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Management of Hazardous Substances: An Overview

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Abstract.—Hazardous wastes are common, generated in large volumes, and present modes of management are not sufficient. Hazardous wastes are generated by driving a vehicle and the manufacture of cosmetics, food, and vehicles, and so forth. Seven major federal regulations control, limit, and manage hazardous wastes. Public perceptions of the issues regarding hazardous substances management are clouded due to the absence of standards for determining acceptable risks, and because it is difficult to distinguish between toxic and hazardous materials. Current technologies used to manage hazardous wastes include incineration, use as fuel, solidification and stabilization, solvent and metal recovery, wastewater treatment, disposal in landfills, land treatment, underground injection, and waste minimization and recycling. Effective public policy and practice only will evolve when there is a better understanding of the problems, development of acceptable public health risk standards and streamlined processes for approval of new facilities, and appropriate incentives for reducing the annual volume of hazardous wastes.

Modern society is the product of constantly advancing technology. Technological progress is responsible not only for our high average living standard but also for significant pollution and waste. In the mid-1970's the significant deleterious environmental and public health impacts associated with the improper management of hazardous substances used in, and resulting from, the conversion of raw materials into products stimulated public and political concern. Although there were many alarming incidents, the most notorious were those associated with Love Canal in New York (USEPA 1982), Minamata (mercury contamination) and Itai-itai (cadmium contamination) diseases in Japan (Friberg et al. 1974; Hartung and Dinman 1974), and the dioxin problem in Times Beach, Missouri (EPA 1986).

The present public and political process has evolved out of these increasing concerns. The early phases of the process, in the late 1970's, centered around investigation and definition of sites and processes which represented existing and potential public health and safety problems. About 1985, another phase began with the development of requirements and controls for hazardous substances management systems and increased enforcement efforts to assure compliance with the changing rules. Now, a third phase is underway with an attempt to collect data on the generation, treatment, storage, disposal, and recycling of wastes. The results of this phase will allow for more definitive waste-source controls on the use of hazardous materials in industrial processes and increase the effectiveness of current controls on the generation, storage, recycling, minimization, and disposal of hazardous wastes.

Scope of the Problem

It is estimated that three to five billion metric tons of solid wastes including solids, liquids, sludges, garbage, and wastewater are discarded in the developed portions of the world every year. If developing countries are included, the sum is nearly eight billion metric tons (Bright 1988). Although the composition of the wastes varies from country to country, the wastes typically found in the United States serve to illustrate the magnitude of the problem.

Several billion metric tons of solid wastes are discarded in the United States each year. For example, in 1986 about 160 million metric tons of municipal wastes were discarded (EPA, 1988), and about 300 million metric tons of hazardous wastes were generated by industry (EPA 1987). Collectively, these wastes include common household trash, industrial wastes, sewage sludge, agricultural residues, mining refuse, and pathological wastes. The initial results from a 1989 U.S. Environmental Protection Agency (USEPA) data base study on hazardous wastes indicate that 250 million to 600 million metric tons of hazardous wastes are generated annually (Krieger 1989), about 72% of which are treated or disposed of at the site of generation.

Until recently, the traditional mode of disposal for all these wastes was landfilling. However, due to technological progress, the character of the solid wastes has changed. For example, about 490 new chemical compounds have been introduced since 1965 (Amer. Chem. Soc. 1988). Also, the volume of wastes has increased, so that traditional landfilling practices have become inadequate. The most common problems were soil and ground water contamination as well as the generation of noxious and/or hazardous emissions. Studies on these problems revealed that many landfills were improperly sited or improperly operated. The USEPA has estimated that, of 161,416 landfills, 57% receive municipal solid wastes, 21% receive industrial wastes, 16% receive demolition debris, and 6% handle miscellaneous materials (USEPA 1988). Many of the existing landfills are known to have integrity problems resulting in loss of liquids into the adjacent soil and ground water, and many have operational problems such as odors and hazardous air emissions. The common failure of landfills has prompted reforms in the requirements for construction and operation of landfills, increased limitations on the types of materials disposed of in landfills, and the investigation of new designs for landfills and of new methods for disposal.

There are about 2970 major hazardous waste Treatment, Storage and Disposal (TSD) facilities in the U.S. (Krieger 1989). About 50 of these facilities manage 90% of the total volume generated. The other 2920 facilities manage the remaining 10%. Among the classes of wastes managed, the greatest volumes are classified as: industrial organic chemicals, petroleum refining and national security wastes, electrical service sludges, plastic and resins residues, industrial inorganic chemicals, and plating and polishing sludges and residues.

The diversity of hazardous wastes and the problems associated with traditional disposal options have stimulated efforts to evolve new methods for the management, recycling and reuse of hazardous substances such as use as blended fuels (Bright 1988).

Sources of Hazardous Wastes

Hazardous wastes are generated by a variety of activities associated with the manufacture of products such as liquid drain cleaner, petroleum products, synthetic fibers and cosmetics. A significant percentage of the wastes produced by industry are recycled at the point of generation, and many of those wastes are treated prior to discharge to sewers, storm drains, and waterways. Other wastes are discharged directly into the atmosphere, placed in landfills or deep injection wells, or incinerated. Definitive data are not available on the total volume of all types of hazardous wastes produced, the amount safely treated at the point of generation, and whether the concentrations in discharged wastes are safe. However, there are significant concentrations of hazardous emissions in the air over all major U.S. cities, and hundreds of sites (landfills, TSD facilities, other disposal sites, and commercial and industrial sites) which are experiencing significant soil and ground water contamination. Perhaps the most onerous aspect of these emissions is the increasing potential for contamination of drinking water supplies and the possibility of teratogenic, mutagenic, and carcinogenic effects.

Major Environmental Regulations

There are hundreds of U.S. environmental regulations, many often overlapping, associated with all levels of government. The following illustrates the general relationships among the various levels of regulation. First, no local, regional, or state agency may have regulations which are less stringent than those imposed by the federal government; however, local, regional, or state regulations may be more stringent than federal regulations. Second, if there are no precise regulations covering a given aspect of hazardous substances management, any agency at any level of government may develop its own regulations. Third, due to overlapping jurisdictions, the implementation (enforcement) of regulations often is not consistent. By way of further illustrating this relationship, in California, the primary air quality control agency is the California Air Resources Board (CARB), while local air quality control is accomplished through various air quality management boards and air pollution control districts. CARB develops air quality regulations, which cannot be less stringent than the federal requirements, and the local air quality boards/districts implement the CARB regulations or develop their own regulations which also cannot be less stringent than the CARB rules.

There are seven major Federal regulations covering the generation, storage, transport, recycling, and disposal of hazardous wastes:

(1) Clean Air Act (CAA)

Enacted in 1970, the goal of the CAA was to achieve and maintain certain air quality conditions which would protect public health and welfare. The USEPA was directed to establish National Ambient Air Quality Standards. Primary standards were to protect public health and secondary standards were to protect public welfare (Raffle 1978). Compliance with these standards has been difficult in many large cities, such as Los Angeles and New York, and consequently air quality often has continued to degrade. The principal sources of air pollutants are combustion processes, particularly motor vehicles. For example, a CARB study indicated that in the greater Los Angeles area during 1986, 13.8 million cars driving

103 million miles per day while completing 13.8 million trips generated daily emissions of 171 tons of nitrogen oxides, 196 tons of organic gases, 1773 tons of carbon monoxide, 9 tons of sulfur oxides, and 30 tons of particulate matter (soot and dust) (CARB 1988). By comparison, a modern 61 ton per day capacity hazardous waste incinerator produces daily emissions of 0.0455 tons of nitrogen oxides, 0.0014 tons of organic gases, 0.0011 tons of carbon monoxide, 0.0274 tons of sulfur oxides, and 0.0589 tons of particulate matter (Bright & Associates 1986).

(2) Clean Water Act (CWA)

Enacted in 1972, the CWA established a national policy to eliminate the discharge of pollutants into navigable waters and prohibit the discharge of harmful amounts of hazardous pollutants into these water bodies. The programs established pursuant to the CWA involve: (a) acquisition of knowledge regarding the human and environmental impacts of water pollution; (b) allocation of federal funds to assist states and local governments in the construction of Publicly Owned Treatment Works (POTW's); (c) development of the National Pollution Discharge Elimination System (NPDES) standards; and (d) development of a permit and licensing system to enforce such standards (Collins 1985).

(3) Toxic Substances Control Act (TSCA)

Enacted in 1976, TSCA was established to correct the lack of health and safety information that existed concerning chemical substances and mixtures, and to prevent unreasonable risk of injury to human health and the environment from harmful chemicals. TSCA was designed to ensure that industrial data on production, use, and resultant health and environmental effects of chemical substances and mixtures are obtained by the USEPA so that the degree of risk associated with such chemicals can be reasonably determined. TSCA also provides the USEPA with the means to regulate the manufacturing, processing, distribution in commerce, and use and disposal of chemical substances and mixtures (USEPA 1984).

(4) Resource Conservation And Recovery Act (RCRA)

Enacted in 1976 as an amendment to the Solid Waste Disposal Act, RCRA was designed to eliminate the loopholes in environmental law and to assure proper disposal of waste on land. RCRA required the USEPA to identify and list the characteristics of hazardous wastes and to develop standards applicable to waste generators, transporters, and owners and operators of hazardous waste treatment, storage, and disposal facilities. It also required the development of guidelines for authorizing the establishment of state hazardous waste programs and the development of standards for issuing permits for treatment, storage, or disposal of hazardous wastes (House of Representatives 1979).

(5) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

Enacted in 1980, CERCLA established a mechanism for cleaning up abandoned hazardous waste sites. This is commonly called the Superfund program. CERCLA imposed liability on various classes of responsible parties, including current and certain prior owners of property where hazardous materials are found. Liability under CERCLA is for a wide range of costs associated with cleanup of sites on which hazardous substances have been released (Bourdeau 1987).

(6) Hazardous and Solid Waste Amendments (HSWA)

Enacted in 1984, the HSWA modified virtually every part of RCRA. In general, the amendments required the USEPA to conduct various studies to determine whether the criteria in RCRA applicable to solid waste management and disposal facilities are adequate to protect human health and the environment from groundwater contamination (USEPA 1988).

(7) Superfund Amendments and Reauthorization Act (SARA)

Enacted in 1986, SARA revised and extended the authorities established under CERCLA. SARA Title III established new authorities for emergency planning and preparedness, community right-to-know reporting, and toxic chemical release reporting (Fed. Reg. 1987). The Title III requirements parallel those in the U.S. Occupational Health and Safety Act (29 CFR 1910, Subpart Z) with regard to description of working conditions and advising workers of the presence and nature of any hazardous or toxic materials in the workplace.

Public Health Concerns

The impact of a hazardous substance on human health varies greatly depending upon chemical and physical characteristics and concentration in the environment and in humans. Some hazardous substances, such as hydrogen cyanide, are highly toxic in small concentrations and must be utilized under tightly controlled circumstances. Other hazardous substances, such as perchloroethylene, are tolerated by the human body at substantiantially higher concentrations and are present in processes, such as dry cleaning, used widely throughout the world.

There is a distinct difference, with regard to planning and management, between toxic and hazardous substances, yet, to date, it has been very difficult to achieve public understanding of this difference. The key difference between toxic and hazardous substances is the concentration of these materials at which human health impacts are detected. Although the specific definitions vary around the world, the term "toxic" is applied to those materials or wastes which can result in an immediate and prolonged loss of normal function or in death in humans from short-term, low concentration exposure. The term "hazardous" is applied to those materials which may result in a delayed or progressive loss of normal function in humans upon prolonged exposure. Sometimes these definitions break down. For example, if you place your hand in a container of corrosive hazardous material, the health impacts are immediate. Similarly, certain hazardous materials are considered to be toxic (by meeting the requirements of the USEPA toxicity test) if they exist in circumstances where public health impacts can result. The use of gasoline is common, but gasoline is hazardous because it is ignitable. Gasoline, when combusted, because it contains benzene and other organic compounds, produces by-products which can be toxic. As a result of such differences, it is not easy to determine if and when a given substance is hazardous and/or toxic. Yet, both hazardous and toxic substances, if managed properly, can be used without significant public health impacts.

Table 1. Health risk comparison for common types of exposure.

Source of health risk	Level of risk
Estimated statistical risks	
Smoking 1.4 cigarettes in a lifetime	1 in 1,000,000
Eating 40 tablespoons of peanut butter	1 in 1,000,000
Drinking 384 ounces of diet pop containing saccharin	1 in 1,000,000
One chest X-ray taken in a good hospital	1 in 1,000,000
Living 2 months in an average stone or brick building	1 in 1,000,000
Spending one hour in a coal mine	1 in 1,000,000

Sources: Crouch, E., Estimates of Risk (1980); and Kelly, K., Health Risk Assessment of Hazardous Waste Incineration Stack Emissions (1985).

The common guideline for unacceptable health risk is an increased risk of one per million persons exposed. This means that if one million persons were exposed to a given concentration of a contaminant, an increased risk of one additional event, such as one additional case of cancer or one adverse health reaction, could be expected. It also follows that if one million persons were exposed, no additional adverse health risks would be expected for 999,999 individuals. Common health risk comparisons are given in Table 1, and actual mortality rates are given in Table 2.

Inherent in any health risk assessment is the determination of what risk is acceptable. For example, as noted in Table 1, smoking constitutes a significant health risk. Yet, that level of risk is accepted daily by many individuals. Because of the uncertainty in establishing specific risk levels for different types of risks, acceptable health risk guidelines have been established using worst-case estimates, using health impacts established during laboratory studies, or using multiple factors, i.e., determining a given level of risk and then setting a standard 2 or 3 times higher or lower.

In areas where there are concentrated industrial and commercial facilities producing significant levels of hazardous substances or where meteorological conditions (such as an atmospheric inversion) coupled with high levels of air emissions result in unhealthy accumulations on a significant number of days per year, there is evidence that the risk of both short-term and long-term health impacts is significantly greater than in other areas of the U.S. In a recent study covering 45 counties bordering a portion of the Mississippi River, where there are numerous industrial and commercial operations, it is noted that the release of air emissions, use of pesticides, and discharge of wastes has been as much as 55 times higher than in the rest of the U.S. (Public Data Access 1988). This same report concludes that 66,000 more deaths occurred during the 1968–83 period than would have been expected based on normal U.S. mortality rates.

Definitions

The environmental regulations dealing with the management of hazardous wastes constitute an "alphabet soup." For example, in an industrial operation where hazardous substances are used in the workplace and production results in a hazardous waste, a typical description of the hazardous materials management process could include compliance with RCRA, OSHA, HSWA, NPDES limits, TTLC and STLC limits, and so forth. Although the use of acronyms allows one to

Table 2. Actual mortality rates associated with common health risks.

Source of health risk	Level of risk
Actual mortality rates	
Common cold	1 in 1,000,000
Diptheria	1 in 1,000,000
Rubella	1 in 1,000,000
Acute polio	1 in 1,000,000
Accident in which individual is hit by a bicycle	1 in 100,000
Anesthesia complications during surgery	1 in 100,000
Cataclysmic event (tornado/hurricane/flood/earthquake)	1 in 100,000
Animal bite/sting or plant sting	1 in 100,000
Electrocution	1 in 10,000
Falling off a building	1 in 10,000
Being hit by a falling object	1 in 10,000
Firearm accident	1 in 10,000
Accidental poisoning (drug or medicine)	1 in 10,000

Sources: Crouch, E., Estimates of Risk (1980); and Kelly, K., Health Risk Assessment of Hazardous Waste Incineration Stack Emissions (1985).

distinguish between various rules and regulations, the very complex nature of the regulations results in considerable conflict and confusion on the part of the general public. For this reason, the general public often responds to hazardous waste issues in a black or white decision mode.

