DE/EV/01322-132

MASTER

DEPARTMENT OF ECOLOGY AND BEHAVIORAL BIOLOGY

UNIVERSITY OF MINNESOTA

MINNEAPOLIS, MINNESOTA 55455

VERTEBRATE BEHAVIOR AND ECOLOGY

Progress Report

for Period July 1, 1977 - May 31, 1980

John R. Tester and Donald B. Siniff
University of Minnesota
Minneapolis, Minnesota 55455

June 1980

Prepared for
U.S. Department of Energy
UNDER DONTRACT NO. DE-AC02-76EV01332

Institution and Address:

Department of Ecology and Behavioral Biology
University of Minnesota
Minneapolis, Minnesota 55455

Principal Investigators:

Dr. John R. Tester, Professor
Dr. Donald B. Siniff, Professor

Project Titles:

Overall Project Title :

VERTEBRATE BEHAVIOR AND ECOLOGY

Subproject Titles:

(1) Engineering Design and Development

(2) Application of Radiotelemetry to Selected Problems in Vertebate Censusing and Population Study

Period Covered in PROGRESS REPORT:

July, 1979 through May, 1980

PROGRESS REPORT

SUMMARY

Engineering design and development concentrated on five aspects during the past year: (1) development of high power output transmitters for monitoring animals from greater distances, (2) improvement and updating of a sonic transmitting and receiving system for monitoring fish and marine mammals, (3) design and testing of corrosive links which permit a transmitter to release from an animal at a specified time, (4) development of high frequency transmitters and (5) development and testing of time delay transmitters. Field efforts resulted in further information on activity patterns and movements of sea otters in California and Alaska and of walleye pike in experimental channels. Three manuscripts and two theses presented as part of this report describe these aspects in detail.

SUBPROJECT ONE

ENGINEERING DESIGN AND DEVELOPMENT

As in previous years, engineering effort can be divided into two categories; continuing and new design and development. This report summarizes five areas of progress during this last year.

1) <u>High Power Output Transmitters</u>: Work has continued on the development of small, high power output transmitters. The goals of this project are to design a transmitter that will be reliable, efficient and have a power output compatible with the maximums allowed by lifetimes required and battery carrying capability of the animal. Most transmitters in current use are two stage frequency doubling designs whose maximum power can be altered very little by increasing current drain or battery voltage.

One alternative is to purchase a modular amplifier such as those supplied by Avantek, Watkins-Johnson and others, however all of these designs are linear and are designed to operate at specific voltages. The linear characteristic would preclude their operating at high efficiency but this could be partially alleviated by using a switch to turn the transmitters on and off, since most transmitters are operated at a low duty cycle.

A more serious problem is the requirement to operate at 12 volts or higher. Unfortunately not only would the power output be reduced but stability problems would occur when operating at reduced voltages, i.e., transmitters would tend to go into spurious oscillation. Transmitters could be operated at the higher voltages using four lithium cells in series; however the bulk of these cells would preclude their use in most applications. This is especially true when current drains are high, thus requiring a high current output from the battery. This high output requires the use of larger cells having sufficient surface area to supply the current.

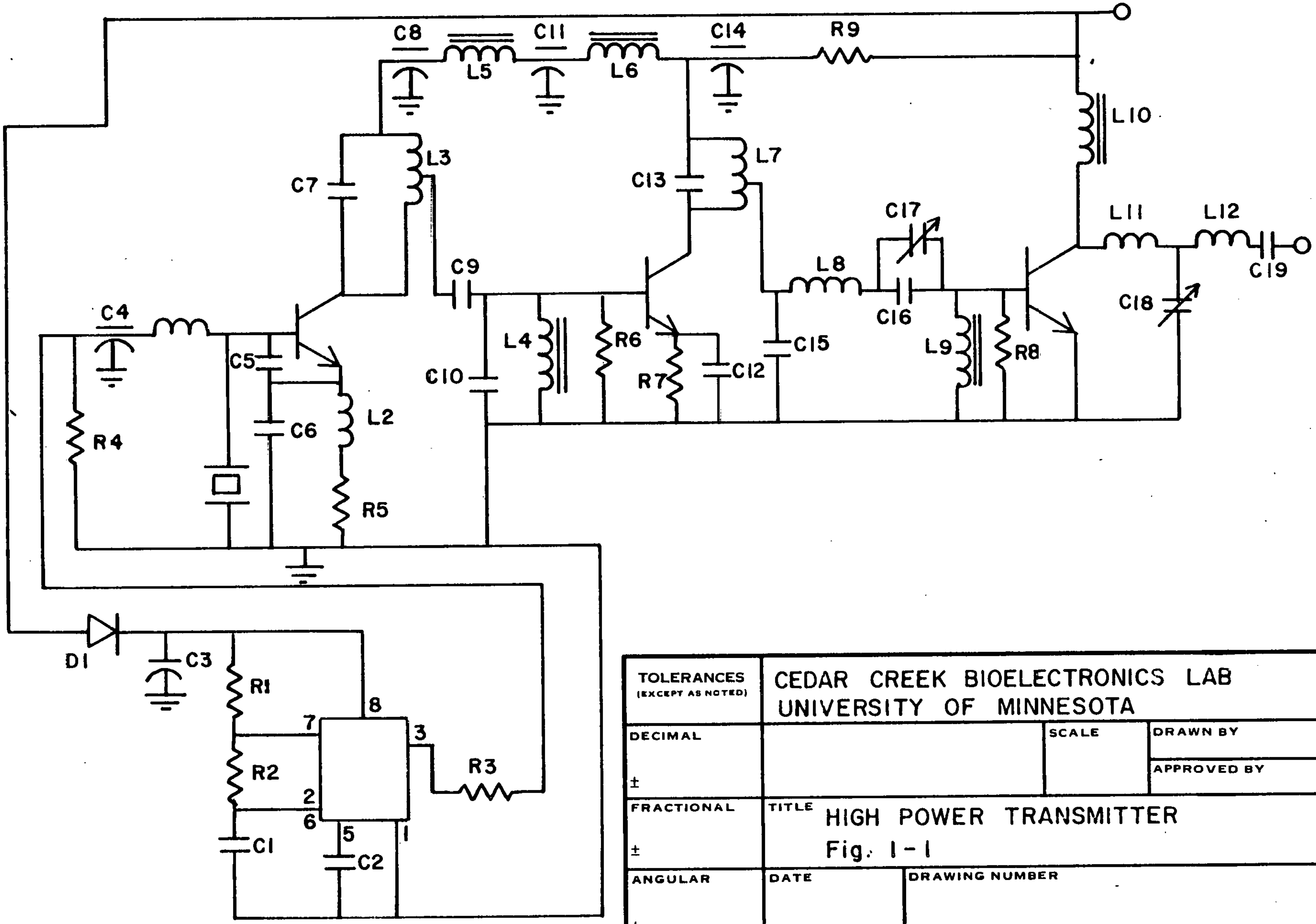
Over the last two years we have worked on several designs to meet these needs. We have been partially successful, although more work needs to be done. Transistors can be easily characterized using the technique outlined in last years report to measure the input capacitance and resistance and also the output capacitance. These measurements have proven very helpful in designing the matching networks to produce the gain and high efficiency we desire. They are also used in attempting to stabilize the amplifiers to prevent spurious oscillations when the load changes. Load changes are caused by an animal changing the surroundings of the antenna.

We have been successfull in each of these design goals; however, when the transmitters are encapsulated in electrical resin for waterproofing they are no longer unconditionally stable. We have been able to reduce the problem somewhat but have not been able to eliminate it. The major problem appears to be caused by capacitance between the conductors on the printed circuit board. When potting is added the dielectric constant of the potting material is different from air and thus changes the capacitance of the circuit. Several approaches were used to reduce the problem. First we attempted to reduce the interlead capacitance by careful placement of components and ground areas. Secondly we attempted to use low loss, low dielectric constant encapsulants such as those supplied by Emerson and Cummings. These were largely unsuccessful because of the toxicity and high heat required for complete cure. At present, this approach is deemed unacceptable. Our third effort was to reduce the Q's between the stages thus making them less susceptible to spurious oscillations caused by capacitance changes. Again this has been partially successful. Although we can now maintain the gain levels before and after potting we have not been able to maintain unconditional stability. Unconditional stability means that the amplifier will remain stable from no load to short curcuit conditions. Although we would hope such conditions would not occur, they may be approached depending on what the animal does with the antenna. Sufficient stability has been obtained by careful adjustment and testing after potting. Since this is time consuming and requires sophisticated equipment we would like to eliminate that problem in our next design attempt. In spite of the above problems, high power output transmitters have been used successfully on a number of species (Fig. 1-1).

2. Ultra Sonic Receivers and Transmitters:

To meet the needs for tracking in salt water a sonic receiver and transmitter system was developed. It is an updated version of an earlier approach using a three hydrophone array system to locate animals under water. It is designed for battery operation and for use at depths to at least 1000 meters.

The receiver was redesigned with digital tuning to allow rapid frequency changes to accomodate different fish. With digital tuning different frequencies can be selected instantaneously. The remainder of the receiver is of conventional design. Gain is purposely kept low in the



TOLERANCES
(EXCEPT AS NOTED)

CEDAR CREEK BIOELECTRONICS LAB
UNIVERSITY OF MINNESOTA

DECIMAL
±

SCALE

DRAWN BY

APPROVED BY

FRACTIONAL
±

TITLE HIGH POWER TRANSMITTER
Fig. 1-1

ANGULAR
±

DATE

DRAWING NUMBER

MADE IN U.S.A.

input stages to reduce problems with cross modulation and also because we chose not to use tuning in the first stages. A high pass filter is used at the input to reduce low frequency sea noise, especially that due to ships and animal calls. Another unique feature of the receiver is the use of a phase locked loop as the signal detector, resulting in a very low false alarm rate. This rate is maintained even under high noise conditions.

The improved transmitter uses dual 555 circuits for timing and frequency control. This results in greater accuracy in timing control for variations in voltage and temperature. It also reduces the number of parts required. A second improvement is in redesign of the output power transformer to yield maximum power output while still maintaining linear operation. The design could be further improved in cases where high efficiency is required by adding a inductance in series with the transducer to resonate the approximately 3000 pf reactance of the transducer. We chose not to do this because in our case transmitter life was not a critical design parameter and because the inductance would have to be different for each transmitter frequency, a difficult task if a larger number of frequencies are used. The transducers are resonant at approximately 60 KHz and the power output of the transmitters was measured at 70 db re lubar @ 1 meter. It could be further increased by redesigning and increasing the size of the power transformer.

The potting for these transmitters was Products Research Corporation urethane. This material is waterproof and has very good acoustic window properties. All gas bubbles were evacuated before the potting was poured. Range for these transmitters is about 5 km under quiet sea conditions and they have been tested to depths of 600 meters with no observable change in characteristics.

3) Corrosive Links:

A third area of effort was the design and testing of corrosive links. Generally a telemetry study involves attaching a device to an animal and releasing it back to its natural environment. In most cases the animal's life expectancy is greater than that of the transmitter. It is therefore desirable to remove the transmitter after it has expired. This is becoming especially important when working with endangered species where a multiplicity of concerns must be accomodated. In many cases the animal can be recaptured and the transmitter removed, while in others this cannot be readily done. To meet these needs we began testing and developing corrosive links that would decay with time allowing the device to fall off after a desired time interval.

We experimented with both active and passive devices. Active devices have the advantage of not being dependent on their environment for corrosive action. Although we have experimented with a number of electrochemical cells we have not been successful in developing a device that will work reliably. We believe that we can build a reliable active device but that it will take more time.

We have been more successful with passive devices which depend on salt water as the electrolyte and use metals of different potentials to form the cathode and anode of the corrosive cell. Metals which do not passivate (for their own protection) easily are chosen. The time of decay can be controlled by chosing different metals and by varying the size of cathode and anode. The results of these tests have been summarized (See

Appendix B, SUBPROJECT TWO) and several devices are being field tested on sea otters, polar bear and manatees. They have performed well on sea otter, releasing in 4-6 weeks, and on manatees, releasing after one year. Data from tests on polar bears are not yet available.

4) Development of High Frequency Transmitters

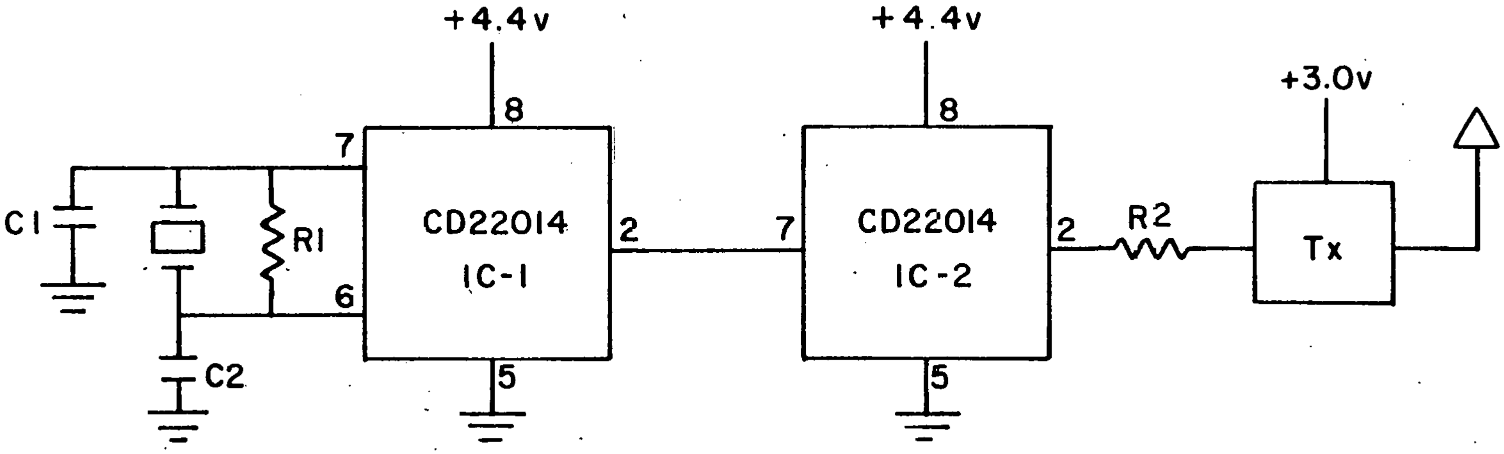
As more and more telemetry devices come into use, the FCC is becoming more concerned with control. This has resulted in a number of frequency bands being authorized for use in ocean, animal, and medical telemetry. These regulations are covered in Part II paragraph 5.108 and 15.176 of FCC Rules and Regulations. The lower frequencies present no problems, however new design was required at the 216-220 MHz band.

During the past year we have developed transmitters similar to the 164 MHz types that operate in this higher range. Techniques have been developed to construct them easily and reliably. The major problem remaining is increasing the power output. For the 164 MHz designs we are able to use 82 MHz crystals and double to the output frequency. However, we have not been able to do this successfully with 110 MHz crystals and thus have had to go to a tripling scheme, using a crystal at approximated 70 MHz. Since the power output is approximately equal to $1/n^2$ where n is the number of the harmonic (2 and 3 in our case), it can readily be seen that the power output will be lower. Two solutions are possible; one is to add a third stage to increase the power level, the other is to find a crystal that will operate at these frequencies or develop a different oscillator circuit. The latter seems to hold the most promise. Thus we have successfully built transmitters at 220 MHz but have not been able to achieve the power output levels of our earlier models.

5) Time Delay Transmitters:

Time delay transmitters that will turn on in the field after some pre-determined delay time have wide application in ecological research. They can also be cycled on and off to save power. These devices are especially useful for studies where battery size is critical and life important. We developed time delay transmitters earlier, using watch circuits. Unfortunately the state of the art in watch circuits changed rapidly, incorporating new features and dropping the older basic ones. Thus, the circuit we were using is no longer manufactured. We have developed a new version using standard COSMOS circuitry. A diagram of our current version is shown in Figure 1-2. It is now being tested on sea otters in Alaska.

DATE	SYM	REVISION RECORD	AUTH.	DR.	CK.



TOLERANCES (EXCEPT AS NOTED)	CEDAR CREEK BIOELECTRONICS LAB UNIVERSITY OF MINNESOTA		
DECIMAL ±		SCALE	DRAWN BY APPROVED BY
FRACTIONAL ±	TITLE TIME DELAY TRANSMITTER Fig. 1-2		
ANGULAR ±	DATE	DRAWING NUMBER	

SUBPROJECT TWO

APPLICATION OF RADIO TELEMETRY TO SELECTED PROBLEMS IN VERTEBRATE CENSUSING AND POPULATION STUDY

Our long term goal has been to utilize the experience, technology and equipment developed over the years in radio telemetry to resolve basic problems in animal census and population studies. Currently we are shifting this focus somewhat to concentrate on specific problem areas critical to new DOE missions. In October 1982 we will initiate studies on impacts of the utilization of wetland biomass as an energy source and a study on quantification of spatial use patterns and foraging strategies (See Renewal Proposal).

During the past year we have concentrated on measurement of important population parameters, particularly dispersal patterns, of the sea otter and on methods of monitoring and analyzing movements and behavior of fish. This progress report consists of drafts of 2 theses and 3 papers which are being prepared for publication. These theses and papers, presented in their entirety, are:

A) Experiments on the response of sea otters to oil contamination (APPENDIX A)

B) Corrosive links for use with animal biotelemetry (APPENDIX B)

C) Fall movements and activity patterns of sea otters in California (APPENDIX C)

D) Fentanyl and azaperone produced neuroleptanalgesia in the sea otter (APPENDIX D)

E) Behavior of walleye pike in experimental channels as monitored by a microprocessor utilizing radio telemetry (APPENDIX D)

Experiments on the response of sea otters (Enhydra lutris) to oil contamination.

D. B. Siniff[1], T. D. Williams[2], A. M. Johnson[3], and
D. L. Garshelis[1].

[1]Dept. of Ecology and Behavioral Biology, University of Minnesota,
Minneapolis, Minnesota. 55455
[2]Ocean View Veterinarian Clinic, 109 Central Ave. Pacific Grove, CA
93950
[3]U.S. Fish and Wildlife Service, 4454 Business Park Blvd. Anchorage,
Alaska 99503.

Abstract

Two oiling experiments were conducted from 1977-1979 on sea otters in Prince William Sound, Alaska. In the first experiment, 4 captured otters were instrumented with radio-transmitters and released following contamination of their pelage with 25 cc of Prudoe Bay crude oil; a fifth individual was oiled and cleaned with detergent prior to being released. For all experimental animals activity increased dramatically during the first week following treatment; this effect was accentuated in the otter cleaned with detergent. Most of the increase in activity corresponded to increased grooming, whereas frequency of feeding (as measured by dive pattern analysis) did not appear to increase. It appeared that all experimental otters survived the first experiment, probably because only a small portion of the pelage was treated, and because food resources in

the study area were abundant. In the second experiment we observed behavioral reactions of 2 otters in an above-ground swimming pool which was partly covered with crude oil. Both otters spent very little time on the oiled side of the pool (less than 1 minute per hour), but occasionally surfaced in it for brief periods and eventually became contaminated. One of these individuals was not cleaned and died within 24 hours of first encounter with the oil; the other was cleaned and released with a radio-transmitter that failed shortly afterwards.

Introduction

Oil spills in marine environments have increased dramatically over the last decade (Gelder-Ottway and Knight 1976). The persisent effects of oil spills on marine organisms, often spanning periods of 5-15 years, have been well documented (Atlas et al. 1978; Vandermeulen 1978). Sea otters (Enhydra lutris) may be particularly vulnerable to oil contamination because of their high metabolic rate and dependence on dense fur rather than blubber for insulation (Kenyon 1969). Kooyman et al. (1976) have shown that thermal conductivity is greatly increased in oil stained sea otter pelts. Thus, fur contaminated with oil causes loss of body heat and, in compensation, metabolic activity increases. Increased metabolism due to oil contamination of the pelage has been observed in fur seals (Callorhinus ursinus) (Kooyman et al. 1976), muskrats (Ondatra zibethica) (McEwan et al. 1974), and various species of waterfowl (Hartung 1967; McEwan and Koelink 1973). In contrast, aquatic species which rely on blubber for insulation, such as ringed seals (Phoca hispida) and harp seals (P. groenlandica), are much less susceptable to such effects (Geraci and Smigh 1976).

Bouyancy also may be affected by soiling of the pelage. Wragg (1954) demonstrated the loss of bouyancy in oiled muskrats. Sea otters depend on their ability to remain afloat in a resting position for several hours a day to conserve energy; thus, contamination of the pelage and subsequent loss of bouyancy would increase their daily energy expenditure.

Sea otters spend considerable time grooming their pelage to maintain insulation and buoyancy (Kenyon 1969), but whether they can remove oil from their fur by vigorous grooming is unknown.

Barabash-Nikifirov et al. (1947:115) suggest that sea otters can sense oil contaminated surface waters and avoid contact. However, Kooyman et al. (1976) noted that behavioral responses of sea otters to oil have not been tested and are thus poorly understood.

With the recent completion of the Trans-Alaskan Pipeline, oil contamination to Alaskan coastal waters seems inevitable (see Atlas et al. 1978). A large population of sea otters in Prince William Sound, the southern terminus of the Alaskan pipeline, invites large scale effects from such a spill. Smaller populations of sea otters, such as the newly established population off the coast of British Columbia, may be extirpated by an oil spill (Ellis 1979). Increased mortality may occur directly from contamination of the pelage or ingestion of oil contaminated invertebrates, or indirectly due to oil-caused diminished densities and retarded growth rates of marine invertebrates comprising the sea otter's diet (see Krebs and Burns 1977; Gilfillan and Vandermeulen 1978).

The questions and complexities outlined above spurred our efforts to study the reaction of sea otters to oil on the ocean surface and to monitor possible adjustments in normal life patterns to mediate the effects of oil contamination of the fur. We also were interested in determining whether oil contaminated fur can be cleaned, and animals restored to normal health. Such cleaning attempts have been generally unsuccessful with seals (Davis and Anderson 1976) and seabirds (Clark 1978).

METHODS

Two types of oiling experiments were conducted during the summers of 1977-1979 in Prince William Sound, Alaska (Fig. 1). In one experiment, 4 captured otters were instrumented with radio-transmitters and released following contamination of their pelage with 25 cc of Prudoe Bay crude oil; another otter was captured, oiled and cleaned prior to being released. In the second experiment, behavioral reactions of otters to crude oil on the water surface in an above-ground swimming pool were observed.

Experiment 1: Oil and Release

Otters were captured for the first experiment using 22 cm (8 3/4") stretch mesh gill nets, anchored at one end and without weights on the lead line. This technique has been used by several investigators previously to capture otters for transplant to other areas, or for scientific study. The unweighted lead line allowed otters entangled in the net to surface and remain there until extricated by research personnel.

After capture, a radio-transmitter weighing 25 to 30 grams was attached across a digit on a rear flipper (Fig. 2) so that the whip antenna pointed upward when the animal was floating on its back in normal resting posture. During grooming, swimming or feeding, the antenna would dip below the surface of the water, thereby interrupting transmission of the radio signal. These occasional interruptions of the radio signal were used as an index of activity, and could be recorded on a strip chart at an automatic monitoring station. For the 1977 and 1979 field seasons, the system was adjusted to sample the activity of each otter for 15

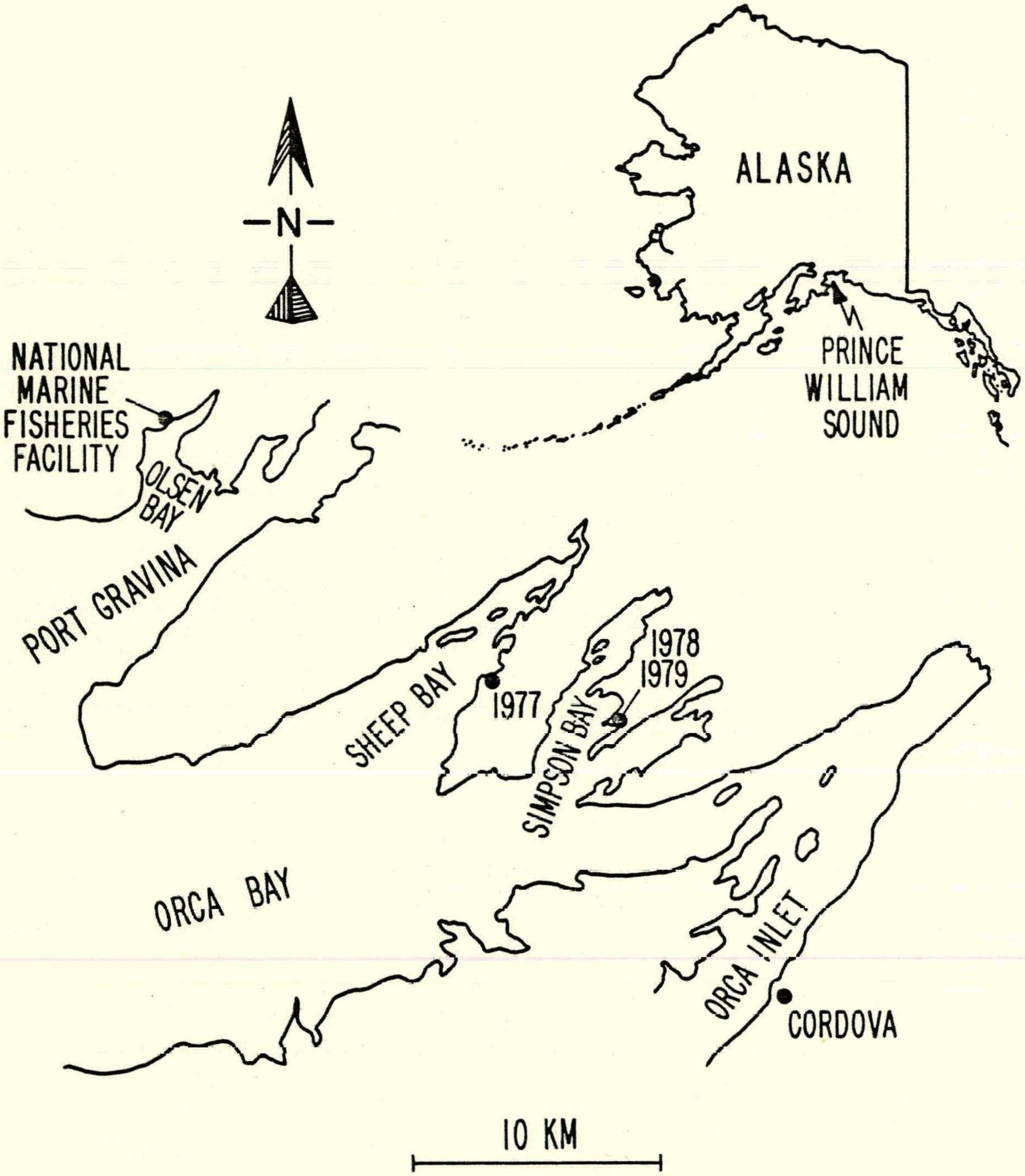


Fig. 1. Map of study area showing locations of field camps used during the 1977, 78 and 79 seasons, and National Marine Fisheries Service facility used for the captive study in 1977.

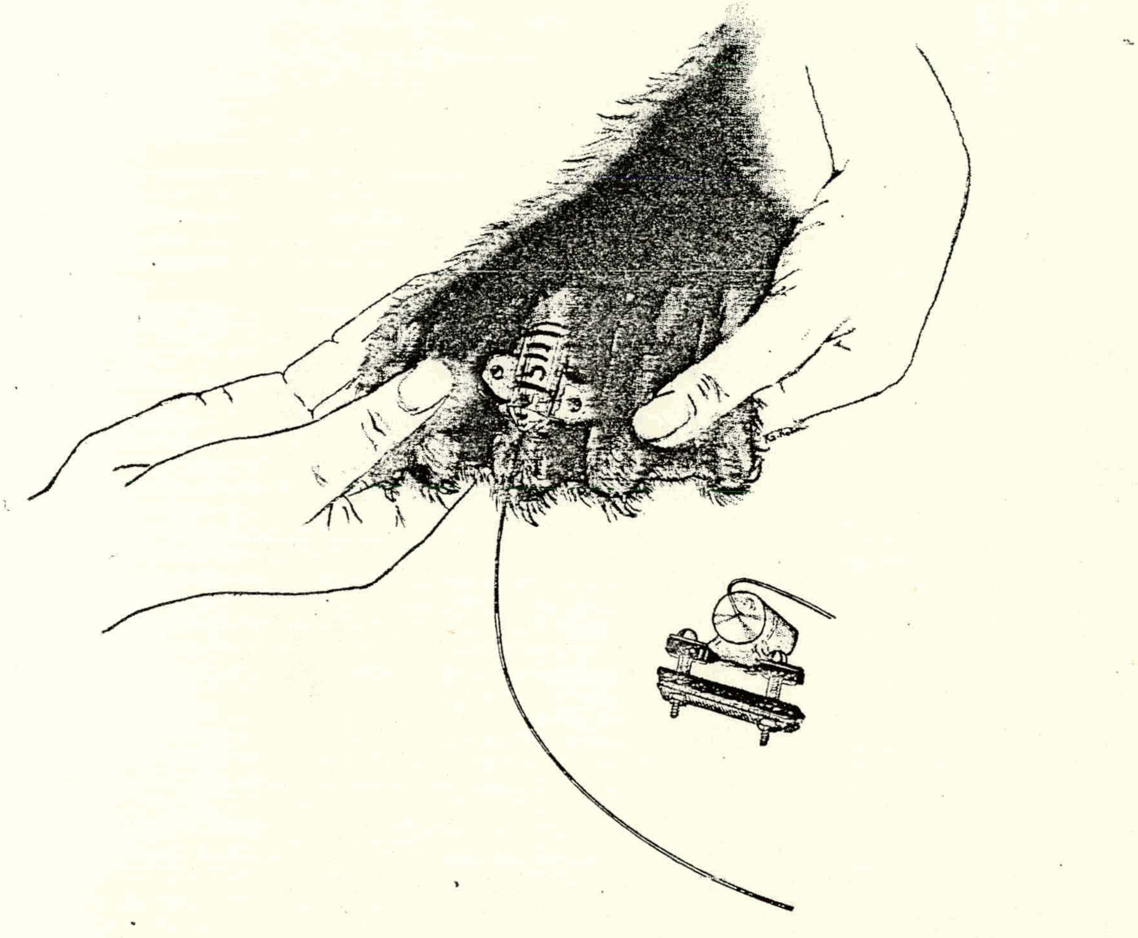


Fig. 2. Radio transmitter attachment for sea otters. Lower diagram shows cross-section of transmitter package. Upper diagram shows transmitter in place on otter's rear flipper.

seconds or less during each scan through the frequencies of instrumented otters programmed on the receiver. The activity of each otter was sampled 4-8 times every 10 minutes, depending on the number of otters being monitored. The percentage of active readings recorded in each 10 minute period was used as a random sample of activity. For the 1978 field season, a 4 minute sampling interval was used. These longer sampling intervals in 1978 permitted differentiation between feeding and other modes of activity, based on the amount of time the radio signal was interrupted. Interruptions of 30 seconds or more were considered feeding dives, and for each such case, a feeding dive time was measured. Independent observations of activity, made while animals were in visual range, were used to test the accuracy of the automatic monitoring station. There were many 4 minute intervals recorded on the strip chart where the activity could not be classified during the analysis; however, for those intervals where activity was determined, we considered the mode of activity recorded to be independent of previous and subsequent activities (i.e., each recording was a random sample of activity) and we considered each of the 3 categories of activity (feeding, resting, other activities) to be recorded with equal probability by the recording system (i.e. the system was unbiased).

Activity data were recorded both for control as well as experimental animals contaminated with 25 cc Prudoe Bay crude oil, covering 130-260 cm^2 of their anterior dorsal surface. All animals were adult males living in all-male groups and weighed between 20-35 kg. One animal was oiled in 1977, one in 1978 and two in 1979. Another animal in 1979 was oiled and then cleaned with Polycomplex-11 before release. This cleaning agent has been used by the California Department of Fish and Game for cleaning oil contaminated waterfowl, and was highly rated as a general cleaning agent for oil contaminated wildlife by Berkner et al. (1977).

Field work in 1977 was done in Sheep Bay, whereas field work in 1978 and 1979 was conducted in Simpson Bay (Fig. 1).

Experiment 2: Captive Observations

Studies on behavioral reactions of otters to oil on the water surface were carried out in 1977 in a 5 m diameter above-ground swimming pool set up on the shore adjacent to the National Marine Fisheries Facility in Olsen Bay (Fig. 1). The pool was filled with sea water to a depth of 120 cm and was divided in half by a partition extending about 30 cm into the water. Two equal sized haul-out platforms were constructed, one at each end of the partition (Fig. 3). Behavioral observations were made from a warehouse adjacent to the pool.

Two male otters from Sheep Bay, both weighing 28-29 kg, were used in this experiment. They were transported to a floating holding facility in Olsen Bay where they were left for at least 3 days to become accustomed to eating squid. One morning at 1000 hours they were placed in the swimming pool. Timed behavioral observations were taken over the next 8 hours to determine which side of the pool the otters preferred. At 1800 hours, 2 liters of Prudoe Bay crude oil was dumped into the side of the pool most preferred by the otters. This oil rapidly spread over the entire side of the pool. The partition worked well in restricting the oil to one side, but eventually the clean side became contaminated as the otters swam back and forth under the partition, occasionally surfacing in the oil.

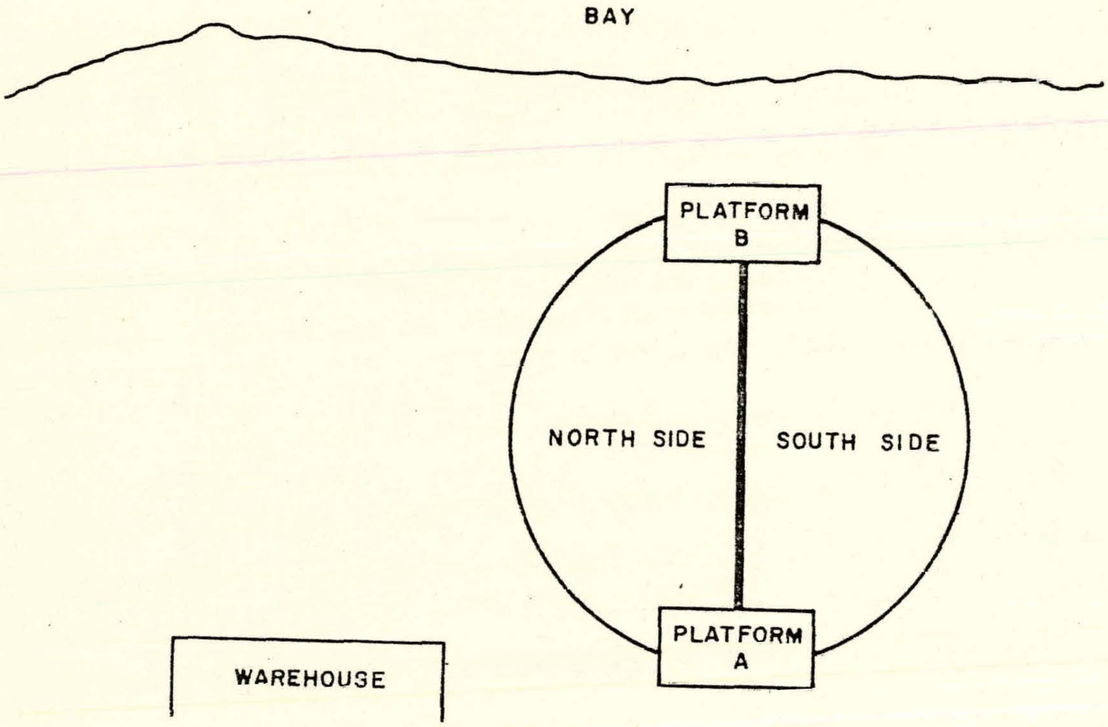


Fig. 3. Diagram showing design of facilities for oil contamination captive study, July 1977.

RESULTS

Experiment 1: Oil and Release

Three of the 4 otters oiled and released with radio-transmitters were appreciably more active than control animals during the first week after oiling. It was often difficult to receive any radio signal at all from these animals during this first week due to their extreme activity. The otter oiled in 1977 was very active for the first 4 days after release (Fig. 4), but then moved out of range of the automatic receiving station; thus, no further information could be obtained on this individual. The animal oiled in 1978 was monitored for about 3 weeks. The first week was represented by a high level of activity (P 0.01), the second week by a seemingly normal level of activity (P 0.05), and the third week by decreased activity (P 0.01) in relation to control animals (Fig. 5).

The daily pattern of activity was significantly different from the control group only during the second week (P 0.05), apparently because the oiled animal exhibited an unusually high percentage of activity during the hours 2000-2400 (Fig. 5). The activity pattern of the control group did not vary significantly (P 0.05) from a uniform distribution during any week of the study.

Both individuals oiled in 1979 were tracked for about 3 weeks. One animal was extremely active for the first 1 1/2 weeks, after which its activity was not significantly different from that of the control group. No decrease in activity comparable to the 1978 oiled otter was observed prior to the time the transmitter fell off, 19 days after capture. The other animal oiled in 1979 moved out of range of the receiving station shortly after capture, but activity was sampled at least once daily using portable tracking equipment and visual observations. No significant

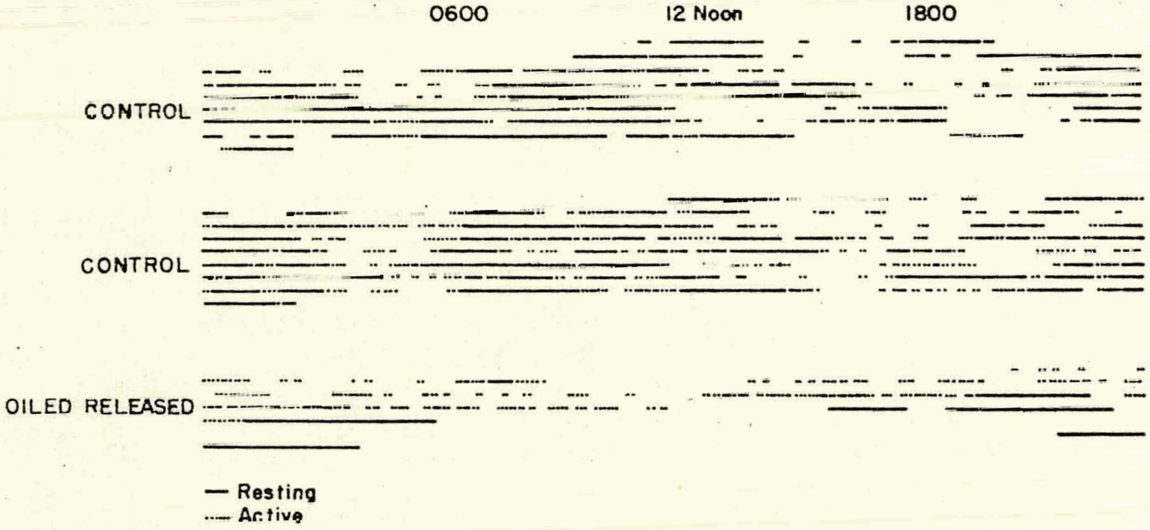


Fig. 4. Twenty-four hour activity patterns obtained via telemetry for a sea otter partially soiled with oil and two control animals, July 1977.

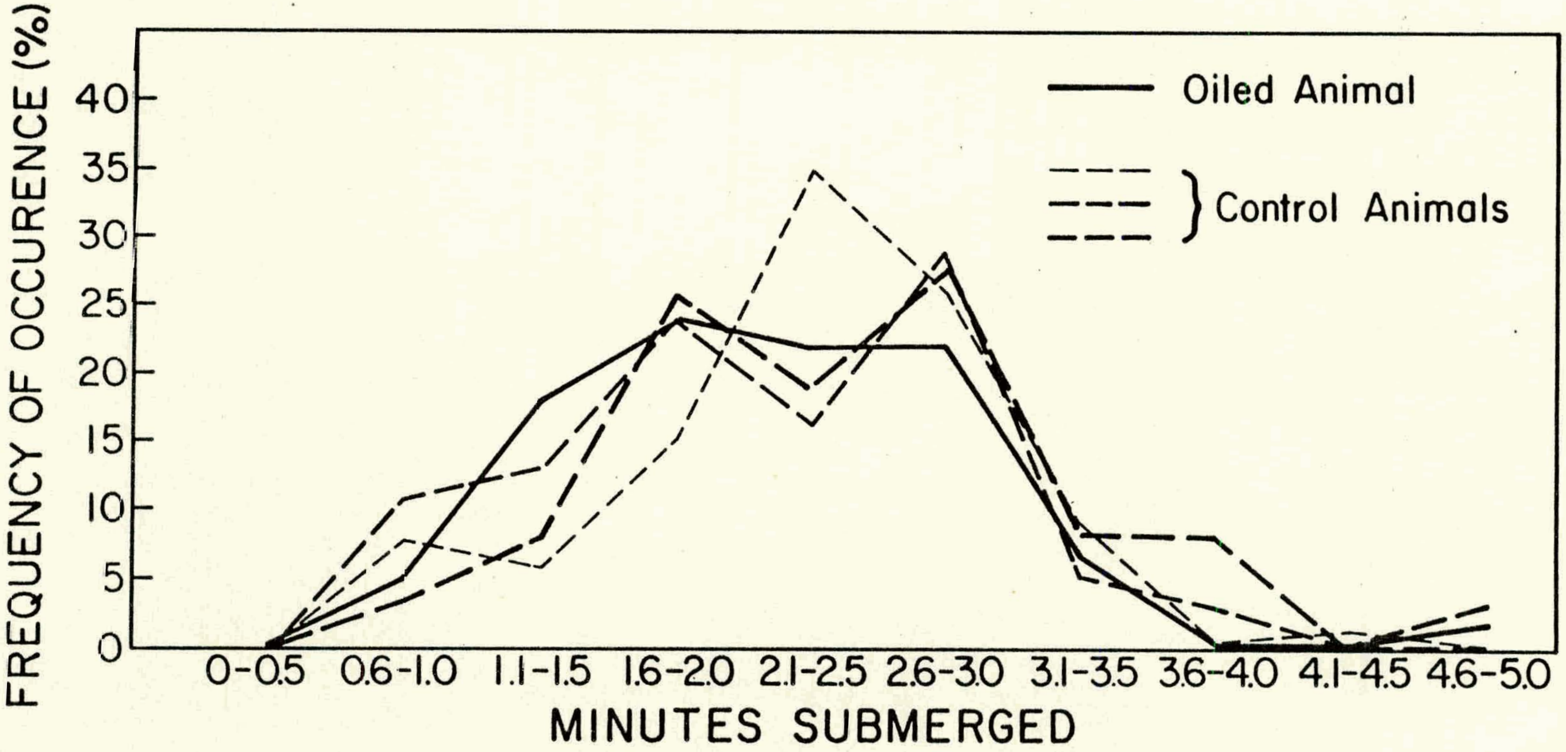


Fig. 5. Comparison of activity pattern and level of activity for an otter partially oiled and a control group, during 3 successive weeks after oiling. Data were obtained by telemetry monitoring. Level of activity of oiled otter was significantly above control group during first week and significantly below control group during third week. Level of activity significantly different between successive weeks for control group. Activity pattern significantly different for oiled and control group only during second week.

alterations in activity were apparent for this individual even during the first week after oiling. However, the different monitoring procedure used for this individual made comparisons of its activity with that of other otters difficult.

The otter oiled and cleaned in 1979 was significantly more active than control otters for the first 2 weeks after release (P 0.01), whereas activity returned to near average levels during the third and fourth weeks.

From the standpoint of their activity, both oiled and cleaned otters appeared to be recovering from the contamination of their pelage. This observation is related to the diminishing levels of activity by these individuals, as well as the concurrent increase in activity of control animals to which experimental individuals were compared. In 1978, control animals were more active the first week of August than the last week of July (P 0.01)(Fig. 5). In 1979, control animals were more active the first 2 weeks of September than the last 2 weeks of August (P 0.05).

A comparison of the dive times recorded on the strip chart in 1978 for the oiled animal and 3 control animals shows no evident difference in distribution (Fig. 6). Nevertheless, it cannot be assumed that the oiled animal did not change to a different feeding strategy (e.g. gathering more food per dive) or a different food source. Oiling apparently did affect feeding frequency. In 1978 during the first week after contamination, the oiled individual spent a smaller proportion of time feeding than control animals (Table 1). However, because the oiled otter was extremely active (its radio antenna was frequently submerged)

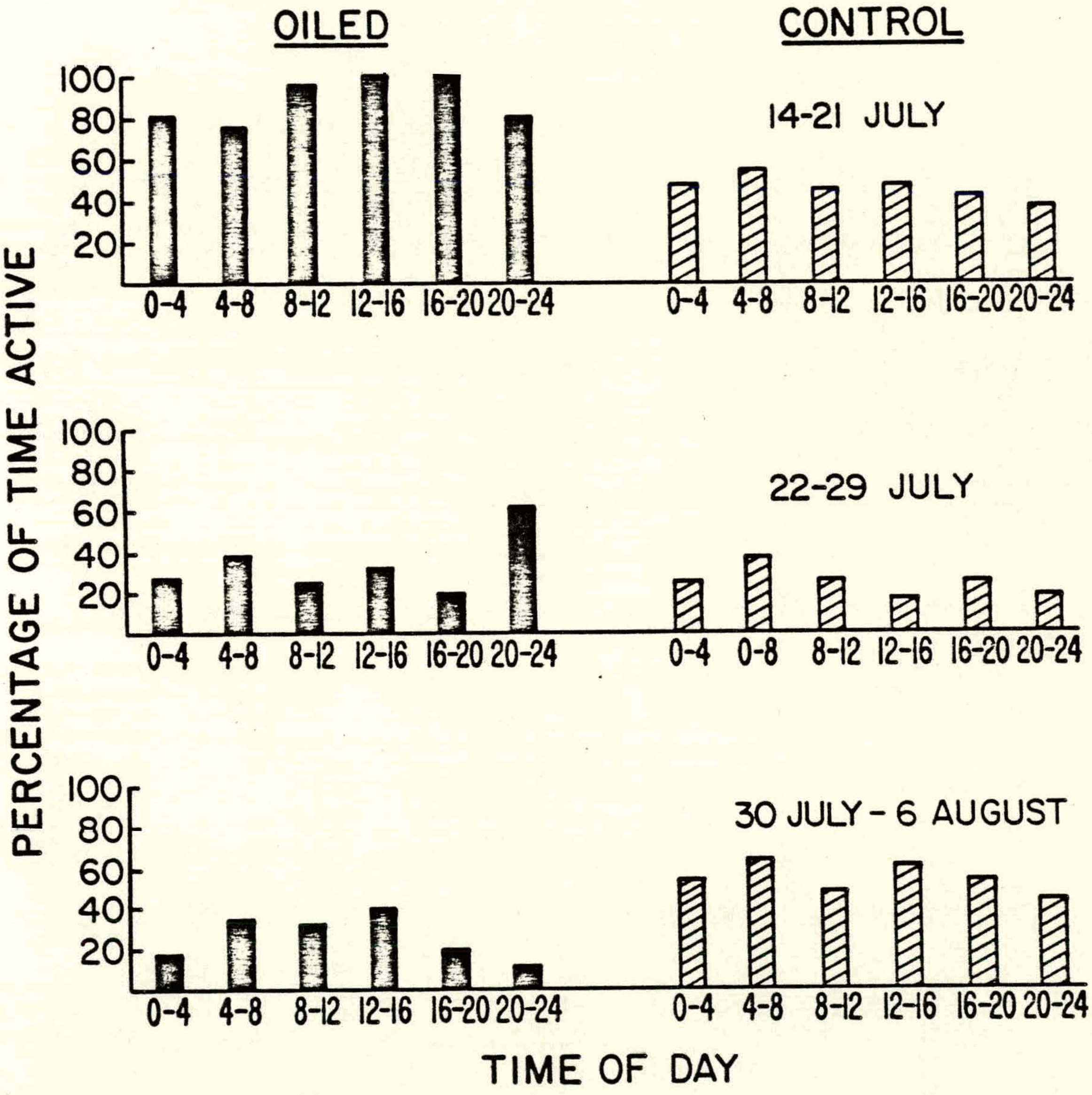


Fig. 6. Comparison of frequency of dive times during feeding for a partially oiled otter and 3 non-oiled otters, July 1978.

and often far from the tracking station (the radio signal was weak) during the first 4 days after contamination, we tested for differences in activity during days 1-4 and days 5-8 independently. During both of the time periods, the oiled otter fed less frequently than control otters, although the difference was less dramatic during the second 4 day period than during the first. This suggests that the feeding regime was interrupted most just after oiling. Grooming was apparently the principal activity during this period (Table 1). During the second week, after oiling, no significant differences were observed in the frequency of feeding, grooming and resting by oiled and control animals (Table 1). By the third week, however, the oiled animal spent less time feeding and grooming and more time resting than did control animals (Table 1).

Experiment 2: Captive Observations

The captive experiment involving the oil contamination of one side of a swimming pool containing 2 sea otters indicated that the animals were aware of the oil and preferred to avoid it. Immediately after addition of the oil to the pool at 1800 hours, the otters became nervous and curious, even though the oil was contained on the opposite side of the partition. Intensity of feeding and grooming increased, and occasionally the otters would rear up on the partition and stare at the oil. They also made what seemed to be more determined efforts to escape than had previously been noted. However, the oil was not totally avoided. When swimming under water around the perimeter of the pool, the otters would occasionally surface on the oiled side, but would remain for only a few seconds, quickly diving back under water. While the otters spent less than one minute per hour on the oiled side, they both eventually became covered with a coat of oil. One otter intermittently raised its head and shoulders out of the water and shook itself vigourously, presumably in attempt to rid itself of the oil. Feeding was fairly frequent for the first several hours of the experiment, but resting became more prevalent as the otters were observed through the night. One of the otters preferred resting on a haul-out platform, but this behavior was noted prior to the addition of oil.

The otters were removed from the pool at 0600 the next morning, 12 hours after encountering the oil. One otter was cleaned with Polycomplex -11. The oiled fur was wet with the cleaning agent, rinsed in sea water, and rubbed thoroughly with towels. The animal was then allowed to dry and groom itself for 8 hours before being placed in the floating holding facility. The fur immediately became saturated with water, whereupon the animal was removed, re-dried, and left overnight in a dry pen. The next day a transmitter was attached, and this animal was released back in Sheep Bay. Malfunction of the transmitter 24 hours later precluded further observation of this animal.

The other otter was not cleaned, but placed back in the floating holding facility where it died 10 hours later. Gross autopsy and histopathology suggested hypothermia as the cause of death, although toxicity from ingestion of oil groomed off the fur, could not be entirely discounted.

DISCUSSION

Increased activity by otters partly contaminated with oil was expected, considering the animals' needs to maintain body temperature and weight. Costa and Kooyman (1979) observed metabolic rates 40% above average for sea otters with oil applied to 20% of their body surface. These experiments with oiled and released otters suggest that otters spend considerable time grooming in an effort to remove the oil and restore the insulatory properties of the pelage. Vigorous grooming by one of the oiled otters in the pool experiment was observed. Within one week after contamination, grooming appeared to subside. Whether by that time the animals had removed a substantial portion of the oil, or could not continue excessive grooming due to energy constraints is unknown. One otter exhibited seemingly normal activity during the third week after contamination, whereas activity of another oiled individual appeared depressed during the third week. We could not determine the fate of individuals past the third week after oiling, but extensive searches of the shoreline in 1978 and 1979 failed to reveal carcasses of any of the otters oiled in 1977 and 1978. Normally sea otters haul out on land just prior to death, or if they die in the water, are subsequently washed ashore. Thus, we feel it is probable that these otters survived the oiling experiments.

One otter that was not part of these experiments was apparently debilitated by pneumonia when captured in 1979. We followed the individual using radio-telemetry and noted several aberrant behaviors. Activity was greatly depressed and the activity pattern itself was abnormal. Social interactions, usually quite extensive in this portion of Prince William Sound where males congregate in large groups, were avoided as this individual moved into an area entirely devoid of other otters. It eventually died and was found on the beach. That none of the oiled or oiled and cleaned otters exhibited abnormalities in movement or social behavior attests to our conclusion that, at least during the time we observed them, these otters were not fatally ill.

In view of the increased grooming and increased metabolism of oiled otters, both necessary for thermoregulation, alterations in the feeding strategy of these animals to compensate for the greater expenditure of energy were anticipated. No changes were observed in the distribution of dive times (indicative of the kinds of food sought and the area used for feeding), whereas the frequency of feeding dives actually decreased just after oiling. Therefore, it seems likely that oiled otters were not able to increase food consumption in response to greater energy demands, and thus may have been losing weight. However, because of the recent expansion of the otter population into this study area, food resources appear to be more abundant than in other parts of Prince William Sound where otters have been established for several years (Ancel Johnson, pers. observ.). Thus, otters are apparently heavier in this study area than elsewhere in the Sound. It is likely that oil contamination could have more deleterious effects on otters in areas of high density and diminished food supplies.

The fact that oil was applied to less than 10% of the surface area of experimental otters in our study also may have permitted their eventual recovery. In the captive experiment, one animal was left completely covered with oil and died less than 24 hours after soilage. Complete contamination of the pelage may be likely where otters encounter oil spills under natural situations.

Natural oil spills, however, may be circumvented by sea otters. The captive experiment indicated a preference to escape the oil, although the confined area of the swimming pool may have precluded total avoidance.

Nonetheless, it is probable that at least some otters would be contaminated by an oil spill in Prince William Sound. This possibility prompted the cleaning experiments. Results of these experiments indicated that otters oiled and cleaned with detergent are even more active than otters oiled and released uncleaned. Evidently the detergent removes natural body oils necessary to prevent saturation of the fur (Williams, 1978). Also, Costa and Kooyman (1979) found that metabolic rates of otters subjected to cleaning were almost 50% higher than animals subjected only to oiling. Some seabird cleaning experiments utilized synthetic compounds to replace the natural water repellent compound from the preening gland which had been removed by the detergent (Larsson and Odham 1970). Because the micro-structure of bird feathers, destroyed by the oiling and cleaning, is probably more important in preventing saturation than the waxy compound from the preening gland, attempts to restore oil contaminated seabird feathers have been generally unsuccessful (Clark 1978). In contrast, natural oils are probably more important for water repellency in aquatic mammals. Thus, future cleaning studies with sea otters should seek a substance which could be added to the fur to temporarily restore the water repellent properties after cleaning. Further studies are also needed to improve capture and immobilization techniques if they are to be used in attempts to rescue oil-contaminated sea otters. Such rescue attempts may not be feasible, or, if otters can survive at least partial soiling of the pelage, may not even be necessary. Long term studies of oiled otters are needed to evaluate the latter possibility.

LITERATURE CITED

Atlas, R. M., A. Horowitz, and M. Busdosh. 1978. Prodoe crude oil in arctic marine ice, water, and sediment ecosystems: degradation and interactions with microbial and benthic communities. J. Fish. Res. Board Can. 35:585-590.

Barabash-Nikifirov, I. I., V. V. Reshetnikov, and N. K. Shidlovshaya. 1974. The sea otter. Transl. from Russian by A. Birron and Z. S. Cole, Israel Prog. for Sci. Transl., 1962. Jerusalem. 227 pp.

Berkner, A. B., D. C. Smith, and A. S. Williams. 1977. Cleaning agents for oiled wildlife. Ecolibrium 6(3):15-19.

Clark, R. B. 1978. Oiled seabird rescue and conservation. J. Fish. Res. Board Can. 35:675-678.

Costa, D. and G. Kooyman. 1979. Effects of crude oil contamination on the sea otter's ability to thermoregulate. Paper presented at the Third Biennial Conference on the Biology of Marine Mammals, Oct. 1979, Seattle, Wash.

Davis, J. E. and S. S. Anderson. 1976. Effects of oil pollution on breeding grey seals. Mar. Pollution Bull. 7:115-118.

Ellis, D. V. 1979. Sea otters at risk from oil spills. Mar. Pollution Bull. 10:68.

Gelder-Ottway, S. V. and M. Knight. 1976. A review of world oil spillages 1960-1975. Pages 483-520 in J. M. Baker ed. Marine Ecology and Oil Pollution. J. Wiley and Sons, N.Y. 566 pp.

Geraci, J. R. and T. G. Smith. 1976. Direct and indirect effects of oil on ringed seals (Phoca hispida) of the Beaufort Sea. J. Fish. Res. Board Can. 33:1976-1984.

Gilfillan, E. S. and J. H. Vandermeulen. 1978. Alterations in growth and physiology of soft-shelled clams, *Mya arenaria*, chronically oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-76. J. Fish. Res. Board Can. 35:630-636.

Hartung, R. 1967. Energy metabolism in oil-covered ducks. J. Wildl. Manage. 31:798-804.

Kenyon, K. W. 1969. The sea otter in the eastern Pacific Ocean. U.S. Bur. Sport Fish. Wildl., N. Amer. Fauna 68. 352 pp.

Kooyman, G. L., R. L. Gentry, and W. B. McAlister. 1976. Physiological impact of oil on pinnipeds. U.S. Dept. Commerce, unpublished mimeo report, Dec. 1976, 23 pp.

Krebs, C. T. and K. A. Burns. 1977. Long-term effects of an oil spill on populations of the salt-marsh crab *Uca pugnax*. Science 197:484-487.

Larsson, K. and G. Odham. 1970. Larodan for cleaning oiled seabirds. Mar. Pollution Bull. 1:122-124.

McEwan, E. H., and A. F. C. Koelink. 1973. The heat production of oiled mallards and scaup. Can. J. Zool. 51:27-31.

McEwan, E. H., N. Aitchison, and P. E. Whitehead. 1974. Energy metabolism of oiled muskrats. Can. J. Zool. 52:1057-1062.

Vandermeulen, J. H. 1978. Introduction to the symposium on recovery potential of oiled marine northern environments. J. Fish. Res. Board Can. 35:505-508.

Williams, T. D. 1978. Chemical immobilization, baseline hematological parameters and oil contamination in the sea otter. Report No. MMC-77/06, Final report to Marine Mammal Commission, 1625 I Street N.W., Washington, D.C. 20006.

Wragg, L. E. 1954. The effect of D.D.T. and oil on muskrats. Can. Field Nat. 68:11-13.

Table 1. Frequency of categories of activity of an oiled sea otter versus a control group during 3 successive weeks after oiling. Active, non-feeding category refers primarily to grooming.

	Week 1		Week 2		Week 3	
	Oiled individual	Control group	Oiled individual	Control group	Oiled individual	Control group
Feeding	17	136	28	88	12	65
Active, not feeding	92	179	45	99	26	176
Resting	20	402	142	474	108	222
	**		NS		**	

** X^2, p 0.01

APPENDIX B

CORROSIVE LINKS FOR USE
WITH ANIMAL BIOTELEMETRY

Marvin J. Ross

University of Minnesota
Department of Ecology
Minneapolis, Minnesota 55455

February 1980

INTRODUCTION

Radio telemetry techniques have developed in the last 20 years to the point where they are consistently providing information to wildlife researchers, unobtainable with other methods. Typically, a telemetry study involves capturing an animal followed by transmitter application and subsequent release of the animal back to its natural surroundings. Generally, the useful life of a radio transmitter is from 15 days to 3 years depending on the battery size an animal can carry. Transmitter life is usually less than the life expectancy of the tagged animal. Therefore, when the transmitter's useful life is finished, it is desirable to remove the transmitter so that the tagged animal is not unnecessarily burdened with carrying a non-functional transmitter.

Transmitter removal is often impractical, especially for marine mammals, because recapture is usually difficult, expensive, time consuming, and in some cases impossible. Recapturing externally tagged animals with nets also poses problems of transmitter entanglement and injury to the animal. All of these problems are magnified in polar ocean environments where field seasons are short, animal handling facilities are limited and working conditions are subject to drastic weather changes.

In January 1979, as part of ongoing marine mammal research, the Cedar Creek Bioelectronics Laboratory initiated a limited program to develop transmitter attachments that would decay with time. Thus, spent transmitters would release from an animal precluding the need for recapture.

EXPERIMENTAL APPROACH AND RATIONALE.

Both active and passive release mechanisms were considered. Active mechanisms include transponder devices such as guilitines or explosive capsules that could sever attachment connections upon command from a radio frequency signal. The advantage of such devices is close control over release timing. However, there are several significant disadvantages. Active release mechanisms could add considerably to transmitter size and weight, and would not function in cases when the tagged animal was out of radio contact. They could substantially increase battery drain and shorten transmitter operating life. Additionally and potentially the largest drawback, is the possibility of injury to the tagged animal from active severing devices. Passive release mechanisms typically depend upon chemical breakdown with time such as corrosion or hydrolysis. Advantages of chemical release devices include: 1. small size, 2. ready incorporation into existing attachment methods, 3. no power consumption, 4. no range restriction on tagged animals, 5. low cost, 6. reduced potential for injury. The only disadvantage is that chemical reactions subject to environmental variables are not easily controlled. Due to the problems and cost of active release mechanisms we decided to pursue passive release mechanisms.

Two types of passive release were selected for initial experiments; corrosive links and absorbable sutures. Corrosive links operate on the principle of galvanic corrosion when two dissimilar metals are in contact with salt water. Metal from the anode is oxidized until the it disappears. Absorbable sutures have been used for many years in the medical field and opperate by water hydrolyzing the suture material.

Galvanic corrosion is subject to several variables including temperature, salinity, metal ratios, metal configurations, metal combinations, exposure time and type, and differences in stress on the corrosive link. Therefore, it is difficult to predict with confidence what the corrosion rate will be. Especially difficult is the problem of exposure time and type because the amount of time a transmitter is alternately exposed to saltwater and/or air is determined by the behavior of a tagged animal. Furthermore, behavior can change with age, season, sex, reproductive status, etc.

The general approach for the initial tests was to observe several metal combinations holding all other variables constant to find a combination of metals that would deteriorate roughly in a time frame of two weeks to two years. Secondly, we wanted to look at the effects of cathode to anode ratio, temperature, salinity, and differing configurations to determine effects of these variables on corrosive rates. The two remaining variables; stress, and exposure time and type were not examined because they were beyond the scope of initial testing.

METHODS

1. Metal Combinations

Six metals; brass, steel, aluminum, zinc, monel, and magnesium were selected for preliminary analysis. These metals were either purchased commercially or machined from raw stock to 10-24 x 1" machine screws and nuts. In all cases screws formed the cathode and nuts formed the oxidizing anode. Table 1 presents the combinations for this test. Combinations were selected based on the position of each component in the E.M.F. Series (Fontana & Green 1978). All combinations were immersed in instant ocean saltwater 30-35% (normal sea water salinity) in aerated aquaria at room temperature (21^{o}C nominal). The experimental procedure was to remove the corrosive links for approximately 8 hours each day for air exposure followed by 16 hours of continuous immersion. Based on preliminary results, brass, steel, aluminum and magnesium were selected for further testing. Preliminary magnesium tests were conducted somewhat differently because of magnesium's fast corrosion rate in salt water. First, circular magnesium 6/32 nuts were machined from raw stock. These nuts were then applied to brass and nylon 1" machine screws. The combination was continuously immersed in 1' L beakers of salt water at room temperature. Second, identical magnesium nuts were dipped in scotchcast electrical resin for corrosion protection. Third, identical magnesium nuts were coated with scotch cast resin and a #56 drill used to bore 4 holes through each side of the nut. This last trial was an attempt to obtain faster more even corrosion than was observed with the totally coated nuts. The coated and coated-drilled nuts were treated the same as other magnesium combinations.

Table 1. Metal combinations, 10-24 X 1" machine screws and nuts.

Cathode (machine screws)	Anode (nuts)			
	Steel	Aluminum	Zinc	Magnesium
Brass	X	X	X	X
Steel		X	X	
Monel	X	X	X	

Table 2. Metal ratios, machine screw-nut configuration.

Cathodes, (brass machine screws)	Anodes			
	Steel Nuts			
	4-40	2-56	6-32	2-56 modified to 4-40
4-40 X ½"	X			
4-40 X 1"	X			
4-40 X ½"				X
4-40 X 1"				X
2-56 X ½"		X		
2-56 X 3/4"		X		
6-32 X ½"			X	
6-32 X 1"			X	
6-32 X 2"			X	

Table 3. Metal ratios, washer-pin configuration.

Cathodes washers	Anodes					
	Rods (0.22 Dia).		Steel Cotter pins (Diameter in mm)			
	Steel	Aluminum	0.12	0.20	0.28	0.35
Brass 5/8"	X	X	X	X	X	X
Steel 5/8"		X				

2. Metal Ratios

The effect of cathode to anode ratio was tested with brass machine screw cathodes and steel nut anodes. Varying lengths of machine screws were equiped with standard size nuts, except 4-40 x 1" and 4-40 x 1/2" screws were also tested with 2-56 nuts that had been drilled and retapped to fit 4-40 screws. Table 2 summarizes the combinations. Experimental procedure was identical to that used in the metal combination tests.

3. Metal Configurations

A second corrosive link configuration consisting of a large washer cathode and a pin anode was tested to observe configuration differences. Table 3 summarizes these tests. Included in this experiment were varying ratios of cathode to anode by using different sized cotter pins. Again the experimental procedure consisted of immersion in room temperature seawater for 16 hours followed by an 8 hour air exposure.

4. Temperature

Temperature effects are being tested using a single configuration of brass 4-40 x 1" machine screws and steel 4-40 nuts. Experimental procedure remains identical to that described for other experiments with the addition of aquaria at 7°C and 30°C.

5. Salinity

Brass 4-40 x 1" machine screws and steel 4-40 nuts are also being tested in fresh tap water to contrast salinity effect. Again experimental procedure remains identical to that described for other tests.

6. Miscellaneous tests

Five other tests are being conducted. First vicryl 0 and 4-0 size absorbable suture material (Ethicon corp.) was sewn to a thin plastic sheet and tested with the same experimental procedure used for corrosive links. Secondly, 6-32 x 1/4" nylon, brass and steel machine screws were continuously immersed in a beaker of concentrated sulfuric acid at room temperature. Based on the results from the acid test, steel bolts were selected for an acid-bolt design. Steel bolts 1/4" x 1 1/2" were drilled out from the top one third of the way down the center line of the bolt. The hole was then tapped so a teflon coated cap screw could cover the hole. The resulting wall thickness of the bolt was .040". Half of the bolts were then machined down to a wall thickness of .020". Varying concentrations of sulfuric acid were then injected into the cavity and the bolt sealed with a teflon coated cap screw. Spring tension was applied between the bolt and nut to assist with a cleaner break when (if) the acid had sufficiently deteriorated the bolt. Fourth, three sea otter transmitters are currently on the usual laboratory test procedure at 5°C. These transmitters have two brass 8-32 x 1" machine screws drilled in cross section and secured by 1, 3/32" diameter cotter pin. We have not tested this exact cathode/anode configuration in the laboratory. However, these transmitters, identical in all respects to those currently being used in California and Alaska, will serve as a good indicator of how close our laboratory testing procedure estimates corrosive rates in the natural environment. Finally, in one short term experiment we attempted to accelerate and retard galvanic corrosion by polarizing the cathode and anode. An external 12 VDC power source was connected to a brass cathode and magnesium and steel anodes in a 1 L beaker of saltwater.

Measurements of corrosion rates were made in two ways. First, anodes were removed from the corrosive link, excess oxides mechanically removed and then the anode weighed. However, as corrosion progressed, anode removal became impossible so anodes were measured with a calipers after oxides had been removed. Each data point generally represents one sample. Since, removal of oxides for measurement alters the test conditions, the measured link can no longer be used for test purposes. Therefore, sampling in any one test group is limited.

RESULTS

1) Metal Combinations

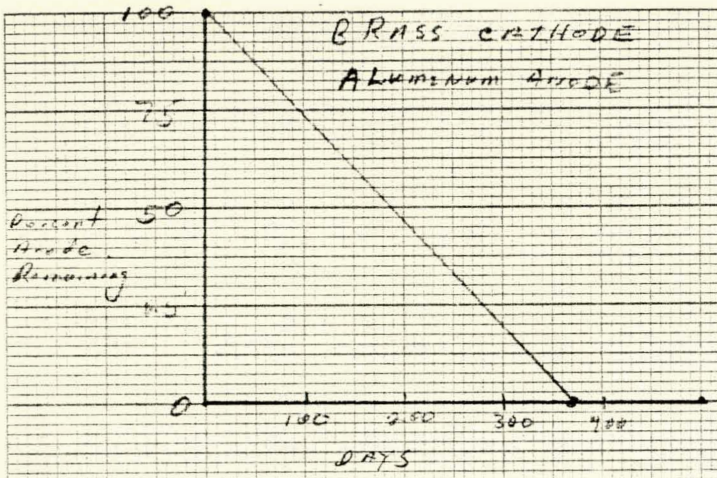
Figure 1 presents results for 370 days of testing various metals in saltwater. Brass and monel cathodes with either steel or aluminum anodes appear to corrode at rates that are closest to what we need for long life transmitters. Zinc anodes show very slow (if any) corrosion. Monel was found to be very difficult to machine and not readily available in most configurations. Since there was little difference in corrosion rates between brass and monel cathodes, we used brass cathodes for further tests. Aluminum showed little initial corrosion. The nut became covered and probably insulated by a white oxide. Also aluminum corrosion rates were more variable than steel, so steel was selected as the anode for further testing.

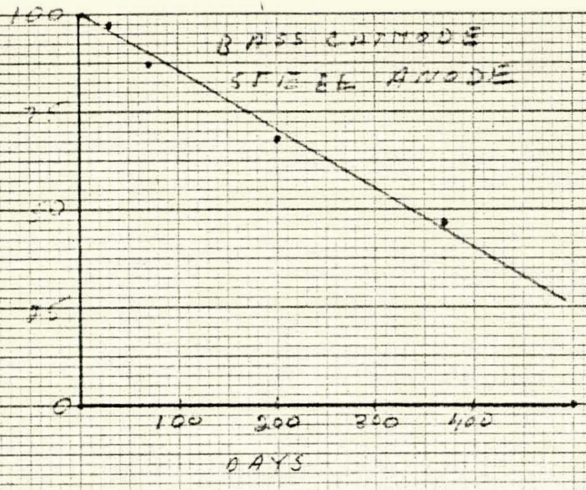
Unprotected magnesium nuts coupled to brass screws were oxidized in 48 to 96 hours after immersion. Scotch cast protected anodes lasted between 25 and 30 days coupled to brass screws. Scotch cast protected magnesium nuts also lasted approximately 30 days when applied to inert nylon screws. This suggests that the self oxidation of magnesium in saltwater is more important than galvanic effects. When protected and unprotected magnesium nuts alone were immersed in saltwater the unprotected nuts lasted longer. However, amonolous results were obtained with the coated-drilled nuts in the various tests. The drilling increased corrosion rates in some tests while retarding it in others.

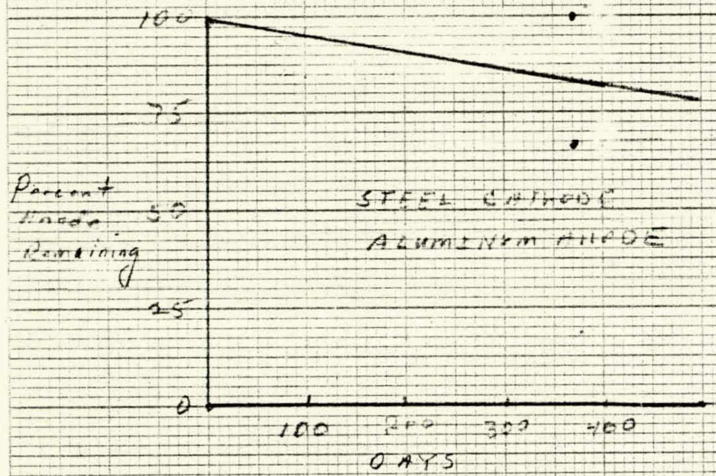
2) Metal Ratios

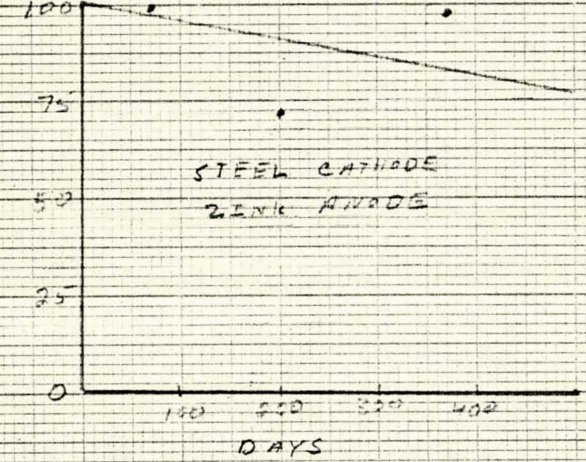
The metal ratio tests with brass cathodes and steel anodes indicated a variety of corrosion rates could be obtained by selecting cathode to

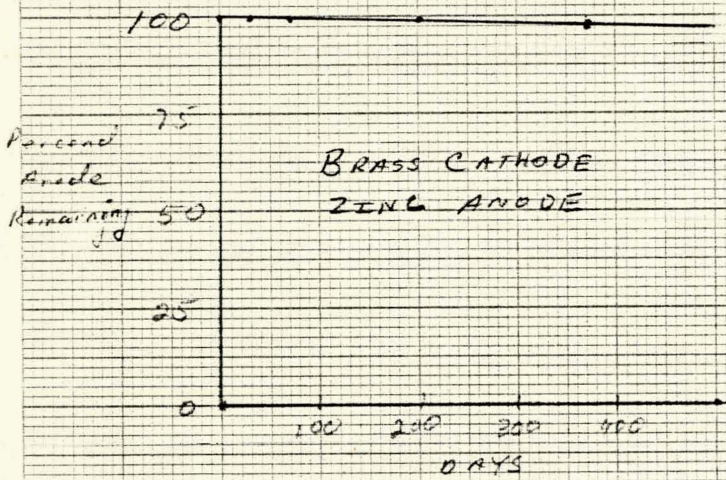
Figure 1. Expected corrosion rates for various metal combinations. All combinations are 10-28 machine screw cathodes with 10-28 nut anodes.

