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ASSESSMENT OF IMPACTS AND EVALUATION OF RESTORATION METHODS ON AREAS AFFECTED BY A WELL BLOWOUT, NAVAL PETROLEUM RESERVE NO. 1, CALIFORNIA

December 1996

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Naval Petroleum Reserves in California
P.O. Box 178, Tupman, California 93276

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ABSTRACT

In June 1994, an oil well on Naval Petroleum Reserve No. 1 blew-out and crude oil was deposited downwind. After the well was capped, information was collected to characterize the release and to assess effects to wildlife and plants. Oil residue was found up to 13.7 km from the well site, but deposition was relatively light and the oil quickly dried to form a thin crust on the soil surface. During initial surveys of the affected area, two dead darkling beetles (*Eleodes* spp.) were found, but there was no other direct evidence of mortality due to oiling. Elevated levels of hydrocarbons were found in livers collected from Heermann's kangaroo rats (*Dipodomys heermanni*) from the oiled area but polycyclic aromatic hydrocarbons (known carcinogens or mutagens) were not detected in the livers. Restoration techniques (surface modification and bioremediation) and natural recovery were evaluated within three portions of the oiled area. Two trapping grids were established at each oiled site and at a control site to monitor abundance of rodents and invertebrates. Herbaceous cover and production, and survival and vigor of desert saltbush (*Atriplex polycarpa*) were also monitored within each trapping grid. Rodent species diversity was similar at trapping grids and all sites were dominated by Heermann's kangaroo rats. During 1994, population estimates of Heermann's kangaroo rats were significantly higher on control grids than on oiled grids during 67% of the comparisons. During 1995, there were few differences in population estimates of Heermann's kangaroo rats between sites. The average number of darkling beetles seen per grid was higher on control sites than on some oiled sites in October and November of 1994, but afterwards there were no significant differences in abundance. The number of trapsites with ants (Family Formicidae) was never significantly different between sites. In April 1995, herbaceous cover and production were highest on one bioremediation grid, but there were no other differences between sites. Shrub survival between October/November 1994 and June 1995 was 100% on all sites. Shrub vigor was highest on control sites in October/November 1994. In June 1995, shrub vigor was not significantly different between control, surface modification, and natural recovery grids, but shrub vigor tended to be lowest on bioremediation grids. Results indicated that plant and animal populations within the oiled area recovered within one year and that natural recovery may be the most appropriate "restoration" option for similar releases of crude oil.

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1. INTRODUCTION

Well 313H-26R, located near the center of Naval Petroleum Reserve No. 1 (NPR-1), blew-out Tuesday morning, 21 June 1994 and the resulting spray of crude oil was deposited south of the well site. By Tuesday afternoon, the flow of oil had decreased substantially as a result of control actions. The well was capped on 26 June 1994, and site evaluations of injury to natural resources were initiated on 27 June 1994. A map of the affected area was developed using information collected during road surveys and from color aerial photographs taken on 30 June 1994 (Figure 1). Some light oil spray was deposited as far as 13.7 km south of well 313H-26R. However, the most heavily affected area was within 0.8 km of the well and approximately 24 ha in size.

Although well blowouts are rare, these events have the potential to contaminate large areas (Odu, 1972; Freedman, 1989). For example, oil released during a blowout in Nigeria contaminated approximately 607 hectares, much of which was farmland (Odu, 1972). Despite the seriousness of a well blowout, there are few guidelines for rehabilitating areas affected by these types of releases. Techniques for remediating releases of crude oil were developed primarily for marine and freshwater environments or very localized spills. The blowout of well 313H-26R affected a large area and this provided an opportunity to develop and evaluate methods for restoring large areas of land that have been sprayed with crude oil.

In August 1994, an assessment, remediation, restoration, and monitoring plan was completed (Kato et al., 1994). The plan included methods of assessing impacts, and specific plans for restoring oil-affected areas and monitoring the effects of restoration treatments. This report summarizes the results of these studies.

The specific objectives of this report are to summarize information concerning: (1) the severity of the release, (2) impacts to biota, including threatened or endangered species, (3) recovery of plant and animal populations within the affected areas, and to (4) evaluate restoration methods designed to accelerate the recovery of the impacted area.

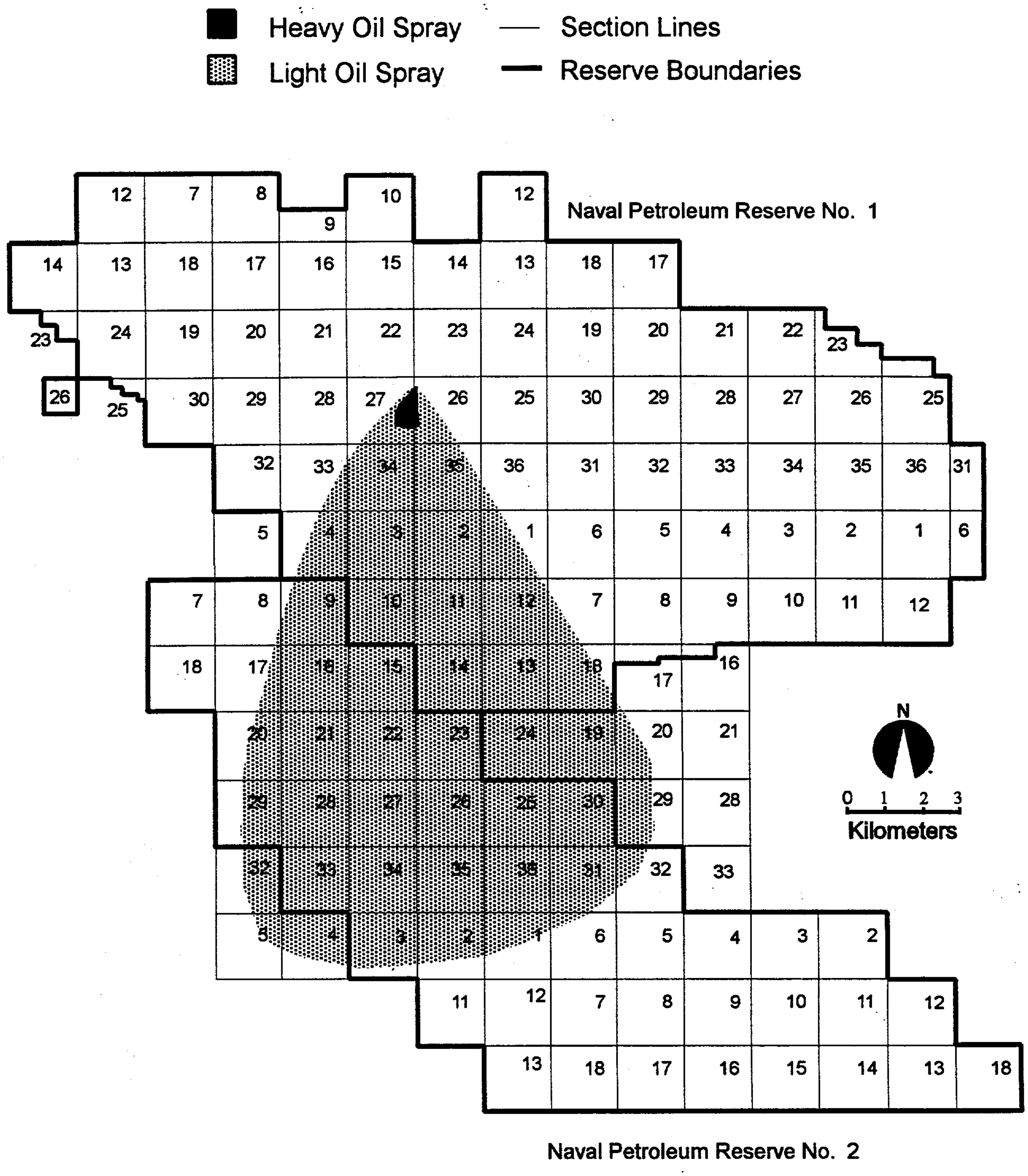

Figure 1. Approximate area sprayed with crude oil during the blowout of well 313H-26R, Naval Petroleum Reserves in California, June 1994.

2. STUDY AREA

NPR-1 encompasses approximately 19,120 ha and is located approximately 42 km southwest of Bakersfield, California. Topography varies from moderately steep slopes near the center of the reserve to relatively flat terrain near the northern and southern boundaries. Elevations range from 88 to 473 m. Annual weather patterns consist of hot, dry summers and mild, humid winters (National Oceanic and Atmospheric Administration, 1995). Weather data recorded in Bakersfield indicate that average daily maximum temperatures range from 37° C in July to 14 ° C in January and average daily minimum temperatures range from 4 ° C in December to 21 ° C in July. Precipitation averages 15 cm annually and most precipitation (90%) falls between October and April.

NPR-1 lies within the Valley Grassland vegetation type (Heady, 1977). Herbaceous vegetation is dominated by red brome (*Bromus madritensis rubens*) and red-stemmed filaree (*Erodium cicutarium*). The most common shrub species is desert saltbush (*Atriplex polycarpa*) but other locally common species include cheesebush (*Hymenoclea salsola*), bladderpod (*Isomeris arborea*), spiny saltbush (*Atriplex spinifera*), and matchweed (*Gutierrezia californica*).

Soils in the uplands are well drained sandy loams of varying thickness and are classified as Elk Hills and Torriorthent series (U. S. Department of Agriculture, 1986). Soils in the flat terrain near the perimeter of NPR-1 are very deep, well drained, alluvial sandy loams and are classified as Cajon and Kimberlina series.

The major land use at NPR-1 is facility development and operational activities related to oil and gas production. Drilling and petroleum production began in the early 1900s. The Naval Petroleum Reserves Production Act of 1976 directed the Department of Energy to develop and produce petroleum resources at the maximum efficient rate consistent with sound engineering practices. Since then, oil field development on NPR-1 increased substantially.