Public Perceptions

As a result of the rapid means of information distribution and the tendency for the news media to describe only the "bad" events, the general public believes that any commercial or industrial activity requiring or generating hazardous substances is bad. This perception is understandable but incorrect. Two cases follow which demonstrate why the public is afraid of hazardous substances situations. In 1978, the water supplies of Toone and Teague, Tennessee, were contaminated with organic compounds when water leached from a nearby landfill. When the landfill was closed, in about 1972, about 350,000 drums were left at the site, many of which were leaking pesticide wastes. These two towns now must import water from other locations. In another situation, a truck driver was killed in 1978 as he discharged waste from his truck into one of four open pits at a disposal site in Iberville Parish, Louisiana. He was asphyxiated by hydrogen sulfide produced when liquid wastes were mixed in an open pit (Kiang and Metry 1982). Almost all communities have experienced a problem with hazardous substances. Some such situations include the evacuation of homes until toxic fumes were dissipated, excavation of contaminated soil, treatment of contaminated ground water, or the illegal disposal of wastes by dumping into sewer or stormdrains. Yet, few of these events have resulted in significant health problems when the events were properly managed. It is in the absence of proper management or responsibility that both the environment and public health can be subjected to significant impacts.

Because of the connotations of the words "hazardous," "toxic," "garbage," and "sewage sludge," public concern is almost immediate regarding the development of any kind of facility which handles such materials. This concern generally occurs in two forms: NIMBY or MONY. NIMBY refers to NOT-IN-MY-BACK-YARD.

In other words, if the facility is really needed, build it somewhere else. MONY refers to MINE-ONLY-NOT-YOURS. This is a bit less parochial than NIMBY, in that it allows for the handling of hazardous substances provided they are generated only within the local area served by the facility.

Mixed with this general public negativism about hazardous waste management facilities is a "blind spot." There are a variety of common everyday products and services that result in the generation of hazardous wastes during production or use, but which are not considered by the public to be troublesome. Examples include gasoline, cosmetics, mothballs, pool chemicals, antifreeze, transmission fluid, batteries, disinfectants, paints, flea collars and sprays, roach and ant killers, and thinners and turpentine.

Realistically, almost everyone, when engaged in typical daily activities, is exposed to extensive public health risks. Driving in the Los Angeles area engenders at least three risks, i.e., health hazards from a vehicle accident, mishandling of the hazardous materials (gasoline and oil) required to operate the vehicle, and from accumulated exhaust emissions in the atmosphere. The data in Table 1 show that eating just 40 tablespoons of peanut butter results in a one in a million level of risk. In essence, there is not existence without some risk. Thus, the critical questions become: what level of risk is acceptable and in what manner can each individual determine what level of risk is acceptable?

At this time, there is tremendous fear, skewed public perception, and industry frustration regarding an acceptable level of risk. The current level of public and industrial perception of the hazardous substances issues must mature to evolve mechanisms which are based on levels of risk which best meet public health economic, and general environmental needs.

Management of Hazardous Substances

Various technologies are used in hazardous waste management. The USEPA has just completed the first phase of a survey on waste generation and treatment, storage, disposal and recycling (Krieger 1989). These data indicate that there currently are several techniques or options for managing hazardous substances used in manufacturing, and hazardous wastes resulting from various industrial processes.

Incineration

Incineration is an engineered process that uses high temperature thermal oxidation to convert a waste to a less bulky, less hazardous material. Operation of a modern incineration facility yields three principal products: flue gases, water vapor and ash. Achieving good combustion requires carefully controlled operations and the use of air pollution control equipment. If the incineration process is conducted improperly and inefficiently, the wastes may be converted into intermediate products called products of incomplete combustion (PICs). PICs can be more harmful than the original hazardous wastes introduced into the incinerator. For any incineration system, there are three critical operational aspects: (1) the temperature in the primary and secondary combustion chambers; (2) the residence time of the wastes in the two combustion chambers; and (3) the design and efficiency of the air pollution control system. If the temperatures are too low and/or the residence time too short, PICs can be produced. If the air pollution control equipment is not well designed, there can be significant emissions of pollutants, such as nitrogen oxides, sulfur oxides, and particulate matter. A modern hazardous waste incinerator can be operated so that the emissions are very low and the related health risks are less than one in a million (Bright & Associates 1986).

There are several types of incineration systems. These include multiple hearth, fluidized bed, liquid injection, fume, rotary kiln, multiple chamber, cyclonic, auger combustor, and ship mounted incinerators. Each incinerator type has advantages and disadvantages and each is more or less appropriate for given types, volumes, or diversities of wastes, ambient air quality conditions, and BTU values of wastes.

There are thirteen commercial hazardous waste incinerators in the U.S., located in the states of Texas, New Jersey, Louisiana, Arkansas, Ohio, Illinois, Missouri, Kentucky, North Carolina, and South Carolina (Black and Gushee 1989). There are an estimated 175 on-site hazardous waste incinerators at industrial and commercial facilities. An informal check with USEPA regional offices during January, 1989, indicated that there were about 25 pending applications for commercial hazardous and toxic waste incinerators.

Incineration has been hailed by various federal and state organizations and politicians as one of the most effective means of disposal for hazardous wastes. Yet, it has not been possible to develop additional incineration capacity because of the NIMBY problem. It has been estimated that about 23% (63 million metric tons) of all hazardous wastes are suitable for incineration (Oppelt 1987). However, no more than 5% of that total actually is currently being incinerated. It takes 4 to 6 years to complete the regulatory review process for new incineration facilities. The absence of this capability has required the USEPA to modify plans to prohibit landfill disposal of certain hazardous wastes for fear that such wastes would only be illegally dumped in the absence of a viable alternative such as incineration.

Incineration has been given an important role in the hierarchy of waste management methods. Whether incineration will be able to fulfill this role depends upon resolution of two issues: the NIMBY problem and the need to establish an acceptable level of risk.

Direct Use as Fuel

This option consists of using selected hazardous wastes as supplementary fuels in various industrial processes, such as industrial boilers, furnaces, or kilns. This is a common practice in many cement plants where solvent-derived fuel (SDF) is used with a prime fuel, such as natural gas, coal, or petroleum coke. Most regulatory agencies limit the use of supplementary fuel to no more than 50% of the total fuel used in order to limit the potential for the production of PICs. With increased waste minimization and recycling efforts, this option will be less useful since solvent wastes will be recycled, leaving only a sludge or residue. Such sludges or residues are not suitable for direct use as fuels without further processing (fuel blending), and significant modifications or additions to the air pollution control and fuel feed systems are often required for their use.

Fuel Blending

This option consists of gathering and blending various types of organic and inorganic wastes into fuels with certain minimum characteristics, such as a minimum heat content of 10,000 BTU per pound and low concentrations of lead, arsenic, cadmium, and hexavalent chromium (Stolin 1988).

Blended fuels are commonly used around the world at cement, lime, and light aggregate facilities. There are 35 such facilities operating in the U.S. and another dozen are awaiting approvals to use blended fuels. These types of facilities are well suited for the use of blended fuels, since ash and other products of fuel combustion are incorporated into the final product, largely in an insoluble form, and the destruction and removal efficiency of the hazardous components in the fuel is about 99.99%.

Initial testing is underway using mixtures of liquid, sludge, pasty, and solid wastes. Results from these studies indicate that even household garbage can be used as a blended fuel. This option, with further research, could be very important as a means of converting what is considered to be a waste into a resource.

Solidification/Stabilization

Solidification and stabilization refer to treatment processes that are designed to accomplish one or more of the following: (a) improve physical characteristics of the waste, as by sorption of any free liquids in the waste; (b) decrease the surface area of the waste where transfer or loss of contaminants can occur, such as loss of vapors to the atmosphere; and (c) limit the solubility of any constituents of the waste which are hazardous, such as by adjusting the pH or potential for sorption (Cullinane et al. 1986).

Solidification implies that the wastes are converted into a solid block of waste material which has high structural integrity. Since the contaminants do not necessarily interact chemically with reagents during this process, they are generally considered to be mechanically locked within the solidified matrix. Mixing cement with a given waste to generate a solid mass is a type of solidification.

Stabilization generally is a process which limits the solubility or mobility of the contaminants with or without altering the physical characteristics of the waste. Examples include the addition of lime or sulfide to a metal hydroxide waste to precipitate the metal ions or the addition of an absorbent material to liquid waste to create a sludge or solid. Stabilization typically is the addition of materials to ensure that the hazardous components are maintained in the least mobile or toxic form.

Neither solidification nor stabilization are long-term solutions. They provide a means of limiting the potential environmental problems associated with the waste until another more permanent disposal option can be used.

Solvent Recovery

Waste solvents typically are either disposed of at a landfill or used as a supplemental fuel. The widespread use of solvents has resulted in increased demand that the solvents be recycled. This option basically consists of removing any extraneous materials, such as printing inks, from the solvent, and putting the solvent back into service. This practice has not received strong support from industry because of concerns that the recycled solvent will not be as "pure" as virgin solvent. Recent tests have shown, however, that for many applications, recycled solvent is adequate and its use does not result in any loss of product quality.

Fig. 1. Disposal of municipal wastes at the Brea-Olinda landfill, Orange County, California.

A large volume of solvents is used in small businesses such as neighborhood vehicle repair shops. Those solvents could be recycled. However, a simple cost-effective process is not currently available.

Metal Recovery

Many hazardous wastes contain metals, such as zinc, lead, mercury, and chromium. Such wastes are common at plating and metal manufacturing facilities. If the concentration of metals in a waste is sufficiently high, the waste can be recycled and the metals recovered. There are a few metal recycling facilities in the U.S.; however, the majority of the metal recovery operations are overseas.

Thousands of metric tons of metal wastes, particularly those containing zinc, are exported to the Pacific Rim countries and to Europe, where the metals are extracted. The metals then are sold to manufacturing facilities in all parts of the world.

Export of hazardous wastes has become a critical issue around the world. It has been described as "waste tourism." The concern is not with cases where proper facilities exist, but rather, where wastes are shipped to countries, particularly Third World countries, without proper facilities, and summarily dumped, often in drums, and with no further management.

Since the current economics of metal recovery are very good, there is no reason why such recovery efforts cannot continue as long as the facilities where the recovery occurs are properly designed and operated.

Wastewater Treatment

Wastewater treatment can be complex because wastewaters are diverse. Some industrial wastewaters may contain only 1–2% of very difficult-to-manage contaminants, while others may have 20–30% of easy-to-manage contaminants. Further, the physical and chemical characteristics of the contaminants may dictate the appropriate method of treatment.

In the past, wastewater was collected and transported to a disposal site such as a landfill or a wastewater treatment plant. The emphasis was on total disposal rather than on recovery or recycling of the contaminants. As the regulatory process has matured and the cost of disposal has increased, several options which emphasize separating the water from the contaminants have emerged.

The most common means of dewatering sludges, slurries, and various wastewaters is by use of a filter press. The wastewaters must first be analyzed and a determination made as to the most appropriate processing option. Then they are processed by literally "squeezing" the water out and collecting the contaminants on the filter. The resultant mass is commonly called filter cake. Filter cake can be further dried or stored as is, and then taken to an approved disposal site, if other uses are not feasible. This option does not result in final treatment of the wastes, but it does significantly reduce the volume of wastes and, with the removal of the water, decreases the potential for various biodegradation processes and contaminant migration from the landfill disposal site.

Surface Impoundment

Surface impoundments are collection ponds where wastewaters and various sludges and slurries are placed after removal from adjacent processing and manufacturing facilities.

Traditionally, surface impoundments were evaporation ponds where the water fraction was lost to the atmosphere. This resulted in a sludge or slurry on the bottom of the impoundment and the potential for soil and ground water contamination.

Surface impoundments are being phased out and replaced by wastewater treatment processes. Surface impoundments also are being designed as temporary holding facilities through the use of liners and other devices that significantly limit the potential for contaminant migration into the soil or ground water.

Landfill

The standard method for disposal of solid waste has changed over the past 25 years from the use of open dumps that were periodically set on fire to reduce the volume of material, to the modern sanitary landfill in which waste materials are deposited and periodically covered with a layer of soil. Even with these changes, two major problems have been identified: the production of landfill gas and the production of leachate (liquid with various chemical components derived from the breakdown of the materials added to the landfill). In response to these problems, landfills now must be designed to maintain the integrity of the "collection basin" through consideration of basic geological conditions, the use of membrane liners, continual monitoring to determine the rate of gas and leachate production, and control or collection of landfill gas and leachate.

Certain of the problems associated with landfill operations are due to the mixing of various types of wastes, such as mixing household and industrial refuse with liquid hazardous wastes. Such mixtures provide a "primal" environment for various chemical and biological oxidation processes. The latest trend in landfill

Fig. 2. Improper storage of drums containing hazardous wastes at a landfill in northern California.

operations is to design landfills so that gas and leachate can be controlled and collected safely, and to limit the composition of the materials deposited in the landfill.

Landfills will continue to be a means for waste disposal. However, they will become more specialized, and will no longer be called landfills; rather, they will be called repositories (secure landfills). These repositories will be characterized by special designs for the receipt, storage, and processing of selected waste materials.

Development of new landfills suffers from the NIMBY and MONY problems. Until there is public understanding that wastes will continue to be generated at an alarming rate, development of new landfills will be slow. It is estimated that within the next 5–6 years there will be a shortage of municipal waste landfill capacity in a majority of the states (USEPA 1988).

Land Treatment

The land treatment option often is called land farming and has been used widely in the petroleum industry to treat wastewater sludges and slurries left in evaporation ponds. It also is used as a means of cleanup at sites where various contaminants have been lost to the soil, such as from a leaking underground storage tank at an industrial facility or service station, where other means of cleanup are not technically feasible or are too costly.

The most common land treatment process involves the use of bacteria. The bacteria may be naturally occurring in the materials being treated or they may be artificially added in the form of innoculant from selected "active" strains grown in culture. The bacteria are stimulated to achieve high biotic rates by the addition

Fig. 3. Hazardous Materials Response Team collecting hazardous wastes thrown away along Ortega Highway, Orange County, California.

of water, nitrogen, and oxygen in a fertilizer or by direct application of hydrogen peroxide. This process enhances the natural biodegration of the contaminant.

In some situations, a recycler unit may be used. Such a unit is a simple oven through which the contaminated soil is passed, heated to a temperature of 750°F or higher, and then allowed to cool. The oven serves to "drive off" the contaminants and oxidize them. One negative aspect of this treatment is that the soil is sterilized and must have the nutrients replenished before revegetation can take place. The recycler also can be used in conjunction with the application of hydrogen peroxide. Hydrogen peroxide facilitates the oxidation of certain metals, converting them from an insoluble to a soluble form.

A recently developed technique consists of injection of steam into the contaminated in situ soil. This converts the contaminant to a recoverable vapor which can be extracted and treated.

Underground Injection

Disposal of aqueous hazardous wastes by deep-well injection has been a common, but not widespread, practice. Approximately 20 to 35 million metric tons of hazardous wastes have been disposed of annually into deep-well injection systems. About 10% of all RCRA hazardous wastes managed in the U.S. are placed in deep-wells (USEPA 1987).

The deep-wells are located in geologic formations where the potential for migration of the wastes is deemed to be very slight, if it exists at all. However, in a few circumstances some migration has been demonstrated, although the significance of such migrations remains unknown.

The use of deep-wells is not widely accepted by the public because of the perceived potential for ground water and drinking water contamination. Long-term use of this option is not anticipated.

Waste Minimization and Recycling

Reducing the volume of hazardous wastes produced is one of the more effective ways of reducing contamination of soil, water, and air and, in turn, reducing public health and environmental risks. Recovering the usable portions of wastes (recycling) provides "new" resources and also reduces the volume of waste that must be disposed of in landfills, impoundments, incinerators, and so forth.

Reducing the volume of hazardous wastes can be accomplished if manufacturers and consumers make concerted and, hopefully, simultaneous adjustments. Manufacturers must develop different processes which reduce either the need for the use of hazardous substances, or the volume of wastes produced during manufacturing. Consumers must adjust their buying habits so that they rely less on products which are manufactured with, or result in the production of, hazardous substances. Although these solutions sound simple, they will not be easy to achieve since neither the manufacturers nor the consumers are willing to make the necessary adjustments without proper incentives. Achieving sufficient waste reduction/minimization to reverse the cycle of increasing volumes of hazardous wastes produced per year does not appear to be immediately achievable since it will require changes in consumer life styles as well as research and development efforts at the points of manufacture.

Recycling is a cultural phenomenon. It has been approached unsuccessfully in several large cities during the past ten years. Recycling requires a concerted effort by each household to sort trash, and to segregate glass, metal, and papers so that each type of material can be handled separately. This takes time and normally is not readily acceptable to the general public. Recent recycling efforts have centered on payment for the return of beverage bottles and cans. Even under these circumstances, the efforts have not be fully successful.

Waste minimization and recycling of waste components must become a strongly supported, publicly accepted practice that is as common as putting out the trash can or feeding the dog.