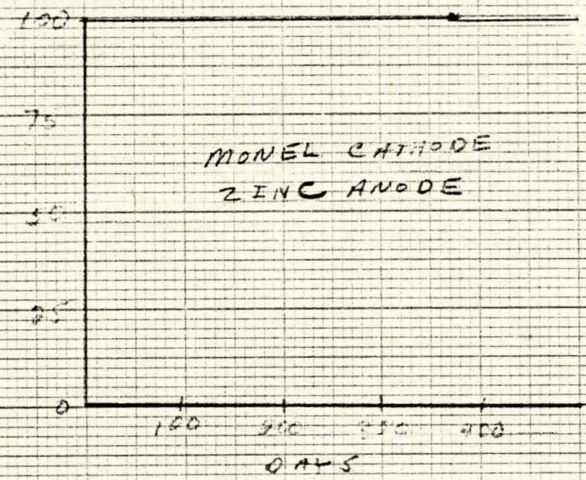

BRASS CATHODE
ALUMINUM ANODE
Percent Anode Remaining
100
75
50
25
0
100
200
300
400
DAYS

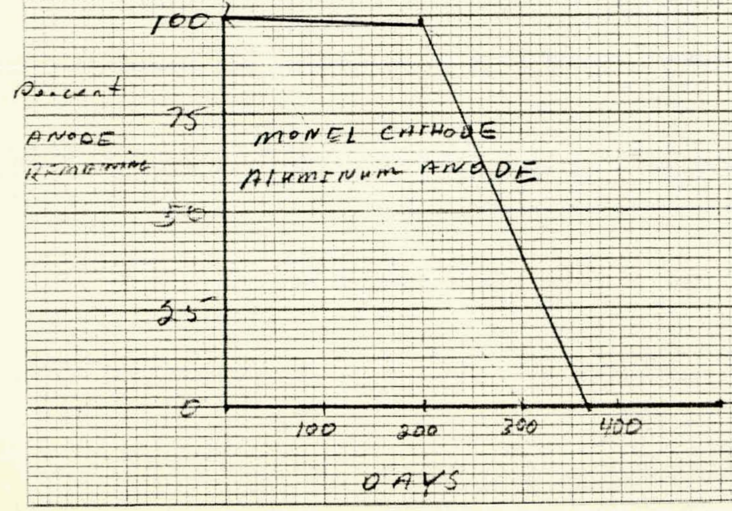

BRASS CATHODE
STEEL ANODE
100
75
50
25
0
100
200
300
400
DAYS

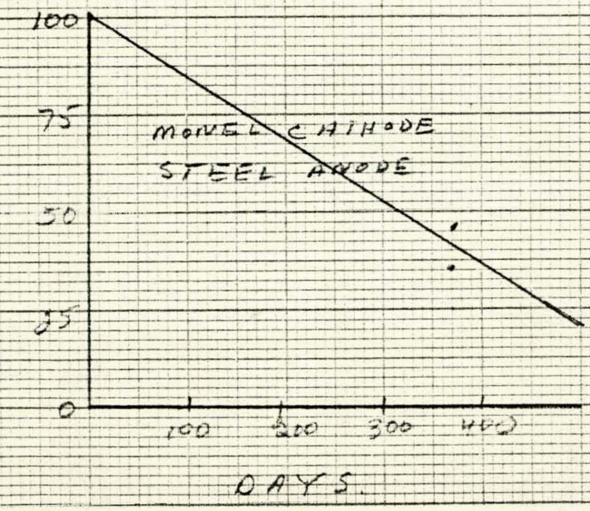

STEEL CATHODE
ALUMINUM ANODE
Percent Anode Remaining
100
75
50
25
0
100
200
300
400
DAYS


STEEL CATHODE
ZINC ANODE
100
75
50
25
0
100
200
300
400
DAYS


BRASS CATHODE
ZINC ANODE
Percent Anode Remaining
100
75
50
25
0
100
200
300
400
DAYS


MONEL CATHODE
ZINC ANODE
100
75
50
25
0
100
200
300
400
DAYS


MONEL CATHODE
ALUMINUM ANODE
Percent ANODE REMAINING
100
75
50
25
0
100
200
300
400
DAYS


MONEL CATHODE
STEEL ANODE
100
75
50
25
0
100
200
300
400
DAYS.

anode ratio (Fig. 2). The fastest rate was obtained with 4-40 x 1" cathode coupled to a undersize (2-56) nut. These nuts were completely oxidized approximately 250 days after initial immersion. Other combinations of small sized brass machine screws coupled to steel nuts resulted in corrosive rates expected to completely oxidize the anode between 280 and > 500 days.

3) Metal Configurations

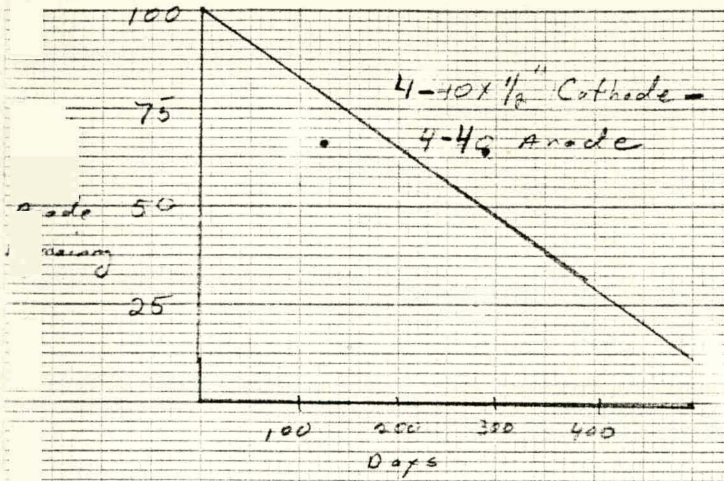
The second metal configuration consisting of large washer cathodes and pin type anodes indicated a brass and steel link was best for this configuration (Fig. 3). Corrosive rates for oxidation of the pin varied from 120 to > 500 days. While combinations of steel with aluminum and brass with aluminum showed very little if any corrosion.

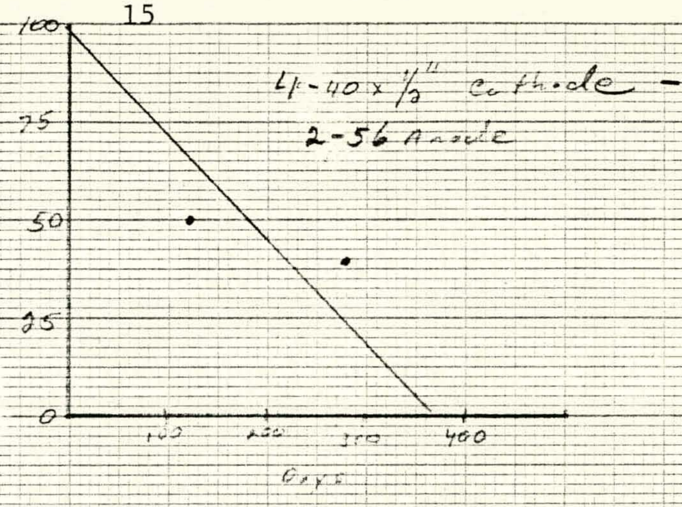
Two significant results became apparent when corrosive rates are compared between the nut-screw configuration and washer-pin configurations. The cathode to anode ratio was plotted against time expected for complete anode oxidation for each configuration (Fig. 4). First, for a given cathode to anode surface area ratio, the 'washer-pin' link corroded approximately 33% faster than the nut-screw configuration. Secondly, the linear correlation coefficient between cathode to anode ratio and time was -0.96 for the washer-pin configuration compared to a coefficient of -.53 for the nut-screw combination. This indicates that corrosion rates in the washer-pin configuration were much more predictable.

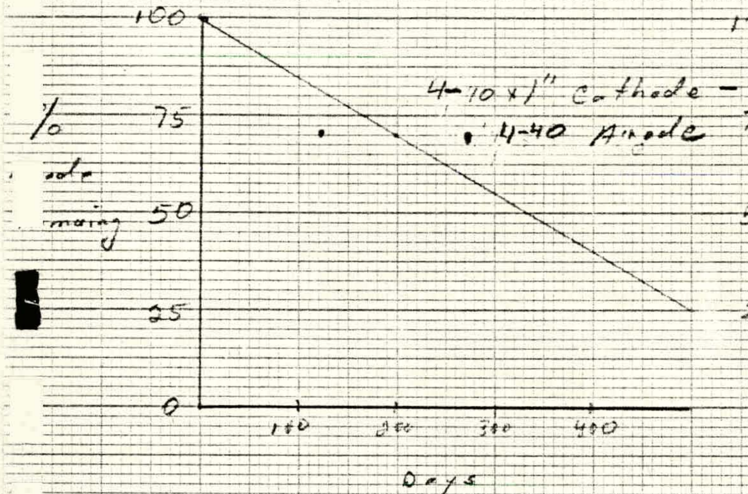
4. & 5. Temperature and Salinity

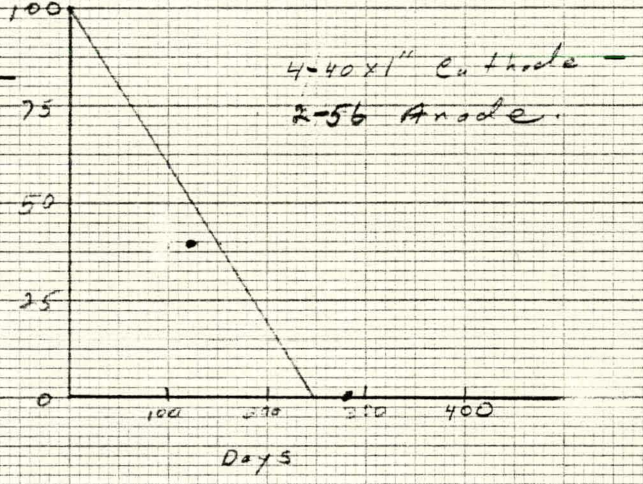
Temperature and salinity tests were begun between Sept. 15, 1979 and January 29, 1980. Sufficient time has not elapsed to evaluate these parameters.

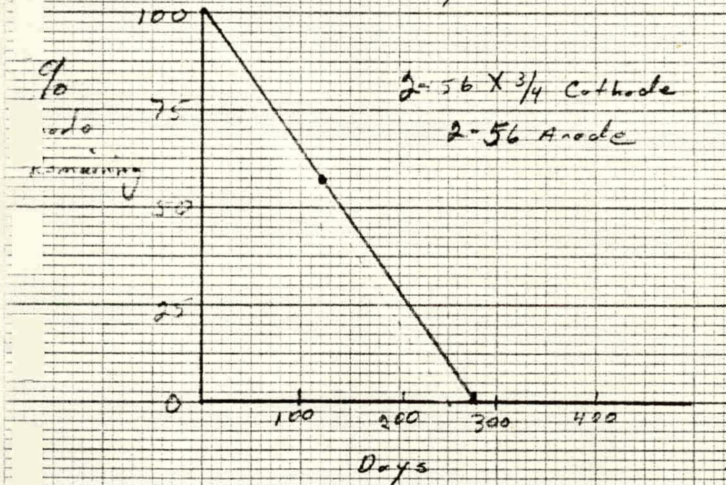
Figure 2. Expected corrosion rates for various cathodes to anode ratios with brass machine screw cathodes and steel nut anodes.

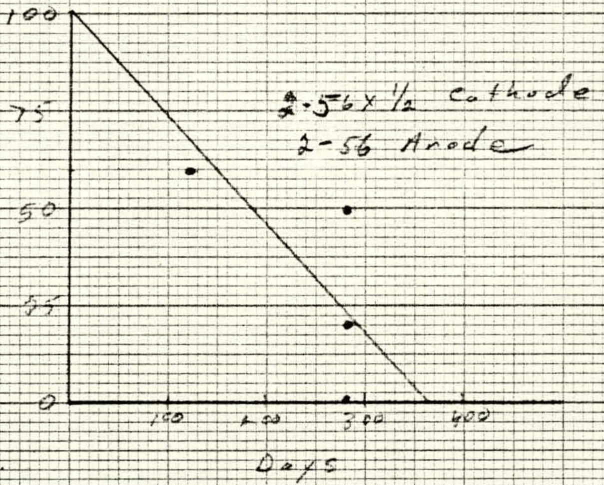

4-40 x 1/2" Cathode -
4-40 Anode
100
75
50
25
ode
aining
100
200
300
400
Days

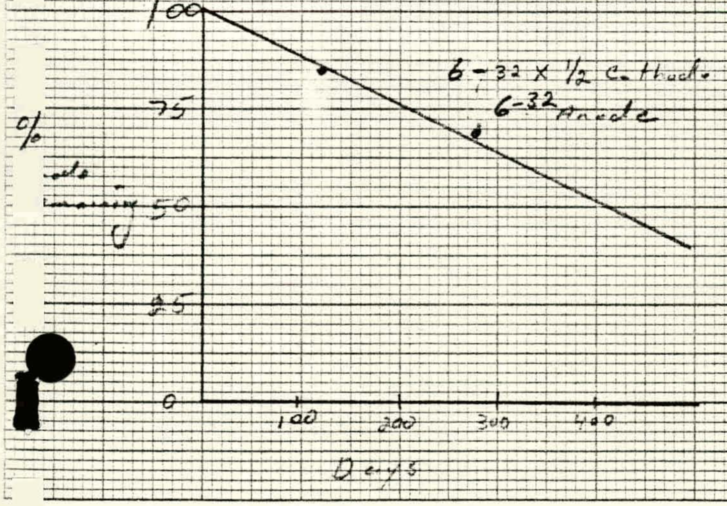

4-40 x 1/2" Cathode -
2-56 Anode
100
75
50
25
0
100
200
300
400
Days


4-40 x 1" Cathode -
4-40 Anode
%
ode
maining
100
75
50
25
0
100
200
300
400
Days


4-40 x 1" Cathode -
2-56 Anode.
100
75
50
25
0
100
200
300
400
Days


2-56 x 3/4 Cathode
2-56 Anode
%
ode
remaining
100
75
50
25
0
100
200
300
400
Days


2-56 x 1/2 Cathode
2-56 Anode
100
75
50
25
0
100
200
300
400
Days


6-32 x 1/2 Cathode
6-32 Anode
%
ode
maining
100
75
50
25
0
100
200
300
400
Days

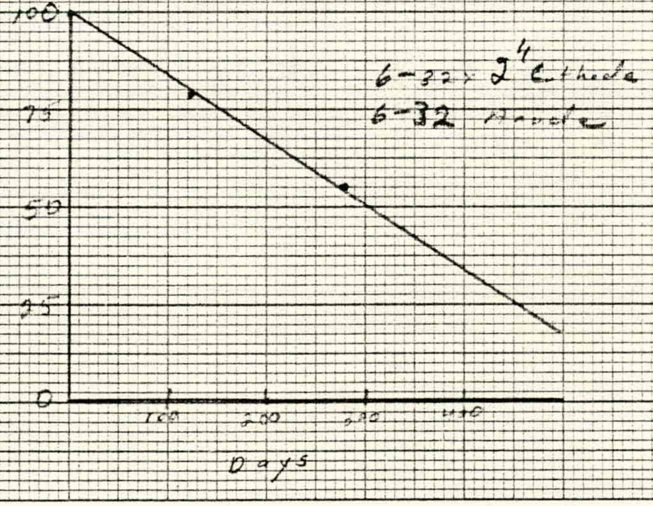
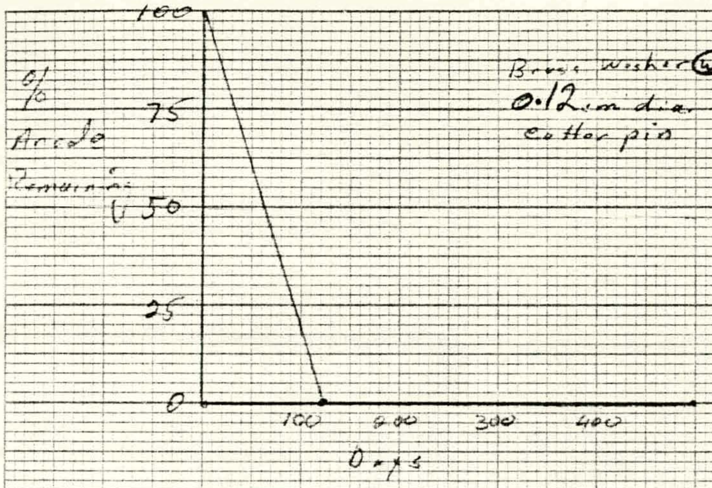
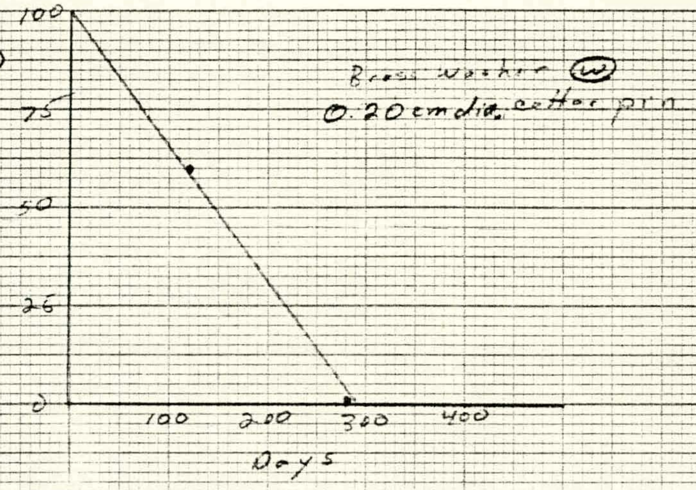
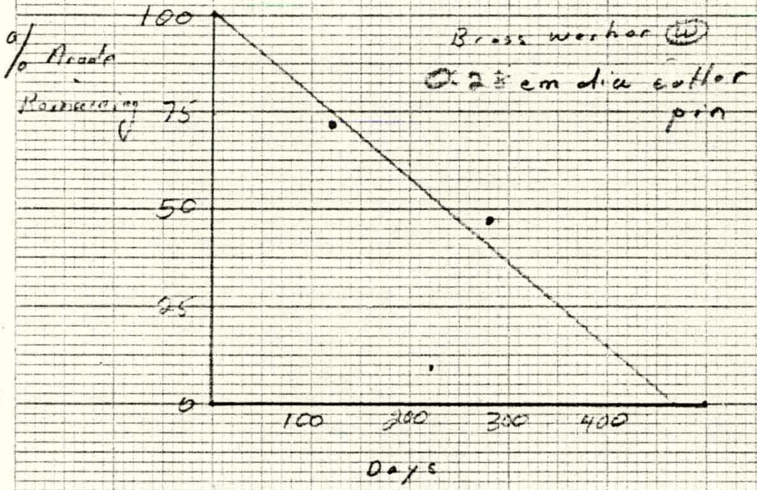
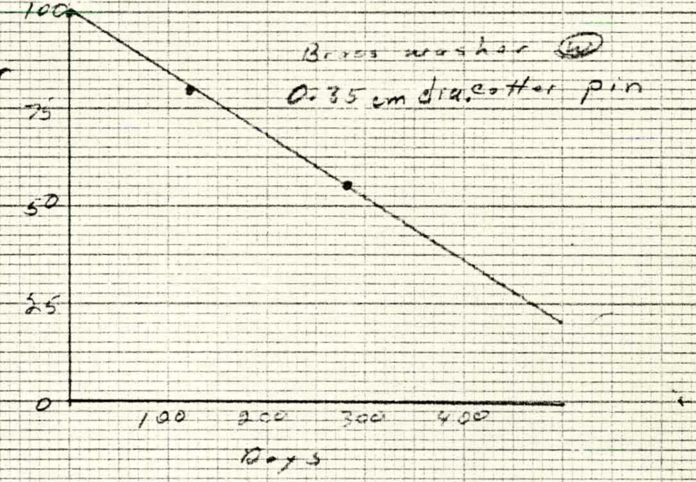

6-32 x 2 4 Cathode
6-32 Anode
100
75
50
25
0
100
200
300
400
Days

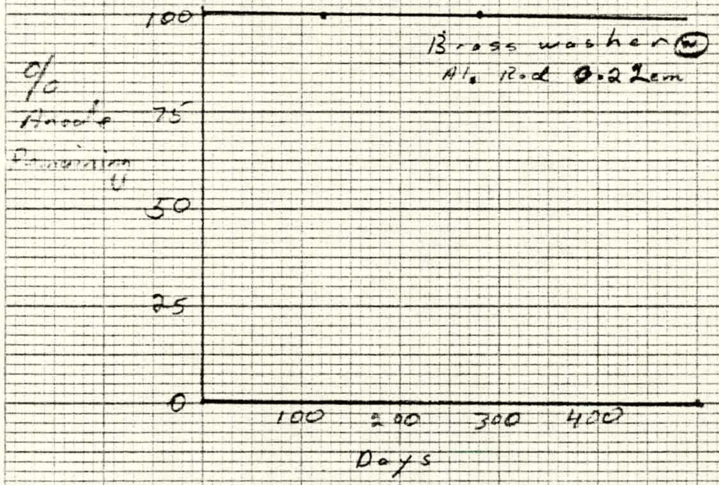
Figure 3. Expected corrosion rates for various cathode to anode ratios with 5/8" washer anodes and pin type anodes.

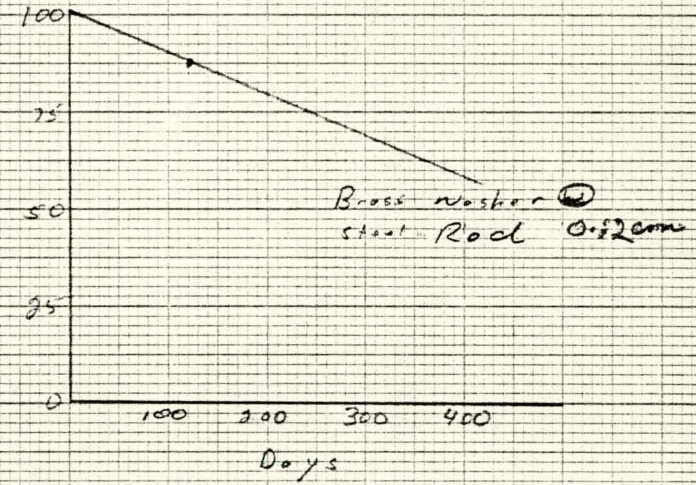

% Anode Remaining
100
75
50
25
0
100
200
300
400
Days
Brass washer (w)
0.12 cm dia. cotter pin

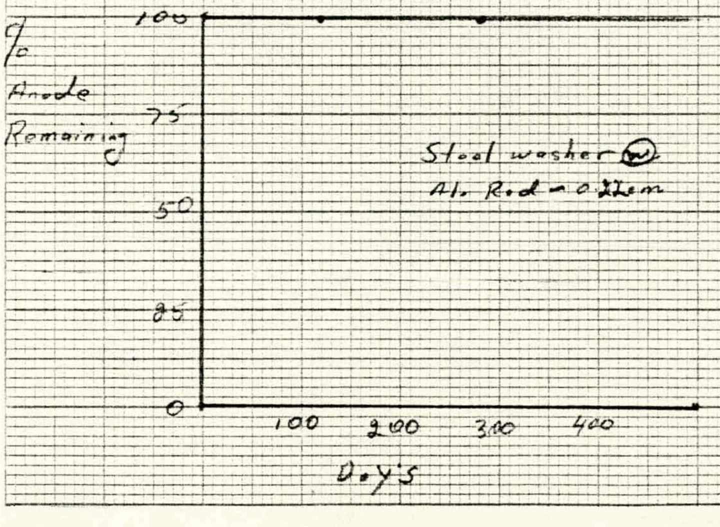

100
75
50
25
0
100
200
300
400
Days
Brass washer (w)
0.20 cm dia. cotter pin


% Anode Remaining
100
75
50
25
0
100
200
300
400
Days
Brass washer (w)
0.25 cm dia cotter pin


100
75
50
25
0
100
200
300
400
Days
Brass washer (w)
0.35 cm dia. cotter pin


% Anode Remaining
100
75
50
25
0
100
200
300
400
Days
Brass washer (w)
Al. Rod 0.22 cm


100
75
50
25
0
100
200
300
400
Days
Brass washer (w)
Steel Rod 0.22 cm


% Anode Remaining
100
75
50
25
0
100
200
300
400
Days
Steel washer (w)
Al. Rod – 0.22 cm

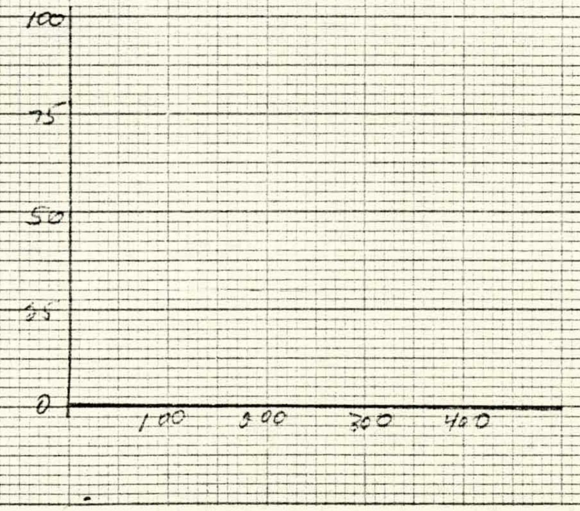
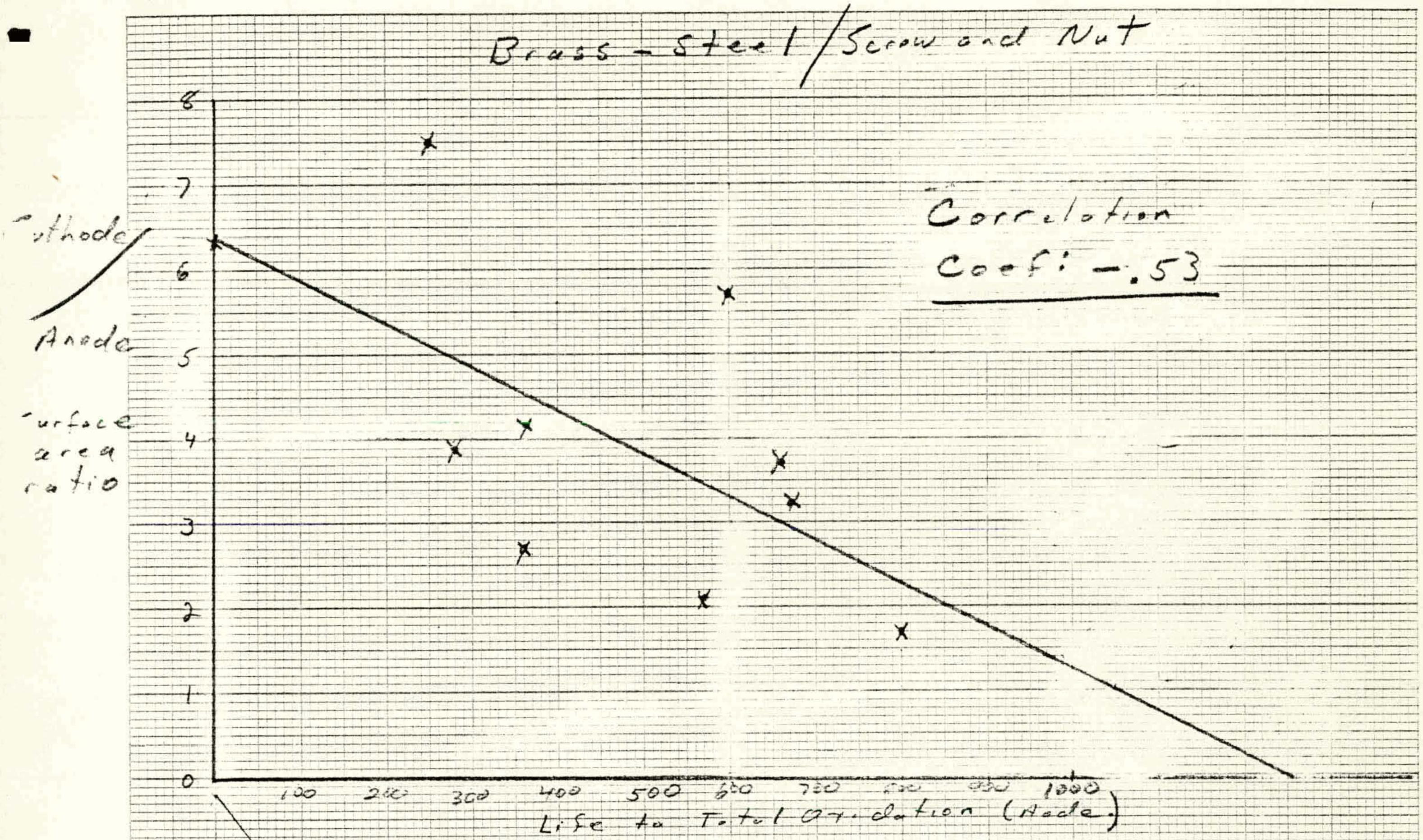
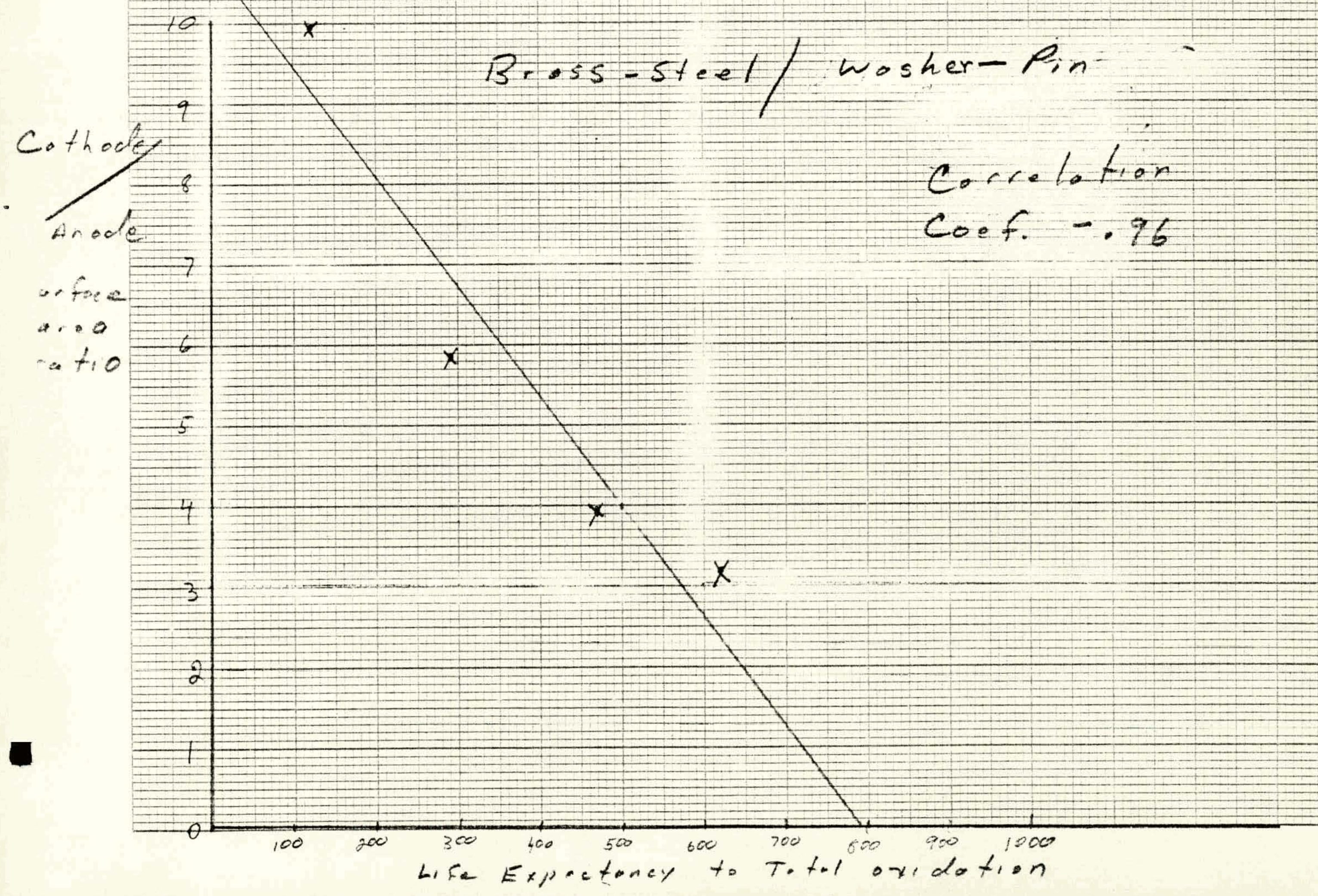

100
75
50
25
0
100
200
300
400

Figure 4. Corrosion rates plotted as a function of cathode to anode ratio for the various ratios in the nut-screw and pin-washer configurations.


Brass - Steel / Screw and Nut
Correlation Coef: -.53
Cathode / Anode surface area ratio
0
1
2
3
4
5
6
7
8
100
200
300
400
500
600
700
800
900
1000
Life to Total Oxidation (Anode)


Brass - Steel / Washer - Pin
Correlation Coef. -.96
Cathode / Anode surface area ratio
0
1
2
3
4
5
6
7
8
9
10
100
200
300
400
500
600
700
800
900
1000
Life Expectancy to Total oxidation

6) Miscellaneous Tests

Absorbable suture material appeared to remain intact for the first 177 days of the test. However by the 188th day both sizes were broken very easily with the slightest pull. By the 201st day after immersion the suture material had totally lost integrity, only a broken line of powdery substance remained on the plastic plate where sutures had previously been. Nylon, brass and steel 10-32 machine screws immersed in concentrated sulfuric acid resulted in the following average rates of decay; nylon 100% 6 days, brass 69% 127 days, steel 2% 127 days. The acid-bolt experiment has not been going long enough for results. Preliminary attempts to control galvanic corrosion, by polarizing the anode and cathode indicated that the amount of power needed for observable results was greater by at least an order of magnitude above the current drains typically used to drive animal transmitters. Since this approach also has a restricted application due to cathode and anode spacing and electrical insulation problems it was not pursued.

DISCUSSION AND APPLICATION

Results obtained to date indicate that life expectancies can be obtained for corrosive links depending on three major factors: metal combinations, corrosive link configuration and cathode to anode ratio. Temperature and salinity doubtless have significant effects; these variables have not been analyzed yet. However, for temperatures near 20°C and salinity at 30-35%, a range of life expectancies from 24 hours to > 500 days has been obtained by varying metals, ratios and configurations. Preliminary tests with magnesium indicate it to be the metal of choice for short term links, 20 days or less. Laboratory and field tests indicate that combinations of brass with steel and absorbable suture material form links for longer term application. Ethicon vicryl absorbable suture material has an added advantage of an avalanching type of decay near the end of its life expectancy.

Application of laboratory data obtained in relatively stagnant aquaria to field situations is difficult and must be done with several cautions. Corrosive link exposure time and type to saltwater and/or air may alter corrosion rates. In all probability corrosive rates will be accelerated in the field. Animal born transmitters will likely be subject to high water velocities and jarring thereby removing oxides from the anode surface. In the laboratory, oxides tend to build up, insulating the anode and reducing corrosion rates. As an anode decays, the cathode to anode ratio increases, therefore corrosions rates should increase with time. This does not appear to be the case in the laboratory, probably because oxides are also building up with time and tend to counteract the expected increasing cathode to anode ratio effect. Without oxide build up in the field corrosion rates should be increased. Secondly, stress forces acting on metals increase corrosion rates. So, any application of a corrosive link under stress will accelerate corrosion. Finally, most corrosive link designs will fail structurally before the anode is completely oxidized for two reasons. Uneven corrosion has been observed to occur in most experiments. One side of a nut may completely disappear while the other side oxidizes more slowly, so the nut falls off. Second, as corrosion proceeds, structural strength is reduced to a point where the link will fail. It is difficult to design tests to determine structural failure points for the conceivable applications of corrosive links. However incidental observations suggest structural failure will generally occur when the anode is 50% to 75% oxidized.

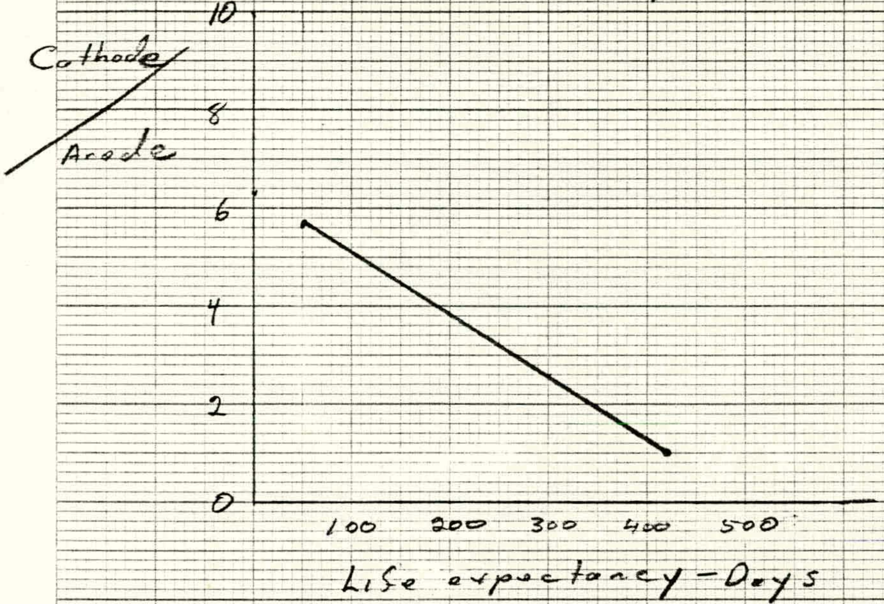
Three field trials with corrosive links have been attempted to date. These include a #8 brass machine screw-steel bolt link on manatee harnesses and two trials of a brass screw-cotter pin configuration for sea otter transmitters. The sea otter configuration consists of two #8 brass machine screws connected with a 0.09 cm dia. cotter pin as the anode. Preliminary results indicate the manatee link will last approximately 500 days. Sea otter transmitters lasted 20-40 days on Alaska and California sea otters. Laboratory testing is still in progress on the actual sea otter transmitter configuration. However very preliminary observations suggest that the sea otter link will last at least 33% longer than in the field trials. Comparing our data to preliminary field results suggests that the manatee link lab estimate is about 25% too long.

The following nomographs (Fig. 5) is intended to assist in selecting corrosive links for marine mammals. It represents predictions based upon preliminary data and should be used with caution, especially for nut-screw links as substantial variability was noted for this configuration in the laboratory. For example, if it is important to the animal that a transmitter fall off within a given time frame, I would suggest choosing a link with a shorter life estimate. Conversely, if a study requires maximal transmitter retention select a link with a liberal margin for error. The nomographs are constructed based on laboratory data adjusted for a 25% decrease in life expectancy for use in non-stagnant environments and assuming that the link will fail when 65% of the anode is oxidized. Initial testing has indicated that some variability can be expected among identical corrosive links. Therefore, any corrosive link design should be either a single link, or if multiple links are used, they should be a compound link at one attachment point. If multiple links are used at more than one attachment point, the transmitter could be released from one attachment point while remaining attached at another. The resulting loose attachment could do considerable damage to an animal, thus negating the purpose of a release mechanism.

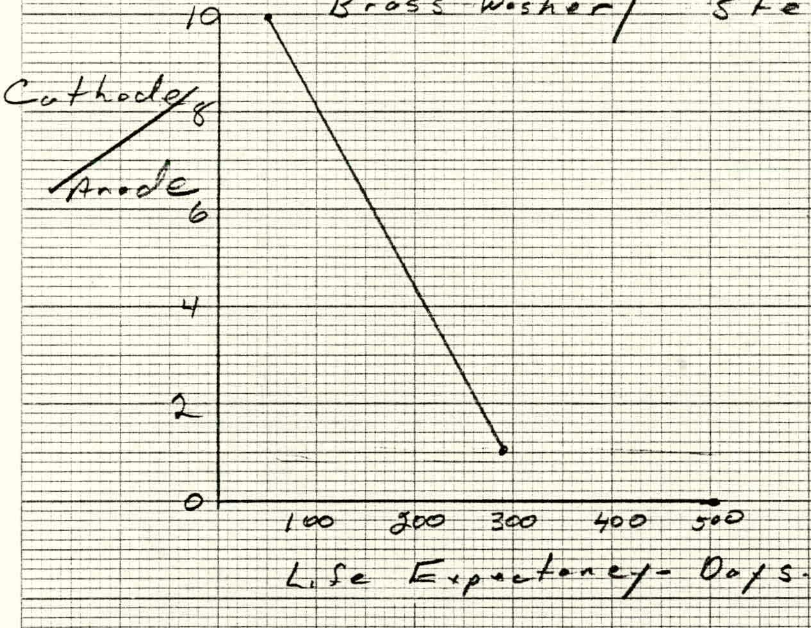
Future work should include several areas. First we will continue existing experiments with metal ratios and configurations concentrating on brass cathodes and steel anodes in an attempt to refine life expectancy estimates. Second, the recently initiated experiments with

Figure 5. Nomograph: corrosive link life estimate for nut-machine screw and pin-washer configurations. Adjusted to field conditions.

Brass-screw/ Steel nut



Brass-washer/ Steel Pin



temperature and salinity variables will continue. Third, experiments with the acid-steel bolt configuration will continue and an acid-brass bolt configuration will be added. These configurations show the most promise for larger terrestrial vertebrates. The magnesium tests and absorbable suture experiment will be repeated because these links appear promising for short term applications and we need more data on variability. Most importantly, we need more data on field trials to determine effects of exposure time and type. The cooperation of researchers applying transmitters to a variety of marine mammals is essential. The data needed from field work could be easily obtained, essentially all we need to know is: corrosive link configuration, cathode surface area, anode surface area, water temperature and, if possible, salinity. Perhaps an additional approach could be to experiment on captive animals held at a facility such as Sea World. Finally, corrosive link experiments consist of long term testing. In order to even approximate the life of a specific design we need a minimum time for testing equal to the desired life of the corrosive link, and additional time is required to refine these estimates.

Literature Cited

Fontana, M. E. and N. E. Green 1978. Corrosion Engineering. McGraw-Hill New York. 465 p.

APPENDIX C

FALL MOVEMENTS AND ACTIVITY PATTERNS OF SEA OTTERS (ENHYDRA LUTRIS) IN CALIFORNIA

(Preliminary Draft)

A Thesis

Submitted to the Faculty of the Graduate School

of the University of Minnesota

by

Christine Ann Ribic

In Partial Fulfillment of the Requirements

for the Degree of

Master of Science

August 1980

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

One of the many things I learned in this study was that no one can work on marine mammals without a lot of help. First and foremost, I thank my advisor, Dr. D.B. Siniff, for giving me the opportunity to work on this project, for the help in keeping the project going, and for all the advice and guidance given to me. For logistic support, without which this project could not have been done, I express thanks to the U.S. Fish and Wildlife Laboratory, especially R. Jameson and the rest of the Piedras Blancas Field Station staff, D. Irons and Dr. G. Van Blaricom and thanks to the California Department of Fish and Game sea otter project - R. Hardy, project leader, F. Wendell, J. Ames, B. Hatfield, and L. Smith. For help in transition from Minneapolis to California, I thank Dr. T. Williams and family, and for making the stay at the lighthouse enjoyable, I thank G. Jameson and family and B. Van Blaricom and family. From the University of Minnesota, I thank Dr. D. DeMaster and Dr. J. Thomas for their help and guidance in smoothing over many of the initial rough spots in getting the project started. I thank Cedar Creek Bioelectronics Laboratory for building the radios. For the 1979 season, I thank L. Ferm, whose help and companionship was invaluable. For data analysis, I thank Dr. S. Wasserman for help with the movement and activity data and for general discussions on methodology and thank J. Packard for formulation of the behavioral repertoire and analysis of the behavioral data. I thank R. Rice and D. Stinson-Bernstein for typing this manuscript so many times and L. Ferm for help with figures. And, finally, for all those people who stopped on Highway 1 to ask me what I was doing, this is what I did.

ABSTRACT

Movements and activity patterns of sea otters in the area of San Simeon and Cayucos Point in California were studied during the fall of 1978 and the fall of 1979. Sixteen otters in 1978 and 12 in 1979 were equipped with radio telemetry devices and monitored. Average distance moved by males in 1978 was 2.06 km and, in 1979, 0.39 km. These means reflect the occurrence of some males in 1978 moving from point of capture to the southern edge of the population's range north of Port San Luis. Females in 1978 and 1979 had average movements of 1.79 km and 1.22km, respectively. Females tended to move more within their home ranges and were less predictable in those movements than males who stayed in the vicinity of capture. Average home range length for males in 1978 was 20.4 km and, for females, 14.3 km. Excluding otters who moved greater than 10 km reduced these lengths to 2.7 km and 6.4 km, respectively. In 1979, the average length for males was 0.1 km and 4.3 km for females. In both years, females had the longer home range lengths than males who stayed in the vicinity of their capture.

Individual rhythms were detected though there was a great deal of variation within an individual. The pattern appeared to be ultradian rather than circadian. Otters spent half their time being active and half their time being inactive. The active period was

broken up into 4 periods of 3 hours in length while the inactive period was divided into 3 periods of 4 hours in length. No tidal effect was detected. Daytime pattern of the population tended to follow that of individuals.

INTRODUCTION

Movements of individual sea otters in California over the course of a season or year are relatively unknown. Woodhouse et. al. (1977) concluded that otters were not migratory and that movements resulted from wanderings by young males and from adult males in search of estrous females. From resightings of tagged individuals over the course of a year, Wendell (1979) reported movements of 40 km for a male and about 120 km for a female. One otter moved 48 km in less than 22 hours (2.2 km/hr) and a second moved at a rate of 1.3 km/hr. From a transplant done in California (Odemar and Wilson 1969), at least 5 of 17 otters travelled 72 km back to the area from which they were captured in 2 months.

Movements throughout the day have been studied by various authors (Odemar and Wilson 1969, California Fish and Game 1976, Loughlin 1977). The otters have appeared to rest in the kelp beds, coming inshore to feed, with resting and feeding areas constant over time. In California, Loughlin (1977) estimated home ranges as 80 ha for females, and 29 ha and 44 ha for territorial and non-territorial males, respectively .

Activity pattern work has been hampered by the inability to follow individual otters for a 24 hour period, and most researchers (Fisher 1939, Hall and Schaller 1964, Shimek and Monk 1977, Sandegren et. al. 1973) have concentrated on changes in activity of groups of unmarked otters throughout the day. Their conclusions, summarized by Woodhouse et. al. (1977), have been that otters are active early in the morning, rest and groom during the midday, and feed in the late afternoon until dark, and have another feeding bout around midnight. However, Loughlin (1977, 1979) concluded that individual otters did not have distinct rhythms.

The objectives of this study were to determine 24-hr movements of individual otters throughout the fall (September-December), document differences between males and females, and determine the distances moved. For activity patterns, the objectives were to document the circadian pattern for individuals, calculate time budgets for various activities, and detect differences between males and females. Behavioral observations were recorded as possible to support the activity studies and to determine effects of tagging on the otters.

Description of Study Area

The study was conducted in the vicinity of Point San Simeon and Cayucos Point October to mid December 1978 and Point San Simeon October to November 1979 (Fig. 1). Ocean conditions were considered to be the best during that time with low swell and small seas. The wind usually blew from the northwest in the afternoons at about 27 km/hr. Temperatures ranged between 10°C and 15°C during the day and between -1.1°C and 4.4°C during the night (Barrett 1966). Fog in the morning and occasionally lasting all day occurred about half the time during the 1978 field season and large swells of 3.05 m to 3.65 m hampered work during the 1979 season.

The kelp community in which sea otters were found consisted of Macrocystis pyrifera as the dominant upper canopy kelp, Pterygophora californica and Laminaria dentigera as the understory kelps and a red algal turf. Macrocystis pyrifera grows in 9 m to 18.3 m of water and extends out 650 m to 750 m from shore. At the end of the 1978 season and during the 1979 season, the kelp beds were harvested by a commercial company so the actual distribution of the beds changed throughout the season. Common invertebrates (Table 1) living in the kelp beds included Pisaster giganteus, Pugettia producta, Cancer antennarius, Balanus crenatus, Tegula spp., and Calliostoma spp.. Besides the sea otter, common vertebrates included Sebastes spp., Hexagrammos decagrammos, Ophiodon elongatus, Scorpaenichthys marmoratus, Phoca vitulina, and many wintering birds (G. Van Blaricom, personal communication).

METHODS

Sixteen sea otters in 1978 and 12 in 1979 (Table 2) were captured with floating gill nets used by the U.S. Fish and Wildlife Service (Fig. 2) or with a diver-held trap used by the California Department of Fish and Game (Fig. 3). The animals were taken from the net or trap, restrained on board a boat, and tagged through the webbing of the rear feet with temple tags obtained from the California Department of Fish and Game. The tags were color-coded and position-coded so each otter could be uniquely identified (Fig. 4). Radio telemetry devices (Fig. 4) were attached across the third digit of either rear foot with corrodable bolts the first year and with a corrodable cotter pin or iron wire the second year. After the attachment decayed in the salt water, the radio dropped off. Average time for radio loss was 4 months in 1978 (n=6) and, in 1979, 1 month (n=12). The radios, built by Cedar Creek Bioelectronics Laboratory, University of Minnesota, were 5.5 cm in length with a 23.5 cm long antennae, and weighed between 20-25 grams. The radios put out a continuous signal, had an expected life of 4-6 weeks, and had a range of about 6.4 km.

Movement data was gathered by finding the radios an average of twice a day. All locations were obtained by stopping along the coast by car at regular pulloffs an average of 2.4 km apart. A directional four-element Yagi antennae and receiver was used to get directions. In 1978, lines were drawn directly onto maps for triangulations, with landmarks and rocks on the coast for reference. Directions from a hand-held compass were taken for triangulations in 1979.

Locations were plotted by hand on separate sets of maps for each otter. U.S. Geological Service topography maps were used in 1978. In 1979, maps traced from aerial photos were acquired from the California Department of Fish and Game. Straight line distances between points were measured by hand and converted into kilometers.

Daylight movements were defined as those that occurred between sunrise and sunset and nightly movements as those that occurred between sunset and sunrise. Most daylight locations were taken an average of 5 hrs apart and nightly movements an average of 19 hours apart. Averages of overall movements, then, were based on distances measured over a variety of time intervals. The greatest distance measured between points was used as an estimate of home range length. Since sea otters were rarely seen beyond the outer edge of the kelp beds, which usually corresponds to the 18.3 m depth line (Loughlin 1977, R. Jameson personal communication), home range width was measured out to the 18.3 m depth line. Area of home range was then calculated by assuming a rectangular shape. Three-dimensional maps of the percentage of locations per square in an arbitrary x-y coordinate system (Appendixes A and B) were drawn by computer utilizing the University of Minnesota FORTRAN subprogram PLOT3D.

A natural log transformation was used on all distance measurements to satisfy the homogeneity of variance assumption in the t-tests and analyses of variance, and only otters with at least five observations were used in subsequent analyses. Utilizing the SPSS statistical package (Nie et. al. 1975), differences in movements of individual otters were tested with standard ANOVA analysis with posterior contrasts done with Scheffe's test at =

Table 1. Common flora and fauna of the giant kelp (*Macrocystis pyrifera* L.) beds in the vicinity of Point Piedras Blancas, California. Invert. = invertebrates and vert. = vertebrates. (G. Van Blaricom, personal communication).

Category	Scientific Name	Common Name	Source
Flora	*Macrocystis pyrifera*	giant kelp	Abbott and Hollenberg (1976)
	Pterygophora californica	sea palm	"
	Laminaria dentigera		"
	Botryoglossum farlowianum	red algae	"
	Calliarthron cheilosporioides	red algae	"
Fauna Invert.	*Pisaster giganteus*	sea star	Smith and Carlton (1975)
	Patiria miniata	"	"
	Pugettia producta	kelp crab	"
	Cancer antennarius	rock crab	"
	Loxorhyncus crispatus	decorator crab	"
	Balanus crenatus	barnacle	"
	Cryptochiton stelleri	chiton	"
	Corynactis californica	anemone	"
	Tegula spp.	turban snail	Smith and Carlton (1975)
	Calliostoma spp.	snail	"
	Ceratostoma foliatum	snail	"
Vert. Midwater Fish	*Sebastes mystinus*	blue rockfish	Miller and Lea (1972)
	Sebastes serranoides	olive rockfish	"
	Sebastes melanops	black rockfish	"
Bottom Fish	*Sebastes atrovirens*	kelp rockfish	"
	Sebastes chrysomelas	black-and-yellow rockfish	"
	Oxylebius pictus	pointed greenling	"
	Hexagrammos decagrammos	kelp greenling	"
	Ophiodon elongatus	lingcod	"
	Embiotoca lateralis	striped seaperch	"

Table 1 (cont.).

Category	Scientific Name	Common Name	Source
	Scorpaenichthys marmoratus	cabezon	"
	Brachyistius frenatus	kelp seaperch	"
Mammals	*Zalophus californianus*	California sea lion	Walker (1975)
	Phoca vitulina	harbor seal	"
	Enhydra lutris	sea otter	"

Table 2. Sea otters captured in Fall 1978 and 1979 near Point San Simeon and Cayucos Point, California. Dates are in monyh/day/year/, M = male, F = female, lgt = light, drk = dark, # = number, and all weights are in kilograms.

Date	Location	Right Tag	Left Tag	Sex	Wght	#
09/30/78	near Pt. Piedras Blancas	white	drk blue	M	29.5	903
"	"	"	purple	"	34	803
10/06/78	north of Pt. San Simeon	"	pink	"	29.5	416
"	"	"	drk green	"	28	222
10/09/78	lgt green	white	F	23	703	
11/04/78	"	white	gold	M	30.5	608
11/14/78	Cayucos Pt.	silver	chartreuse	"	14.5	819
"	"	"	drk green	F	17	595
"	"	"	pink	M	23	350
11/15/78	"	"	drk blue	"	25	523
"	"	"	red	"	18	440
11/16/78	"	"	lgt green	F	17	850
11/17/78	"	"	silver	M	29.5	395
"	near Cambria	drk blue	lgt blue	F	18	315
"	"	"	lgt green	"	18.5	242
"	"	"	red	"	17	106
11/01/79	North of Pico Pt.	"	silver	"	20	585
11/02/79	South of Pt. San Simeon	"	gold	"	20	298
"	South of Pico Pt.	"	lgt blue	"	16.4	605
11/03/79	South of Pt. San Simeon	"	lgt green	"	18.6	453
"	"	white	red	M	12.7	780
11/09/79	"	drk blue	"	F	20	706
"	"	"	white	"	21.8	648
11/11/79	near Cambria	white	chartreuse	M	33.6	821
11/12/79	South of Pt. San Simeon	"	lgt green	"	30.4	746
"	South of Pico Pt.	drk blue	pink	F	22.7	636
"	"	"	orange	"	18.2	692
"	"	"	chartreuse	"	13.2	345

.05 (Snedecor and Cochran 1967). Tests of differences between sexes and years for average lengths of home ranges were done with t-tests (Snedecor and Cochran 1967).

Activity data were collected in two ways. The first was using a Rustrak recorder (Fig. 5). With this device, the radio signal was transformed into an electronic pulse that displaced a needle. The needle marked the paper as it moved through the machine. Since salt water attenuates the radio signal, the machine recorded the pattern of the radio being held above the water (constant signal) or below the water (no signal). Twenty-four hour activity patterns were collected by monitoring the machine in an area where a radio could be clearly heard. The second method was a systematic sampling scheme based on the restriction that only one signal could be recorded continuously on the Rustrak machine. Listening to other radios in the area at half hour intervals, the observer spent a few minutes on each channel noting if the signal was constant, intermittant, or no signal. More patterns were collected during 1979 due to the help of a second person. Data were analyzed by looking at lengths of active and inactive periods and average percent activity per hour per individual throughout a 24-hr period. For determining lengths of the active and inactive periods from the half-hour samples, whatever the signal was at the time of the sample was assumed to be the signal for the entire half hour. Thus, only periods of greater than a half hour were used in the activity analysis. After a natural log transformation of the lengths of the active and inactive periods, differences between and within sexes and between years were tested with ANOVA analysis as described in the previous paragraph on movement data. For visual comparisons among individuals, graphs of the average percent activity per hour plus and minus one standard deviation were drawn. During the day, visual observations were taken on radioed otters with a Questar telescope to correlate activity and inactivity with the Rustrak signal. The area where the signal was being recorded was scanned hourly with the Questar telescope on 80X to record unmarked otters and their activities for a general idea of the activity of the population. These data were pooled at hourly intervals over the entire season, percent activity per season was plotted, and compared visually with the activity graphs of individual otters.

In 1978, behavioral data were collected on marked and unmarked otters using focal animal samples (Altmann 1974) in order to detect effects of the transmitters on the otters. All data were taken using a Questar telescope and interval timer with an audible signal to mark the time. Five general categories of resting, grooming, interacting, locomoting and feeding were used and a list of sea otter behavioral patterns developed in Alaska (Packard and Ribic, manuscript in preparation, Appendix C) was used and amended in California. Samples of 8 min in length were taken as often as possible though some samples were less than that due to visually losing the focal animal. A total of 300 8-min samples of radioed and non-radioed otters were collected. For nonradioed otters, 53 grooming, 81 resting, 37 feeding, and 9 interacting samples were obtained. For radioed otters, 30 grooming samples, 64 resting, 28 feeding, and 7 interacting samples were collected. Only the categories of grooming and resting contained enough samples for further analysis. For each focal animal sample of 8-min in length, frequencies of individual behavior patterns were tabulated. Since the total number of 10-sec intervals in the sample was 48, each pattern could take on a value from 0 to 48. Differences between radioed and nonradioed otters were evaluated with chi-square tests (Snedecor and Cochran 1967) and, for each behavior included in the chi-square analysis, Freeman-Tukey deviates were calculated (Bishop et. al. 1975). In addition, discriminant analysis, done with the SPSS statistical package (Nie et. al. 1975), was used to separate groups.

RESULTS

Movement and Home Range

Movements

Looking at Table 3, there was a great deal of variation in averge distance moved over the fall season among individuals in both years irregardless of sex. For each year, the tests for equality of overall movement averages within sex were rejected (p .007 in all cases)(Table 4). From Scheffe's test, within the 1978 males, there appeared to be two subsets of males. One group consisted of two males, numbers 222 and 903, who moved to the southern edge of the population's range and the other containing males that did not move far from their capture points (numbers 416, 803, 395, 350 and 819). There were no distinct subsets within the 1978 females while within the 1979 females, there was one female (number 648) separated from the other females. This female had an average overall movement much less than the other females. The 1979 males were all different from one another. In view of this individual variation, tests between males and females were not done.

Overall movements of the otters were divided into daylight and nightly movements (Table 5). Within individual otters, there were no significant differences between average daylight and average nightly movements (paired t-test, t=-0.19, d.f.=15, p=.45). There did not appear to be a large correlation between weights of the otters and average overall movement (r=0.27).

Looking at the fastest rate of travel for otters with at least 5 locations, there was a range from .09 km/hr to 1.74 km/hr (Table 6). The fastest rate for males in 1978 was 1.49 km/hr and .77 km/hr in 1979. For females, the fastest was .79 km/hr and 1.74 km/hr in 1978 and 1979, respectively. Within years, there were no significant differences between males and females for average rate of travel (t=2.21, d.f.=8, .05 p .10 for 1978; t=0.86, d.f.=8, p=.4 for 1979), nor was there a difference between 1978 and 1979 for average rate of travel (t=0.09, d.f.=18, p .50). There was a small correlation between rate of movement and weights of the otters (r=0.42) with heavier otters tending to move faster than lighter otters.

Home Range

Average lengths of home ranges in 1978 and 1979 were 18.21 km and 3.51 km, respectively (Table 7). The 1978 average reflects the effect of 5 otters having ranges with lengths greater than or equal to 10 km (Table 8). If these lengths are removed, the 1978 average is 4.4 km. Removing the lengths greater than and equal to 10 km for analysis, there were no significant differences between females in both years (t=0.99, d.f.=11, p .5) though there was a significant difference between males (t=7.75, d.f.=6, p .005). Between females and males in each year, there were significant differences in average lengths of home range (t=2.38, d.f.=17 .025 p .05 in 1978; t=6.23, d.f.=15, p .005 in 1979). There was a low correlation between lengths of home ranges and weights of the otters (r=0.43) with heavier otters tending to have the longer home range lengths. There was a smaller correlation between lengths of home ranges and rates of movements.

Areas of home ranges, listed in Tables 7 and 8, tend to be overestimates as areas not utilized by the otters are included in the estimates due to the assumption of a rectangular home range. In addition, not all parts of a home range were used with equal intensity by an individual otter. Appendix D contains maps for each individual's home range. In 1978, most of the otters stayed in the vicinity of capture but five of the otters did not. Of the five, three otters (numbers 903, 222 and 608) were males that moved out of the capture area the day of capture and were later found 80 km down the coast in the vicinity of the southern edge of the population's range. The other two otters were females (numbers 703 and 315). Number 703, later found to be pregnant during fall 1978 (R. Jameson, personal communication), moved between the capture area and three different areas while number 315 moved from the capture area north to a second area. In 1979, the three males and three of the eight females (numbers 648, 605, and 636) did not move far from their capture locations. Three of the remaining five females (numbers 585, 298, and 453) moved up and down a 3.57 km length of coast which included their capture areas. The other two (numbers 692 and 345) were captured together with number 345 moving north from the capture spot and staying in the new area and number 692 moving north from the capture area and then back to the vicinity of the capture area. There appeared to be much overlap among females captured in locations close together (Fig. 6) while the males' ranges only overlapped when the animals were caught from a large group of otters (Fig. 7) or the radioed otters ended up moving long distances from their capture points. In one instance where two 1979 males (numbers 780 and 746) had adjacent ranges, there was little overlap between the ranges (Fig. 8). Number 780 stayed in an area to the northeast of number 746 and was located within the range of number 746 during only one afternoon during the two and a half months of number 780's radio life. Otherwise, number 780 rested in a small kelp patch in a bay to the north of a public pier and fed out in the kelp beds and in the vicinity of and southwest of Point San Simeon. A female, number 648 (Fig. 9), on the other hand, almost completely overlapped with number 746's range and was frequently observed resting in the same group as number 746.

Pattern of use of an area appeared to be similar among otters. Most otters that were observed had separate locations for resting, which usually were offshore in the kelp beds, and feeding, which were usually inshore (numbers 746, 803, 416, 648, and 636) (Fig. 10).This was not invariable as radioed otters were observed feeding within the kelp beds (number 703) and in isolated kelp patches outside the edge of the main kelp beds (number 780) along with other unmarked otters.

Table 3. Average distance between locations in km over the fall season for radioed sea otters in California in 1978 and 1979. s.d. = standard deviation and n = sample size.

			Overall Movement		
Year	Otter	Sex	Mean	s.d.	n
1978	416	M	0.55	0.38	28
	819	"	0.59	0.35	20
	350	"	0.55	0.39	9
	395	"	0.46	0.25	15
	608	"	7.16	11.44	3
	903	"	4.81	3.61	3
	222	"	1.86	1.5	9
	803	"	0.50	0.58	52
	850	F	0.62	0.36	15
	242	"	0.91	0.67	13
	106	"	0.98	1.11	21
	703	"	2.98	4.39	37
	315	"	3.46	3.09	4
	-	all	1.96	2.09	13
	-	males	2.06	2.54	8
	-	females	1.79	1.32	5
1979	821	M	0.63	0.22	5
	780	"	0.32	0.21	75
	746	"	0.23	0.15	54
	585	F	2.73	4.67	13
	605	"	0.51	0.34	22
	345	"	2.13	2.05	10
	298	"	1.07	0.80	28
	648	"	0.31	0.21	74
	453	"	1.02	0.68	26
	692	"	1.11	0.91	27
	636	"	0.89	0.82	32
	-	all	0.99	0.79	11
	-	males	0.39	0.21	3
	-	females	1.22	0.81	8

Table 4. ANOVA table for average ln(overall movements) by sex and year of radioed sea otters in California during the fall seasons of 1978 and 1979. SS = sum of squares and MS = mean square.

Year	Sex	Source	d.f.	SS	MS	F Ratio	F Prob.
1978	Males	Among	6	41.09	6.85	10.54	.01
		Within	121	78.17	.65		
		Total	127	119.26			
	Females	Among	3	15.63	5.21	4.41	.01
		Within	77	90.98	1.18		
		Total	80	106.61			
1979	Males	Among	2	4.81	2.41	8.36	.01
		Within	115	33.11	.29		
		Total	117	37.92			
	Females	Among	7	44.74	6.39	11.09	.01
		Within	207	119.32	.58		
		Total	214	164.06			

Table 5. Average daylight and nightly movements in km of radioed sea otters in Fall 1978 and 1979 in California. M = male, F = female, s.d. = standard deviation, and n = sample size.

			Daylight			Nightly		
Year	Otter	Sex	Mean	s.d.	n	Mean	s.d.	n
1978	803	M	0.52	0.69	32	0.48	0.36	19
	416	"	0.50	0.37	12	0.59	0.40	16
	395	"	0.50	0.17	5	0.44	0.29	10
	819	"	0.42	0.29	7	0.68	0.35	13
	350	"	0.32	0.09	3	0.67	0.43	6
	222	"	2.03	2.1	2	1.08	0.59	2
	703	F	1.21	0.92	11	2.79	4.58	22
	106	"	0.74	0.52	6	1.15	1.29	14
	242	"	0.87	0.61	5	0.93	0.74	8
	850	"	0.57	0.19	4	0.64	0.42	11
	-	all	0.77	0.51	10	0.94	0.69	10
	-	males	0.71	0.65	6	0.66	0.23	6
	-	females	0.85	0.27	4	1.38	0.96	4
1979	821	M	-	-	-	0.59	0.24	4
	780	"	0.35	0.22	40	0.29	0.20	35
	746	"	0.23	0.16	27	0.23	0.15	27
	585	F	1.57	0.87	7	1.12	1.04	6
	605	"	0.59	0.33	10	0.45	0.35	12
	345	"	0.41	0.19	3	2.87	2.23	6
	298	"	1.13	0.81	14	1.01	0.82	14
	648	"	0.30	0.23	41	0.33	0.18	33
	453	"	1.01	0.52	14	1.03	0.86	12
	692	"	0.80	0.73	8	1.15	0.91	18
	636	"	0.93	0.79	12	0.88	0.86	20
	-	all	0.73	0.43	10	0.90	0.74	11
	-	males	0.29	0.08	2	0.37	0.19	3
	-	females	0.84	0.41	8	1.10	0.77	8

Table 6. Fastest rates of travel in km/hr for radioed sea otters in California in Fall 1978 and 1979. M = male, F = female, and standard deviations are in parentheses.

Year	Otter	Sex	Rate
1978	222	M	0.88
	416	"	0.36
	803	"	1.49
	903	"	0.99
	608	"	1.71
	523	"	0.55
	703	F	0.79
	106	"	0.17
	242	"	0.09
	315	"	0.34
	-	all	0.74 (0.54)
	-	males	0.99 (0.52)
	-	females	0.35 (0.31)
1979	746	M	0.17
	780	"	0.77
	636	F	0.82
	453	"	0.72
	692	"	0.37
	345	"	0.21
	298	"	1.14
	648	"	1.74
	605	"	0.53
	585	"	0.77
	-	all	0.72 (0.46)
	-	males	0.47 (0.42)
	-	females	0.79 (0.48)

Table 7. Average areas (km2), lengths (km), and widths (km) of home ranges of radioed sea otters in Fall 1978 and 1979 in California. s.d. = standard deviation, n = sample size, and * = removed lengths _ 10 km.

		length			width			area		
year	sex	mean	s.d.	n	mean	s.d.	n	mean	s.d.	n
1978	all	18.3	22.2	14	1.5	0.4	14	26.7	33.9	14
	males	20.4	24.9	9	1.6	0.3	9	29.8	36.5	9
	females	14.3	17.9	5	1.3	0.5	5	21.1	31.9	5
1978*	all	4.4	2.7	9	1.5	0.4	9	5.6	1.9	9
	males	2.7	0.5	5	1.7	0.2	5	4.6	0.8	5
	females	6.4	3.0	4	1.2	0.5	4	6.8	2.3	4
1979	all	3.5	2.6	12	0.9	0.2	12	3.7	3.1	12
	males	0.1	0.11	3	0.8	0.1	3	0.8	0.3	3
	females	4.3	2.6	9	1.1	0.2	9	4.7	2.9	9

Table 8. Areas (km^2), lengths (km) and widths (km) of home ranges of radioed sea otters in Fall 1978 and Fall 1979 in California.

Year	Otter	Sex	Length	Width	Area
1978	416	M	3.1	1.4	4.3
	803	"	3.2	1.5	4.8
	222	"	50	1.3	65.0
	395	"	1.8	1.9	3.4
	350	"	2.8	1.9	5.3
	819	"	2.7	1.9	5.1
	903	"	50	1.2	60.0
	608	"	60	1.7	102.0
	523	"	10	1.9	19.0
	106	F	7.6	1.2	9.1
	703	"	46	1.7	78.2
	242	"	8.6	0.9	7.7
	850	"	1.9	1.9	3.6
	315	"	7.6	0.9	6.8
1979	780	M	1.2	0.9	1.1
	746	"	1.0	0.7	0.4
	821	"	1.0	0.8	0.8
	585	F	6.7	1.1	7.4
	298	"	3.1	1.2	3.7
	605	"	1.9	0.8	1.5
	453	"	3.3	1.3	4.3
	706	"	2.5	1.0	2.5
	648	"	1.4	0.8	1.1
	636	"	5.5	1.1	6.1
	692	"	5.4	1.1	5.9
	345	"	9.3	1.1	10.2

Activity

Interpretation of the Rustrak signal

In 1978 and 1979, otters with radios were simultaneously observed and had their signals recorded on the Rustrak recorder for a total of 26.5 hrs. In all cases when an otter was resting, the radio signal was continuous (Fig. 11a). However, behaviors such as stroking, rubbing, rocking, rowing, and looking (see Appendix C for descriptions of behavior patterns) were performed without putting the rear feet in the water. With the behavior pattern "rocking", an audible fading in and out of the signal as part of the antennae went in and out of the water was noticeable. The Rustrak recorder, however, was not sensitive to these rapid changes in tone and a constant signal pattern was produced. If rocking and slow stroking and rubbing are considered to be part of the resting category, then the underestimate of activity from the Rustrak recording comes during the grooming bout. A grooming bout produces a pattern consisting of a period of intermittant signals between 2 periods of constant signal periods (Fig. 11b). An average grooming bout was 21.00 min (n=18) with an average of 13.24 min or 63% spent in activities where the feet were held above the water (Ferm and Ribic, manuscript in preparation). Assuming an average of 6 grooming bouts in a 24 hr period (see results on rhythms), an approximate 1% underestimate of activity results from using the Rustrak record. An otter actively grooming or feeding always produced an intermittant signal . Feeding tended to produce a characteristic pattern (Fig. 11c) of a straight line for an average of 2 min alternating with a constant signal of 2 to 3 min. This pattern, however, varied with the individual otter's habit of holding its feet during feeding. For example, number 608 consistently held its rear feet ventral side up so the antennae was submerged and no consistent pattern was produced during its feeding bouts. Number 703, on the other hand, held its feet ventral side down so the antennae was laying on top of the water and a signal was produced. Because of the inconsistencies in distinguishing between grooming and feeding categories, only the two categories of active (grooming, feeding, other activity) and inactive (resting) were considered.

Activity Patterns

Lengths of active and inactive periods by sex and year are listed in Table 9. There are too few data points to test for differences between sex or length of periods in 1978. However, if the raw data of 1978 are plotted by grouping individuals (Fig. 12), the general trend supports the results of the tests of the 1979 data. There were no significant differences between active and inactive periods within females for either category ($p \quad .05$) (Table 10). For males, there was no significant difference for the active period ($p=.87$) though there was for the inactive period (p=.04)(Table 10). Lumping the data within sexes, there were no significant differences between sexes for either active or inactive periods (t=1.91, d.f.=77, p=.06 for active period; t=.27, d.f.=73, p=.79 for inactive period). So, looking at active period length versus inactive period length, there was no significant difference between the lengths of the two periods (t=.12, d.f.=108, p=.9). For 1979, the average active period was 3.33 hrs. and the average inactive period was 3.75 hrs (Table 9). Therefore, the ideal average otter was active an average of 12 hours broken up into about 4 hr periods while the inactive period was broken into approximately 3 periods of 4 hrs in length.

There appeared to be a pattern for each otter (Figs. 13-16) though individual variation tended to mask any distinct rhythm. Most otters appeared to be active in the early morning from about 0400-0800 with activity increasing in the mid afternoon (1300-1700) with a third variable period around 2300-0200. Population activity levels (Fig. 17) for both years showed an increased activity level during the early morning and late afternoon. Variability between individuals was seen by pooling onset of activity over all otters. Lumping in 2-hr. blocks, onset of activity did not differ from a uniform distribution (X^2 = 12.94, d.f.=11, .25 p .5). There did not appear to be any tidal effect on onset of activity (X^2 = .71, d.f. = 2, .5 p .75) but due to lack of data on weather and ocean conditions, no other environmental effects were tested for.

Table 9. Average lengths in hours of active and inactive periods for radioed sea otters in Fall 1978 and 1979 in California. M=male, F=female, s.d. = standard deviation, and n=sample size.

			Active			Inactive		
Year	Otter	Sex	Mean	s.d.	n	Mean	s.d.	n
1978	416	M	-	-	-	3.52	1.29	3
	350	"	-	-	-	2.4	1.79	2
	395	"	4.72	3.61	2	4.26	1.6	2
	803	"	5.36	0.70	4	2.99	0.31	3
	608	"	1.8	0.66	2	-	-	-
	222	"	2.01	1.9	3	4.56	5.06	3
	703	F	2.79	2.6	4	6.79	4.12	4
	106	"	-	-	-	2.42	0.24	3
	-	all	3.34	1.61	5	3.85	1.69	7
1979	746	M	4.12	1.6	17	4.07	2.3	15
	780	"	4.04	2.36	26	3.32	2.55	32
	648	F	2.68	1.27	24	5.10	2.68	21
	453	"	3.21	0.59	6	4.78	2.33	6
	605	"	3.79	1.9	9	2.46	1.16	9
	636	"	3.09	2.02	27	2.86	2.30	28
	692	"	2.55	1.42	10	4.12	2.04	13
	-	all	3.33	0.59	7	3.75	0.92	7
	-	males	3.00	1.2	2	3.69	0.53	2
	-	females	3.08	0.44	5	3.76	1.07	5

Table 10. ANOVA table for active and inactive periods by sex of radioed sea otters in California during the 1979 fall season. SS = sum of squares and MS = mean square.

Sex	Type	Source	d.f.	SS	MS	F-Ratio	F-Prob.
Female	Active	Among	5	1.99	.39	1.22	.31
		Within	65	21.15	.32		
		Total	70	23.14			
Female	Inactive	Among	5	3.42	.68	1.95	.09
		Within	65	22.84	.35		
		Total	70	26.26			
Male	Active	Among	1	.01	.01	.03	.87
		Within	36	11.76	.33		
		Total	37	11.77			
Male	Inactive	Among	1	1.66	1.66	4.44	.04
		Within	36	13.43	1.37		
		Total	37	15.09			

BEHAVIOR

Behavioral Effects of Transmitters

In the resting category, floating was the most frequent behavior seen (Table 11). Other behaviors such as rocking and rubbing occurred with a lesser frequency. Graphical separation of the radioed and non-radioed otters was not distinct (Fig. 18) but the X^2 value was significant (p .005)(Table 12). Looking at the Freeman-Tukey deviates (Table 12), radioed otters did not appear to nibble and rub as much as non-radioed otters. Using discriminant analysis, the separation between radioed and non-radioed otters (Fig. 19a) was significant (p = .001).

In grooming, the most frequent behaviors were stroke, nibble, rock, rub/stroke, logroll, and somersault (Table 13). As in resting, graphical separation of the 2 types of otters was not distinct (Fig. 20) but the X^2 value was significant (p .005)(Table 14). Using nonradioed otters as the norm, radioed otters can be seen, from the Freeman-Tukey deviates (Table 14), to engage in rub/stroking more often than non-radioed otters. However, the separation of groups from discriminant analysis (Fig. 19b) was not significant (p = .186).

Table 11. Counts and percentages in parentheses of behavior patterns seen in the resting category for nonradioed and radioed sea otters in Fall 1978 in California.