3. METHODS

The severity of the release was assessed during field observations and by determining total petroleum hydrocarbon (TPH) concentrations of soil samples obtained within oiled areas. A soil sample was collected at a given site by scraping off the upper 0.6 cm of soil and placing it in a clean glass jar. A chain of custody sheet was filled out for each soil sample. The samples were analyzed for TPH using the Environmental Protection Agency (EPA) 418.1 method (Zalco Laboratory; Bakersfield, California). Initial soil samples were taken at oiled sites located 0.5, 1.3, and 2.3 km south of well 313H-26R and a control site 0.3 km north of the well in June 1994 (Figure 2a). Additional soil samples were collected on 15 September 1994 to more precisely determine TPH levels and to evaluate degradation of TPH through time. Nine samples were collected at eight points starting 0.5 km south of well 313H-26R and running south for 1.2 km (Figure 2a). Fifteen soil samples were also collected on 2 March 1995 along a line roughly parallel to the line of samples taken in September 1994 and at a control site (Figure 2b). Three samples taken in March 1995 were offset to the west of the September samples to avoid an area contaminated with crude oil that escaped from a tank setting vent stack in January 1995. Details of this oil release are given in Section 4.1. On 28 September 1995, additional samples were taken within each trapping grid (Figure 2b) located in the heavily oiled area.

Direct effects of the released oil on plants and animals were assessed during transect surveys and during other work activities in and near the affected area. When access to the blowout area was permitted, nine biologists walked transects spaced 40 m apart in the most heavily affected areas (within 0.8 km of well 313H-26R). Any observations of dead and living animals, amount of oil, or evidence of threatened or endangered species were recorded and mapped during surveys.

On 8 July 1994, Heermann's kangaroo rats (*Dipodomys heermanni*) were collected from a heavily oiled area, a lightly oiled area, and a control area (Figure 2c) to determine if they had ingested crude oil hydrocarbons. The heavily oiled area was approximately 0.5 km south of well 313H-26R, the lightly oiled site was approximately 1.9 km south of the well, and the control site was located approximately 0.3 km northeast of the well.

Twenty-five trapping stations each consisting of two live traps placed under a metal tent for protection from the sun, wind, and rain were established on each of the three areas. Traps were baited with seeds and a peanut butter-oatmeal mixture and were operated for one night. Three male Heermann's kangaroo rats were collected from each of the three sites the following morning. The collected kangaroo rats were killed by cervical dislocation and their livers were removed, placed in clean glass vials, and frozen. To assure an adequate quantity of tissue for analyses, the three liver samples for a given site were combined into one composite sample. Stomachs were also removed and their contents were visually inspected for oil residue using a dissecting microscope. Liver samples were sent to a laboratory (Global Geochemistry Corporation (GGC); Canoga Park, California) to characterize crude oil hydrocarbons found in the tissues.

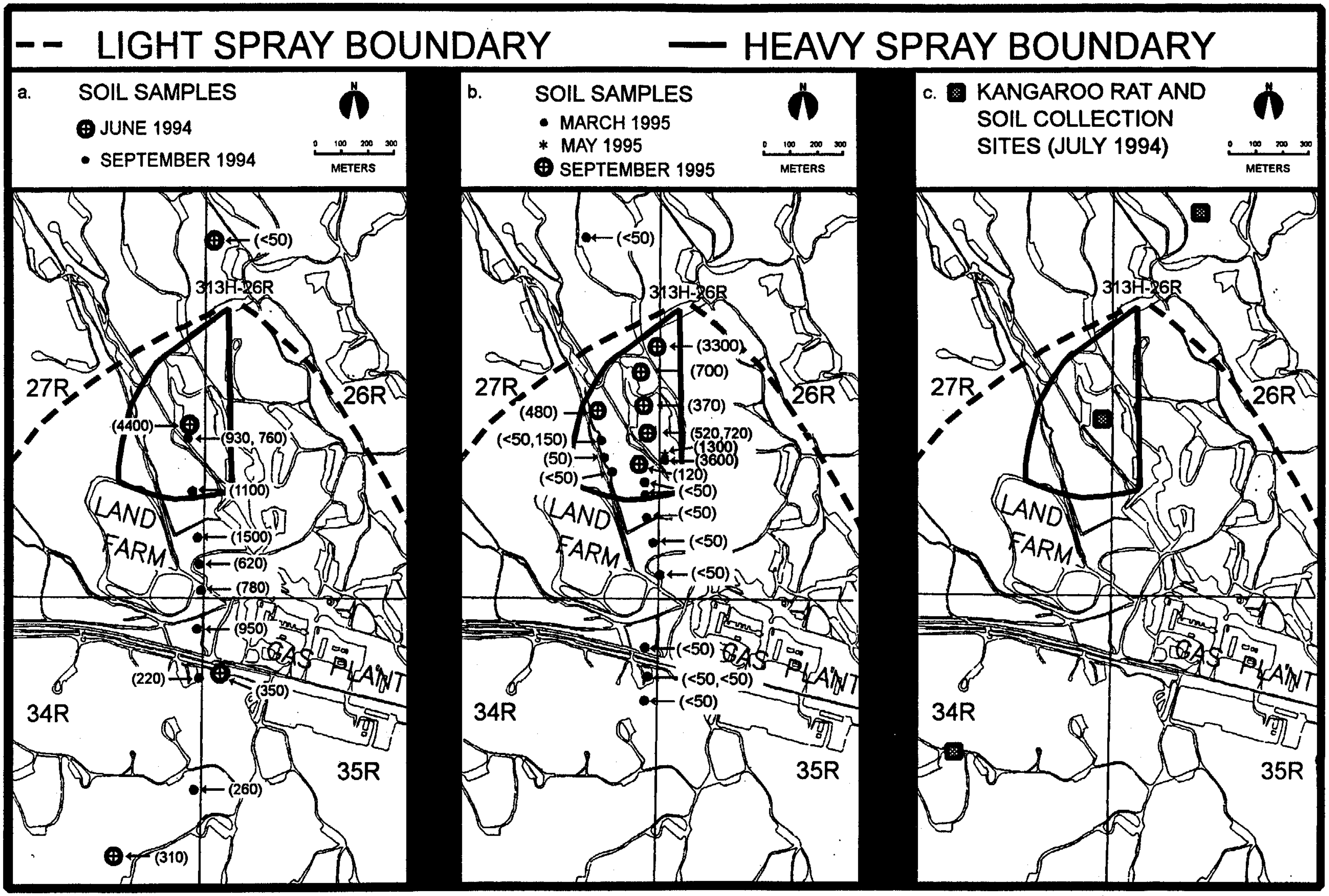

Figure 2. Kangaroo rat and soil collection sites established within areas affected by oil spray from well 313H-26R and control sites, Naval Petroleum Reserve No. 1, California. Numbers in parentheses are levels of total petroleum hydrocarbons in parts per million. Commas between numbers indicate that more than one sample was taken at the site.

To determine if hydrocarbons found in kangaroo rat livers matched hydrocarbons present in oil released during the blowout, crude oil and soil samples were also collected for analysis. One soil sample was collected at the surface (upper 0.6 cm of soil) at each of the three trapping sites. After the soil on the surface was removed, a sub-surface sample was collected at a depth of 0.6 to 5 cm below the surface. A crude oil sample was collected from a nearby well (312A-26R) that was extracting oil from the same geologic formation as well 313H-26R. Crude oil and soil samples were placed in glass jars and frozen until they were submitted to GGC for analyses. A chain of custody sheet was prepared for the samples submitted to GGC.

At the laboratory, petroleum hydrocarbons found in crude oil and soil samples and kangaroo rat livers were analyzed by a gas chromatograph mass spectrometer (GCMS). Results from the GCMS were used to characterize hydrocarbons found in samples and to compare these results between sites. Kaplan et al. (1996) provides a more thorough description of methods used for hydrocarbon characterization.

The most heavily oiled area was divided into three portions ranging in size from 5-9 ha (Figure 3). In October 1994, the restoration techniques of surface modification and bioremediation were implemented on two sites. Surface modification consisted of lightly scarifying the soil surface by dragging chain-link fence material or metal grating behind a light-weight tractor. Bioremediation included scarifying the soil surface and applying a slow-release granular [1]fertilizer designed to stimulate the action of soil microbes that degrade crude oil. No treatment occurred on the third site so that natural recovery of plant and animal communities could be monitored. In addition, a site was established 0.5 km northwest of well 313H-26R in an unaffected (control) area.

In October 1994, (prior to the restoration treatments) two 7 X 7 trapping grids (10-m spacing) were placed within each of the four sites to monitor small mammal and invertebrate abundance (Figure 3). One grid was placed in a drainage and one grid was placed on a hillside with a northeastern aspect. Each of the 49 stations per grid contained one Sherman non-folding live trap placed under a metal tent. Traps were baited and operated for three consecutive nights. Each captured rodent was eartagged, weighed, and sexed before release at its capture site. Population size of Heermann's kangaroo rats at each grid was determined using the jackknife estimator of program CAPTURE. The jackknife estimator was used because it is robust to variation in capture probabilities (Otis et al., 1978).

Shannon diversity indices (Zar, 1984) were determined by trapping session for small mammal species captured at each grid. A t-test was used to determine if diversity of small mammal species differed between trapping grids each session.

Max Bac; #CB 94-204; 23% nitrogen, 2% phosphorus, 8% potassium; 6-7 month formulation @ 21.1 °C. Horner and Company, Mayne Island, BC, Canada.