Conclusions

The management of hazardous substances is complex, and represents a troublesome mixture of chemistry, regulatory responsibility, negative public perceptions, and big business. Understanding the processes and procedures is difficult, and, accordingly, it will be difficult to evolve an acceptable policy which fosters a balance among economic, public health, and environmental concerns.

In order to develop an effective public policy regarding hazardous substances management, several shifts and changes in public perception and policy are needed:

Public Understanding of The Problem

Until the public grasps the major tenets of hazardous substances management and recognizes that effective management will alter present lifestyles, it will be difficult to evolve a workable hazardous materials management structure, which achieves balance among economic, public health, and environmental concerns.

Public perception and understanding of the hazardous waste problem must be altered to achieve a clear understanding of differences between the common use of hazardous substances and the use of hazardous substances in industrial and commercial facilities. Until the public is aware that the use of common items is hazardous and has the same potential for environmental and public health problems as the disposal of wastes resulting from the manufacture of fuels, cosmetics, and food products, it will not be possible to evolve public understanding of the hazardous waste problem, to develop acceptable public health risks, and to overcome the NIMBY and MONY problems.

Development of Acceptable Public Health Risks

Development of policies on acceptable health risks will require that regulatory agencies and research institutions evolve better risk estimating processes. Improved risk communication and better public education methods also must be developed to foster a greater understanding of the risks associated with day-to-day activities and the wastes generated by such activities. It also is important that the public understand that no risk is the greatest risk of all.

Development of a Policy for Determining Types and Location of New Hazardous Waste Facilities

Current processes for siting new facilities are inadequate and soon will result in a critical shortage of modern treatment, storage and disposal facilities. Streamlined procedures are needed, and such procedures must allow for appropriate, but not obstructive, public review and comment. Overcoming the NIMBY and MONY problems is essential if the siting of new facilities is to be based on prudent management, enabling location of facilities where appropriate quantities of wastes can be received and where significant impacts on the local environment are avoided.

Use of the Carrot Rather than the Stick

Present regulatory practices are based on enforcement as a means of achieving preset standards. This requires considerable effort to check all facilities to assess the level of compliance. In reality, resources available to the agencies are limited to the extent that many facilities are not checked with any regularity, if at all.

Industrial and commercial operations should be provided with incentives for meeting general standards, and provided greater incentives for achieving even better compliance. In this manner, the initiative for development of better management methods becomes vested in both the regulatory agency and the industrial and commercial operators.

Literature Cited

American Chemical Society. 1988. Annual report for 1987. American Chemical Society, 33 pp.

Black, B. B., and D. E. Gushee. 1989. After regulation of industrial hazardous waste: what role for incineration? Congressional Research Service, The Library of Congress, January 19, 1989, 20 pp.

Bourdeau, K. S. 1987. The impact of SARA on business transactions. Proceedings of the Fifth Annual Hazardous Materials Management Conference, June 9–11, 1987, 668 pp.

Bright, D. B. 1988. Hazardous waste fuels in report of the United Nations Industrial Development

Organization world conference on industrial risk management and clean technologies, Vienna, Austria. Environmental Audit, Inc., Placentia, Calif., 24 pp.

Bright & Associates. 1986. Addendum to the health risk assessment for emissions from the proposed CTTS hazardous waste incinerator, 3691 Bandini Blvd., Vernon, California. Bright & Associates, Placentia, Calif., 39 pp. + Tables.

California Air Resources Board. 1988. On-road motor vehicle inventory based on EMFAC7D-BURDEN 7A. California Air Resources Board, July 13, 1988, 250+ pp.

Collins, J. I. 1985. The complete guide to hazardous materials enforcement and liability. California District Attorneys Association, HW-2-1 to HW-2-28.

Congress of the United States. 1983. Technologies and management strategies for hazardous waste control. Office of Technology Assessment, March, 1983, viii + 407 pp.

Crouch, E. 1980. Estimating risk. Jour. Bus. Admin., Vol. II (102):299–317.

Cullinane, M. J., L. W. Jones, and P. G. Malone. 1986. Handbook for stabilization/solidification of hazardous waste. U.S. EPA, Hazardous Waste Engineering Laboratory, (EPA/540/2-86-001), xiv + 78 pp. + Appendices.

Federal Register. 1987. Emergency and hazardous chemical inventory forms and community right-to-know reporting requirements; final rule. Federal Register, Vol. 53(199), Thursday, October 15, 1987, Part IV:38344–38377.

Franklin Associates, Ltd. 1988. Characterization of municipal solid waste in the United States. U.S. EPA, Office of Solid Waste and Emergency Response, March, 1988, v + summary + 31 pp.

Friberg, L., M. Piscator, G. F. Nordberg, and T. Kjellstrom. 1974. Cadmium in the environment (Second Edition). CRC Press, Cleveland, Ohio, 248 pp.

Hartung, R., and B. D. Dinman. 1974. Environmental mercury contamination. Ann Arbor Science Publishers, Inc., xi + 349 pp.

House of Representatives. 1979. Hazardous waste disposal. 96th Congress, 1st Session, report together with additional and separate views by the subcommittee on oversight and investigations of the committee on interstate and foreign commerce, September, 1979, v + 82 pp.

Kelly, K. 1985. Health risk assessment of hazardous waste incinerator stack emissions. Columbia University, School of Public Health Doctoral Paper, 96 pp. + Appendices.

Kiang, Y., and A. A. Metry. 1982. Hazardous waste processing technology. Butterworth Publisher, xviii + 549 pp.

Krieger, J. 1989. Hazardous waste management database starts to take shape. Chemical & Engineering NEW, Vol. 67(6):19–21.

Oppelt, E. T. 1987. Incineration of hazardous waste: A critical review. Jour. the Air Poll. Contr. Assoc., Vol. 37(5):558–586.

Public Data Access, Inc. 1988. Mortality and toxics along the Mississippi River, a Greenpeace report. Public Data Access, Inc., New York, 61 pp. + Appendices.

Raffle, B. I. 1978. The new clean air act—getting clean and staying clean. Environmental Reporter, Monograph No. 26, May 19, 1978, 27 pp.

Stolin, B. 1988. Use of industrial by-products as an energy source in report of the United Nations Industrial Development Organization world conference on industrial risk management and clean technologies, Vienna, Austria. Environmental Audit, Inc., Placentia, Calif., 6 pp.

U.S. Environmental Protection Agency. 1974. Report to Congress: disposal of hazardous wastes. Office of Solid Waste Management Programs (SW-115), xii + 110 pp.

———. 1980. Everybody's problem: hazardous waste. Office of Water & Waste Management (SW-826), 36 pp.

———. 1982. Environmental monitoring at Love Canal, Volume I. U.S. EPA Office of Research and Development (EPA-600/4-82-030a), May, 1982, xix + 296 pp.

———. 1984. Toxic substances control act: compliance/enforcement guidance manual. Government Institutes, Inc., August, 1984, vi + 1–1 to 1–74.

———. 1986. Public comment draft feasibility study, Times Beach Site, Times Beach, Missouri. U.S. EPA (EPA Contract No. 68-01-7251), December 14, 1986, xv + 204 pp. + Appendices.

———. 1987. The hazardous waste system. U.S. EPA Office of Solid Waste and Emergency Response, iii + 24 pp. + Appendices.

———. 1988. EPA report to Congress, solid waste disposal in the United States, Volumes I and II. U.S. EPA Office of Solid Waste and Emergency Response (EPA/530-SW-88-011B, October, 1988), xvi + 224 pp. + Appendices.

U.S. General Accounting Office. 1988. Hazardous waste: future availability of and need for treatment capacity are uncertain. U.S. General Accounting Office, Report to Congressional Requesters (GAO/RCED-88-95), 42 pp.

———. 1988. Hazardous waste: new approach needed to manage the resource conservation and recovery act. U.S. General Accounting Office, Report to Congress (GAO/RCED-88-115), 90 pp.

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Impacts of a Prescribed Burn on Vernal Pool Vegetation at Miramar Naval Air Station, San Diego, California

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Abstract.—An experimental burn in October 1986 tested the effects of fire on vernal pool vegetation of the coastal mesas of San Diego County. In the two following years, both of which were unusually dry, pool species declined on both burned and unburned areas. In 1987, however, total plant cover was reduced significantly more in burned than in control areas. Within burned basins, relative cover of pool species declined less than in control pools, which showed greater invasion of exotic upland annuals. *Pogogyne abramsii* and *Psilocarphus brevissimus* declined more in burned than in control pools in 1987, but recovered in 1988. Burning appeared to increase mineralization and flux of N and P into basins.

The coastal mesas of San Diego County, California possess extensive areas of distinctive mound-intermound-basin topography, the mounds being known commonly as Mima mounds and the basins filling with water in winter and spring to form temporary ponds, or vernal pools (Zedler 1987). The original vegetation of these mesas is poorly known because of the paucity of early records and the variety and extent of disturbance that has occurred. Some workers (e.g., Heady 1977) believed that the mesas were originally covered by grasslands dominated by *Stipa pulchra* and other perennial bunch grasses. Others (e.g., Cooper 1922) believe that present grasslands in the coastal region have been derived from shrublands by human disturbance. The composition of original California grasslands, even where their existence is uncontested, is uncertain because of their extensive invasion by Mediterranean annual grasses and forbs.

Mima mound and vernal pool landscapes occur on level sites from southern Oregon to northern Baja California, being best developed in the Sacramento and San Joaquin Valleys and in coastal central and southern California (Holland and Jain 1977, Holland 1978). California vernal pools possess a flora of many endemic annual and perennial species that are adapted to the temporary pond microhabitat. Most of these species begin growth when the pool basins are filled in winter or early spring, but flower and fruit after the basins have dried in late spring. The degree of development of this unique flora indicates that the vernal pool environment has existed for a long period of evolutionary time. Vernal pools also contain a distinctive invertebrate fauna. Many of these animals are widespread forms typical of temporary ponds, but some endemics or forms with widely disjunct ranges also occur (Cox 1982). Vernal pool systems are a seriously threatened ecosystem type in California and Oregon.

Most studies of California mound-and-vernal-pool grasslands have centered on the plant communities of the vernal pool basins and neighboring uplands because of the species richness, high endemism, and predominance of native species in this microhabitat (Holland and Jain 1977; Thorne 1984). Vernal pool basins exhibit complex patterns of zonation of species (Holland and Jain 1977) and show strong environmental gradients of moisture, soil texture, and soil nutrients (Bauder 1987). Zedler (1984) concluded that length of inundation played a dominant role in determining this zonation. Extensive recent studies by Bauder (1987) have confirmed this conclusion, and have shown experimentally that exotic upland species are excluded from pool basins by their inability to tolerate prolonged inundation. In addition, Bauder (1987) noted that the native pool species differ from each other in moisture requirements for germination. She found that some species can germinate and grow in upland sites, suggesting that competition is also a major factor in their restriction to basins.

In North America, Mima-mounded grasslands occur in many regions where fire has historically been an important determinant of vegetation type and structure. Such areas include the coastal prairie of Texas and Louisiana (Streng and Harcombe 1982), the tall grass prairies of eastern Oklahoma, Texas, and Missouri (Wright and Bailey 1982), the mound prairies of western Washington (Giles 1970), and the Mediterranean region of southern California (Minnich 1983). In all of these areas the original fire cycle has probably been lengthened (however, see Oberbauer 1978), and in some locations mound areas have been invaded by woody vegetation as a result. On Mima Prairie, Washington, fire exclusion has been correlated with the invasion of the native grassland by Douglas-fir (Giles 1970) and by the disappearance of pocket gophers (Dalquest and Scheffer 1942). The disappearance of pocket gophers may have been the result of changes in plant species composition or plant nutritional quality following fire exclusion. Whether or not woody plant invasion has occurred on the coastal mesas of southern California is uncertain, however. Many mound-and-vernal-pool areas in coastal San Diego County are now covered by chaparral communities dominated by chamise, *Adenostoma fasciculatum,* a species favored by fire intervals of 30–60 years (Hanes 1971). Some workers (Biswell 1956; Axelrod 1975; Dodge 1975; Aschmann 1977) believe that the aboriginal fire regime was frequent (intervals of 5–10 years or less), that grasslands were extensive in coastal mesas and valleys, and that expansion of chaparral occurred with introduction of extensive cattle ranching and reduction of fire in the late 1700's and 1800's. Others (Oberbauer 1978) contend that fire intervals were originally 50–100 years, and that grasslands were of very limited occurrence in this region.

Oberbauer (1978) examined San Diego County grasslands in relation to fire frequency. He mapped original grasslands as expected under fire cycles of 10-, 25-, and 50-year intervals. Under the most frequent fire scenario, large areas of the coastal mesas and cismontane valleys were projected to have been grassland, including essentially all sites now exhibiting Mima mounds. Thus, uncertainty exists about the fire regime under which the present structure of vernal pool systems developed, and of the likely impact of fire on these systems.

The purpose of our studies was to obtain information on fire effects, particularly on native vernal pool plant species, to help understand the role of fire in the ecology of the coastal mesas and to suggest whether or not special restoration procedures must be used for vernal pool areas impacted by fire (prescribed burns or wildfires).

Study Area

The study site, located on Miramar Naval Air Station, is about 46 ha in area and lies east of Interstate 15 and north of San Clemente Canyon. The area is bounded on the south by a paved two-lane road, on the east by a cleared right-of-way for the San Diego Aqueduct, on the north by a narrow dirt vehicle trail, and on the west by Interstate 15. The eastern and western parts of this area are separated by another dirt vehicle trail. The western half of the area (26 ha) was designated as the control area, and the eastern half (20 ha) as the experimental burn area.

The site lies on an elevated, wave-cut terrace or "mesa," the surface of which is covered by Mima mound and vernal pool microtopography developed on Redding Series soils (abruptic durixeralfs) that are underlain by an iron-silica duripan (Cox 1984). The original terrestrial vegetation of the site was probably California valley grassland. This has largely been transformed into Mediterranean annual grassland and invaded by coastal sage scrub and elements of chaparral, particularly chamise, *Adenostoma fasciculatum* (Cox 1986). The site possesses a Mediterranean climate with a long period of summer heat and drought and a mild, damp winter with most rainfall coming in a few heavy storms (Bauder 1987). The mean annual precipitation is about 24 cm.

Methods

In February 1986, ten pools, five in each half of the study area, were selected for investigation. An effort was made to match pools by size in the two areas, but this was not completely possible because of the small number of pools and the fact that some pools had received damage from military vehicle passage, making them unsatisfactory for sampling upland-to-pool vegetation gradients. In the end, two large pools (>30 m in longest dimension), two medium pools (10–30 m long), and one small pool (<10 m long) were selected in the designated burn area and three large, one medium, and one small pool were chosen in the control area. The edges (water margin) of these pools were marked with flags after the pools were filled by heavy rains.

Eight permanent pool-to-basin transects were located along the margin of each pool by a stratified random procedure. A marker was positioned in the center of the pool basin. The pool was then divided into four quadrants by lines from this marker to the nearest edges of the pool (its "sides") and the farthest edges of the pool (its "ends"), these points being identified by markers. A meter tape was then extended between each pair of markers, roughly parallel to the pool edge of that quadrant. Along this tape line, two points were located randomly, using a random numbers table. At each of these locations the nearest point on the pool margin was determined. An upland-to-pool-basin transect was placed at right angles to the pool border at this point. For large and medium pools the transects were 4 m long, and extended from 2 m beyond the pool edge to 2 m into the pool basin. For small pools the transects were 3 m long, extending from 2 m beyond the border to 1 m into the basin. The ends of all transects were marked with steel (rebar) posts.

On each transect 0.1 m^2 quadrats were sampled at five locations: 2 m and 1 m beyond the edge, the edge itself, and either 0.5 m and 1 m (small pools) or 1 m

Table 1. Direct impact of a prescribed burn on upland end, pool edge, and basin end locations along eight permanent transects in each of the five experimental vernal pools at Miramar Naval Air Station on 29 October 1986.