Behavior Pattern	Nonradioed Otters	Radioed Otters
float	311 (94)	2702 (98)
nibble	6 (2)	5 (0.2)
rub	7 (2)	4 (0.1)
rock	4 (1)	6 (0.2)
stroke	2 (1)	16 (0.6)
look	0 (0)	1 (0.03)
shake	0 (0)	1 (0.03)
rub/stroke	0 (0)	1 (0.03)

Table 12. Expected values for the contingency table from the data in table 11 for all behaviors with values greater than zero in both categories of radioed and nonradioed otters. Freeman-Tukey deviates are in parentheses.

Behavior Pattern	Nonradioed Otters	Radioed Otters
float	324.61 (-0.74)	2688.39 (0.27)
nibble	1.19 (2.36)	9.81 (-1.66)
rub	1.19 (3.1)	9.81 (-2.1)
rock	1.08 (1.9)	8.92 (-0.96)
stroke	1.94 (0.19)	16.06 (0.04)

test statistic $X^2 = 63.10$ d.f. = 4 p .005

Table 13. Counts and percentages in parentheses of behavior patterns seen in the grooming category for nonradioed and radioed sea otters in Fall 1978 in California.

Behavior Pattern	Nonradioed Otters		Radioed Otters	
dive	0	(-)	1	(0.1)
float	31	(5)	59	(7)
look	5	(0.8)	21	(3)
logroll	21	(3.5)	46	(6)
nibble	104	(17)	160	(20)
periscope	1	(0.2)	0	(-)
porpoise	1	(0.2)	5	(0.6)
rub	31	(5)	20	(2)
rock	108	(18)	80	(10)
scull	8	(1.3)	6	(0.7)
shake	14	(2.3)	7	(0.9)
submerged	0	(-)	3	(0.4)
somersault	28	(4.6)	50	(6)
stroke	174	(29)	150	(19)
swim	3	(0.5)	21	(3)
tuckroll	7	(1.2)	13	(2)
nibble/rub	5	(0.8)	1	(0.1)
nibble/stroke	0	(-)	6	(0.7)
rub/stroke	60	(10)	154	(19)

Table 14. Expected values for the contingency table from Table 13 for all behaviors with values greater than five in both cells. Freeman-Tukey deviates are in parentheses.

Behavior Pattern	Nonradioed Otter	Radioed Otter
float	39.19 (-1.33)	50.81 (1.13)
look	11.32 (-2.12)	14.68 (1.54)
logroll	29.18 (-1.58)	37.82 (1.29)
nibble	114.98 (-1.02)	149.02 (.90)
rub	22.21 (1.75)	28.79 (-1.72)
rock	81.88 (2.71)	106.12 (-2.68)
scull	6.10 (.79)	7.9 (-.61)
shake	9.15 (1.48)	11.85 (-1.48)
somersault	33.97 (-1.02)	44.03 (.90)
stroke	141.11 (2.64)	182.89 (-2.53)
truckroll	8.71 (-.51)	11.29 (.55)
rub/stroke	93.20 (-3.78)	120.80 (2.85)

Test statistic $X^2 = 78.72$ d.f. = 11 p .005

DISCUSSION

Movements

To clarify terms used in the following discussion, the following definitions from Baker (1978) were used:

> migration - the act of moving from one spatial unit to another.
>
> familiar area - total area ever visited by an animal during its lifetime. Usually a number of discrete areas connected to one another by relatively narrow tracks.
>
> home range - proportion of the habitats within a familiar area visited during any particular limited period of time.

In addition, two types of sea otters were recognized: resident (did not move from vicinity of capture) and nonresident (did move from vicinity of capture).

Because of the limitation of the study to the fall season, the movements of 4 of the 6 males in 1978 to an area 80 km from point of capture could be given at least two interpretations. The first is that these otters have large fall home ranges or the second is that a transition between a summer and winter range was observed. The latter interpretation is supported by observations made by R. Jameson that the 2 resident males in 1978 (numbers 803 and 416) moved to the same area the nonresident males moved to 1 to 2 months later. This movement by resident otters may be analogous to movements made by breeding Peromyscus maniculatus males out of their territories at the end of the breeding season (Fairbairn 1978). In addition, from counts of concentrations of otters by the California Dept. of Fish and Game, there is an increase in otters at the southern edge of the range during the fall and winter to a winter peak of about 200 with the numbers decreasing to about half that number during the spring (California Dept. Fish and Game, personal communication). Thus, there is some indication that male sea otters are seasonally migratory. The females in this study, however, tended to stay near their areas of capture. Only one female (number 703) moved long distances but she moved between three areas on an approximate 2 week basis rather than moving to one area and remaining there.

From looking at the maps in Appendix D, females appeared to utilize their home ranges more evenly than resident males. Areas of rest appeared to correspond with concentrations of otters. Most feeding was solitary though otters were observed feeding in the same general area. Movements of resident males appeared to be more restricted and more predictable. Once feeding and resting areas of the resident males were located, visual observations of these males could almost always be made. This did not hold for the females or nonresident males.

Since area of home range depends on the outermost distribution of the kelp beds, the home ranges reported here are much larger than those reported by Loughlin (1977) and his average home range length of 2.5 km is less than 4.4 km for 1978 and 3.5 km for 1979 found in this study. The two areas studied by Loughlin (1977) and this study were different in the frequency of human disturbance experienced by both otter groups. The amount of human disturbance in the Monterey area (Loughlin 1977) was quite a bit more compared to the San Simeon area and could have affected the movements of the otters. However, in agreement with Loughlin (1977), females tended to have larger home ranges than resident males. The nonresident males had home ranges that appeared to be a group of small areas linked by travel corridors. This corresponds more to the description of a familiar area and the nonresidents' home ranges are not strictly comparable to the fall home ranges of females and resident males.

The importance of movement on population dynamics and population genetics is just beginning to be examined critically (Gadgil 1971, Roff 1975, Baker 1978, Waser and Haven Wiley 1980). The movements of sea otters throughout their range is relatively unknown though this study points out that otters may move long distances in relatively short periods of time. Rates of travel found in this study were less than the maximum of 2.5 km/hr reported by Kenyon (1969). But, one male otter moved 70 km in two days as well as one female moving between areas about 25 km apart in about a day. Information on the sea otter social system is limited (Vandevere 1970, Calkins and Lent 1975), but perhaps there is a more distinct breeding season than previously thought (Woodhouse et. al. 1977) as evidenced by the movements of the resident males during the winter. Some of the questions brought up by the movement data include what determines which otters are residents, what is the amount of site fidelity for resident males, what the contribution of nonresident males to the gene pool is relative to resident males, and how far into the range nonresident males will travel. Many of these questions should be answered by long term studies that follow a variety of individuals over time. The movements, however, of the sea otters in California appear to be similar to those of sea otters in Alaska (Schneider 1978) in that dominant adult males move less and more predictably than other males in search of estrous females and that adult females move the least.

Activity Pattern

Due to small sample size, no differences due to sex were tested for. Contrary to Loughlin (1977), individual otters appeared to have a rhythm though the pattern was ultradian rather than circadian. But individual variation tended to mask a strong pattern. This variation could have been due, in part, to the sampling frame of a month. There are many types of rhythms including weekly, monthly, seasonal, and yearly (Halberg et. al. 1977), many of which may be confounded with a circadian pattern. Any shifting in a pattern due to these other rhythms would contribute largely to the variation when looking for a daily pattern. From the graphs, the frequency of the rhythm may be on the order of 6 to 8 hours which appears to tie in most closely with the physiology and thermoregulation capabilities of the sea otter. Physiological studies are lacking but of the ones published (Stulken and Kirkpatrick 1955, Morrison et. al. 1974, Costa, manuscript in preparation), the rate of passage of food through the digestive system is on the order of 3 hours, absorption of nutrients is low, and energy needed for thermoregulation is high. The apparent similarity between an otter's active/inactive periods and physiological capabilities is an area for further research.

An otter spends approximately half its time resting and half being active. In addition to the finding that movements throughout the day and night appear to be the same, sea otters engage in the same type of activity irregardless of illumination. This is in agreement with Loughlin (1977). Since most of the other studies looked at groups of otters during the day, the percentages reported by authors such as Shimek and Monk (1977) and Estes and Smith (1973) are not directly comparable for individual time budgets.

The overall population pattern, during the daylight hours, of active in the morning and evening appears to be a result of a summation of individual otter patterns. Shimek and Monk (1977) reported that only 50% of the group in view would be engaged in a certain activity during an hour. This points to great individual variation in time of starting and duration of an activity so that looking at the activity of groups of otters during the daylight hours is probably not adequate for estimating total energy budgets of individual otters.

The variation within an individual does not preclude a rhythm, however, and this study points to the possibility of such rhythms. Various authors have speculated as to the evolutionary significance of rhythms and the main ideas are (1) timing behavior in relation to the external environment for, say, the onset of breeding, and (2) in relation to competitors and predators (Cloudsley-Thompson 1970, Bunning 1973, Rusak and Zucker 1975, Saunders 1977). The possibility of a physiological constraint producing the rhythm of otters has already been mentioned but there are other possibilities, not mutually exclusive. Cueing on the rhythms of prey to facilitate prey capture is a possibility. However, little is known of the rhythms of benthic organisms on which the otters in California primarily feed (F. Barnwell, personal communication). There is some evidence for this explanation in the Alaskan work of Estes et. al. (1978). They found that otters that fed on fish tended to have a distinct morning and afternoon foraging peak which might have been correlated with the time both day-active and night-active fish were present and chances of catching fish were maximized. However, they looked at rhythms of the population rather than of individuals. A second idea is that of reducing competition between species though, with sea otters, the competitors would probably be conspecifics. Loughlin (1977) felt that some individuals tended to feed at night, others during the day, and others both day and night. With this study, the clearest discrepancy between individuals was the onset of early morning feeding. Some of the otters tended to start feeding between 0300 and 0500 while others tended to feed between 0500 and 0800. Since there is some evidence for food stealing by individuals (Fisher 1939, Packard and Ribic, manuscript in preparation), feeding before or after others may reduce the risk of losing prey to others. The magnitude of food loss by stealing and, thus, the importance of avoiding others during feeding is unknown. There needs to be a longer study of many individual sea otters with a more detailed breakdown of activity into the various categories, such as feeding and grooming, to fully assess the importance of such rhythms for the individual otter.

Effect of Transmitters

Determining the effect of radios on otters is important for the applicability of results to the rest of the otter population. In the grooming category, there were no clear cut effects from the radios. Specific behaviors such rub/stroke increased significantly in frequency but the overall importance of this on an individual otter was not clear. The discriminant analysis suggests that no consistent differences between radioed and nonradioed otters could be detected. In the resting category, the radioed otters did not appear to nibble or rub as much as nonradioed otters. But, on average, the discriminant function separated the radioed and nonradioed otters on the basis of rub and stroke, which are grooming behaviors. From the observations, the radioed otters appeared to increase rubbing and stroking the rear feet and transmitter before floating for long periods of time. So perhaps the transition between grooming and resting was prolonged. The effect of this on an otter is probably not significant in terms of additional energy expended doing these behaviors more frequently than nonradioed otters compared to the overall energy expended over a 24-hr. period.

LITERATURE CITED

Abbott, I. A., and G. J. Hollenberg. 1976. *Marine algae of California*. Stanford Univ. Press, Stanford, Ca. 827 pp.

Altmann, J. 1974. Observational study of behavior sampling methods. Behaviour 49:227-267.

Baker, R. R. 1978. *The evolutionary ecology of animal migration*. Holmes and Meier Publishers, Inc., New York. 1012 pp.

Barrett, R. H. 1966. History and status of introduced ungulates on Rancho Piedra Blanca, California. M.A. Thesis, University of Michigan, Ann Arbor. 141 pp.

Bishop, Y. M. M., S. E. Feinberg, and P. W. Holland. 1975. *Discrete multivariate analysis: theory and practice*. The MIT Press, Cambridge, Mass. 557 pp.

Bunning, E. 1973. *The physiological clock: circadian rhythms and biological chronometry*. Springer-Verlag, New York. 258 pp.

California Department of Fish and Game. 1976. A proposal for sea otter protection and research and request for the return of management to the state of California.

Calkins, D., and P. C. Lent. 1975. Territoriality and mating behavior in Prince William Sound sea otters. J. Mammal. 56:528-529.

Cloudsley-Thompson, J. L. 1970. Recent work on the adaptive functions of circadian and seasonal rhythms in animals. J. Interdiscpl. Cycle Res. 1: 5-19.

Estes, J. A., R. J. Jameson, and E. B. Rhodes. 1978. Sea otter activity and foraging behavior in relation to population status and community structure. Abbrev. version of paper presented at II Congressus Theriologicus Internationalis, 20-27 June, 1978, Brno, Czechoslovakia.

Estes, J. A., and N. S. Smith. 1973. Research on the sea otter, Amchitka Island, Alaska. Amchitka Bioenvironmental Program Final Report. 68 pp.

Fairbairn, D. J. 1978. Dispersal of deer mice, Peromyscus maniculatus. Oecologia 32: 171-193.

Fisher, E. M. 1939. Habits of the southern sea otter. J. Mammal. 20:21-36.

Gadgil, M. 1971. Dispersal: population consequences and evolution. Ecology 52:253-261.

Halberg, F., F. Carandente, G. Cornelissen, and G. S. Katinas. 1977. Glossary of chronobiology. Chronobiologia 4 (suppl. 1): 1-189.

Hall, K. R. L., and G.B. Schaller. 1964. Tool using behavior of the California sea otter. J. Mammal. 45:287-298.

Kenyon, K. W. 1969. The sea otter in the eastern Pacific Ocean. U.S. Bureau of Sport Fish. and Wildlife, N.A. Fauna Series No. 68. 352 pp.

Loughlin, T. R. 1977. Activity patterns, habitat partitioning, and grooming behavior of the sea otter, Enhydra lutris, in California. Ph.D. dissertation, Univ. of Calif., L.A. 110 pp.

Loughlin, T. R. 1979. Radio telemetric determination of the 24-hour feeding activities of sea otters, Enhydra lutris. IN A handbook on biotelemetry and radio tracking, (C.J. Amlander and D.W. MacDonald, eds.), Pergamon Press, New York. pp. 714-724.

Miller, D.J., and R.N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dept. Fish and Game Fish Bull. 157:1-235.

Morrison, P., M. Rosenmann, and J. A. Estes. 1974. Metabolism and thermoregulation in the sea otter. Physiol. Zool. 47:218-229.

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrunner, and D. H. Bent. 1975. Statistical package for the social sciences 2nd edition. McGraw-Hill Book Co., New York. 675 pp.

Odemar, M. W., and K. C. Wilson. 1969. Results of sea otter capture, tagging and transporting operations by the California Department of Fish and Game. Proc. Ann. Conf. on Biological Sonar and Diving Mammals 6:73-79.

Roff, D. A. 1975. Population stability and the evolution of dispersal in a heterogeneous environment. Oecologia 19: 217-237.

Rusak, B., and I. Zucker. 1975. Biological rhythms and animal behavior. Ann. Rev. Psychol. 26: 137-171.

Sandegren, F. E., E. W. Chu, and J. E. Vandevere. 1973. Maternal behavior in the California sea otter. J. Mammal. 54:688-679.

Saunders, D. S. 1977. An introduction to biological rhythms. John Wiley and Sons, New York. 170 pp.

Schneider, K. B. 1978. Sexual segregation of sea otters. Federal Aid in Wildlife Restoration Final Report: projects W-17-4 through W-17-8.

Shimek, S. J., and A. Monk. 1977. The daily activity of the sea otter off the Monterey Peninsula, California. J. Wildlife Manage. 41:277-283.

Smith, R. I., and J. T. Carlton (eds). 1975. Light's manual: intertidal invertebrates of the central California coast 3rd edition. Univ. of California Press, Berkeley, CA 716 pp.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. Iowa State Univ. Press, Ames, Iowa. 593 pp.

Stulken, D. E., and C. M. Kirkpatrick. 1955. Physiological investigation of captivity mortality in the sea otter (Enhydra lutris). Trans. N.A. Wildlife Confer. 20:476-494.

Vandevere, J. E. 1970. Reproduction in the southern sea otter. Proc. Ann. Conf. on Biological Sonar and Diving Mammals 7:1-7.

Walker, E. P. 1975. Mammals of the world, 3rd edition. John Hopkins Univ. Press., Baltimore, Maryland. 1500 pp.

Waser, P. M. and R. Haven Wiley. 1980. Mechanisms and evolution of spacing in animals IN Handbook of behavioural neurobiology vol. 3, (P. Marler and J. G. Vanderbergh, eds.), Plenum Publishing Corp., New York, pp. 159-223.

Wendell, F. 1979. Sea otter tagging program. Talk given at Sea Otter Workshop, Santa Barbara Museum of Natural History, 23-25 Aug. 1979, Santa Barbara, Calif.

Woodhouse, C. D., Jr., R. K. Cowan and L. R. Wilcoxon. 1977. The summary of knowledge of the sea otter Enhydra lutris, L., in California and an appraisal of the completeness of biological understanding of the species. Marine Mammal Commission Report No. MMC-76/02. 71 pp.

Figure Legends

Fig. 1 Map of study area during Fall 1978 and Fall 1979 in California.

Fig. 2 Floating gill nets used by the U.S. Fish and Wildlife Service to capture sea otters.

Fig. 3 Diver-held trap used by the California Department of Fish and Game to capture sea otters.

Fig. 4 Color-coded temple tags and radio telemetry device attached to the rear feet of a sea otter.

Fig. 5 Rustrak event recorder used to monitor activity of sea otters.

Fig. 6 Comparison of the home ranges of number 453 (a), and number 298 (b) during Fall 1979 in California.

Fig. 7 Comparison of the home ranges of number 819 (a), and number 350 (b) during Fall 1978 in California.

Fig. 8 Comparison of the home ranges of numbers 746 (a) and 780 (b), both males captured in Fall 1979 in California.

Fig. 9 Comparison of the home ranges of number 746(a), a male, and number 648(b), a female, during Fall 1979 in California.

Fig. 10	Composite map of all observations of feeding and resting sea otters in Fall 1978 (a) and Fall (1979). Blank areas represent feeding observations, striped areas resting, and dotted areas both feeding and resting.
Fig. 11	Examples of Rustrak recordings of resting (a), grooming (b), and feeding (c) from radioed sea otters Fall 1979 in California.
Fig. 12	Histograms of lengths of active (a) and inactive (b) periods for all sea otters monitored in Fall 1978 in California.
Fig. 13	Graphs of percent activity per hour ± one standard deviation for number 780 (a) and number 746 (b) Fall 1979 in California.
Fig. 14	Graph of percent activity per hour ± one standard deviation for number 692 (a) and number 636 (b) Fall 1979 in California.
Fig. 15	Graph of percent activity per hour ± one standard deviation for number 453 (a) and number 605 (b) Fall 1979 in California.
Fig. 16	Graph of percent activity per hour ± one standard deviation for number 298 (a) and number 648 (b) Fall 1979 in California.
Fig. 17	Graph of percent activity per hour for groups of sea otters during Fall 1978 and Fall 1979 in California.

Fig. 18 Graph of percent behavior for behaviors seen during the resting category for radioed (a) and nonradioed sea otters (b) Fall 1978 in California.

Fig. 19 Discriminant analysis of the resting category (a) and grooming category (b) for radioed and nonradioed sea otters (b) Fall 1978 in California.

Fig. 20 Graph of percent behavior for behaviors seen during the grooming category for radioed (a) and nonradioed sea otters (b) Fall 1978 in California.

Fig. 1

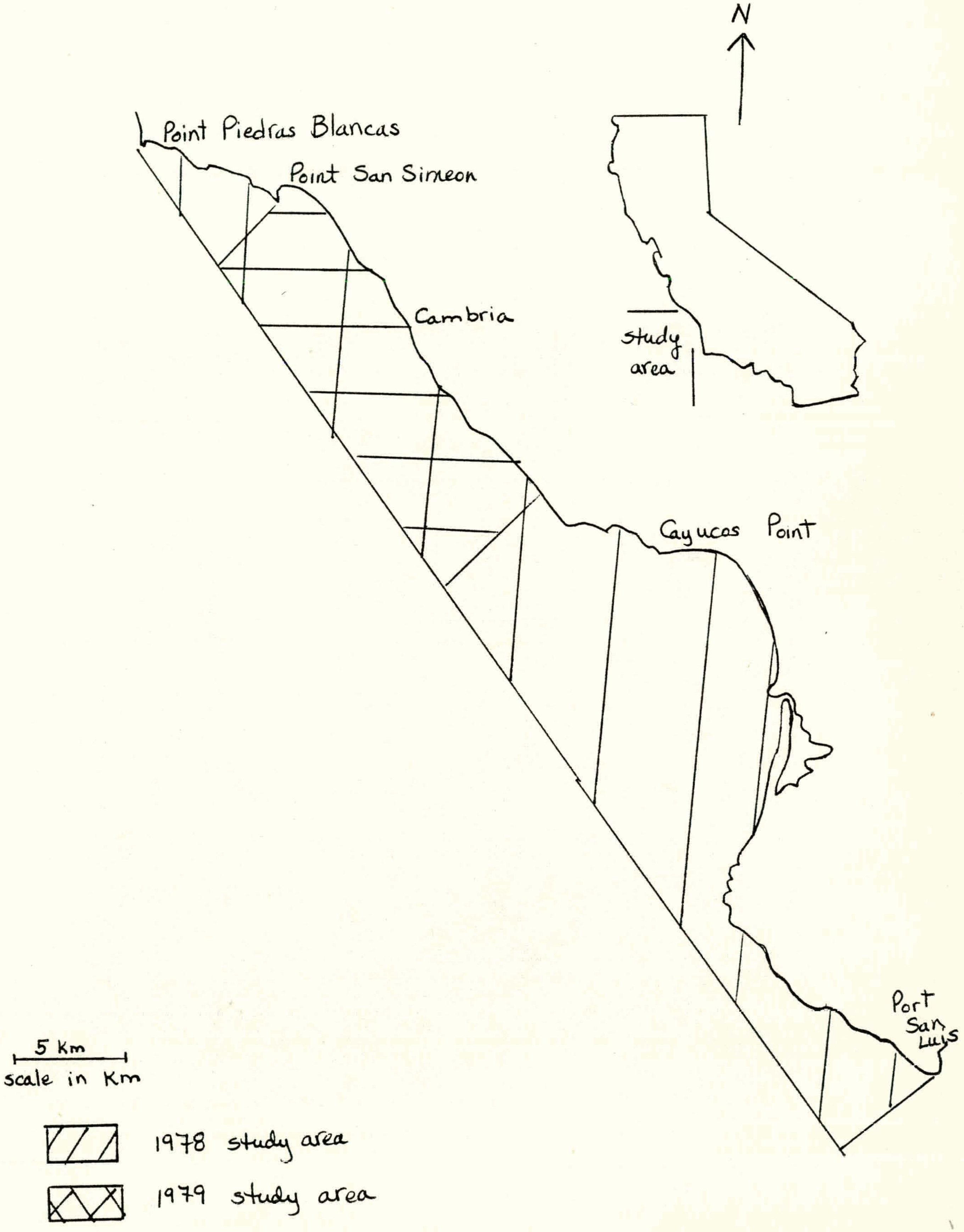
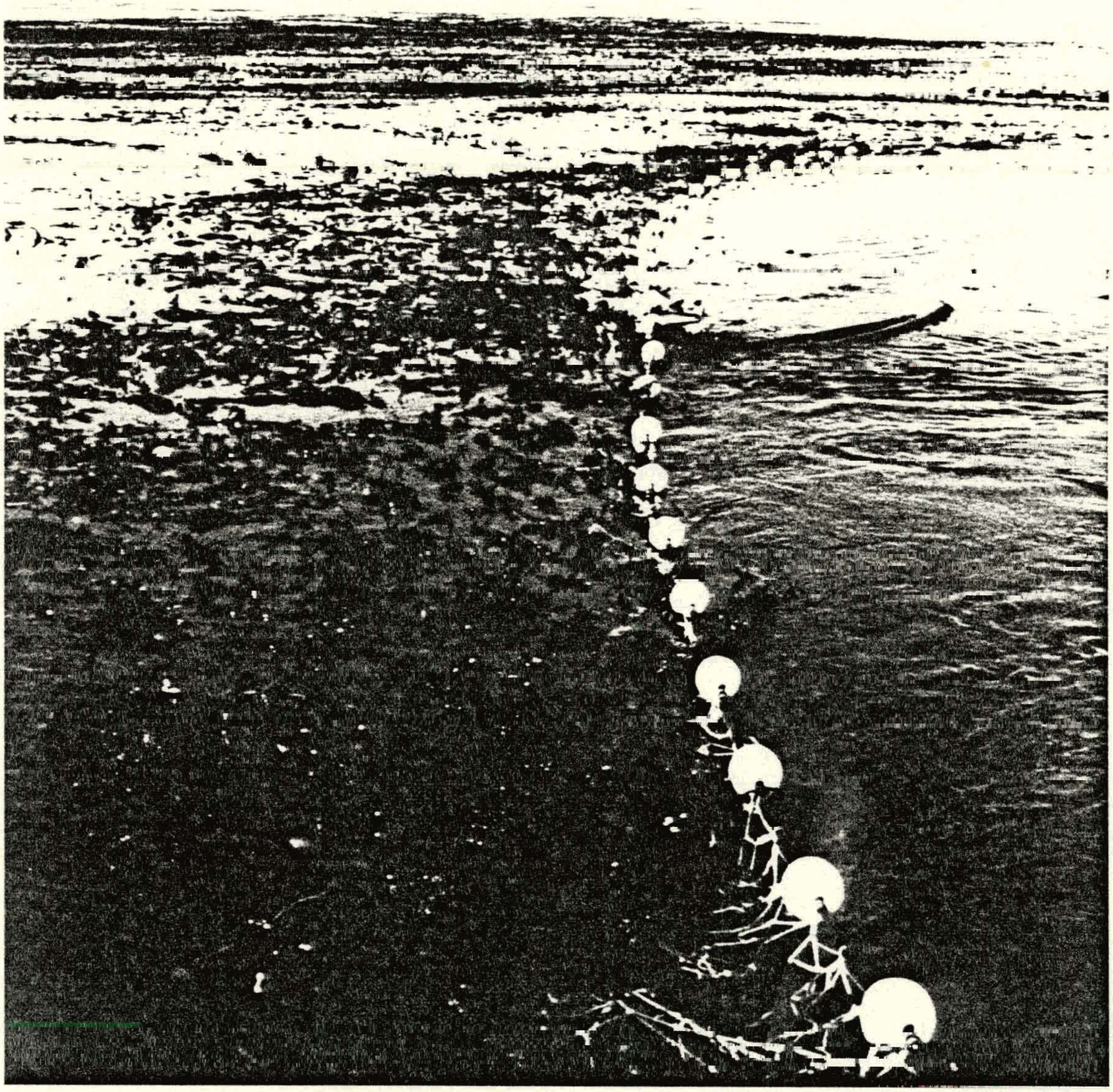

N
Point Piedras Blancas
Point San Simeon
Cambria
Cayucos Point
Port San Luis
study area
5 Km
scale in Km
1978 study area
1979 study area

Fig. 2



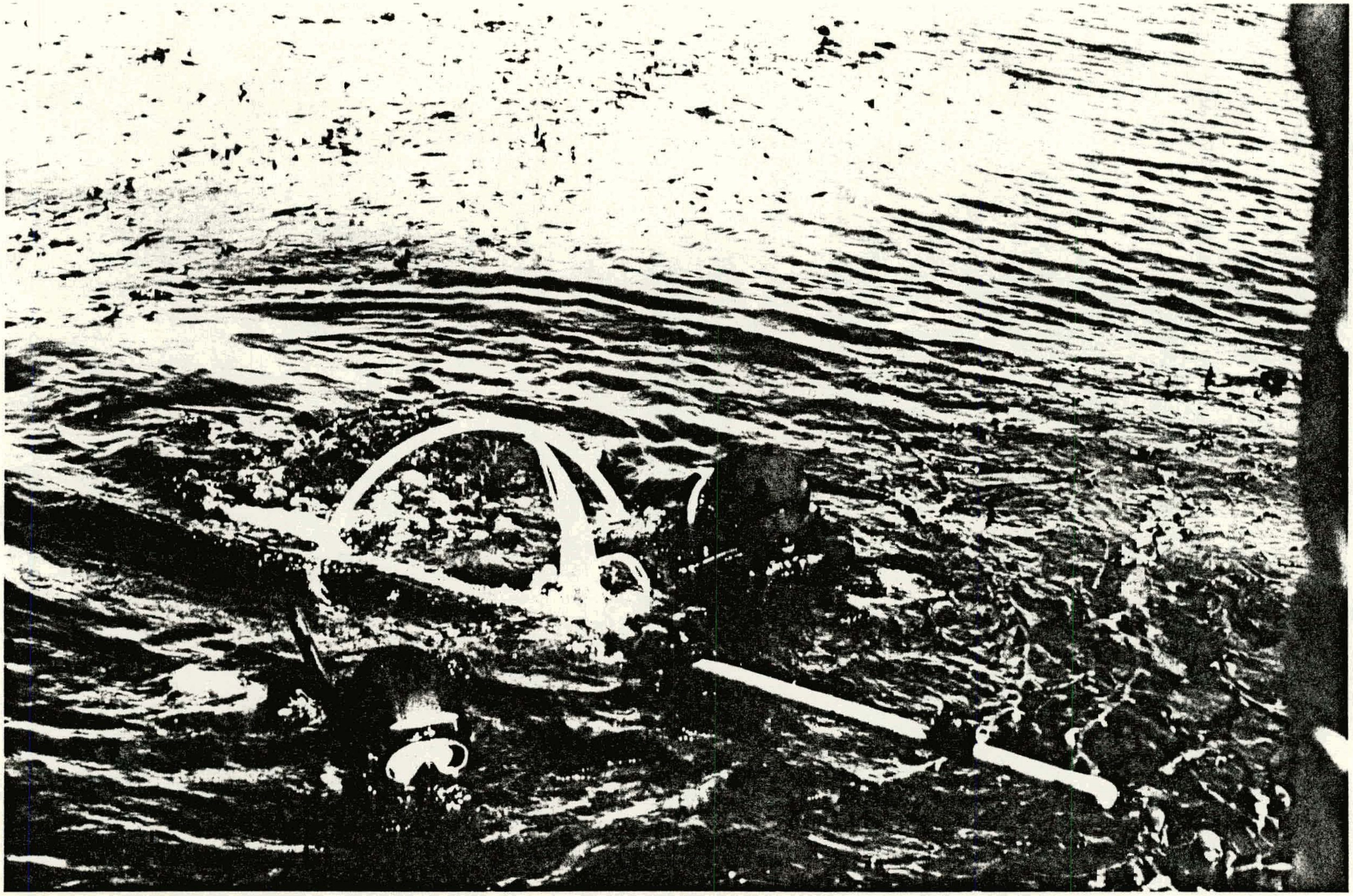


Fig. 3

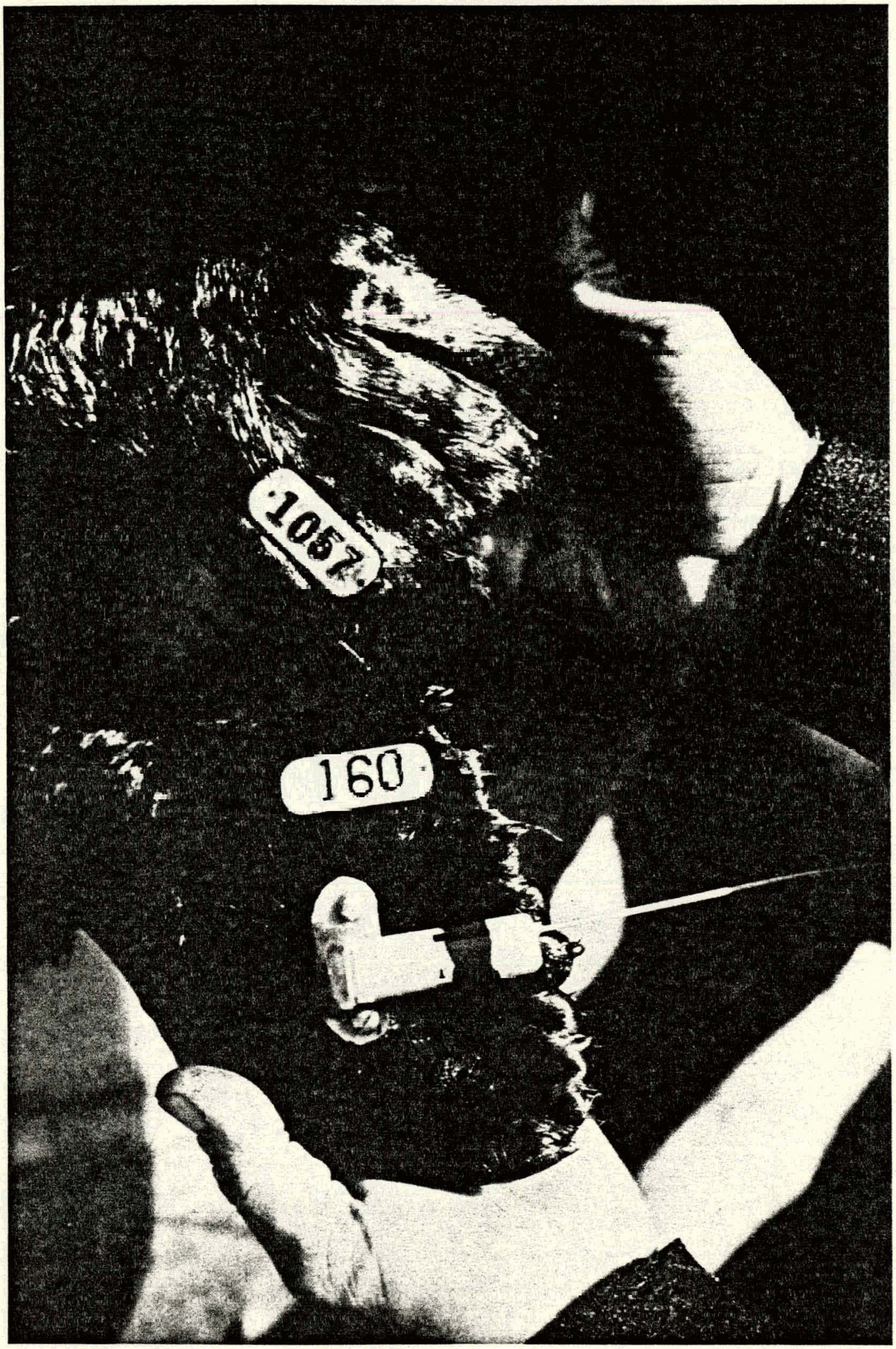


Fig. 4

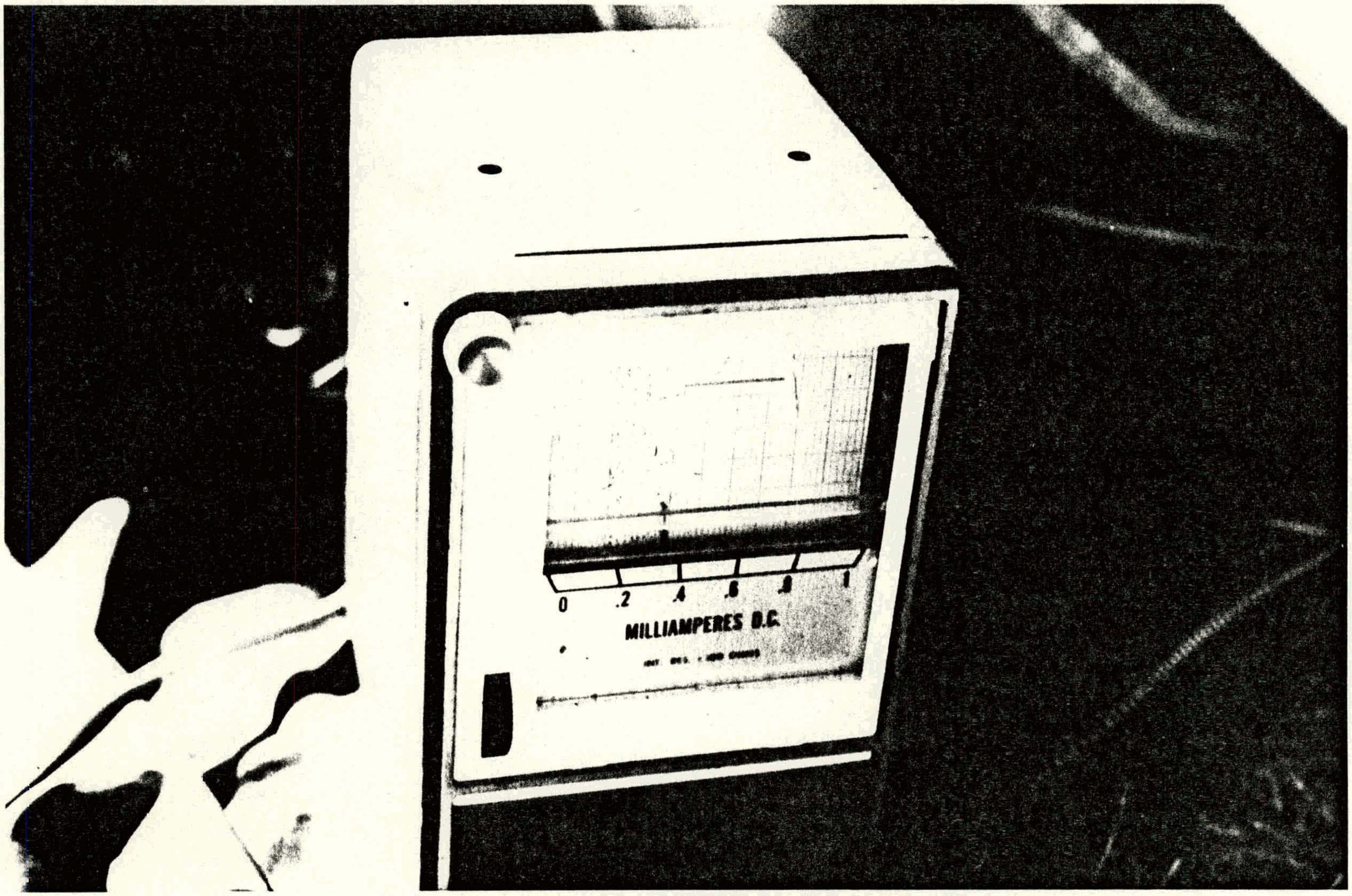


Fig. 5

Fig. 6

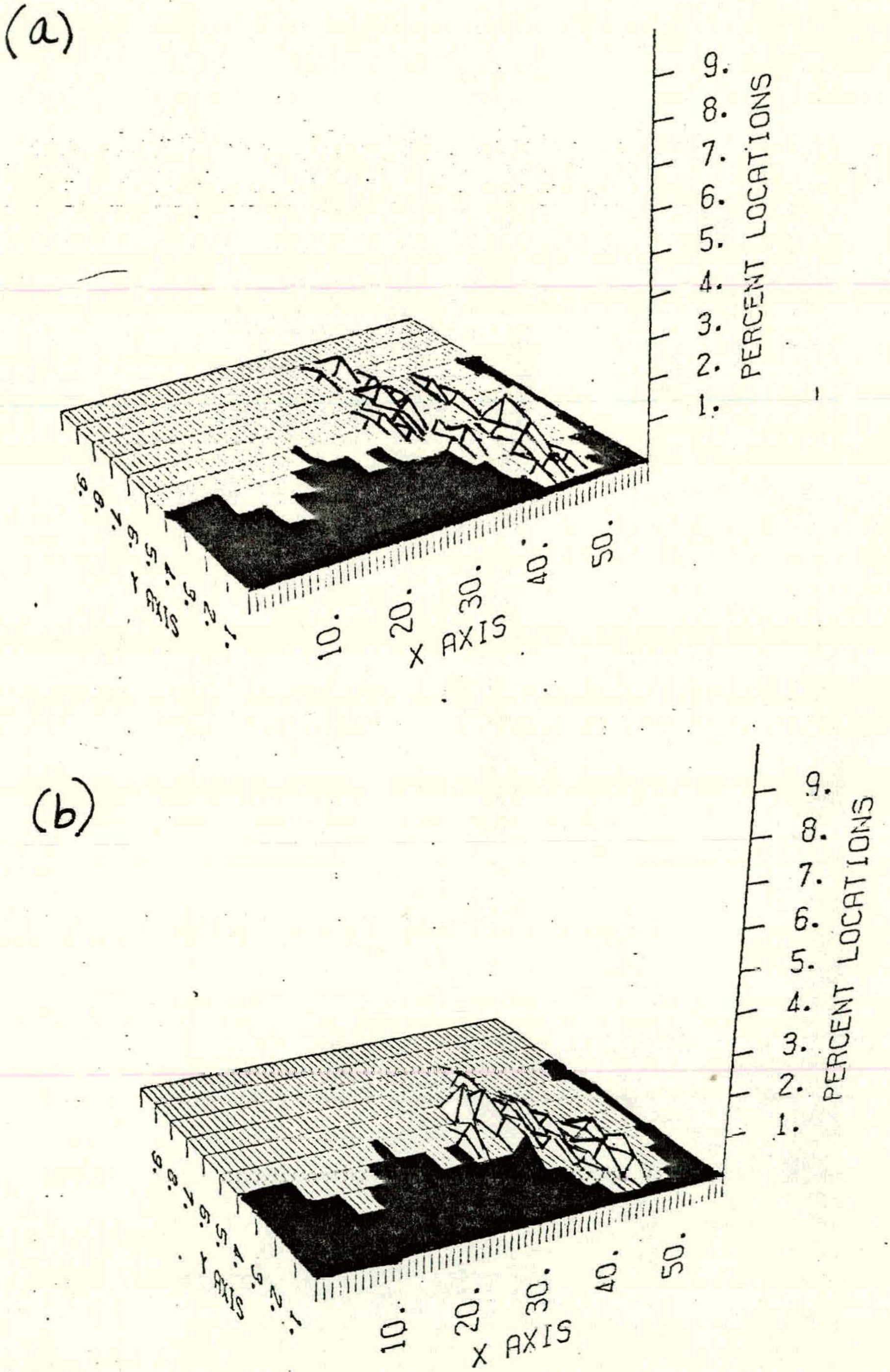
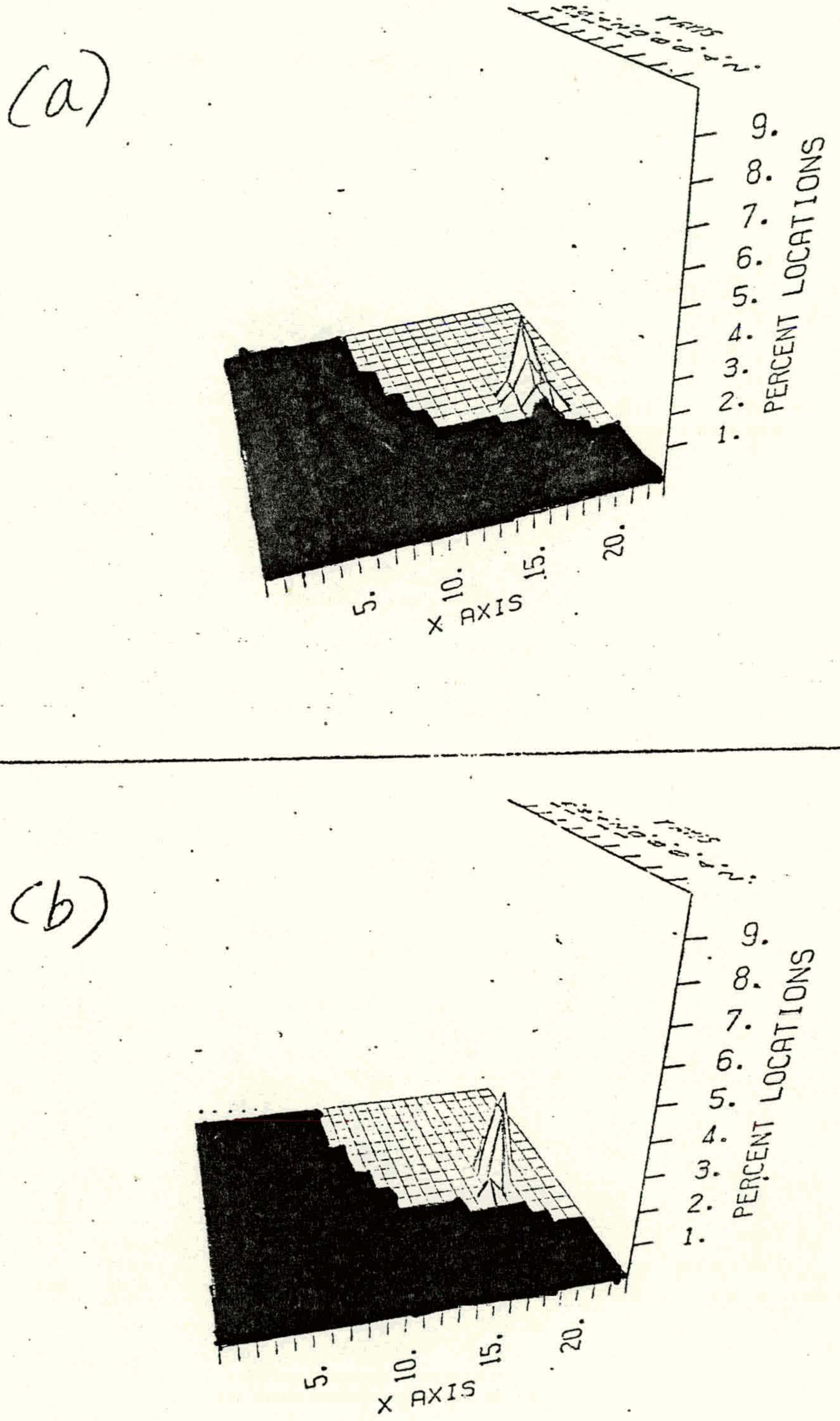
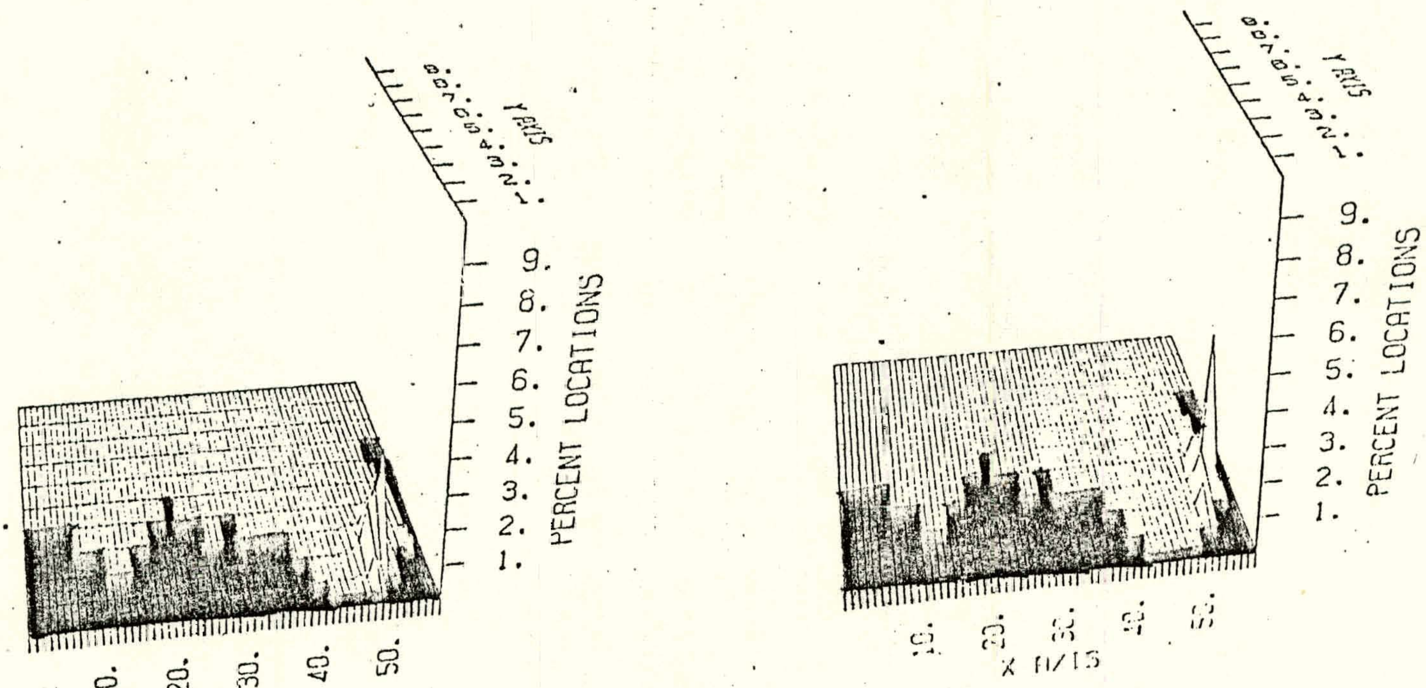

(a)
9.
8.
7.
6.
5.
4.
3.
2.
1.
PERCENT LOCATIONS
10.
20.
30.
40.
50.
X AXIS
Y AXIS
(b)
9.
8.
7.
6.
5.
4.
3.
2.
1.
PERCENT LOCATIONS
10.
20.
30.
40.
50.
X AXIS
Y AXIS

Fig. 7



(a)
9.
8.
7.
6.
5.
4.
3.
2.
1.
PERCENT LOCATIONS
5.
10.
15.
20.
X AXIS
(b)
9.
8.
7.
6.
5.
4.
3.
2.
1.
PERCENT LOCATIONS
5.
10.
15.
20.
X AXIS

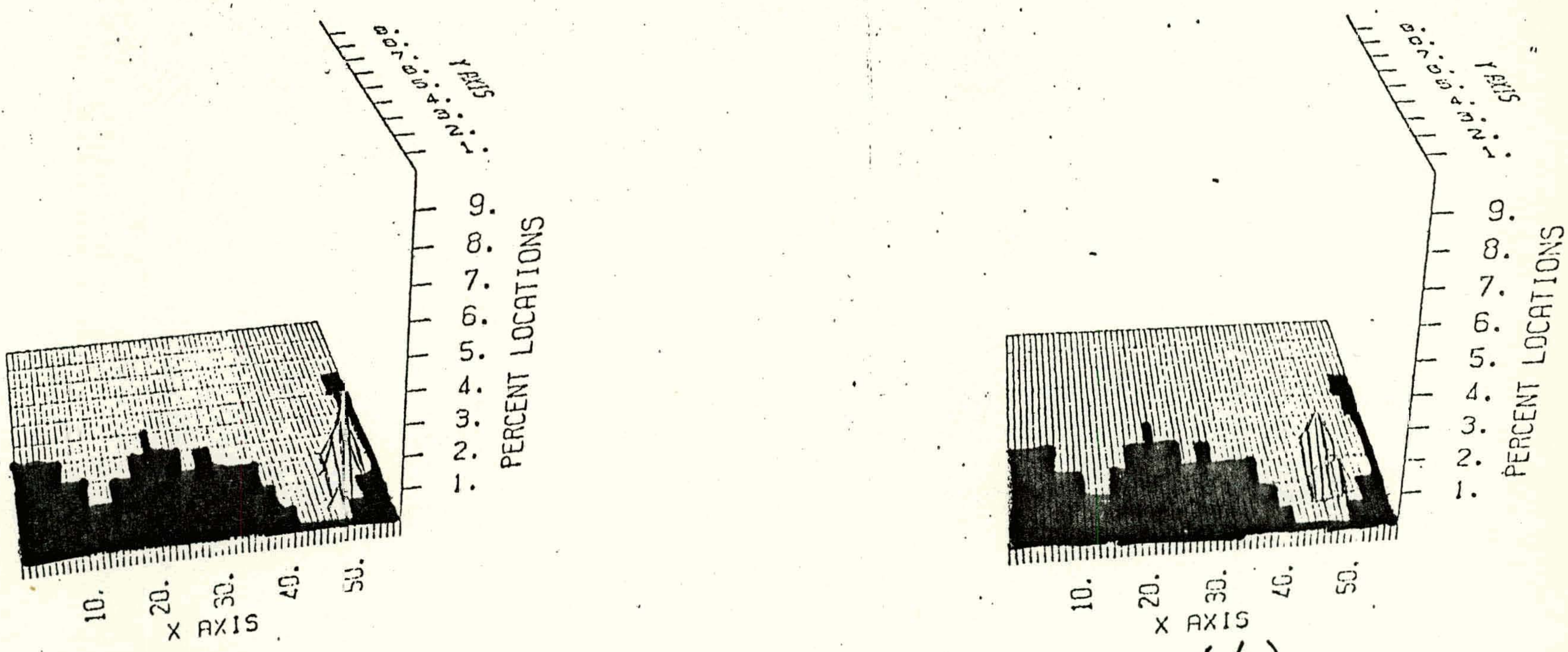

Y AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
10.
20.
30.
40.
50.

(a)

(b)

Fig. 8

Fig. 9


PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
10.
20.
30.
40.
50.
Y AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.

(a)

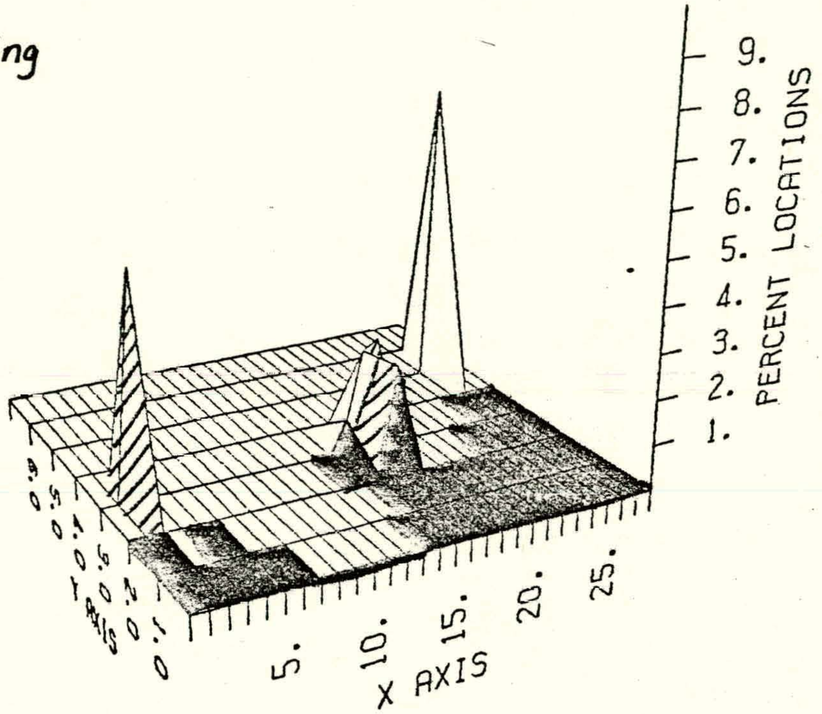
(b)

Fig. 10

1978

▨ = feeding
░ = feeding + resting
☐ = resting

(a)



1979

(b)

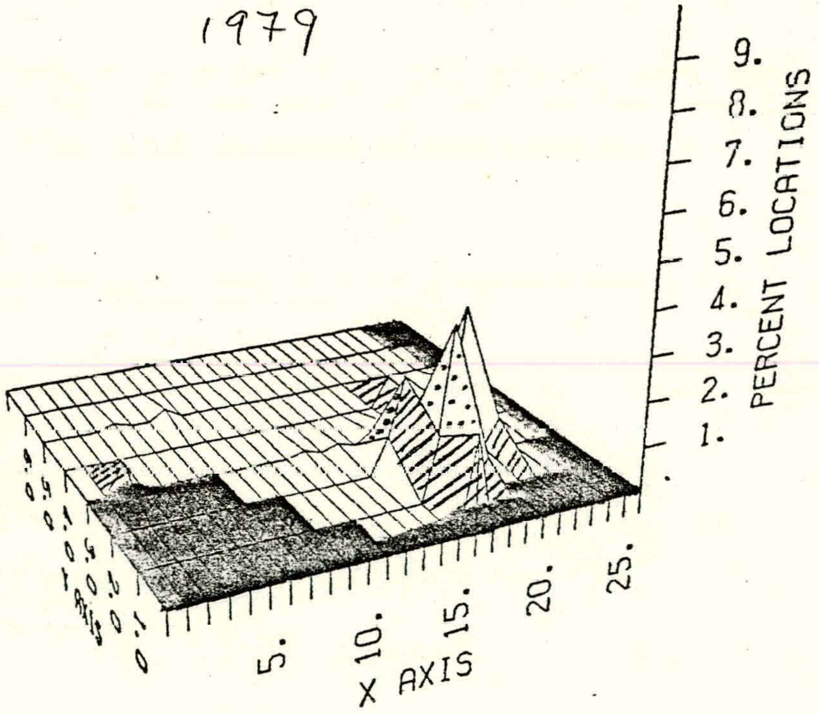
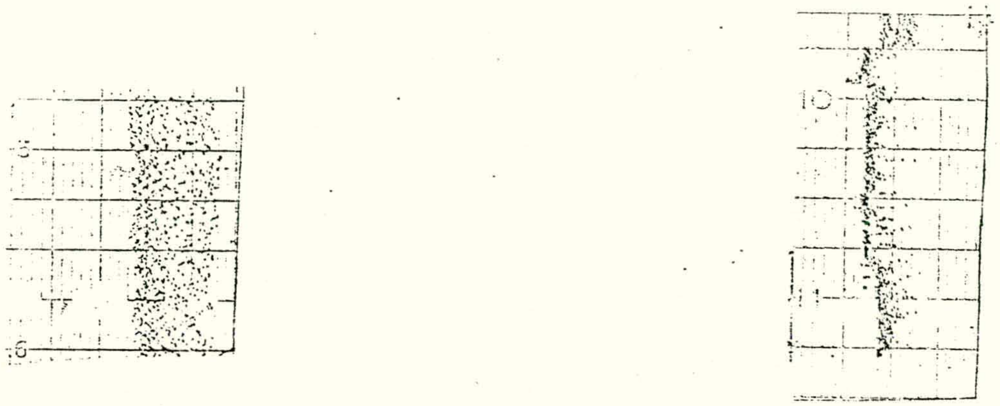


Fig. 11

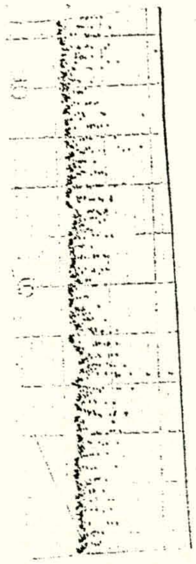


(a)

Resting

(b)

Grooming



(c)

Feeding

Fig. 12

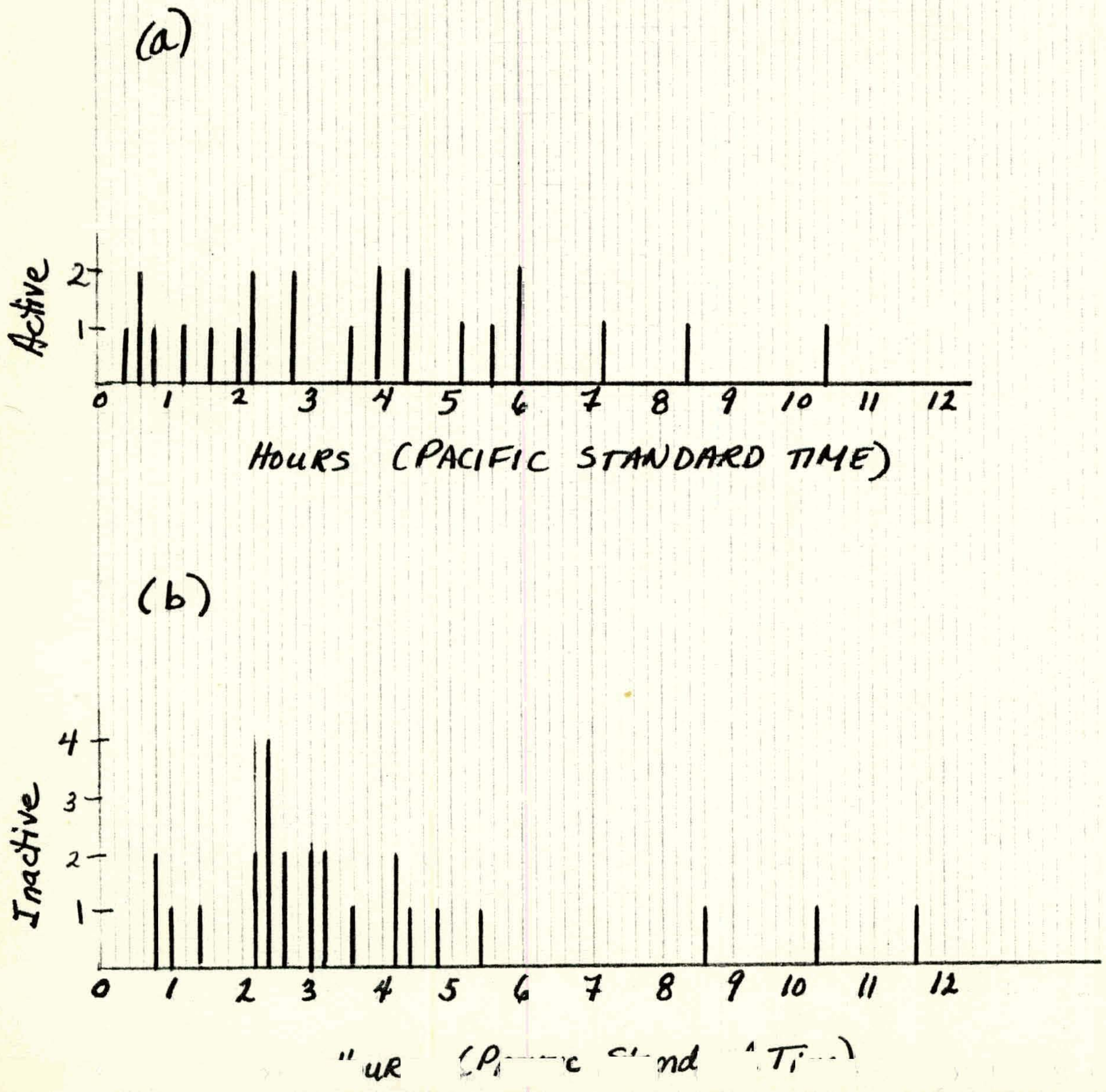

(a)
Active
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS (PACIFIC STANDARD TIME)
(b)
Inactive
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12

Fig. 13

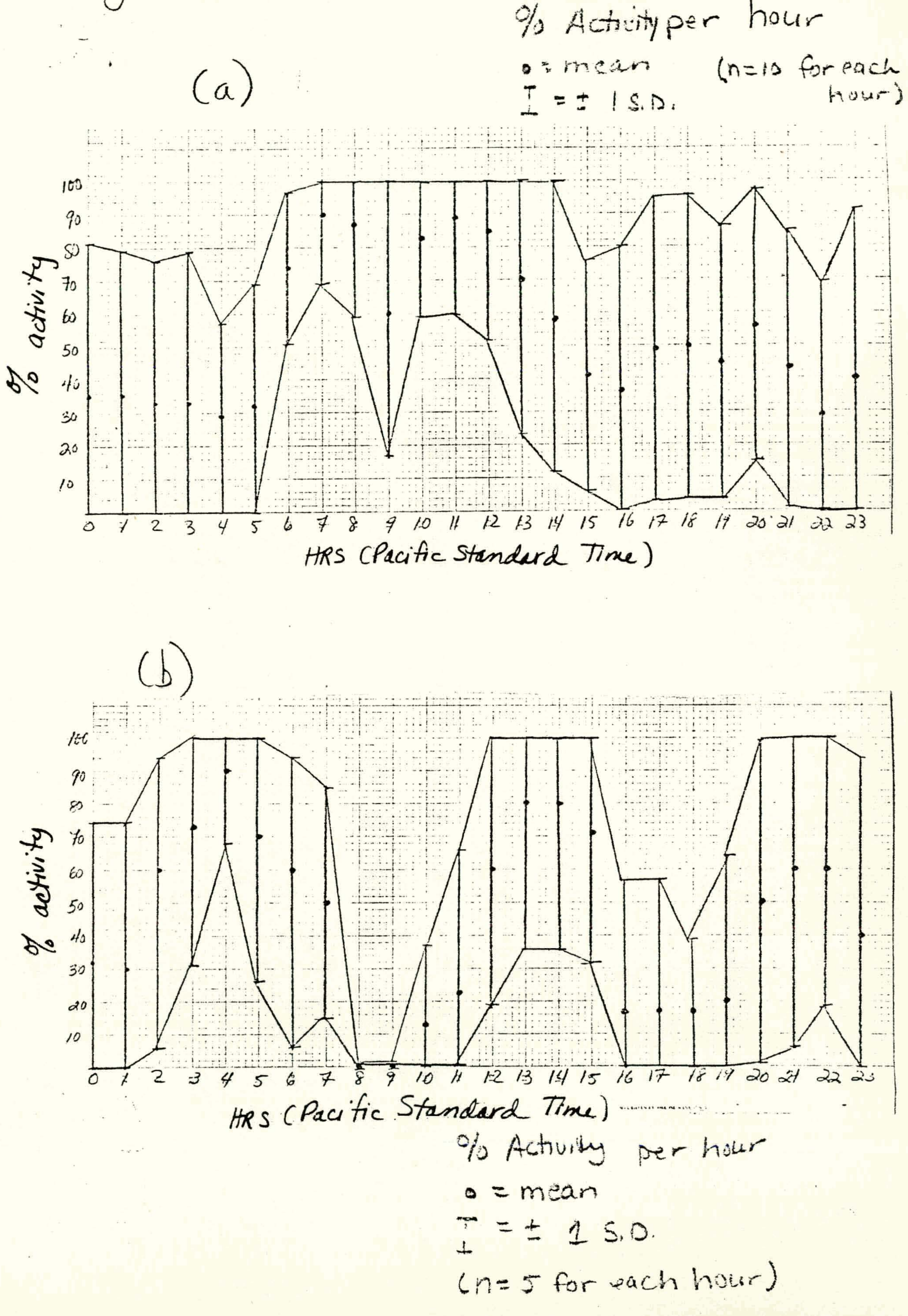
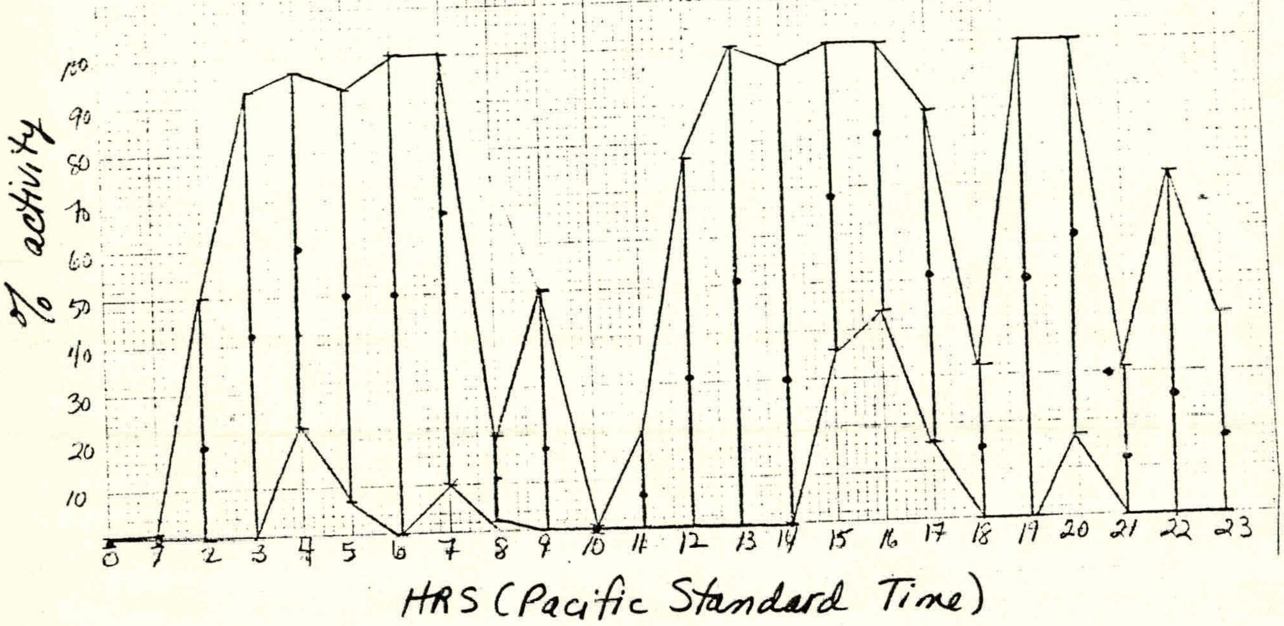

% Activity per hour
o = mean
I = ± 1 S.D.
(n=10 for each hour)
(a)
% activity
100
90
80
70
60
50
40
30
20
10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
HRS (Pacific Standard Time)
(b)
% activity
100
90
80
70
60
50
40
30
20
10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
HRS (Pacific Standard Time)
% Activity per hour
o = mean
I = ± 1 S.D.
(n = 5 for each hour)

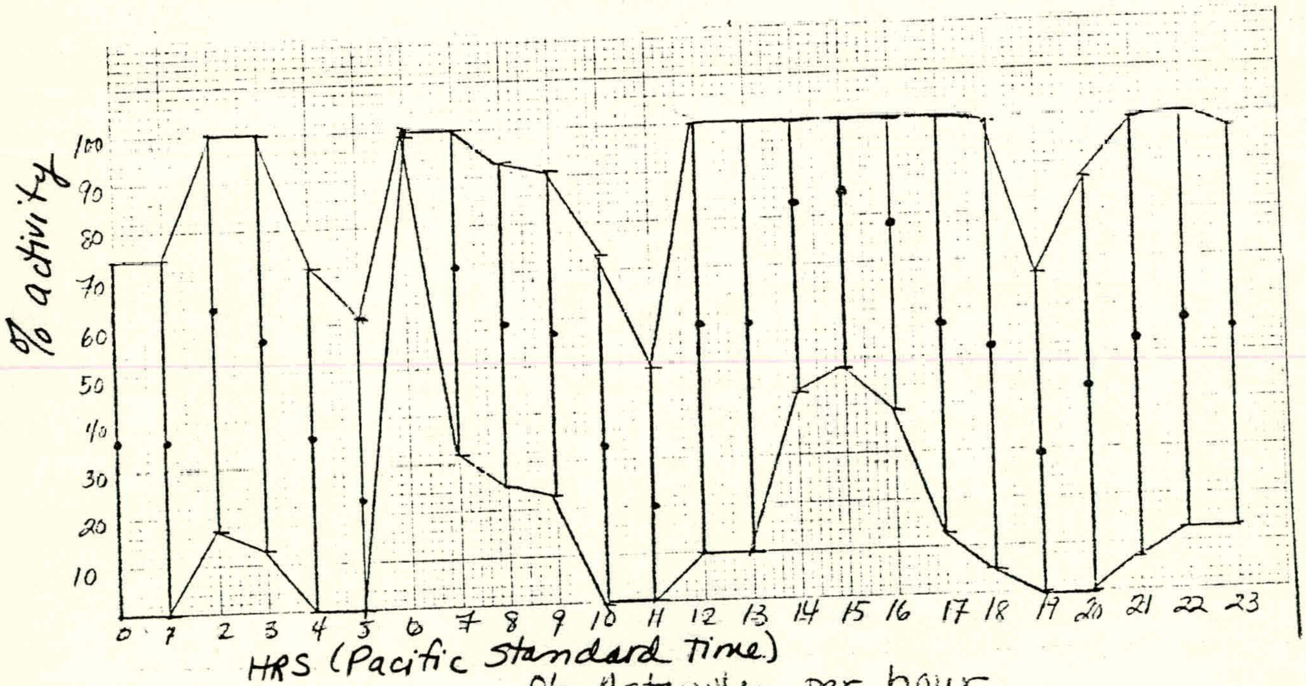
Fig. 14

% Activity per Hour
• = mean
I = ± S.D.
(n = 4 for each hour)

(a)



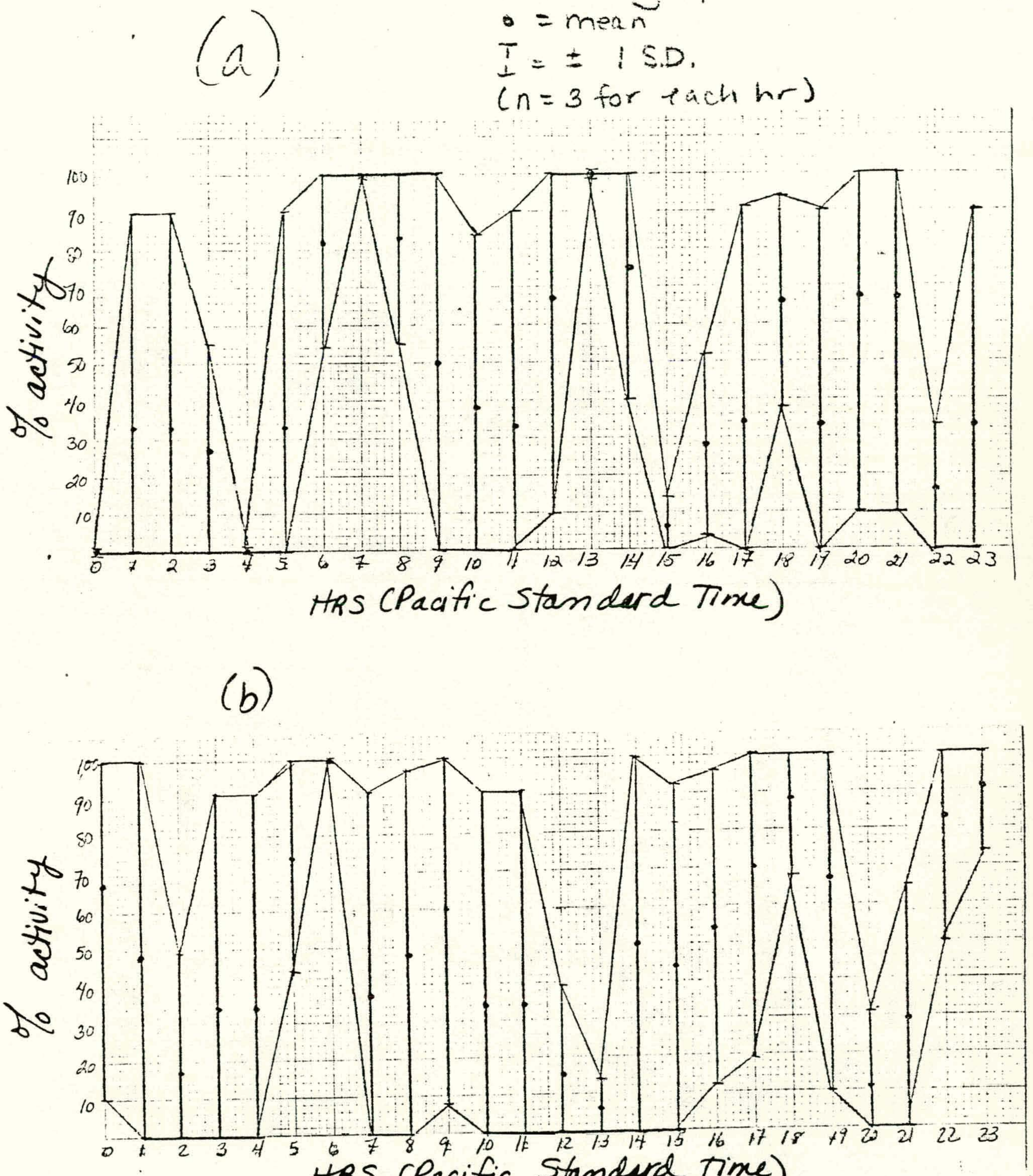
(b)



% Activity per hour
• = mean
I = ± 1 S.D.
(n = 7 for each hour)

Fig. 15

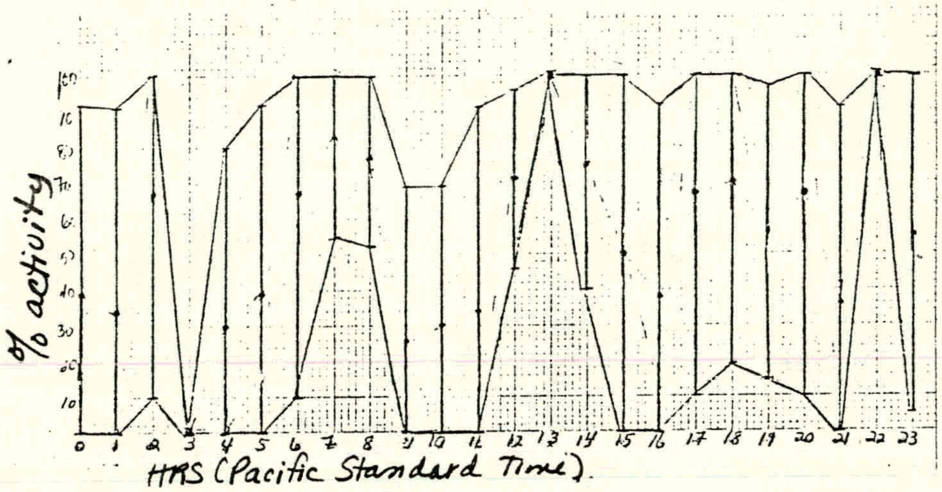
% Activity per Hour
• = mean
I = ± 1 S.D.
(n = 3 for each hr)



• = mean
I = ± 1 S.D.
(n = 3 for each hour)

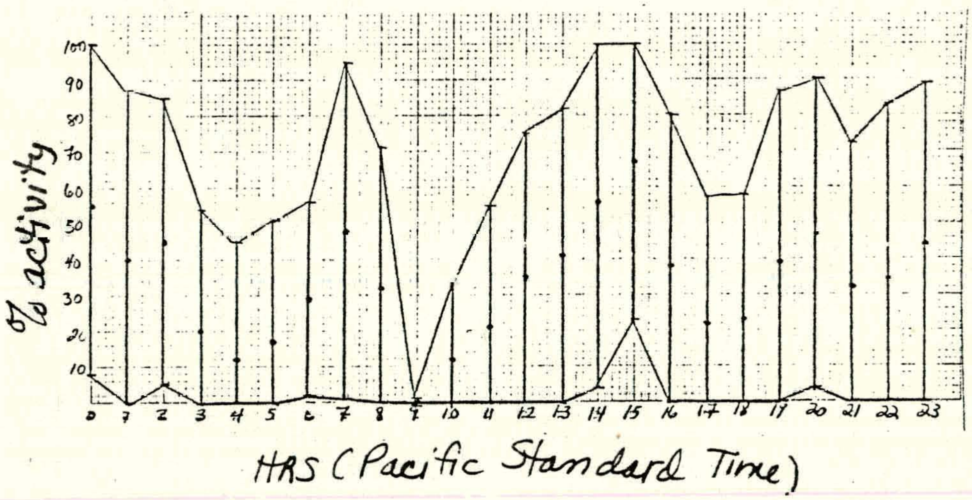
Fig. 16

(a)



• = mean
⊥ = ± 1 s.d.
(n=3 for each hour)

(b)



% Activity per hour

• = mean

⊥ = ± 1 S.D.