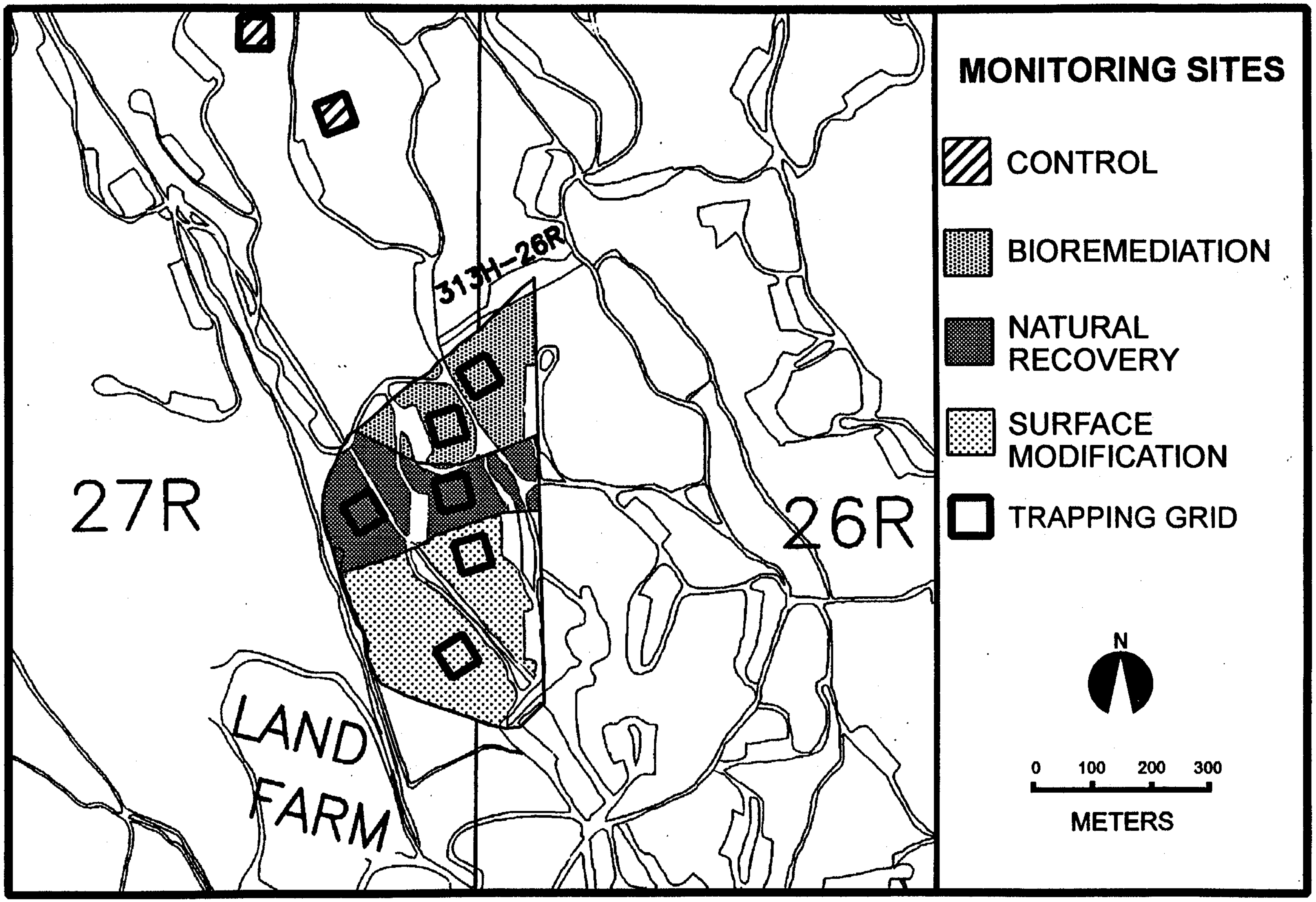

Figure 3. Sites established to monitor restoration treatments and natural recovery of an area oiled during the blowout of well 313H-26R and an adjacent control site, Naval Petroleum Reserve No. 1, California.

Ground dwelling invertebrates were also monitored during small mammal trapping sessions. Darkling beetles (*Eleodes spp.*) and ants (Formicidae) are common invertebrate species at NPR-1 and they are attracted to bait used for trapping rodents. Therefore, trapping sessions also provided an opportunity to index the abundance of these species. Number of darkling beetles observed and presence or absence of ants within a 1-m radius of each trap was recorded each time a trap was checked. The average number of trapsites with ants per grid each day and the average number of beetles observed per grid each day were used to compare abundance of these invertebrate species between the study sites. Surveys for birds and reptiles were also conducted during trapping sessions for small mammals. The number and species of reptiles seen were recorded while baiting traps. Species of birds seen on grids were recorded when traps were baited and checked.

Six 70-m vegetation transects were established between rows of each trapping grid. Herbaceous production was estimated by harvesting, drying, and weighing all grass and forb plants within six 1/4 m^2 plots spaced at 10-m intervals along each transect. Herbaceous plant cover was estimated by determining the intercept of 100 points along each transect using an ocular point projection device. Points were recorded as intercepting either vegetation (by species), litter, or bare ground.

Saltbush survival was determined by randomly selecting and marking 25 living desert saltbush (*Atriplex polycarpa*) plants within or near each grid in October/November 1994 and revisiting these plants in June 1995. Saltbush vigor was determined by photographing shrubs from above and later projecting the images onto a grid. The number of grid intersections that intercepted green foliage was divided by the total number of grid intersections that intercepted the shrub to obtain an index of vigor.

A *z*-test was used to test for differences in population estimates of kangaroo rats. A Kruskal-Wallis test and Tukey-type multiple comparison test was used to test for differences between grids in number of beetles seen per day, average number of trapsites with ants per day, and average herbaceous production and cover. Differences in shrub vigor were determined using analysis of variance and a Tukey multiple comparison test.

The federally endangered San Joaquin kit fox (*Vulpes macrotis mutica*), blunt-nosed leopard lizard (*Gambelia silus*), giant kangaroo rat (*Dipodomys ingens*), and the threatened Hoover's wooly-star (*Eriastrum hooveri*) occur on NPR-1 and may have been affected by oil released during the blowout. Transects were walked immediately after access to the site was granted to determine if threatened and endangered species were present within the heavily oiled area and to identify any occurrences of incidental take. Data (capture locations and observations) from previous studies of federally threatened and endangered species were used to determine overlap of these species' ranges with the area affected by the released oil. The state threatened San Joaquin antelope squirrel (*Ammospermophilus nelsoni*) is found throughout NPR-1 and its range was thought to overlap most or all of the affected area.

4. RESULTS

4.1 Extent and Severity of the Release

Field observations in June 1994 indicated that even in the most heavily affected area, oil deposition was relatively light and oil did not drip off vegetation or form pools. Saltbush (*Atriplex* spp.) shrubs were lightly coated with oil residue on the windward side and oil was barely noticeable on the leeward side. By 30 June 1994, residue from the oil had formed a dry crust not more than a few millimeters thick on the soil surface even in the most heavily impacted areas.

Soil samples collected on 29 June 1994 indicated that TPH concentrations in soils declined rapidly with distance from well 313H-26R (Figure 2a). Soil samples taken 0.5, 1.3, and 2.3 km south of the blowout site had TPH concentrations of 4400, 350, and 310 parts per million (ppm), respectively. The soil sample collected at the control site 0.3 km north of the well had no detectable TPH (<50 ppm).

Soil samples collected on 15 September 1994 demonstrated that TPH levels had declined considerably since the blowout. Two samples taken 0.5 km from well 313H-26R had TPH concentrations of 930 and 760 ppm. This represents an 80% decline in TPH levels in the first three months after the blowout.

On 5 January 1995, oil was accidentally released from a tank setting's vent stack near the southern boundary of the restoration areas. The spray of crude oil was deposited across much of the original zone of heavy oil spray that resulted from the blowout of well 313H-26R (Figure 4). Approximately 20% of the bioremediation site and 40-60% of the surface modification and natural recovery sites were lightly misted with oil. The most heavily affected area was in the southeast corner of the surface modification site and was about 0.8 ha in size. The amount of oil released from the vent stack was estimated to be approximately eight barrels (159 liters). Within a week of the release, vegetation and shrubs in the lightly affected area appeared green and unaffected by the oil. Because vegetation had already germinated, and affects of this latest release were determined to be minor, no further remediation was attempted. Soil samples were taken in the near-field deposition zone adjacent to the vent stack to monitor degradation of oil during a cool, wet period. TPH levels declined on this area from 3600 ppm in March 1995 to 1300 ppm in May 1995 (Figure 2b).

No petroleum hydrocarbons were detected in soil samples collected outside the heavy spray zone of the blowout of well 313H-26R and in most other samples collected in March 1995 (Figure 2b). TPH levels of soil samples taken in September 1995 (Figure 2b) averaged 884 ppm (range 120-3300 ppm) and levels generally declined with distance from well 313H-26R (Figure 2b). The soil sample from the bioremediation hillside grid has a TPH level of 3300 ppm. Because this sample had a high TPH level, it was retested, but results were similar (2800 and 3000 ppm). Three additional soil samples were collected from the bioremediation hillside grid in March 1996 and the average TPH concentration had dropped to 364 ppm (range 83-580 ppm).

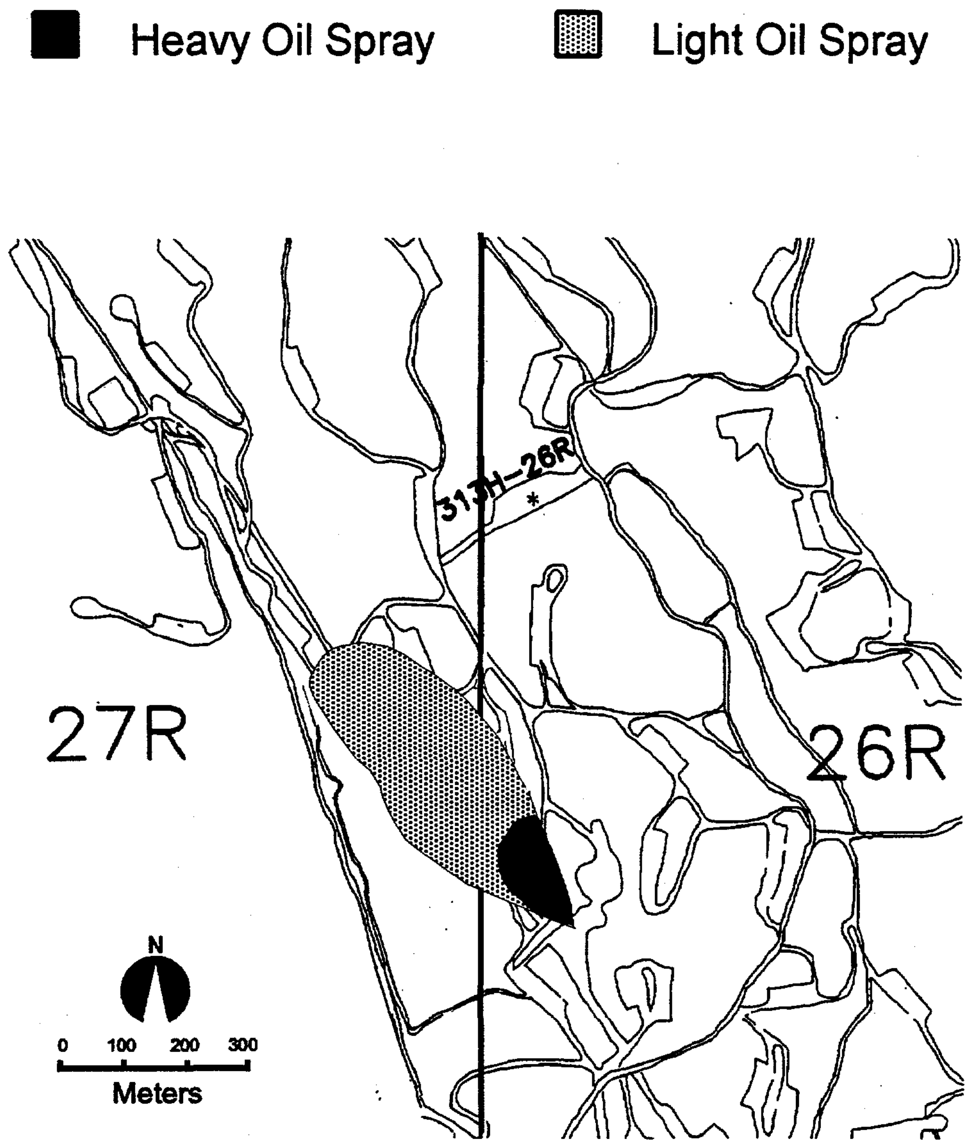

Figure 4. Approximate areas sprayed with crude oil during a release from a vent stack associated with tank setting 3-26R, Naval Petroleum Reserve No. 1, California, January 1995.