Pool No.		Number of transects		
		Upland end	Pool edge	Basin end
1.	Burned	8	5	
	Unburned		3	8
2.	Burned	8	5	
	Unburned		3	8
3.	Burned	8	8	6
	Unburned			2
4.	Burned	8	7	
	Unburned		1	8
5.	Burned	8	7	1
	Unburned		1	7
Total	Burned	40	32	7
	Unburned		8	33

and 2 m (medium and large pools) into the basin. These sampling points were relocated in 1987 and 1988 by measurement from the ends of the transects. The elevations of each quadrat relative to the pool edge were measured in cm with a line level. Cover of each species of vascular plant in each quadrat was rated on an eight-point scale: <1%, 1–5%, 5–25%, 25–50%, 50–75%, 75–95%, 95–99%, and >99%.

In 1986, vernal pool transects were sampled between 7 March and 7 April, with secondary checks being done between 16 and 25 April to determine the presence and maximum cover of late-season species. In 1987, pool transects were sampled between 17 and 26 March, with late-season checks being made on 18 April. In 1988, pools were sampled on 29 and 30 March.

Pre-burn soil samples (0–5 cm depth) were taken on 1 October 1986, prior to the first major autumn rains. In the designated control and experimental pools replicate samples were taken at the upland end, pool edge, and basin end of transects #1 and #5. Soil sampling was repeated on 16 December 1986, after the first major autumn rains, but before standing water had accumulated in the pools. The third set of samples was collected on 20 December 1987, again after the first major winter rains. These samples were analyzed at San Diego State University for available nitrogen (nitrate N, ammonium N), total Kjeldahl nitrogen, total phosphorus, and available phosphate. For ammonium and nitrate N, soils were extracted with 2N KCl, for phosphate with a mixture of 0.05 N HCl and 0.025 NH_2SO_4 (Flannery and Markus 1971). For total phosphorus and Kjeldhal nitrogen, samples were preoxidized with H_2O_2 and subjected to block digestion with sulfuric acid and mercuric oxide catalyst at 400°C for 1 hr, a procedure similar to that of Isaac and Johnson (1976). Concentrations of the various forms of N and P were measured in an AutoAnalyzer by Technicon Methods No. 158-71W/At (ammonium N, nitrate N), No. 155-71W (available phosphate), and No. 329-74W/B (total phosphorus and Kjeldhal nitrogen) (Technicon Industrial Systems, Bran/Lubbe Analyzing Technologies, Inc., Elmsford, New York).

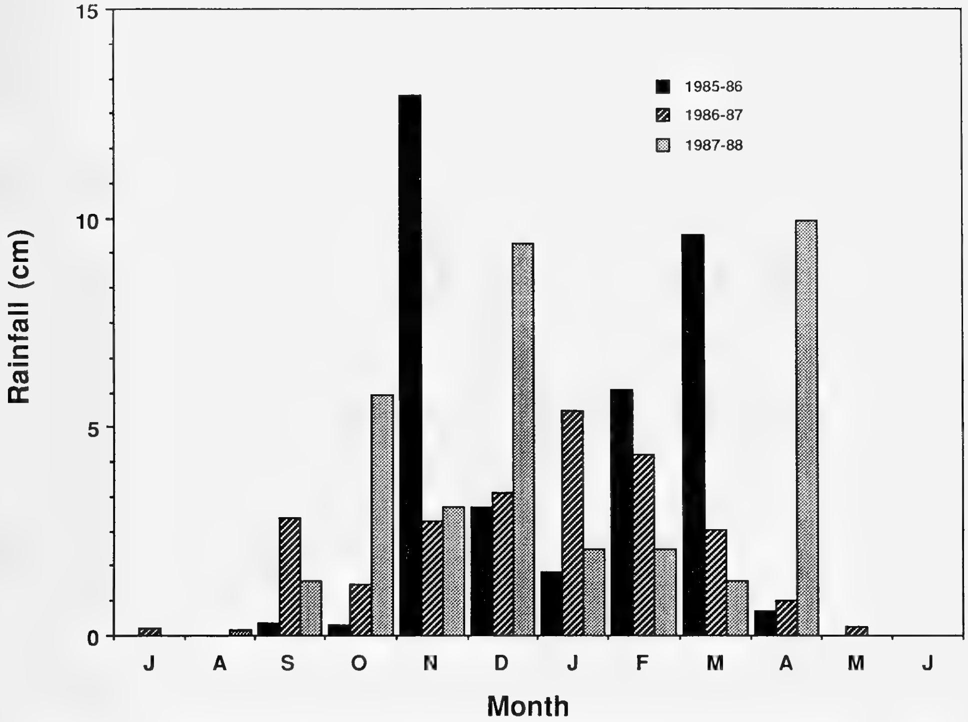

Fig. 1. Monthly rainfall at the Miramar Naval Air Station weather station from 1985–86 through 1987–88.

The prescribed burn was conducted on 29 October 1986, between 1330 and 1500 hrs. During this period, the temperature was about 22.2°C, the relative humidity about 65%, and winds about 10 MPH from the northwest. Immediately before the burn, soda-can pyrometers were positioned to measure the intensity of the fire heat. Soda cans (375 ml) filled with water were placed at the upland end, pool edge, and basin end of three transects in each of the experimental pools. Six soda cans were also placed in comparable sites in the control area.

Rainfall and temperature data for the study period were obtained for the U.S. Weather Bureau station at Miramar Naval Air Station, or, if values for this station were missing, from the station at Montgomery Field (<5 km distant) or Lindbergh Field (15 km distant). Changes in diversity and cover of the plant community, or major components thereof, in response to control and experimental conditions over the three years were tested by analysis of variance. Responses of individual species were tested by Chi Square contingency analysis of frequencies of different cover classes at stations along the upland-to-basin transects. Soil nutrient data were analyzed by analysis of variance.

Results

The intensity of the fire was very light in all pool areas. Water losses from pyrometers on the burned plot averaged only 0.1–0.2 percent greater than those from control pyrometers. Immediate post-fire observations along transects of the experimental pools (Table 1) revealed that the upland ends of all transects had

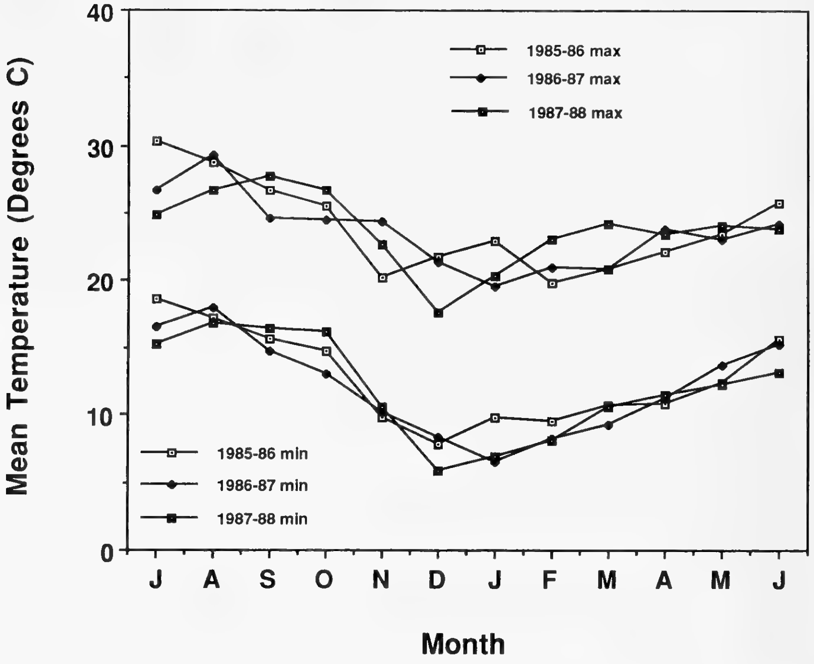

Fig. 2. Mean monthly minimum and maximum temperatures at the Miramar Naval Air Station weather station from 1985–86 through 1987–88.

been burned. Pool edge locations were burned on 80% of the transects, but the basin ends of transects were burned in less than 20% of cases. In three pools, none of the basin ends of transects were burned, and in a fourth pool, only one of the eight was burned.

During the 1985–86 winter growing season, prior to the burn, the rainfall pattern was favorable for filling of vernal pools and the growth of vernal pool plants (Fig. 1). Total rainfall during this season was 34.2 cm, with substantial rain occurring in November and December, stimulating early germination of vernal pool plants, as well as in February and March. Warm conditions prevailed during January, 1986 (Fig. 2), so that considerable early plant growth occurred. The pools were full on 21 February 1986, when control and experimental pools were selected. At this time a number of upland annuals and perennials were in flower, together with some individuals of the pool species *Lasthenia californica* and *Downingia cuspidata*. An additional 4.27 cm of rain between 8 and 12 March maintained pools in a full state.

In the 1986–87 growing season, total rainfall was only 23.7 cm, and was spread at widely spaced intervals from October through April so that pool basins never fully filled (Fig. 1). No unusual pattern of monthly mean temperatures was evident (Fig. 2).

In 1987–88, substantial early rains occurred in October and December, but because of the dry soil conditions the pool basins did not fill completely (Fig. 1). Very dry, warm conditions prevailed from January through late April, 1988, so that very little growth of plants occurred either in the vernal pool basins or in the neighboring uplands (Fig. 1, 2). Although the total rainfall during this growing

Table 2. Numbers of plant species encountered in sampling vernal pools at Miramar Naval Air Station in 1986, 1987 and 1988.

	Vernal pool species		Upland species		
Pool group	Native	Exotic	Native	Exotic	Native shrubs
Control—1986	20	3	26	10	7
—1987	14	3	23	10	7
—1988	16	2	17	8	5
Burn—1986	18	3	24	9	3
—1987	15	2	24	8	3
—1988	15	2	16	7	3
Total species	22	3	29	12	9

season was 35.1 cm, 9.91 cm of this came on and after 15 April, when many annuals had already ceased growth and had set seed. Thus, both years following the experimental burn were poor years for growth of vernal pool plants.

Some 75 species were encountered in sampling quadrats (Table 2). These included 9 species of woody or semi-woody upland shrubs. Herbaceous species were classed as vernal pool species if their distributions were centered within the basins, or upland species if their distributions were centered beyond the pool margin. Of the 25 vernal pool species found, 22 were native species. Of the 41 upland species encountered 29 were natives. Exotic upland species were often very abundant, however, so that the general pattern was of pool basins dominated by native species and uplands dominated by exotics, but having a rich assortment of native species of limited coverage.

The number of species encountered along the sampling transects was greatest in 1986, before the burn (Table 2). In 1987, in control ponds, six species of native pool plants present in 1986 did not appear: *Callitriche marginata, Isoetes orcuttii, Lillea scilloides, Montia fontana, Navarretia hamata,* and *Pilularia americana.* Two of these, *C. marginata* and *N. hamata,* reappeared in trace amounts in 1988. In post-fire seasons, however, these species were negligible in cover, presumably due to the poor pool conditions. In the experimental burn pools, nearly the same pattern was seen. Four native pool species present in 1986 were absent in 1987: *C. marginata, I. orcuttii, Plagiobothrys acanthocarpus,* and *L. scilloides.* In 1988, only *I. orcuttii* reappeared, and then only in low abundance.

For upland species, a different pattern was seen in both control and experimental pools. Although the greatest numbers of both native and exotic species were recorded in 1986, the number of species did not decline greatly in 1987. In 1988, however, a substantial decline in number of native species, both annuals and perennials, was noted.

For both control pools and experimental pools (Fig. 3), the mean number of species was greatest in quadrats at the edge of pool basins in 1986 and 1987. The difference in number of species between the edge and the interior of the pool basin was less in 1987 than in 1986, however. In 1988, the greatest number of species for both control and experimental pools was noted in quadrats midway into the pool basin. This shift in the point of maximum diversity along the upland-to-basin transects was highly significant ($F_{8,32} = 2.7$, $P < 0.001$) and was due to a very strong decline in the number of vernal pool species at the edge of the pool

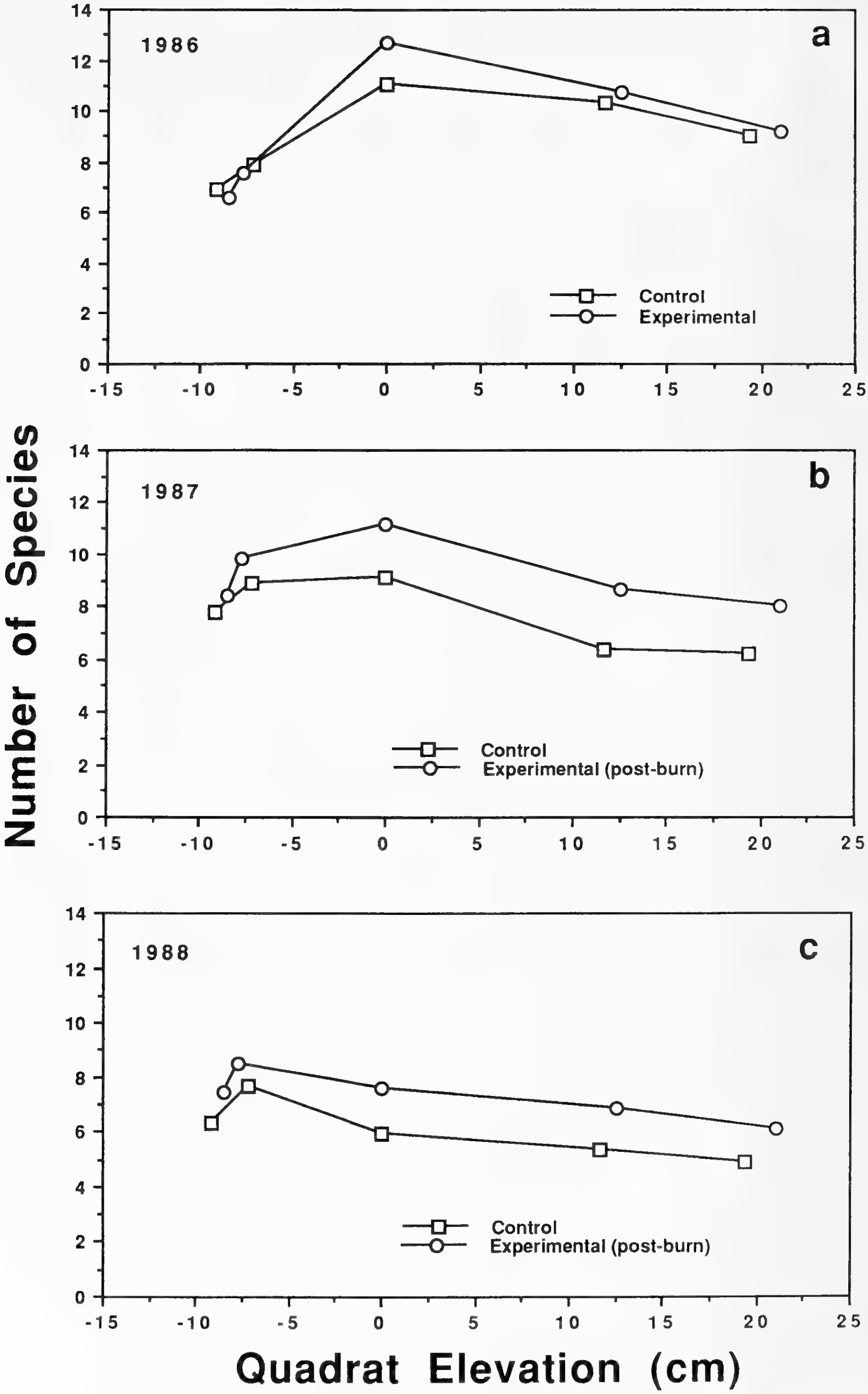

Fig. 3. Mean number of total species in 0.1 m^2 quadrats at different elevations along transects from upland to pool basin for control and experimental pools from 1986 through 1988.

basin and lesser declines of vernal pool species number in the basin proper, coupled with a large increase in number of upland species in the basin proper. Shrubs were recorded only at or above the pool edges; their diversity tended to decline slightly from 1986 through 1988.

Total plant cover did not show a clear trend along the gradient from upland to pool basin in control or experimental pools in any year. Total cover changed significantly over the 3-year period on the experimental plot ($F_{2,8} = 29.2$, $P < 0.001$). In 1987, total cover on the burned area was lower at all transect stations than for 1986 or 1988. The recovery of total cover in 1988 was strong, but reached values equal to those prior to the burn only at the mid-upland station. In 1988, total plant cover for control pools exceeded that noted in 1986 at all stations except at the upland end of the transects.