(n = 9 for each hour)

Fig. 17

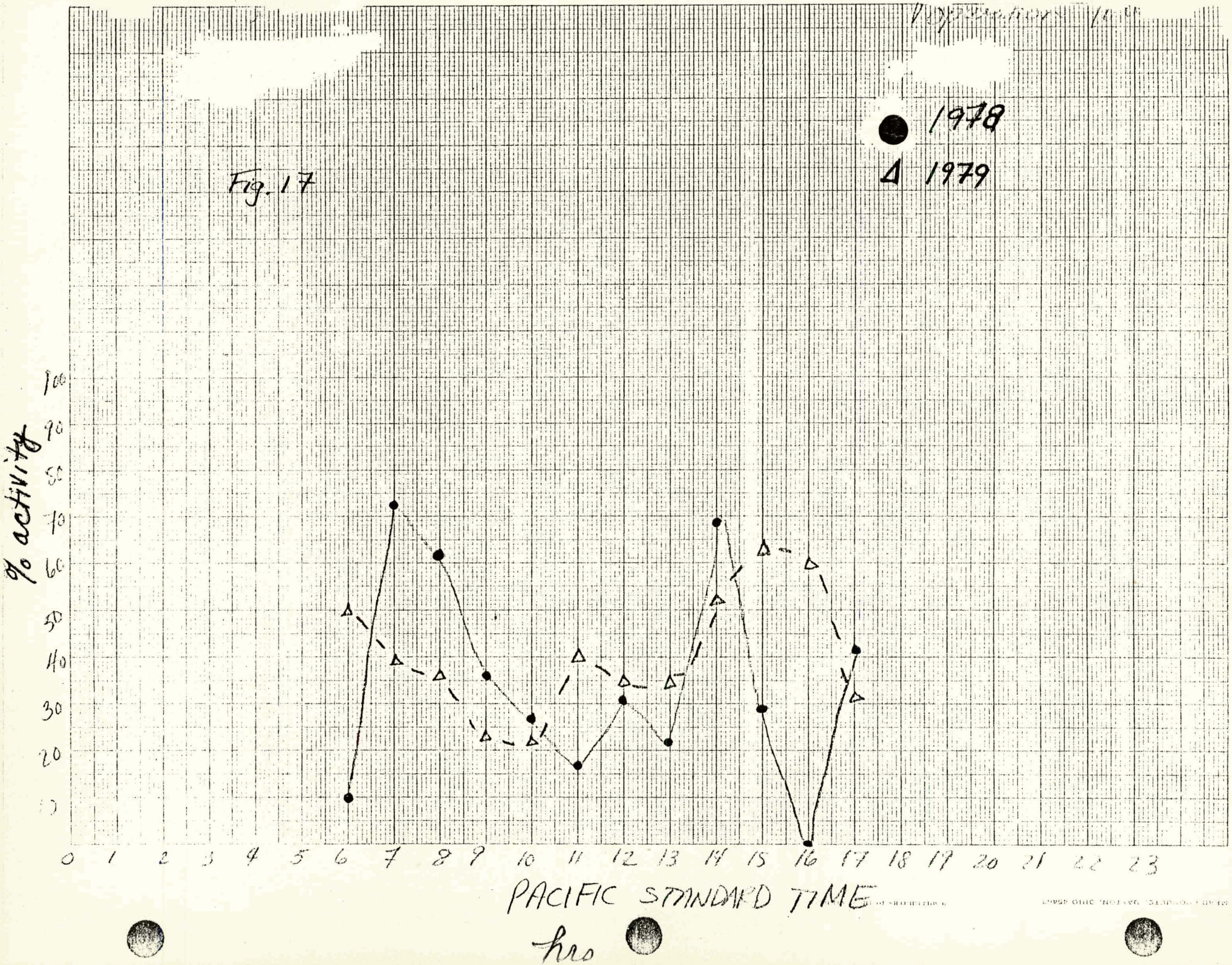
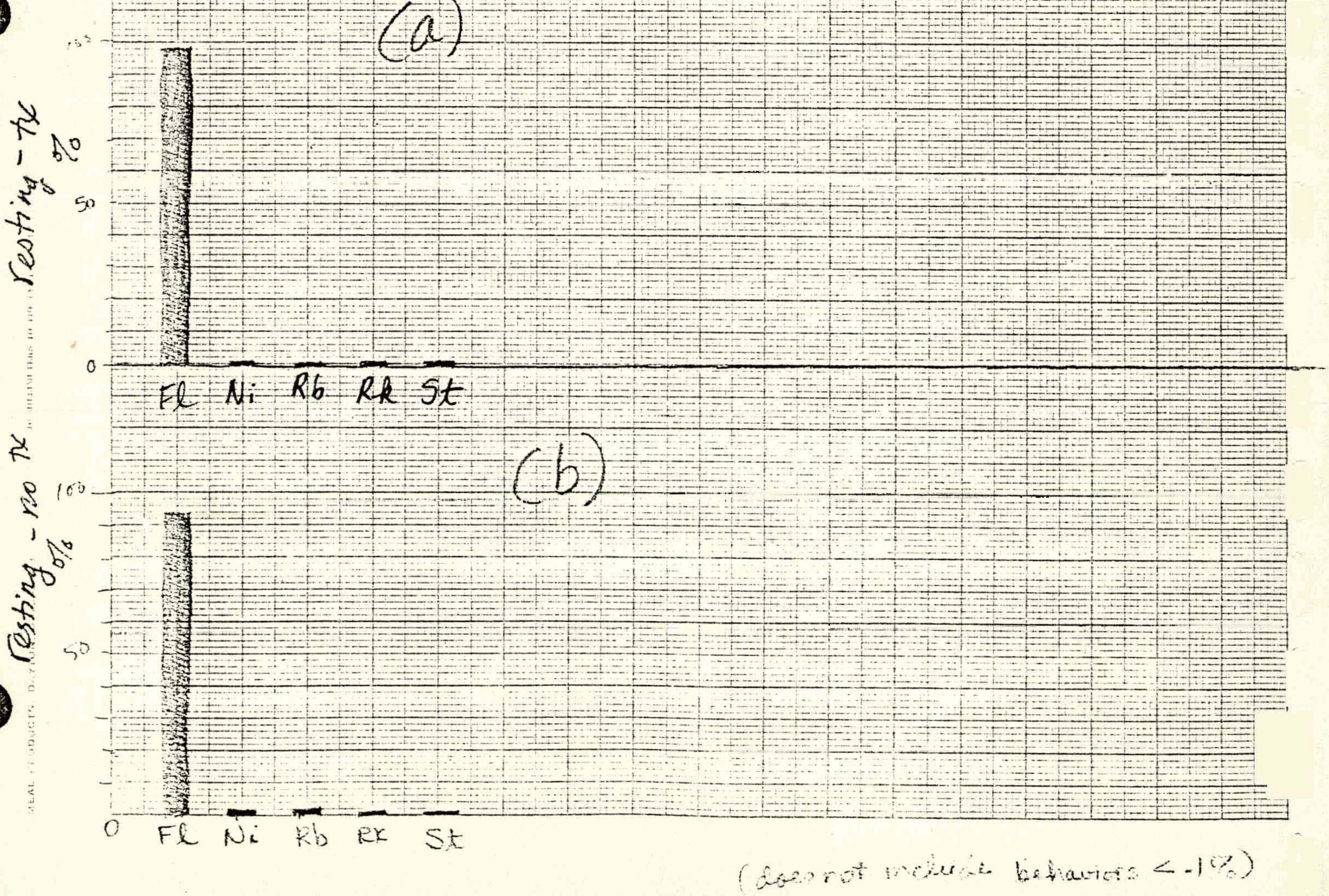

● 1978
Δ 1979
% activity
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
PACIFIC STANDARD TIME
hrs

Fig. 18



(does not include behaviors <.1%)

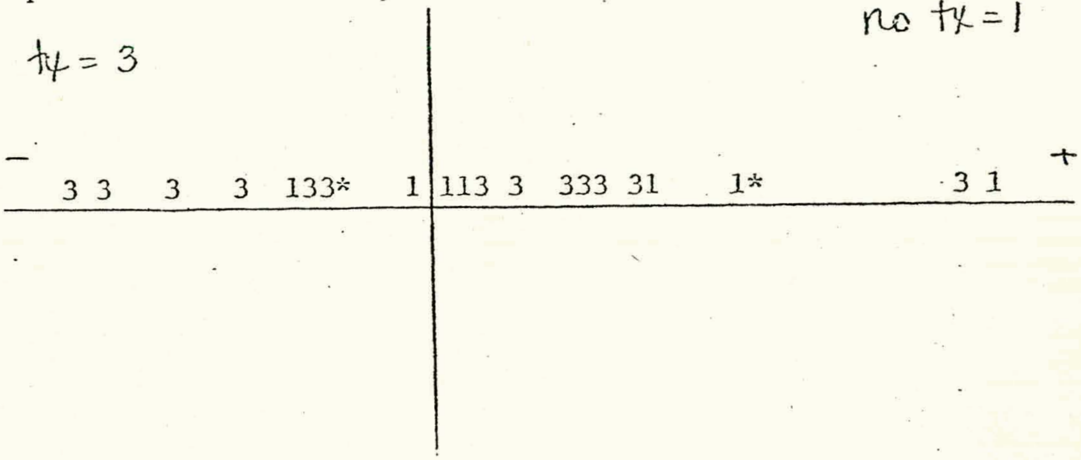
Fig. 19

Discriminant Analysis   1978 California   No Tx vs Tx

(a)

Resting   (significance = .001)

Group 1   1.80713   (n=11)
Group 3   -.28398   (n=70)



(b)

Grooming   (significance = .186)

Group 1   1.07803   (n=23)
Group 3   -.82649   (n=30)

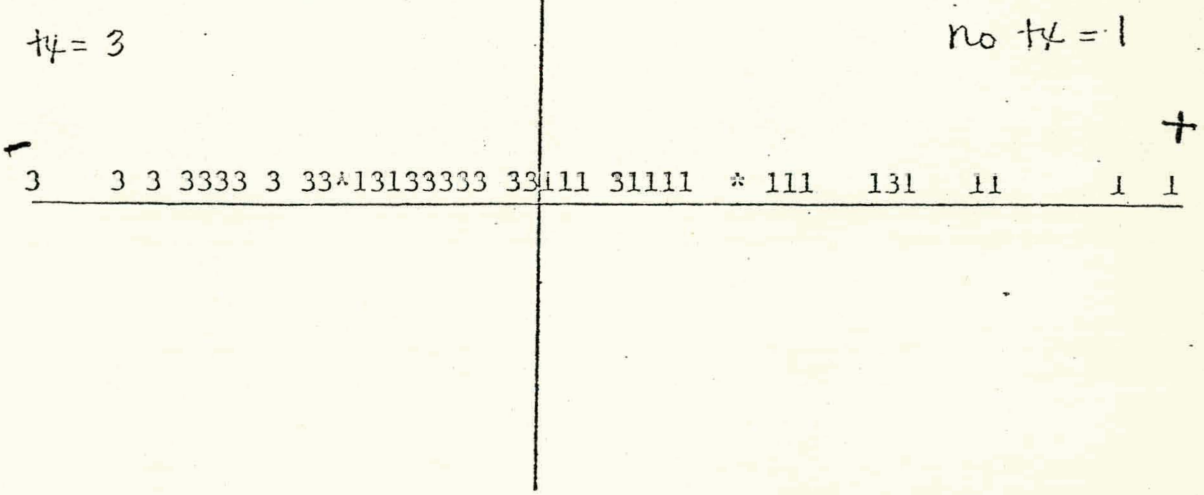
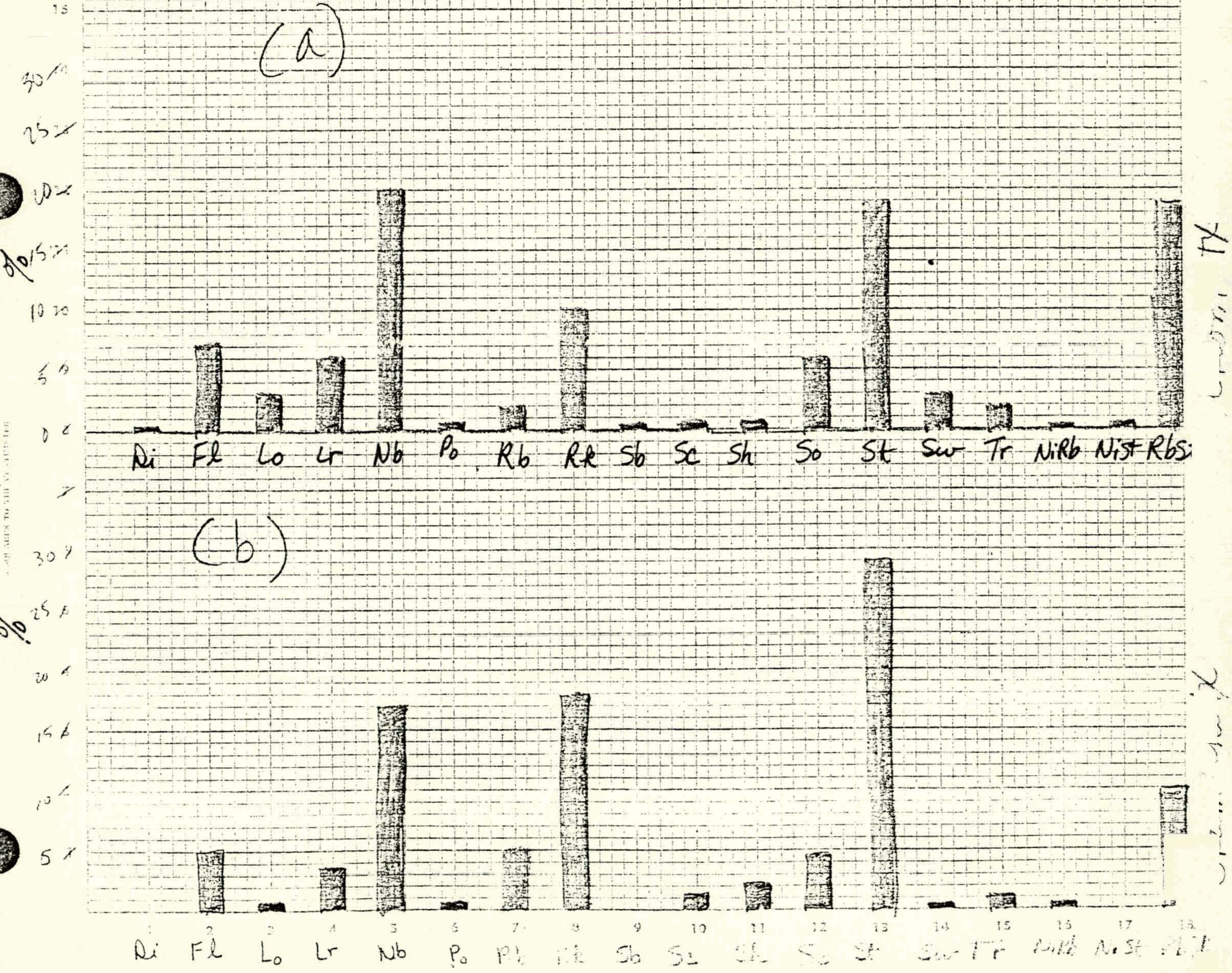


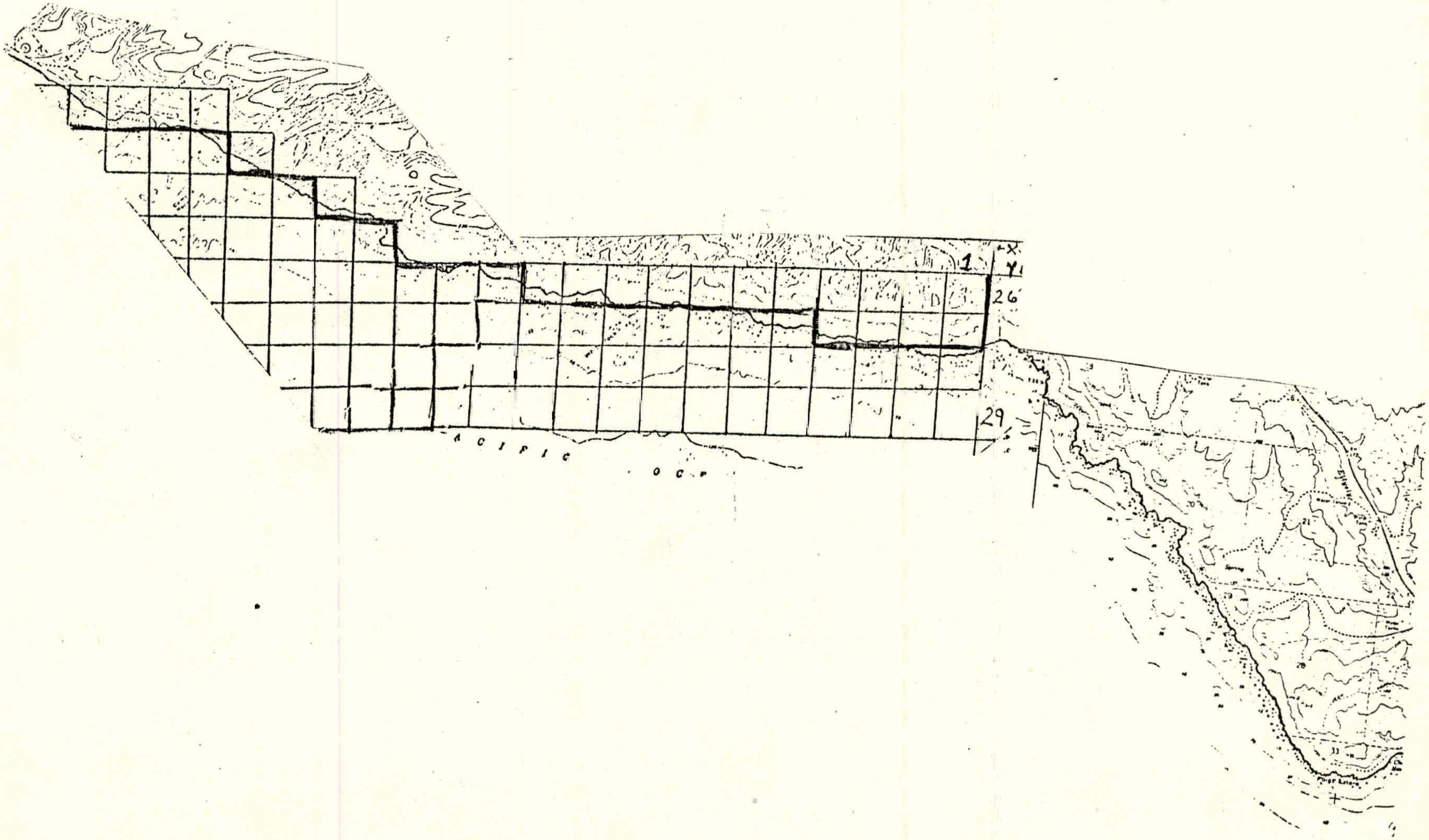
Fig. 20



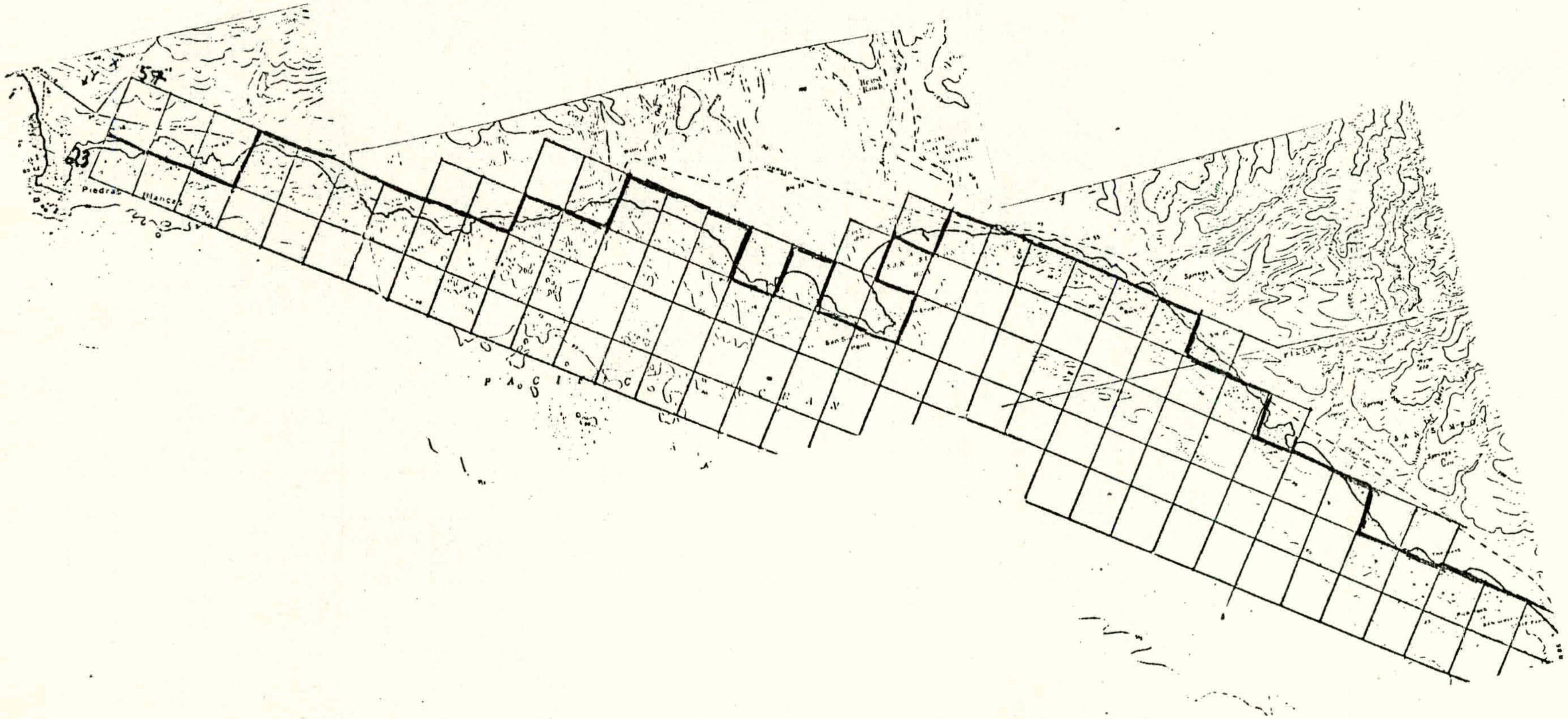
(a)
%
30 %
25 %
20 %
15 %
10 %
5 %
0 %
Di
Fl
Lo
Lr
Nb
Po
Rb
Rk
Sb
Sc
Sh
So
St
Sw
Tr
NiRb
NiSt
RbSt
(b)
%
30 %
25 %
20 %
15 %
10 %
5 %
Di
Fl
Lo
Lr
Nb
Po
Pl
Rk
Sb
Sc
Sh
So
St
Sw
Tr
NiRb
NiSt
RbSt

Appendix A. Grid system used to plot locations of sea otters followed during the fall seasons of 1978 and 1979 using the University of Minnesota FORTRAN subprogram PLOT3D.

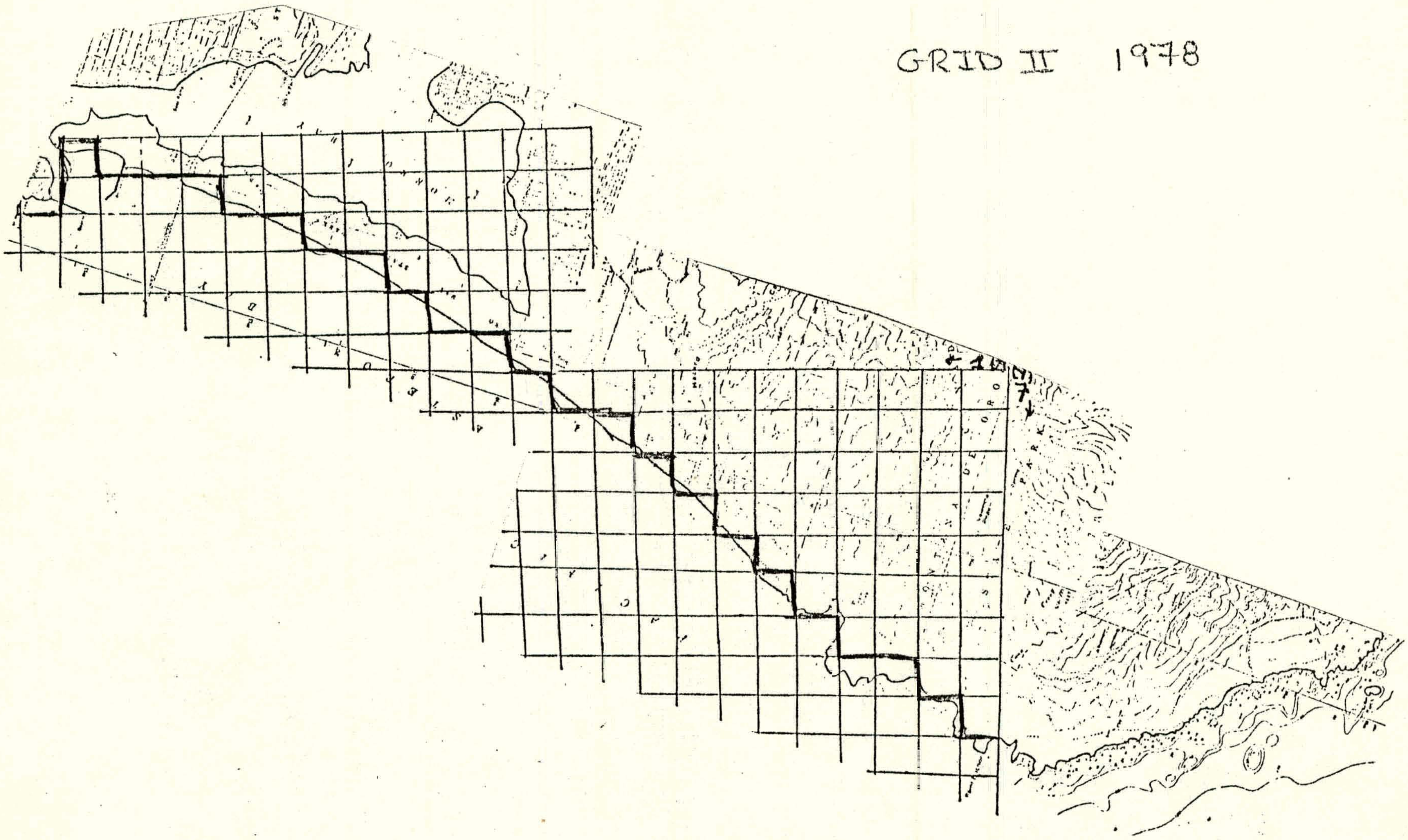
GRID I 1978



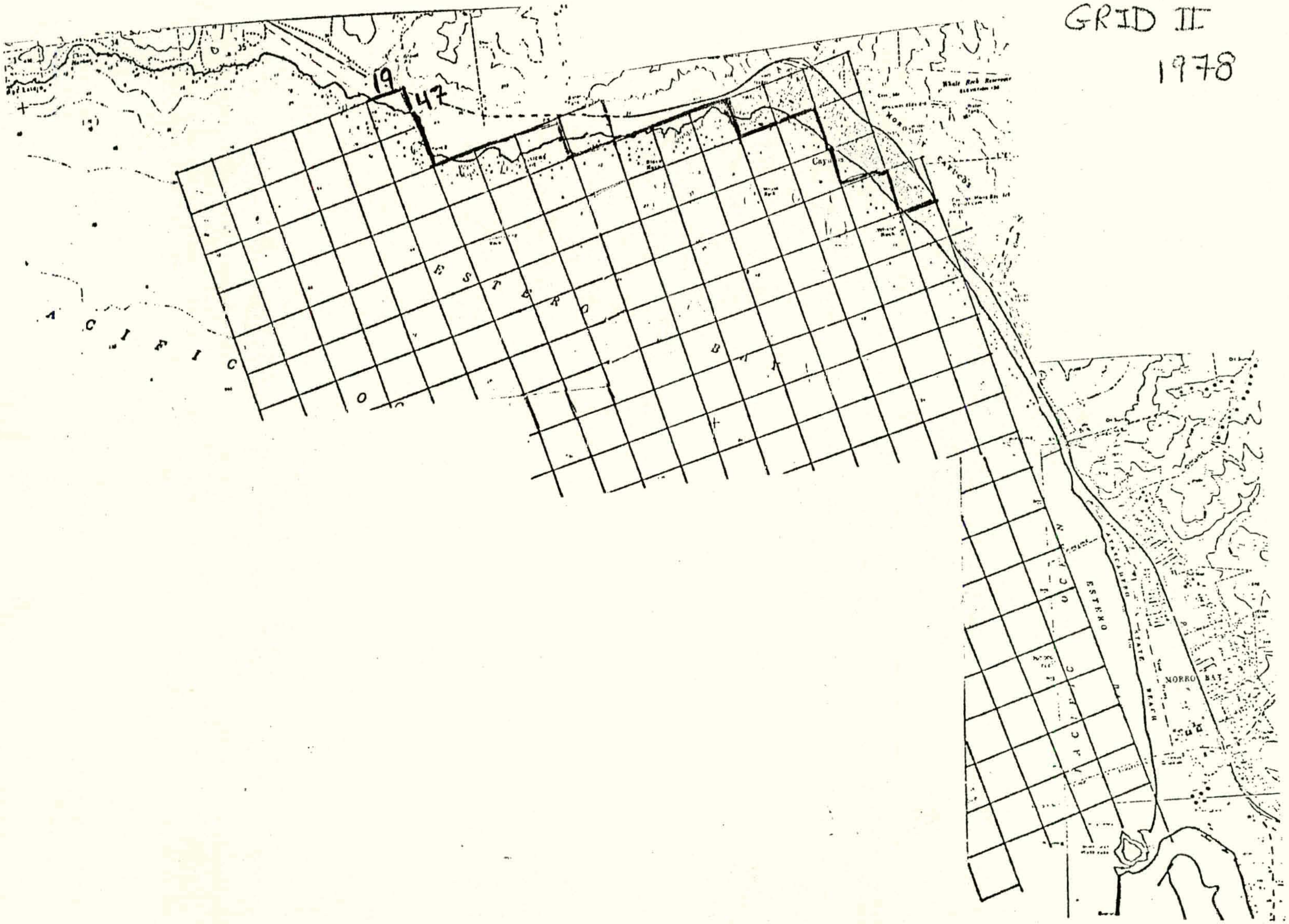
GRID I 1978



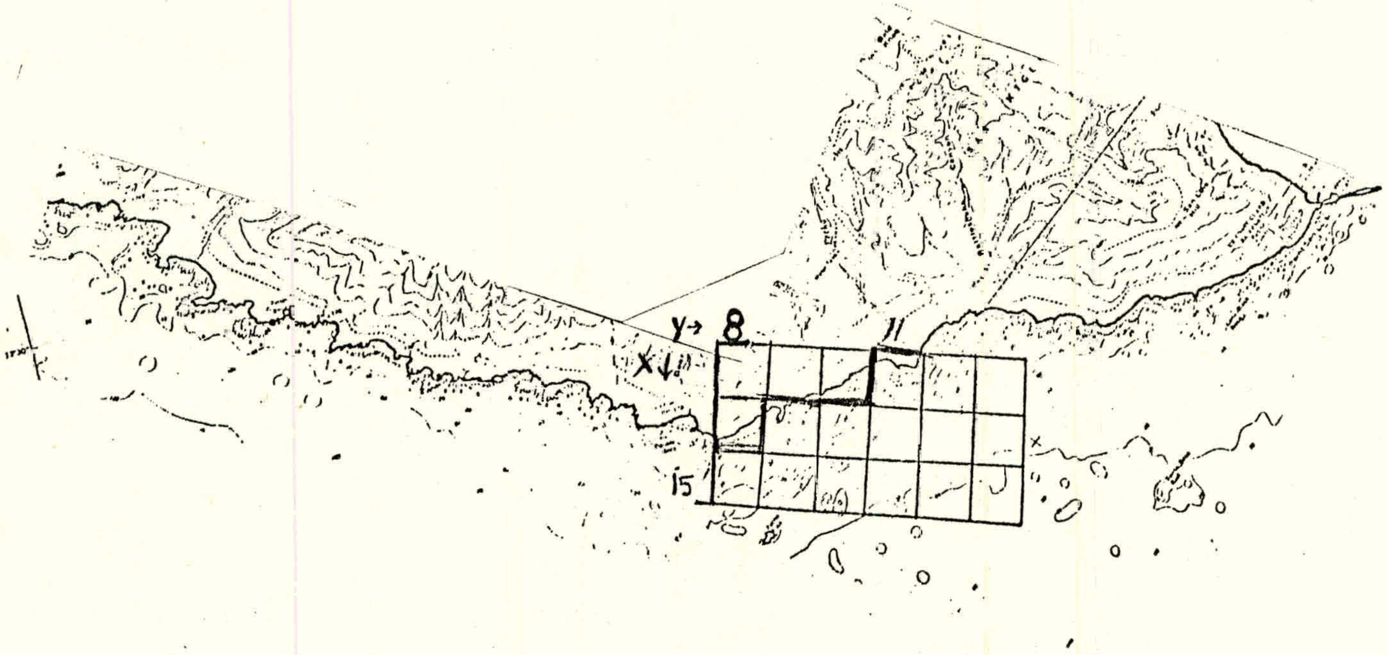
GRID II 1978



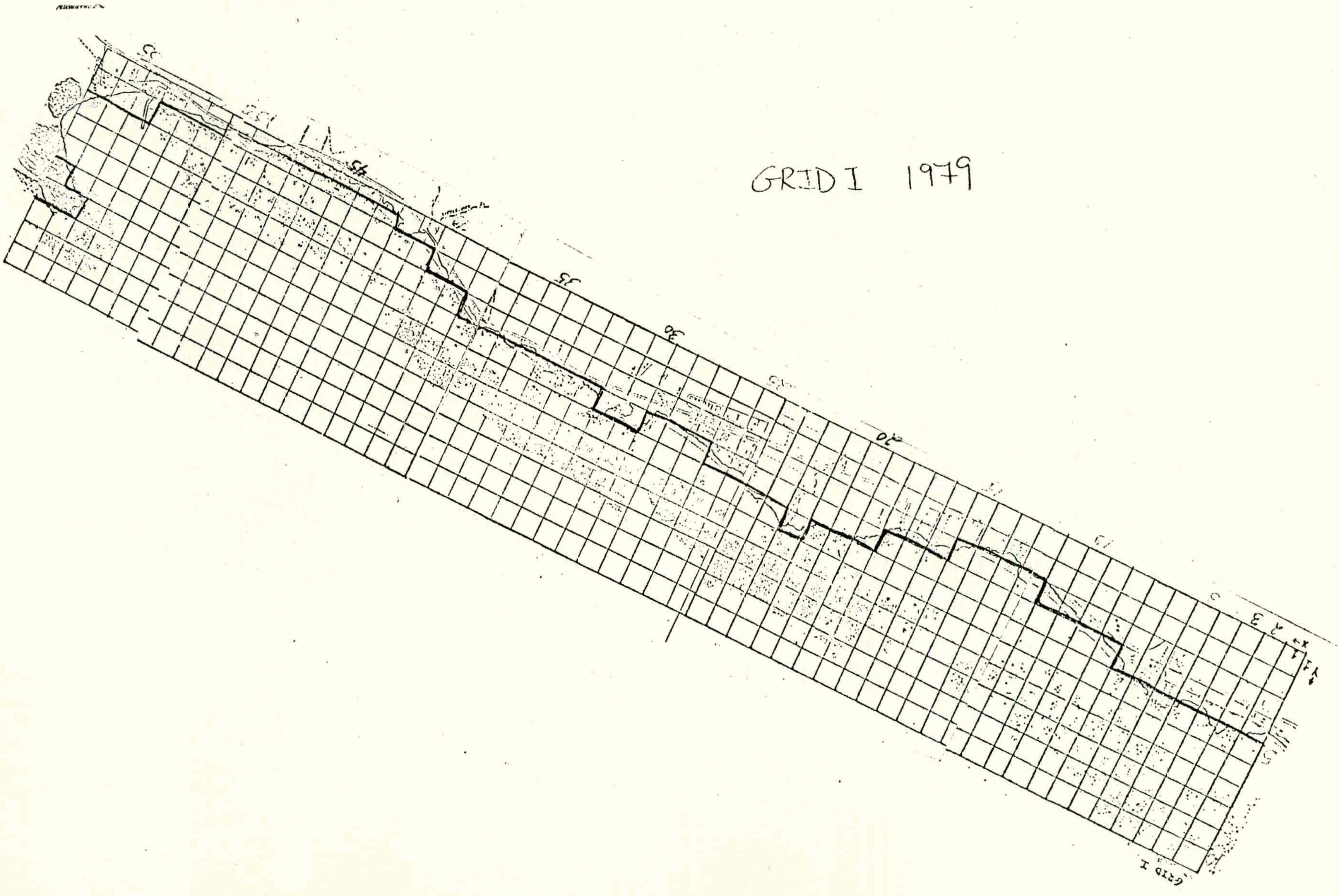
GRID II
1978


19
147
Whale Rock Reservoir
Cayucos
ESTERO BAY
PACIFIC OCEAN
ESTERO
STATE BEACH
MORRO BAY

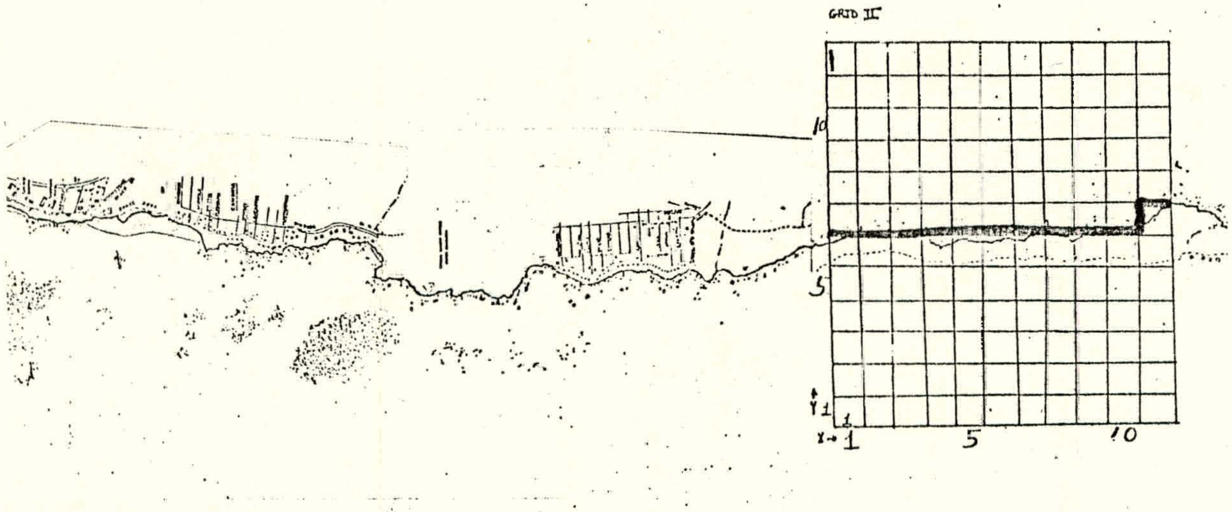
GRID III 1978



GRID I 1979



GRID II 1979



APPENDIX B. Number of locations per grid per sea otter tagged with radio-telemetry devices located during fall 1978 and 1979 in California.

Year	Number	Grid #	Grid Coordinates (x,y)	# pts. per grid
1978	803	1	(48,24)	1
			(49,23)	2
			(49,24)	2
			(50,22)	4
			(50,23)	19
			(50,24)	8
			(51,22)	6
			(51,23)	19
			(52,23)	1
			(54,22)	1
			(54,23)	1
			(56,23)	2
1978	416	1	(38,21)	1
			(39,21)	1
			(40,21)	6
			(41,21)	8
			(41,22)	3
			(42,20)	1
			(42,21)	12
			(42,22)	1
			(43,21)	3
			(45,22)	1
1978	106	1	(6,28)	1
			(10,28)	1
			(12,27)	1
			(13,26)	1
			(13,27)	2
			(14,26)	3
			(14,27)	1
			(15,25)	1
			(15,26)	9
			(15,27)	4
			(16,25)	1
			(17,25)	1
			(21,23)	1
			(22,23)	1
1978	242	1	(4,29)	1
			(6,28)	2
			(6,29)	2
			(7,28)	5
			(8,27)	1

Year	Number	Grid #	Grid coordinates (x,y)	# pts. per grid
			(8,28)	2
			(8,29)	2
			(9,27)	1
			(9,29)	2
			(12,26)	1
			(13,27)	1
			(16,25)	1
1978	315	1	(1,29)	3
			(5,28)	1
			(6,28)	1
			(7,28)	1
			(9,27)	1
			(16,25)	1
			(16,26)	1
1978	819	2	(43,10)	1
			(43,11)	1
			(44,7)	1
			(44,8)	2
			(44,9)	2
			(44,4)	4
			(44,7)	7
			(44,12)	1
			(45,9)	2
			(45,10)	1
			(45,11)	3
			(45,12)	2
1978	350	2	(43,9)	1
			(44,10)	4
			(44,11)	4
			(44,12)	2
			(45,11)	1
			(45,12)	4
1978	850	2	(43,9)	1
			(43,11)	2
			(44,9)	3
			(44,10)	3
			(44,11)	6
			(44,12)	2
			(45,9)	1
			(45,11)	4
			(45,12)	3

Year	Number	Grid #	Grid coordinates (x,y)	# pts. per grid
1978	395	2	(44,10)	2
			(44,11)	5
			(44,12)	4
			(44,13)	1
			(45,11)	5
			(45,12)	4
			(40,12)	3
1978	903	1	(45,22)	1
			(52,23)	1
		2	(6,13)	1
			(8,12)	1
			(21,3)	1
			(33,2)	1
1978	222	1	(41,21)	1
		2	(6,13)	1
			(7,12)	1
			(9,11)	1
			(10,9)	1
			(11,10)	1
			(13,9)	1
			(13,10)	1
1978	703	1	(10,28)	1
			(22,22)	1
			(23,21)	1
			(24,22)	1
			(24,23)	2
			(25,23)	1
			(26,22)	1
			(27,21)	5
			(27,22)	1
			(28,20)	1
			(28,21)	8
			(31,20)	1
			(32,19)	1
			(32,20)	1
			(39,22)	1
			(40,19)	1
			(41,20)	1
			(42,19)	1
			(42,20)	5
			(42,21)	1
			(43,21)	2
			(44,20)	1
			(44,21)	1

Year	Number	Grid #	Grid coordinates (x,y)	# pts. per grid
			(47,21)	1
		2	(8,12)	1
			(9,12)	1
			(10,10)	1
			(44,18)	1
1978	608	1	(19,25)	1
			(43,21)	1
		2	(45,11)	1
			(45,12)	1
		3	(14,11)	1
			(15,9)	1
1979	648	1	(44,4)	1
			(45,4)	1
			(46,2)	1
			(46,3)	2
			(46,4)	5
			(46,5)	1
			(47,2)	1
			(47,3)	2
			(47,4)	9
			(47,5)	2
			(48,3)	6
			(48,4)	14
			(48,5)	1
			(49,2)	3
			(49,3)	6
			(49,4)	10
			(50,2)	1
			(50,3)	4
			(50,4)	3
			(51,2)	3
			(51,3)	5
			(51,4)	1
			(52,3)	3
1979	780	1	(49,3)	1
			(50,3)	1
			(51,4)	1
			(51,5)	1
			(52,5)	3
			(52,6)	1
			(53,3)	7
			(53,4)	3
			(53,7)	1
			(54,3)	6

Year	Number	Grid #	Grid Coordinates (x,y)	# pts. per grid
			(54,4)	10
			(54,5)	7
			(54,6)	3
			(54,7)	1
			(55,3)	7
			(55,4)	47
			(55,5)	6
			(55,6)	2
			(46,3)	1
1979	746	1	(47,3)	1
			(48,2)	1
			(48,3)	1
			(48,4)	1
			(49,3)	3
			(49,4)	1
			(50,2)	6
			(50,3)	11
			(50,4)	1
			(51,2)	2
			(51,3)	15
			(51,4)	6
			(52,3)	23
			(52,4)	3
1979	298	1	(34,6)	1
			(36,6)	1
			(36,9)	1
			(37,5)	1
			(37,7)	1
			(38,6)	1
			(39,6)	1
			(39,7)	2
			(39,9)	2
			(40,4)	1
			(40,6)	2
			(41,5)	1
			(41,6)	1
			(41,7)	1
			(41,8)	1
			(42,4)	2
			(45,2)	1
			(46,3)	1
			(47,2)	1
			(47,3)	2
			(47,4)	1
			(47,7)	1

Year	Number	Grid #	Grid Coordinates (x,y)	# pts. per grid
			(48,2)	1
			(48,3)	3
			(48,4)	4
			(46,1)	1
			(49,3)	2
			(49,4)	1
			(50,2)	1
			(50,4)	3
1979	605	1	(25,5)	1
			(25,8)	1
			(28,7)	1
			(28,8)	1
			(29,5)	1
			(29,7)	2
			(30,5)	2
			(30,6)	4
			(30,7)	2
			(30,8)	2
			(30,10)	1
			(31,5)	2
			(31,6)	3
			(31,7)	3
			(32,7)	1
			(33,7)	1
			(34,4)	1
1979	636	1	(11,5)	1
			(18,7)	1
			(19,6)	1
			(20,7)	2
			(21,6)	1
			(21,7)	1
			(22,6)	1
			(22,7)	1
			(22,8)	1
			(22,9)	1
			(23,7)	2
			(24,6)	2
			(24,7)	1
			(25,6)	2
			(25,7)	1
			(26,6)	1
			(26,7)	1
			(29,10)	1
			(30,6)	1
			(30,7)	1

Year	Number	Grid #	Grid Coordinates (x,y)	# pts. per grid
			(31,5)	1
			(31,6)	2
			(32,6)	1
			(32,7)	1
			(34,6)	2
			(34,8)	1
			(37,6)	1
			(37,7)	1
			(39,4)	1
			(39,5)	1
			(39,5)	1
			(40,4)	1
1979	453	1	(33,5)	1
			(34,5)	2
			(36,6)	4
			(39,4)	2
			(39,5)	2
			(39,6)	3
			(40,6)	2
			(40,7)	1
			(41,6)	1
			(42,5)	1
			(42,7)	1
			(42,8)	1
			(43,4)	1
			(43,6)	1
			(44,2)	1
			(44,4)	1
			(44,6)	1
			(45,3)	1
			(45,6)	1
			(46,5)	1
			(47,3)	2
			(48,2)	2
			(48,3)	1
			(48,4)	1
			(49,3)	1
			(49,4)	2
			(50,3)	2
1979	585	1	(13,8)	1
			(19,7)	1
			(20,7)	1
			(23,8)	1
			(24,6)	2
			(25,6)	2

Year	Number	Grid #	Grid Coordinates (x,y)	# pts. per grid
			(27,8)	1
			(29,5)	1
			(30,5)	1
			(31,5)	1
			(31,6)	2
			(32,7)	1
			(32,9)	1
			(34,6)	1
			(36,6)	1
			(47,3)	2
			(48,4)	1
1979	345	1	(4,6)	1
			(19,6)	1
			(23,6)	1
			(23,7)	1
			(24,6)	1
			(36,5)	1
			(38,8)	1
			(45,3)	1
			(48,3)	1
			(49,2)	1
			(49,3)	1
			(49,4)	1
			(53,3)	1
1979	692	1	(9,5)	1
			(9 7)	1
			(10,5)	1
			(11,5)	1
			(12,4)	1
			(12,5)	1
			(14,6)	2
			915,5)	1
			(17,7)	2
			(17,9)	1
			(18,7)	1
			(19,7)	2
			(19,8)	1
			(20,6)	1
			(20,7)	1
			(21,7)	2
			(22,8)	1
			(23,6)	1
			(23,7)	2
			(23,8)	4
			(24,7)	1

Year	Number	Grid #	Grid Coordinates (x,y)	# pts. per grid
			(25,8)	1
			(25,9)	1
			(37,6)	1
1979	821	2	(2,9)	1
			(3,10)	1
			(4,12)	2
			(5,11)	1
			(8,10)	1
			(10,10)	2

Appendix C. Behavioral repetoire, adapted from Packard and Ribic (manuscript in preparation), used to record sea otter behavioral sequences during Fall 1978 and Fall 1979 in California.

APPENDIX C

Functional Category: COMFORT BEHAVIOUR

Behavior pattern	Behav	Int	Obj	General Description	Head	Front Paws	Torso	Rear Feet	Tail
Nibble or lick	Ni	–	 p b r l z	Mouth contact is made with some part of the otter's own body, in a nibbling or licking movement. Common objects include: Paws Belly Feet Tail Transmitter	Nibbling: a forward push "nosing" or biting with teeth. licking: repeated up/down movements with tongue	may clasp the part of body being nibbled	Flexed or straight depending on which area of body is nibbled	On or above surface while nibbling fore-part of body; spread or waving when rear pulled toward mouth	On or below water surface when nibbling other body parts. Pulled to mouth when tail (and usually rear feet) groomed
Stroking	St	 1...... 2......	 c h r b l s k	Front paws repeatedly stroke some area of the otter's own body. low intensity: slow movement high intensity: rapid Common body parts include: Chest Head Rear feet Belly Tail Side Back	Position dependent on area of body groomed.	Repetitious combing or rubbing movement	same	On or above water surface pulled toward head	same
Rubbing	Rb			Rear feet rub some area of otter's own body		May groom head or chest			
		1...	r	low intensity: the 2 rear feet are rubbed against each other, usually slowly, in a "hand washing" movement	on surface		Belly up on surface	Rubbing	On or below surface
		2...	k h s	high intensity: rapid movement of one foot similar to a dog scratching – directed toward back, neck, or side of body.	on or above surface		May be twisted	Scratching by one	May be above surface
Somersault	So	–		Forward somersault as the head is tucked close to the belly. Often only the curved back is visible until the head reappears at the end of the roll; Full 360° forward roll.	Held near belly –may be nibbling or licking	Usually not visible –may be stroking	Curved in a circle head to toe	Pulled up toward head	Curled toward head or flips to aid in turning
Floating	Fl	 1...... 2......		Otter floats belly up on the surface, rear feet up, no sculling, feeding or grooming movements low intensity – body motionless high intensity – movement of paws, head or feet	Above surface	Folded on chest, tucked under chin, covering eyes or cheeks, or held vertically separately.	Belly up position	May be fanned separately; vertical and placed one over the other; toes tipped toward nose; or digits flexed toward palm	On or below surface

APPENDIX C (continued)

SOCIAL INTERACTION (continued)

Behavior pattern	Behav	Int	Obj	General Description	Head	Front Paws	Torso	Rear Feet	Tail
Chinning	Ch			The otter swims slowly toward its partner, and places chin on chest, belly, or near the head of the other otter	Contact with the partner	Not visible	Usually belly down position	On or below the surface	On or below the surface
Nosing	No			Nose/mouth contact made with another otter. Difficult to distinguish between nibbling and sniffing as the two movements are often intermixed. Area of body which is nosed may be indicated in object column	Mouth/nose contact with another otter	May grasp partner	Variable	Variable, usually below surface	Same as feet
		1		......Low intensity: brief duration (<2 sec).					
		2		......High intensity: longer duration (>2 sec).					
			*	Mutual nosing between two otters					
Riding	Ri			The otter places its body on the belly of another otter. This may be accomplished by swimming up slowly and over the belly of the partner. The forepaws may or may not be used to pull the otter onto the belly of its partner. Occasionally the otter may roll sideways onto its partner. The other otter may move away or remain stationary.	Above water	May be used to pull otter onto belly of partner	Belly down	On or below surface	On or below surface
		1		......Low intensity: front half of body covers head and front half of partner's body			Half of torso contacts partner		
		2		......High intensity: full body contact			entire torso contacts partner		
Tumbling	Tu			Two otters roll over and over each other. The arched backs are usually visible, with an occasional glimpse of feet, tails, or heads. The body contact is highly variable - sometimes it appears they are wrestling, at other times making jaw contact	Usually below surface, occasionally appearing briefly as a new lunge is initiated	Not always distinguishable. Appear to make contact with the other otter	Flexed ventrally actively turning and twisting. Arched back usually visible.	Usually below surface, occasionally protrude	May stick out at odd angles if visible

APPENDIX C (continued)

COMFORT BEHAVIOUR (continued)

Behavior pattern	Behav	Int	Obj	General Description	Head	Front Paws	Torso	Rear Feet	Tail
Tuck Roll	Tr		-	Head is brought toward chest, but bent over to side while otter does a 360° side roll.  Intermediate between a somersault and a log roll.	Turned to one side, may be nibbling belly, back, or side.	Usually not visible -may be stroking	Initially belly up, then twisted with shoulders to belly or side	Submerged	Submerged
Log Roll	Lr		-	From a belly up position, the otter rotates to the side like a rolling log. Differs from rocking in that feet and paws are submerged.	On, above or under water surface	May be held near chest or be involved in grooming or feeding.	Extended horizontally. Differs from rocking in that torso is not arched.	On or above surface	On surface
Rocking	Rk			From a belly up position, the otter does a side roll with torso arched such that the feet and paws remain out of the water	Above surface	Above surface, may be held to mouth	Flexed ventrally while belly up, then dorsally while the belly is down	Above water	Above or on surface
		1		......low intensity: otter rocks from side to side (180°)					
		2		......high intensity: otter rolls 360° in one direction					
Shake	Sh	-	-	The head is rotated rapidly from side to side in a typical shaking movement; water flies; the nose may be outstretched; the shake may involve part of the body as well.	Rapid side to side rotation. Nose may be outstretched.	Activity is interrupted	In several positions -horizontal to vertical depending on preceding behavior.	Dependent on preceding behavior.	Dependent on preceding behavior.
Hanging	Ha	-	-	Belly down with both rear and head submerged. The arched back remains visible at the surface motionless for a few seconds	Submerged	Submerged	Arched back above surface	Submerged	Submerged
Dunk	Dk		-	While floating on the back, otter briefly dips the head in and out of the water. The chin is extended moving the back of the head dorsally	Above surface, submerged, then above surface	Variable, above water	Belly up	Variable	In water

APPENDIX C (continued)

Functional Category: FEEDING BEHAVIOUR

Behavior pattern	Behav	Int	Obj	General Description	Head	Front Paws	Torso	Rear Feet	Tail
Pounding	Pd			Rapid up and down pounding movements are made onto the chest with or without an object held between the forepaws. A hard object may be balanced on the chest as the otter floats on its back. Observer can often hear pounding	On surface	Pounding movements and grasp object	Belly up position	On or above surface	On surface
Eating	Ea			While floating on the back, the fore paws are brought repeatedly to the mouth. Sometimes the movement looks like "cramming" something into the mouth, at other times it resembles biting off pieces.	Above surface; biting or chewing movements	Hold object (not always visible) to mouth	Belly up position	On or below surface with occassional wave -possibly sculling	On or below surface

Functional Category: INVESTIGATION

Behavior pattern	Behav	Int	Obj	General Description	Head	Front Paws	Torso	Rear Feet	Tail
Looking	Lo			Belly up or on side, the otter turns its head in various directions. If its gaze is oriented primarily in direction, that may be indicated in object column.	Above surface	Variable	Belly up or on side	Variable	Variable
		1		......Low intensity: slow movements; occasional head turns.	Turned as if scanning				
		2		......High intensity: rapid agitated movements of head from side to side	Turned as if alarmed				
Periscope	Pe	-		Only the shoulders and head are visible above the water, as the otter takes a few seconds to "look around". Usually precedes a high-intensity dive.	Above surface; may be turned as if the animal seeks visual orientation cues.	Below surface	In vertical plane	Below surface	Below surfa

APPENDIX C (continued)

Functional category: LOCOMOTION

Behavior pattern	Behav	Int	Obj	General Description	Head	Front Paws	Torso	Rear Feet	Tail
Sidestroke	Si		+ –	The otter moves along the surface on its side. One foot may be waved above surface and head may be oriented toward an object	Above surface	One may be visible	One side down	One above or on surface, one below surface	On or below surface
Submerged	Sb		+ –	Body totally submerged, the otter reappears at a distance indicating it has swum under water.	Not visible	Not visible	Not visible	Not visible	Not visible
Porpoise	Po	1	+ –	Low intensity: As the otter swims just below the surface, the arched back repeatedly appears on the surface	Submerged	Submerged	Arched back visible at intervals	Submerged	Submerged
		2	+ –	High intensity: Repeatedly the otter leaps out of the water with back arched in an inverted U. General movement is in the forward direction as contrasted with the leap preceding a feeding dive.	Appears in the arching movement of the leap, below surface between leaps	Held close to chest	Arched in inverted U during leap, below surface between leaps	May or may not come above surface in leap	Same as feet
Swimming	Sw		+ –	Belly down, the head and back are visible moving along the surface	Above surface, chin in water	Below surface	Back above surface	Below surface	Below or on surface
Sculling	Sc		+ –	Belly up, the otter moves along the surface propelled by movement of the tail and/or feet.	Above surface, chin out of water	On chest or touching chin/head	Belly up position	Above or on surface, may paddle	Below or on surface moving from side to side
Dive	Di	1	–	Low intensity: From a belly down position, the otter submerges head then feet. Arching of the back is minimal.	Submerged first	Variable	Minimal arch as feet follow head	Submerged as torso follows head	Same as feet
		2		High intensity. Otter leaps out of water in a single porpoise. Arched torso clearly visible.	Submerged first	Tucked to chest	Initially vertical, flexes ventrally at peak of leap	Submerged as torso follows head	Same as feet
Folding dive	Fd	–	–	From a belly up position, the rear feet and shoulders move toward the center of the body and the otter sinks backward into water	Above surface, moves toward feet, submerged after the belly	May stick up vertically or be tucked to chest	Flexed ventrally from a belly up position	Above surface, move toward shoulders, submerged at same time as head	Same as feet
Rowing	Rw		–	Lying belly up, otter folds ventrally in a V shape then straightens. Head, rear feet and fore paws held out of water similar to folding dive, but may be repeated and otter does not submerge	Held above surface	Held up vertically above surface	Flexes ventrally in V shape then straightens	Above surface	In water

APPENDIX C (continued)

SOCIAL INTERACTION (continued)

Behavior pattern	Behav	Int	Cbl	General Description	Head	Front Paws	Torso	Rear Feet	Tail
Shove	Sv			Otter forcefully pushes another otter away with forepaws	Above water	Push another otter	Variable	Submerged	Submerged
Interfere	In			Otter attempts to move body between two other interacting otters	Usually above water	Variable	Variable	Variable	Variable
Give	Gi			Holding food or an object, otter moves paws toward another otter. The object is relinquished when the other otter takes it.	Feeding movements common	Hold an object, move toward other otter	Usually belly up	Variable	Variable
Take	Ta			With paws or mouth, otter grasps an object held by another otter	May grasp object with mouth	May grasp object with paws or contact body of other otter	Variable	Variable	Variable
		1......		Low intensity: not successful at obtaining object					
		2......		High intensity: successfully obtains object					
Beg	Be			Otter remains near the side or head of of a feeding otter. Head is oriented toward the feeding otter. Paws may or may not make contact.	Above water, oriented toward feeding otter	May rest on chest or shoulders of other otter	If vertical shoulders may be above surface. May be belly down	Usually submerged	Submerged
Suckle	Su			Pup has mouth in area of female's nipples	At inguinal area of female	Usually contact female	Belly down, may rest on female, or float perpendicularly to female	Submerged or on female	Submerged or on female
		1......		Low intensity: suckling interrupted					
		2......		High intensity: continuous contact with nipples					
Clasp	Cl	-		Female uses front arms to hold pup to her chest. The pup is usually clasped around the chest, neck, or head and becomes limp.	Above surface	Encircle upper part of pup's body	Variable	Submerged	Submerged
Grab	Gr			Jaws are closed on the body of another otter, maintaining prolonged contact		Usually submerged	Usually belly down	Usually submerged	Usually submerged
			o or p	Female grabs pup by neck					
			j or x	Male grabs female by nose					

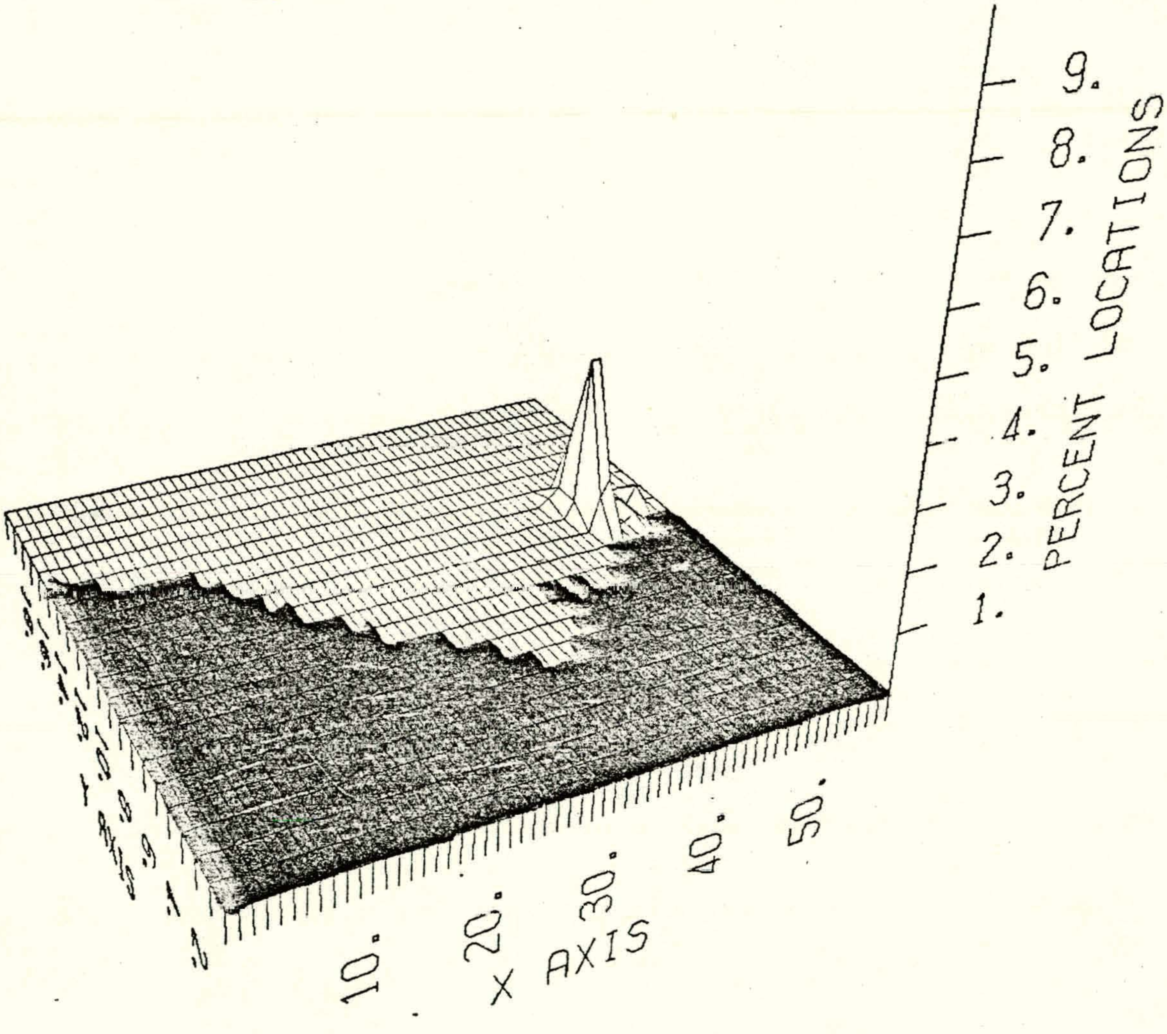
APPENDIX C (continued)

Functional Category: SOCIAL INTERACTION

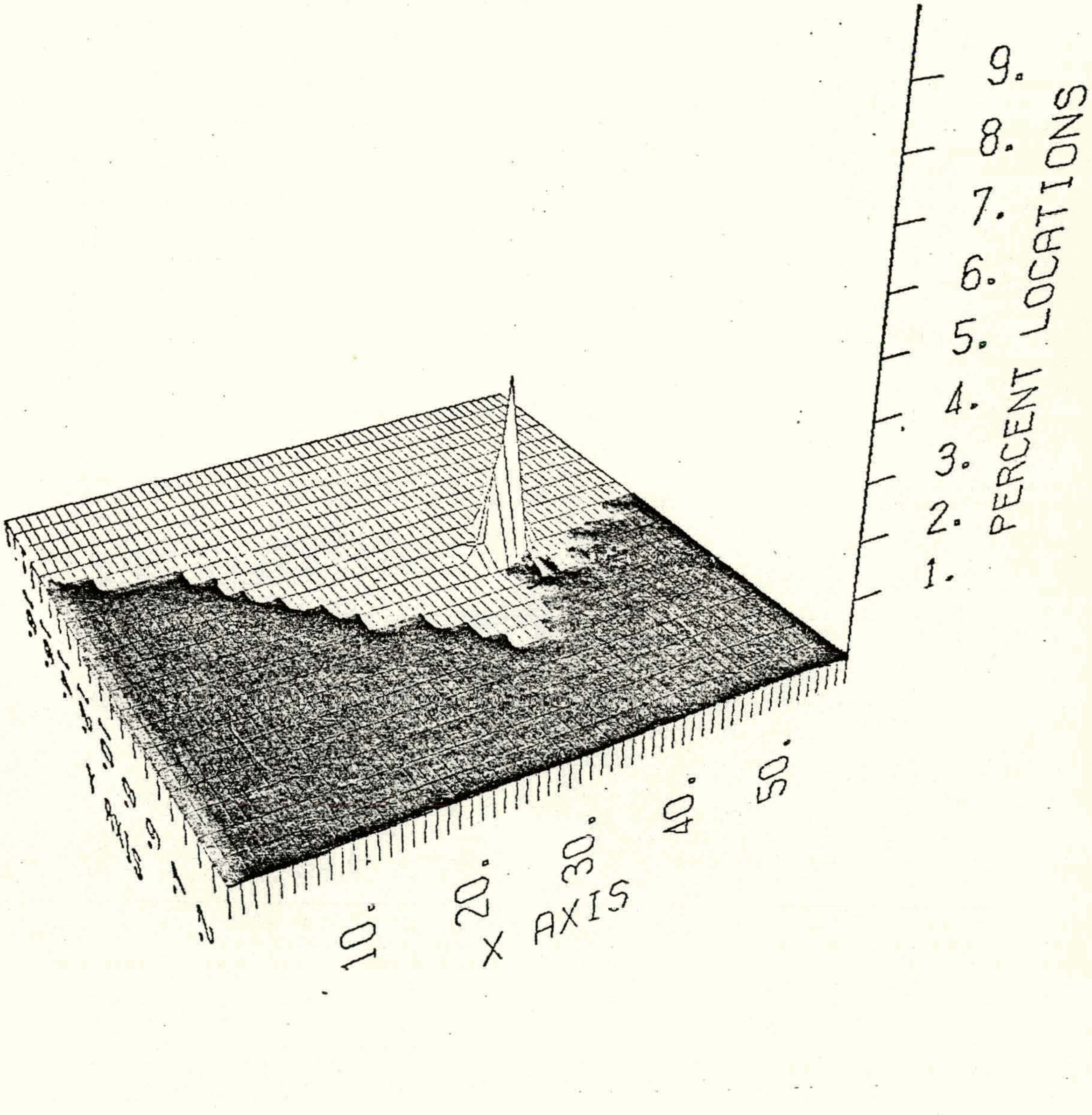
Behavior pattern	Behav	Int	Obj	General Description	Head	Front Paws	Torso	Rear Feet	Tail
Wrestling	Wr			Two otters actively grasp each other with forearms around the head and shoulders, and twist to break the hold.	Above water	Grasp the partner around neck or shoulders		Below surface	Below surface
		1		......Low intensity: in a a vertical position, head and shoulders above the water.			Vertical position usually shoulders are visible		
		2		......High intensity: more rapid movements, alternating with tumbling at the water surface.			Variation between vertical and horizontal		
Gape	Ca			Otter holds the mouth open, usually oriented toward partner's head. It may lunge without making contact, or parry lunges made by partner	Above surface Open mouth, no biting	May be used in wrestling movement	Lunging movement-varies from vertical to horizontal. Shoulders above water	Below surface	Below surface
		1		......Low intensity: brief duration, quality of a threat					
		2		......High intensity: prolonged interaction similar to the jawing play of dogs.					
Lunge	Lu			Sudden forward body movement toward another otter	Oriented toward other otter	Probably above surface	Dependent on previous behavior	Usually below surface	Usually below surfac
		1		......Low intensity: no contact					
		2		......High intensity: lunge and nip, mouth contact	biting contact of short duration				
Mutual porpoising	Po		a	Porpoise as described under locomotion. Synchronously or in close sequence with a partner moving in same direction	See locomotion	See locomotion	See locomotion	See locomotion	See locomotion
Pawing	Pa			With one forepaw, the otter reaches out to contact its partner. May be a shoving or patting movement.	Usually eyes directed toward partner	Above water-one reaches out	Dependent on preceding behavior	Same as torso	Same as torso
Splash	Sl			Belly up, otter moves partly submerged front paws away from body towards another animal, making water splash.	Above water oriented toward another animal	Shoving movement splashes water	Belly up	Below surface	Below face

Appendix D. Maps of locations of sea otters tagged with radio-telemetry devices tracked during Fall 1978 or Fall 1979 in California.

