environmental and ecological science within the British scientific establishment, a cultural change for which Carson can take some of the credit.

Looking beyond Britain, however, and despite much effort, even today about 40 per cent of the world's crops are lost to rodents, insect pests, disease, poor storage, and the lack of transportation infrastructure. About nine hundred million people are underfed, and a few million children die each year from malnourishment. Those numbers are forecast to grow. Furthermore, millions of people worldwide are still being poisoned by pesticides,[76] and the intensification of farming in Britain has resulted in the sharp decline, and even loss, of many farmland birds, such as the corn bunting, linnet, lapwing, and yellowhammer. It is estimated that, during the final twenty years of the twentieth century, about ten million breeding individuals of ten species disappeared from the countryside, and that parallel losses were experienced elsewhere in Europe.[77] This new loss of biodiversity, not limited to birds, is due not so much to pesticides as to loss of habitat. Clearly, we need to think about such problems, about wastage, and about the merits of traditional farming practices. It was the latter that produced the landscapes that people grew to love, and that allowed for the existence of many of the species now threatened.

[76] The WHO website has data showing that the number of pesticide poisonings is in the millions each year, and that deaths are in the thousands. It also shows that, especially in South Asia, pesticides are a major factor in suicides. Death and chronic illness resulting from pesticide poisoning, especially among children, is a far more serious problem than was realised in the 1970s. According to Graham Matthews, writing in 1983, more people were dying in Sri Lanka from pesticide poisoning than from malaria. See Graham Matthews, "Can We Control Insect Pests?" *New Scientist*, 12 May 1983, 368–72. Even in Canada, 6,000 cases of pesticide poisoning were reported in 2006 (CanWest News Service, 21 June 2007). Very different standards for pesticide residues on foods exist around the world. For the UK, see the website of the government's Pesticide Residues Committee (http://www.pesticides.gov.uk/guidance/industries/pesticides/advisory-groups/PRiF). For data on hunger and child deaths, see UN World Food Programme website (http://www.wfp.org/). For today's crop losses due to insect pests, as well as concern over new insect-borne diseases entering Britain because of climate change, see Simon Leather et al. (fifteen signatories), letter to *The Times*, 20 September 2010, 21. Leather signed as a reader in applied entomology at Imperial College London. The letter expresses concern that entomological expertise, while vital to our wellbeing, is being lost. Entomology is less well supported and has fewer students in Britain today than it had in the 1960s and 1970s.

[77] John R. Krebs, Jeremy D. Wilson, Richard B. Bradbury and Gavin M. Siriwardena, "The Second Silent Spring?" *Nature* 400 (1999): 611. In Britain, bird censuses are carried out by the British Trust for Ornithology.

Were Rachel Carson alive today, she would have been sensitive to the more recent changes in the countryside, to intensification in agriculture, and to what has been named the Second Silent Spring. Trained in marine biology, Carson was an outstanding nature writer on a wide range of topics. Along with others, she became alerted to environmental problems in the 1950s, and used her literary skill to alert others — to great effect. But it was her focus on chemical pesticides in her book *Silent Spring* that caught the imagination of people worldwide. Although the book did not launch the environmental movement, it helped to accelerate it. It influenced a younger generation, and was a factor in the growth of the environmental sciences and insect ecology during the 1970s. This, in turn, led to an acceleration in research into biological control, and to a more integrated approach to the fighting of pests. Because of its far-reaching influence, *Silent Spring* must surely count as one of the most important science books of the twentieth century.

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