Cover of vernal pool forbs and grasses declined progressively from 1986 through 1988 in both control and experimental pools ($F_{2,8} = 14.9$, $P < 0.01$), with this decline being greatest at the edge of the pool basins (Fig. 4). Responses of vernal pool species along the transect gradient differed significantly, however ($F_{8,32} = 2.24$, $P = 0.05$). In the experimental pools, total cover of vernal pool species increased slightly at transect locations above the pool edge in 1987, immediately after the burn, compared to 1986 (Fig. 4). This increase was short-lived, and disappeared in 1988. At the edge of experimental pools and within their basins, cover of vernal pool species declined markedly between 1986 and 1987. In 1988, however, plant cover in burned pools declined only at the edge of the basins, remaining constant midway into the basins and increasing at the basin end of transects.

In both control and experimental pools, upland forbs and grasses showed very significant, progressive increases in cover from 1986 through 1988 ($F_{8,32} = 7.4$, $P < 0.001$) at locations from the edge of the pool basin to the basin end of the transects (Fig. 5). In experimental pools, the same general pattern was evident, but the magnitude of the actual increases was significantly less ($F_{4,16} = 12.1$, $P < 0.001$).

Shrub cover tended to decline progressively from 1986 through 1988 in the upland zones of the control pools. In the experimental pools, cover was sharply reduced in 1987, compared to 1986, but recovered partially in 1988.

Responses of individual species over the three-year period were diverse. Of the 16 vernal pool species recorded in both control and experimental pools in 1986 and 1987, five showed apparent absolute increases in the pools subjected to the experimental burn: *Brodiaea orcuttii, Cotula coronopifolia, Deschampsia danthonioides, Plagiobothrys undulatus,* and *Veronica peregrina.* An additional seven species declined less in the burned pools than expected from their performance in the control pools: *Crassula aquatica, Eleocharis macrostachya, Juncus bufonius, Juncus dubius, Lythrum hyssopifolium, Navarretia hamata,* and *Plantago bigelovii.* Only four species appeared to decline more in the burned pools than in the control pools: *Anagallis minimus, Downingia cuspidata, Pogogyne abramsii, Psilocarphus brevissimus.*

Among vernal pool annual plants, the impact of the experimental burn was of foremost concern for the San Diego mesa mint, *Pogogyne abramsii,* a federally listed Endangered Species. In control pools, mesa mint showed a progressive decline in mean cover from 1986 through 1988 in pool edge and mid-basin

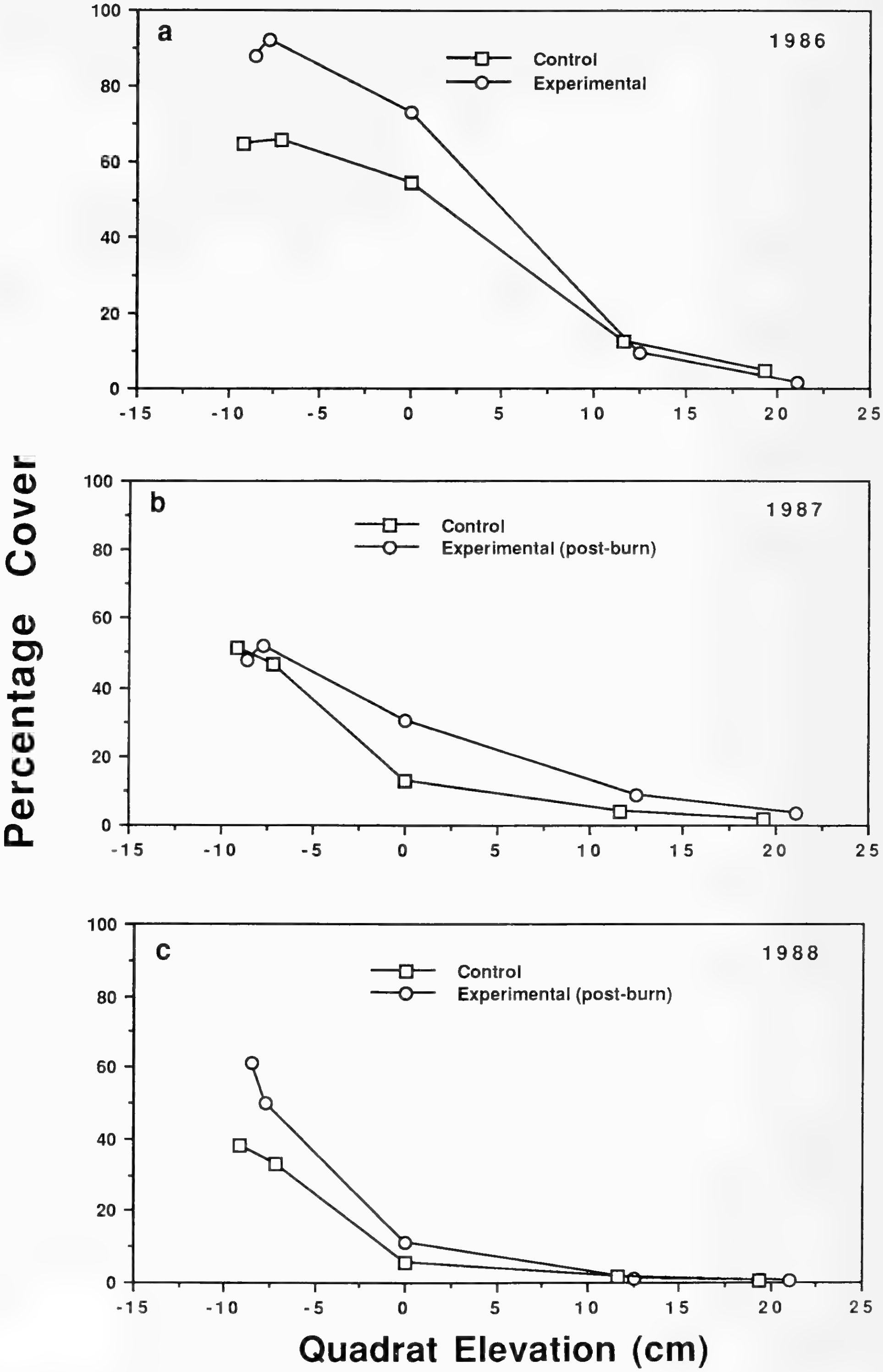

Fig. 4. Mean vernal pool plant cover in 0.1 m^2 quadrats at different elevations along transects from upland to pool basin for control and experimental pools from 1986 through 1988.

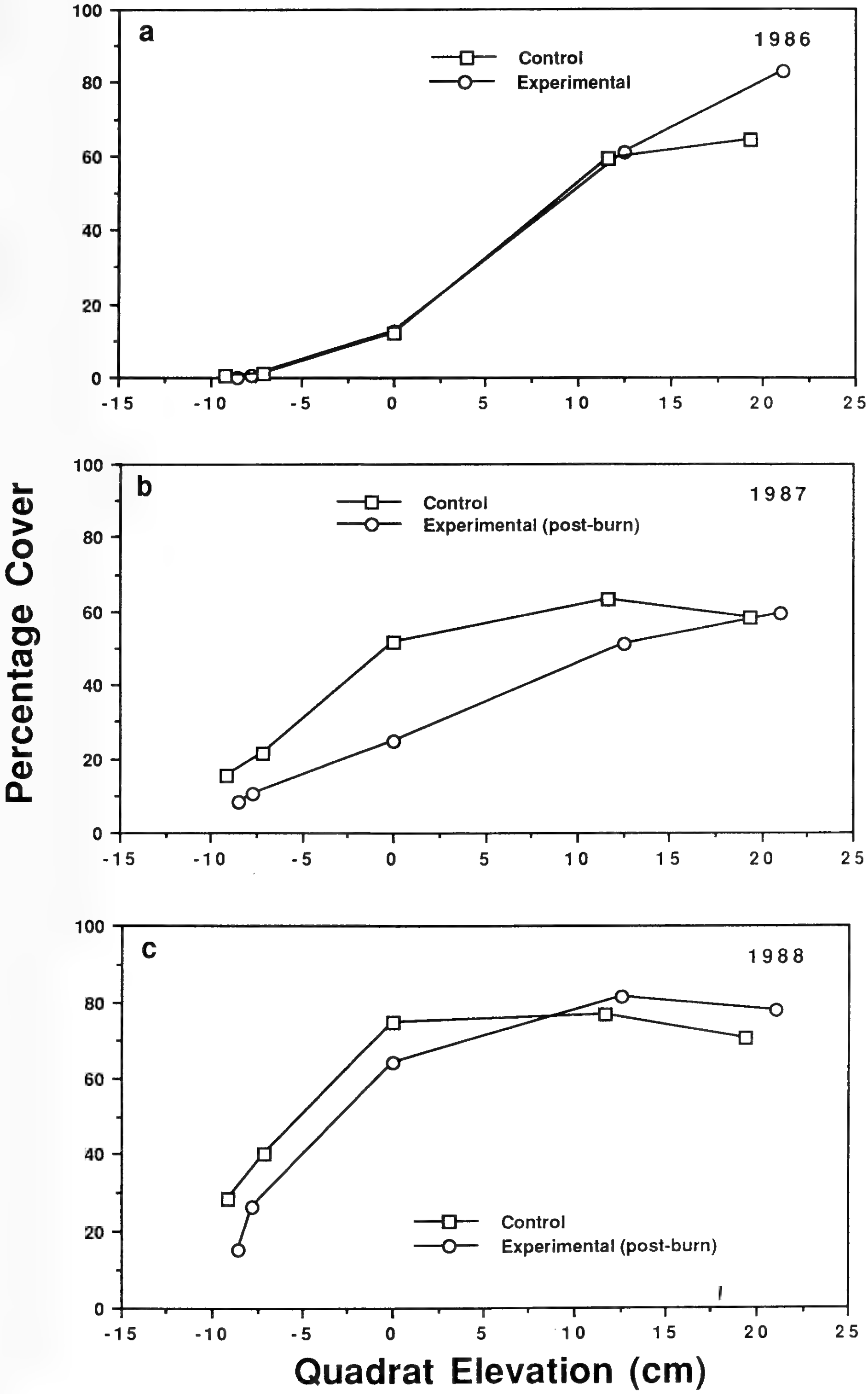

Fig. 5. Mean upland herbaceous plant cover in 0.1 m^2 quadrats at different elevations along transects from upland to pool basin for control and experimental pools from 1986 through 1988.

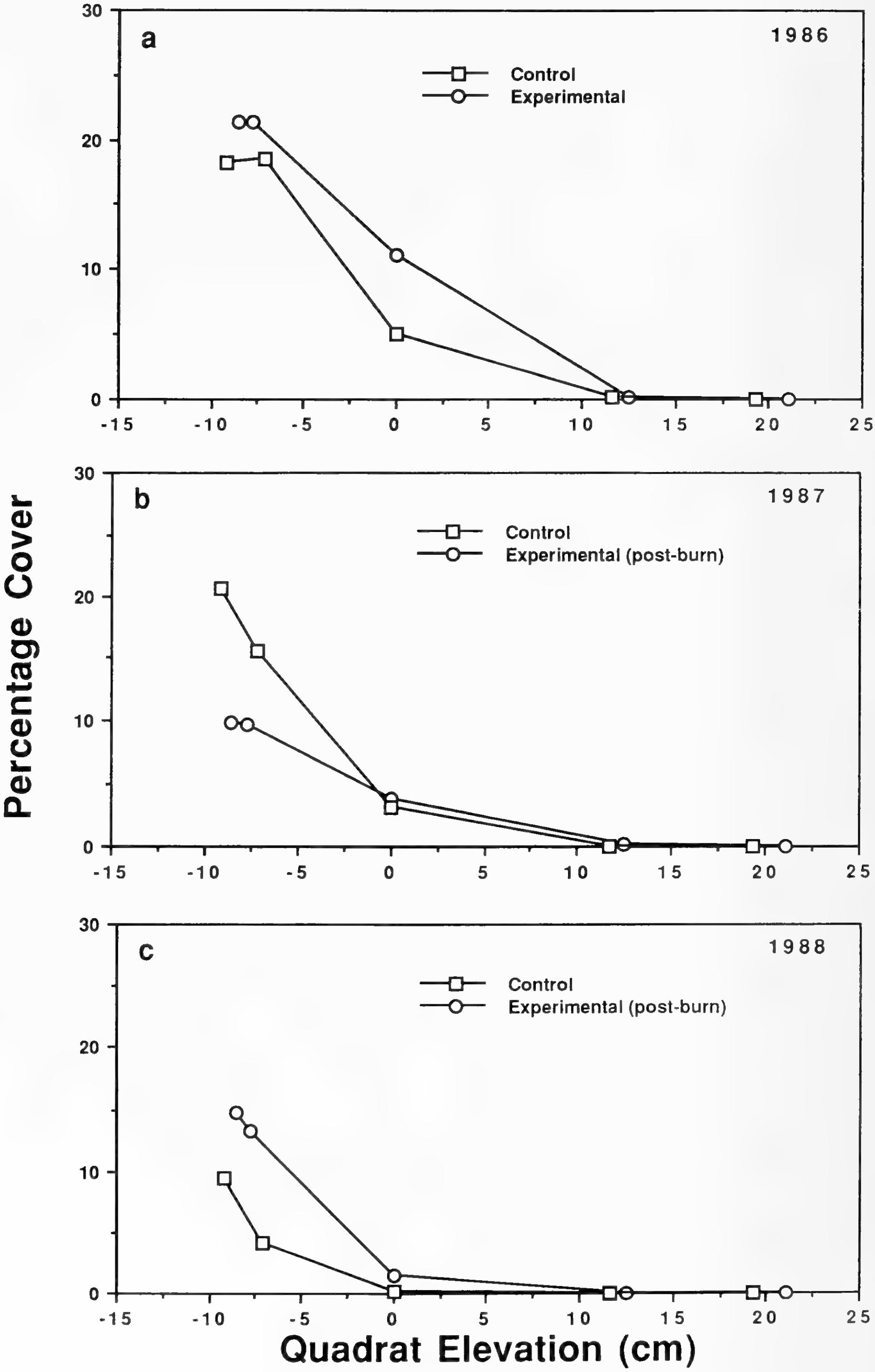

Fig. 6. Mean cover of San Diego Mesa Mint, *Pogogyne abramsii,* in 0.1 m^2 quadrats at different elevations along transects from upland to pool basin for control and experimental pools from 1986 through 1988.

sampling locations (Fig. 6). At the basin end of the transects, however, no decline was evident until 1988. In 1986, frequencies of cover classes of *Pogogyne* did not differ for control and experimental pools ($\chi^2 = 8.6$, df = 5, $P > 0.05$). In the burned pools (Fig. 6), mesa mint declined in cover more than in control pools in 1987 ($\chi^2 = 41.7$, df = 4, $P < 0.001$). *Pogogyne* recovered to levels not significantly different from those of control pools in 1988.

Psilocarphus brevissimus showed a similar pattern, declining progressively in cover from 1986 through 1988 at edges of both control and experimental pools. Within the basins, cover declined markedly in 1988 in control pools, but remained nearly constant in experimental pools. Prior to the burn, *Psilocarphus* was significantly more abundant in experimental than in control pools ($\chi^2 = 16.6$, df = 4, $P > 0.01$). This difference was not significant in 1987 ($\chi^2 = 8.5$, df = 4, $P > 0.05$), indicating a significantly greater decline of this species in burned than control pools. In 1988 *Psilocarphus* cover was once again significantly greater in experimental than in control pools ($\chi^2 = 22.6$, df = 4, $P < 0.001$).

The other pool species appearing to show greater declines in burned than in control pools were *Downingia cuspidata* and *Anagallis minimus. Downingia* declined in mean cover in both control and experimental pools from 1986 through 1988 at sampling locations within the pool basins. For quadrats within the pool basins, mean cover of *Downingia* was 5.6–11.9 percent in 1986 and 2.4–3.3 percent in 1988. Frequencies of cover classes changed significantly from 1986 to 1988 for control and experimental pool data combined ($\chi^2 = 29.4$, df = 8, $P < 0.001$). Within years, however, mean cover values for *Downingia* were very similar at corresponding points on control and experimental transects, and cover class frequencies did not differ significantly. Cover class frequencies for *Anagallis* changed significantly from 1986 to 1987 for both control ($\chi^2 = 26.8$, df = 3, $P < 0.001$) and experimental ($\chi^2 = 57.4$, df = 3, $P < 0.001$) pools. In 1988, *Anagallis* declined to a very low level in both control and experimental pools. Frequencies of cover classes did not differ significantly for *Anagallis* in control and burned pools in any year. For these two species, it is therefore doubtful that significant relative changes in cover occurred in the burned pools.