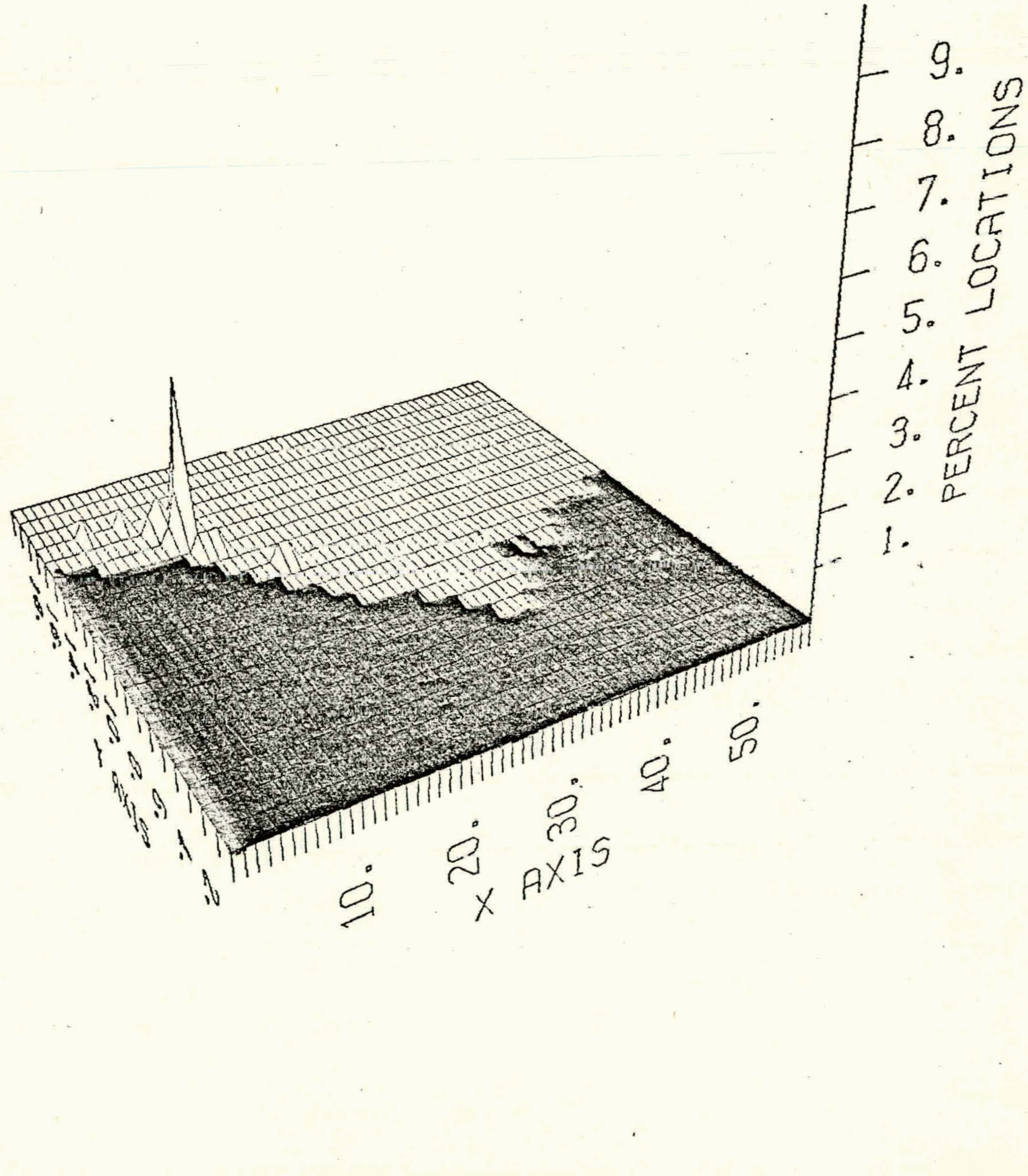
1978 Tx 803


9.
8.
7.
6.
5.
4.
3.
2.
1.
PERCENT LOCATIONS
10.
20.
30.
40.
50.
X AXIS
3.
6.
9.
12.
15.
18.
21.
Y AXIS

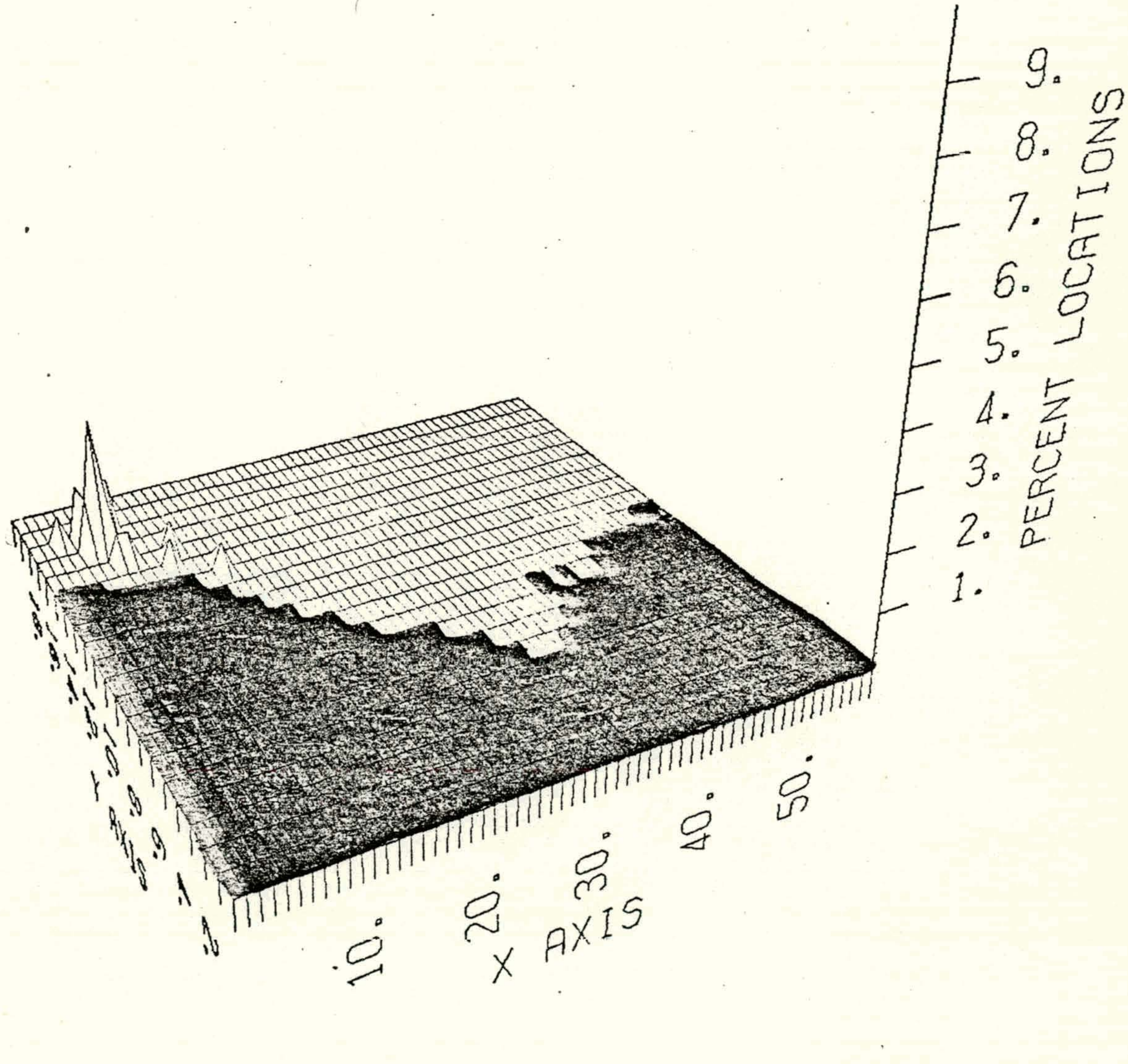
1978 Tx 416



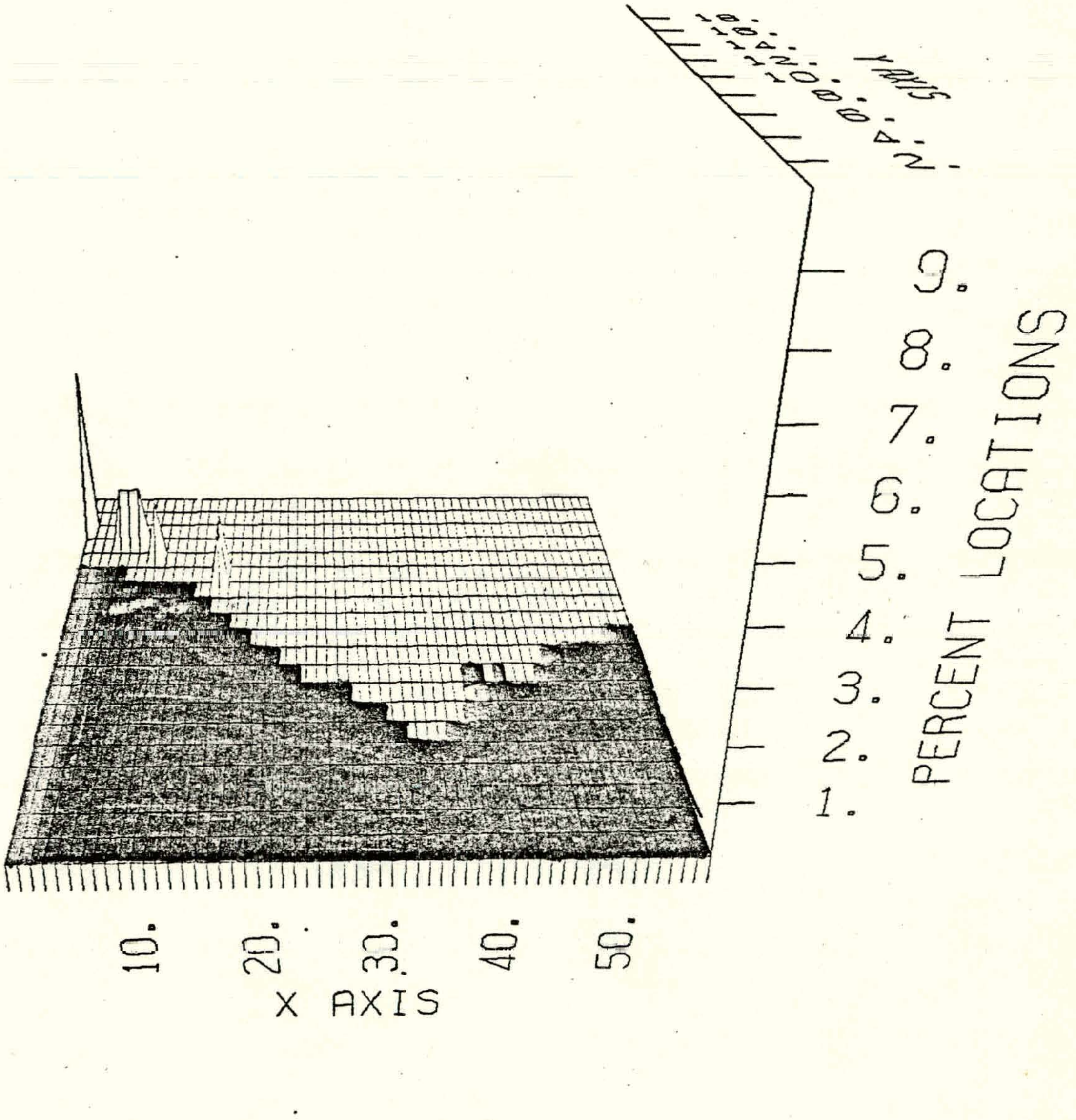
1978   Tx 106



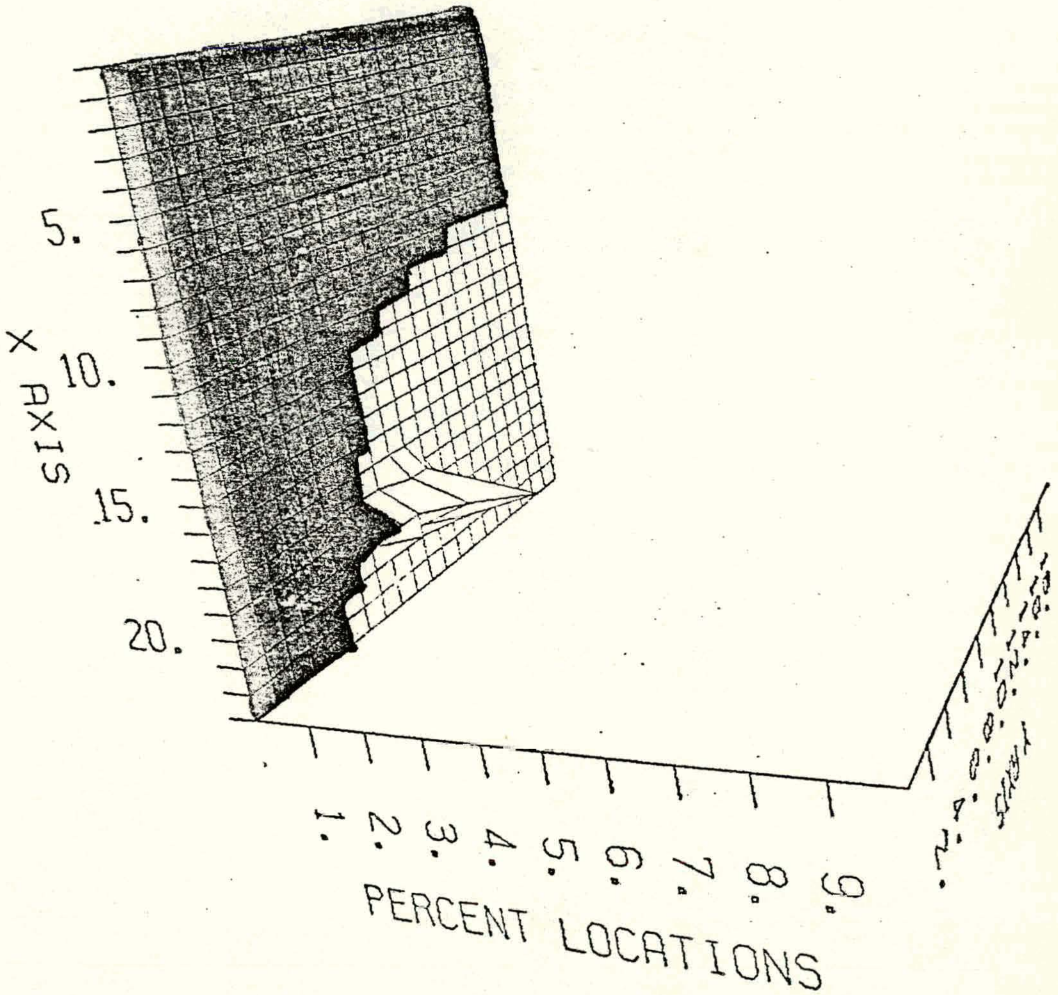
1978 Tx 242



1978 Tx 315

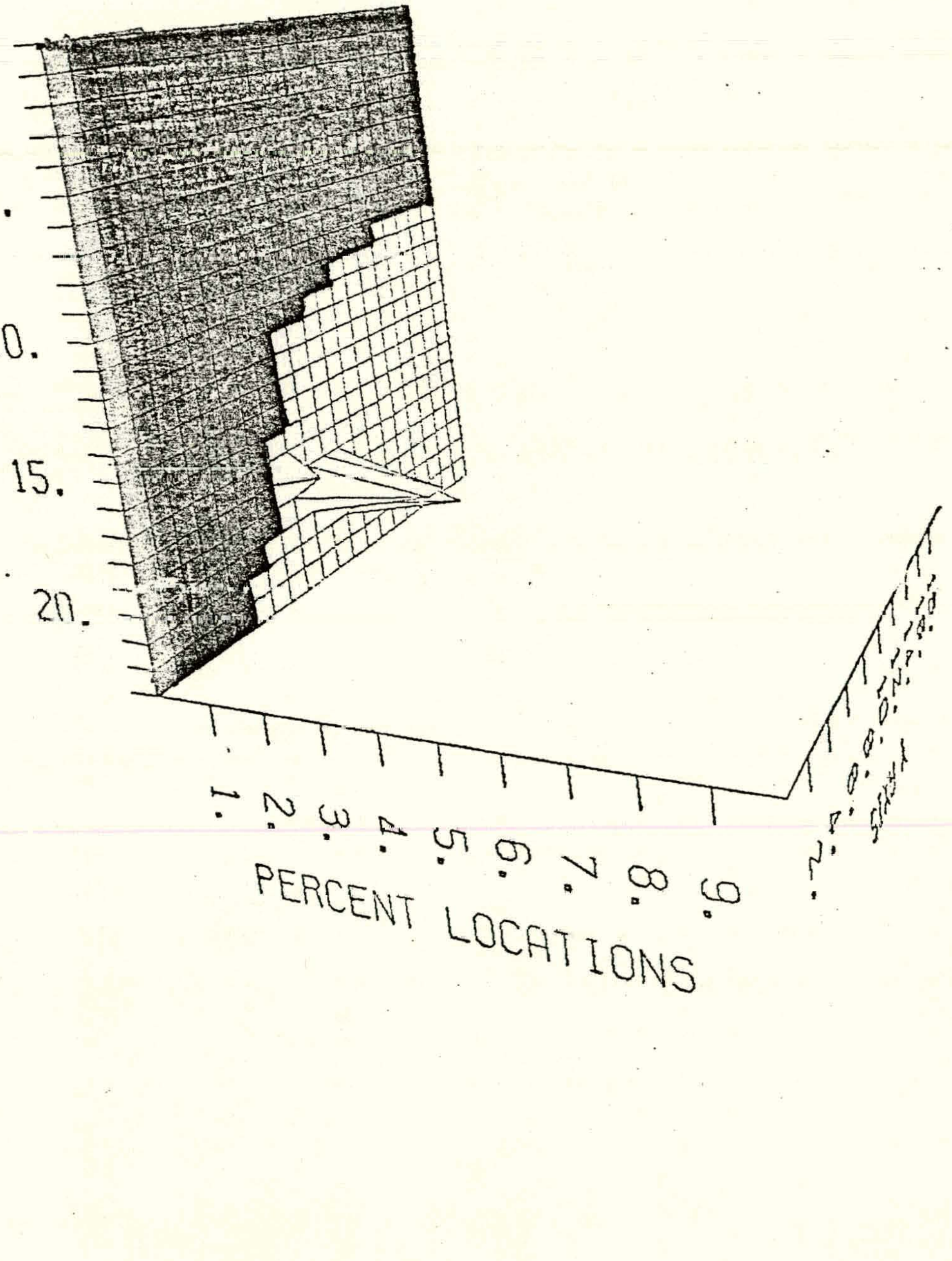

Y AXIS
2.
4.
6.
8.
10.
12.
14.
16.
18.
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
20.
30.
40.
50.
X AXIS

1978 Tx 819

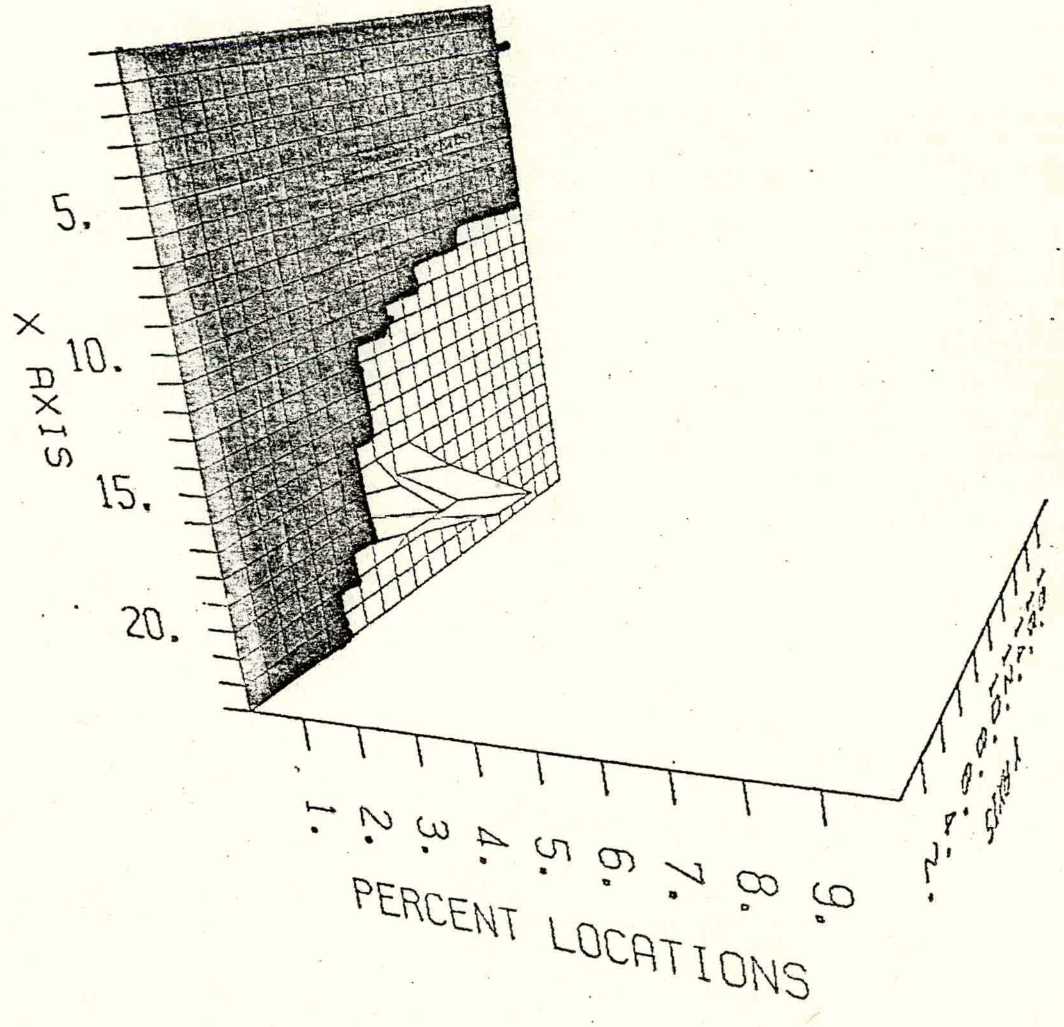


5.
10.
15.
20.
X AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.
PERCENT LOCATIONS
2.
4.
6.
8.
10.
12.
14.
16.
18.
Y AXIS

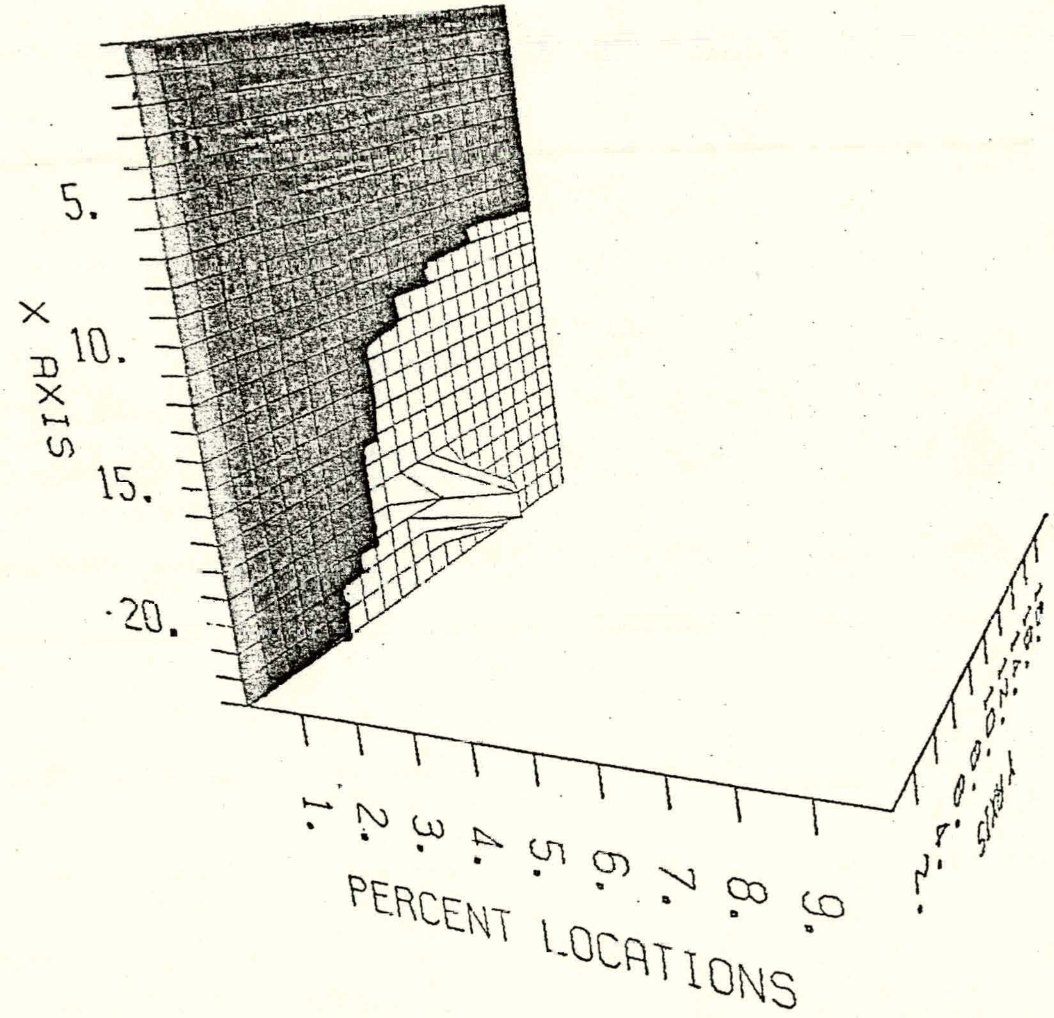
1978 Tx 350

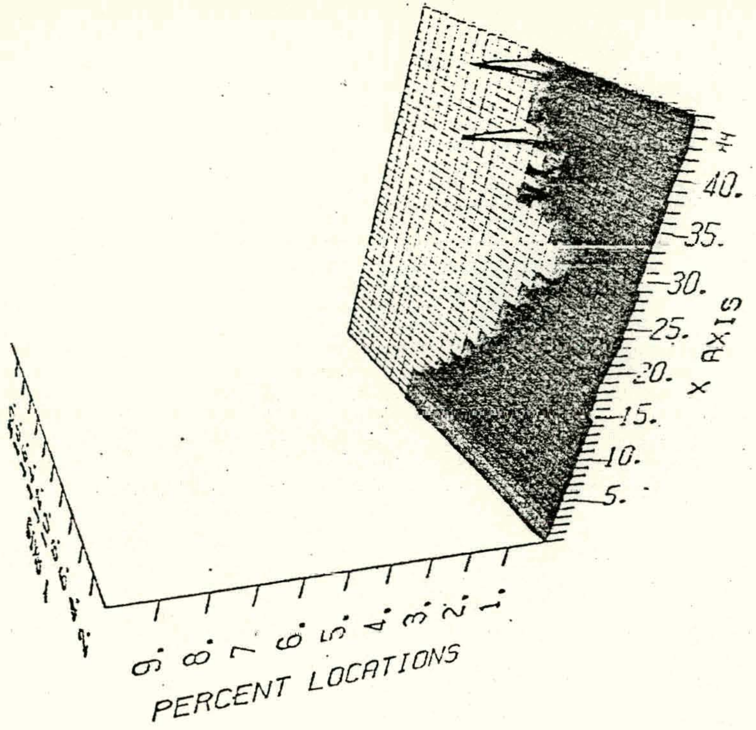

X AXIS
5.
10.
15.
20.
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
Y AXIS
2.
4.
6.
8.
10.
12.
14.
16.
18.

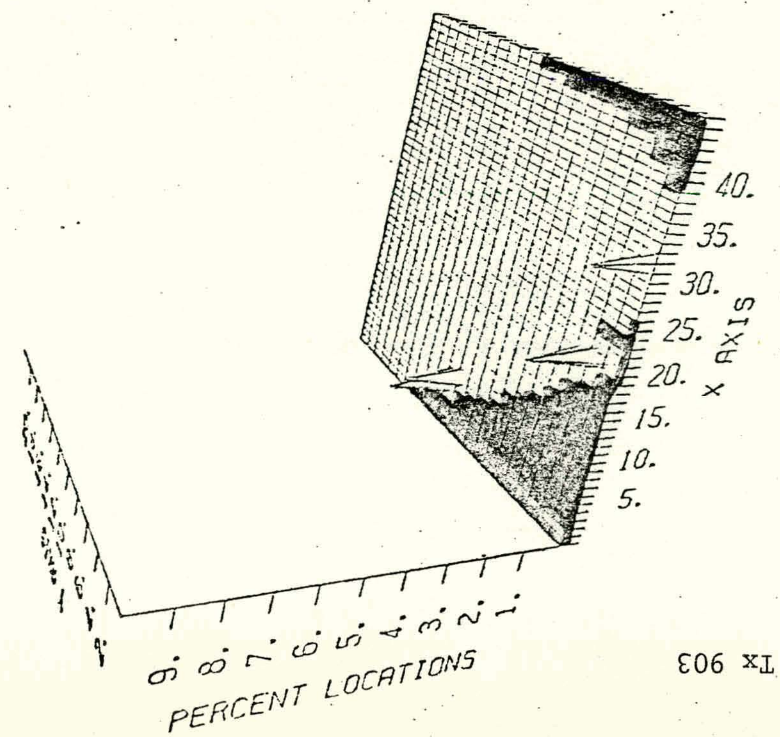
1978 Tx 850


X AXIS
5.
10.
15.
20.
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
Y AXIS
2.
4.
6.
8.
10.
12.
14.
16.
18.

1978 Tx 395

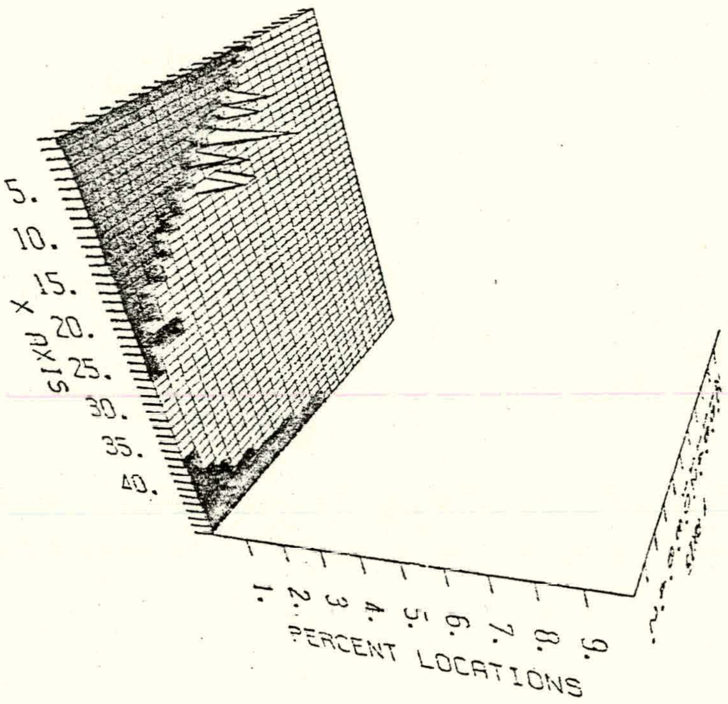

5.
10.
15.
20.
X AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.
PERCENT LOCATIONS
2.
4.
6.
8.
10.
12.
14.
16.
18.
Y AXIS


9.
8.
7.
6.
5.
4.
3.
2.
1.
PERCENT LOCATIONS
5.
10.
15.
20.
25.
30.
35.
40.
44
X AXIS

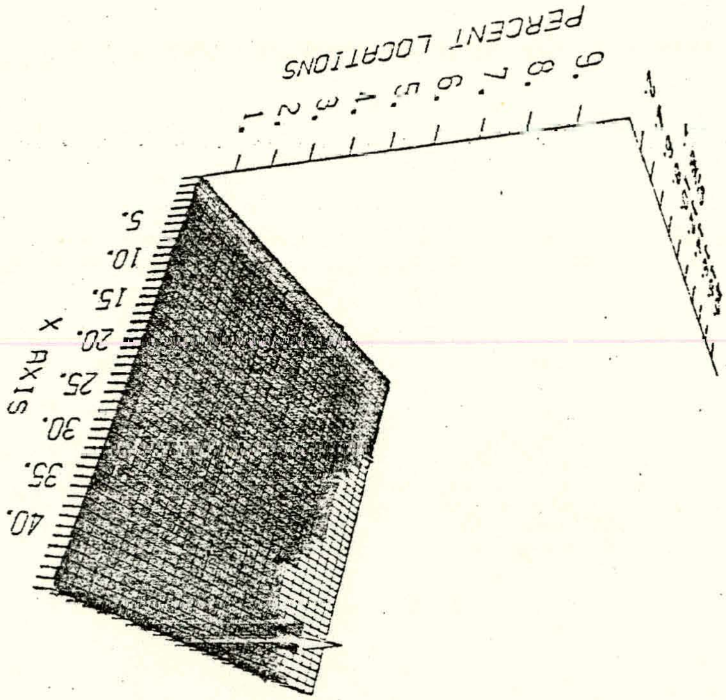

9.
8.
7.
6.
5.
4.
3.
2.
1.
PERCENT LOCATIONS
5.
10.
15.
20.
25.
30.
35.
40.
X AXIS

1978 Tx 903

1978 Tx 222

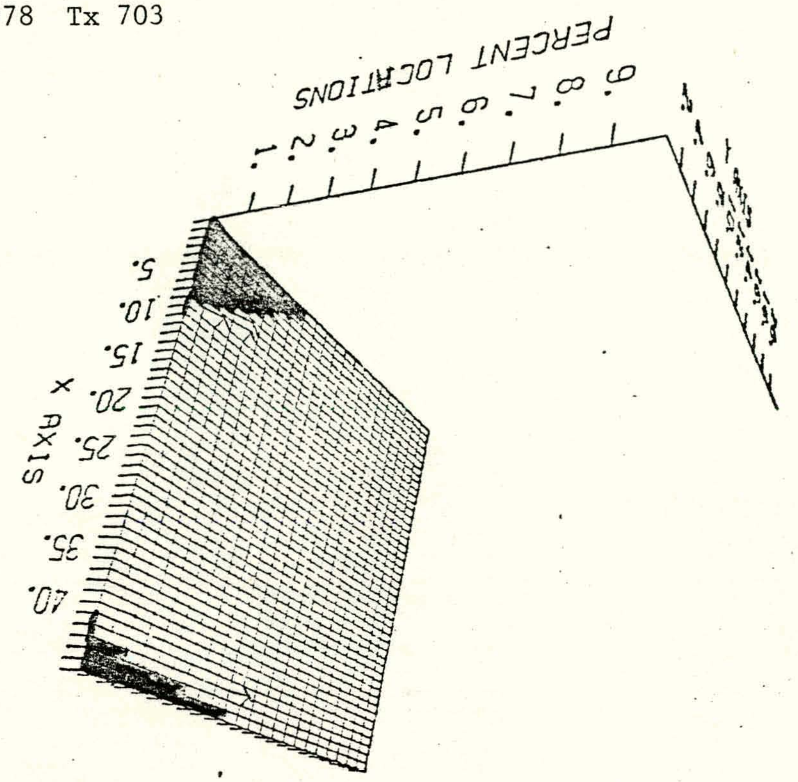


5.
10.
15.
20.
25.
30.
35.
40.
X AXIS
1.
2.
3
4.
5.
6.
7.
8.
9.
PERCENT LOCATIONS

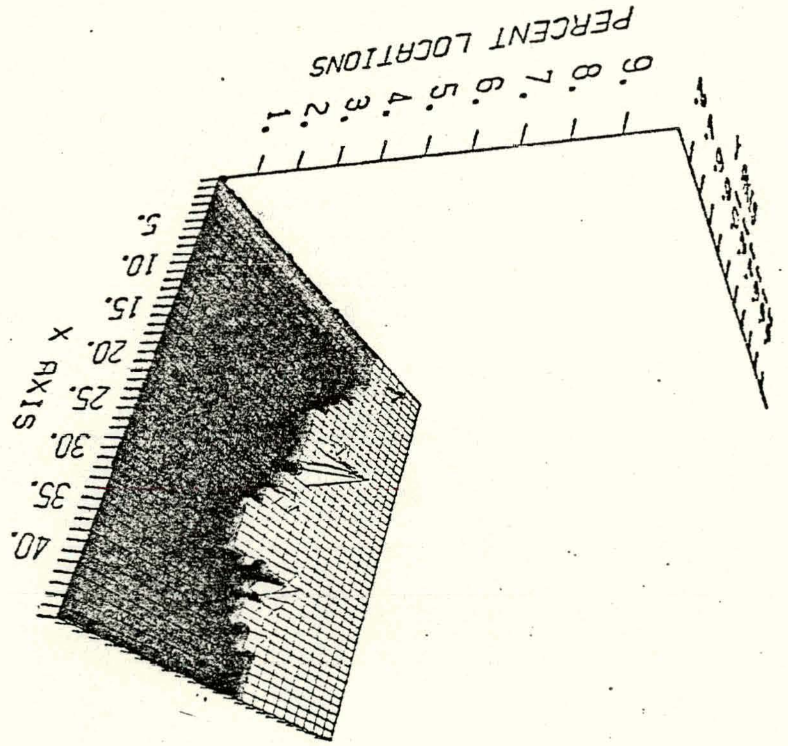


PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
5.
10.
15.
20.
25.
30.
35.
40.
X AXIS

1978 Tx 703

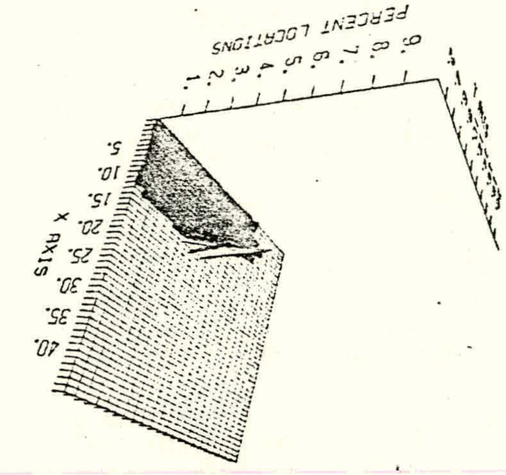


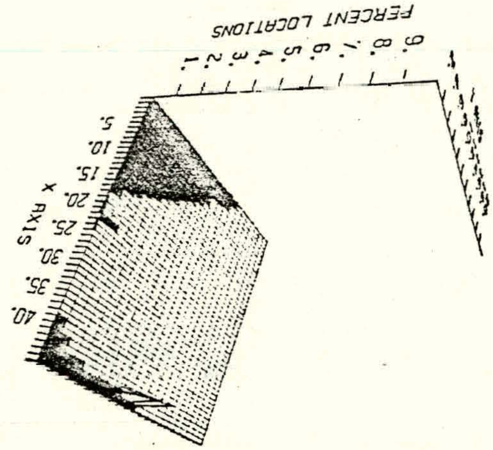
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
5.
10.
15.
20.
25.
30.
35.
40.

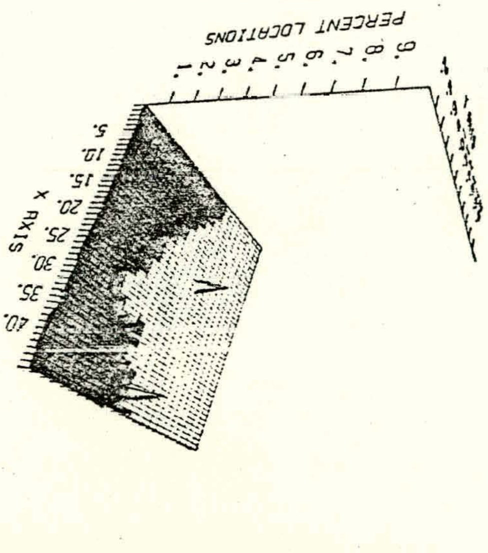


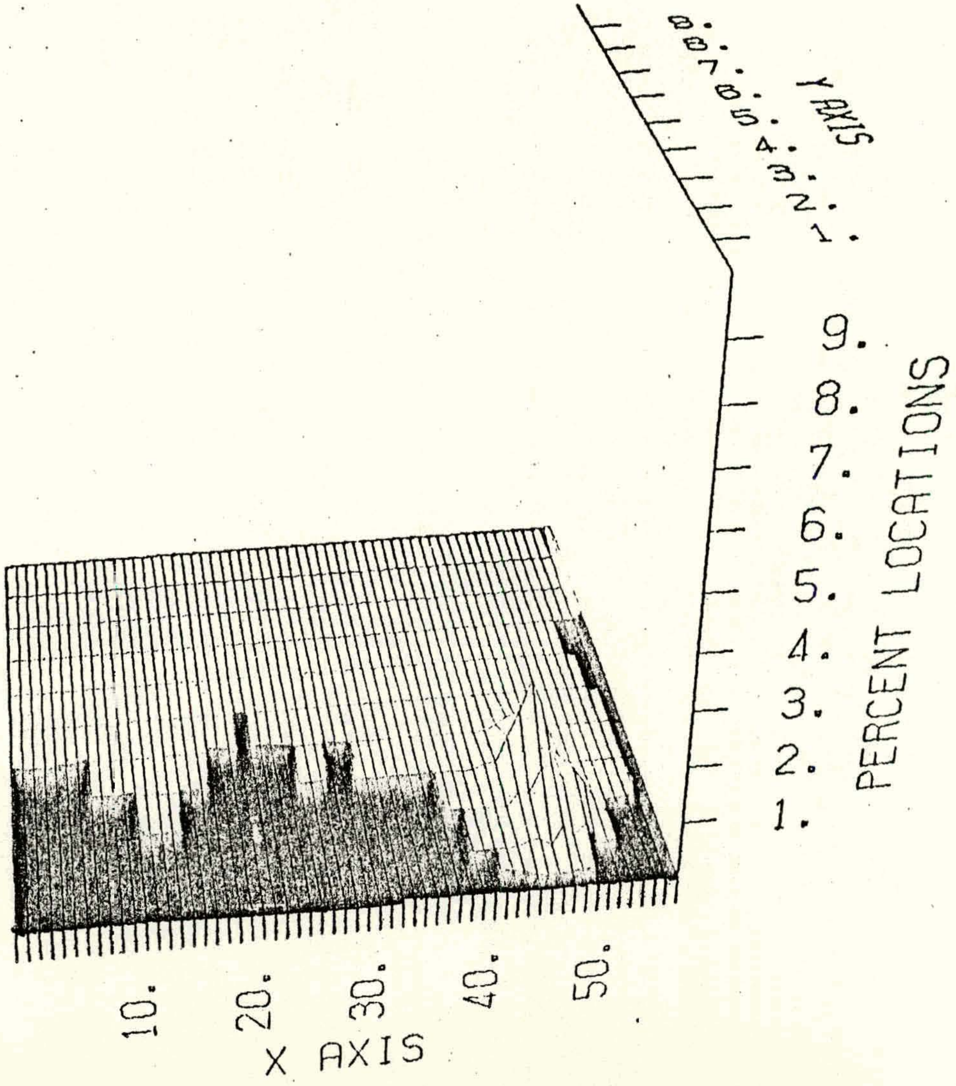
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
5.
10.
15.
20.
25.
30.
35.
40.

1978 Tx 608


PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
5.
10.
15.
20.
25.
30.
35.
40.


PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
5.
10.
15.
20.
25.
30.
35.
40.

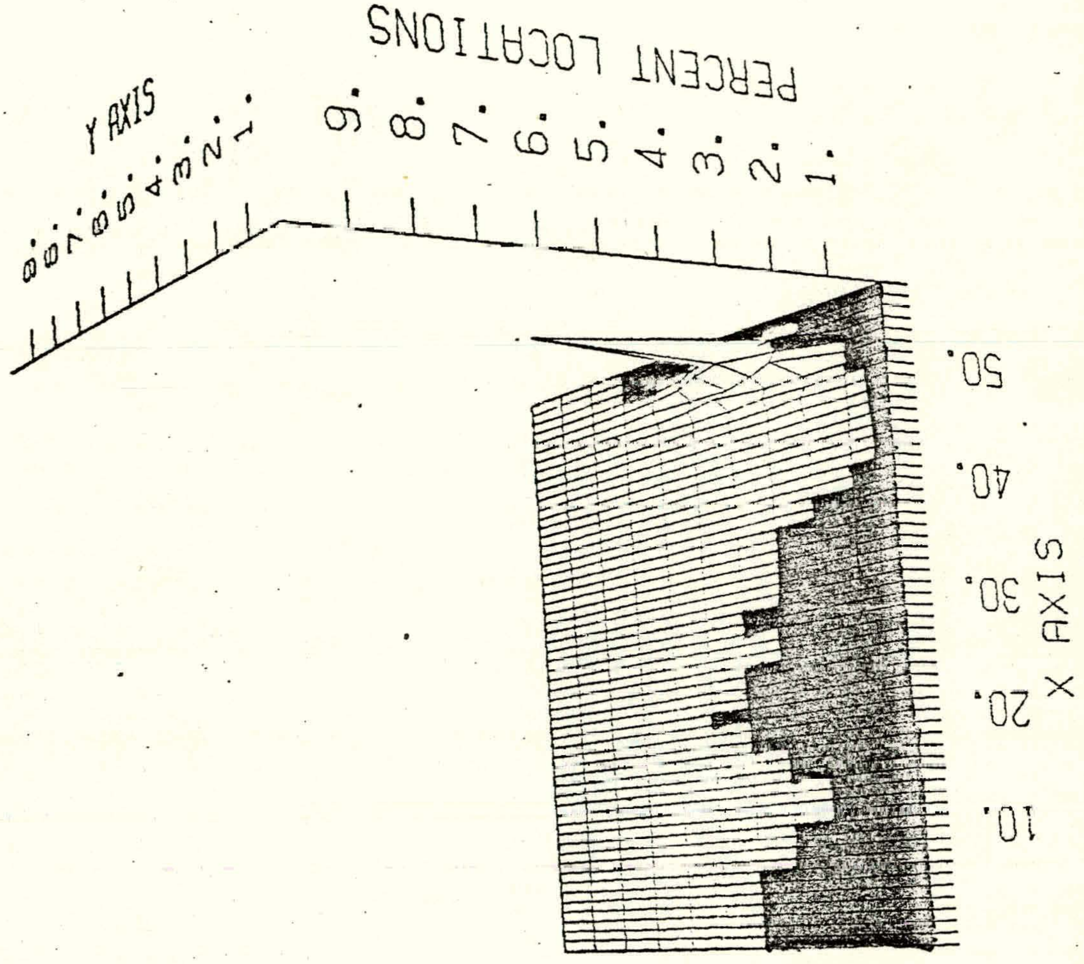

PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
5.
10.
15.
20.
25.
30.
35.
40.



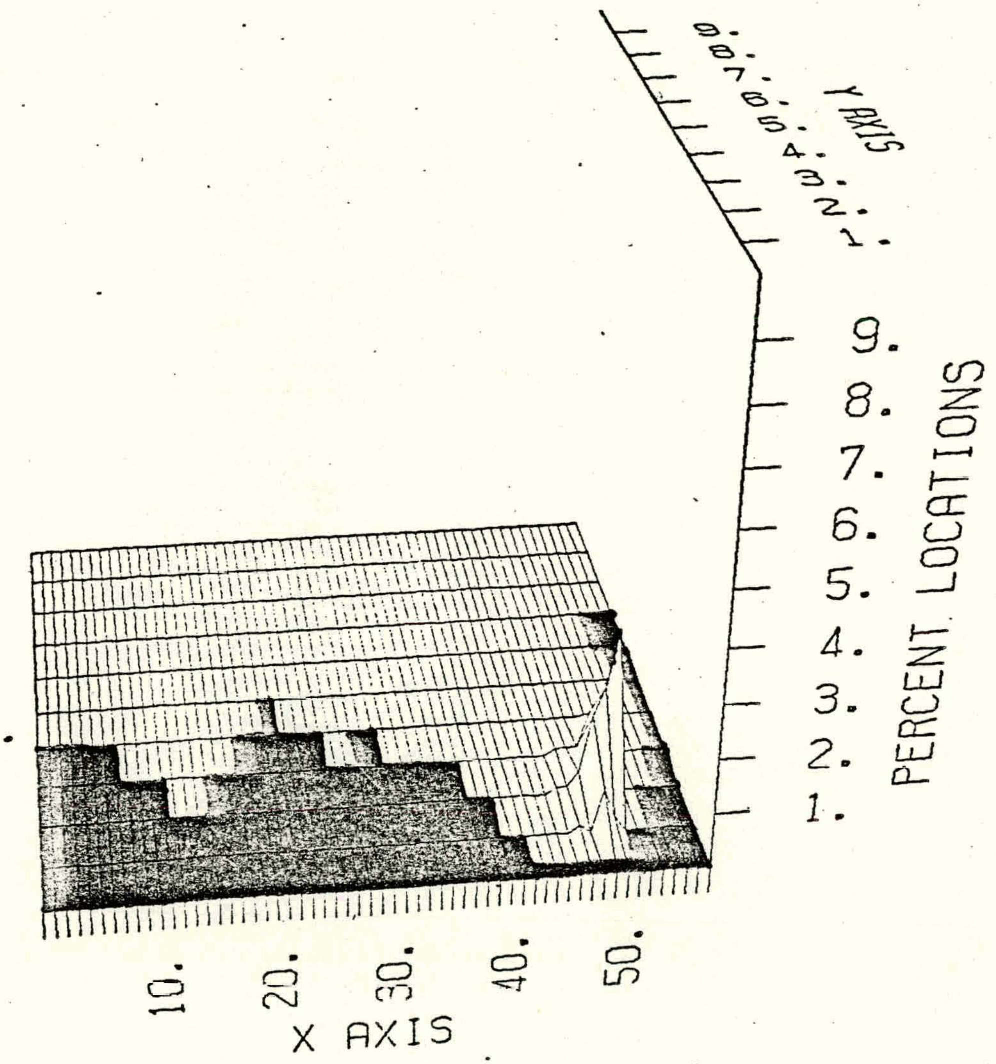
Y AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
20.
30.
40.
50.
X AXIS

1979 Tx 648

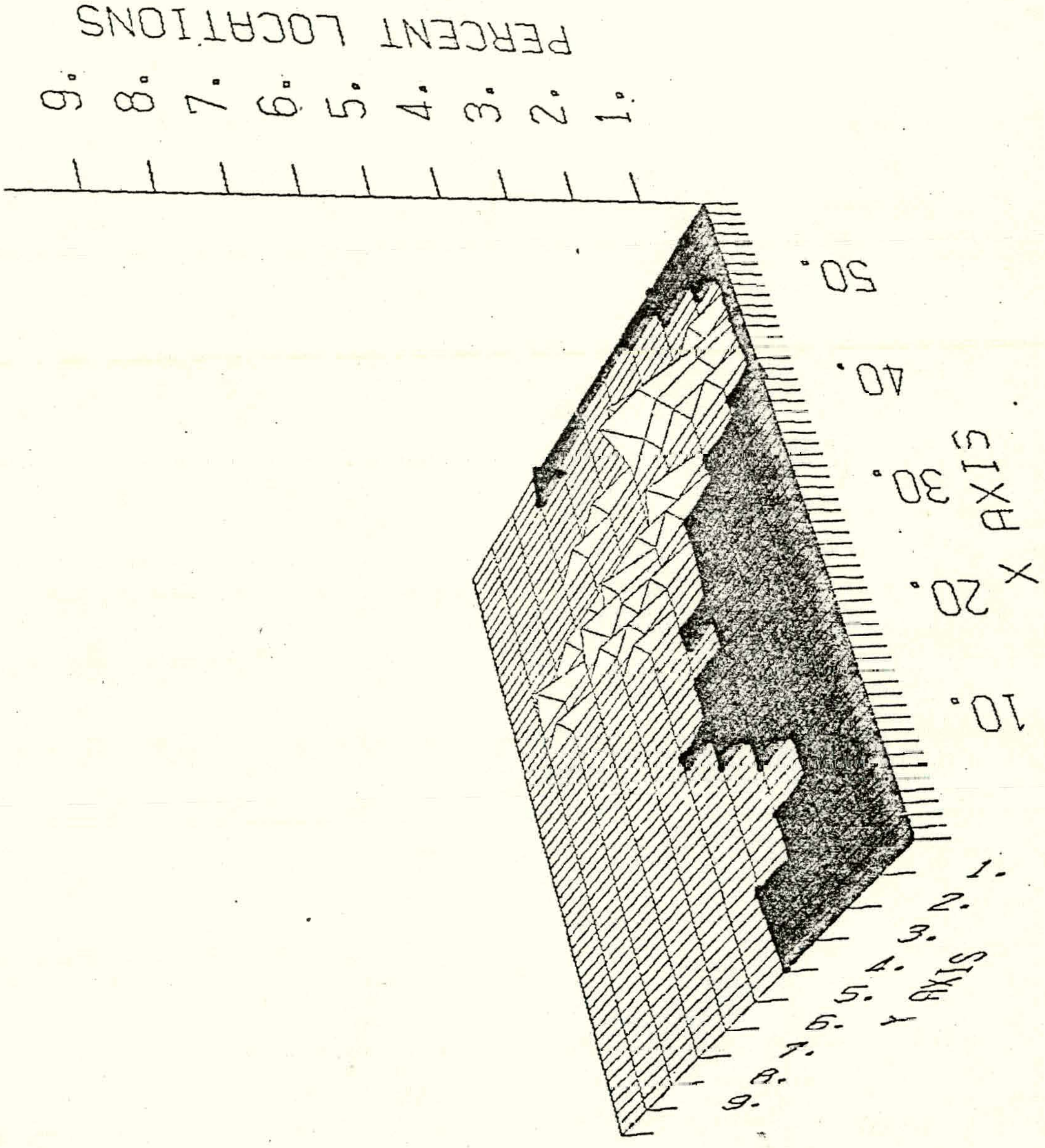
1979 Tx 780


PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
Y AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
10.
20.
30.
40.
50.

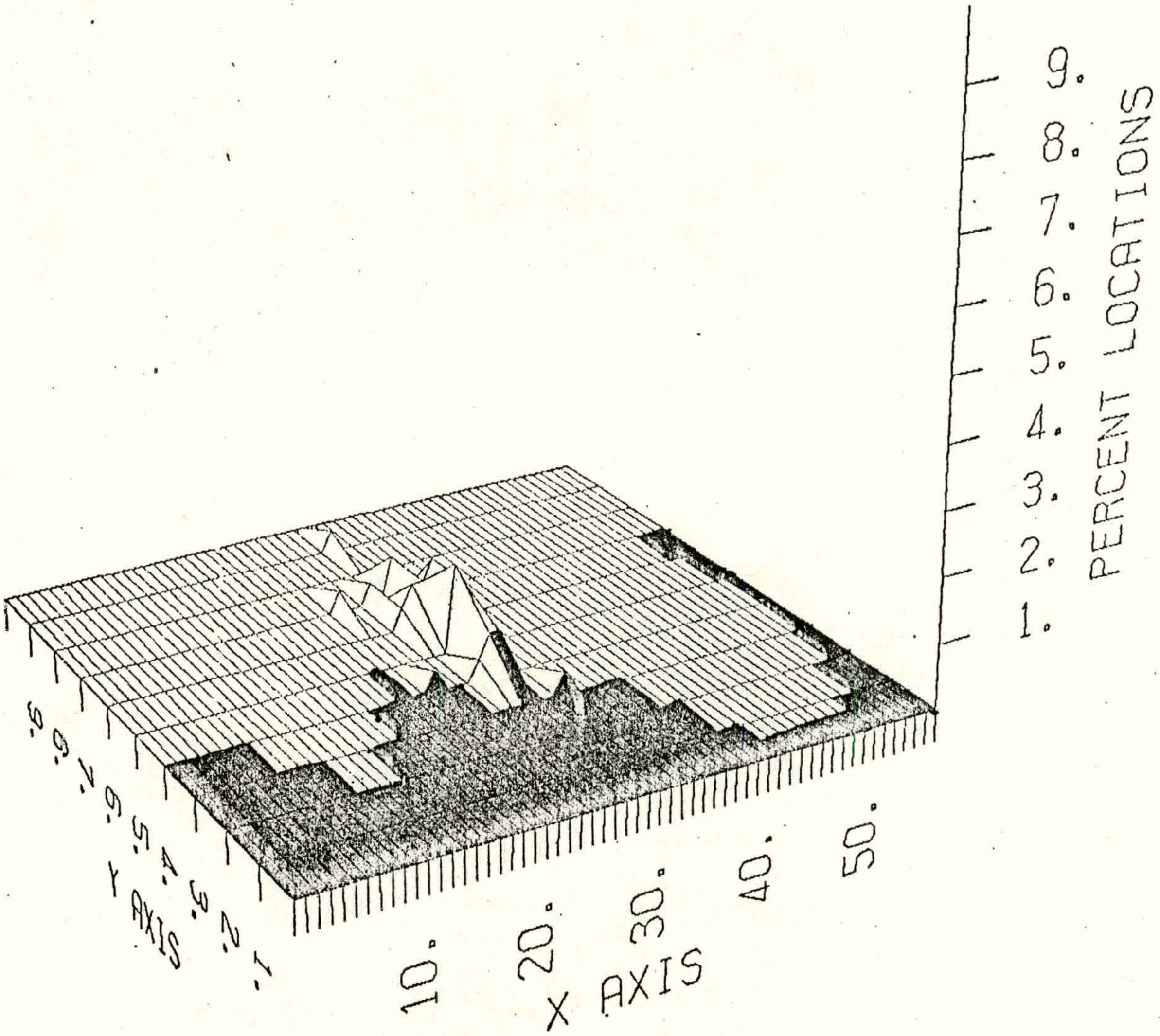
1979 Tx 746


Y AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
10.
20.
30.
40.
50.

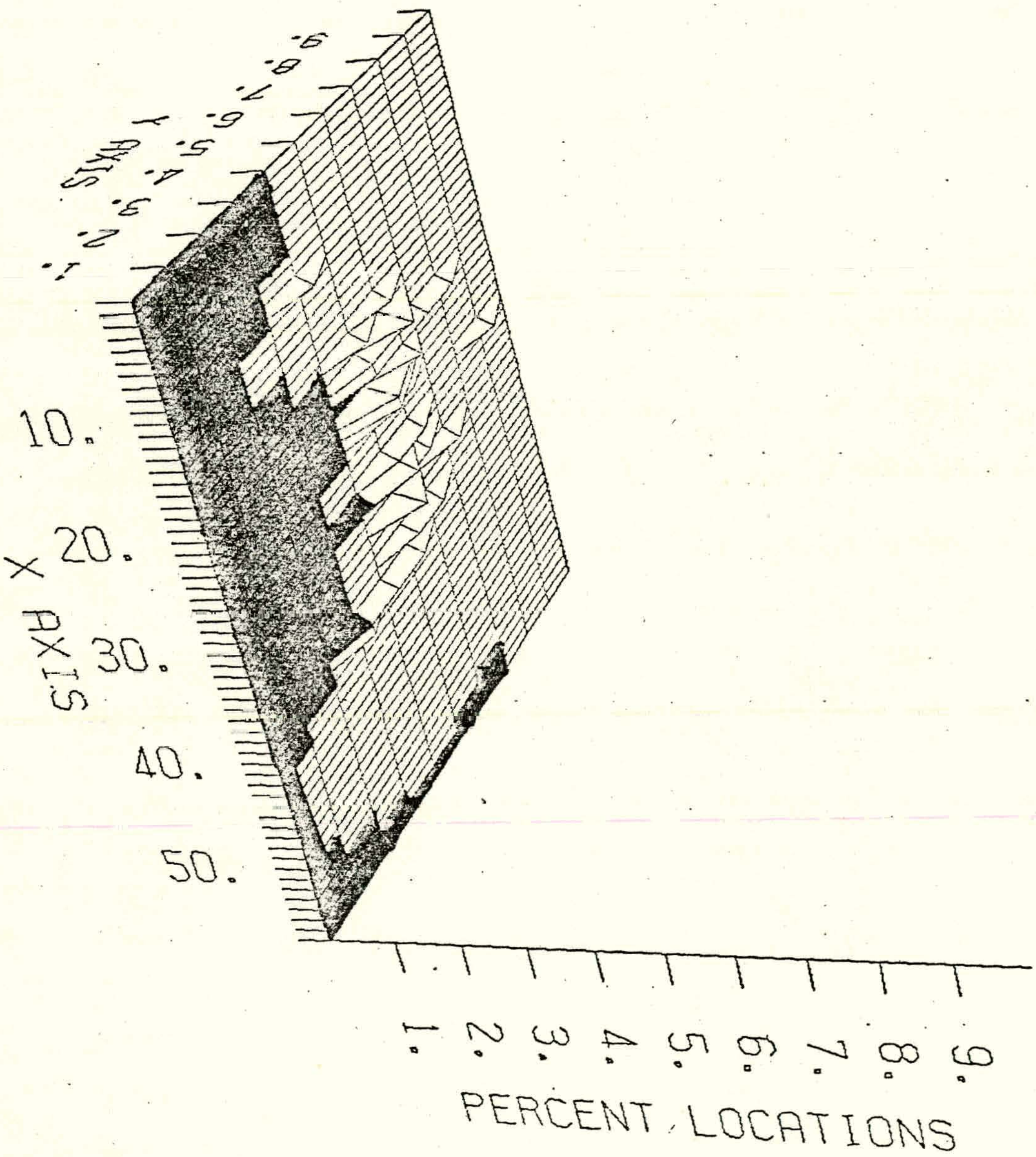
1979 Tx 298



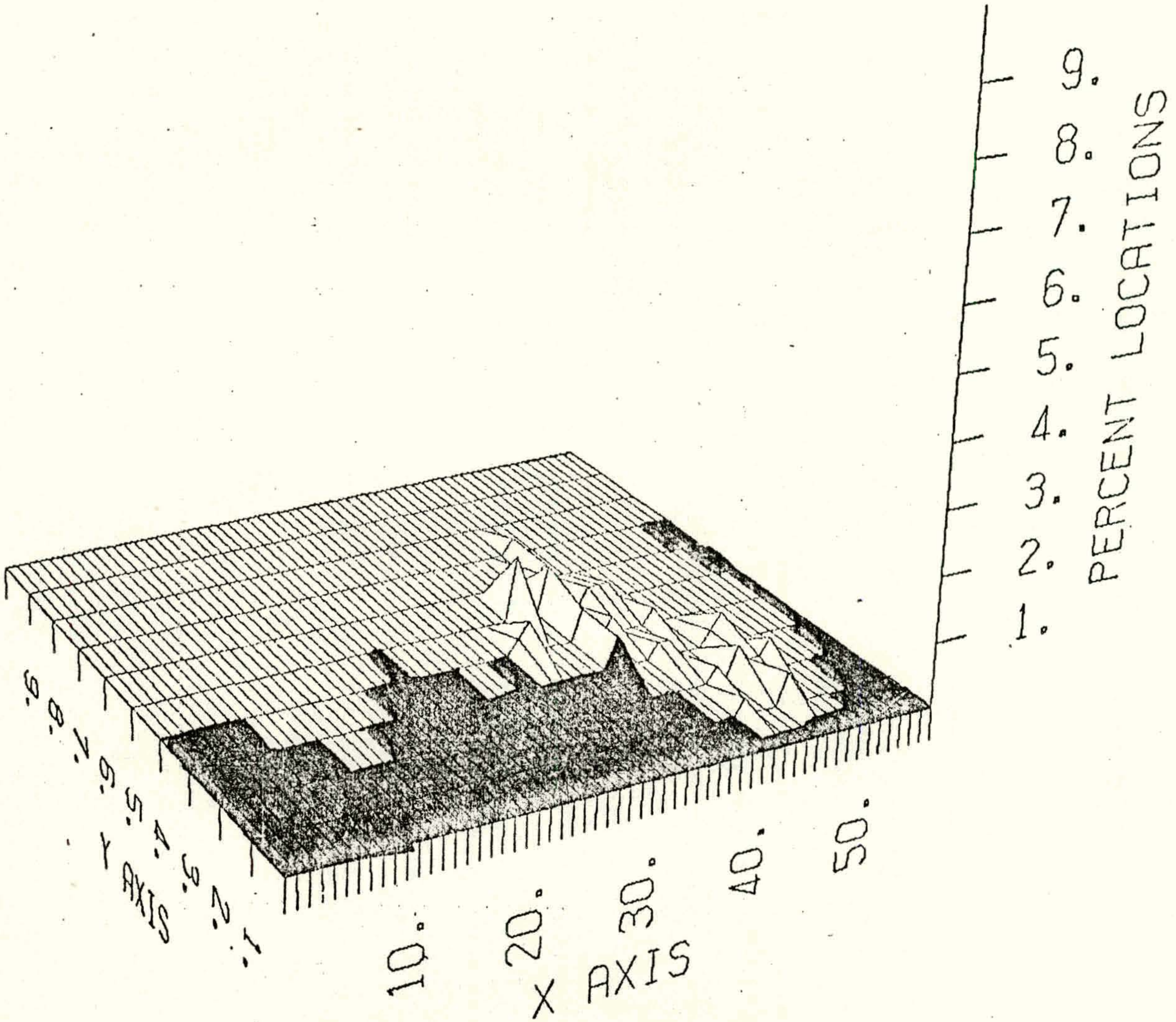
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
10.
20.
30.
40.
50.
Y AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.


9.
8.
7.
6.
5.
4.
3.
2.
1.
PERCENT LOCATIONS
9.
8.
7.
6.
5.
4.
3.
2.
1.
Y AXIS
10.
20.
30.
40.
50.
X AXIS

605 Tx 1979


Y AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
10.
20.
30.
40.
50.
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.

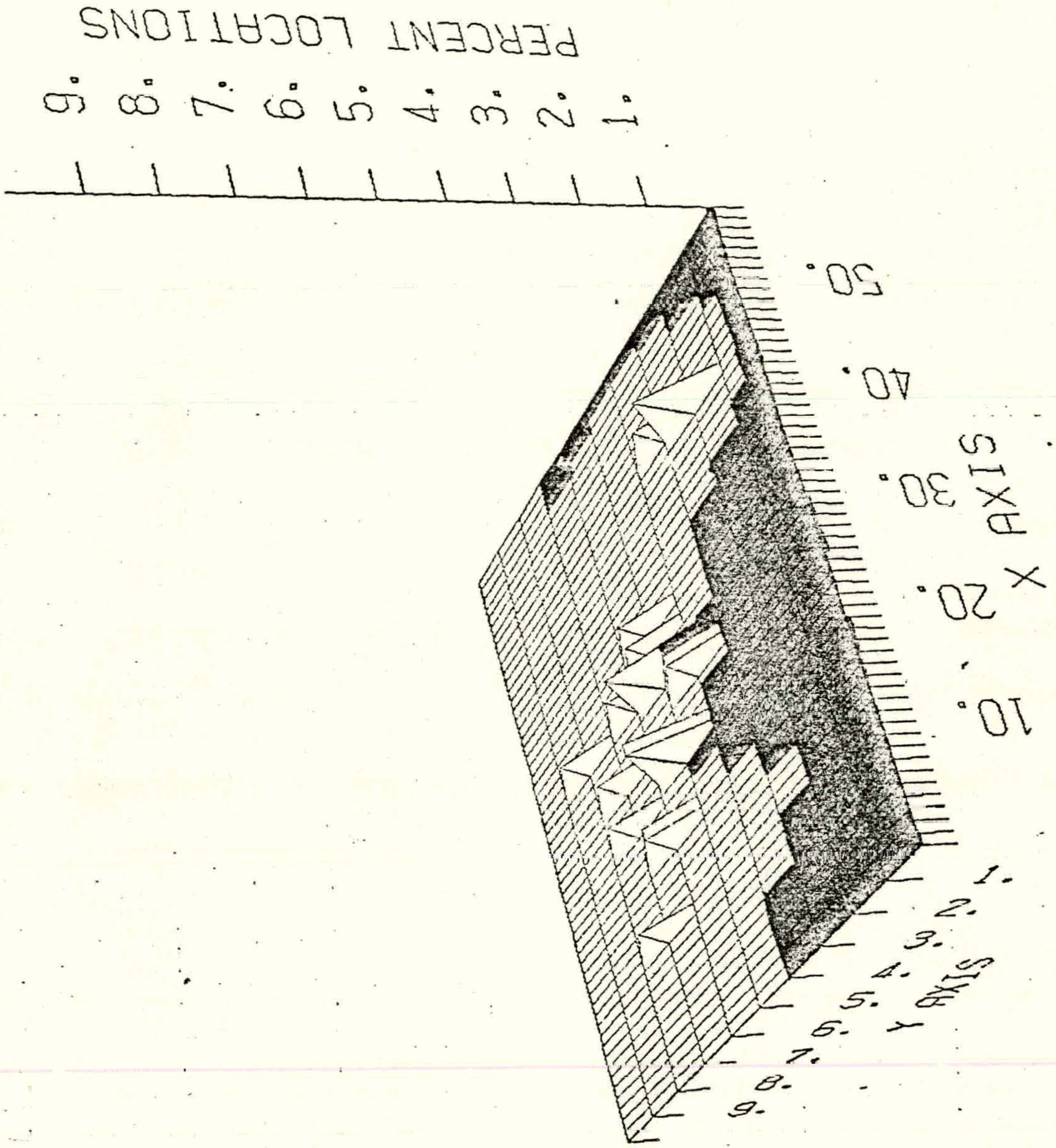
1979 Tx 636

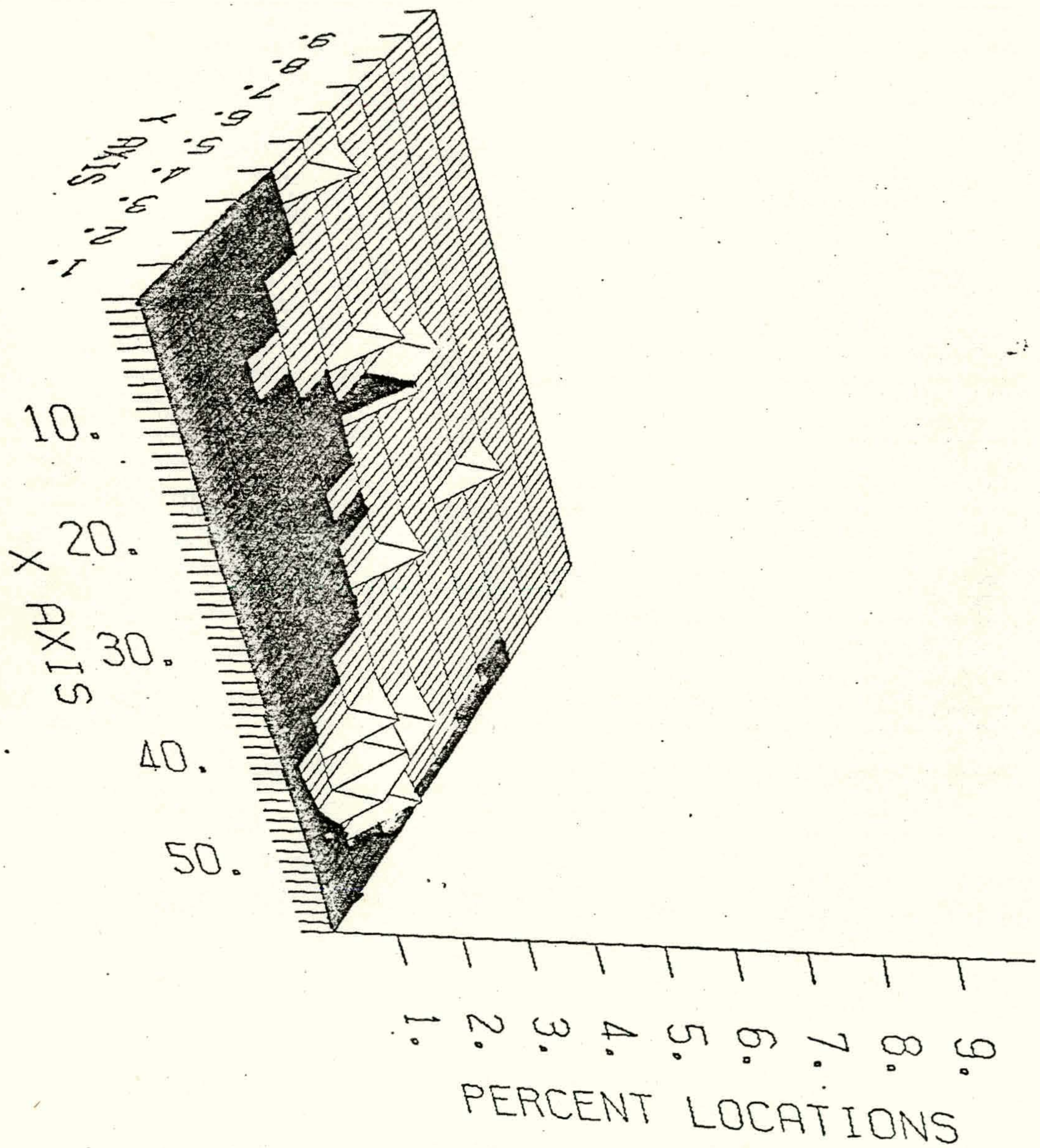


PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
10.
20.
30.
40.
50.
Y AXIS
.1
.2
.3
.4
.5
.6
.7
.8
.9

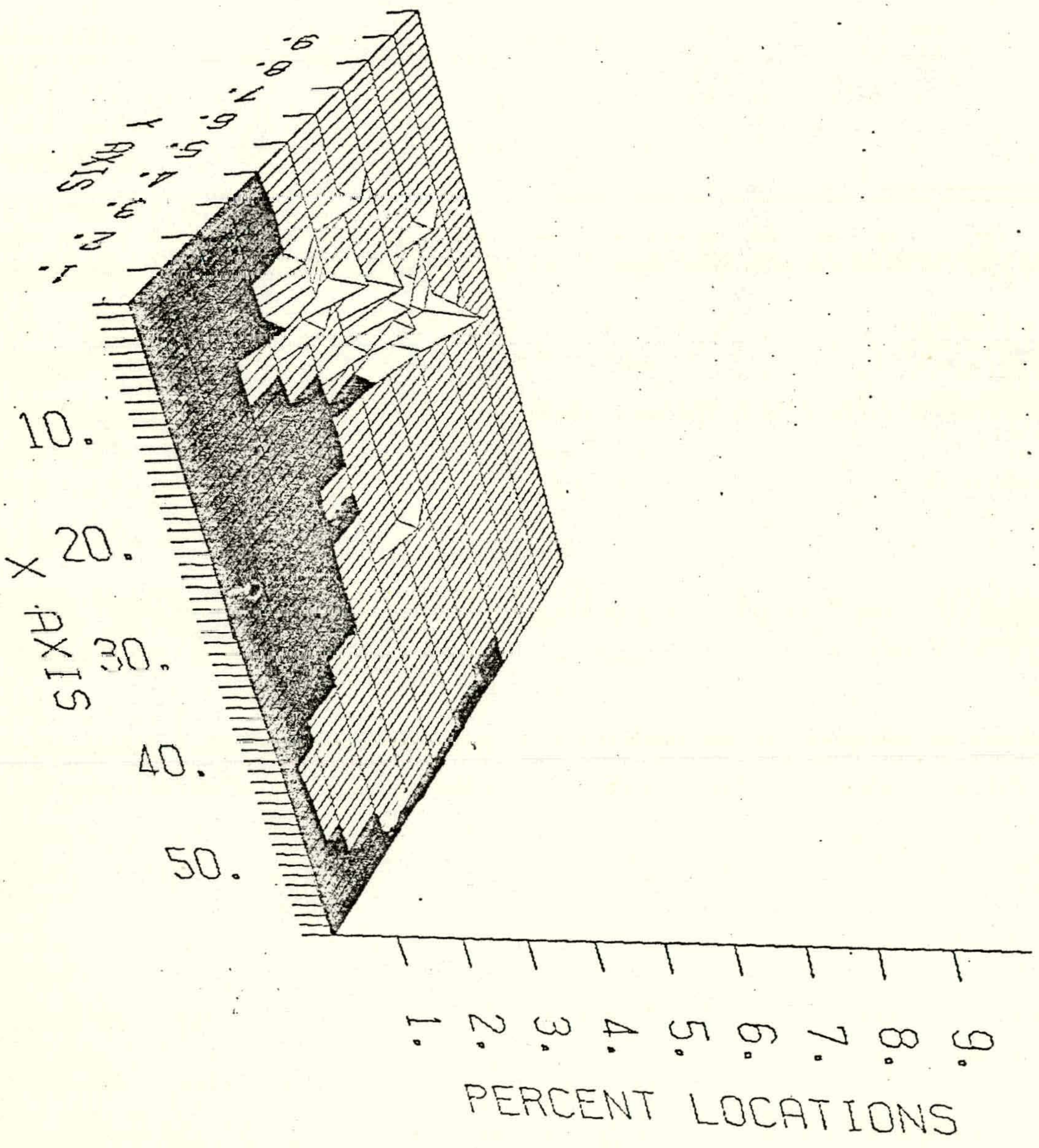
1979 Tx 453

1979 Tx 585


PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
X AXIS
10.
20.
30.
40.
50.
Y AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.