In May 1996, three samples were analyzed for TPH to determine if fertilizer used during bioremediation may have interfered with the EPA 418.1 test. Two soil samples were collected from an unaffected area approximately 2 km east/southeast of well 313H-26R and placed in clean glass jars. The fertilizer used during bioremediation was added to one of the soil samples and only fertilizer was placed in a third glass jar. Water was added to both samples that contained fertilizer to dissolve nutrients. Samples were then air dried for approximately three weeks to evaporate the water. All three samples were then tested for TPH levels using EPA method 418.1. The fertilizer sample and the soil/fertilizer sample had TPH levels of 640 ppm and 120 ppm, respectively. No petroleum hydrocarbons were detected in the soil sample without fertilizer.

4.2 Assessment of Direct Mortality

The oiled area south of well 313H-26R was first surveyed on 27 June 1994. Transects were walked through approximately 24 hectares of the most heavily oiled area. The only dead vertebrates found during the surveys were two desiccated rodents. Their condition indicated that they had died before the blowout. Two dead darkling beetles were also found and these may have been killed by the released oil. Many observations of live vertebrates were made during the survey including 42 lagomorphs (desert cottontail, *Sylivilagus audubonii* and black-tailed jackrabbit, *Lepus californicus*) two coveys of California quail (*Lophortyx californicus*), four burrowing owls (*Speotyto cunicularia*), and one barn owl (*Tyto alba*).

There was no evidence of plant mortality in the oil affected areas. In September 1994 it was observed that most oil-coated shrubs had sprouted new growth and some had leaders 10-15 cm in length. Annual herbaceous plants within oiled areas germinated in October and were green and appeared healthy.

4.3 Ingestion of Hydrocarbons by Small Mammals

Three male Heermann's kangaroo rats were collected from a heavily oiled site, a lightly oiled site, and a control site during a trapping session on 8 July 1994 (Figure 2c). Stomach contents of kangaroo rats ranged in color from pale yellow to light brown. There were small black or brown particles which looked like oil residue in the stomach contents from one kangaroo rat from the heavily oiled area. However, stomach contents from two kangaroo rats in the control area also contained similar black particles. Based on visual inspections, there were no clear differences in stomach contents between kangaroo rats from oiled and control sites.

Heterocyclic hydrocarbons belonging to the sterane, terpane and monoaromatic, and triaromatic sterane families were identified in livers from kangaroo rats inhabiting the oiled areas (Table 1). The composite liver sample from the heavily oiled site had approximately two to ten times the concentration of these hydrocarbons as the sample from the lightly oiled area. These hydrocarbons were either found in trace amounts or not detected in the composite liver sample from the control site. C_{25}-C_{35} alkane levels were also significantly higher in tissues collected at the heavily oiled site than at the lightly oiled and control sites. However, these alkanes were not useful in estimating crude oil uptake because they were dominated by naturally occurring hydrocarbons typical of epicuticular plant waxes. There was no significant incorporation of polycyclic aromatic hydrocarbons (PAH) or low molecular weight n-alkanes (C_{13}-C_{25}) in liver tissues from any of the sites (Kaplan et al., 1996).

Table 1. Levels of hydrocarbons (ppm) found in liver samples from kangaroo rats collected from a control site and two sites oiled during the blowout of well 313H-26R, Naval Petroleum Reserve No. 1, California.

Sample	C_{25}-C_{35} Alkanes	Steranes	Terpanes	*MAS	*TAS
Liver (control)	0.52	Trace	Trace	Trace	Not Detected
Liver (lightly oiled area)	1.39	0.39	0.35	0.08	0.11
Liver (heavily oiled area)	2.61	0.86	0.73	0.99	1.01

* MAS = monoaromatic steranes; TAS = triaromatic steranes

Hydrocarbons were extracted from all soil samples, but highest levels were found in surface soil from the heavily oiled site (Table 2). Surface soil from the heavily oiled area had approximately 50 times the concentration of hydrocarbons as the lightly oiled area and 1000 times the concentration of the control site. Sub-surface samples at both oiled sites showed only slight evidence of contamination with crude oil hydrocarbons. Hydrocarbons found in control samples were primarily from plant waxes, but there were very low levels of some petroleum hydrocarbons at this site also. These low-level petroleum hydrocarbons may have come from emissions from diesel vehicles or other oil production activities (Kaplan et al., 1996).

Results indicated that oil from well 312A-26R (same geologic formation as 313H-26R) matched hydrocarbons extracted from soil samples and kangaroo rat livers (Kaplan et al., 1996). Soils collected from heavily and lightly oiled sites were contaminated with crude oil identical to that from well 312A-26R and the distribution of hydrocarbons in crude oil and soils were also very similar to the distribution in kangaroo rat livers.

Table 2. Weight and concentration of extracted hydrocarbons* from soil samples taken at a control site and two sites oiled during the blowout of well 313H-26R, Naval Petroleum Reserve No. 1, California.

Site	Sample Depth	Sample Weight (g)	Weight of Extract (mg)	Concentration of Extract (ppm)
Control	Surface	50.0	0.35	7.0
Control	Sub-surface	50.1	0.24	4.8
Lightly Oiled	Surface	50.3	6.93	138.6
Lightly Oiled	Sub-surface	50.0	0.54	10.8
Heavily Oiled	Surface	50.1	365.80	7300.0
Heavily Oiled	Sub-surface	50.3	0.54	10.7

* Extract may contain some lipid material in addition to hydrocarbons.

4.4 Small Mammal Abundance

The 8 July 1994 trapping session provided the first data on species composition and abundance of small mammals inhabiting the area affected by the blowout. During 150 trapnights, 55 rodents were captured on the three sites (Table 3). Six species were captured including Heermann's kangaroo rat, short-nosed kangaroo rat (*Dipodomys nitratoides brevinasus*), southern grasshopper mouse (*Onychomys torridus*), San Joaquin antelope squirrel, deer mouse (*Peromyscus maniculatus*), and San Joaquin pocket mouse (*Perognathus inornatus inornatus*). Heermann's kangaroo rats were captured on all three sites and this species made up 85% of the total captures. Similar numbers of small mammals were captured at the heavily affected site (24) and the control site (20), but only about one half as many small mammals (11) were captured on the lightly affected site. The smaller number of rodent captures at the lightly affected site may have been due to reduced vegetative cover associated with the southern exposure of this site and a burn in this area in 1993. Rodents captured on the oiled sites had little or no accumulation of oil on their pelage. Some kangaroo rats had small black flecks on their pelage that may have been dried oil residue, but these were barely noticeable and their ventral surfaces did not appear to be discolored.

Table 3. Summary of captures of small mammals on 8 July 1994 at two sites affected by oil residue from the blowout of well 313H-26R and one control site, Naval Petroleum Reserve No. 1, California.

Species	Heavily Oiled Site	Lightly Oiled Site	Control Site
Heermann's kangaroo rat	21	8	18
Short-nosed kangaroo rat		2	
Southern grasshopper mouse	1		1
Deer mouse	1		
San Joaquin pocket mouse	1		
San Joaquin antelope squirrel		1	1
Total	**24**	**11**	**20**

Six additional trapping sessions were conducted during the study to monitor effects of the release and to evaluate restoration techniques. One pre-treatment trapping session was conducted in October 1994. Post-treatment sessions were conducted in November and December of 1994 and March, June, and September of 1995.

During the six trapping sessions, 905 small mammals were captured and trapping success was 52.5% (3,698 captures/7042 trapnights). Heermann's kangaroo rats were the most frequently captured rodent (91.5% of individuals), followed by San Joaquin pocket mice (4.0%), deer mice (2.1%), southern grasshopper mice (1.3%), San Joaquin antelope squirrels (0.6%), and short-nosed kangaroo rats (0.3%). The average recapture rate of Heermann's kangaroo rats within trapping sessions was 0.60 (range = 0.28-0.83). The Heermann's kangaroo rat was the only species captured often enough to estimate population size.

Within drainage grids, population estimates of Heermann's kangaroo rats were significantly higher on the control grid than on other grids during the October, November, and December sessions (Figure 5). Population estimates declined on all grids in March and the only significant difference was that the natural recovery grid had a higher population than the bioremediation grid. In June, the population on the control grid was significantly higher than that on the bioremediation grid. By September 1995, there were no differences in population estimates.