Brodiaea orcuttii, a native perennial associated with, but not confined to, vernal pool basins showed a strikingly different pattern. In both control and experimental pools its abundance was greatest at the pool edge. The mean cover of this species declined progressively in control pools from 2.51% in 1986 to 1.04% in 1988. In experimental pools, *Brodiaea* cover class frequencies did not differ significantly from control pools in 1986. Mean cover increased to 3.94% and cover class frequencies were significantly different from those of control pools in 1987 ($\chi^2 = 19.0$, df = 3, $P < 0.001$). In 1988, *Brodiaea* cover declined at all levels, but cover remained significantly higher than before the burn ($\chi^2 = 9.4$, df = 3, $P < 0.05$).

Exotic annuals likewise showed different responses to drought and the experimental burn. In control pools, *Avena barbata* cover increased in 1987 and 1988 from pool edges into the pool basins. In the experimental area, *Avena* showed less tendency to invade pool edge and basin sites, and was significantly less frequent here than in control pools in 1988 ($\chi^2 = 4.2$, df = 1, $P < 0.05$). In the control area, *Erodium botrys* also increased progressively from 1986 through 1988, especially at sites from the pool edges into the pool basins. The burn produced a marked reduction of *Erodium* in upland locations, however, and invasion of the

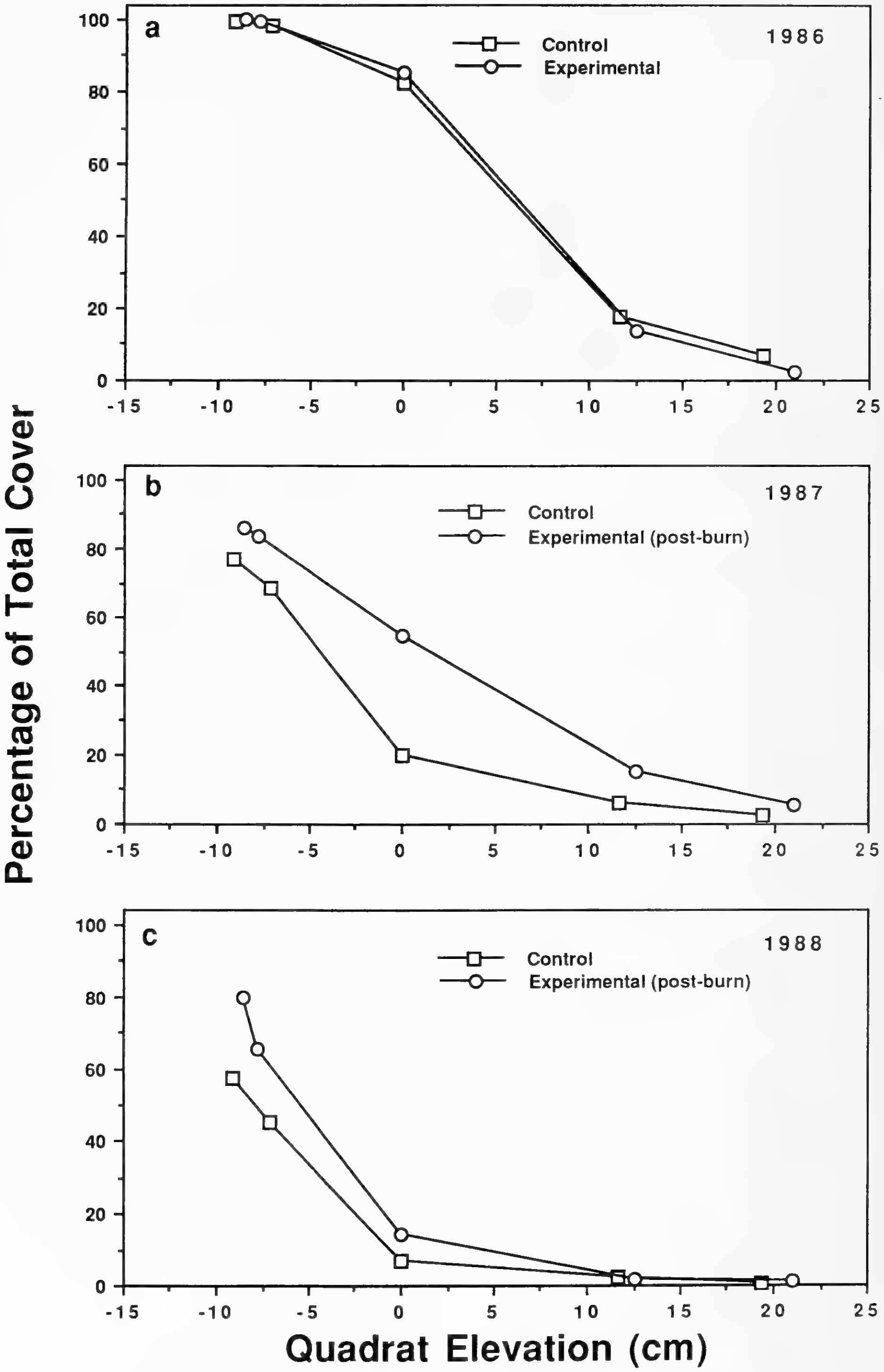

Fig. 7. Mean vernal pool plant cover as a percentage of total herbaceous in 0.1 m^2 quadrats at different elevations along transects from upland to pool basin for control and experimental pools.

Table 3. Extractable phosphate concentration (mg/kg) in surface soils samples from vernal pools in control and experimental areas at Miramar Naval Air Station. Values are means ± standard error.

	Pre-burn	Post-burn	
	1986	1987	1988
Control pools			
Upland	2.39 ± 0.34	1.53 ± 0.23	4.44 ± 1.00
Edge	1.92 ± 0.19	1.65 ± 0.14	3.00 ± 0.38
Basin	2.76 ± 0.24	2.35 ± 0.22	4.58 ± 0.60
Experimental pools			
Upland	2.92 ± 0.32	2.55 ± 0.28	4.81 ± 0.58
Edge	2.40 ± 0.42	1.85 ± 0.14	3.57 ± 0.45
Basin	3.02 ± 0.36	2.69 ± 0.26	5.67 ± 0.74

pool basins was weaker than in control pools. In 1988, mean cover of *Erodium* at pool edge and basin locations was 19.74% for control pools and 10.13% for burned pools ($\chi^2 = 19.7$, df = 4, $P < 0.001$). *Hypochoeris glabra* exhibited a very strong tendency to invade the basins of control pools in the dry years of 1987 and 1988, attaining a mean cover nearly equal to that of upland areas. In the experimental pools, this tendency was significantly weaker, based on cover class frequencies ($\chi^2 = 42.8$, df = 4, $P < 0.001$), but by 1988 this difference had disappeared.

When vernal pool plants were considered as a percentage of total herbaceous cover (Fig. 7), a striking difference between control and experimental pools was evident. Curves for control and experimental pools in 1986 were nearly identical, with vernal pool plant cover approaching 100% within the pools. In 1987 and 1988, when many upland species invaded the pool basins, pool species constituted a greater percentage of herbaceous cover in burned pools than in control pools. In other words, invasion of the basins by upland species was less in burned than in control pools.

Soil Nutrients

Extractable phosphate, an indicator of plant-available P, showed significant differences among the upland, pool edge, and pool basin sites ($F_{2,8} = 8.0$; $P < 0.05$), when data for both control and experimental areas were combined (Table 3). Values were highest in the pool basins and lowest at the pool margins. Values also differed significantly for the three years ($F_{2,8} = 79.7$; $P < 0.001$), being lowest in 1986 and highest in 1988. In 1987, at the beginning of the first growing season after the burn, mean concentrations were significantly higher in the burned area than in the control area ($F_{1,30} = 8.9$, $P < 0.01$). Total phosphorus concentrations (g/kg) showed significant variation along the upland-to-basin gradient in the control and experimental pools ($F_{2,8} = 48.5$, $P < 0.001$), being highest in the basins and lowest at pool edges, as for phosphate.

Ammonium N concentrations varied significantly ($F_{2,8} = 20.1$, $P < 0.001$) over the three-year period in the control and experimental pools, being much higher in 1988 than in 1986 or 1987 (Table 4). The relative levels of ammonium on control and experimental areas varied significantly among years ($F_{2,8} = 5.2$, $P <$

Table 4. Ammonium N concentration (mg/kg) in surface soils samples from vernal pools, in control and experimental areas at Miramar Naval Air Station. Values are means ± standard error.

	Pre-burn 1986	Post-burn 1987	Post-burn 1988
Control pools			
Upland	7.03 ± 1.12	4.95 ± 0.61	33.77 ± 12.84
Edge	3.78 ± 0.49	3.97 ± 0.48	14.79 ± 3.40
Basin	3.86 ± 0.75	4.57 ± 0.73	12.60 ± 1.82
Experimental pools			
Upland	7.07 ± 1.00	5.03 ± 0.48	19.14 ± 3.28
Edge	6.34 ± 0.98	4.24 ± 0.51	24.02 ± 4.84
Basin	5.30 ± 0.83	3.19 ± 0.32	51.65 ± 20.83

0.05), as well, with levels in the burned area being only slightly greater than those in the control area in 1987, moderately greater in 1986, and much greater in 1988.

Nitrate N levels in the control and experimental pool samples varied significantly among years ($F_{2,8} = 205.6$, $P < 0.001$), being lowest in 1987 and highest in 1988 (Table 5). Over all years, nitrate values were also significantly higher ($F_{1,4} = 42.8$, $P < 0.01$) in the experimental area than in the control area. The degree of this difference varied significantly among years ($F_{2,8} = 32.6$, $P < 0.001$), however, being much greater in 1987 and 1988 than in 1986.

Kjeldahl nitrogen varied significantly along the upland-to-basin gradient in the control and experimental pools ($F_{2,8} = 8.0$, $P < 0.05$), being lowest at the pool edges. The levels in the experimental area were significantly greater than those in the control area ($F_{1,4} = 27.2$, $P < 0.01$), over all years, as for nitrate. The degree of this difference did not change over the three-year period, however.

Discussion

Several factors must be kept in mind in interpreting these results. First, the experimental burn was followed by two years of rainfall conditions that were unfavorable to the filling of vernal pools. In 1987, pools on the control and experimental areas filled only partially, and in 1988 only in their deepest levels. Second, the burn was conducted in late October, near the end of the fire season, and was thus not only a late-season fire under the current fire regime of southern California, but probably a very unusual phenomenon under the fire regime prevailing prior to Euro-American settlement. Third, the fire was of low intensity in the pool basins and their immediate surroundings. Nevertheless, some important conclusions can be drawn from this study.

Overall, the fire did not exert an adverse effect on native vernal pool herbs. In fact, the fire appeared to mitigate the effects of the dry basin conditions in 1987 and 1988. Total cover of these species remained constant or increased in 1988 in the burned pool basins, whereas it continued to decline in control pools (Fig. 4). In both 1987 and 1988, in burned pools, vernal pool species formed a greater percentage of total herbaceous cover than did upland species at levels from the pool edge downward (Fig. 7). These responses suggest that the seed banks of vernal pool annuals, located in basins that were only partially burned, suffered less

Table 5. Nitrate N concentration (mg/kg) in surface soils samples from vernal pools, in control and experimental areas at Miramar Naval Air Station. Values are means ± standard error.

	Pre-burn 1986	Post-burn 1987	Post-burn 1988
Control pools			
Upland	4.69 ± 0.68	1.78 ± 0.34	37.21 ± 8.74
Edge	4.30 ± 0.67	1.41 ± 0.18	26.78 ± 6.86
Basin	9.94 ± 1.65	1.93 ± 0.22	43.17 ± 9.59
Experimental pools			
Upland	8.05 ± 1.83	5.33 ± 0.79	38.83 ± 11.18
Edge	7.02 ± 0.85	3.07 ± 0.28	56.01 ± 11.39
Basin	10.21 ± 1.79	3.74 ± 0.36	69.84 ± 21.62

damage than those of Mediterranean exotics, which were concentrated in upland areas that were more heavily burned.

Although vernal pool species in general were not adversely affected by the burn, certain annual pool species did decline more in burned pools than in control pools immediately after the fire. For one of these, *Pogogyne abramsii,* the seeds are known to be retained in the calyces of dead flowers, thus making them vulnerable to destruction when dead plant material on the soil surface is burned (Scheidlinger 1984; Bauder 1987). The same is probably true of *Psilocarphus brevissimus,* a second species that was reduced more in burned than in unburned pools in 1987 (E. Bauder, pers. comm.). We therefore suggest that species with this seeding characteristic are more vulnerable to immediate post-fire depression in abundance.

Upland exotic annuals progressively invaded the basins of both control and experimental pools in 1987 and 1988 (Fig. 5), due to the fact that the pool basins filled only partially and for very short periods. None of these invaders performed better in the burned pools than in the experimental pools. The species showing the greatest increases in burned pools were *Erodium botrys* and *Hypochoeris glabra,* both rosette plants with good dispersal mechanisms and highly variable size at maturity. Their success is probably due largely to the ability of individual plants to grow to large size in a low competition environment, rather than to an increased influx of seeds to the burned pool basins. Grasses, particularly the large-seeded *Avena* and *Bromus* species, showed a relatively weak tendency to invade burned pool basins.

Bauder (1987) found that species diversity in pools on nearby areas of Kearny Mesa peaked at locations of intermediate inundation time along the mound-intermound gradient. Holland and Jain (1984) noted that species diversity in California vernal pools was, in general, greatest at pool margins. Our 1986 results (Fig. 3) also show this pattern. The downward shift in location of maximum diversity in 1987 and 1988 reflected the dry conditions in these years, which reduced the survival of vernal pool species at higher levels and favored upland species that are intolerant of long inundation at lower levels.

Since the chemical analyses of soils were conducted at three separate occasions, with samples having been stored for different times prior to analysis, we feel that the most meaningful interpretations relate to relative differences within years, rather than absolute year-to-year differences. Under unburned conditions, soil N and P showed highest concentrations at the extremes of the topographic gradient: pool basins and upland high points. In both control and experimental pools, phosphorus, phosphate, and Kjeldahl nitrogen were lowest in concentration at the pool edges, and for phosphorus and phosphate, highest in the pool basins (Table 3).

The experimental burn increased the concentrations of most nutrients on the burned plots relative to control plots. Phosphate increased significantly in concentration in burned pools, relative to unburned pools, in 1987 compared to values noted in 1986 (Table 3). Ammonium N, in 1987, showed a reduced difference between control and experimental pools, but in 1988 the difference increased to its highest level (Table 4). Nitrate N levels also increased markedly at all points along the transects in burned pools in 1987 and 1988, relative to values in control areas (Table 5).

These data suggest that topographic high points and pool basins are sinks for nutrients in the mounded mesa environment. Fire probably increase the flux of nutrients into the pool basins during years immediately following. Other factors, however, certainly interact with fire to determine the direction and magnitude of nutrient fluxes within this system.

Acknowledgments

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Literature Cited

Aschmann, H. H. 1977. Aboriginal use of fire. Pp. 132–141 *in* Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. (H. A. Mooney and C. E. Conrad, eds.), U.S. For. Serv. Gen. Tech. Rep. WO-26.

Axelrod, D. I. 1975. Evolution and biogeography of Madrean-Tethyan sclerophyll vegetation. Ann. Missouri. Bot. Gard., 62:280–334.

Bauder, E. T. 1987. Species assortment along a small-scale gradient in San Diego vernal pools. Ph.D. Dissertation, San Diego State University, San Diego, Calif., and University of California, Davis, Calif.

Biswell, H. H. 1956. Ecology of California grasslands. J. Range Manag., 9:19–24.

Clements, F. E. 1934. The relict method in dynamic ecology. J. Ecol., 22:39–68.

Cooper, W. S. 1922. The broad sclerophyll vegetation of California. An ecological study of the chaparral and its related communities. Carnegie Inst. Wash. Pub. 319.

Cox, G. W. 1982. *Systylis hoffi* (Protozoa: Ciliata) in California vernal pools. Trans. Am. Microsc. Soc.,101:294–298.