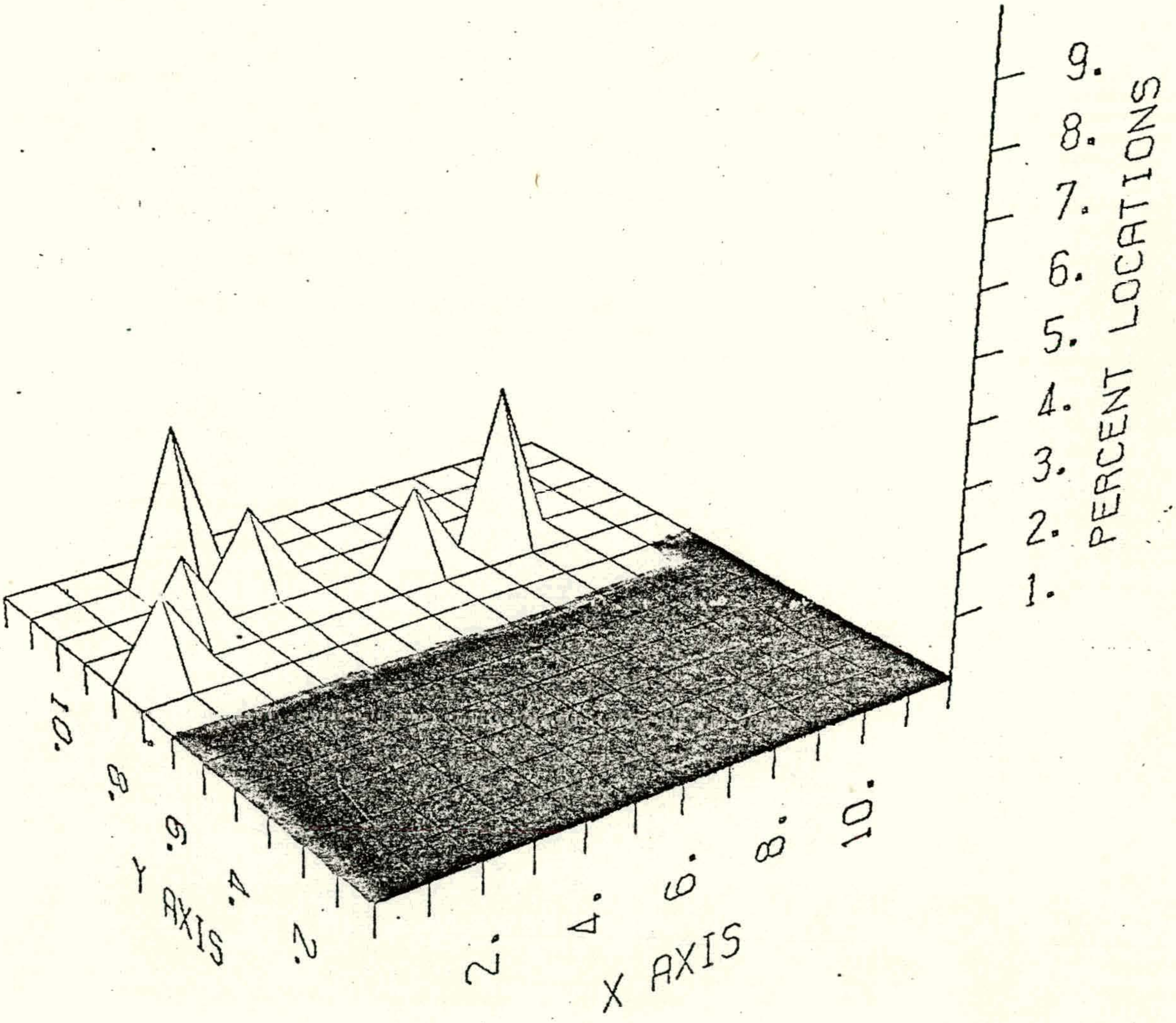

X AXIS
10.
20.
30.
40.
50.
Y AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.
PERCENT LOCATIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.

1979 Tx 345


.1
.2
.3
.4
.5
.6
.7
.8
.9
Y AXIS
10.
20.
30.
40.
50.
X AXIS
1.
2.
3.
4.
5.
6.
7.
8.
9.
PERCENT LOCATIONS

1979 Tx 692

1979 Tx 821



APPENDIX D

Fentanyl and Azaperone Produced Neuroleptanalgesia in the Sea Otter

Thomas D. Williams, DVM, A. Lesley Williams, and Donald B. Siniff, Phd

SUMMARY

Fentanyl, given intramuscularly (I.M.) at dosages of .05 to .11 mg/kg of body weight and in combination with azaperone at dosages of .11 to .45 mg/kg was used to effectively produce neuroleptanalgesia in sea otters under field conditions. Thus in general, fentanyl at a dosage of .05 mg/kg when combined with azaperone at a dosage of .20 mg/kg met most of the requirements for a safe, short acting, reversible immobilizing agent used under field conditions.

Chemical immobilization of the sea otter (Enhydra lutris) is essential prior to field investigation requiring manipulation. Previous description of the fatal use of sodium pentobarbital and ketamine hydrochloride in the sea otter, emphasize the need for an immobilizing agent with a wide safety margin, rapid reversibility and no undesirable side-effects. [1,2]

From the Ocean View Veterinary Hospital, 109 Central Ave, Pacific Grove, Calif. 93950 (Williams, Williams); Dept. of Ecology and Behavioral Biology (Siniff), 318 Church Street S.E. Minneapolis, Minnesota 55455.

This project was partially funded by the Dept. of Energy DOE-EY 76-S-02-1332 and the California Dept. of Fish and Game.

The authors thank Dave Garshelis, Jack Ames, Robert Hardy, Fred Wendel, and Pitman-Moore, Inc. for supplying fentanyl and azaperone.

CI744, etorphine and halothane have all been used successfully in the sea otter but each has limitations for field application.[2] Etorphine, at a dose of 0.75 mg per adult otter met most of the requirements for field use, but chronic convulsions and cyanosis were undesirable side effects.[2] Fentanyl has been tested in sea otters in dosages as high as 0.04 mg/kg with no immobilization occurring.[2] Haigh has reported the successful use of fentanyl in hooded seals (Cystophora cristata) at dosages of 0.3 to 0.6 mg/kg, enabling tagging and blood sampling in the field.[3]

Fentanyl (0.5 ml/kg) has also produced profound neuroleptanalgesia in ferrets (Mustela putorius furo) suggesting its further application in the sea otter.[4]

Materials and Methods

Twenty-two sea otters were captured in modified gill nets in Prince William Sound, Alaska, and 6 sea otters were captured with a diver held net in Monterey Bay, California, during the summer and fall of 1979.

While the otters remained entangled in the net a rear limb was secured and fentanyl or fentanyl and azaperone were injected I.M. The dosage of fentanyl ranged from .05 to .11 mg/kg (10mg/ml) of body weight, with or without a concurrently administered dose of .11 to .45 mg/kg (40 mg/ml) of azaperone.

After capture in Alaska, otters were subjected to biological sampling, fitted with radio-telemetry devices, given an antagonist and released. In California, the otters were subjected to biological sampling, given an antagonist and confined in a holding pen for 3 to 5 days, after which they were released. During confinement otters were fed squid and abalone.

Neuroleptanalgesia was reversed in 22 cases with naloxone at dosages of .010 to .053 mg/kg and in 6 cases with diprenorphine at dosages of .052 to .113 mg/kg.

After immobilization was achieved, otters were removed from the net, rectal temperatures were recorded, respiratory rate was determined visually, and heart rate was established by palpation. Twenty-three of the otters were males, 5 were females, body weights ranged from 15.0 to 38.6 kg. All were adults.

Effectiveness of the dosage was judged by the otters resistance to handling, its amount of voluntary movement, its response to external stimuli and its reflex response.

Results

The results of the immobilization of 28 sea otters are presented in table I. In 10 trials with fentanyl, induction occurred within 3:40 minutes and 9:00 minutes, with an average induction time of 5:29 minutes. Induction time was not dose related. The total immobilization time varied from 24 minutes to 37 minutes and was dose related. The total immobilization time was 30.2 minutes. In 18 trials using fentanyl in combination with azaperone induction occurred within 2:45 minutes and 11:15 minutes, with an average induction time of 6:58 minutes. The total time of immobilization ranged from 24 to 73 minutes with an average of 40 minutes. The two antagonists used were naloxone hydrochloride and diprenorphine. Naloxone hydrochloride in dosages from .010 to .053 mg/kg I.M. resulted in recovery from 30 seconds to 46 minutes with an average of 4:50 minutes, with the exception of trial #24. Diprenorphine was used as an antagonist in 6 trials in dosages of .052 to .113 mg/kg and resulted in recovery times from 1:45 to 7:30 minutes, with an average of 6:20 minutes.

With extreme values omitted and a 95% confidence interval, the mean respiratory rate was 14.9 to 17 respirations per minute, the mean heart rate was 133.4 to 157.2 beats per minute and the mean temperature was 36.7 c to 37.4 c.

All otters returned to pre-immobilization motor function and behavior after recovery.

Discussion

Neuroleptanalgesia is a useful technique in sea otter immobilization. It produces a state of analgesia and sedation without complete unconsciousness, allowing for biological sampling and surgery without anesthesia.[5,6] Fentanyl is more potent, faster and relatively shorter acting than other analgesics in clinical use and its strength is approximately 100 times that of morphine.[6,7,8] Under field conditions, estimation of the weight of the animal for dose calculation is a major problem.[9] In sea otters, there is the additional factor of occasional hypothermia resulting from capture, which decreases the metabolic rate and the ability to metabolize the immobilizing agent, necessitating a lower dose. Therefore, the use of an immobilizing agent such as fentanyl with a wide margin of safety, thus allowing for miscalculations, is critical.[5]

Azaperone is used as a neuroleptic with its action potentiated by the immobilizing compound, fentanyl.[10] The safety margin of fentanyl is higher when given in combination with azaperone.[10] Azaperone is virtually non-toxic, does not reduce body temperature at low therapeutic doses and appears to have no adverse effects on heart rate, cardiac output and aortic blood flow.[10,11] Azaperone also counteracts the respiratory depressant effects of fentanyl and prevents traumatic shock.[7,10,12]

In this study, fentanyl used alone provided rapid induction, adequate immobilization an no adverse side effects. Recovery time was short but upon recovery the otters behavior seemed to indicate anxiety as they dove for long periods of time upon release. Two otters with high fentanyl doses experienced short, mild clonic contractions indicating the desirability of a reduced dose, even though a higher dose did not appear life threatening.

Fentanyl and Azaperone, in combination, had a number of desirable features. Induction time was slightly increased but was well within an acceptable range. Otters receiving a dose of azaperone above .20 mg/kg, regardless of the fentanyl dose, frequently exhibited clonic contractions and had a prolonged recovery time. The great advantage to the addition of azaperone was that recovery was smooth and otters exhibited little anxiety. At the highest dose studied, (.11mg/kg fentanyl and .45 mg/kg azaperone) respiration was significantly increased, heart rate was higher than average and temperature was elevated. Recovery time was prolonged and necessitated an additional dose of antagonist but no after effects were noticed.

The results of this study indicate that a dosage of .05 mg/kg of fentanyl combined with a dosage of .10 to .20 mg/kg of azaperone provides safe, uncomplicated, easily reversible immobilization in sea otters. A distinct advantage to this drug combination is that the dose can be administered intramuscularly while the otters remain in the water. After injection the otter floats safely until immobilization occurs then the animal can be handled with no danger to investigators.

Naloxone and diprenorphine, both narcotic antagonists, readily reverse the neuroleptanalgesic state produced by fentanyl and azaperone. The dosage of naloxone used was calculated on the basis that 1 mg was sufficient to antagonize 10 mg of fentanyl.[13] It is known that doubling the dose of naloxone increases the protective effect, therefore suggesting a dosage of at least .01 mg/kg.[14]

Thermoregulation in an immobilized otter can become unbalanced, therefore any immobilized sea otter must have its temperature closely monitored. When temperature is above 101° F, it should be reduced with cold water. Conversely, otters left in the capture nets for long periods (as a result of capturing more than one at a time) sometimes experience profound temperature drops. Handling immediately after capture is ideal.

Two of the otters used in this study, numbers 7 and 26, died subsequently in 21 and 14 days respectively. Necropsy of otter #7 revealed interstitial emphysema that had been present for 1 to 2 weeks, pulmonary congestion and severe seminiferous tubular atrophy and aspermatogenesis. Otter #24 was found in an advanced state of decomposition after being seen dead but not recovered one week previously. Cause of death in both animals was undetermined. It is recognized, however, that the stress of capture and handling can lead to death in sea otters, especially if they are debilitated. In the field, adequate assessment of the otters state of health is superficial.

Subsequent to the study reported here, the California Department of Fish and Game have successfully immobilized 24 sea otters with the recommended fentanyl and azaperone combination.

TABLE I. - Results of 28 trials with Fentanyl and Azaperone

Otter No.	Sex	Weight (kg)	Fentanyl mg/kg	Azaperone mg/kg	Induction time (min)	Antagonist* mg/kg	Recovery time (min)	Respiration	Heart Rate	Temp °F	Comments
1	M	28.6	.07	-	5	.014 N	1:30	10-14	94-108	101.5	
2	M	29.5	.07	-	5	.014 N	:30	12	104-140	99.0	MCC +
3	M	38.6	.05	-	4:30	.010 N	3:15	16	124	99.0	
4	M	30.9	.06	-	5:30	.026 N	2:00	16-20	140-150	101.6	MCC
5	M	25.0	.08	-	4:45	.032 N	3:30	12	104	99.0	
6	M	29.1	.07	-	5:15	.027 N	2:45	16	140	97.0	
7	M	32.2	.06	-	9:00	.025 N	1:20	16	100	98.4	
8	M	32.7	.06	-	7:30	.061 D	3:30	12	106	101.5	
9	M	38.6	.05	-	3:40	.052 D	1:45	20	100	101.4	
10	M	27.7	.07	-	4:40	.029 N	4:10	16	100	99.5	
11	M	36.3	.06	.11	8:00	.022 N	2:50	12-16	136-152	97.0	
12	M	24.1	.08	.33	10:00	.033 N	5:15	16	144-172	99.0	MCC
13	M	27.7	.07	.29	11:15	.029 N	4:30	16	124-168	98.0	MCC
14	M	28.1	.07	.43	7:00	.028 N	10:00	16	168-	96.0	MCC
15	M	32.7	.06	.37	6:20	.061 D	4:30	16-20	132-168	95.2	MCC
16	M	23.8	.09	.26	10:00	.034 N	4:00	20	156-172	97.2	MCC
17	M	25.0	.08	.24	6:00	.080 D	7:30	16	172	99.2	MCC
18	M	29.1	.07	.21	7:45	.027 N	2:45	20	164	99.4	
19	M	26.3	.08	.23	2:45	.030 N	10:00	12	144	97.4	MCC
20	M	29.1	.07	.21	3:45	.027 N	4:55	20	184	99.4	
21	M	22.7	.09	.26	7:00	.090 D	7:00	16	116	97.0	
22	M	34.5	.06	.17	6:40	.012 N	4:45	16	172	97.6	
23	M	27.2	.07	.29	8:00	.029 N	5:30	16	176	100.4	MCC
24	F	17.7	.11	.45	6:00	.023 N .113 D	46:00 9:00	34	200	102.8	Overdose
25	F	20.9	.05	.19	5:00	.038 N	3:00	12	192	97.0	
26	F	15.0	.07	.27	7:00	.053 N	4:00	16	156	99.0	
27	F	20.0	.05	.20	7:00	.040 N	4:00	20	136	99.4	
28	F	16.4	.06	.24	6:00	.048 N	2:00	16	184	98.0	

* Naloxone - N , diprenorphine - D   + MCC - Mild clonic contractions

References

1. Stulken DE, Kirkpatrick CM: Physiological investigation of captivity mortality in the sea otter (Enhydra lutris), in Transactions of the 20th North American Wildlife Conference, pp 476-494, 1955.

2. Williams TD, Kocher FH: Comparison of anesthetic agents in the sea otter. JAVMA 173: 1127-1130, 1978.

3. Haigh JC, Stewart REA: Narcotics in hooded seals (Custophora cristata): a preliminary report. Can J Zool 57: 946-949, 1979.

4. Green CJ: Anesthetizing ferrets. Vet Rec 102:269, 1978

5. Soma LG, Shields DR: Neuroleptanalgesia produced by fentanyl and droperidol. JAVMA 145:897-902, 1964.

6. Anon, Immobilization and restraint of large wild mammals with azaperone and fentanyl. Beerse, Belgium, Janseen Pharmaceutica, Animal Health Department, 1974.

7. Haigh JC, Fentanyl based mixtures in exotic animal neuroleptanalgesia. AAZV Proceedings, St. Louis: 164-180, 1976.

8. Harthoorn AM: The Chemical Capture of Animals. London. Balliere Tindall. 1976. pp 246-274.

9. Hammond D, Elsner R: Anesthesia in phocid seals. J Zoo Anim Med 8: 7-13, 1977.

10. Harthoorn AM: Review of wildlife capture drugs in common use. In The Capture and Care of Wild Animals. Edited by Young, Ralph Curtis Books, Hollywood, Fla. (1975): 20-26.

11. Maarsboom R: On the pharmacology of azaperone, a neuroleptic used for the restraint of wild animals. Acta Zool. Path. 48: 155-161, 1969.

12. Gardocki JF, Yelnosky J: A study of some of the Pharmacologic actions of fentanyl citrate. Tox Appl Ph 6: 48-62, 1964.

13. Smuts GL: An appraisal of naloxone hydrochloride as a narcotic antagonist in the capture and release of wild herbivores. JAVMA 167:

559-561, 1975.

14. Foldes FF, Duncalf D, Kuwabara S: The respiratory, circulatory, and narcotic antagonistic effects of nalorphine, levallorphan, and naloxone in anesthetized subjects. Can Anaes Soc J 16: 151-161, 1969.

APPENDIX E

BEHAVIOR OF WALLEYE PIKE IN EXPERIMENTAL CHANNELS AS MONITORED BY A MICRO-COMPUTER UTILIZING RADIO TELEMETRY

A THESIS

SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL

OF THE UNIVERSITY OF MINNESOTA

By

KATHLEAN CAIN ZINNEL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF SCIENCE

June 1980

TABLE OF CONTENTS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

PREFACE

The Monticello Ecological Research Station (Monticello, Minnesota), was established to gather data on complex freshwater systems under semi-natural conditions. Experimental channels are used to study the effects of pollutant stresses on populations, communities, and ecosystems. The emphasis of research conducted at the station is on defining responses to toxicant stress that are then used as the basis for evaluating water quality standards. One research technique is to observe the response of free ranging vertebrates to the manipulation of environmental parameters. Because of the difficulties of direct observation underwater, telemetry is a useful tool for monitoring movement patterns of aquatic animals. In order to evaluate and measure the responses of free-ranging fish to environmental stimuli, the Monticello Ecological Research Station awarded a two phase contract to the Cedar Creek Bioelectronics Laboratory for the development and testing of an automatic fish tracking/monitoring system.

Previous underwater telemetry studies involved manual monitoring of radio frequency (rf) transmitters by hand-held receivers from shore or boat with subsequent plotting of triangulated locations on a map (Winter et al., 1978; Ross, 1978). The Monticello Remote Sensing System records one location per fish every fifteen minutes by comparing signal intensity and is accurate to the nearest pool or riffle in the channel. Therefore, it is now possible to monitor closely movement patterns of rf-tagged fish in response to the manipulation of environmental factors. The development of this system required research in the areas of automatic recording of position information, filtering of interference from random noise sources, and accessing data for analysis.

The major design difficulty in phase I was surmounting the high level of background electrical noise in the vicinity of the power plant and transmission lines. Monitoring reference transmitters and open channels (noise) proved useful in determining system reliability. Other problems addressed were transmitter characteristics and the difficulty that the system antennas were not equally distant from the receiver/conversion device. As defined by the original proposal, phase II of the Monticello project required: (1) testing the system with rf-tagged fish in the channel for accuracy and resolution of any other problems primarily connected with data recording; (2) determining behavioral responses of study species after the attachment of rf-transmitters.

Solutions to specific problems encountered in phase I are discussed in Chapter One. Chapter Two describes how the Monticello Remote Sensing System was used during performance testing to determine overall location selection by individual rf-tagged fish and to investigate patterns of movement behavior, especially in response to light cues. The walleye pike, Stizostedion vitreum vitreum, was selected as the test species because published data were available and because the fish tolerated transmitter attachment well in preliminary studies. Other goals of the field performance experiment were to measure tagging recovery times, feeding behavior, and pre-mortality movements.

STUDY SITE

The Monticello field station of the National Water Quality Laboratory (Duluth, Minnesota) was designed to facilitate field studies of aquatic organisms under controlled conditions. Eight experimental channels each 487 meters in length and composed of alternating pools and riffles (Figure 1) are located on 34 acres of land leased from the Northern States Power company adjacent to the Monticello Nuclear Generating Plant. The average dimensions of a pool are 33 meters long by 4.0 meters wide by 0.6 meters deep; the riffles are approximately 33 meters long by 2.6 meters wide by .33 meters deep. Mississippi river water is pumped in at one end of each channel and returned to the river through a culvert at the lower end of the channel. Flow rates, pH, and water temperature are all under experimental control; light intensity can be manipulated by installing shades or covers over part or all of the channel system. Separate instrumentation systems monitor pH, temperature, dissolved oxygen, and light intensity at various locations along a selected channel.

Experiments planned at the Monticello Research Station involving manipulation of light intensity, pH, temperature, and dissolved O_2 necessitate a high degree of precision and reliability in monitoring fish movement. To achieve the design specifications and to allow easy adaptation to different experimental situations, a monitoring system controlled by a micro-processor was designed. The development of MRSS (Monticello Remote Sensing System) was carried out by the University of Minnesota under E.P.A. Contract R-805-290-01-0 "Development and Testing of an Automatic Fish Tracking and Monitoring System for the Monticello Ecological Research Station". Design and construction of electronic hardware was performed at the Cedar Creek Bioelectronics Laboratory and field tests were conducted at the Monticello field station during May 1979.

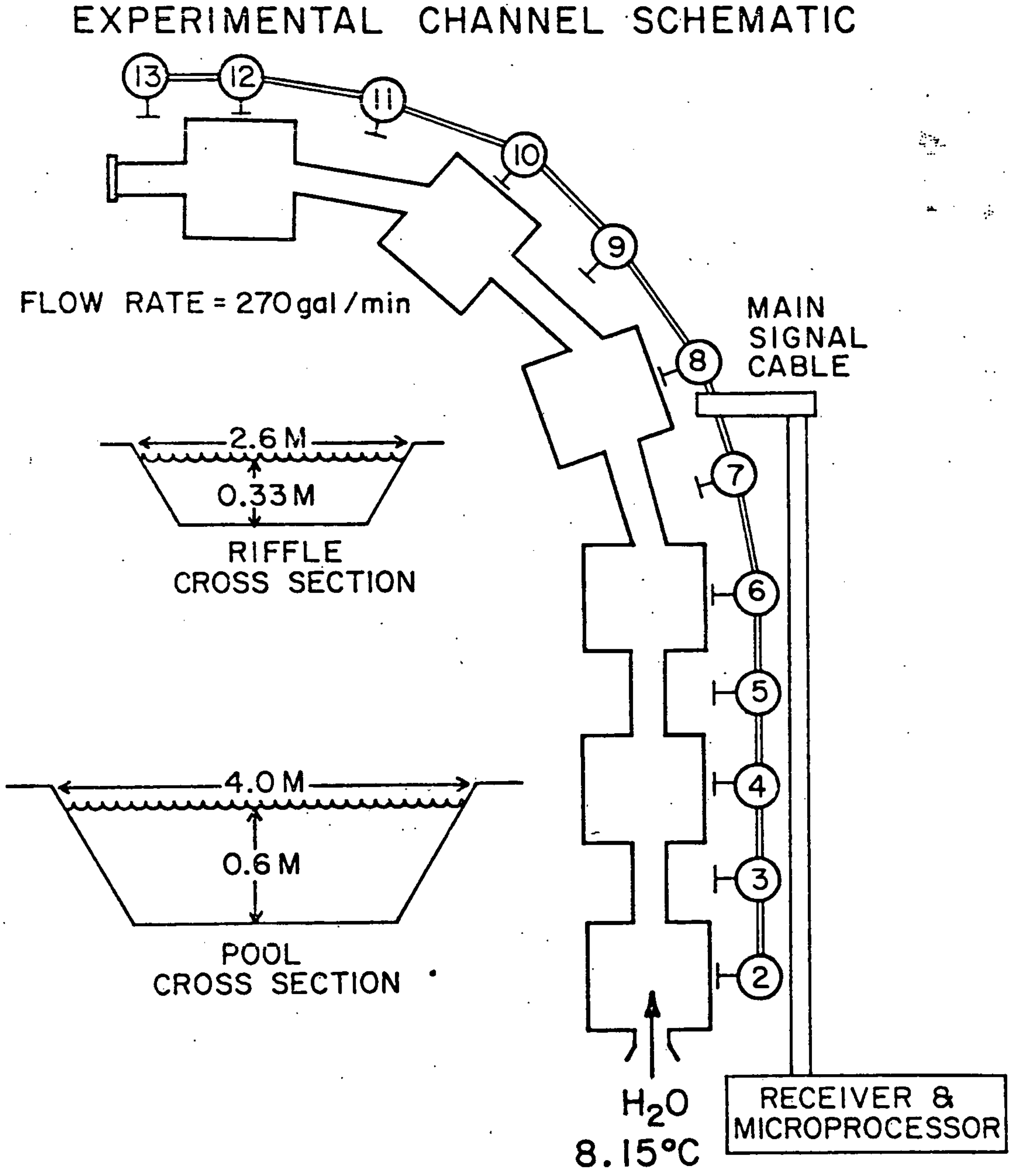


Figure 1. Diagrammatic representation of experimental channel #5 at the E.P.A. field station, Monticello Minnesota.

CHAPTER ONE

Operational Characteristics of the System

INTRODUCTION

Developmental aspects of the Monticello Remote Sensing System (MRSS) discussed in Chapter One are: the system hardware configuration together with the software program implementation, the characteristics of MRSS in operation, and an evaluation of the data from the field testing of the system done during May, 1979. The conceptual model for the engineering design of the hardware is discussed in the materials section, while the framework for the software implementation is discussed in detail in the methods section. The results and discussion sections focus on the operational characteristics of MRSS, examining the accuracy of position information obtained with the system and also the experimental difficulties with respect to external conditions at Monticello.

A 28 day performance test using 11 walleyes, *Stizostedion vitreum vitreum*, with surgically implanted radio-transmitters was made in order to provide baseline data on the operation of MRSS and guidelines for interpreting the position information recorded. Manual testing of accuracy was also done to verify that both the hardware and software were operating according to specification. To continuously monitor reliability, transmitters in fixed, known locations were used as references. For the first 36 hours of operation of MRSS, there were reference transmitters at each pool (antenna #'s 2,4,6,8,10, and 12). Then the transmitters at pool #8 and #12 were attached to cement blocks and submerged in the center of the channel until May 29th, the termination of the field tests. Also monitored were 4 "open channels", i.e. frequencies without actual transmitters, but within the range of the operating frequencies. These were used to determine whether interference from external electrical noise could disrupt operation of MRSS.

Materials: Engineering Design of Hardware Components

The organization and operation of MRSS was designed around the RCA COSMAC microprocessor (CDP1802) central processor unit (CPU), a small component that fetches and executes binary instructions. The CDP1802 was selected because CMOS (complementary metal oxide semiconductor) technology has provided components that consume less power than those of TTL design and have maximum noise immunity, thus allowing construction of hardware suitable for field situations. Most of the 91 available microprocessor instructions (including 14 input/output instructions) are one memory word (8 bits) in length, but some require 2 or 3 words per operand (Appendix A). All eight classes of CDP1802 instruction functions were used by MRSS, memory reference, register operation, logic operations, arithmetic operations, branch, skip, CPU control, and I/O byte transfer.

MRSS instructions reside in two types of memory; read only (ROM) and read/write (RAM). The Monticello Remote Sensing System has three 256_{10} byte RAM locations in Page Zero (0000-00FF), Page One (0100-01FF), and Page Two (0200-02FF); and one 512 byte ROM at addresses 8000-81FF for the utility program that controls the system micro-terminal. In addition, there is another 32-byte RAM that is used for register storage by the utility ROM at memory addresses 8200-821F. Along with the six peripheral devices shown in Figure 2, the microprocessor and the memory components comprise a simple computer system.

MRSS HARDWARE CONFIGURATION

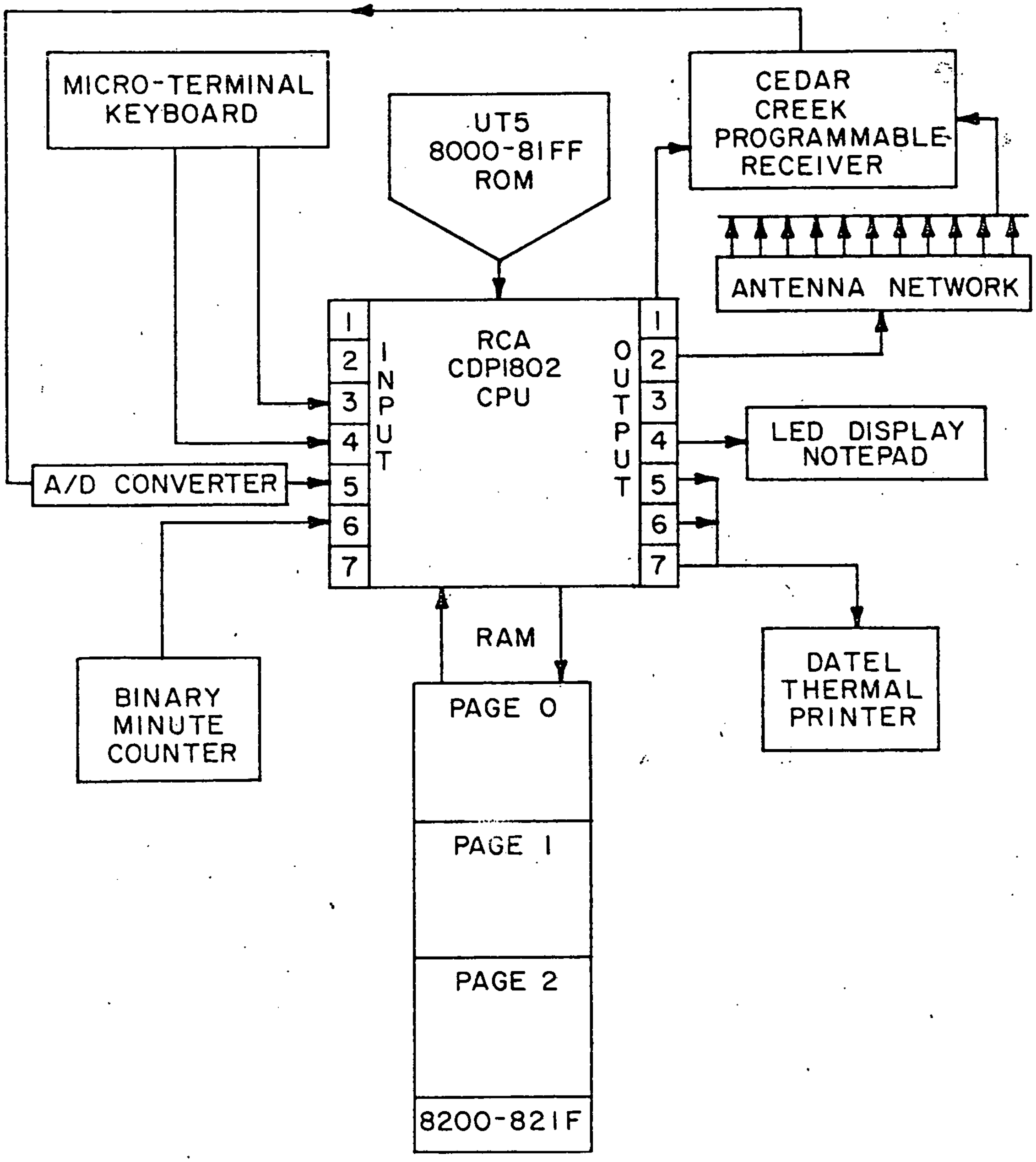


Figure 2. The Monticello remote sensing system hardware device organization and information flow.

MRSS software was written in RCA COSMAC assembly language. The University of Minnesota Cyber 74 time-sharing facility, under the NOS 1.2 operating system, was used to generate the hexadecimal machine language code from the RCA support package, a cross-assembler and debugger written in FORTRAN. Assembly language allows programs to be written and modified using mnemonic symbols rather than manipulating machine binary instructions. Moreover, the Cyber 74 time-sharing system provides facilities for archiving previous, current, and future versions of programs as well as simulating operation of the programs before field testing.

A portable data entry/readout device designed to operate with the CDP1802 central processor unit and utility program (UT5) is referred to as the microterminal (Figure 2). This "notepad" is a low power, low cost, small-size alternative to the teletypewriter frequently used as an input device with small computer systems. It is particularly effective in a field situation where portability is a major objective.

The programmable scanning RF receiver is manufactured at Cedar Creek as described by Tester and Siniff (1976) and Kuechle et al. (1971); and is used to detect radio-transmitters functioning in the 53 MHz band. After a transmitter has been attached to a fish, its frequency is entered into the memory of the receiver to the nearest KHz, which is thereafter associated with a particular selection code known as a "channel". MRSS allows 32 channels to be scanned per cycle, but the potential system capability allows a maximum of 64 channels. Cedar Creek receivers are built to cover a 1 MHz frequency range, which discriminates 100 different frequencies at recommended spacings of 10 KHz intervals.

Twelve horizontally polarized whip antennas were installed along one of the eight experimental channels at Monticello, so as to center one antenna by each pool or riffle. Antenna tests were performed to determine optimal signal reception at close distances (Figure 3). A switching network connected one antenna at a time to the receiver, in response to a unique selection code issued by the microprocessor control unit. An analog to digital (A/D) conversion of the signal intensity at the selected antenna was initiated by the micro-processor after allowing for "settling" time, and the resulting binary value was stored in an array for subsequent analysis.

To record time of day, a binary minute counter was tied to the 2 MHz clock on the CPU board. The microprocessor reads the binary minute counter as a peripheral device to determine elapsed time (Figure 2). Both time and location information were recorded by a Datel Thermal printer, model DPP-Q7. This six character per line, non-impact printer was TTL (transistor-transistor logic) rather than CMOS, but also had a low power consumption characteristic suitable for field installations.

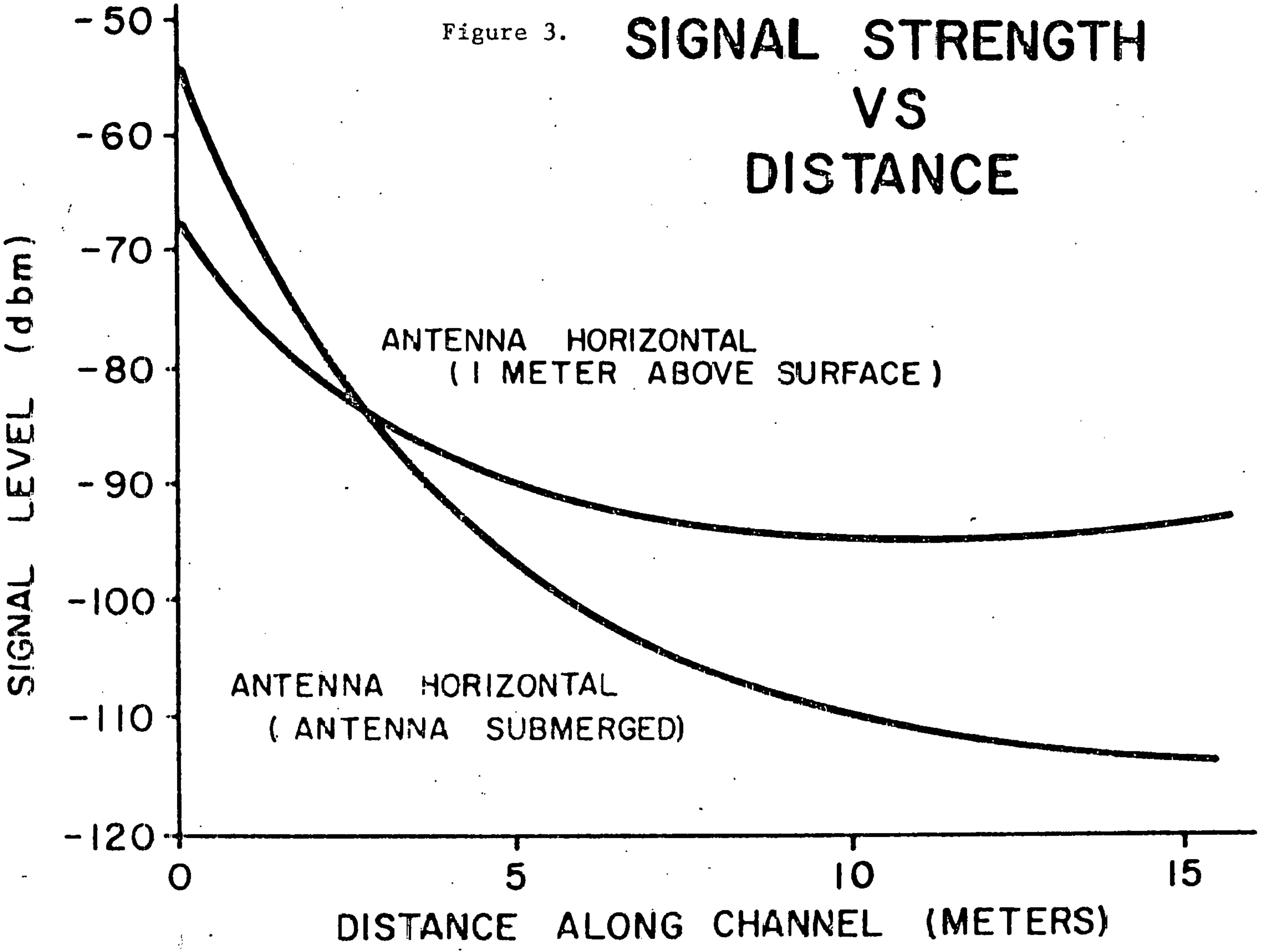


Figure 3. SIGNAL STRENGTH VS DISTANCE

Methods: Software Design and Implementation

MRSS has twelve distinct software modules, each performing a particular task, that together comprise the application program. This section discusses the function, timing and organization of each module; a complete listing can be found in Appendix B. In order of program origin, the modules are defined as: Bootstrap, Channel Ready List, Delay Loop, Binary to BCD Conversion, Initialization, Reset for Cycle, Print Cycle Headings, Pass Initialization, Channel Skip, Antenna Switching, Result Calculation, and Update System Clock. The program also contains areas of memory used as data storage buffers and can be modified via installation parameters.

MRSS is initiated by pressing "Reset" and "Run Program" on the micro-terminal notepad. This is effectively a "Master Clear" and begins execution at location 0000 with scratch pad register zero as the program counter. The bootstrap segment of code sets up scratch pad register 3 as the application P-counter and transfers control to the initialization segment. Memory is organized so that the more mutable locations are in Page Zero, but the bulk of the code resides in Page One.

The Channel Ready List is an array of permissable frequency select codes. During field testing of MRSS, codes 0 to 31 were defined, having the same function as the memory channel selector switch on the front panel of a radio tracking receiver. The Cedar Creek programmable receiver used with MRSS has a BCD memory which allows frequency to be paired with channel select codes. After establishing the best frequency to be used for a particular radio transmitter, the three front panel frequency selector switches and the memory write selector are used to enter the frequency in KHz. The corresponding frequency select code is then turned on in the Channel Ready List via the notepad. This is done by changing bit 7 from one to zero. For example, to track a fish whose frequency is selected by channel 00 on the receiver, the contents of the list location (4F) must be changed from 80_{16} to 00_{16}. The current day, hour, and minute are entered in hexidecimal into locations 64_{16}, 63_{16} and 62_{16} respectively. MRSS will update these time parameters while running, but can be stopped and reset at any time by using the "Reset" and "Run Utility" keys of the notepad.

To control the timing of events such as issuing frequency select codes, switching antennas, initiating A/D conversions, and waiting for the printer, the micro-processor executes a "delay" function. The Delay Loop subroutine takes 980 milli-seconds (msecs) to execute, and is used primarily while waiting for the completion of an external event, such as printing a line. This is important because if a print command is issued less than 330 msecs after the previous print command, the data are lost because the printer is "busy". There are only two scratch pad memory registers used by the delay subroutine, R(D) as the p-counter and R(2) as the delay counter.

The Binary to BCD Conversion subroutine is used to convert binary data values to their BCD equivalent which is necessary for the recording of data by the thermal printer. Usage of four scratch pad memory registers is required for this purpose: the p-counter (R(7)), a pointer to the address of the data value to be converted (R(B)), another register pointing to where in memory to store the BCD result (R(C)), and also a register for intermediate arithmetic results (R(4)).

The Initialization module insures that a current clock reading is obtained from the binary minute counter each time the application program starts. The user is responsible for entering the correct time before starting, but the system updates these values at the end of each cycle by comparing previous and current readings of the binary minute counter.

The Reset for Cycle module is always executed at the begining of each cycle which occurs only at fixed intervals. Because the Monticello [E.P.A.] Research Station specified 4 readings per hour, each active frequency is sampled with all twelve antennas once every 15 minutes and the results printed. However, this is an installation parameter with a maximum limit of one cycle every 4 hours and a minimum of one cycle every 7 minutes for 32 channels or 15 minutes for 64 channels. Reinitialization of all operating registers occurs at the beginning of each cycle of the main program.

A blank line to separate data recorded for each cycle, followed by the time, is printed at the beginning of each cycle. Because of the need to convert data to BCD and the wait for the printer to go "not busy", this segment takes around 2500 msecs to execute. Scratch pad register E is used as a pointer for the printer output buffer, plus the other registers required for passing parameters to the delay and conversion subroutines.

A pass consists of a sequential scan of all 12 antennas on one particular frequency corresponding to a channel in the ready list. The antennas are sampled beginning with #13, which is located farthest away from the ADP room, the location of the microprocessor and receiver, and ending the pass with the antenna located at the closest station, #2. Before the pass is made, the frequency select code in the channel ready list is tested for bit 7 being set; if it is not, the pass is initiated. If bit 7 of the select code is set, this indicates the frequency for this channel is not to be used this cycle. Instead, the microprocessor proceeds to the next frequency select code in the channel ready list. The channel select code for a particular pass is output via I/O port #1, followed by a 1 second delay while the microprocessor waits for the receiver to lock on to the requested frequency. At the beginning of each pass the memory storage location for the sum of the signal intensity readings (VSUM) is set to zero.

The antenna select codes are output to the network over I/O port #2; followed by a delay of 2 seconds before initiating the A/D conversion, thus allowing the signal to settle. After initiating a conversion, the CDP1802 waits until error flag #1 (EF1) goes zero before reading the A/D result for that antenna latched into I/O port #5. Each unit resulting from the A/D conversion represents 20 millivolts of signal intensity. The reading obtained for each antenna is compared against the current maximum value for the pass in progress and, if the value just read exceeds the current maximum, scratch pad register B is set to the memory address where the just read signal intensity value was stored. Next this value is divided by sixteen and added to the current pass total in memory location VSUM. If the address pointer in scratch pad register A is not equal to the end of the antenna select code array, the program branches back to select the next antenna in the list.

If the end of the list is reached, the pass is complete. Then the number of the antenna with the maximum A/D reading is computed by a logical 'and' of a four bit mask with the memory address of the maximum A/D reading. This antenna ordinal is then converted to BCD and stored in the printer output buffer as characters 3 and 4. This number, which corresponds to a physical pool or riffle, is the location of the transmitter. The quantity contained in VSUM is a measure of the level of background noise occuring during the just completed pass. As shown by Figure 4a, a distinct signal has a pronounced center of mass around the antenna with the strongest signal while an open channel with only noise appears as in Figure 4b. Because an average of the 12 A/D values obtained from a normal transmitter would give an unreasonably high estimate of the background noise, as each neighboring antenna also registered some signal; the sum of the 12 A/D values is divided by 16 instead of 12.

This background noise level estimate (VSUM/16) is then subtracted from the maximum A/D reading obtained from the antenna corresponding to the location of the transmitter to calculate the "level of signal distinctness". The larger this value, the more distinct the signal was at the antenna number reported as the transmitter location. The formula used for calculating level of signal distinctness when recording locations allows even weak transmitters to be distinguished from background noise. The level of signal distinctness is then converted to BCD and stored in the printer output buffer as characters 5 and 6. Finally the channel number that corresponds to the frequency used for the pass is converted to BCD and stored in the printer output buffer as characters 1 and 2. Subsequently, the line is output to the printer using I/O ports 5, 6, and 7; with the six characters being latched into a holding buffer until the activity on port 7 initiates printing.

After the results of the pass are printed (Figure 5), the address in scratch pad register 8 is compared to the last address of the Channel Ready List. If it is not equal, the program begins a new pass with the next frequency select code. If the last frequency select code has been reached the cycle is complete. The clock

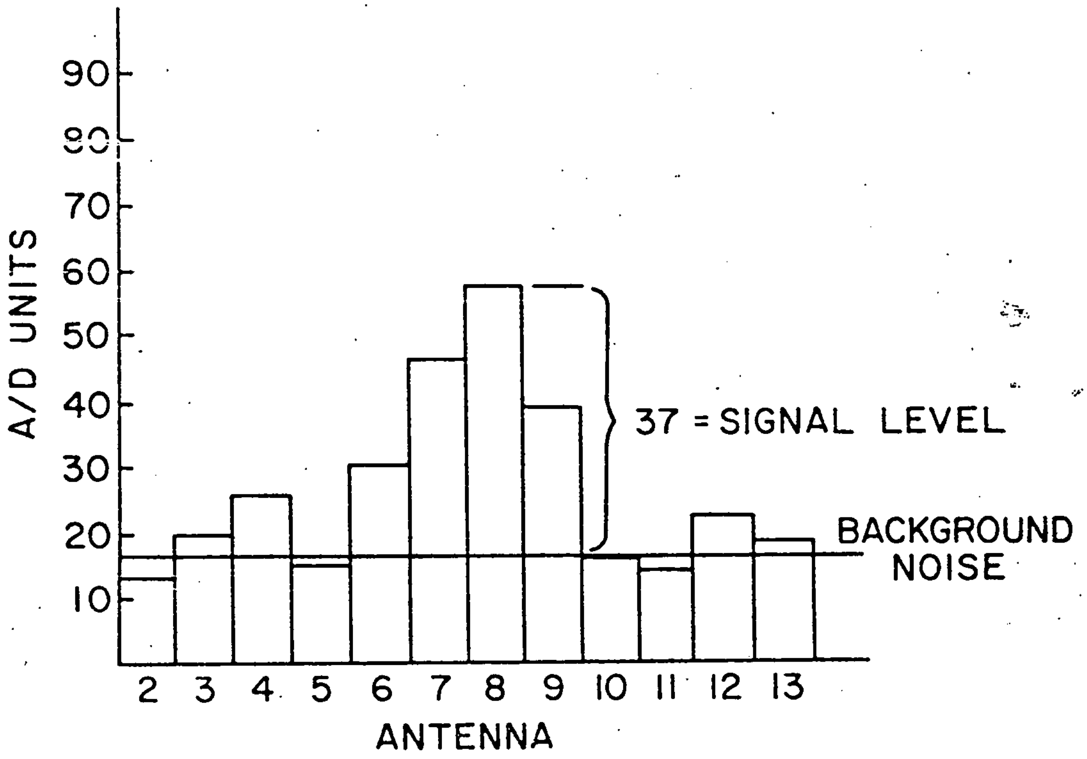


Figure 4a. Raw data from each antenna for a good quality transmitter located in pool #8 during one pass.

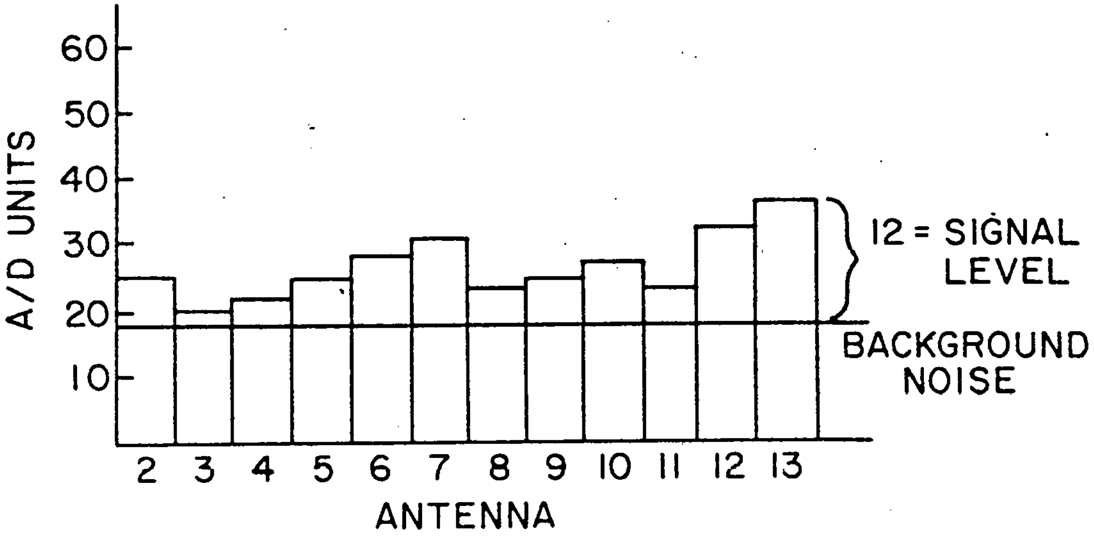


Figure 4b. Raw data from each antenna for an open channel with no transmitter during one pass.

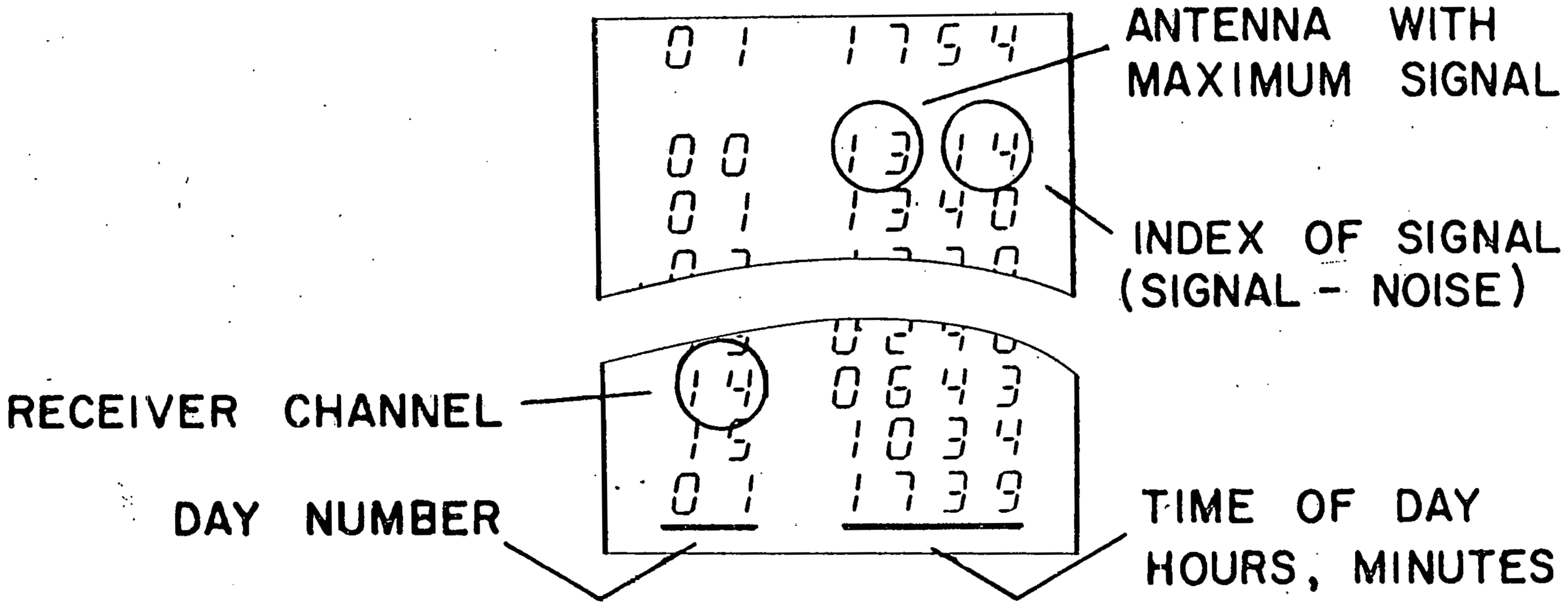


Figure 5. Data recorded by the Monticello remote sensing system on thermal paper.

value for the start of the last cycle is stored into the previous clock memory location and a new value for the next cycle is obtained by reading a value from the binary minute counter on I/O port #6. The number of minutes elapsed since the beginning of the last cycle is calculated and used to update the memory locations reserved for the day, hour and minute information. If the maximum value for day (99) is reached, it is reset to zero. The values for hour and minute are kept in standard military time. A one second delay for the completion of printing is executed before branching back to the beginning of the main program to begin a new cycle.

RESULTS

Data recorded by MRSS for each transmitter consist of a channel number, the antenna designation for the pool/riffle determined to be the location of the transmitter, and the level of signal distinctness, a signal to noise ratio analog for the frequency assigned to the channel (Figure 5). When the data tapes were transcribed, each location determination became a computer card (case containing) the following information: date and time at the beginning of the cycle, a unique designation assigned to each frequency sampled, channel code used by MRSS, antenna ordinal of the transmitter location, signal level of distinctness, transmitter type and transmitter frequency. Following the encoding process, the raw data cards were read into a 'permanent file' on the Cyber 74 and prepared for analysis.

To prepare the raw data for input to SPSS (a Statistical Package), a computer program was used to calculate movement information. First the raw data were sorted into ascending sequential order according to the following hierarchy: identification number, date, time and receiver channel number. To insure that movement parameters were generated only for location determinations with the required temporal spacing, a julian date was calculated using JDATE = (DAY*24*60)+(HOUR*60)+MINUTE. Movement was defined as a change in position as denoted by the absolute difference (moves) in station number between two successive location determinations no more than 15 minutes apart for the same identification number unique to each transmitter or open channel frequency. Another parameter (DIRECTION) was set to 0 if no movement was indicated, to 1 if the change of position indicated movement up the channel towards station #2, or to 2 if the movement was down the channel toward station #13.

The third parameter (CHANGE) denoted change of direction of movement and was only calculated for 3 successive location determinations in a 30 minute period. The change parameter was blank if there was no movement, 0 if there was only one isolated movement, 1 if the three location determinations indicated two sequential movements in the same direction, or 2 if the two sequential movements were in opposite directions.

Finally, the composite data were processed into an SPSS system file for subsequent analysis. At this time, if any variables were found to have invalid parameters (possibly garbled in the transcription process) the entire case was deleted. The 36,290 cases used for analysis fall into 3 categories as summarized in Table 1: (1) reference transmitters (identification number calculated as 4000 plus the number of the pool where they were stationed), (2) walleyes (identification numbers correspond to actual Atkin's tag attached to dorsal fin, 4038-4047), and (3) open channels (identification number calculated as 4100 plus channel number (0-3) used to record on printout).

Table 1. Summary of the information produced by MRSS during field testing.

53 MHZ Frequency	Atkin's Tag Designation	Number of Locations Determinations	Average Signal Level in A/D Units	S.D. of Signal Level	Transmitter Type
.030	4002	79	43.5	8.4	SP
.020	4004	79	43.3	3.6	FP
.040	4006	79	38.9	4.7	MP
.450	4008	2490	15.0	2.2	CN
.100	4010	79	36.8	4.6	MP
.200	4012	2491	53.1	8.4	SP
.210	4038	2123	44.6	19.2	CN
.180	4039	1877	35.5	7.2	FP
.230	4040	2489	24.2	4.8	MP
.220	4041	2492	25.6	8.6	FP
.240	4042	2492	42.3	10.3	SP
.060	4043	2492	26.9	4.9	MP
.100	4044	1135	30.4	7.0	MP
.020	4045	2402	31.1	7.7	FP
.030	4046	2401	28.8	7.3	SP
.040	4047	1136	25.8	7.1	MP
.010	4100	2489	9.3	1.8	OC
.120	4101	2487	18.0	5.7	OC
.260	4102	2488	12.4	3.9	OC
.380	4103	2490	10.7	3.2	OC

'CN' = Continuous
'OC' = Open channel

'SP' = Slow pulsing
'MP' = Medium pulsing
'FP' = Fast pulsing

DISCUSSION

To measure the performance characteristics of transmitters, consider the standard deviation of the average level of signal distinctness for reference transmitters from Table 1 as an indication of variability in the signal level for the different transmitter types. Continuous transmitters are the least variable, fast pulsing are slightly less variable than the medium pulsing, and the slow pulsing transmitters are four times more variable than the continuous types. Calculation of the coefficient of variation for the signal levels of each transmitter indicated that variability for transmitters in fish, or for open channels, was twice that of transmitters used as references. However, when the coefficients of variation were compared for the references versus fish and for the reference versus open channels using the t-statistic, there were no significant differences.

As the field testing progressed, there appeared to be a slight tendency for signal levels to gradually become lower, presumably a function of water temperature, water conductivity changes, or the battery being drained of power. This was confirmed by analysis of covariance on the data for signal level for six walleyes that survived the entire period. The most significant factor was the inherent signal level of each transmitter, with the date (i.e. length of time in operation) half as important. The lowest levels of signal distinctness occurred during the 1200-1559 time period and the highest during 2000-2359. Effect for time-of-day was not significant, only varing by 2.25 units. Average levels of signal distinctness for individual walleyes could vary by 20 units of signal intensity, depending upon where the fish were positioned in a pool. Comparing average levels of signal distinctness for each transmitter in each pool/riffle suggested that riffles generally had lower signal levels than pools, but analysis of covariance did not detect a significant effect.

Location determinations can be further classified according to the signal level of distinctness recorded when assigning the location of the transmitter to a particular pool/riffle. The frequencies with which signal levels were found to occur during field testing suggest a trimodal distribution such that a 'poor' quality location determination is defined as having a level of distinctness less than 20 A/D conversion units. 'Good' quality fixes fall in the range of greater than 20 but less than 50 A/D units, while signal levels greater than 50 are 'excellent' quality fixes; and, as discovered by manual accuracy testing, these only occur when a strong transmitter is directly in front of an antenna installation.

Table 2 summarizes the data on signal quality including the percent of location determinations in each usage category achieving a particular level of distinctness, and also the percent of each quality category attributed to usage. These data indicate signal levels for walleye transmitters were much more distinct than the open channels, i.e. high enough to override interference. There were a few good and excellent quality signal levels for the open channels which were probably a result of a vehicle with an unshielded ignition system being used too close to the instrumented channel.

Because two factors, signal level and variability, affect the accuracy of MRSS, a weak but continuous type transmitter (4008=53.450 MHz) was used for the reference at station # 8, and a strong but slow pulsing type (4012=53.200 MHz) was used for the reference at station #12. As can be seen from Table 3, almost all the fixes for reference 4008 were "poor" while the fixes for variable reference 4012 were either "good" or "excellent". In order to answer the question "Does a low level of signal distinctness affect accuracy?", it is necessary to consider the signal levels of the 68 errors that occurred during the 28 day test period. Errors were defined as a location determination recorded for a reference transmitter at some pool or riffle other than the true location.

Including all the reference transmitters from Table 1, there were 5297 location determinations on reference transmitters with 68 errors occurring, i.e. 98.72% accuracy. Moreover, 46.7% of all location determinations on reference transmitters were of "poor" quality and 61.8% of the errors occurred at these low levels of

Table 2. Comparison of the three categories of location determinations (fixes) as a function of quality as determined by level of signal distinctness expressed in analog to digital conversion units.

Statistic	Reference	Walleye	Open Channel
Average Signal:	34.45	31.47	12.69
S.D. for Signal:	19.51	11.69	5.20
N of fixes:	5297	21,039	9,954

Percent of total location determinations.

Signal Quality	Reference	Walleye	Open Channel
Poor	6.76	6.90	25.05
Good	3.74	47.04	2.46
Excellent	3.96	4.04	0.03

Percent of each usage category

Quality	Reference	Walleye	Open Channel
Poor	46.7	11.9	91.2
Good	25.9	81.1	8.7
Excellent	27.4	7.0	0.1

Percent of each quality category

Usage	Poor	Good	Excellent
Reference	17.5	7.0	49.3
Walleyes	17.8	88.3	50.3
Open Channels	64.7	4.7	0.4

Table 3. Summary of location determinations on primary reference transmitters.

Quality	4008 (%)	4012 (%)
Poor	2472 (49.63)	1 (0.02)
Good	17 (0.34)	1065 (21.38)
Excellent	1 (0.02)	1425 (28.61)
Total Fixes	2490	2491

All errors occurring for reference transmitters.

Signal Quality	4008(%)	4010(%)	4012(%)	TOTALS(%)
Poor	42 (61.8)	0 (0.0)	0 (0.0)	42 (61.8)
Good	12 (17.6)	2 (2.9)	5 (7.4)	19 (27.9)
Excellent	1 (1.5)	0 (0.0)	6 (8.8)	7 (10.3)
Total Errors	55 (80.9)	2 (2.9)	11 (16.2)	68

signal distinctness (Table 3). Correspondingly, 25.9% of the fixes were of "good" quality and accounted for 27.9% of the errors, while 27.4% of the reference location determinations were of "excellent" quality but included only 10.3% of the errors. To test whether transmitters with signal levels greater than 20 units are more accurate, a X^2 test with 1 df was made using the observed accuracy results for the reference transmitters. Expected values were calculated under the hypothesis of independence given the accuracy rate of 98.72%. From the results shown by Table 4, Ho can be rejected, concluding that there is a slightly higher error rate for "poor" signal level determinations ($<$ 20 units of signal intensity).

Assuming that the same proportion of errors would occur with low signal levels for rf-tagged fish, accurate data would be assured by selecting for implantation only those transmitters producing levels of signal distinctness greater than 20 units. Fortunately, Table 2 indicates that data recorded for walleyes during field testing of MRSS are primarily of good or excellent signal level quality. Moreover, a weak transmitter used as a reference (4008) contributed 61.8% of all reference errors from the half of those location determinations which were of poor quality. Since only 12% of the walleye data were of "poor" quality, it is probable that accuracy is closer to 99% for walleye location determinations.

Reliability of position information is also a function of each antenna in the network. Differences in sensitivity to radio signals or susceptibility to interference could cause erroneous results. If this were the case during field testing, the pattern of location determinations for the open channels

Table 4. Chi-square test of accuracy for low signal level of distinctness.

Treatments	Accurate		Erroneous		Totals
Signal levels	Obs.	Exp.	Obs.	Exp.	
.LT. 20 A/D units	2432	2442	42	32	2474
.GE. 20 A/D units	2797	2787	26	36	2823
Totals	5223		68		5297

Ho: Occurence of errors is the same in the two different signal level groups: i.e. $P_1 = P_2$.

$$5.98 = \sum((\text{obs.} - \text{exp})^2/\text{exp}); \; X^2_1(\alpha = .025) = 5.02$$

would result from random noise and reflect antenna malfunction. As can be seen in Table 5, the percentages of the 3 quality levels of fixes which occur at each antenna were quite different for the open channels versus walleye location determinations.

If the location determinations made by MRSS for the walleyes were random noise like the open channels, then they should have the same pattern of distribution. Using the actual number of locations occurring at each antenna from Table 5, where both fish data and open channel data were for the whole test period, a G^2 goodness-of-fit test (Fienberg 1977) can be calculated as $G^2 = 2 \sum \text{Obs} \times (\log_e(\text{Obs}/\text{Exp}))$. The resulting value for G^2 is 9226.5 with 11 d.f., and can be tested by the values of the X^2 distribution.

The value for X^2_{20} (α = .005) = 40., which signifies that the pattern of distribution of fixes for the open channels and the walleyes are definitely not equivalent. Since the probability of the null hypothesis being correct is much less than .001, the individual antennas in the network were reliable and accurate to the nearest pool or riffle even though they were not equally distant from the receiver and conversion devices.

Table 5. Percent of location determinations of each signal level category occurring at each antenna in the network for walleyes and open channels.

	% Poor		% Good		% Excellent		N of Locations	
Antenna	Open	Fish	Open	Fish	Open	Fish	Open	Fish*
2	60.24	2.53	2.94	1.15	0.01	0.02	6341	597
3	5.79	0.26	2.14	0.55	0.01	0.01	766	128
4	7.33	0.84	0.55	7.68	--	1.57	766	1435
5	0.45	0.44	0.03	1.16	--	0.03	50	242
6	0.79	1.39	0.04	14.83	0.01	0.52	80	1279
7	9.51	1.34	0.56	3.93	0.01	0.12	1005	824
8	0.52	1.40	0.05	21.18	0.01	3.51	60	4858
9	0.71	0.81	0.06	3.95	--	0.16	79	838
10	0.38	1.40	0.01	15.22	--	0.25	40	2898
11	0.61	0.80	0.42	2.31	--	0.06	100	327
12	0.18	3.34	0.05	3.62	--	0.50	20	554
13	4.76	3.63	1.74	5.54	0.05	0.20	647	227
Total	91.23	11.91	8.67	81.12	0.10	6.97	9954	14207

* locations used only for surviving fish

Conclusions

The Monticello remote sensing system has been shown to report accurate position information by time of day for individual radio transmitters. No insurmountable experimental difficulties were associated with either the hardware or software. Location determinations on reference transmitters were 98.72% accurate and the level of signal distinctness was a reliable indicator of the quality of any location determination. Therefore, MRSS can provide reliable information on the location of free-ranging walleyes with implanted radio transmitters. These data are comprehensive enough to discern movement patterns in response to daily, or even hourly, fluctuations of light intensity or other external factors.

CHAPTER TWO

Walleye Behavioral Responses

INTRODUCTION

The walleye is a temperate mesothermic freshwater fish of the family Percidae, a dominant species of the boreal forest zone (Scott and Crossman 1973). The Percidae lack the specific adaptations to lacustrine life apparent in the laterally compressed Centrarchidae and Cichilidae, having diverged less from their anadromous ancestors (Collette et al. 1977). Although walleyes are tolerant of a great range of environmental situations, their riverine physiological characteristics limit the optimum habitat available. The critical factors include ultimate upper incipient lethal temperatures from 29° to 35°C, limited osmo-regulatory capacity, and less efficient swimming performance. Large shallow turbid lakes support abundant walleye populations, but large streams or rivers provide suitable habitat if they are deep or turbid enough to reduce light penetration (Scott and Crossman 1973).

The Monticello experimental channel system is well suited for walleyes with conditions equivalent to those in temperate rivers or in the littoral and sub-littoral environment of lakes proposed as the preferred habitat (Kitchell et al. 1977). The analogous habitat conditions present at Monticello include sand and/or gravel substrate, low current velocity (Figure 1), reduced light penetration (Figure 6), and temperature optimal for growth in adults (less than 27°C).

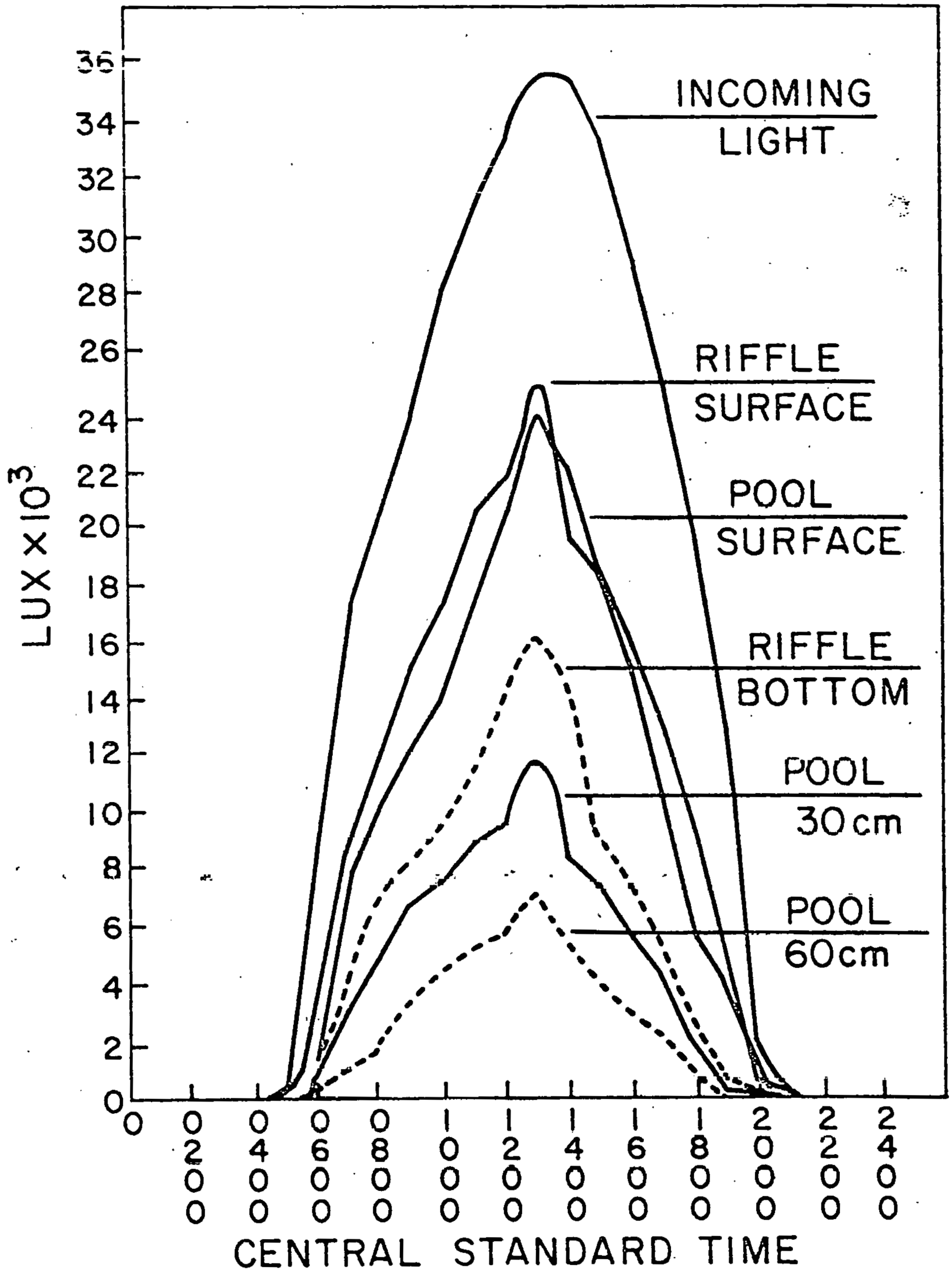


Figure 6. Summary of light penetration through the water of pool #10 at Monticello on May 23rd, 1979.

Walleyes observed by divers in lakes are most often (98%) observed swimming in that portion of the lake where perceptible currents exist (Ryder 1977). Furthermore, flow rates in a running water system, the supposed walleye ancestral habitat, undergo seasonal fluctuations depending on geographic location. Water temperature is also directly affected by solar insolation, following a daily cycle with a maximum in the early afternoon corresponding to the maximum in total incident radiation and varying with the rate of change of incident sunlight (Figure 7).

Thus within a running water ecosystem there are several types of stimulus that could provide an organism with information about the 24-hour day. Because biotic processes are affected, aquatic vertebrates would be expected to show a distinct temporal organization correlated with the rotation of the earth (both seasonal and time-of-day). Periodic movements of walleye involve a spring spawning run, daily changes in depth in response to light intensity, and daily or seasonal movements in response to temperature or food availability (Scott and Crossman, 1973).

Therefore, the analysis of "time niches" in a running water ecosystem should be a necessary complement to the studies of "space niches" in determining the effects of pollution stress on aquatic vertebrates. From the location information produced by MRSS, temporal movement patterns can be analyzed. Repeated observations of the same individuals are possible without disturbance and the sampling method is instantaneous.

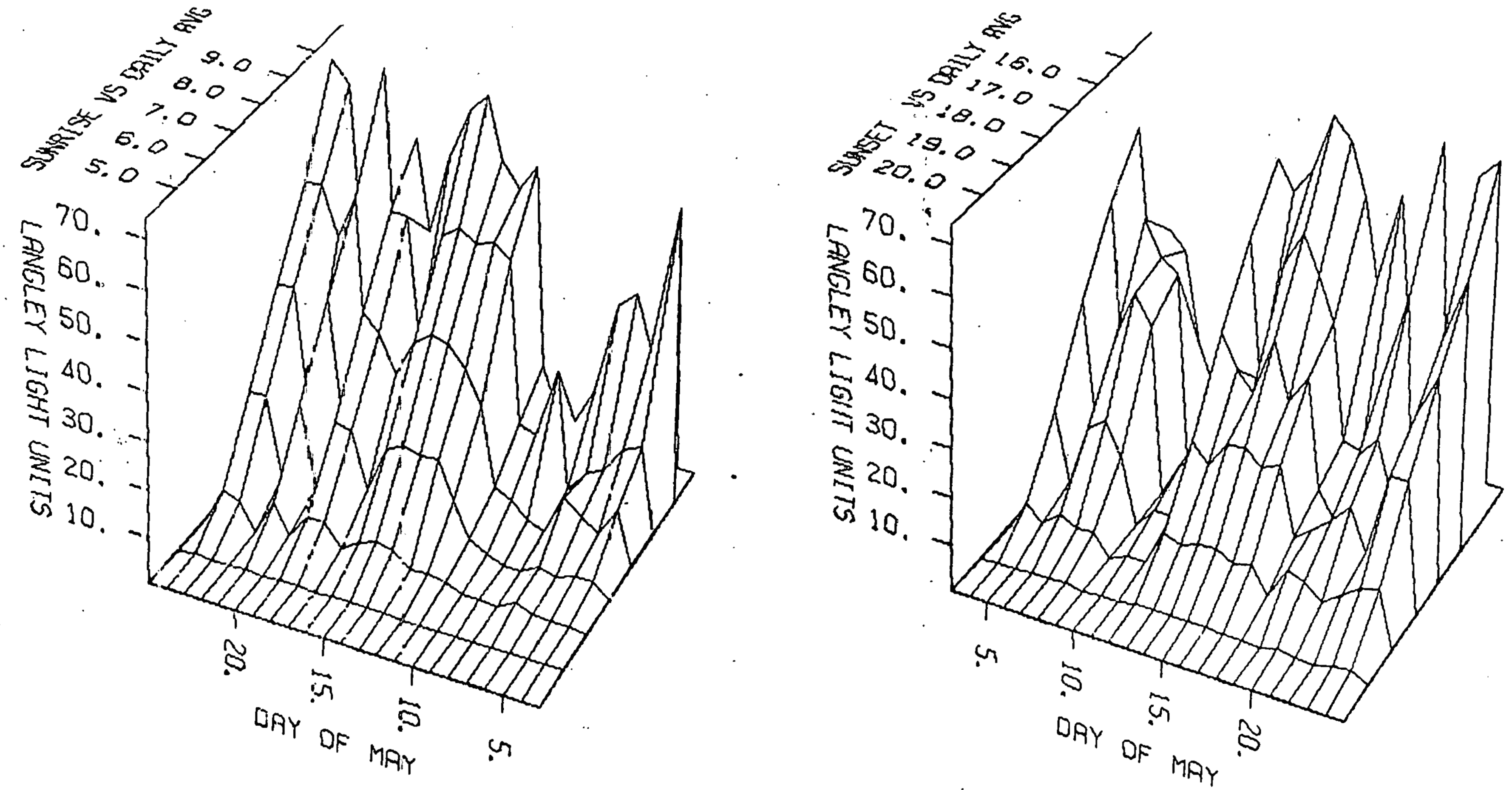


Figure 7. Incident solar radiation at sunrise and sunset from May 4th to May 24th, 1979. Unlabeled y-axis tic mark represents a daily average for light units recorded from 10:00 to 15:00.