In October 1994, population estimates of Heermann's kangaroo rats at the hillside grids were higher on the grid to receive the bioremediation treatment than on the grid that was to receive the surface modification treatment (Figure 5). In November 1994, the population estimate on the control grid was significantly higher than the estimate on the surface modification grid and the bioremediation grid. In December 1994, the control grid was significantly higher than the surface modification grid. In March, June, and September 1995, estimates on the surface modification grid were significantly smaller than all other grids. However, population estimates for the surface modification grid after December were based on less than 20 individuals captured

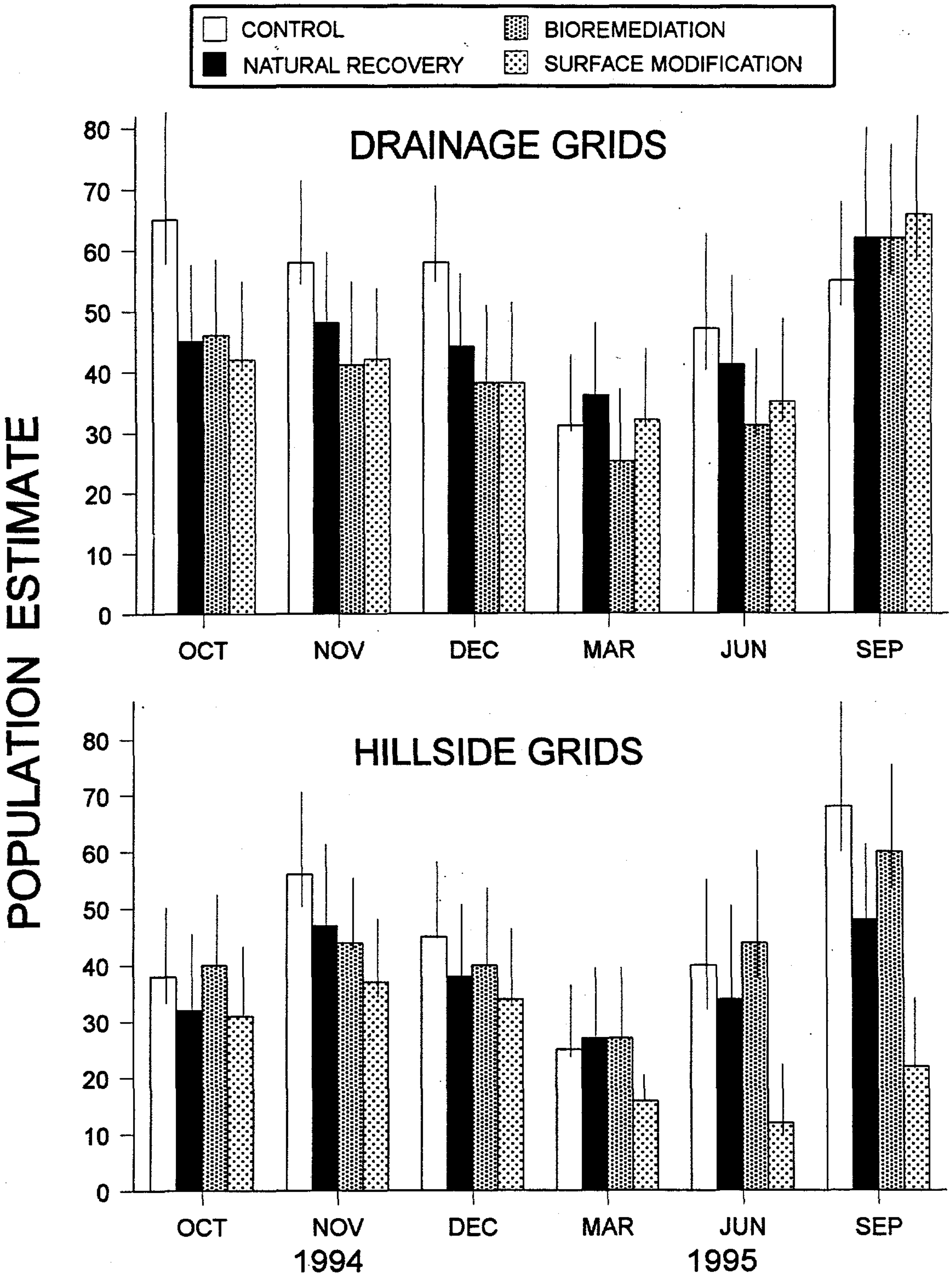

Figure 5. Population estimates (± 95% confidence intervals) of Heermann's kangaroo rats on trapping grids established within areas affected by the blowout of well 313H-26R and control grids, Naval Petroleum Reserve No. 1, California. Population estimates were derived using the jackknife estimator of program CAPTURE.

and these should be viewed with caution because they are probably biased (White et al., 1982). The only other significant difference occurred in September, when the population estimate from the control grid was higher than that for the natural recovery grid.

4.5 Diversity of Small Mammals

Shannon diversity indices for each trapping grid ranged from 0 to 0.30 (Table 4). There were no significant differences in diversity indices between grids for a given session ($P > 0.50$). All trapping grids were dominated by Heermann's kangaroo rats and consequently rodent species diversity was relatively low. Diversity of rodent species decreased during winter and spring months and increased again in summer and fall months.

Table 4. Shannon diversity indices for rodents trapped at grids established within oiled areas and control sites after the blowout of well 313H-26R, Naval Petroleum Reserve No. 1, California. Oiled areas were either treated with bioremediation or surface modification or left to recover naturally.

Grid/Treatment*	Trapping Session						Average (SE)
	10/94	11/94	12/94	3/95	6/95	9/95	
Drainage Grids							
Surface Modification	0.13	0.0	0.05	0.12	0.22	0.09	0.10 (0.03)
Natural Recovery	0.09	0.0	0.0	0.06	0.16	0.05	0.06 (0.02)
Bioremediation	0.14	0.05	0.05	0.0	0.07	0.09	0.07 (0.02)
Control	0.20	0.05	0.11	0.0	0.0	0.21	0.09 (0.04)
Hillside Grids							
Surface Modification	0.12	0.0	0.0	0.0	0.16	0.30	0.10 (0.05)
Natural Recovery	0.21	0.18	0.15	0.08	0.12	0.14	0.15 (0.02)
Bioremediation	0.05	0.0	0.05	0.0	0.06	0.05	0.04 (0.01)
Control	0.06	0.05	0.0	0.08	0.0	0.17	0.06 (0.03)
Average (SE)	0.13 (0.02)	0.04 (0.02)	0.05 (0.02)	0.04 (0.02)	0.10 (0.03)	0.13 (0.03)	0.08 (0.01)

4.6 Other Vertebrate Species

Lizards were seen twice during trapping sessions. One side-blotched lizard (*Uta stansburiana*) was seen on the control drainage grid in October 1994, and one side-blotched lizard was seen on the hillside-bioremediation grid in March 1995.

Seven species of birds were seen on grids including western meadowlark (*Sturnella neglecta*), California quail, common raven (*Corvus corax*), fox sparrow (*Passerella iliaca*), loggerhead shrike (*Lanius ludovicianus*), burrowing owl, and northern mockingbird (*Mimus polyglottos*) (Table 5). The average number of species seen on each grid was 2.4 (range = 1-4). The most species of birds seen on a grid was four on the natural recovery-hillside grid and the fewest species of birds seen (one) occurred on the bioremediation-hillside grid.

Table 5. Species of birds seen on trapping grids established within oiled areas and control sites after the blowout of well 313H-26R, Naval Petroleum Reserve No. 1, California. Oiled areas were either treated with bioremediation or surface modification or left to recover naturally.

Species	Trapping Grid							
	Drainage Grids				Hillside Grids			
	*SM	NR	B	C	SM	NR	B	C
Western Meadowlark	X	X		X	X	X	X	X
California Quail	X	X	X	X	X	X		X
Common Raven			X					
Northern Mockingbird						X		
Fox Sparrow						X		
Loggerhead Shrike								X
Burrowing Owl					X			
Total No. Species	2	2	2	2	3	4	1	3

*
SM = surface modification
NR = natural recovery
B = bioremediation
C = control

4.7 Invertebrates

With the exception of three grids in December, darkling beetles were seen on all grids in every trapping session (Table 6). On drainage grids, darkling beetle abundance (average number seen per day) was significantly higher on the control grid than on the natural recovery grid in October 1994. On hillside grids, the abundance of darkling beetles was significantly higher on the control grid than the surface modification grid in November 1994 (Table 6). There were no other significant differences in beetle abundance. Observations of darkling beetles decreased in winter months and increased again in summer and fall of 1995. Number of sightings was generally lower in September 1995 than in October 1994.

Table 6. Average number of darkling beetles seen per day (SE) on trapping grids established within oiled areas and control sites located within drainages and hillsides of Naval Petroleum Reserve No. 1, California. Oiled areas were either treated with bioremediation, surface modification, or left to recover naturally. Averages with the same letter in common are not significantly different at p=0.05. Comparisons were not made between drainage and hillside grids.

Grid/Treatment	Average no. of beetles seen/day during each trapping session					
	10/94	11/94	12/94	3/94	6/95	9/95
Drainage Grids						
Surface Modification	29.7[ab] (3.2)	20.7 (0.9)	0.3 (0.3)	6.0 (0.6)	2.3 (1.2)	3.7 (2.0)
Natural Recovery	12.7[a] (3.3)	24.7 (4.2)	0.3 (0.3)	2.7 (1.2)	4.7 (2.3)	13.0 (9.6)
Bioremediation	14.3[ab] (1.3)	16.7 (3.8)	0.3 (0.3)	3.0 (0.6)	2.7 (1.3)	20.0 (1.0)
Control	62.3[b] (14.4)	27.3 (9.5)	0.7 (0.3)	6.0 (0.6)	2.7 (0.7)	23.0 (1.0)
Hillside Grids						
Surface Modification	15.7 (4.2)	3.3[a] (3.3)	0.0 (0.0)	3.3 (1.9)	1.7 (1.2)	5.7 (3.2)
Natural Recovery	21.3 (5.4)	9.7[ab] (2.0)	0.0 (0.0)	2.3 (0.9)	2.0 (1.2)	22.0 (2.9)
Bioremediation	21.7 (9.8)	8.7[ab] (2.9)	0.0 (0.0)	0.3 (0.3)	2.0 (1.2)	18.7 (9.4)
Control	32.7 (5.2)	16.3[b] (1.5)	0.7 (0.7)	3.7 (1.7)	4.7 (2.0)	13.3 (6.7)

Ants were present on all grids except four during trapping sessions held in December 1994 and March 1995 (Table 7). Average number of trapsites with ants varied from zero to 41. However, there were no statistically significant differences in ant abundance between grids during any session ($P > 0.05$). Control grids tended to have fewer ants than other grids. Ants were rarely seen at traps in winter months, but by the following summer and fall ants were seen at most traps and seemed to be more abundant than in the previous fall. There was considerable variation in the number of ants seen per day and this probably made the statistical tests low in power.

Table 7. Average number of trapsites with ants per day (SE) at trapping grids established within oiled areas and control sites located within drainages and hillsides of Naval Petroleum Reserve No. 1, California. Oiled areas were either treated with bioremediation, surface modification, or left to recover naturally.