———. 1984. The distribution and origin of Mima mound grasslands in San Diego County, California. Ecology, 65:1397–1405.

———. 1986. Mima mounds as an indicator of the presettlement grassland-chaparral boundary in San Diego County, California. Amer. Midl. Nat., 116:64–77.

Dalquest, W. W., and V. B. Scheffer. 1942. The origin of the Mima mounds of western Washington. J. Geol., 50:68–84.

Dodge, J. M. 1975. Vegetational changes associated with land use and fire history in San Diego County. Ph.D. Dissertation, Univ. of California, Riverside.

Flannery, R. L., and D. K. Markus. 1971. Determination of phosphorus, potassium, calcium, and magnesium simultaneously in North Carolina, ammonium acetate, and Bray P_1 soil extracts by AutoAnalyzer. Pp. 97–112 *in* Instrumental methods for analysis of soils and plant tissue. (L. M. Walsh, ed.), Soil Sci. Soc. Amer., Ames, Iowa.

Giles, L. J. 1970. The ecology of the mounds on Mima Prairie with special reference to Douglas-fir invasion. M.S. Thesis, Univ. of Washington, Seattle.

Hanes, T. L. 1971. Succession after fire in the chaparral of southern California. Ecol. Monogr., 41: 27–52.

Heady, H. F. 1977. Valley grassland. Pp. 491–514 *in* Terrestrial vegetation of California. (M. G. Barbour and J. Major, eds.), John Wiley and Sons, New York.

Holland, R. 1978. The geographic and edaphic distribution of vernal pools in the Great Central Valley, California. Calif. Nat. Plant Soc., Spec Pub. No. 4, Sacramento, Calif.

———, and S. Jain. 1977. Vernal pools. Pp. 515–533 *in* Terrestrial vegetation of California. (M. G. Barbour and J. Major, eds.), John Wiley and Sons, New York.

———, and ———. 1984. Spatial and temporal variation in plant species diversity of vernal pools. Pp. 198–209 *in* Vernal pools and intermittent streams. (S. Jain and P. Moyle, eds.), Institute of Ecology, University of California, Davis, Pub. No. 28.

Isaac, R. A., and W. C. Johnson. 1976. Determination of total nitrogen in plant tissue using a block digester. J. Assoc. Org. Analyt. Chem., 59:98–100.

Minnich, R. A. 1983. Fire mosaics in southern California and northern Baja California. Science, 219:99–107.

Oberbauer, T. A. 1978. Distribution dynamics of San Diego County grasslands. M.S. Thesis, San Diego State Univ., San Diego, Calif.

Scheidlinger, C. R. 1984. Population studies in *Pogogyne abramsii.* Pp. 223–231 *in* Vernal pools and intermittent streams. (S. Jain and P. Moyle, eds.), Institute of Ecology, University of California, Davis, Pub. No. 28.

Streng, D. R., and P. A. Harcombe. 1982. Why don't east Texas savannas grow up in forest? Amer. Midl. Nat., 108:278–294.

Thorne, R. F. 1984. Are California's vernal pools unique? Pp. 1–8 *in* Plant communities of southern California. (J. Latting, ed.), Calif. Native Plant Soc., Spec. Pub. No. 2, Riverside, Calif.

Wright, H. A., and A. W. Bailey. 1982. Fire ecology. John Wiley and Sons, New York.

———. 1984. Micro-distribution of vernal pool plants of Kearny Mesa, San Diego County. Pp. 185–197 *in* Vernal pools and intermittent streams. (S. Jain and P. Moyle, eds.), Institute of Ecology, University of California, Davis, Pub. No. 28.

Zedler, P. H. 1987. The ecology of southern California vernal pools: a community profile. National Wetlands Research Center, Fish and Wildlife Service, Washington, D.C.

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Taxonomy and Distribution of *Sigmodon* in California

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Abstract.—Cotton rats, genus *Sigmodon,* occur commonly in grassland habitats throughout the southern United States and Mexico. The most widespread species is *S. hispidus,* which is known to occur in California, although previous studies give reason to believe *S. arizonae* also occur in the state. Cotton rats were studied in California using a combination of karyology and skull morphology. Results indicate two species of *Sigmodon* occur in California: *S. hispidus* in extreme southeastern California and the Imperial Valley and *S. arizonae* along the Colorado River north of the Palo Verde Mountains.

Cotton rats are a common grassland rodent throughout most of the southern United States and Mexico (Hall 1982). The most widespread species is *Sigmodon hispidus,* which reaches its western-most distribution in California as the subspecies *S. h. eremicus* and *S. h. plenus* (Cameron and Spencer 1981; Hall 1982). Zimmerman (1970) reclassified *S. h. plenus* as *S. arizonae* based upon identical karyotypes and skull morphologies. Because *S. arizonae plenus* occurs in California, its reclassification implies that two species of *Sigmodon* occur in California. Thus, Hall (1982) recognized both *S. hispidus* and *S. arizonae* in California. However, neither Hall (1982) nor Zimmerman (1970) examined specimens of *Sigmodon* from the state. Considered here are species identities and distributions of *Sigmodon* in California using karyology and skull morphology.

Methods

Sigmodon were collected in southeastern California (Fig. 1) during 1979. Live cotton rats were transported back to the lab and were karyotyped following the procedures of Patton (1967) and Zimmerman (1970).

One hundred ninety standard skin and skull specimens were examined (see specimens examined); 13 juvenile and damaged specimens were eliminated. Cotton rats having a zygomatic arch width of 18 mm or greater were classified as adults (Chipman 1965; Green and Jameson 1975).

Each skull was examined for four qualitative characteristics (Hoffmeister 1986; Severinghaus and Hoffmeister 1978; Zimmerman 1970) as follows: 1) the shape of the occipital shield (angular in *S. hispidus,* rounded in *S. arizonae*); 2) width of the ventral surface of the presphenoid (narrow in *S. hispidus,* broad in *S. arizonae*); 3) shape of the spine of the infraorbital plate (blunt in *S. hispidus,* sharp in *S. arizonae*); 4) shape of the lateral borders of the nasal bones (curved in dorsal view in *S. hispidus,* straight in dorsal view in *S. arizonae*).

Standard body measurements of total length, tail length, hind foot length, and ear length were taken from collection tags. Total length minus tail length yielded body length. Nineteen skull dimensions (Hooper 1952; Zimmerman 1970) were measured to the nearest 0.1 mm using dial calipers as follows: diameter of the foramen ovale, lambdoidal breadth, condylobasilar length, greatest length of skull, interorbital breadth, breadth of brain case, length of maxillary toothrow, length of diastema, palatilar length, nasal length, length of incisive foramen, depth of skull, breadth of rostrum, distance between temporal and occipital ridges, length of temporal ridge, breadth of zygomatic arches, length of rostrum, diameter of third lower molar, and breadth of mesopterygoid fossa.

Quantitative analysis of skull characters utilized programs available on BMDP (Dixon and Brown 1977) and CLUSTAN (Wishart 1979) at California State University Long Beach. Simple descriptive statistics were obtained for each species. Specimens were next classified into twelve discrete locality groups (Fig. 1). Means were calculated for each variable for each of the twelve locality groups. Missing data were replaced using the data estimation and replacement program (BMDP-AM).

Sexual dimorphism within each locality group was examined using a variable-by-variable t-test. Few variables displayed significant ($P > 0.05$) sexual dimorphism, and the pattern among localities was not consistent. Therefore, I followed Chipman (1965) and Zimmerman (1970) and combined the sexes.

Ward's (1963) method of cluster analysis was used (Ward's option within the procedure hierarchy of CLUSTAN) to analyze linear skull and body measurements, standardized to Z-scores. Following the cluster analysis, a discriminant function analysis was performed on the clusters resulting from Ward's analysis.

The following institutions provided specimens for this study: American Museum of Natural History (AMNH); California Academy of Science (CAS); California State University Long Beach (CSULB); Field Museum of Natural History (FMNH); Natural History Museum of Los Angeles County (LACM); San Diego Society of Natural History Museum (SDMNH); National Museum of Natural History (USNM); University of Arizona (UA); University of Illinois Museum of Natural History (UIMNH); and University of Michigan Museum of Zoology (UMMZ). The list of specimens examined includes the locality grouping code used in Figure 1, which is the numeral enclosed in parentheses immediately following the location.

Sigmodon hispidus eremicus. Specimens examined (118). Mexico, Sonora, Cienega Well (8), 2 (USNM); Monument 204 (8), 4 (USNM); Mouth of Hardy's River (8), 5 (USNM); USA, Arizona, Yuma Co., vic. of Gadsden (6), 4 (AMNH); 6 (SDMNH); vic. of Yuma (9), 7 (USNM), 4 (AMNH), 4 (UA); 1 (CSULB); 2 (LACM); 28 (UMMZ), 22 (UIMNH); California, Imperial Co., vic. of Bard (11), 1 (LACM); 18 (SDMNH); vic. of Holtville (11), 3 (CSULB); 3 (LACM); Imperial Co. only (11), 1 (CAS); Imperial Dam (11), 4 (CSULB).

Sigmodon arizonae arizonae. Specimens examined (8). USA, Arizona, Yavaipai Co., Camp Verde (1), 8 (USNM).

Sigmodon arizonae cienegae. Specimens examined (13). USA, Arizona, Cochise Co., Fairbank (10), 6 (FMNH); Pima Co., vic. of Tucson (10), 6 (CSULB); Santa Cruz Co., Pena Blanca Lake (10), 1 (CSULB).

Sigmodon arizonae major. Specimens examined (5). Mexico, Nayarit (12), 3 (CSULB); 1 (LACM); Sinaloa (12), 1 (CSULB).

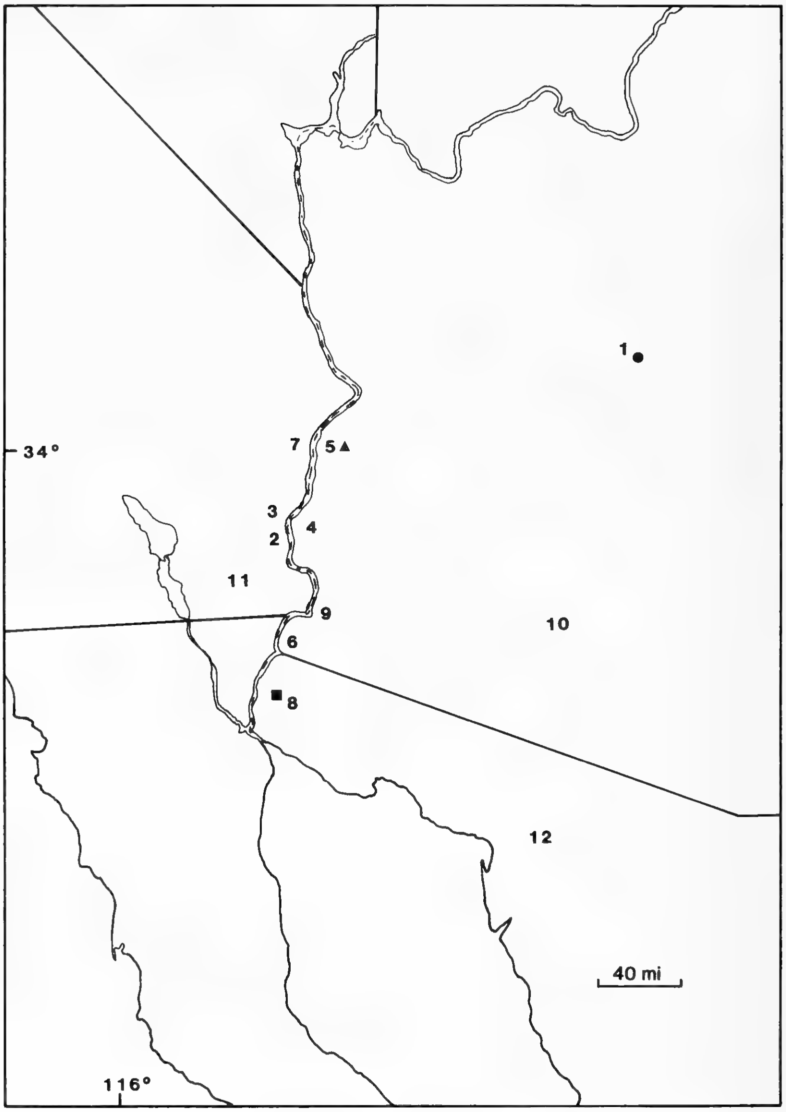

Fig. 1. Locality codes used in the quantitative analyses. The closed circle is the type locality for *S. arizonae arizonae,* the closed triangle is the type locality for *S. arizonae plenus,* and the closed square is the type locality for *S. hispidus eremicus.* Forty miles is equal to approximately 65 kilometers.

Sigmodon arizonae plenus. Specimens examined (46). USA, Arizona, Yuma Co., vic. of Ehrenberg (4), 1 (CSULB); 2 (UA); 9 (UIMNH); 1 (USNM); vic. of Parker (5), 14 (UIMNH); California, Imperial Co., Palo Verde (2), 1 (CSULB); 2 (LACM); Riverside Co. only (3), 1 (CSULB); 4 (LACM); 2 (USNM); San Bernardino Co. only (7), 8 (CSULB); 1 (USNM).

Results

Qualitative analysis divided specimens into two groups. One group of individuals was from the Colorado River south of the Palo Verde Mountains and the

Table 1. Descriptive statistics, sexes combined, for *Sigmodon arizonae* and *Sigmodon hispidus*. Means and Standard Error of the Mean (S.E.) reported. All measurements are in mm.

	S. arizonae		*S. hispidus*	
Variable	Mean N = 72	S.E.	Mean N = 118	S.E.
Diameter of foramen ovale	0.98	0.04	0.76	0.02
Lambdoidal breadth	6.40	0.08	5.70	0.05
Condylobasilar length	33.60	0.29	31.60	0.21
Greatest length of skull	34.70	0.29	32.90	0.21
Interorbital breadth	5.20	0.04	4.70	0.02
Breadth of braincase	14.50	0.05	13.90	0.04
Length of maxillary toothrow	6.20	0.08	5.90	0.05
Length of diastema	8.90	0.12	8.30	0.09
Length of palate	6.90	0.03	6.50	0.03
Length of nasals	7.10	0.08	6.60	0.06
Length of incisive foramen	13.20	0.14	12.50	0.10
Depth of skull	12.40	0.07	12.50	0.04
Breadth of rostrum	5.00	0.03	4.50	0.02
Distance between temporal and occipital ridges	3.40	0.05	2.50	0.05
Length of temporal ridge	5.70	0.08	4.80	0.06
Breadth of zygomata	20.40	0.10	19.30	0.10
Length of rostrum	11.70	0.12	11.00	0.09
Diameter of lower third molar	1.80	0.01	1.70	0.01
Breadth of mesoptyergoid fossa	1.30	0.03	1.30	0.02
Total length	151.00	2.50	141.30	1.80
Tail length	118.00	2.00	107.90	1.30
Hind foot length	34.30	0.32	31.40	0.21
Ear length	19.70	0.16	17.90	0.19

Imperial Valley (localities 6, 8, 9, and 11). This first group displayed characteristics of *S. hispidus.* The second group consisted of specimens from the Colorado River north of the Palo Verde Mountains (localities 1, 2, 3, 4, 5, 7, 10, and 12). This second group displayed characteristics of *S. arizonae.* No simple qualitative character was consistently useful in separating specimens. However used in combination, the four were 100% effective in separating specimens *S. hispidus* from *S. arizonae.*

Mean values for each variable of each species are listed in Table 1. A *t*-test (BMDP-3D) reported that the two species were significantly different at or beyond the .05 level for each variable. Hotelling's T-square test (BMDP-3D) resulted in an overall significant difference between the species beyond the .05 level.

Ward's analysis of the twelve localities resulted in several distinct clusters (Fig. 2). Based upon the qualitative comparisons, one set of clustered localities represents *S. arizonae* (localities 1, 2, 3, 4, 5, 7, 10, 12). The second group of clusters comprised specimens referable to *S. hispidus* (localities 6, 8, 9, 11). The species level clusters were separated from each other by nearly seven standard deviation units.

Discriminant function analysis demonstrated palatilar length, diameter of the foramen ovale, interorbital breadth, and breadth of rostrum discriminate best between the species (Tables 1 and 2). These characters correctly identified 95.5% of the individuals to their respective species.