Materials and Methods

Eleven male walleyes were obtained from the U.S. Fish and Wildlife Service at New London, Minnesota, transported by truck to Monticello and placed in covered outdoor tanks on April 27, 1979. The fish were rf-tagged with 9 gm transmitters and released in pool #4 to swim freely in experimental channel 5 on May 2nd and May 3rd. The method of transmitter implantation was to surgically open the body cavity of the anesthetized fish along the linea alba, placing the mass of the transmitter into the peritoneal cavity midway between the ventral and anal fins under the ventral muscles (Hart & Summerfelt 1975). A modification of this technique allowed the nine inch whip antenna to exit via a second opening cut about 2 cm in front of the anal opening. After carefully positioning the antenna using a "tunnel" of surgical tubing, the openings were sutured with 5.0 ethilon thread at 3-5 mm intervals (Ross and Kleiner 1980). Before release, weight and length measurements were taken and a yellow Atkin's tag was attached to the dorsal fin.

On June 1, 1979, the 7 fish still living were recaptured and the transmitters recovered. All surviving walleyes had healed well, showed no infection of the sutures, and appeared not to have had internal ruptures or bleeding from the presence of the transmitters. Sutures on one fish had worn or torn at the antenna exit hole. At the beginning of the field test, the average weight of all 11 fish was 710 gms (S.D. = 180) and the average length was

43.5 cm (S.D. = 3.24). At the time of capture after the experiment, the average weight loss for 4 fish was 26 gms but one fish gained 10 grams and a fifth fish was too large for the scale and couldn't be weighed. Weight and length measurements were not obtained for all survivors, or for the walleyes that died before May 29th.

The four rf-tagged walleyes that died during field testing had Atkin's tag designations 4039, 4044, 4045, and 4047. One transmitter (4037) failed at the beginning of the experiment even though the walleye survived and was recaptured at the termination of testing. Five of the surviving fish (4038, 4040, 4041, 4042, 4043) were tracked by MRSS for 28 days and the sixth (4046) for 27.

Location Distribution Patterns

Figures 8 through 17 summarize the location determinations recorded by MRSS during field testing at Monticello. The y-axis units represent the station numbers (2-13) of the antenna installations and correspond to the arrangement of the experimental channel system. For the x-axis, each unit represents a 24 hour time period defined from noon to noon. The contour lines depict the percentage of location determinations occurring at each antenna during each period; i.e. usage of each individual pool or riffle by each walleye over time. In addition, the caption for each figure gives the weight and length measurements of that fish taken at the time of tagging.

Each walleye favored one pool on a given day, or series of consecutive days. However, there was a great deal of variation among individuals as to the primary pool utilized, and the degree of movement into other pools. For example, Figure 15 shows that fish 4045 died in pool #6 on the eighth day of field testing, but because the decomposing body was lodged in pool #6, this fact was not discovered until after termination of testing. In effect, there was an additional reference transmitter at pool #6 for most of the experiment.

In contrast, data for 4039 (Figure 9) and 4044 (Figure 14) show that the current in the experimental channel carried a weakened or dead fish downstream until it encountered the barrier across the

PAGES 45 to 54

WERE INTENTIONALLY

LEFT BLANK

bottom end of riffle #13. Thus, compact contour lines indicate that the fish was staying in a particular pool, as illustrated by Figure 12 (4042). As verified during the course of the experiment, 4042 would swim back and forth in pool #8 but seldom ventured outside. In comparison, 4040 moved extensively, showing spread-out contour lines and concentrations seldom exceeding 70% (Figure 10).

If one examines the contour maps in order of increasing walleye weight, the five larger individuals seemed to move away from the initial release pool much sooner than the smaller fish. Of the walleyes that survived the entire test period, 2 were small (567 gms, 580 gms), 2 were medium sized (606 gms, 649 gms) and 2 were very large (916 gms, 1116 gms). During the last five days of the experiment, pool #8 was the primary pool used by 1 small, 1 medium, and 1 large fish. Pool #10 was the major area used by 1 medium and 1 large walleye while pool #6 was being utilized primarily by 1 small fish. Ryder (1977) reported that schools of active walleyes usually consisted of 3 or 4 individuals, but may contain as many as 50 fish. Scott and Crossman (1973) characterized walleyes as remaining in loose but discrete schools with separate spawning grounds and summer territories.

Examination of the data for 4046 (Figure 16) and 4043 (Figure 13), the 2 largest fish, illustrates their utilization of mutually exclusive primary pools for most of each time period. The usage patterns for the medium-sized fish (4038, 4040) were also mutually exclusive over almost all the experimental period, as was also the situation for the 2 smallest fish, 4042 and 4041. Although the sample size is too small to provide conclusive evidence, there was the strong suggestion of a partitioning of available habitat on the basis of body size. Because of limited optimum habitat in the experimental channel, avoidance or exclusion may have been directed towards individuals.

To investigate whether avoidance or association existed between pairs of walleyes, a computer program was used to analyze the data for the 6 survivor walleyes by comparing position information for the exact same fifteen minute interval and tabulating how many stations separated each 2 walleyes. The resulting 15 comparisons are summarized by Figure 18, and Table 6 defines the comparison assigned to each X-axis ordinal. The comparisons have been ranked according to the percent of time intervals each pair of walleyes was together in the same pool or riffle at the same time. In addition, the body size information from Table 6 is depicted relative to amount of association by Figure 19.

Apparently walleyes 4042, 4038, and 4043 formed a discrete group of heterogeneous-sized fish. Another sub-group, 4046 and 4040, was strongly associated and of different size; while 4041 was a loner. All comparisons of equivalent body size fall in the region of 20% association except 4038 vs 4042. This was interpreted as being the normal probability of association as there were 5 pools and the walleyes normally were found in the pools, moving through the riffles only when necessary to get from pool to pool. The high incidence of association between 4038 (606 gms) and 4042 (567 gms) results from their status as "familiars" or preferred companions of the largest walleye, 4043. Overall, these patterns of association seem to indicate non-random selection of location by individual walleyes, preferred aggregations, and avoidance of non-group members.

The two largest walleyes, 4043 (1116 gms) and 4046 (916 gms), appear to be focal individuals, separated by at least 35 meters 80% of the time. Thus a distinct polarity existed between the two largest walleyes, 4043 (1116 gms) and 4046 (916 gms). The only occurrence of their utilization of the same primary pool (#10) was during May 4-6th, the tagging recovery period. Apparently 4046 was displaced into pool #12 during May 7-9th, returning to pool #10 only after 4043 had moved to pool #8 (Figures 13 & 16). Competition for the limited food available would explain avoidance behavior occurring between these two walleyes for the rest of the field test experiment.

Besides looking at overall patterns of distribution of locations in a 24 hour period, MRSS can be used to detect movement or changes in position, thus allowing determination of temporal movement patterns of walleyes. Table 7 presents the percent of all location determinations that represented or simulated changes of position occurring during a four hour time-of-day period, summarized for each

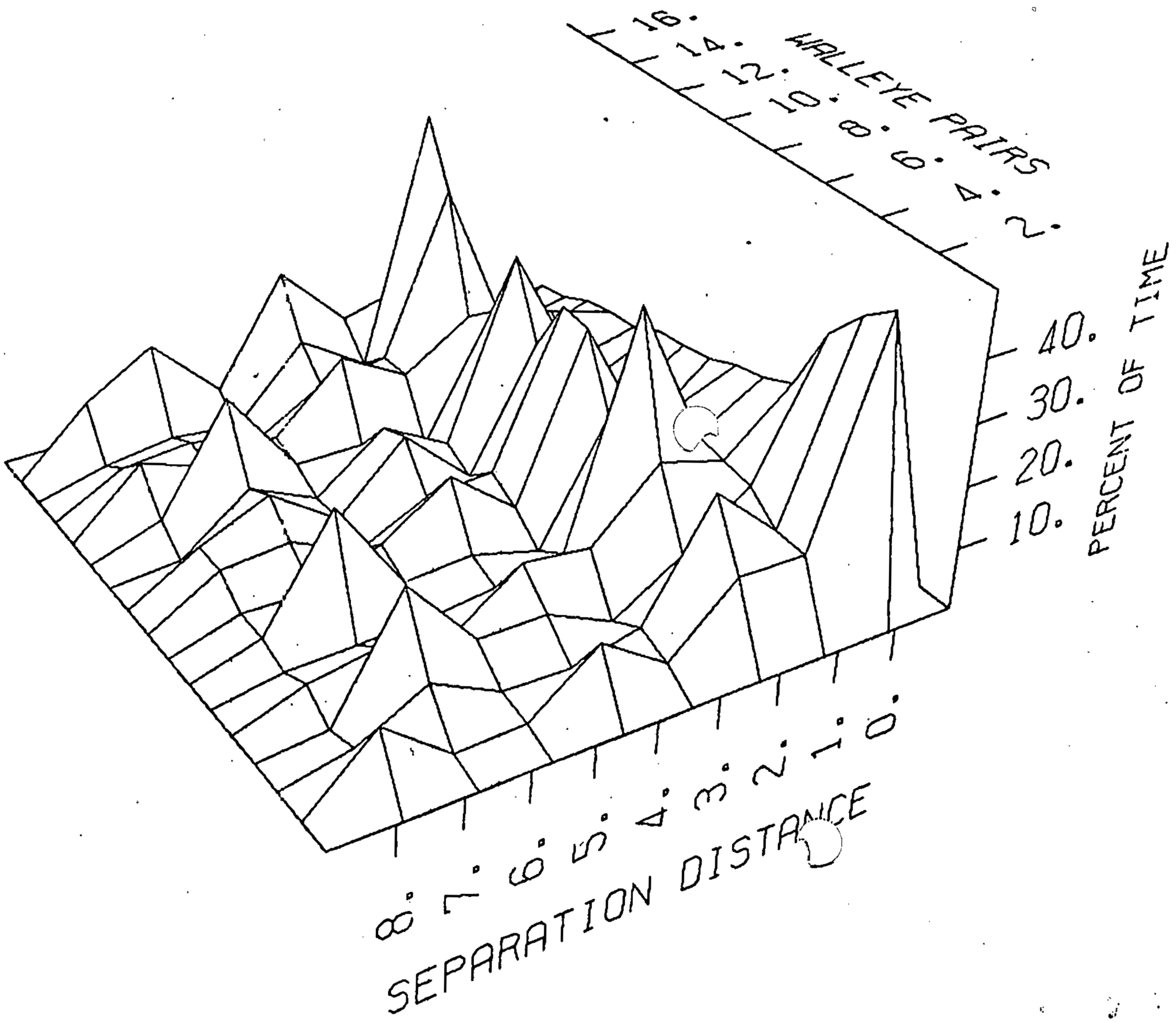


Figure 18. Summary of percent of time intervals that each pair of the six survivor walleyes were associated. X-axis ordinal definitions of the pairs of walleyes compared are found in Table 6.

Table 6. Comparison of the percent of time intervals spent in the same pool and respective weights for pairs of surviving walleyes.

Figure 18. X-axis Ordinal	Walleyes Compared	Percent of Time Associated	Respective Weights in Grams
1	4038 vs 4042	47.0	606, 567
2	4038 vs 4043	43.1	606, 1116
3	4042 vs 4043	37.5	567, 1116
4	4046 vs 4040	26.5	916, 649

5	4040 vs 4042	24.3	649, 567
6	4041 vs 4042	23.2	580, 567
7	4046 vs 4043	21.0	916, 1116
8	4038 vs 4040	20.1	606, 649
9	4041 vs 4038	19.5	580, 606

10	4046 vs 4042	17.2	916, 567
11	4040 vs 4041	15.7	649, 580
12	4041 vs 4043	16.6	580, 1116
13	4040 vs 4043	13.4	649, 1116
14	4038 vs 4046	12.3	606, 916
15	4041 vs 4046	7.8	580, 916

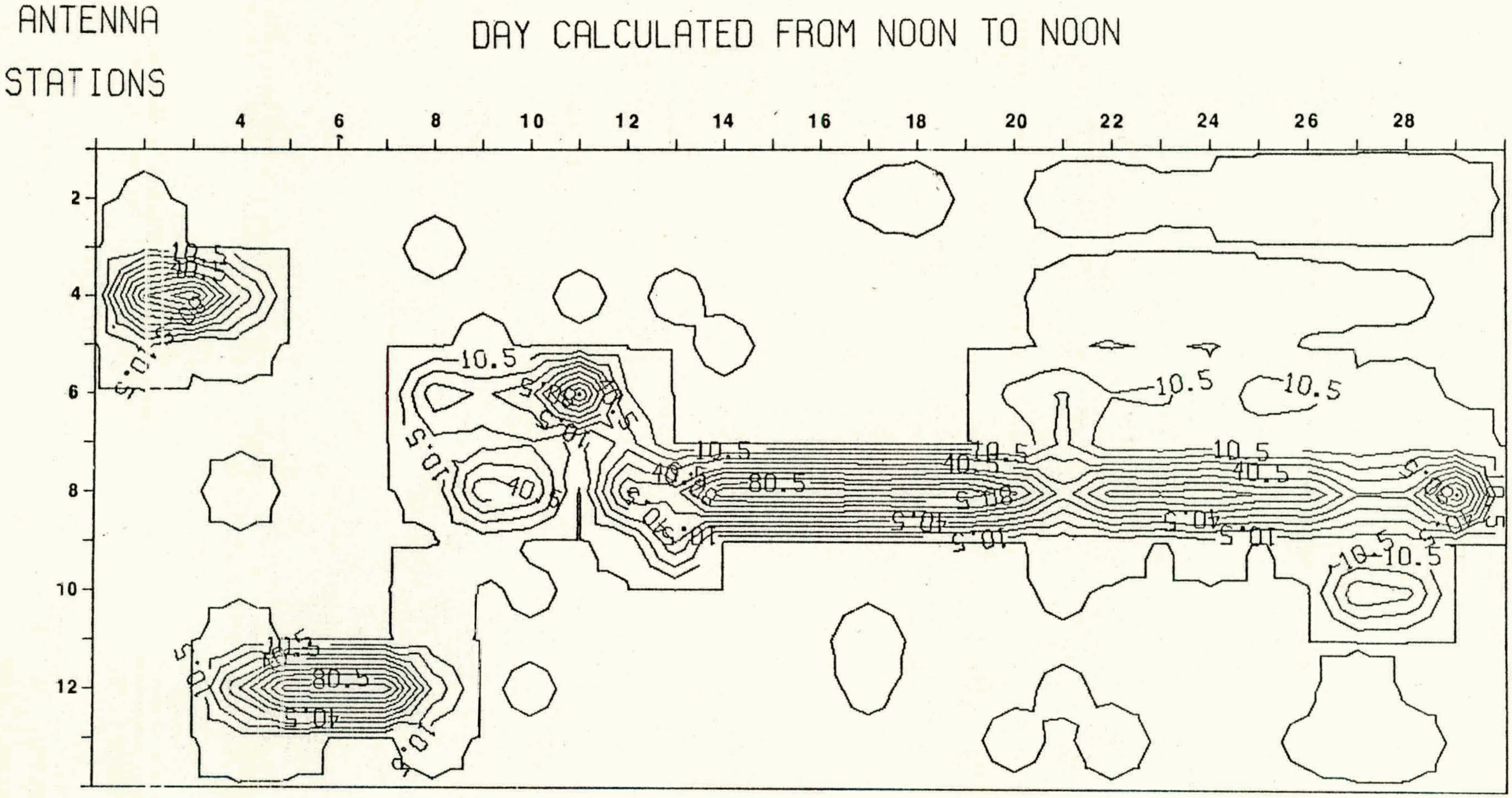


Figure 8.

Contour map of the percent of location determinations in a 24 hour time period occurring in each pool or riffle for walleye 4038 (606 gms, 41.0 cm).

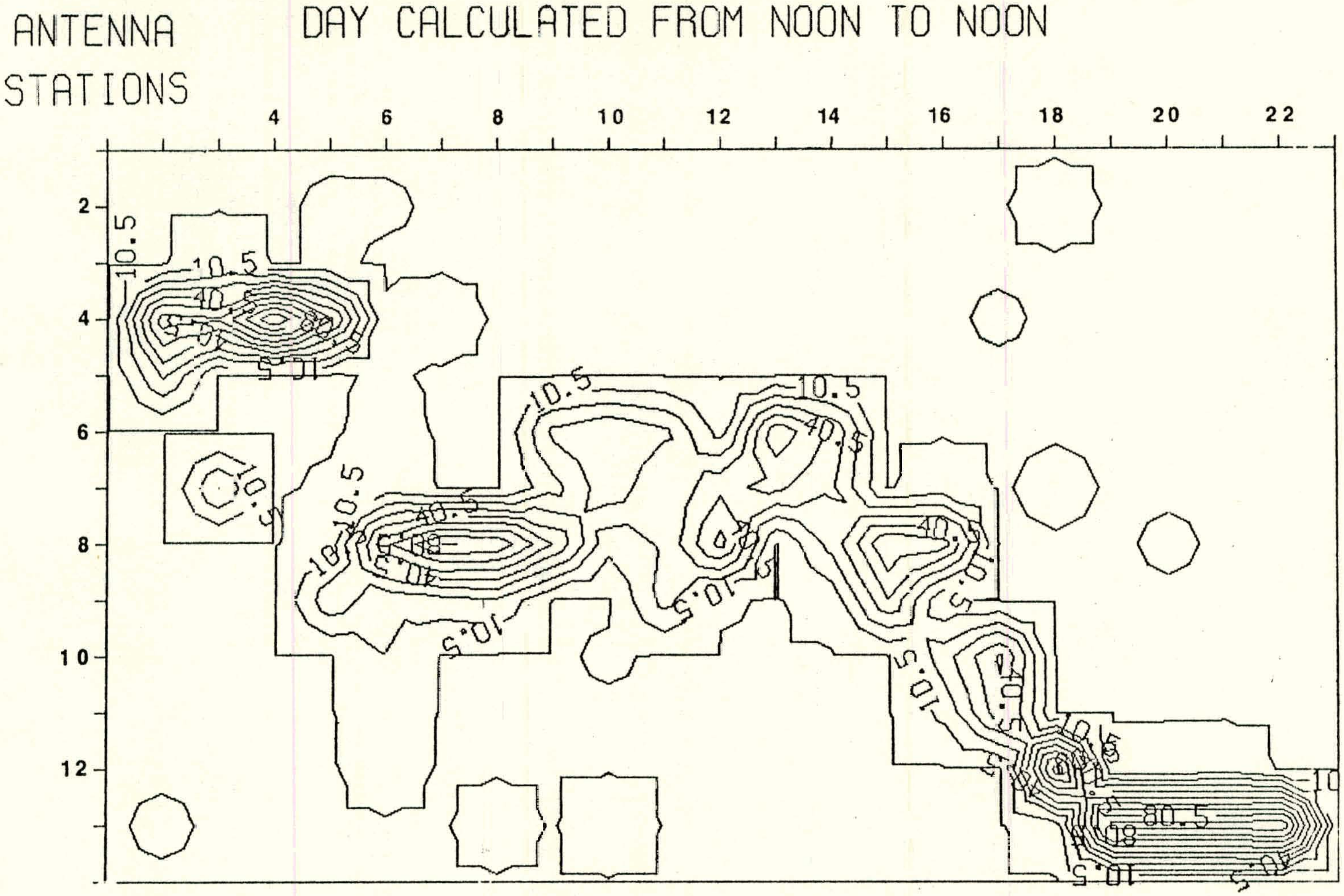


Figure 9.

Contour map of the percent of location determinations in a 24 hour time period occurring in each pool or riffle for walleye 4039 (532 gms, 40.9 cm).

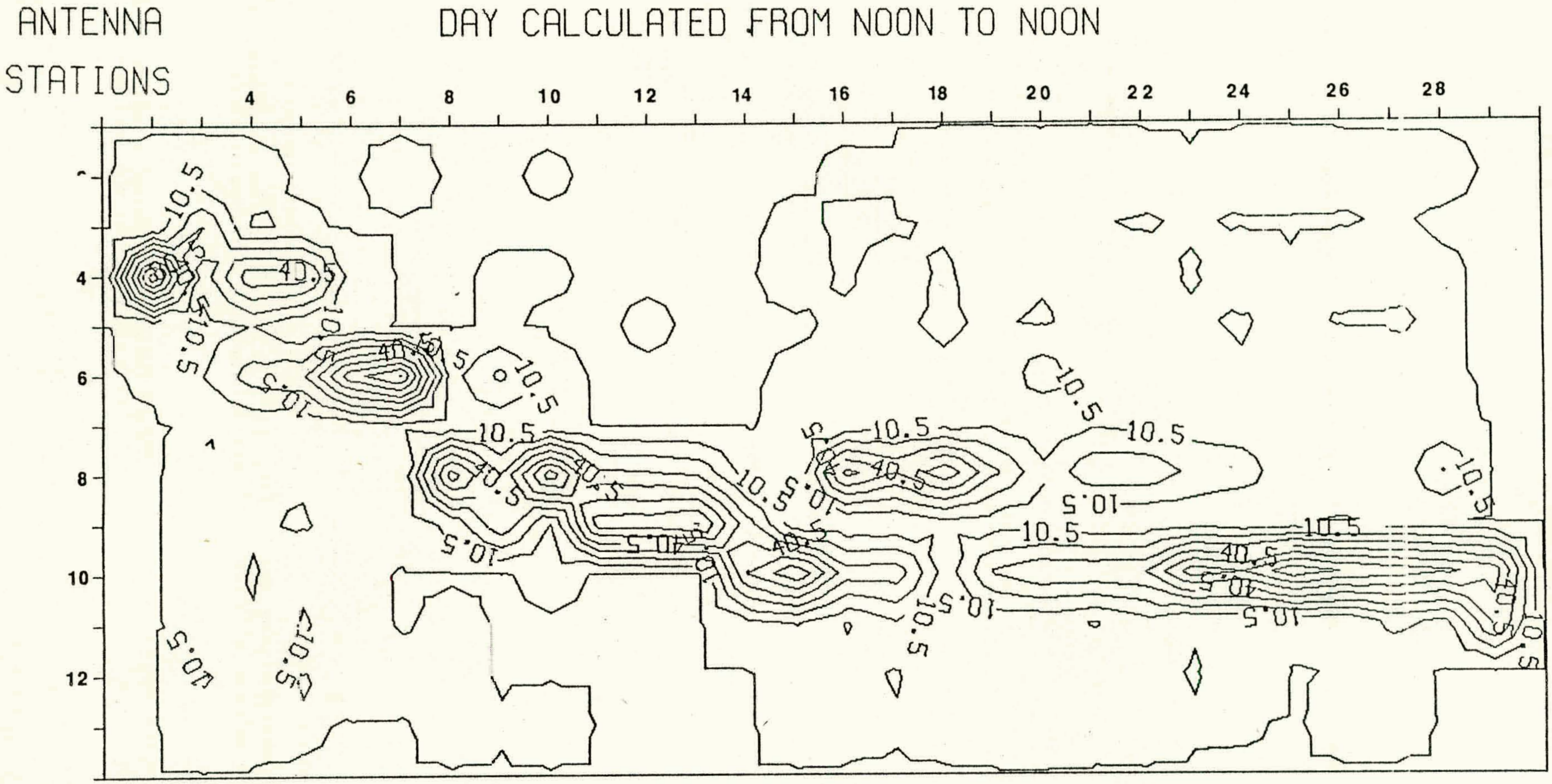


Figure 10.

Contour map of the percent of location determinations in a 24 hour time period occurring in each pool or rifflr for walleye 4040 (649 gmd, 42.0 cm).

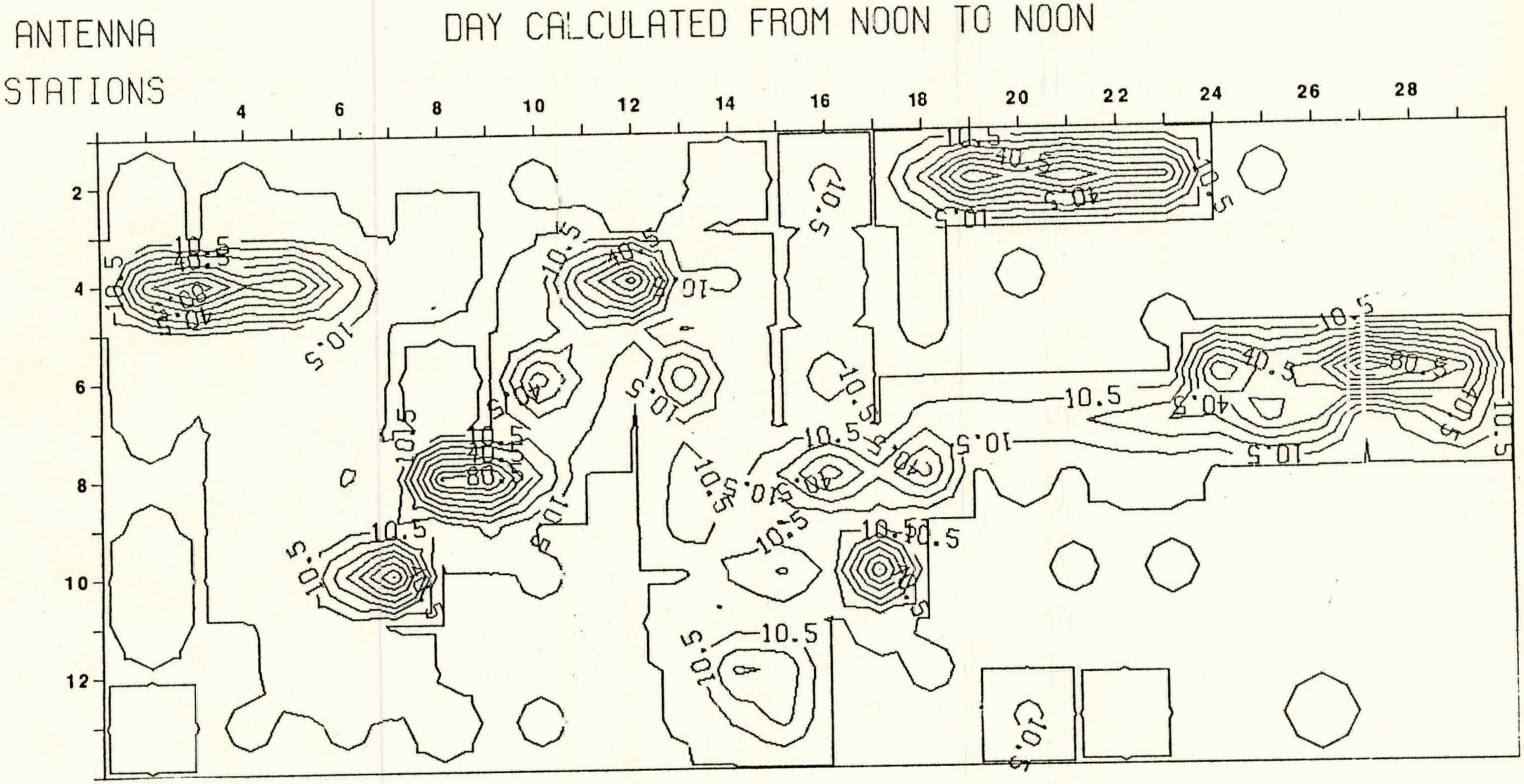


Figure 11.

Contour map of the percent of location determinations in a 24 hour time period occurring in each pool or riffle for walleye 4C41 (580 gms, 40.5 cm).

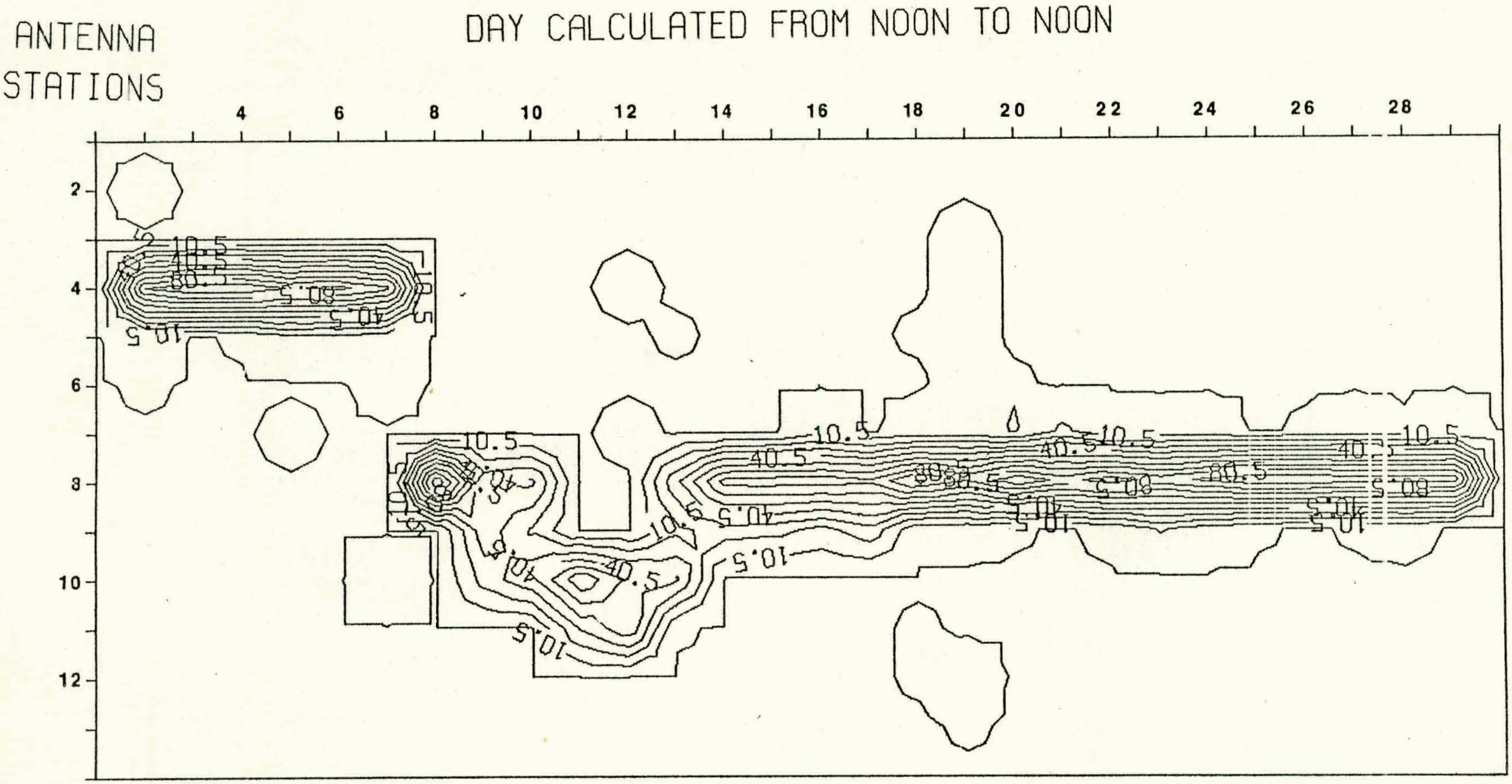


Figure 12.

Contour map of the percent of location determinations in a 24 hour time period occurring in each pool or riffle for walleye 4042 (567 gms, 40.6 cm).

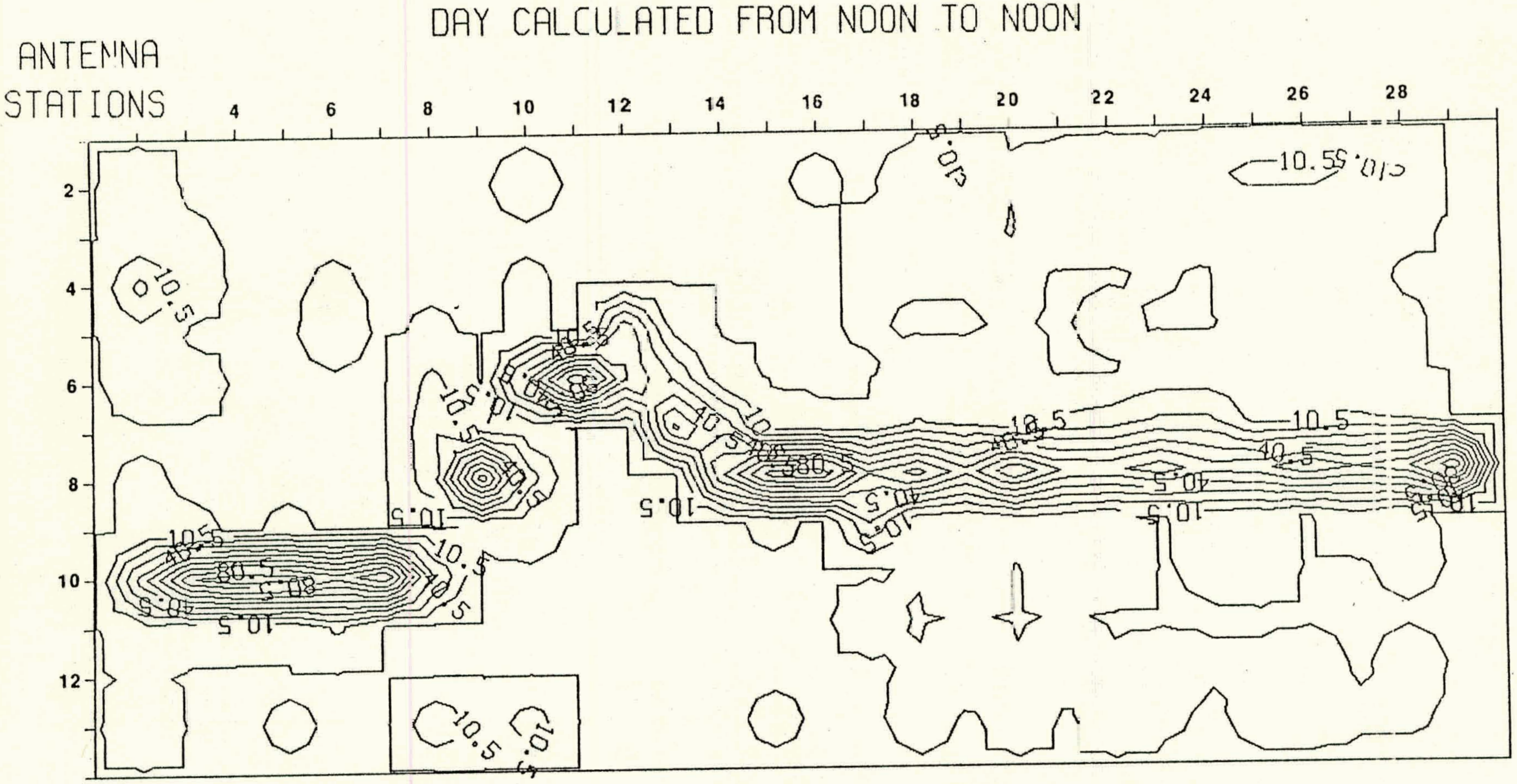


Figure 13.

Contour map of the percent of location determinations in a 24 hour time period occurring in each pool or riffle for walleye 4043 (1116 gms, 49.3 cm).

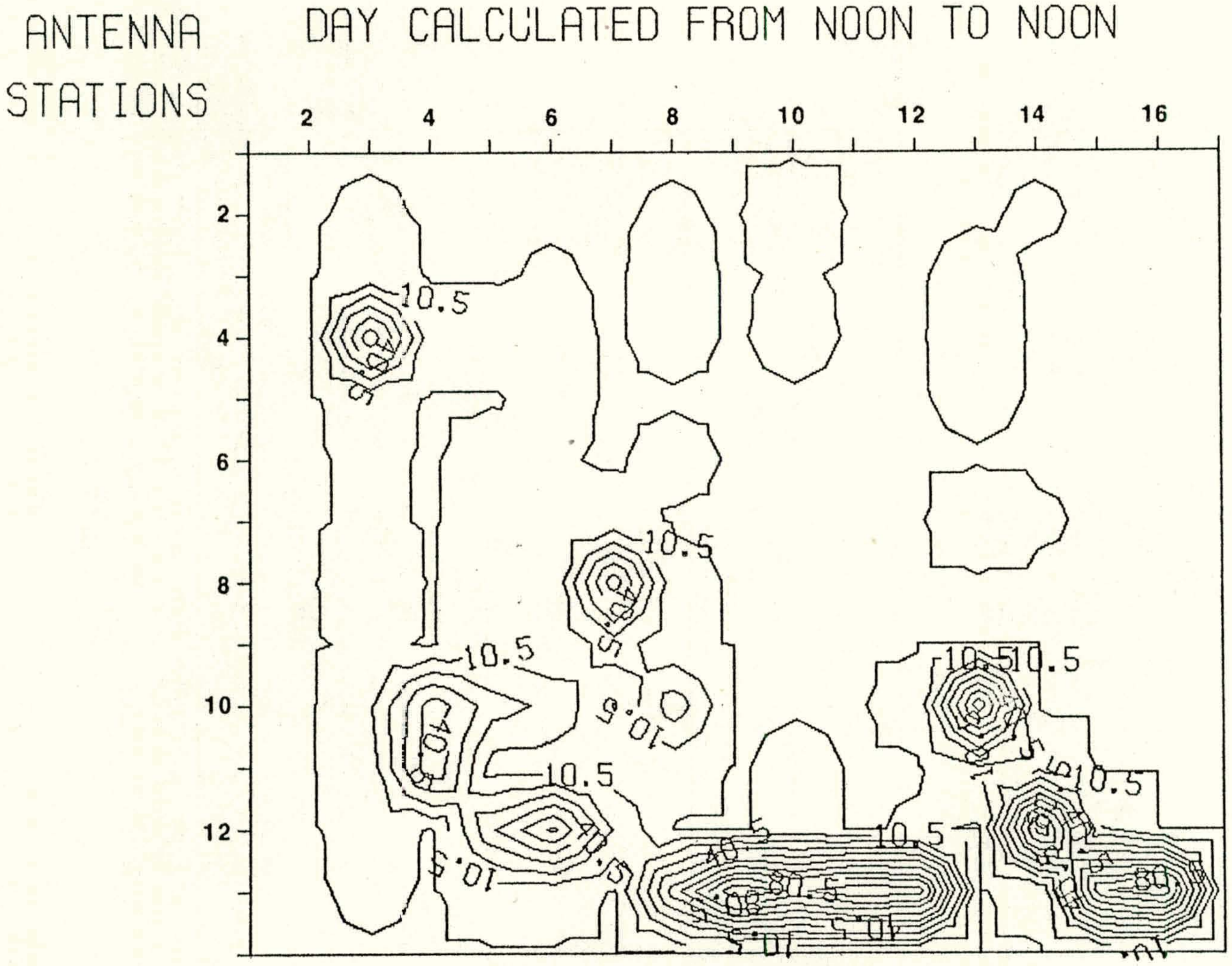


Figure 14.

Contour map of the percent of lacation determinations in a 24 hour time period occurring in each pool or riffle for walleye 4044 (696 gms, 44.0 cm).

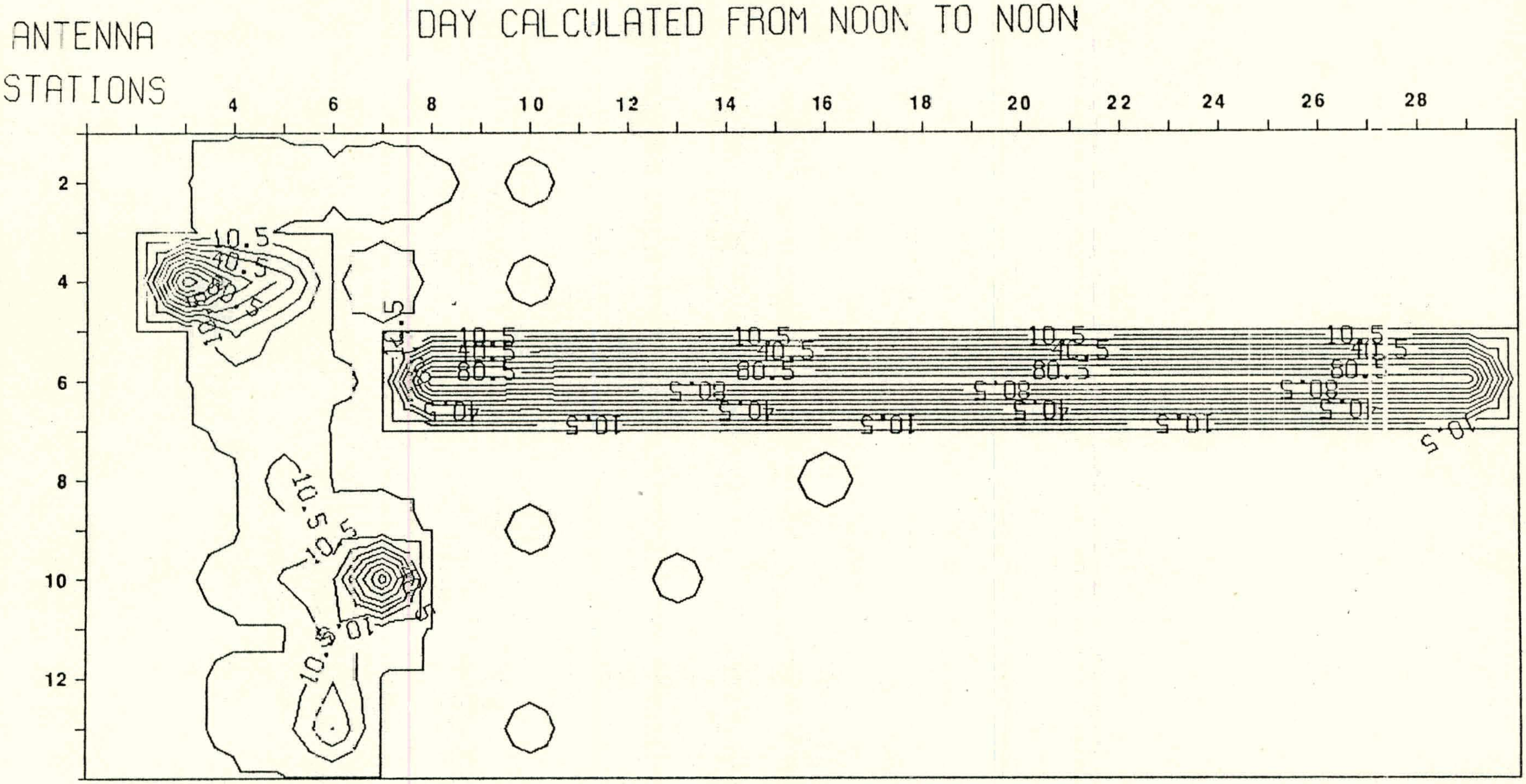


Figure 15.

Contour map of the percent of location determinations in a 24 hour time period occurring in each pool or riffle for walleye 4045 (581 gms, 41.5 cm).

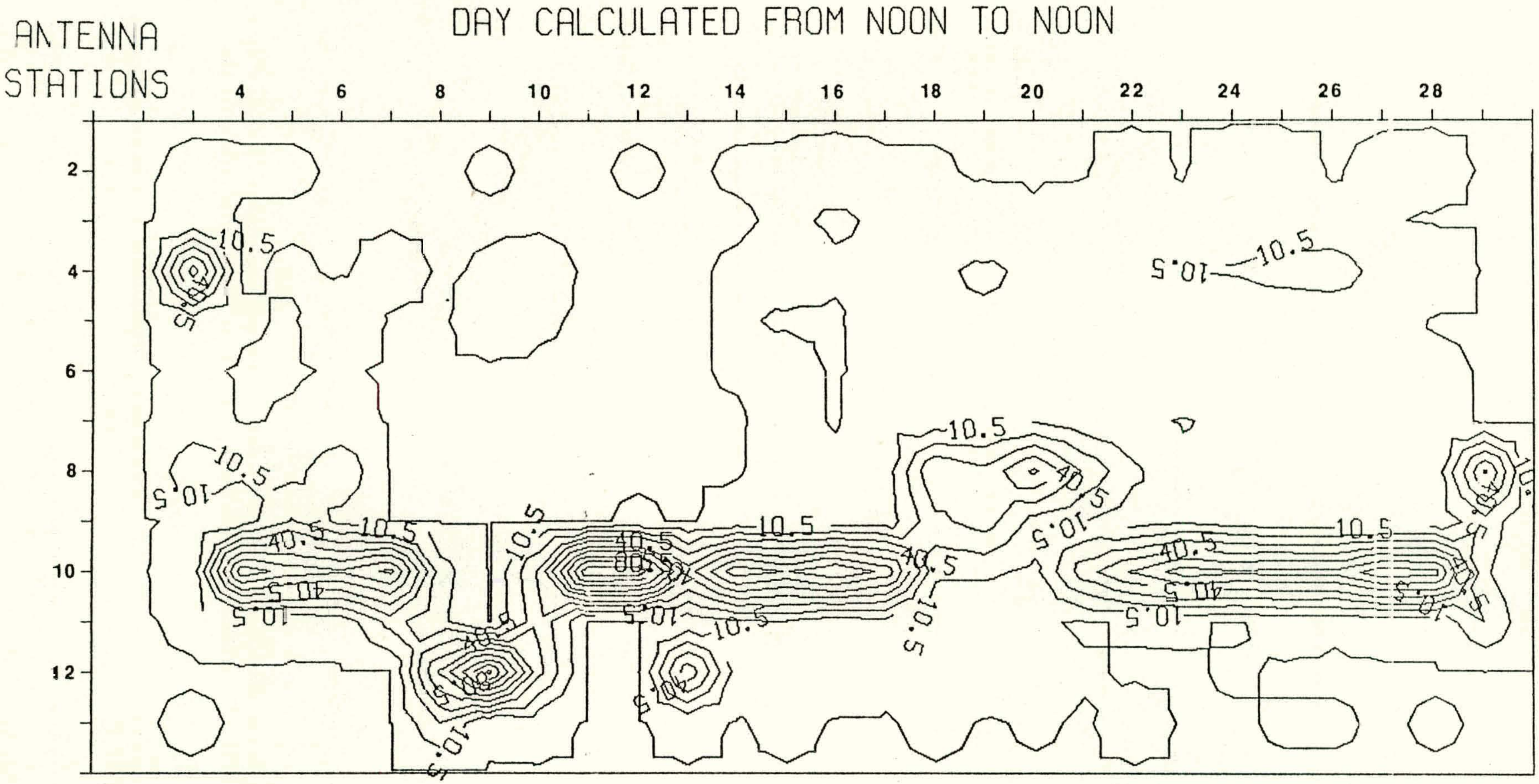


Figure 16.

Contour map of the percent of location determinations in a 24 hour time period occurring in each pool or riffle for walleye 4046 (916 gms, 48.3 cm).

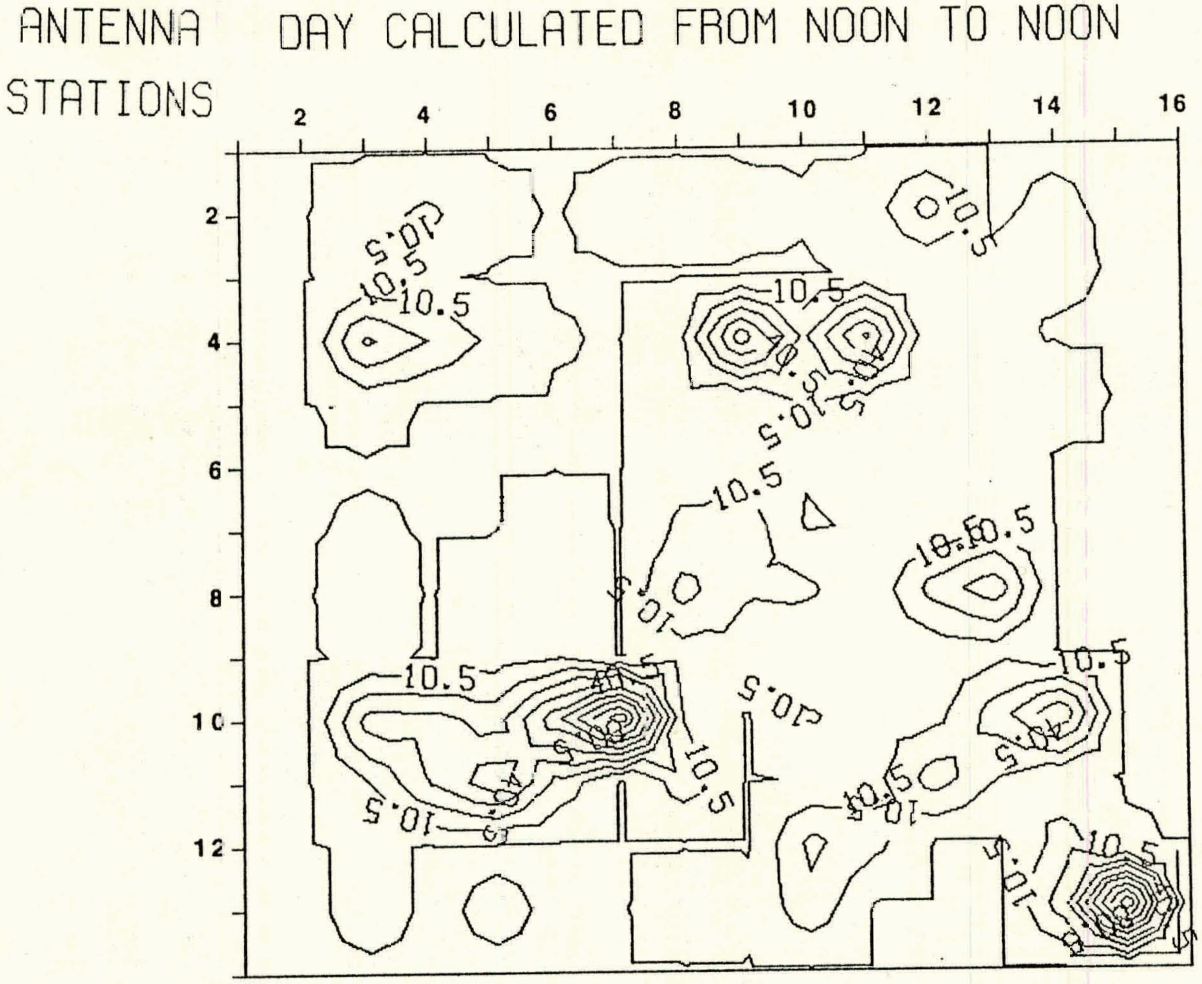


Figure 17.

Contour map of the percent of location determinations in a 24 hour time period occurring in each pool or riffle for walleye 4047 (841 gms, 46.9 cm).

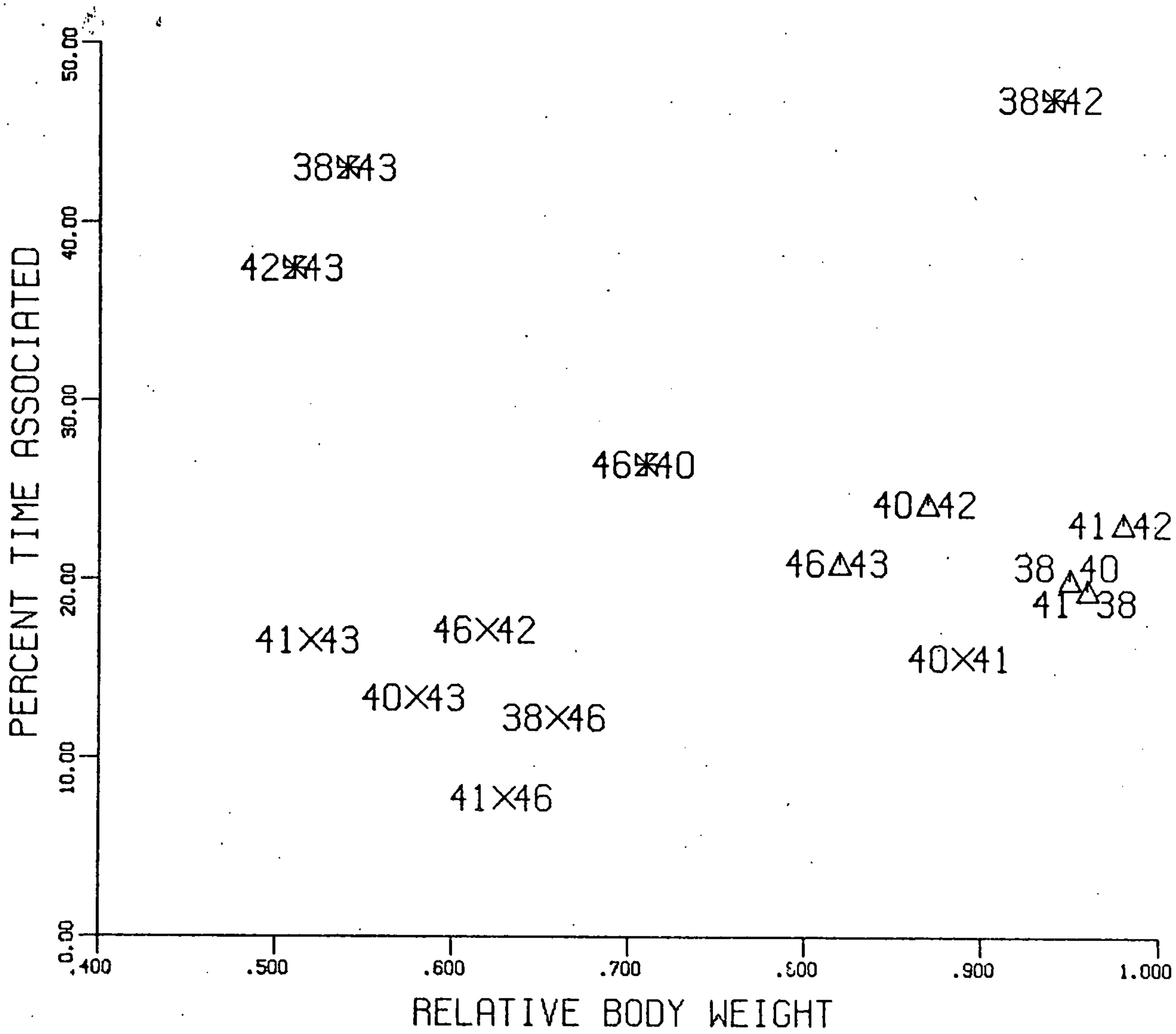


Figure 19. Percent of time pairs of survivor walleyes spent in the same pool or riffle versus their body-weight ratio.

usage category. Reference transmitters are not expected to show movement whereas the random noise on the open channels fluctuates widely, frequently simulating movement.

As shown in Table 7, movements by walleyes do not show the same temporal pattern of distribution as either reference errors simulating movement or open channel background noise interference detected as change of position. The patterns of simulated movements caused by reference errors indicate that no particular time-of-day was more error prone than any other. Contrasting walleye movements with open channels demonstrates a walleye preference for nocturnal activity whereas noise on the open channels simulates a constant high frequency of movement at all times of the day.

In addition to the temporal distribution, another technique for analyzing movement involves comparing the intensity or frequency of changes in position as reported by MRSS. For this reason, an analysis of covariance of the number of stations that fish moved by 4-hour period was performed with the signal level of distinctness and the date (expressed as elapsed hours) as covariates. The grand mean of the 14207 fixes used was .5 stations, which is roughly equivalent to 18.5 meters. Table 8 summarizes average distance moved by each walleye and Table 9 averages movement by time of day for the same 6 fish from least to most movement. Overall, the variation between the intensity and frequency of movements by individual fish was not significant.

Time of day had a significant effect on movement as the two major periods of activity shown by the raw data were post sunset and

Table 7. Percent of total fixes during the specified time period that represent or simulate changes in position.

	Usage Category		
Time	Walleyes	Reference	Open channels
2000-2359	30.3	2.2	25.1
0000-0359	23.5	3.0	23.6
0400-0759	16.0	1.5	24.8
0800-1159	11.6	2.3	28.3
1200-1559	13.8	2.5	34.4
1600-1959	12.9	1.6	28.1

Table 8. Comparison of movement intensity for individual survivor walleyes.

Fish	Size Rank	Average Movement (meters)
4042	6 (567 gms)	9.6
4038	4 (606 gms)	12.7
4041	5 (580 gms)	13.6
4043	1 (1116 gms)	18.3
4040	3 (649 gms)	18.9
4046	2 (916 gms)	19.5

Table 9. Composite temporal pattern of movement intensity for survivor walleyes.

Time of day	Average Movement (meters)
1200-1559	9.0
1600-1959	9.6
0800-1159	9.9
0400-0759	14.3
0000-0359	22.3
2000-2359	28.2

pre-dawn, as previously reported for walleyes by Kelso (1976). In addition, there was a very significant effect for the covariate, signal level of distinctness, but not for elapsed time. As determined by manual accuracy checks, when the fish are near the extreme ends of the pools, the signals can often be picked up better by the neighboring riffle antennas. However the signal levels are lower than if the fish had actually been in the riffle.

An analysis of covariance was also done on the number of stations moved with time of day and direction of movement as explanatory variables and the elapsed time in hours as covariate. There was no significant effect for time of day or elapsed time affecting direction of movement as it affects frequency and intensity of movement. Ryder (1977) reported observing most schools of walleyes oriented with their heads facing upstream. When disturbed they would often swim or drift rapidly downstream, then gradually work their way back upstream to their original position in the current or eddy. The equivalent number of cases in complementary categories of movement types from Table 10 confirms this same pattern of behavior from the experimental walleyes. Moreover, Table 10 indicates walleyes usually move from pool to pool as the modal value for the number of stations moved is consistently 2. In summary, although movement appears continuous at a low level, telemetry has been used to demonstrate that walleyes in an experimental channel situation exhibit diel periodicity with respect to changes of position.

Table 10. Analysis of direction of movement for 3 successive locations no more than 30 minutes apart for all walleyes.

Move type category	N of cases	Av. # of stations moved
Stationary	17,108	0
Isolated move north	878	2.41
Isolated move south	798	2.18
North-North	282	2.38
South-South	255	2.54
South-North	771	2.46
North-South	788	2.97

Correlation of Walleye Movement and Light

Since the major environmental factor of interest at Monticello was light, this experiment focused on fish movements with respect to total light available and the rate of change of light intensity. During most of the field testing, a Lambda Quantum Sensor (190-M) was used to detect total incident solar radiation. Units of light (23.4 langleys) incoming during the previous hour were recorded by a Lambda voltage integrator (L1-550). For purposes of this analysis, total incident sunlight and rate of change at sunrise and sunset were calculated on a daily basis (Figure 7).

Muntz & Wainwright (1978) reported that light of short wavelengths and long wavelengths affect fish habitat conditions differently. Downwelling light intensity was strongly correlated with incident sunlight (short wavelengths); attenuation of downwelling light was strong in water discolored by suspended mud. At the surface with long wavelengths (i.e. sunset and sunrise) there was more upwelling light than on even the clearest of days at noon. This was presumably caused by the high degree of backscatter from suspended material. Short wavelengths attenuate quickly, not penetrating beyond a depth of 0.6 meters (Muntz & Wainwright 1978). Because of the varying transmission of light through the water at Monticello (Figure 6), a non-linear relationship, such as a threshold effect, was indicated in the relationship between activity phasing and light. The tapetum lucidum in walleyes (Underhill & Eddy 1974), an adaptation for visual perception in dim light, results in scotopic vision permitting nocturnal activity (Ryder 1977) at levels of illumination insufficient for percids with photopic vision such as yellow perch, Perca flavescens.

Under natural light conditions, activity maxima in crepuscular fish, such as Atlantic salmon (Salmo salar) and brown trout (S. trutta), are always closely related to dawn and dusk independent of season (Eriksson 1977). Variations in photic behavior among percids can probably be accounted for by differences in the structural organization of the eye. It is generally known that adult and sub-adult walleyes make crepuscular or nocturnal feeding forays on submerged boulder shoals, beds of macrophytes, or other shallow areas (Ali and Anctil 1977). Apparent diurnalism or nocturnalism in fish is thought to depend on the season (i.e., the distance between dawn and dusk) and the amount of activity appearing at either side of the daily light maximum and minimum (Eriksson 1977).

Feeding forays in 3 age classes of walleyes have been shown to be inversely proportional to ambient subsurface illumination, which in turn is governed by a variety of exogenous factors including turbidity, water color, wave action, and ambient illumination at the surface (Ryder 1977). In turbid lakes where transparency is at or below 2 m on a Secchi disc, feeding occurs throughout the day; but in clear water the sensitivity of the tapetum lucidum restricts feeding to dark periods (Scott and Crossman 1973). A pertinent question would be whether there is any indication of an endogenous timing component governing nocturnal rhythmic activity behavior, such as a pronounced onset and cessation of activity. As shown by data from 902 bullheads (Ictalurus nebulosus), only about 2% of all activity onsets take place before dusk and 40% of all activity ends before dawn for these nocturnal fish (Eriksson 1978).

When the data from Table 7 are arranged it so as to contrast light and dark periods, it appears that walleyes show a dichotomous pattern of movement behavior. These values are the percent of location determinations in the specified time period interpreted as changes in position and suggest a preference for nocturnal movement. It is also important to note that the walleyes used in this experiment were in spawning condition, which is thought to partially disrupt the negative phototaxis through hormonal changes initiated through photoperiodic control (Ryder 1977).

Spawning normally begins shortly after ice breakup (April-June) but is temperature dependent. Males move to the spawning ground before females but are not territorial and no nest is built. Spawning grounds are rocky areas in white water of streams or shoals of lakes with coarse gravel to boulder substrate. Spawning occurs at night in groups of one larger female with one or two smaller males, or two females and up to six males. Courtship behavior occurs prior to spawning but hatching success depends on dissolved

O_2 ($>$2 mg/l) with no parental care of the eggs or fry. Cannibalism occurs frequently and overall fry mortality is 99% (Scott & Crossman 1973). However no spawning could have occurred during field testing at Monticello because all the walleyes used were males.

Analysis of covariance was used to determine if there was significant temporal variation in movement versus resting behavior, using the antenna number (location) and the elapsed time (in hours) of the experiment as covariates. There was significant ($P < .001$) variation between treatments, allowing the conclusion that the usual period of morning activity is just before sunrise and the pronounced period of evening activity follows sunset (Table 11). This model showed a very good fit with r = .874. Neither covariate was significant, indicating no effect for location or sequence. The amount of movement on any given day for individual walleyes was highly variable but was approximately equally divided between clock phase (AM/PM) as shown by Figures 20 and 21.

To evaluate effects for light intensity, certain aggregate statistics were used in conjunction with analysis of variance procedures. First the average AM and PM time of location determination for each walleye were calculated on a daily basis. Although only the daily AM/PM averages for May 4 through May 24th were later used, Figures 22-27 show the composite times for surviving fish from May 3rd through May 27th as hexagon symbols.

Table 11. Frequency and average time of occurrence for location determinations classified according to clock phase and behavior using data for six survivor walleyes.

Treatment	N of cases	CST
A.M. Resting	5599	0607
A.M. Movement	1378	0432
P.M. Resting	5695	1732
P.M. Movement	1535	1907

After the average AM time of activity, AM time of resting, PM time of activity, and PM time of resting were calculated on a daily basis, the response variables, i.e. offsets, were computed by subtracting each AM/PM average time of activity or resting from that day's corresponding AM or PM average time of location determination. Since the standard deviations for all fish in each "offset" category were very similar, the daily averages were used for offset calculation without weighting factors in subsequent analysis (Table 12).

Figures 22 through 27 show all the values used for calculating offsets from the average AM or PM time of location determination for activity and resting behavior. The hexagons represent the average daily time of location determination for the morning or the afternoon period. The "propellor" symbols locate the average time of movement for each 12 hour period and triangles describe the average time of resting for the same period. The distance separating the triangles and hexagons is directly proportional to the amount of movement occurring during that period.

Generally, activity offsets were displaced towards midnight and the resting offsets were displaced towards noon. As May progressed, the offsets became further apart. However, there was much more variation in activity offsets than in resting offsets, and not all fish were active every period. One of the significant explanatory variables was thought to be the rate of change of light at sunset

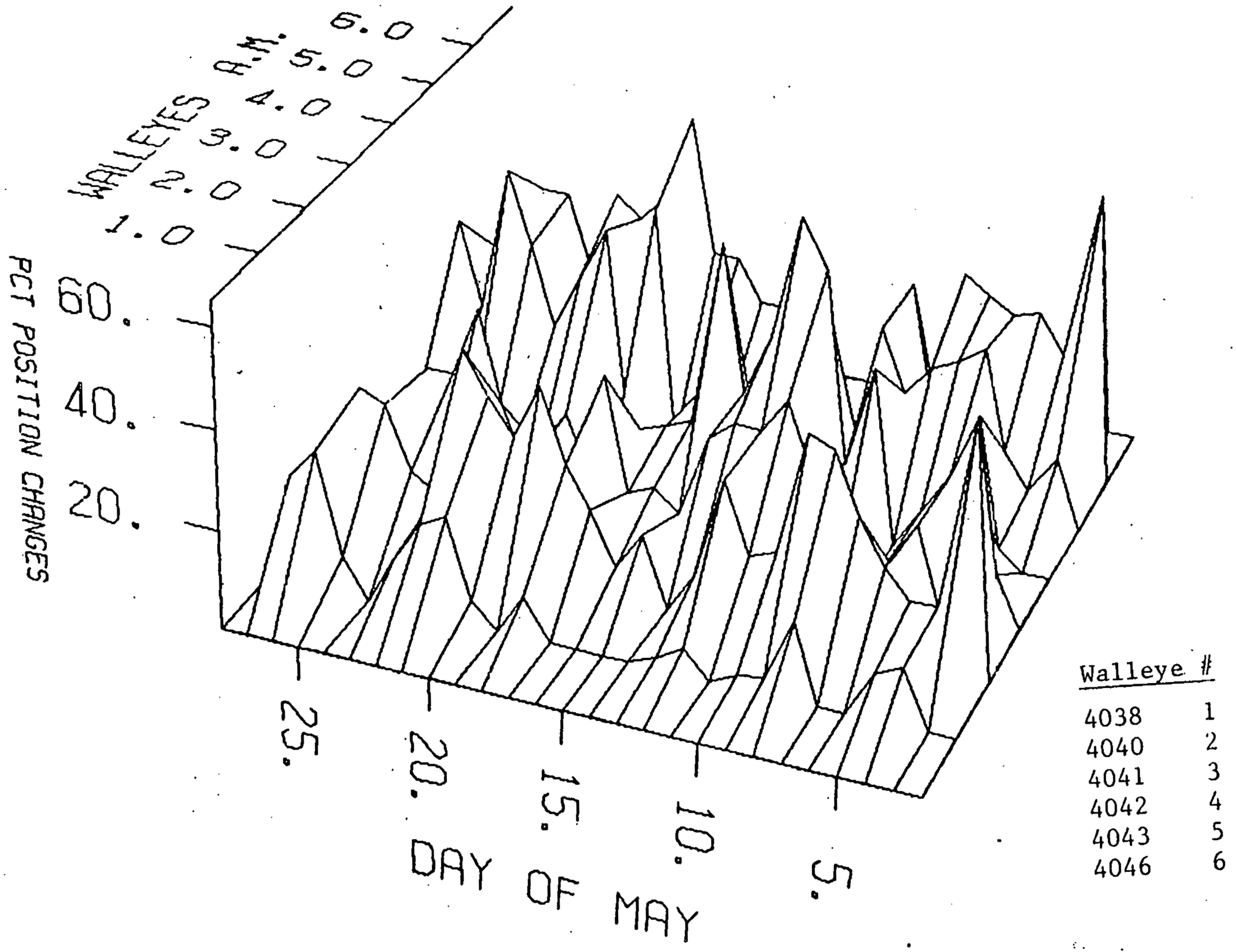


Figure 20. Daily relative occurrence of movement from-0000 to 0600 for the six survivor walleyes.

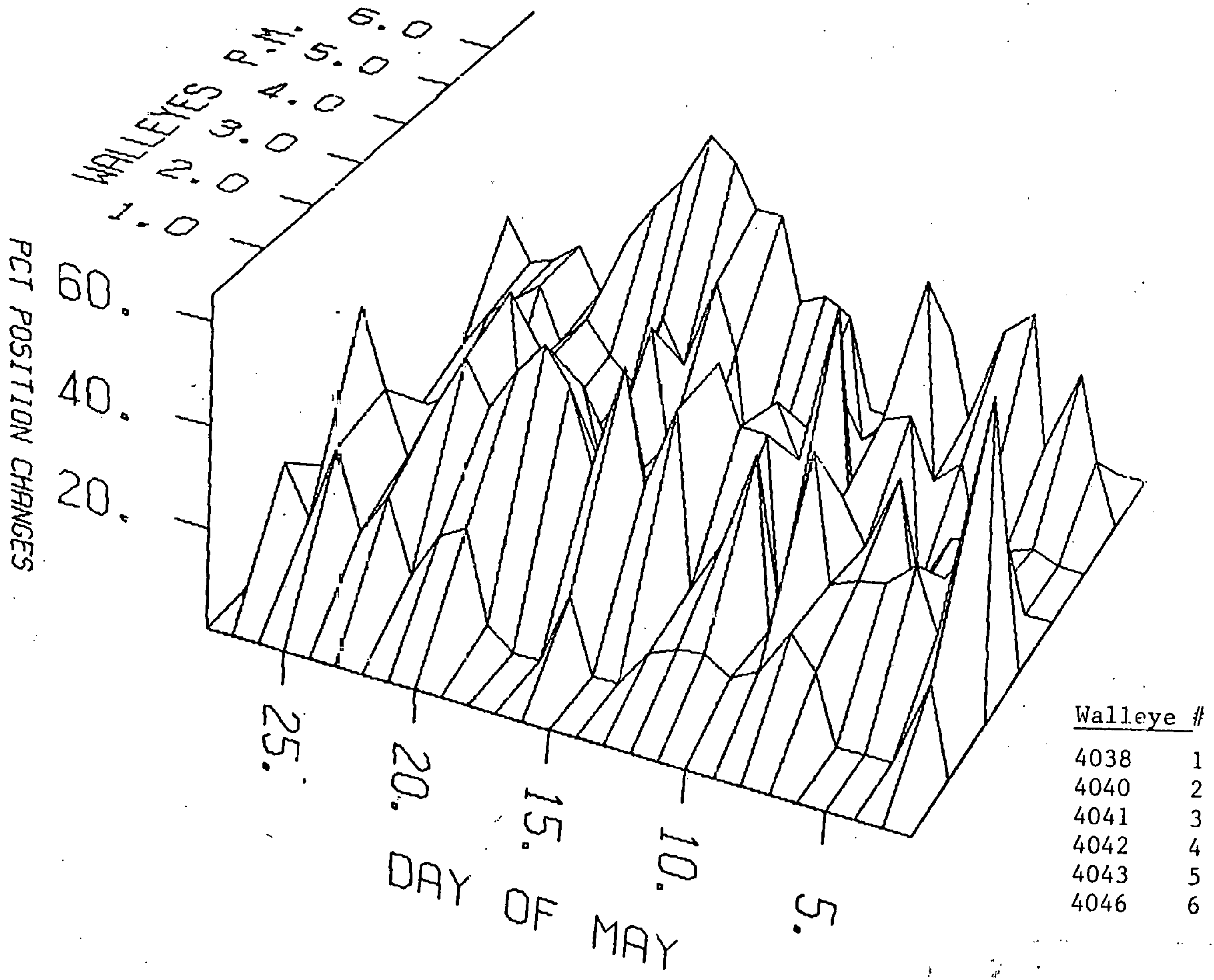


Figure 21. Daily relative occurrence of movement from 1800 to 2400 for the six survivor walleyes.

Table 12. This table demonstrates the homogeneous variance [S.D.] expressed in minutes around the average daily time of resting or activity. The number of cases in each category is in parenthesis.

	AM RESTING	AM ACTIVITY	PM RESTING	PM ACTIVITY
4038	203.751(920)	193.359(88)	204.055(877)	217.031 (105)
4040	200.949(919)	201.256(282)	196.890(858)	201.560 (398)
4041	203.238(992)	211.782(212)	203.199(992)	209.628 (265)
4042	207.576(1008)	197.699(194)	205.053(1061)	204.938 (197)
4043	205.141(919)	206.832(285)	200.742(1039)	196.984 (216)
4046	197.026(841)	191.598(317)	192.988(868)	203.615 (354)

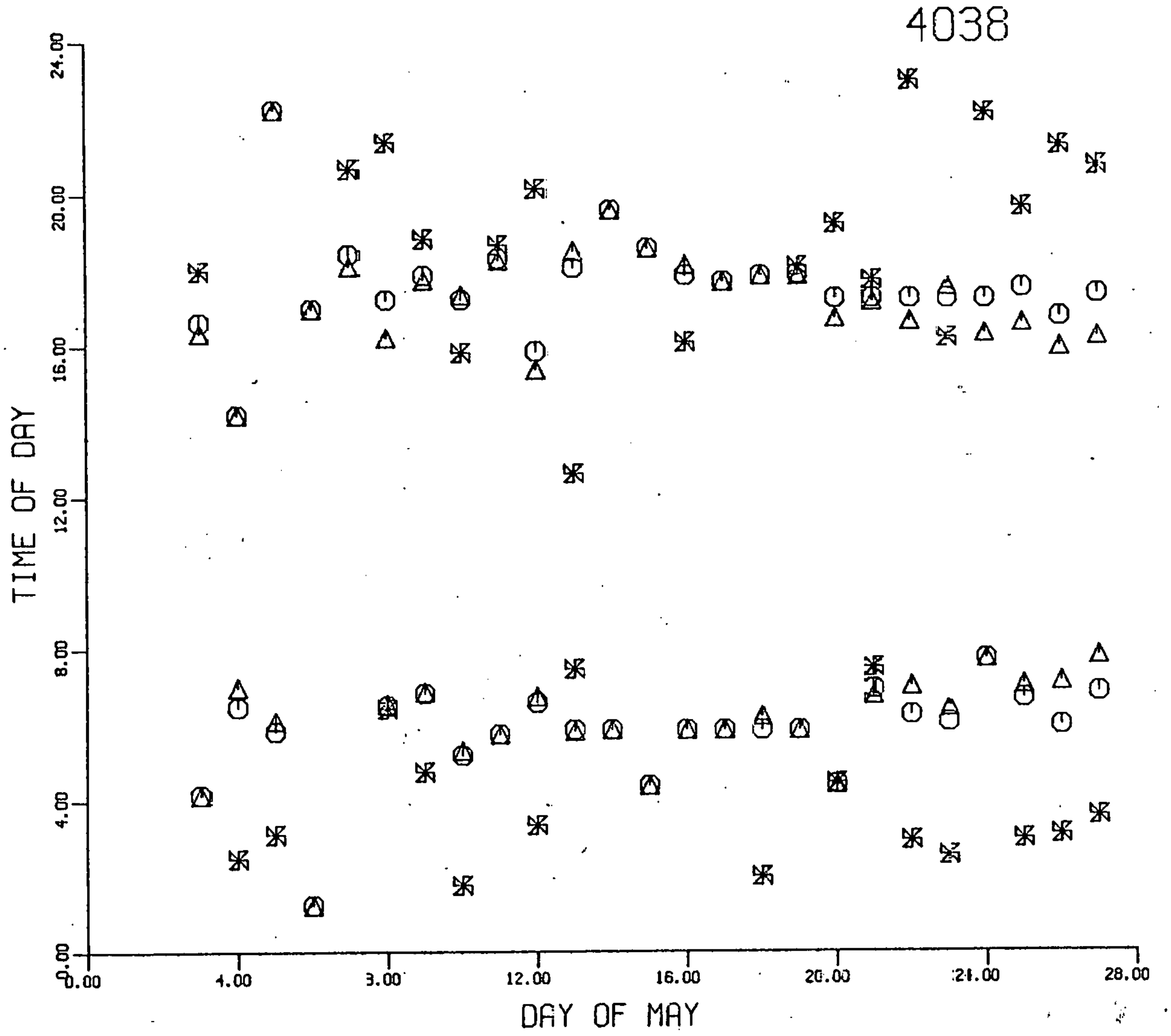


Figure 22. Movement and resting behavior for survivor walleye 4038. Hexagons represent the average time for all location determinations in a 12 hour period. Triangles represent the average time for resting fixes and propellor symbols define the average time for movement. The distance separating the triangle and hexagon is proportinal to the # of position changes.