Grid/Treatment	Average no. trapsites with ants/day during each trapping session					
	10/94	11/94	12/94	3/95	6/95	9/95
Drainage Grids						
Surface Modification	9.3 (2.3)	3.3 (1.8)	0.0	0.7 (0.7)	40.3 (2.9)	31.0 (3.6)
Natural Recovery	3.3 (3.3)	10.0 (5.1)	0.0	1.7 (0.3)	31.3 (9.7)	27.3 (2.3)
Bioremediation	1.7 (0.9)	6.0 (3.5)	0.0	2.0 (1.0)	28.0 (12.1)	26.3 (1.7)
Control	4.3 (2.2)	0.3 (0.3)	0.3 (0.3)	1.3 (0.3)	29.7 (7.0)	20.0 (1.7)
Hillside Grids						
Surface Modification	7.7 (5.4)	4.0 (3.5)	0.7 (0.7)	0.0	34.0 (1.7)	41.0 (4.0)
Natural Recovery	3.3 (1.2)	3.0 (2.5)	0.7 (0.7)	0.7 (0.3)	30.3 (9.3)	33.3 (5.4)
Bioremediation	10.3 (2.6)	6.3 (4.4)	0.0	2.0 (1.0)	24.7 (11.6)	27.0 (4.4)
Control	2.0 (1.5)	3.0 (1.5)	0.3 (0.3)	0.3 (0.3)	22.7 (8.4)	27.7 (7.3)

4.8 Vegetation

Herbaceous cover and production ranged from 79.5% and 2141 kg/ha on the control drainage grid to 96.8% and 4011 kg/ha on the bioremediation hillside grid (Table 8). Herbaceous cover and production did not differ significantly between any of the drainage grids. On the hillside grids, percent cover was significantly higher on the bioremediation grid (96.8%) than the natural recovery (86.7%) and control grid (87.2%) (Table 8). Herbaceous production was also significantly higher on the bioremediation grid (4011 kg/ha) than on the surface modification grid (2561 kg/ha). Herbaceous cover and production levels were generally higher on the hillside grids than the drainage grids.

Table 8. Average percent herbaceous cover and average herbaceous production per transect (n=6) at trapping grids established within oiled areas and control sites located within drainages and hillsides of Naval Petroleum Reserve No. 1, California. Oiled areas were either treated with bioremediation, surface modification, or left to recover naturally. Averages with the same letter in common are not significantly different at p=0.05.

Grid/Treatment	Percent herbaceous cover			Herbaceous production (kg/ha)		
	Average	SE	Range	Average	SE	Range
Drainage Grids						
Surface Modification	88.7	2.9	75-95	2270	290	1198-3290
Natural Recovery	83.3	4.4	63-94	2791	219	2197-3570
Bioremediation	80.3	4.2	64-94	3271	393	2278-4615
Control	79.5	4.5	59-89	2141	261	1299-2848
Hillside Grids						
Surface Modification	92.3[ab]	1.2	88-97	2561[b]	366	1471-3477
Natural Recovery	86.7[b]	2.5	78-93	2687[ab]	174	2103-3356
Bioremediation	96.8[a]	1.8	88-100	4011[a]	351	2958-5115
Control	87.2[b]	1.1	84-92	2799[ab]	301	1893-3979

Shrub survival from September 1994 to June 1995 was 100% for all grids. Stakes used to mark locations of four shrubs were not found in June and these were not included in the sample. Shrub vigor within drainage grids was higher on the control grid and the surface modification grid than on the bioremediation grid in October/November 1994 (Table 9). Shrub vigor at least doubled on all oiled grids by June 1995 and the only significant difference in June was that shrub vigor was significantly higher on the surface modification grid than the bioremediation grid. Shrub vigor within hillside grids was significantly higher on the control grid than the natural recovery and bioremediation grids, and the surface modification grid was significantly higher than the natural recovery grid in October/November 1994 (Table 9). In June 1995, average shrub vigor on the bioremediation grid was significantly less than the other three grids.

Table 9. Average vigor (% green foliage) of saltbush shrubs at grids established within oiled areas and control sites after the blowout of well 313H-26R, Naval Petroleum Reserve No. 1, California. Oiled areas were either treated with bioremediation, surface modification, or left to recover naturally. Averages with the same letter in common are not significantly different at p=0.05.

	Percent green foliage of saltbush plants							
	October/November 1994				June 1995			
Grid/ Treatment	Average	n	SE	Range	Average	n	SE	Range
Drainage Grids								
Surface Modification	32.7[a]	25	4.9	0-71.6	80.1[a]	24	2.5	54.5-95.9
Natural Recovery	24.5[ab]	25	4.9	0-76.4	67.9[ab]	25	3.4	32.3-95.9
Bioremediation	11.8[b]	25	2.7	0-49.0	60.9[b]	23	5.5	4.2-100
Control	36.6[a]	25	3.8	4.7-75.4	70.3[ab]	25	3.6	23.0-96.9
Hillside Grids								
Surface Modification	30.0[ab]	25	5.1	0-86.5	79.1[a]	25	2.7	48.7-99.3
Natural Recovery	6.6[c]	25	2.7	0-44.4	79.0[a]	24	2.6	45.8-100
Bioremediation	25.0[b]	25	3.0	1.3-53.8	56.3[b]	25	5.2	0-94.7
Control	39.8[a]	25	4.4	6.9-78.1	75.1[a]	25	3.0	39.9-96.7

4.9 Effects to Threatened and Endangered Species

During transect surveys of the heavily oiled area, no evidence of threatened or endangered species was found. The known ranges of the San Joaquin kit fox, blunt-nosed leopard lizard, giant kangaroo rat, and Hoover's wooly-star overlapped part of the lightly sprayed area but none of these species' ranges overlapped the heavily oiled area (Appendix). The only sensitive species found within the heavily oiled area was the San Joaquin antelope squirrel which was captured on natural recovery and surface modification grids.

5. DISCUSSION

Information gathered during this study indicated there may have been some negative effects to animals within the heavily oiled area, but these effects were minimal and of short duration. Populations of Heermann's kangaroo rats were generally lower on oiled grids than on control grids during the first three trapping sessions. Beetle abundance also was significantly lower on some oiled grids than on control grids during the first two trapping sessions. Also, two darkling beetles were found dead during the initial survey of the oiled areas and these may have been killed by oil spray. However, after December 1995, differences in abundance of darkling beetles and kangaroo rats within grids were rarely significant. Rodent species diversity did not appear to be affected by the oiling. Shannon diversity indices were low (< 0.30) and all grids were dominated by Heermann's kangaroo rats. Ant abundance did not differ significantly between grids, and tended to be highest on oiled sites.

There was evidence that kangaroo rats within oiled areas had ingested crude oil hydrocarbons shortly after the release occurred. Although there were no consistent differences in stomach contents between the oiled and control areas, chemical analyses of liver samples indicated that some crude oil hydrocarbons had been ingested by kangaroo rats inhabiting the oiled area. The distribution of hydrocarbons in liver tissues closely matched the distribution in soil samples and the crude oil sample, indicating that hydrocarbons in livers were a result of ingesting oil released during the blowout. Kangaroo rats may have ingested these hydrocarbons by eating contaminated seeds or by grooming their oiled pelage (Kaplan et al., 1996). However, there was no evidence the rats had incorporated PAH's in their liver tissues. PAH's were of interest because they are found in crude oil and some are known to be carcinogenic and mutagenic (Sims and Overcash, 1983).

Vegetation also tended to recover quickly after the blowout. By October 1994, herbaceous vegetation had germinated and appeared to be growing at similar rates in both the oiled and non-affected areas. Quantitative measurements made in April 1995 (approximately ten months after the blowout) showed that herbaceous vegetation on oiled sites had similar or higher production and percent cover than control sites. Although some shrubs were completely covered in oil immediately after the release, no shrubs died during the monitoring period and many of them produced new growth within three months of the release. Shrub vigor was significantly higher on control sites than oiled sites closest to well 313H-26R in October/November 1994, but by June 1995 vigor of shrubs within the natural recovery, surface modification, and control grids was not significantly different. Shrub vigor was usually lowest on bioremediation grids and this may have been due to competition with annual plants which produced more growth on the bioremediated area.

Results of soil samples taken from the heavily oiled area indicated that TPH concentrations had declined by approximately 80 percent in the 45 days after the well was capped. Crude oil spilled on land is degraded primarily through evaporation, photo-oxidation, and microbial action

(Albers, 1991). Because low soil moisture limits microbial action (Skujins and McDonald, 1986), evaporation and photo-oxidation were probably responsible for most degradation of the oil during summer and fall. Within areas most heavily oiled during the vent stack release in January 1995, TPH levels declined approximately 64% from March to May 1995. Environmental conditions were relatively cool and wet during this time period and much of the degradation may have been due to microbial activity.

A couple factors probably contributed to the rapid degradation of crude oil released during the blowout. The oil was lightly deposited over a widespread area and this provided a large surface area for degradation of the hydrocarbons. Also, during the blowout and the following week, daily maximum temperatures were high ($\bar{x}$ = 38° C., range = 36° - 41° C.). These high temperatures enhanced the degradation of PAH's (Maliszewska-Kordybach, 1993) and other volatile components of the oil. In addition, clear skies and over 14 hours of sunlight per day in June and July provided optimum conditions for photo-oxidation of oil.

Results obtained from the bioremediation hillside grid seemed to be an exception to the rapid degradation of crude oil seen in other areas oiled during the blowout. A soil sample taken within this grid had a TPH level of 3300 ppm in September 1995 (15 months after the blowout). This was surprising because the bioremediated area did not appear more contaminated than other oiled areas. The higher TPH levels on the bioremediation grid were probably caused in part by the fertilizer which was shown to cause a positive interference in the EPA 418.1 method. EPA method 418.1 was designed for testing water and wastewater, and other authors have noted problems with positive interference when this method is used for testing soils (Thomey et al., 1989). Another possibility is that the higher molecular weight hydrocarbons (which are more resistant to degradation) may have fallen out closer to well 313H-26R and contributed to higher TPH levels on the bioremediation grid adjacent to the well.

As the composition of petroleum is changed through degradation, effects on living organisms are generally reduced (Albers, 1991). Therefore, the rapid degradation and drying of oil probably contributed to this release having few biological effects. Volatile components of petroleum are most toxic to animals and these quickly evaporated or were rapidly degraded. Because the oil dried within a couple days and formed a thin crust on the soil surface, animals were able to move across the landscape without getting contaminated with oil. The rapid recovery of the kangaroo rat population and the relatively clean pelage of kangaroo rats in oiled areas indicate that their exposure to crude oil was minimal. Animals have been killed from terrestrial spills of crude oil on and near NPR-1, but these have generally occurred when they have become mired in pools of oil or after oil has been released in drainages (Kato et al., 1987; Scrivner et al., 1993; Simons and Akin, 1987).