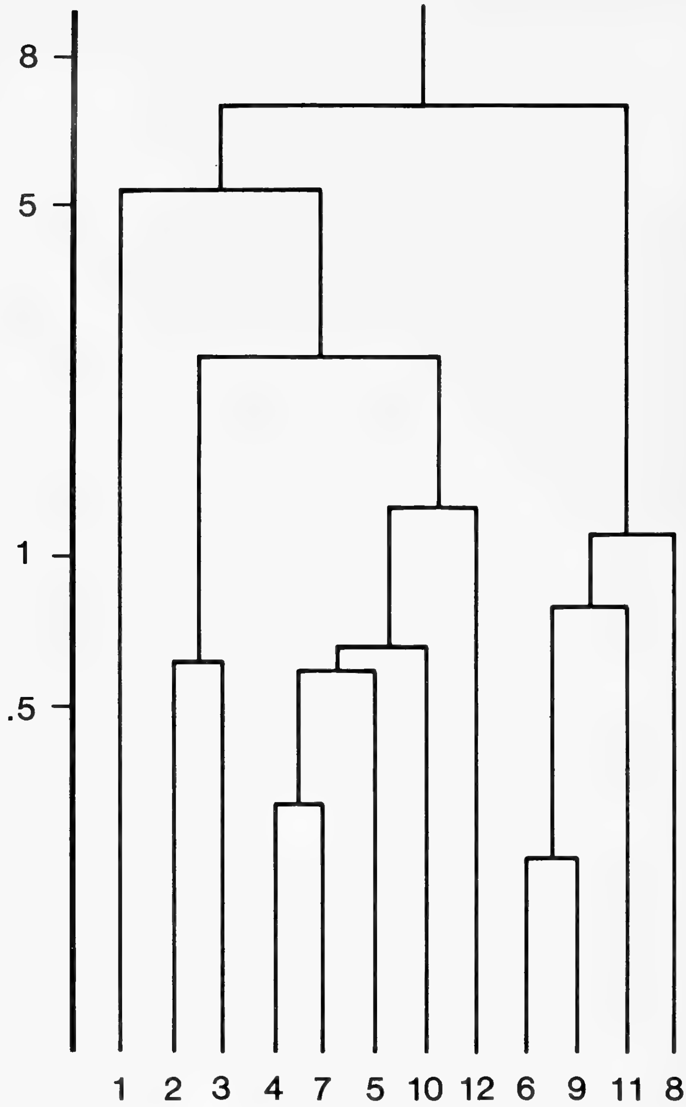

Fig. 2. Ward's Cluster Analysis. The scale represents twice the increase in the error sum of squares caused by the fusion of the groups at that level. The total error sum of squares for any grouping is obtained by adding all the preceding error values up to the grouping level of interest and then dividing by two (Wishart 1979).

Karyotypes revealed that two chromosomal forms of *Sigmodon* occur in California. Populations from north of the Palo Verde mountains (approximately 55 kilometers north of Blythe) possess a 2N of 24 and were morphometrically grouped with those identified as *S. arizonae.* This karyotype appears identical to that reported by Zimmerman (1970) for *S. arizonae* from the vicinity of Parker, Arizona. Elsewhere in its range, *S. arizonae* has a diploid number of 22 (Zimmerman 1970). Cotton rats examined from the vicinity of Holtville (Imperial Valley) and Bard (southern Colorado River) had a 2N of 52, the diploid number

Table 2. Eigenvalues and canonical coefficients of the ten best discriminators from a discriminant function analysis of *S. arizonae* and *S. hispidus.*

Eigenvalue
2.864
Cumulative proportion of total dispersion
100%

Variable	Canonical coefficient
Length of palate	−1.433
Diameter of foramen ovale	−1.346
Breadth of rostrum	−1.177
Interorbital breadth	−1.172
Depth of skull	−1.123
Greatest length of skull	0.828
Distance between occipital and temporal ridges	−0.607
Breadth of zygomata	−0.526
Length of temporal ridge	−0.492
Total length	0.030

reported by Zimmerman (1970) for *S. hispidus.* These specimens grouped with cotton rats identified as *S. hispidus* in the morphometric analysis.

Discussion

Cotton rats in California are represented by three disjunct populations of two species: *Sigmodon arizonae* and *Sigmodon hispidus.* Grinnell (1914) first reported cotton rats along the lower Colorado River Valley. The presence of *Sigmodon* near the Imperial Valley was first reported by Mearns (1907) at Seven Well, California, located along the Alamo River approximately mid-way between the Colorado River delta and the Imperial Valley. The presence of a well established population of *S. hispidus* in the Imperial Valley was reported by Dixon (1922). Later, Clark (1972) reported on crop damage from cotton rats in the Imperial Valley. However, recent summaries of California mammals (Burt and Grossenheider 1976; Hall 1982; Ingles 1965; Jameson and Peeters 1988) have followed Grinnell (1914, 1933) and listed *Sigmodon* as occurring only along the Colorado River.

The two species of *Sigmodon* in California can be distinguished karyologically or morphologically; however, the results of this study agree with the conclusions of Zimmerman (1970) and Hoffmeister (1986) that only a combination of characteristics can be used to correctly separate *S. hispidus* from *S. arizonae* in the absence of chromosome data. In California, however, locality is a good first estimate of species affinity, because the two species are allopatric.

Cotton rats in California represent isolated pockets of their respective species. Zimmerman (1970) reported that extensive collecting between Parker, Arizona and the nearest known population of *S. arizonae* at Prescott, Arizona yielded no cotton rats. The California population of *S. arizonae* is probably a result of colonization by members of the Parker-Ehrenberg populations, because both the Parker and Blythe populations of *S. arizonae* possess the unique karyotype of $2N = 24$.

The Wisconsin glaciation isolated the Yuma population of *S. hispidus* (Zimmerman 1970), and this population is separated from its conspecifics by several hundred kilometers of desert and intervening populations of *S. arizonae.* Imperial Valley *S. hispidus* appear to be isolated from the Yuma population. However, there are possible routes of contact along canals and rivers which run from the Colorado River delta into the Imperial Valley. These possible invasion routes may have been used by *S. hispidus* either early in the twentieth century or after the Wisconsin glaciation. Another possible explanation for the Imperial Valley population is that it is relictual. Cotton rats are common Pleistocene fossils in Southern California (Martin and Prince 1989).

In conclusion, the Imperial Valley cotton rat population shares specific morphometric and karyologic characteristics with the southern Colorado River cotton rat population and should be considered *Sigmodon hispidus eremicus.* Cotton rats from the Colorado River north of the Palo Verde Mountains represent the taxon *Sigmodon arizonae plenus* (Hall 1982; Zimmerman 1970).

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Literature Cited

Burt, W. H., and R. P. Grossenheider. 1976. A field guide to the mammals (3^{rd} ed.). Houghton Mifflin Co., Boston.

Cameron, G. N., and S. R. Spencer. 1981. *Sigmodon hispidus.* Mammal. Species No. 158.

Chipman, R. K. 1965. Age determination of the cotton rat (*Sigmodon hispidus*). Tulane Stud. Zool., 12:19–38.

Clark, D. O. 1972. The extending of cotton rat range in California—their life history and control. Proc. Fifth Vertebr. Pest Conf., 7–14.

Dixon, J. 1922. Rodents and reclamation in the Imperial Valley. J. Mammal., 3:136–144.

Dixon, W. J., and M. D. Brown, eds. 1977. Biomedical computer programs P series. University of California Press, Berkeley.

Green, A., and D. L. Jameson. 1975. An evaluation of the zygomatic arch for separating juvenile from adult cotton rats (*Sigmodon hispidus*). J. Mammal., 56:534–535.

Grinnell, J. 1914. An account of the mammals and birds of the lower Colorado River Valley. Univ. Calif. Publ. Zool., 12:51–294.

———. 1933. Review of the recent fauna of California. Univ. Calif. Publ. Zool., 40:7–234.

Hall, E. R. 1982. Mammals of North America, vol. 2. John Wiley and Sons, New York.

Hoffmeister, D. F. 1986. The mammals of Arizona. University of Arizona Press, 601 pp.

Hooper, E. T. 1952. A systematic review of the harvest mice (genus *Reithrodontomys*) of Latin America. Misc. Publ. Mus. Zool. Mich., No. 77:1–255.

Ingles, L. G. 1965. Mammals of the Pacific states. Stanford University Press, Stanford, Ca.

Jameson, E. W., Jr., and H. J. Peeters. 1988. California mammals. Univ. of California Press, Berkeley, 403 pp.

Martin, R. A., and R. H. Prince. 1989. A new species of early Pleistocene cotton rat from the Anza-Borrego Desert of Southern California. Bull. So. Calif. Acad. Sci., 88(2):80–87.

Mearns, E. A. 1907. Mammals of the Mexican boundary of the United States. Bull. No. 56. U.S. Nat. Mus., 1–520.

Patton, J. L. 1967. Chromosome studies of certain pocket mice genus *Perognathus* (Rodentia: Heteromyidae). J. Mammal., 48:27–37.

Severinghaus, W., and D. F. Hoffmeister. 1978. Qualitative cranial characters distinguishing *Sigmodon hispidus* and *Sigmodon arizonae* and the distribution of these two species in northern Mexico. J. Mammal., 59:868–870.

Ward, J. 1963. Hierarchical grouping to optimize an objective function. Am. Stat. Assoc. Jour., 58: 236–244.

Wishart, D. 1979. Clustan 1C user manual release 2. California State University and Colleges, Long Beach, Calif.

Zimmerman, E. G. 1970. Karyology, systematics and chromosomal evolution in the rodent genus, *Sigmodon.* Publ. Mus. Mich. State Univ. Biol. Ser., 4:389–454.

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Bull. Southern California Acad. Sci.
89(2), 1990, pp. 94–96

Research Note

A New Host in the Northern Hemisphere for the Parasitic Marine Isopod *Ceratothoa gaudichaudii* (Crustacea: Isopoda: Cymothoidae)

The cymothoid isopod *Ceratothoa gaudichaudii* (Milne-Edwards) is a large (12–55 mm, Brusca 1981) ectoparasite of marine fishes. Males are usually found in the gill chamber of the host fish, while females are found in the buccal cavity (Brusca 1981). Adults are obligate symbionts and lack directed swimming ability (Brusca 1981). Individuals, like most cymothoids, are protandrous hermaphrodites (Bullar 1876; Brusca 1981).

Ceratothoa gaudichaudii has an extensive eastern Pacific distribution, ranging from southern California to Cape Horn and around to southern Patagonia (Brusca 1981). Thus, *C. gaudichaudii* can be considered a member of both warm and cold water marine ecosystems. It is unique among the cymothoids in that it ranges south into the cold Magellan province (of Briggs 1974; Brusca 1981). Numerous hosts are known for *C. gaudichaudii,* with most of them being pelagic schooling species (Table 1). Three *Ceratothoa gaudichaudii* were obtained from a Pacific mackerel, *Scomber japonicus* (approximately 50 cm standard length), caught October 23, 1988, off Santa Catalina Island, California, 1 km east of Blue Cavern Cove (33°27′N, 118°29′W). This is the first record of *C. gaudichaudii* parasitizing *S. japonicus* as a host in the Northern Hemisphere (although several records exist for the Southern Hemisphere). The three parasites were captured when they exited the buccal cavity of the fish after the fish had been out of the water for a few minutes. Of the three parasites captured, one was a large female (length = 35.8 mm) and two were males (lengths = 17.4 and 8.9 mm). These individuals were identified and sexed following Brusca (1981). The large female was ovigerous and released most of her eggs from the marsupium upon preservation. A count of these released eggs plus the eggs still remaining within the marsupium revealed that she was carrying 834 eggs, well within the 200–1600 egg range described by Brusca (1981) for other cymothoid species. This is the first egg count reported for *C. gaudichaudii.* These specimens and eggs have been deposited in the collection of the Natural History Museum of Los Angeles County (LACM 88-198.1).

The tongue of the host fish was examined and found to be atrophied. This condition was probably caused by blood-feeding by the large female (Romestand and Trilles 1977). This host–parasite interaction may have been an example of “tongue replacement,” a phenomenon first observed by Brusca and Gilligan (1983) in the snapper *Lutjanus guttatus,* caused by the cymothoid isopod *Cymothoa exigua.* However, the study of additional specimens and a functional analysis of this interaction is in order. The external appearance of the host *S. japonicus* was also examined and found to be greatly deteriorated from that of a normal Pacific mackerel. The normally dark blue dorsal surface was faded and brownish in appearance. White patches that appeared to be fungal growth were also present

Table 1. Host species records for the cymothoid isopod *Ceratothoa gaudichaudii*.

Region	Family	Genus-species	Reference*
California	Mugilidae	*Mugil cephalus*	1
	Kyphosidae	*Hermosilla azurea*	2
	Scombridae	*Scomber japonicus*	3
Baja California	Carangidae	*Trachinotus* sp.	1
	Clupeidae	*Etrumeus teres*	1
Mexico	Exocoetidae	*Cypselurus* sp.	LACM 751-1
Peru	Stromateidae	*Peprilus medius*	1
	Carangidae	*Neptomenus crassus*	1
		Trachurus symmetricus	1
	Scombridae	*Sarda chiliensis*	1
Chile	Scombridae	*Scomber japonicus*	1
		Sarda chiliensis	1
		Gasterochisma melanopus	1
	Carangidae	*Decapterus* sp.	1
		Trachurus sp.	1
	Centrolophidae	*Seriolella violacea*	LACM 1696-01

* 1 = Brusca (1981), 2 = R. Brusca (pers. comm.), 3 = present study.

on both sides of the fish. The deterioration of the body was possibly caused by multiple parasitic infestations (Brusca 1981). The fish may have become more susceptible to disease due to blood-feeding (Romestand and Trilles 1977). Another possible cause of the deterioration of the fish is that the large size of the female isopod hindered the ability of the fish to feed effectively by taking up too much space in the buccal cavity.

The finding that *Ceratothoa gaudichaudii* utilizes *Scomber japonicus* as a host in the Northern Hemisphere indicates that this parasite may have the potential to range much further north than is now thought. *Scomber japonicus* ranges in the Northern Hemisphere from Alaska to Mexico and is most abundant between Monterey Bay and southern Baja California (Eschmeyer et al. 1983). Seasonal migrations of Pacific mackerel are often very extended, with the fish in the Northern Hemisphere moving further northward with increased summer temperatures and southwards for overwintering and spawning (Collette and Nauen 1983). This migratory behavior in its host indicates that *C. gaudichaudii* has the host potential to range at least as far north as Monterey Bay and perhaps even further north. The isopod is able to tolerate cold waters; it has been recorded near the southern tip of South America, in waters off of Patagonia. Detailed examination of central and northern California populations of *Scomber japonicus* may determine whether *Ceratothoa gaudichaudii* ranges further north than southern California.

Acknowledgments

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Literature Cited

Briggs, J. C. 1974. Marine zoogeography. McGraw-Hill, New York, x + 475 pp.

Brusca, R. C. 1981. A monograph on the Isopoda Cymothoidae (Crustacea) of the eastern Pacific. Zoological Journal of the Linnean Society, 73:117–199.

———, and M. R. Gilligan. 1983. Tongue replacement in a marine fish (*Lutjanus guttatus*) by a parasitic isopod (Crustacea: Isopoda). Copeia, 1983:813–816.

Bullar, J. F. 1876. The generative organs of the parasitic Isopoda. Journal of Anatomy and Physiology, 11:118–128.

Collette, B. B., and C. E. Nauen. 1983. Scombrids of the world: an annotated and illustrated catalogue of tunas, mackerels, bonitos, and related species known to date. FAO Fisheries Synopsis No. 125, vol. 2.

Eschmeyer, W. N., E. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Company, Boston, xii + 336 pp.

Romestand, M. B., and J. P. Trilles. 1977. Influence des Cymothoiadiens (Crustacea, Isopoda, Flabellifera) sur certaines constantes hématologiques des poissons hôtes. Zeitschrift für Parasitenkunde, 52:91–95.

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Brattstrom, B. H. 1969. The Condor in California. Pp. 369–382 *in* Vertebrates of California. (S. E. Payne, ed.), Univ. California Press, xii + 635 pp.

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COVER: Disposal of municipal wastes at the Brea-Olinda landfill, Orange County. Photo by Donald B. Bright, p. 49.