Crude oil can negatively affect plants in a variety of ways. There can be toxicity through contact with volatile components of oil, uptake of oil compounds (Albers, 1991), tie-up of nutrients or exhaustion of oxygen in soil by microbes that are metabolizing oil (Udo and Feyemi, 1975), or blockage of air exchange in surface pores (Albers, 1991). Because most herbaceous vegetation on NPR-1 is annual, and therefore dead by June, this component of the vegetative community was not immediately affected by the oiling. Production of herbaceous plants was as high or higher on the oiled sites as on the control sites, indicating that most seeds were not adversely affected by the released oil. Shrubs were alive at the time of the blowout and there was more potential for damage resulting from direct contact with the oil and blockage of surface pores. Possibly in response to the latter, shrubs produced new growth within a couple months after the release. Because there was very little penetration of oil into the soil, root systems were probably not affected and competition between plants and soil microbes for nutrients or oxygen seems unlikely.

With the exception of San Joaquin antelope squirrels, ranges of threatened and endangered species only overlapped lightly affected areas. Because there were few effects to animals and plants within heavily affected areas, it is reasonable to assume that animals and plants were affected to a lesser degree within the lightly oiled areas. Results of the winter 1994 live trapping session for kit foxes provided evidence that this endangered species was not affected by oil released during the blowout. The number of captured foxes was greater in winter 1994 than in the previous 11 years on NPR-1 (EG&G Energy Measurements, Inc., in press). Fox captures were also more widely distributed within the area that was lightly oiled than they had been in years before the blowout. This increase in kit fox abundance in 1994 was observed throughout much of the trapping area and was likely due to increasing prey populations.

There were few evident differences between restoration treatments by the end of the 17 month study. The hillside grid that received surface modification had significantly lower population estimates of Heermann's kangaroo rats than other grids during many of the later sessions. However, this was probably not due to the treatment, because population estimates on drainage grids did not show the same trend. Production and percent cover of herbaceous vegetation tended to be highest on bioremediation grids. This was not surprising because these plots were fertilized and rainfall during the growing season of 1995 was 180% of average. In contrast, shrub vigor was usually lowest on bioremediation grids. Generally, animal and plant populations recovered as quickly on the natural recovery plot as on treated sites. Natural recovery is probably the best "remediation" option in situations similar to those experienced in this study, (no pooling of oil, a light deposition of oil that quickly dries, little or no contamination of root zones of plants). In situations similar to this release, natural recovery is preferred because this option has the advantages of no soil disturbance and no cost, and yet recovery of plant and animal populations is fairly rapid. However, if a release of oil results in contamination of the root zone of plants, or if pools of oil are formed, or the oil remains sticky for several days, there is more potential for harm to animals and plants and a more aggressive treatment is warranted.

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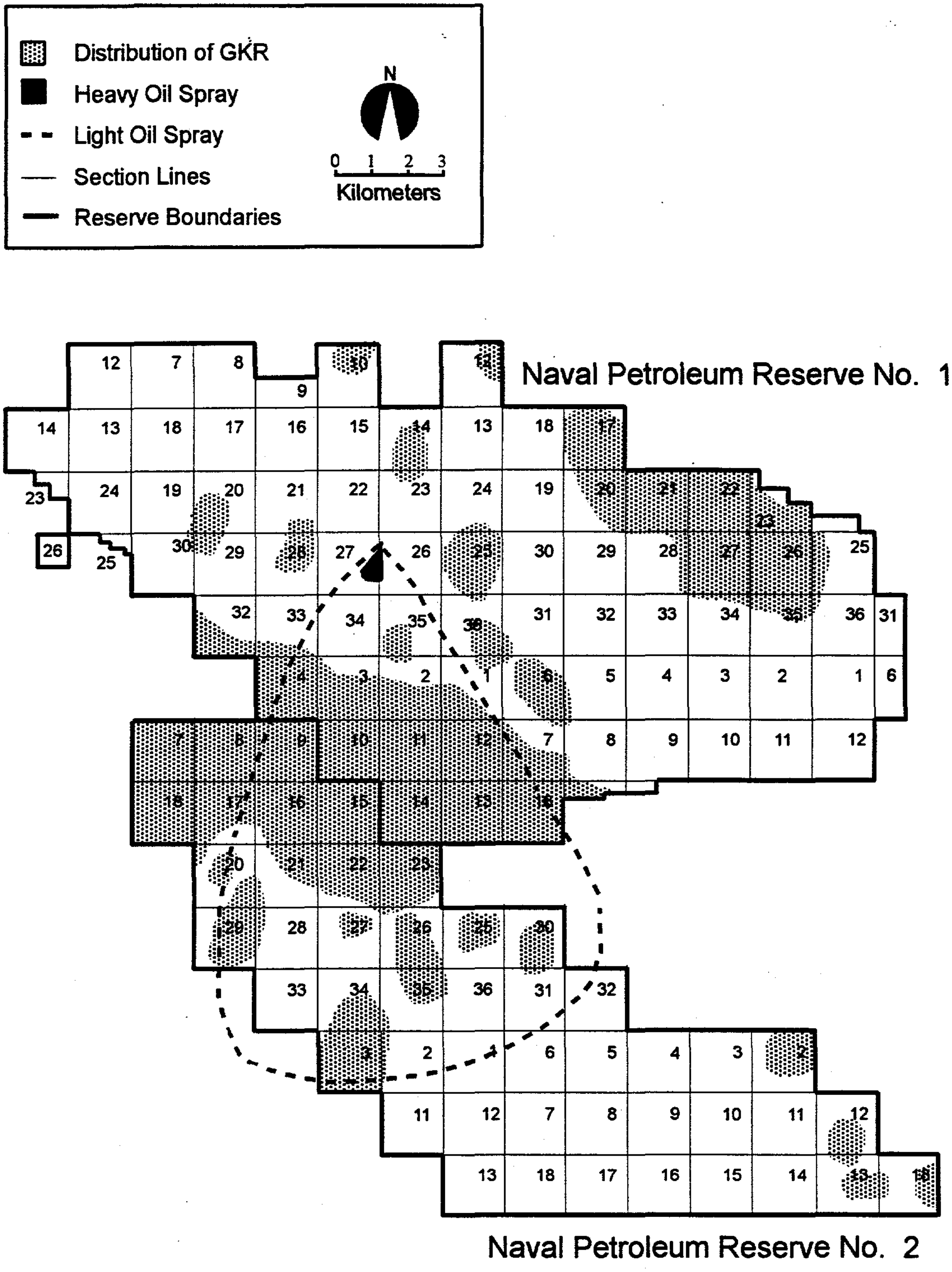
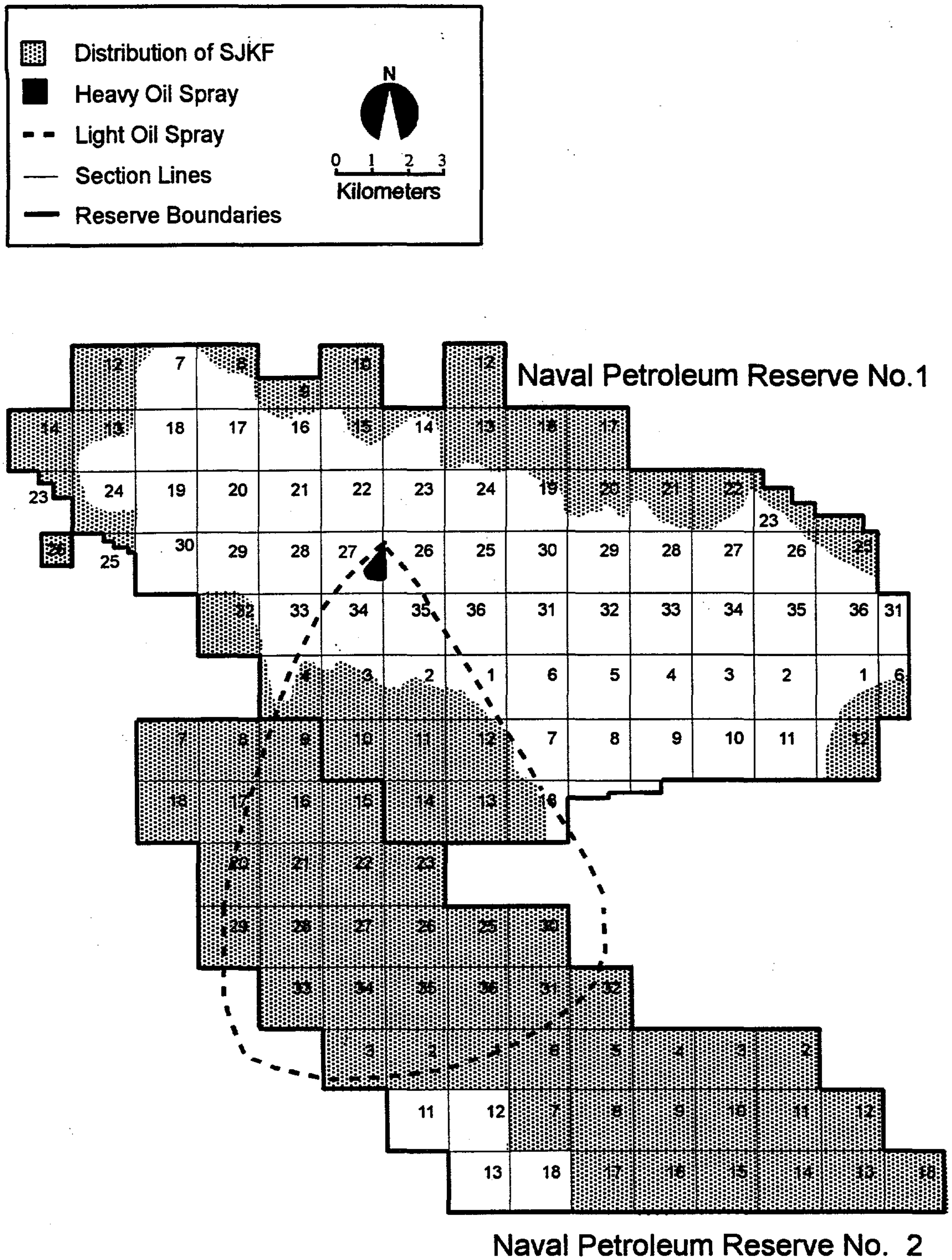
6. APPENDIX

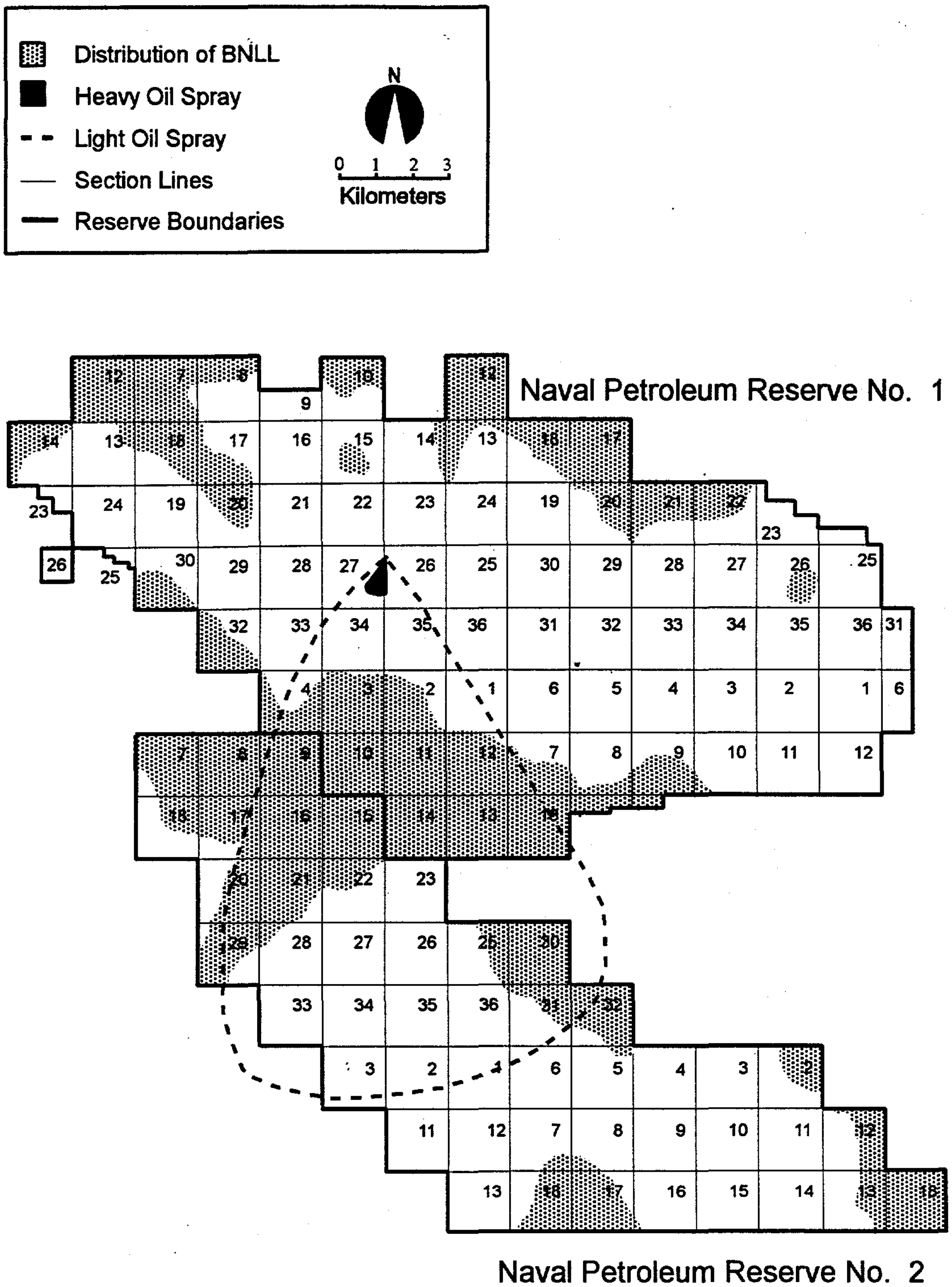
Figures showing the distribution of threatened and endangered species at the Naval Petroleum Reserves in California and the area affected by the blowout of well 313H-26R.



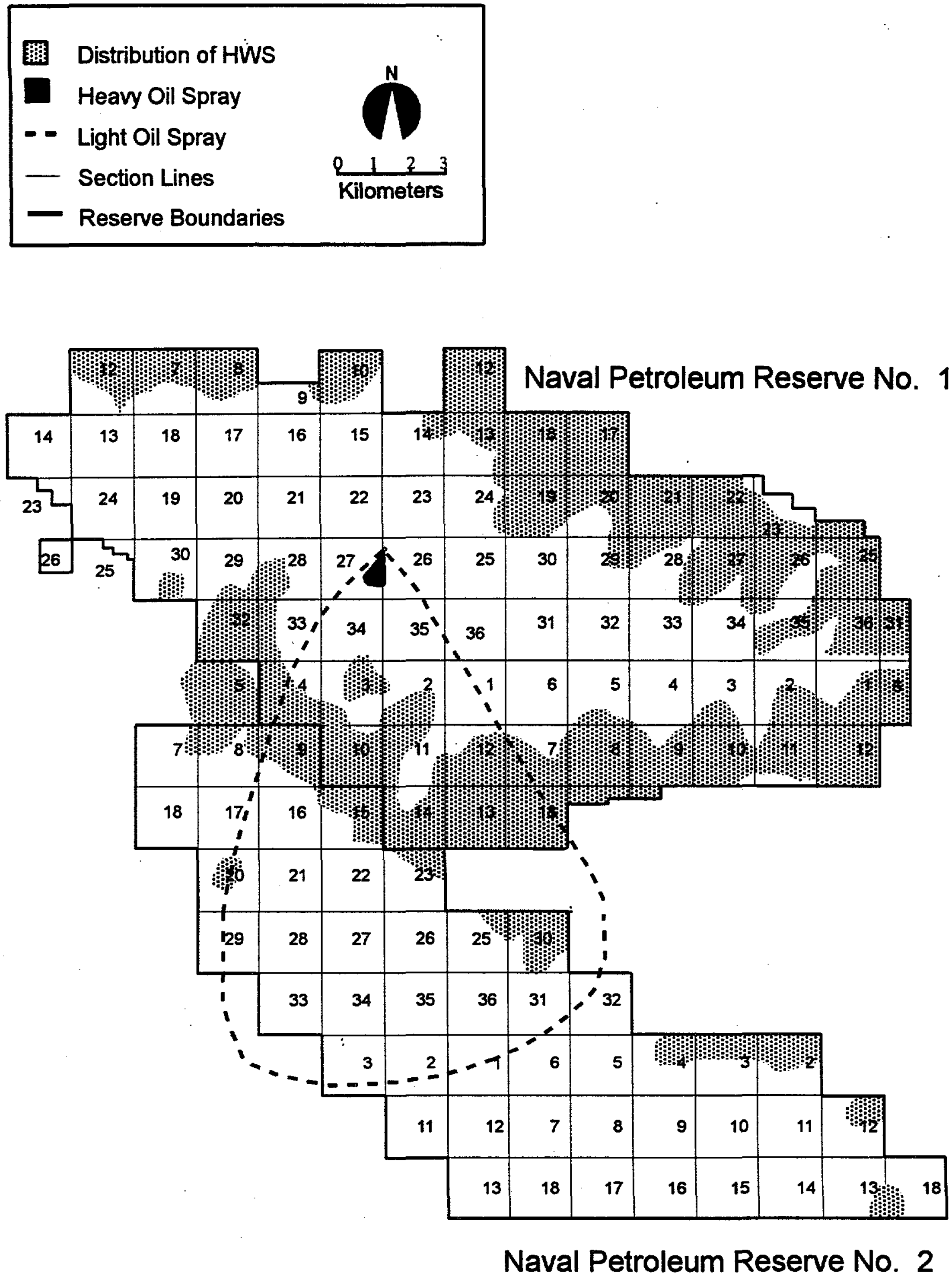
Distribution of giant kangaroo rats (GKR) on the Naval Petroleum Reserves in California based on observations of burrow locations (1981-1994).



Distribution of San Joaquin kit foxes (SJKF) on the Naval Petroleum Reserves based on winter trapping data (1988-1994).



Distribution of blunt-nosed leopard lizards (BNLL) on the Naval Petroleum Reserves in California based on sightings (1979-1994).



Distribution of Hoover's wooly-star (HWS) on the Naval Petroleum Reserves based on sightings (1988-1994).

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R. Schlorff (2)

California Energy Commission
Sacramento, California

J. Brownell
L. Spiegel

California State University
Bakersfield, California

T. Murphy
D. Germano

California State University
Fresno, California

D. Grubbs

California State University, Humboldt
Arcata, California

R. Golightly

Center for Natural Lands Management
Bakersfield, California

G. Hinshaw

Center for Natural Lands Management
Sacramento, California

S. Teresa

Chevron U.S.A. Production Company, Elk Hills
Bakersfield, California

G. Hall

Chevron Research and Technology Center
Richmond, California

P. O'Brien
L. Jackson

Idaho Power Company
Boise, Idaho

G. Holmstead

Kansas State University
Manhattan, Kansas

D. Brillhart

Kern County Library, Main Branch
Bakersfield, California

D. Mooneyham

Lawrence Livermore National Laboratory
Livermore, California

T. Kato

The Nature Conservancy
California Valley, California

T. Nelson

Ricks College
Rexburg, Idaho

J. Scrivner

San Joaquin Valley Endangered Species Recovery Planning Program
Bakersfield, California

E. Cypher

San Joaquin Valley Endangered Species Recovery Planning Program
Fresno, California

P. Kelly (2)
D. Williams

Smithsonian Institute
Paso Robles, California

K. Ralls

Texaco E&P Inc.
Fellows, California

M. Chichester

University of Wisconsin
Stevens Point, Wisconsin

M. Boyce

Wyoming Game and Fish Department
Laramie, Wyoming

T. Thorne

EASI/ORNL
Oak Ridge, Tennessee

B. Easley

EASI/NPRC

D. Craghill
B. Cypher
N. Frost
H. Hill
J. Hinshaw
M. Otten
M. Phillips
G. Warrick
L. White
Library (20)