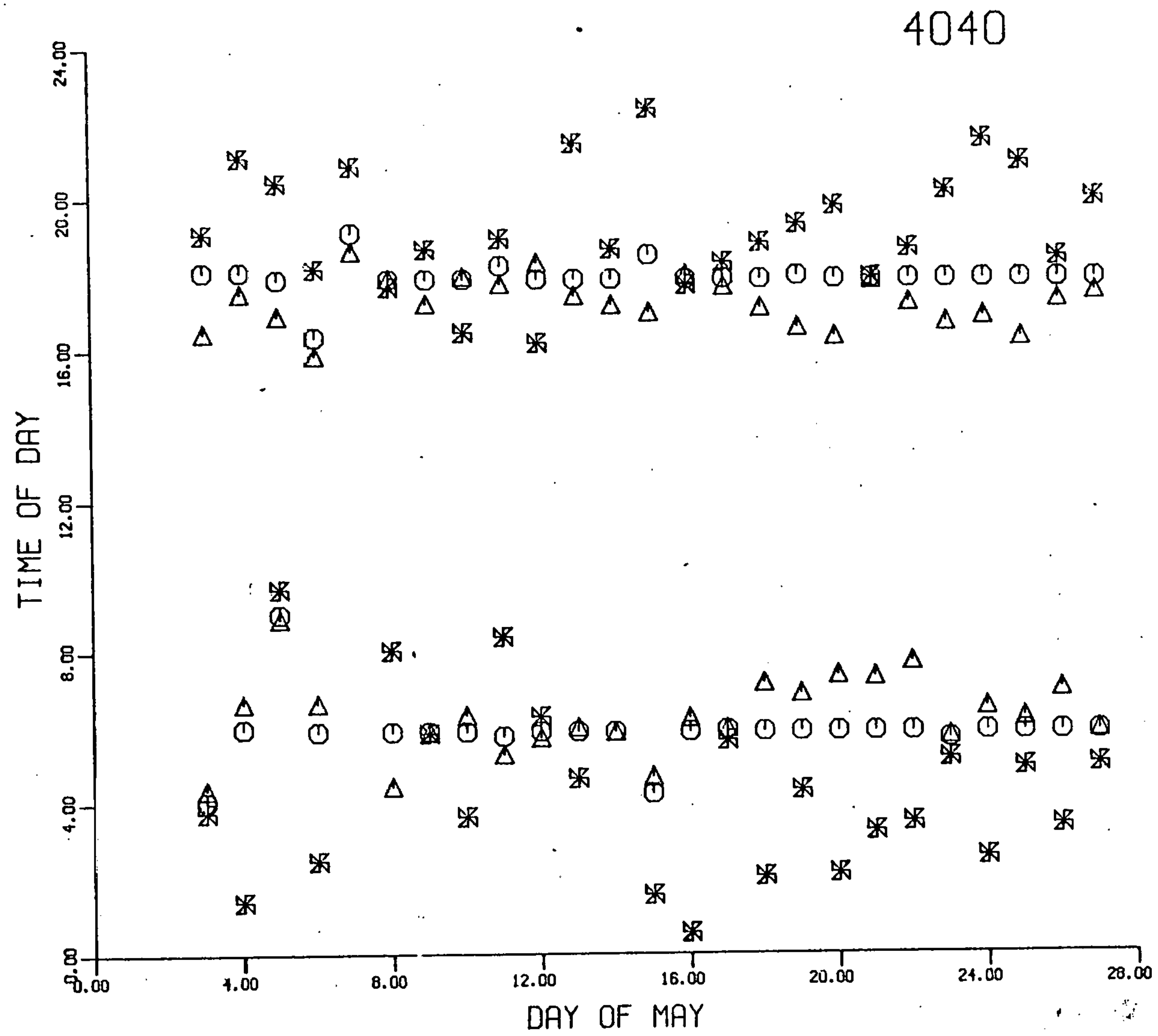


Figure 23. Movement and resting behavior for survivor walleye 4040. Hexagons represent the average time for all location determinations in a 12 hour period. Triangles represent the average time for resting fixes and propellor symbols define the average time for movement. The distance separating the triangle and hexagon is proportional to the # of position changes.

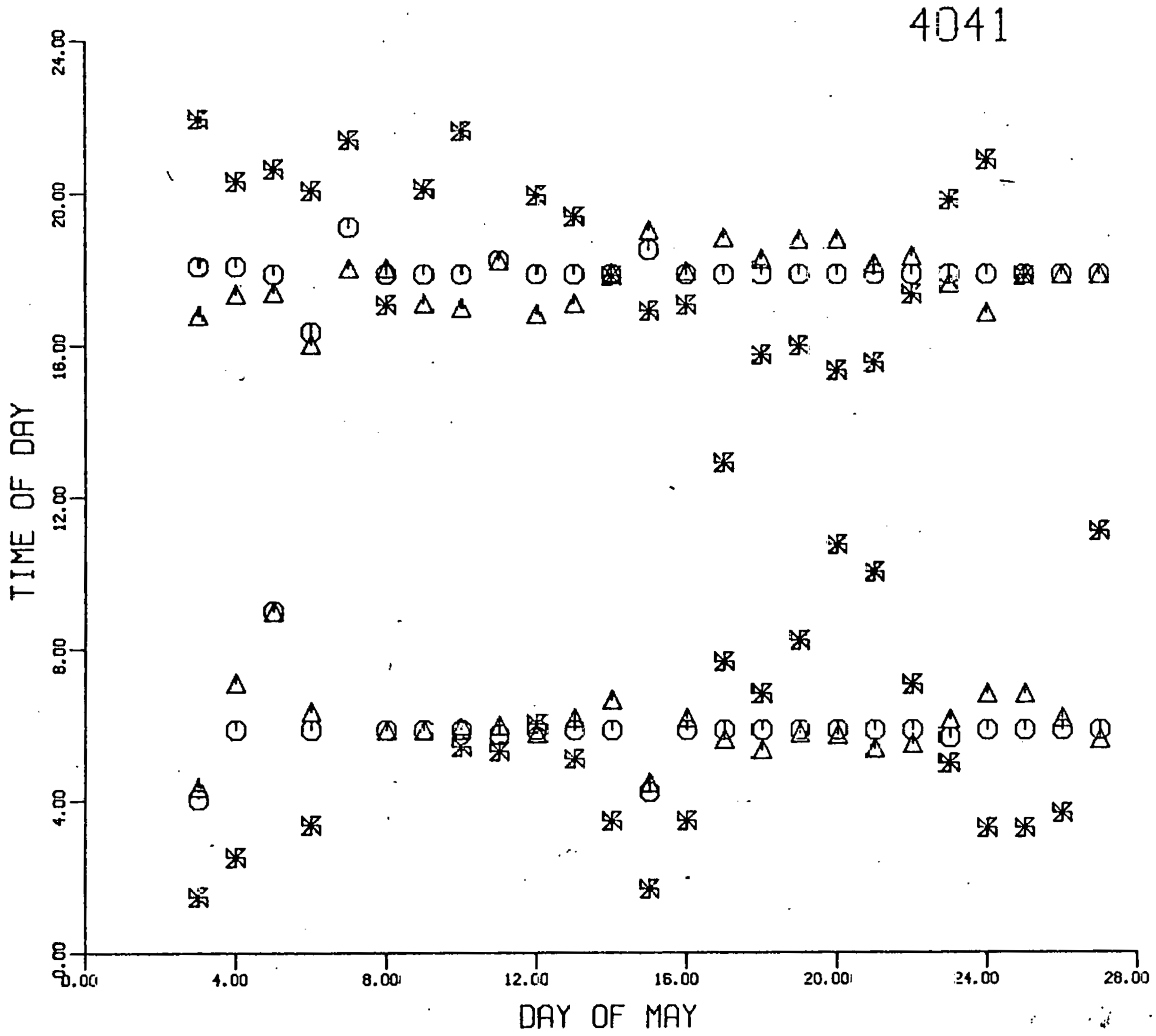


Figure 24. Movement and resting behavior for survivor walleye 4041. Hexagons represent the average time for all location determinations in a 12 hour period. Triangles represent the average time for resting fixes and propellor symbols define the average time for movement. The distance separating the triangle and hexagon is proportional to the # of position changes.

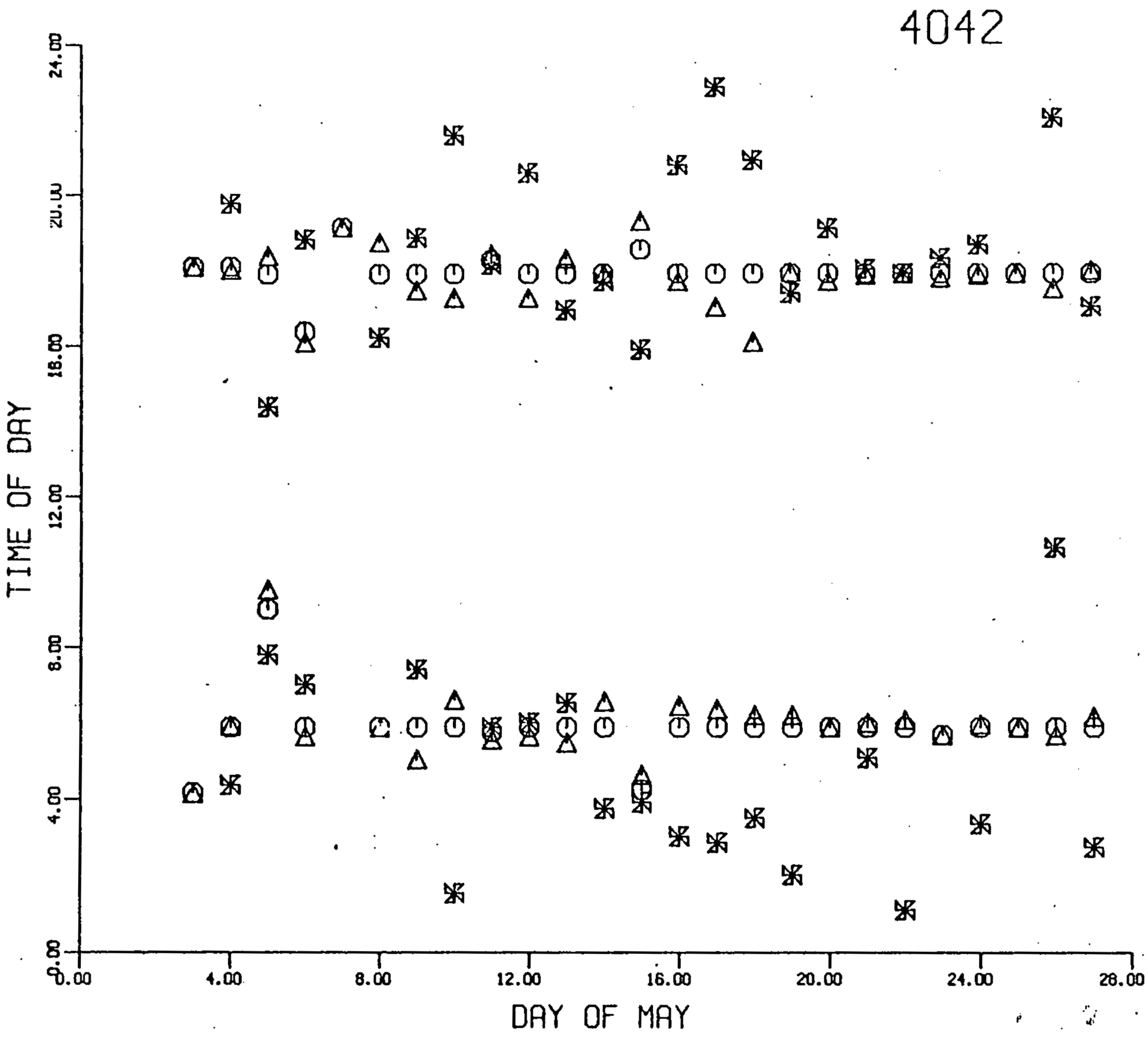


Figure 25. Movement and resting behavior for survivor walleye 4042. Hexagons represent the average time for all location determinations in a 12 hour period. Triangles represent the average time for resting fixes and propellor symbols define the average time for movement. The distance separating the triangle and hexagon is proportional to the # of position changes.

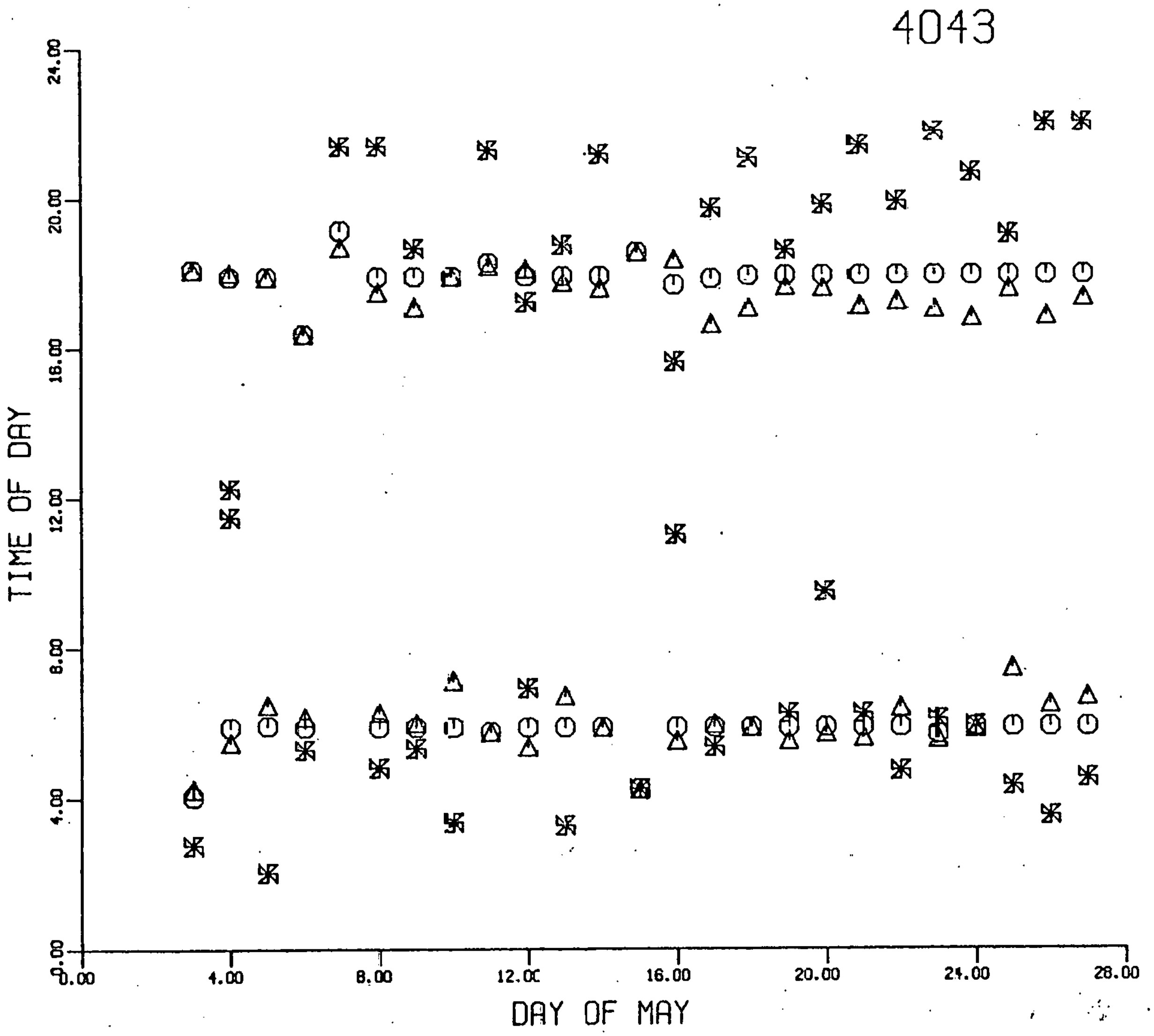


Figure 26. Movement and resting behavior for survivor walleye 4043. Hexagons represent the average time for all location determinations in a 12 hour period. Triangles represent the average time for resting fixes and propellor symbols define the average time for movement. The distance separating the triangle and hexagon is proportional to the # of position changes.

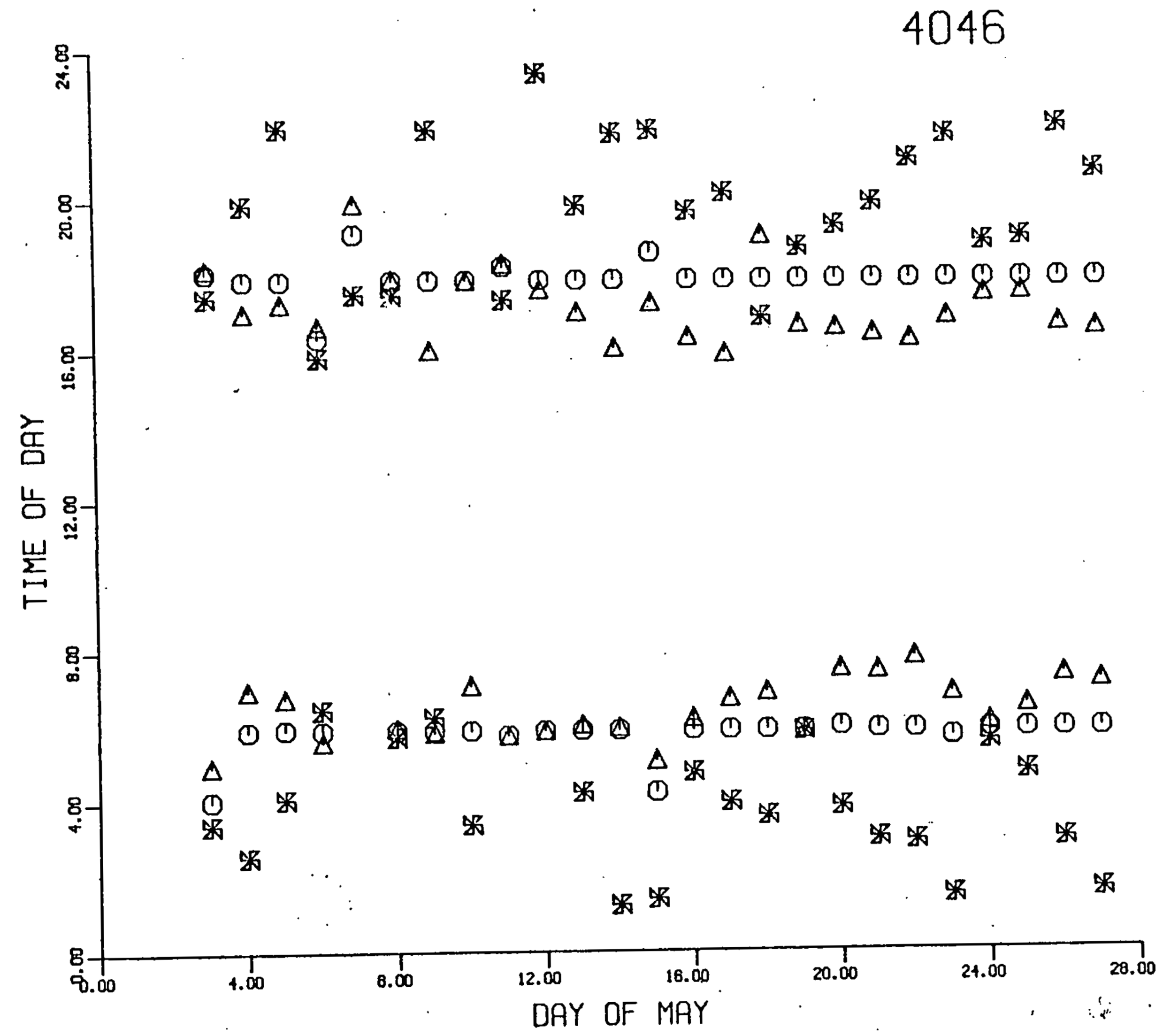


Figure 27. Movement and resting behavior for survivor walleye 4046. Hexagons represent the average time for all location determinations in a 12 hour period. Triangles represent the average time for resting fixes and propellor symbols define the average time for movement. The distance separating the triangle and hexagon is proportional to the # of position changes.

which increased as May progressed (Figure 7). For some walleyes a high rate of change of light at sunset, appeared to correlate with a larger displacement of the evening activity center towards midnight. Also, when the previous day's total incident sunlight was high, the following morning's activity center appeared to be shifted more towards midnight. However, the amount of total sunlight received in a day apparently had no effect on that afternoon's resting offset or the same evening's activity offset.

Initially, one-way analysis of variance was done for individual factors (Table 13), to decide on the forms of the models subsequently tested by analysis of covariance procedures (Tables 14 and 15). A one-way anova of the morning resting offset by calendar date seemed to indicate a significant non-linear component, but the Student-Newman-Keuls procedure ($\alpha = .05$) described the morning resting offsets on all 21 days as falling in the same homogeneous subset. The corresponding one-way anova of morning activity offset by calendar date had no significant terms, and the Student-Newman-Keuls procedure ($\alpha = .05$) again determined all days as part of the same homogeneous subset. The one-way anovas for the evening resting offset and activity offset followed the same pattern as for the morning offsets. There appeared to be no significant variation in these temporal happenings, suggesting an endogenous timing mechanism. MRSS would be extremely useful in a laboratory situation where movements could be detected and recorded under total light or total dark regimes to test this type of hypothesis.

Table 13. The following list defines the factors which were tested with analysis of covariance procedures for having an effect on activity or resting behavior.

LABEL	USAGE*	DEFINITION
DAY	CAT	Day of May 1979
FISH	CAT	Individual survivor walleyes
PPMOSAC	COV	Previous evening activity offset
PLIGHT	COV	Previous days incident sunlight
SLIGHT	COV	Total daily incident sunlight
DPM	COV	Rate of change of light at sunset
AMOSINA	COV	Morning resting offset
AMOSACT	COV	Morning activity offset
PMOSINA	COV	Evening resting offset
PMOSACT	COV	Evening activity offset
AM5toAM9	COV	Units of light incoming during the hour preceeding: 0500,0600, 0700, 0800, 0900
PM16toPM20	COV	Units of light incoming during the hour preceeding: 1600,1700, 1800, 1900, 2000

*CAT=categorical, COV=covariate

Variation in temporal movement patterns for individuals was also examined with one-way analysis of variance. There was significant variation in the morning resting offset ($F_{5,114} = 3.6$); $P <$ .0044. According to the Student-Newman-Keuls procedure ($\alpha = .05$), individual walleyes fall into 2 distinct homogeneous subsets with the large fish at opposite ends:

Atkin's # = 4046 4040 4041 4038 4042 4043
Weight in gms. = 916 649 580 606 567 1116

Considering the morning activity offset in the same manner, there is again significant variation between fish ($F_{5,114} = 2.8$); $P <$ .0199. Moreover, grouping fish into homogeneous subsets by the Student-Newman-Keuls procedure ($\alpha = .05$), the large walleyes again are distinctly different in behavior.

Atkin's # = 4043 4041 4038 4042 4046 4040
Weight in gms = 1116 580 606 567 916 649

One-way anova of the afternoon resting offset by individual fish showed significant individual variation ($F_{5,114} = 2.4756$); $P <$ .0358 at the $\alpha = .05$ level. However, according to the Student-Newman-Keuls procedure ($\alpha = .05$); all fish fall in the same homogeneous subset. There was no significant variation in the evening activity offset for individual fish ($F_{5,114} = 1.3396$); $P <$ .2523. Thus, all walleyes seem to initiate activity concurrently in the evening.

Results of the analysis of covariance models tested (Tables 14 and 15) indicate cyclic crepuscular patterns of movement. The significance of explanatory factors was tested at the $\alpha = .05$ level; each line in the table represents one model, with p-values in parenthesis. Since the lowest levels of movement occur during the daylight hours, it is logical to begin discussing the cycle with the PM resting offset. The resting that walleyes do from 1200-2359 each day is dependent upon when movement occurred that morning and the morning average time of resting; but there was significant variation among individual fish. There was no significant variation in the evening average time of movement for individual fish; all became active after sunset. Morning movement and resting offsets were found to be dependent upon the evening activity, implying that movement in the morning is inversely correlated with activity occurring the preceeding evening (Figures 20 and 21). Note that the total light incident during the day and the rate of change of light at sunset do not affect either resting or movement behavior from 1200-2359 on that day.

Morning (0000-1159) average time of movement or resting behavior varied significantly for individual walleyes. Total incident light for the previous day and the average time for the previous evening's movement activity were significant explanatory variables for both AM resting and activity offsets. Perhaps there may be a time delay for the running water system to react to the abiotic variation. It is known that photosynthesis causes daily variation in O_2, CO_2 and pH, whereas algal metabolic processes result in variation in the concentration of nitrate, phosphate, iron and silicon (Muller, 1978).

Table 14. Variables affecting morning movement behavior* as determined by analysis of covariance on data for six survivor walleyes.

Effect: Yes		No Effect	
Resting	Movement	Resting	Movement
PPMOSAC(.045)	PPMOSAC(.004)	DAY(.130)	DAY(.422)
PLIGHT(.044),FISH(.007)	PLIGHT(.025)		FISH(.051)
PPMOSAC,FISH(.034)			PPMOSAC,FISH(.137)
FISH(.005)	FISH(.021)	AM5(.518)	AM5(.731)
FISH(.005)	FISH(.021)	AM6(.992)	AM6(.753)
FISH(.005)	FISH(.021)	AM7(.873)	AM7(.919)
FISH(.005)	FISH(.021)	AM8(.892)	AM8(.918)
FISH(.005)	FISH(.021)	AM9(.732)	AM9(.669)

*The numbers in parenthesis are the p-values for the null hypothesis: no difference in treatment effects. The variables are defined in Table 13.

Table 15. Variables affecting evening movement behavior* as determined by analysis of covariance on data for six survivor walleyes.

Effect: Yes		No Effect:	
Resting	Movement	Resting	Movement
AMOSINA(.001)	AMOSINA(.003)	DAY(.632)	DAY(.807)
AMOSACT(.001)	AMOSACT(.002)	DAY(.562)	DAY(.782)
FISH(.037)		SLIGHT(.902)	SLIGHT(.705),FISH(.256)
FISH(.023)		DPM(.386)	DPM(.917),FISH(.149)
FISH(.037)		PM16(.961)	PM16(.609),FISH(.256)
FISH(.037)		PM17(.854)	PM17(.355),FISH(.253)
FISH(.037)		PM18(.547)	PM18(.370),FISH(.253)
FISH(.036)		PM19(.365)	PM19(.470),FISH(.254)
FISH(.036)		PM20(.356)	PM20(.217),FISH(.25)
AMOSINA(.001)	AMOSINA(.002)	FISH(.100)	FISH(.402)
AMOSACT(.001),FISH(.030)	AMOSACT(.001)		FISH(.243)

*The numbers in parenthesis are the p-values for the null hypothesis: no difference in treatment effects. The variables are defined in Table 13.

Atypical Behavior Identification

Investigation of the behavior of rf-tagged fish with respect to feeding, periodicity, and mortality was possible from the data produced by MRSS because there were no subjective differences in the way data were obtained for individual walleyes and all samples were instantaneous. The first question to be considered is whether fish that did not survive were too small to support the weight of the transmitter packages since the average percent of body weight was 1.3% and Hart and Summerfelt (1975) reported using transmitters that were only 0.6% of body weight. Using the measurements taken at the time of rf-tagging, the 11 fish were divided into 2 treatments, those that survived to the end of field testing and those that died (Table 16).

To test Ho: No difference in average weight ($\mu_1 = \mu_2$) between the two groups of fish; a t-test with independent samples, unequal sample sizes, and unequal variance was performed. In order to use the correct variance estimate, it was first necessary to test for homogeneity (Table 16). Since $F_{.05}(7,14) = 6.09$, Ho was accepted and a pooled variance estimate was used in the t-test of the null hypothesis; $\mu_1 = \mu_2$ at the $\alpha = .05$ level. Since the P-value of Ho is less than .25 but greater than .10, there was no significant difference in the average weights of fish that died and fish that survived which would affect their capacity to carry a transmitter.

Table 16. Comparison of average weights of walleyes that survived and walleyes that died using the t-statistic.

Measurement	Walleye Mortality	
	No	Yes
Weight	737.6 gms	662.5 gms
Wt. S.D.	205.8	137.4
length	43.6 cm	43.3 cm
l. S.D.	3.7	2.7
# of fish	7	4

$$Ho: \sigma_1 = \sigma_2$$

$$F\ 7,14 \quad \frac{S_1^2}{S_2^2} = 2.24$$

Therefore: $s_d^2 = 34528.68$, and

$$t_d = \frac{737.6 - 662.5}{s_{\bar{d}}} = 4.04 .$$

Postoperative tagging recovery times reported by other authors include 36 hours for flathead catfish, Pylodictis olivaris, (Hart & Summerfelt 1976), and 14 days for Guadalupe bass, Micropterus treculi, (Manns & Whiteside 1979). Although using walleyes with externally attached transmitters, Kelso (1976) reports that "immediately following release, a period of continuous movement occurred followed by a mid-day decline in activity. After sunset activity increased rapidly, primarily short, rapid bursts of speed; and then dropped off to low levels until just prior to dawn when another period of increased activity was apparent." These walleyes were being returned to their original capture sites, so it was assumed that their movements were in response to the transmitter package.

Generally, as displayed by Figures 8 through 17, most walleyes at Monticello showed an initial adjustment period during which movements seemed more frequent and intense. Following surgery the 5 smaller fish took longer, on the average, to leave the release pool (3.2 days) and explore the environment than the 5 largest walleyes (0.5 days). Perhaps the initial period of movement following release was not only related to the surgery but also to familiarization with the available habitat. For the surviving fish, there was a definite rest and recovery period (5.0 days average) following the initial exploratory period (4.6 days average). Each fish that died during the experiment showed a unique individual response so that the only generalizations that can be made about pre-mortality movements (4.5 days average) are: (1) the current pushes the sick fish towards the barrier at riffle #13 and (2) a "last-gasp" attempt was often made to get to pool #2 where the oxygen content of the water was more stable because of the pump.

Event records of intensity of movement on an hourly basis were used to quantify differences in locomotory behavior between sick and healthy fish. Five successive locations were used for each hour, and the sum of the absolute value of the differences between the previous and current location was multiplied by 1 + Log_e (number of 15 minute periods in which movement was indicated) so as to weight continuous movement higher than an isolated change of position.

To evaluate rhythmicity of movement from these data, periodograms (Enright 1965) were calculated for all animals for period lengths ranging from 10 to 40 hours. Where the animal was known to die, data were used only up to 48 hours before death. Wave form estimates were calculated for 24 hour periods, and for any other period lengths whose amplitudes exceeded that of the 24 hour serial correlation value. These wave form estimates are average curves describing the intensity and frequency of movement activity.

The bimodal pattern for surviving fish clearly indicates crepuscular activity (Figures 28 and 29) while the fish that died have no clear cut periodicity (Figure 30). Two surviving fish (4041 and 4042) apparently adjusted their period length to 23 hours; as shown by a higher amplitude for their 23 hour period and a very different, spiked wave form estimate. Even the amplitudes of the second and third best period estimates (36 and 39 hours) for these 2 smallest fish were higher than their corresponding 24 hour serial correlation value. Despite different dominant periods, both 4041 and 4042 show the pronounced evening movement onset at 20:00 CST (Figure 28). The amplitude of the serial correlation value for 24 hours was twice that of the other periods for the four largest survivor walleyes, indicating pronounced periodicity. None of the non-survivors had maximum amplitude at twenty-four hours, but the dominant periods were not significantly above the values for the other periods. As shown by grouping the wave form estimates according to the Student-Neuman-Keuls homogeneous subsets calculated by one-way analysis of variance of the average time of morning movement, walleyes 4038 and 4042 overlap both groups which differ primarily in their pre-dawn temporal movement pattern.

Feeding behavior is an important factor in determining when movements may be atypical. Kelso & Ward (1977) analyzed food ingested by walleyes and found them to be highly opportunistic. Walleyes apparently eat Mayfly larvae when present and amphipods when abundant in spring. In early summer they preyed more heavily upon yellow perch fry. Older perch, essentially littoral throughout the year, are consistent contributors to walleye nutrition. MacLean

Figure 28. 24 hour wave form estimates for surviving walleyes in first S-N-K homogeneous subset characterised by variable early morning activity.

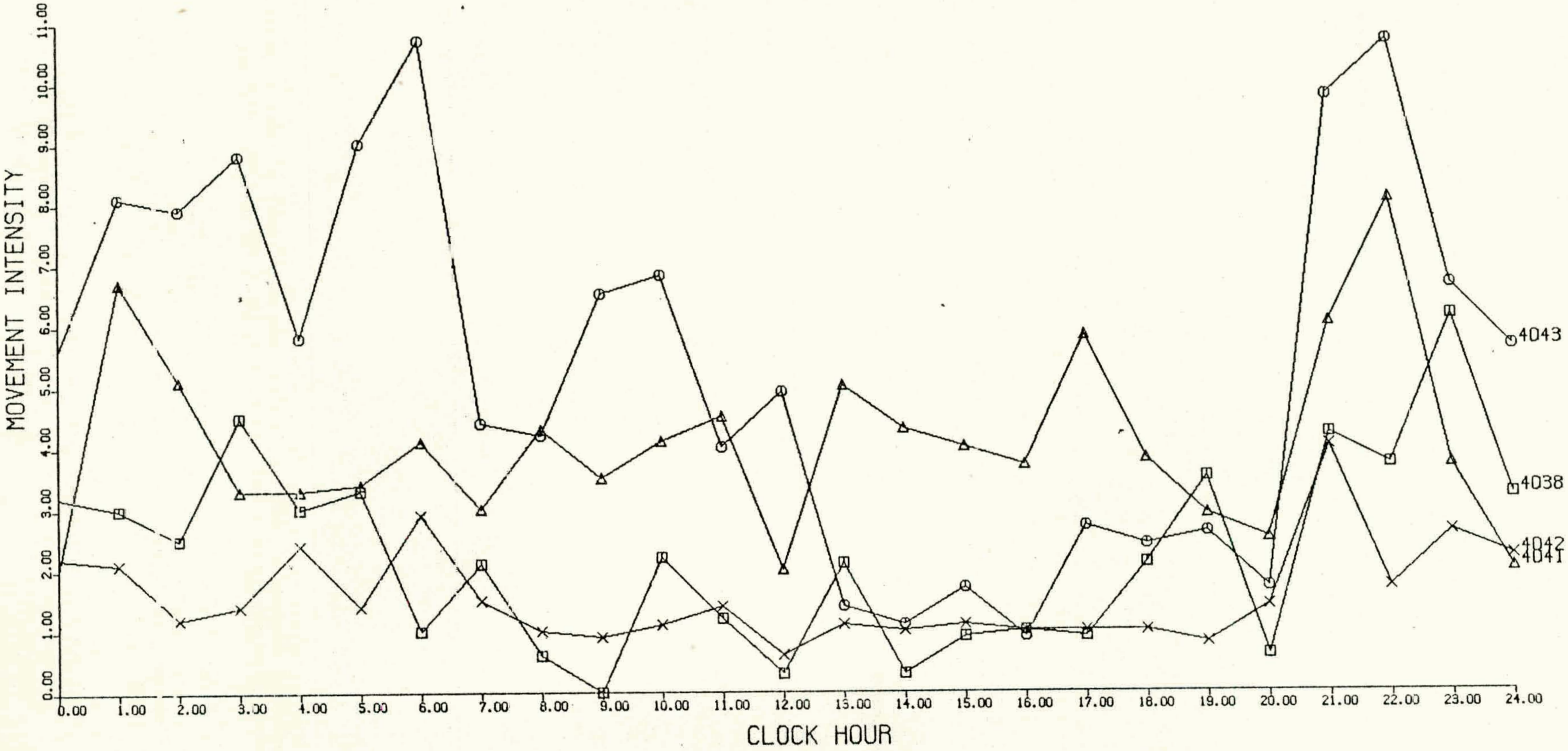


Figure 29. 24 hour wave form estimates for surviving walleyes in second S-N-K homogeneous subset characterised by precise pattern of early morning activity.

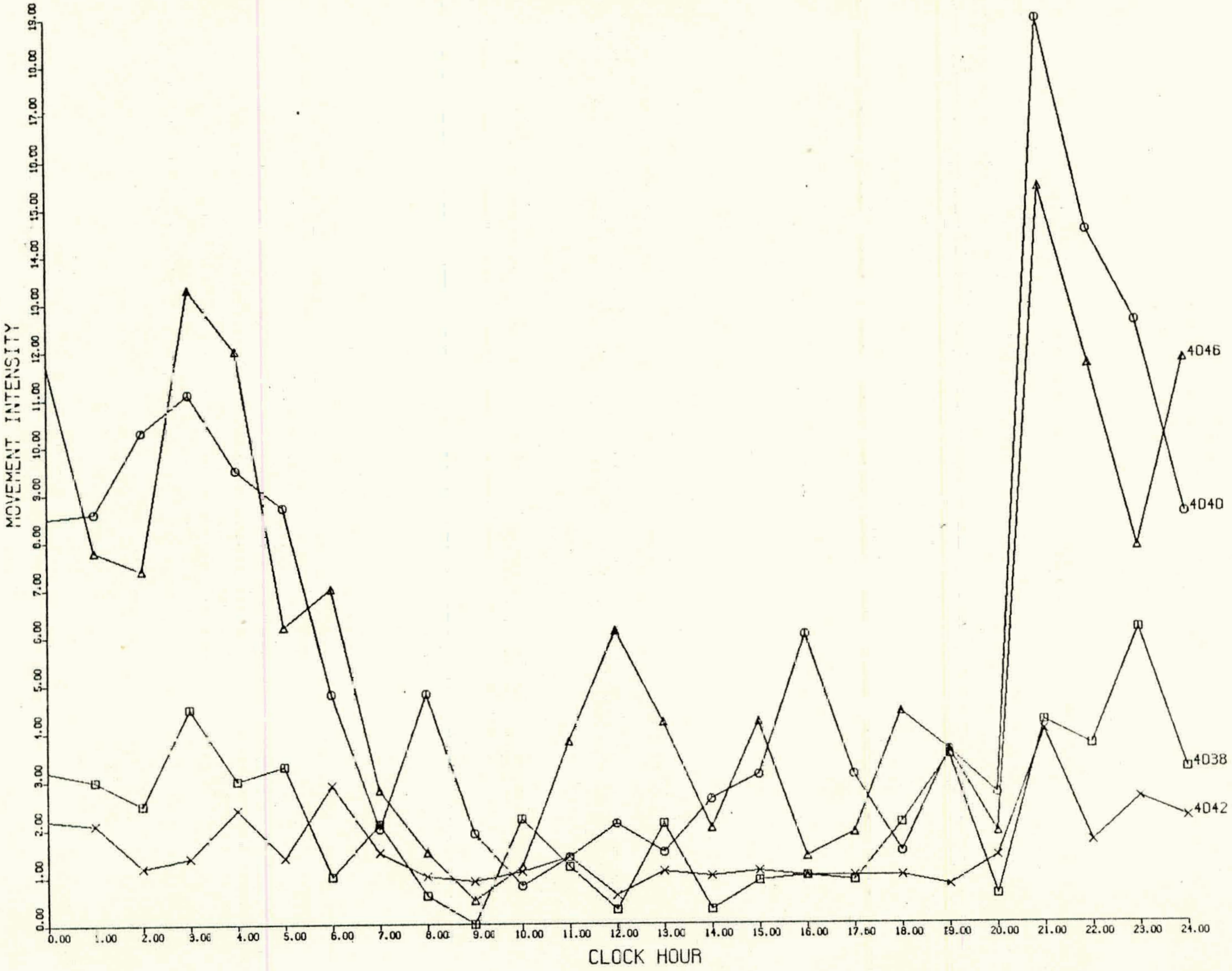
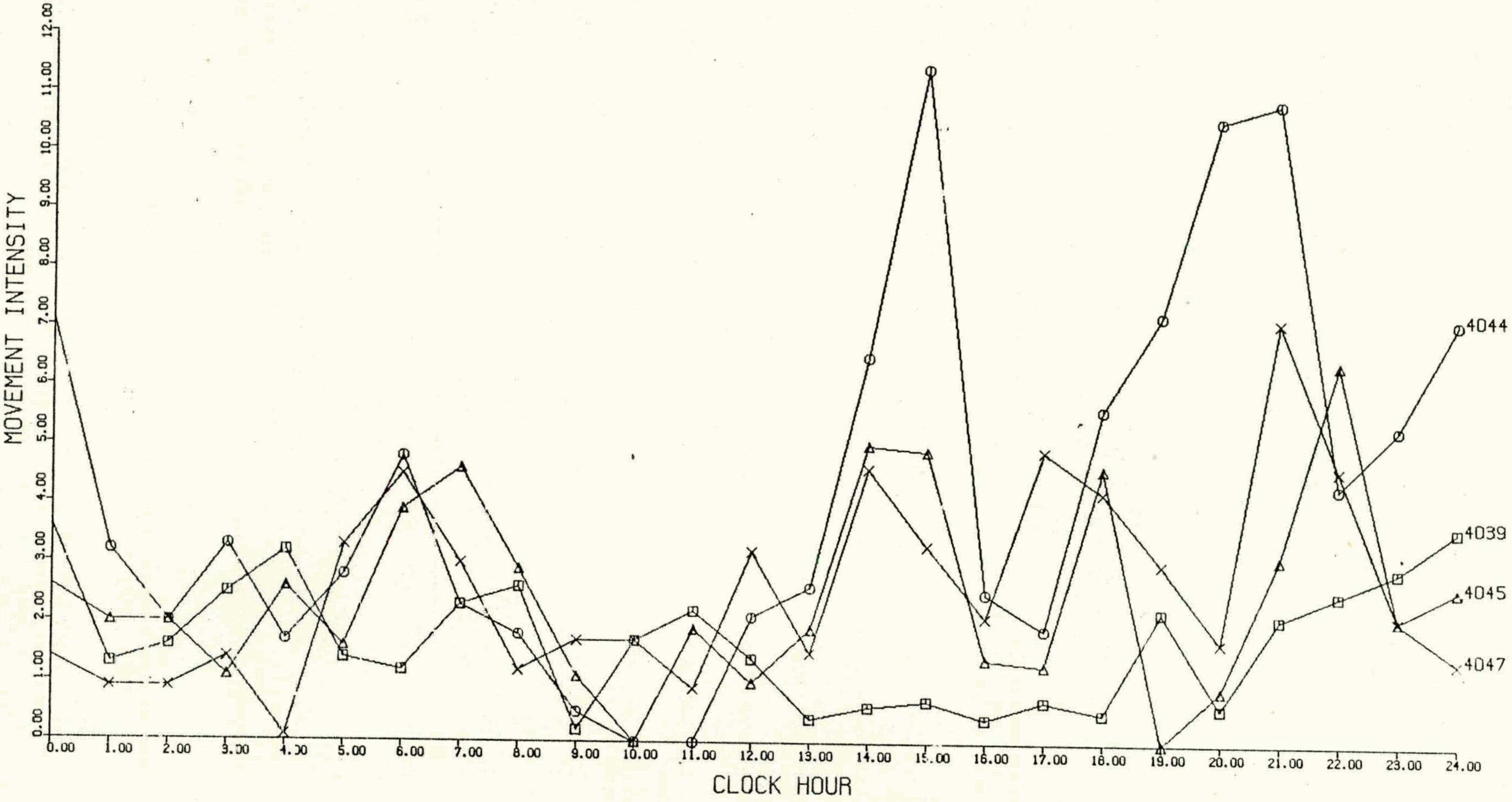


Figure 30. 24 hour wave form estimates for the walleyes that did not survive.



& Magnuson (1977) reported that young walleyes ate small crustaceans, dipteran larvae, minnows, and darters. Scott and Crossman (1973) describe walleyes as utilizing any species of fish readily available to them as food. Other items such as crayfish, snails, frogs, mud puppies and small mammals are taken when fish and insects are scarce; but in general winter food is not particularly different from summer food.

There was no precise estimate of the food supply present in the experimental channel for the walleyes, but it was limited. Since the daily ration of predatory percids during the growing season under optimal feeding conditions (food consumption also depends on temperature) amounts to 3-7% of the body weight (Collette et al. 1977), by May 15th it was assumed that these fish were probably hungry. Also by this time it was apparent that the walleyes were mainly night active. Response to the presence of prey during daylight was investigated by releasing 15 dozen large fathead minnows (*Pinnephales promelas*) at 11:30 CST on May 16th.

The four largest of the survivor walleyes responded to the presence of the minnows with changes of position during the afternoon of May 16th despite the bright sunlight (Figure 7) when they normally would have been resting. For walleyes 4038, 4040, and 4043 the resting and movement offsets are transposed (Figures 22, 23, and 26). Although this pattern of reversal is not shown for 4046 in Figure 27, the raw data show late afternoon activity out of context for the usual pattern of this fish at this time. There was also more late night movement to counteract the afternoon activity when calculating the offset.

For the highly photonegative walleye, light has been described as the most significant exogenous factor in initiating the movement that subsequently results in feeding (Ryder 1977). Also, as described above, total incident sunlight of the previous day was found to have a significant effect. Consequently, the rate of change of illumination would be expected to be the major factor that stimulates the initiation of feeding; however, hungry walleyes do not wait for sunset. Perhaps this is a seasonal (spring) variation in the level of stimulus required to elicit the response. This would be analagous to the adaptation for walleye's feeding in winter that allows the level of illumination required to be one order of magnitude lower (Ryder 1977).

CONCLUSIONS

Analysis of aquatic vertebrate behavior is a potentially useful technique for describing the effects of pollutant stress, a primary ecological concern of today. Because mortality is easy to detect and to correlate with significant changes in environmental conditions, the ways in which toxicants disrupt the biochemistry of an organism are easy to establish. Evaluating the effects of sublethal changes is harder but more valuable in the long run because the questions considered are relevant to the function and organization of individuals and groups of organisms. Whether a toxicant disrupts behavior in an individual, and whether this affects survival of groups in an ecosystem, are essential criteria for independent assessment of pollutant effects.

Small physiological changes in an organism are not necessarily deleterious and could well be within the normal range of adaptation for the species. However, a lack of organization in movement or feeding behavior or inhibition of courtship behavior definitely compromise survival probabilities in aquatic vertebrates. A reduced scope of activity, a change in feeding, and avoidance reactions to introduced toxicants have been demonstrated in the laboratory (Cha~~r~~evin 1973). Changes in social interactions of fish when exposed to pollutants may provide the most sensitive and precise indicator of toxicant stress yet developed (Warner et al. 1966).

Most of the problems of interpreting avoidance reactions in nature can be attributed to the lack of continuous quantitative field observations. Subjectiveness of observers must be overcome and observations for different animals must be concurrent. But along with increased sample size comes the problem of evaluating the total set of results. MRSS represents an application of micro-computer technology to the problem of biological data acquistion. A sampling technique utilizing radio-telemetry is not subjective and provides reliable comparative data for measuring behavior.

During field testing, walleyes selected certain preferred locations. From the data recorded by MRSS, overall usage of available habitat was summarized as the percent of time spent in each pool or riffle. Location data were recorded continuously (15 minute intervals) and instantaneously, negating the usual problems with behavioral sampling techniques. Intensity and periodicity of movement (changes in position) were summarized for individual walleyes and a crepuscular activity pattern was characteristic of healthy fish. From paired samples of data produced by MRSS, social interaction between pairs of walleyes was investigated by summarizing the distance separating each pair for each hour of the day. These results demonstrated association between group members and avoidance of non-group individuals. MRSS was also useful for evaluating tagging recovery times, feeding behavior and pre-mortality movements.

Acknowledgements

I am grateful to all those who made this research possible, particularly the Monticello project principal investigators: Dr. D. B. Siniff and V. B. Kuechle. Dr. J. R. Tester is responsible for my involvement in doing the actual field work for graduate credit and assisted in editing the manuscript. Dr. D. B. Siniff provided computer facilities and financial support for developing the software. V. B. Kuechle inspired the hardware design and provided operational support from Cedar Creek facilities. I am especially grateful to M. Jon Ross for his expert instruction in field techniques for underwater radio telemetry and his supervision of the Monticello project.

The design, construction, and installation of the electronic equipment and micro-processor system was a joint effort by the staff of the Cedar Creek Bioelectronics Laboratory; Larry Kuechle, Dick Reichle, Ralph Schuster, Leonard Cramer, and M. Jon Ross. Lisa Ferm transcribed the data tapes to computer format and Denise Stinson keypunched 36,000+ cards. Rosie Rice produced multiple versions of this manuscript.

Dr. F. H. Barnwell contributed computer programs for analyzing biological rhythms, assistance in interpretation of activity, and programming support from G. F. Uhlig of Control Data Corporation. The cooperation and assistance from the staff of the Monticello Ecological Research Laboratory is gratefully acknowledged, especially Dr. K. E. F. Hokanson, Jack Arthur, Charles F. Kliener, and Roger Hermanitz. The University Computer Center provided a $1050 grant of computer system resource units and supplies for data analysis and several staff members were especially helpful, Michael Skow, Michael Frisch and Jim Foster. Financial support from the U.S. Department of Energy Contract EY-76-S-02-1332 is gratefully acknowledged.

Literature Cited

Ali, M. A., R. A. Ryder and M. Anctil, 1977. Photoreceptors and visual pigments as related to behavioral responses and preferred habitats in Perches (Perca spp.) and Pikeperches (Stizostedion spp.). J. Fisheries Research Board of Canada, Vol. 34, No. 10.

Chavin, Walter (ed.), 1973. Responses of Fish to Environmental Change. Thomas Books, Springfield, Illinois.

Collette, B. B., M. A. Ali, K. E. F. Hokanson, M. Nagiec, S. A. Smirnov, J. E. Thorpe, A. H. Weatherly, and J. Williamson, 1977. Biology of the Percids. Journal of the Fisheries Research Board of Canada, Vol. 34, pp. 1890-1899.

Enright, J. T., 1965. The search for rhythmicity in biological time series. J. Theoretical Biology, Vol. 8, pp. 426-468.

Eriksson, L. O., 1978. Nocturnalism versus diurnalism; dualism within fish individuals. Rhythmic Activity of Fishes, J. E. Thorpe, Ed. Academic Press Inc., New York, U.S.A.

Fienberg, S. E., 1977. The analysis of cross-classified categorical data. The MIT Press; Cambridge, Massachusetts.

Hart, L. G. and R. C. Summerfelt 1975. Surgical procedures for implanting ultrasonic transmitters into flathead catfish. Transactions of the American Fisheries Society, No. 1.

Kelso, J. R. M., 1976. Diel movement of Walleye, Stizostedion vitreum vitreum in West Blue Lake, Manitoba, as determined by utrasonic tracking. Journal of Fisheries Research Board of Canada, Vol. 33.

Kelso, J. R. M., and F. J. Ward, 1977. Unexploited Percid populations of West Blue Lake, Manitoba, and their interactions. Journal of Fisheries Research Board of Canada, Vol. 34.

Kitchell, J. F., M. G. Johnson, C. K. Mimms, K. H. Lofters, L. Grieg, and C. H. Olver 1977. Percid habitat: the river analogy. Journal of Fisheries Research Board of Canada, Vol. 34.

Kuechle, V. B., R. A. Reichle, and R. J. Schuster, 1971. Construction details for an animal tracking receiver. U. of M. Press; Minneapolis, Minnesota.

Manns, R. E. and B. G. Whiteside, 1979. Behavioral variations associated with ultransonic tagging of Guadalupe bass in Lake Travis, Texas. Underwater Telemetry Newsletter, Vol. 9, no. 2.

MacLean, J. H., and J. J. Magnuson 1977. Inferences on species interactions in Percid communities. Journal of Fisheries Research Board of Canada, Vol. 34.

Muller, K. 1978. The flexibility of the circadian system of fish at different latitudes. Rythmic Activity of Fishes, J. E. Thorpe Ed. Academic Press Inc., New York, U.S.A.

Muntz, W. R. A. and A. W. Wainwright 1978. Annual cycles in the light environment and visual mechanisms of fishes. Rythmic Activity of Fishes, J. E. Thorpe Ed. Academic Press Inc., New York, U.S.A.

Ross, M. J. 1978. Distribution of fish and temperature preference of yellow perch in the thermal plume of a power plant as determined by radio telemetry. M.S. Thesis, University of Minnesota.

Ross, M. J. and C. F. Kliener 1980. A new technique for surgically implanting radio frequency transmitters in fish. (Submitted to the Progressive Fish Culturist).

Ryder, R. A. 1977. Effects of ambient light variations on behavior of yearling, subadult and adult Walleyes (*Stizostedion vitreum vitreum*). J. Fisheries Research Board of Canada, Vol. 34, No. 10.

Scott, W. B. and E. J. Crossman 1973. Freshwater fishes of Canada. Bulletin 184; Fisheries Research Board of Canada.

Tester, J. R. and D. B. Siniff 1976. Engineering design and development p. 6-36. Annual progress report for Vertebrate Behavior and Ecology.

Underhill, J. C. and Samuel Eddy 1974. Northern fishes, U. of M. Press; Minneapolis, Minnesota.

Warner, R. E., K. K. Peterson and L. Borgman 1966. Behavioral pathology in fish; a quantitative study of sublethal pesticide toxication. Journal of Applied Ecology, Vol. (3) suppl., pp. 223-247.

Winter, J. D., V. B. Kuechle, D. B. Siniff, and J. R. Tester 1978. Radio tracking freshwater fish. Report #152, Agriculture Experimental Station, University of Minnesota.

Appendix A (Glossary)

This appendix describes the CDP1802 CPU architecture, modes, and states necessary to the understanding of the microprocessor instruction set utilization.

ALU - The Arthmetic and Logic Unit. The ALU performs the arithmetic and logic operations.

CMOS - Complementary Metal Oxide Semi-conductor.

D - The Data register (8 bits). This register is the machine accumulator used in performing arithmetic and logic operations. Data passing between memory and the scratch-pad registers go through D.

DF - The Data Flag (1 bit). Used and set or reset by the add, subtract, and shift instructions. It is also tested by the branch instructions.

IE - The Interrupt Enable flip-flop (1 bit). When IE is set to 1, interrupts are enabled; when IE is 0, interrupts are disabled.

I,N - The Instruction code and N field (4 bits each). These combined registers hold the operation code byte of the fetched instruction; I holds the higher four bits and N the lower four bits. In many cases, I specifies an instruction and N designates a scratch-pad register; otherwise, I and N together specify an instruction.

INC/DEC - The Increment/Decrement logic unit. This unit is used to either increment or decrement a designated register.

M - Memory (up to 800 eight-bit bytes each of RAM and/or ROM).

P - The P designator register (4 bits). Its contents specify which of the scratch-pad registers is the current Program Counter, R(P). The program counter (P-counter) holds the address of the next instruction to be executed.

Q - The Q flip-flop (1 bit). Its contents can be set or reset by instructions and are available externally. It can be tested by certain branch instructions and is used as a general purpose flag.

R - An array of 16 scratch-pad Registers (16 bits each). All references to memory are made with the registers in R used as pointers. These registers may also be used to hold data and loop counters. The entire array is often referred to as a scratch-pad memory (SPM).

T - The Temporary register (8 bits). T can receive the contents of X in its higher four bits and the contents of P in its lower four bits, X and P can take new values and those saved in T can take new values and those saved in T can eventually be restored.

TTL - Transistor-Transistor Logic.

X - The X designator register (4 bits). Its contents specify which of the scratch-pad registers is used to address data. Data addressed by R(X) is used by many instructions, especially the arithmetic and logic ones.

Appendix B (Program)

```
FL LOC   COSMAC CODE       LNNO SOURCE LINE
   0000                     1          ORG  *
   0000  F8F0               2 INIT:    LDI  A.1(BGIN) .. BOOTSTRAP
   0002  B3                 3          PHI  R3
   0003  F850               4          LDI  A.0(BGIN)
   0005  A3                 5          PLO  R3
   0006  D3                 6          SEP  R3     ..R3. IS MAIN P-COUNTER
   0007  00                 7.         IDL         ..SHOULD NEVER GET HERE
   0008                     8..        CONSTANTS USED
   0008                     9 ZERO     =     00    ..CONSTANT ZERO
   0008                    10 ONE      =     01    ..CONSTANT ONE
   0008                    11 TWO      =     02
   0008                    12 FOUR     =     14
   0008                    13 FIFN     =     15
   0008                    14 TEND     =     10    ..TEN DECIMAL
   0008                    15 CTEN     =    #10    ..HEX(BCD) TEN
   0008                    16 SIXT     =     60    ..CONSTANT DECIMAL SIXTY
   0008                    17 XXIV     =     24    ..CONSTANT DECIMAL TWENTY-FOU
   0008                    18 MSK4     =    #0F    ..FOUR BIT MASK
   0008                    19 C100     =    100    ..MAXIMUM DAY COUNTER
   0008                    20 NINT     =    #90    ..BCD NINETY
   0008                    21 FILL     =    #FF    ..BLANK FILL CHARACTER
   0008                    22 MAX      =    #FF    ..MAXIMUM 8 BIT VALUE
   0008                    23 ..
   0030                    24          ORG #30
   0030  1F1E1D1C1B1A1918  25 FQTB:    ,31,30,29,28,27,26,25,24
   0038  17161514131211    26          ,23,22,21,20,19,18,17
   003F  100F0E0D0C0B0A09  27          ,16,15,14,13,12,11,10,9
   0047  0807060504030201  28          ,8,7,6,5,4,3,2,1,0
   0050  0F                29 ENDF:    ORG  *
   0050                    30 ANTB:    =   ENDF-13..TWELVE ANTENNAS TO SCAN
   0050                    31 ENDT:    ORG  *
   0050                    32 NVLD:        ..INVALID ANTENNA SELECT CODE
   0052                    33 ..
   005D                    34          ORG #5D     ..RESERVE A/D STORAGE ARRAY
   005D                    35 ATOD:    ORG *       ..LWA+1 OF A TO D VALUES
   005D                    36 ..
   0060                    37          ORG #60
   0060 00                 38 CCLK:    ,0  ..CURRENT CLOCK READING
   0061 00                 39 PCLK:    ,0  ..PREVIOUS CLOCK READING
   0062 00                 40 MINS:    ,0  ..BINARY MINUTE COUNTER
   0063 00                 41 HOUR:    ,0  ..BINARY HOUR COUNTER
   0064 00                 42 DAYS:    ,0  ..BINARY DAY COUNTER
   0065 000000             43 PRNT:    ,0,0,0      ..PRINTER BUFFER
   0068 00                 44 HOLD:    ,0  ..HOLDS VALUES FOR CBCD SUBROUTINE
   0069 00                 45 ASEL:    ,0          ..CODE TO INIATE A/D CONVER
   006A 00                 46 VSUM:    ,0  ..A/D SUM
```

```
006B            ..
0080                     ORG  #80
0080 F8FF       WAIT:    LDI  MAX    ..WAIT KILLS TIME
0082 A2                  PLO  R2
0083 FF01       LOPR:    SMI  ONE
0085 C4                  NOP
0086 3A83                BNZ  LOPR
0088 22                  DEC  R2
0089 82                  GLO  R2
008A 3A83                BNZ  LOPR
008C D3                  SEP  R3     ..RETURN TO MAIN PROGRAM
008D 00                  IDL
008E
008E F800       CBCD:    LDI ZERO    ..CONVERT BINARY TO BCD
0090 5C                  STR RC
0091 0B                  LDN RB      ..RB HAS ADDRESS OF VALUE TO
0092 A4                  PLO R4      ..R4 IS SCRATCH REGISTER
0093 04         LPCV:    GLO R4      ..REMAINDER
0094 FF0A                SMI TEND    ..SUBTRACT OFF DECIMAL TEN
0096 3BA1                BM  RNEG    ..UNTIL RESULT NEGATIVE
0098 A4                  PLO R4
0099 0C                  LDN RC
009A FC10                ADI CTEN
009C 5C                  STR RC
009D FF90                SMI NINT
009F 3B93                BNF LPCV
00A1 0C         RNEG:    LDN RC      ..QUIT IF RESULT NEGATIVE
00A2 A5                  PLO R5
00A3 84         TRYM:    GLO R4
00A4 32AA                BZ  FINIS
00A6 15                  INC R5
00A7 24                  DEC R4
00A8 30A3                BR  TRYM
00AA 85         FINIS:   GLO R5
00AB 5C                  STR RC
00AC D3                  SEP R3      ..RETURN TO MAIN PROGRAM
00AD 00                  IDL
00AE            ..
00F0                     ORG #F0
00F0 F800       BGIN:    LDI A.1(CCLK)..INITIALISE CLOCK
00F2 BE                  PHI RE
00F3 F860                LDI A.0(CCLK)
00F5 AE                  PLO RE
00F6 EE                  SEX RE
00F7 6E                  INP 6
00F8 F800       MAIN:    LDI A.1(INIT)
00FA B2                  PHI R2
```

```
00FB B4         PHI R4
00FC B5         PHI R5
00FC B6         PHI R6
00FC B7         PHI R7
00FC B8         PHI R8
0100 B9         PHI R9
0101 BA         PHI RA
0102 BB         PHI RB
0103 BC         PHI RC
0104 BD         PHI RD
0105 BE         PHI RE
0106 F800       LDI ZERO
0108 A2         PLO R2
0109 A4         PLO R4
010A A5         PLO R5
010B A6         PLO R6
010C F867       LDI A.0)PRNT+2)
010E AE         PLO RE      ..PRINT A BLANK LINE
010F EE         SEX RE      ..BEFORE TIME AT BEGINNING OF
0110 F8FF       LDI FILL    ..STORE BLANKS
0112 73         STXD        ..IN PRINT BUFFER
0113 73         STXD
0114 5E         STR RE
0115 65         OUT 5
0116 66         OUT 6
0117 67         OUT 7
0118 F880       LDI A.0(WAIT)..DELAY FOR PRINT
011A AD         PLO RD
011B DD         SEP RD
011C F865       LDI A.0(PRBT)
011E AC         PLO RC
011F AE         PLO RE
0120 F864       LDI A.0(DAYS)
0122 AB         PLO RB
0123 F88E       LDI A.0(CBCD)...CONVERT DAYS TO BCD
0125 A7         PLO R7
0126 D7         SEP R7
0127 2B         DEC RB
0128 1C         INC RC
0129 F88E       LDI A.0(CBCD)...CONVERT HOURS TO BCD
012B A7         PLO R7
012C D7         SEP R7
012D 2B         DEC RB
012E 1C         INC RC
012F F88E       LDI A.0(CBCD)...CONVERT MINUTES TO BCD
0131 A7         PLO R7
0132 D7         SEP R7
```

```
0133 EE                     SEX RE        ..(RE)=PRINT FWA
0134 65                     OUT 5         ..CHARS 1 and 2 PRINTED
0135 66                     OUT 6         ..CHARS 3 AND 4 TO PRINTER
0136 67                     OUT 7         ..CHARS 5 AND 6 OUT AND ALL P
0137 F880                   LDI A.O(WAIT)..A.O(WAIT)FOR I/O TO FI
0139 AD                     PLO RD
013A DD                     SEP RD
013B F830                   LDI A.O(FOTB)
013D A8                     PLO R8
013E F843       CYCL:       LDI A.O(ANTB)..START NEW PASS
0140 A9                     PLO R9
0141 E9                     SEX R9       ..MAKE SURE BIT 4 NOT SET
0142 62                     OUT 2        ..WHEN FREQUENCY CHANGES
0143 F880                   LDI A.O(WAIT)
0145 AD                     PLO RD
0146 DD                     SEP RD
0147 F86A                   LDI A.O(VSUM)..CLEAR A/D SUM
0149 AE                     PLO RE
014A F85D                   LDI A.O(ATOD)..SET UP A TO D STORAGE
014C AA                     PLO RA
014D AB                     PLO RB       ..SET UP HOLDER FOR MAX A TO
014E F800                   LDI ZERO     ..CLEAR REGS
0150 5E                     STR RE       ..CLEAR VSUM
0151 5A                     STR RE       ..CLEAR FIRST A/D
0152 5B                     STR RB       ..CLEAR MAX A/C
0153            ..
0153 08                     LDN R8       ..IF BIT 7 OF FREQUENCY SELEC
0154 7E                     SHLC         ..DO NOT USE THIS FREQUENCY
0155 3B5A                   BNF OKTU
0157 18                     INC R8       ..SET TO NEXT FREQUENCY
0158 30C1                   BR SKIP
015A E8         OKTU:       SEX R8
015B 61                     OUT 1        ..OUTPUT FREQUENCY SELECT COD
015C F880                   LDI A.O(WAIT)FOR I/O TO COM
015E AD                     PLO RD
015F DD                     SEP RD
0160 F869       AGIN:       LDI A.O(ASEL)
0162 AC                     PLO RC       ..SAVE CONVERSION INITIATION
0163 E9                     SEX R9       ..SELECT ANTENNA TO READ
0164 09                     LDN R9       ..(D) = ANTENNA
0165 F910                   ORI CTEN     ..(D) = ANTENNA # PLUS HEX 10
0167 5C                     STR RC       ..SAVE IN ASEL
0168 62                     OUT 2        ..OUTPUT SELECT CODE TO NETWO
0169 F880                   LDI A.O(WAIT)..A.O(WAIT) FOR I/O TO FIN
106B AD                     PLO RD
016C DD                     SEP RD       ..JUMP TO DELAY SUBROUTINE
016D F880                   LDI A.O(WAIT):..WAIT FOR 2 SECS
```

```
016F AD          188        PLO RD
0170 DD          189        SEP RD
0171 EC          190        sex rd          ..R(C) POINTS TO ASEL
0172 62          191        OUT 2           ..REQUEST A/D CONVERSION
0173 C4          192        NOP
0174 C4          193        NOP
0175 3C73        194        BN1 *-2         ..WAIT TILL EF1 GOES ZERO
0177 EA          195        SEX RA          ..READ A/D FOR ANTENNA SELECT
0178 6D          196        INP 5
0179 A1          197        PLO R1          ..SAVE A/D IN R1
017A EB          198        SEX RB          ..SEE IF NEW READING IS LARGE
017B F7          199        SM
017C 3B80        200        BNF LTEQ        ..BRANCH IF LESS THAN OR EQUA
017E 8A          201        GLO RA          ..SET NEW MAX A/D ADDRESS
017F AB          202        PLO RB
0180 2A          203 LTEQ:  DEC RA          ..DECREMENT A/D STORAGE ADDRE
0181 F86A        204        LDI A.0(VSUM)   ..DIVIDE A/D BY 16
0183 AC          205        PLO RD
0184 EC          206        SEX RC
0185 81          207        GLO R1          ..RESTORE A/D VALUE
0186 F6          208        SHR
0187 F6          209        SHR
0188 F6          210        SHR
1089 F6          211        SHR
018A F4          212        ADD
018B 5C          213        STR RD          ..STORE SUM BACK
018c 89          214        GLO R9
018D FF50        215        SMI A.0(ENDT)   ..HAVE ALL ANTENNAS BEEN R
018F 3B60        216        BNF AGIN        ..IS PASS DONE?
0191 0B          217        LDN RB          ..YES, GET MAX A/D
0192 F7          218        sm              ..RX POINTS TO VSUM
0193 A1          219        PLO R1          ..SAVE DIFFERENCE
0194 3399        220        BDF NOTN        ..DF IS SET IF NO BORROW
0196 F800        221        LDI ZERO
0198 A1          222        PLO R1
0199 F866        223 NOTN:  LDI A.0(PRNT+1) ..GET SET TO PRINT RESUL
019B AC          224        PLO RC
019C 8B          225        GLO RB          ..COMPUTER ANTENNA DEFINITION
019D FA0F        226        ANI MSK4        ..LOWER 4 BITS OF ANTENNA ADD
019F A2          227        OKI R2
01A0 F868        228        LDI A.0(HOLD)
01A2 AB          229        PLO RB
01A3 82          230        GLO R2
01A4 5B          231        str rb
01A5 F88E        232        LDI A.0(CBCD)
01A7 A7          233        PLO R7          ..CONVERT ANT # TO BCD
01A8 D7          234        SEP R7          ..FOR OUTPUT AS CHARS 3&4
01A9 1C          235        INC RC
```

```
01AA 81         236          GLO R1         ..PRINT DIFF
01AB 5B         237          STR RB         ..STORE IN HOLD
01AC F88E       238          LDI A.0(CBCD)  ..CONVERT DIF = MAX - BIAS
01AE A7         239          PLO R7
01AF D7         240          SEP R7
01B0 F865       241          LDI A.0)PRNT)  ..NOW CHANNEL NMBR
01B2 AC         242          PLO RC
01B3 88         243          GLO R8
01B4 AB         244          PLO RB
01B5 2B         245          DEC RB
01B6 F88E       246          LDI A.0(CBCD)  ..CONVERT FREQUENCY #
01B8 A7         247          PLO R7         ..OUTPUT AS CHARS 1&2
01B9 D7         248          DEP R7
01BA 65         249          OUT 5
01BB 66         250          OUT 6
01BC 67         251          OUT 7
01BD F880       252          LDI A.0(WAIT)  ..DELAY FOR PRINTER
01BF AD         253          PLO RD
01C0 DD         254          SEP RD
01C1 88         255 SKIP:    GLO R8         ..SEE IF CYCLE DONE
01C2 FF50       256          SMI A.0(ENDF)
01C4 3B3E       257          BNF CYCL
01C6 E9         258          SEX R9         ..CLEAR A/D CONVERT
01C7 62         259          OUT 2          ..INVALID ANTENNA CODE
01C8 F800       260          LDI ZERO       ..CLEAR COUNTERS
01CA A4         261          PLO R4
01CB A5         262          PLO R5
01CC A6         263          PLO R6
01CD EE         264          SEX RE
01CE F860       265          LDI A.0(CCLK)
01D9 AE         266          PLO RE
01D1 72         267          LDXA           ..MAKE CURRENT CLOK PREVIOUS
01D2 73         268          STXD           ..STORE VIA X AND DECREMENT
01D3 6E         269 MN15:    INP 6          ..READ CURRENT CLOCK
01D4 1E         270          INC RE         ..R(X) = ADDRESS OF VALUE STO
01D5 F7         271          SM             ..SUBTRACT PCLK FROM A.0(CCLK
01D6 A1         272          PLO R1         ..SAVE MINS ELAPSED
01D7 FF0F       273          SMI FIFN       ..WAIT FOR 15 MINS
01D9 33E2       274          BDF NBRW       ..DF = 1 IF NO BORROW
01DB 2E         275          DEC RE         ..POINT TO CCLK
01DC F880       276          LDI A.0(WAIT)  ..DONT HIT BMC TOO FAST
01DE AD         277          PLO RD
01DF DD         278          SEP RD
01E0 30D3       279          BR MN15        ..READ CLOCK AGAIN
01E2 1E         280 NBRW:    INC RE         ..NOW ADD MINS ELAPSED
01E3 81         281          GLO R1
01E4 F4         282          ADD            ..TO SYSTEM MINUTE COUNTER
01E5 A4         283          PLO R4
```

```
01E6 FF3C         284        SMI SIXT     ..SUBTRACT SIXTY MINUTES
01E8 3BEC         285        BNF CHUR     ..UNTIL LESS THAN A.O(HOUR)
01EA A4           286        PLO R4       ..SAVE REMAINDER
01EB 15           287        INC R5       ..INCREMENT HOUR COUNTER
01EC 84           288 CHUR:  GLO R4       ..GET REMAINDER
01ED 5E           289        STR RE       ..UPDATE MINUTE COUNTER
01EE 1E           290        INC RE       ..POINT TO HOURS
01EF 85           291        GLO R5       ..GET VALUE TO ADD TO HOURS
01F9 F4           292        ADD          ..UPDATE HOUR COUNTER
01F1 A5           293        PLO R5
01F2 FF18         294        SMI XXIV     ..SUBTRACT 24
01F4 3BF8         295        BNF CDAY     ..BRANCH IF LESS THAN DAY
01F6 A5           296        PLO R5       ..SAVE REMAINDER
01F7 16           297        INC R6       ..BUMP DAY SCRATCH
01F8 85           298 CDAY:  GLO R5       ..GET HOURS REMAINING
01F9 5E           299        STR RE       ..UPDATE SYSTEM HOUR COUNTER
01FA 1E           300        INC RE       ..NOW LOOK AT DAY COUNTER
01FB 86           301        GLO R6       ..ADD NEW A.P(DAYS)
01FC F4           302        ADD          ..RESULT IN D-REG
01FD A6           303        PLO R6       ..SAVE IN R6
01FE FF64         304        SMI C100     ..MAX DAY IS 99
0200 3B05         305        BNF DONE     ..IF .LT. 99, PASS DONE
0202 F800         306        LKI ZERO     ..RESET DAY COUNTER TO 0
0204 A6           307        PLO R6
0205 86           308 DONE:  GLO R6
0206 5E           309        STR RE
0207 C4           310        NOP
0208 C000F8       311        LBF MAIN     ..START NEW CYCLE
020B 00           312        IDL
020C              313        END
```

PUBLICATIONS

Abraham, R. L. 1972. Mortality of mallards exposed to gamma radiation. Radiation Res. 49(2):332-337.

Abraham, R. L. 1974. Vocalizations of the mallard (*Anas platyrhynchos*). Condor 76(4):401-420.

Andrews, R. D., G. L. Storm, R. L. Rhillips, and R. A. Bishop. 1973. Survival and movements of transplanted and adopted red fox pups. J. Wildl. Manage. 37(1):69-72.

Archibald, H. L. 1974. Directional differences in the sound intensity of Ruffed Grouse drumming. Auk 91(3):517-521.

Archibald, H. L. 1975. Temporal patterns of spring space use by Ruffed Grouse. J. Wildl. Manage. 39(3):472-481.

Archibald, H. L. 1976. Spatial relationships of neighboring male Ruffed Grouse in spring. J. Wildl. Manage. 40(4):750-760.

Archibald, H. L. 1976. Spring drumming patterns of ruffed grouse. Auk 93(4):808-829.

Archibald, H. L. 1977. Is the 10-year wildlife cycle induced by a lunar cycle? Wild. Soc. Bull. 5(3):126-129.

Ball, I. J., D. S. Gilmer, L. M. Cowardin, and J. H. Riechmann. 1975. Survival of wood duck and mallard broods in north-central Minnesota. J. Wildl. Manage. 39(4):776-780.

Christenson, G., and M. R. Fuller. 1975. Food habits of two long-eared owl families in east-central Minnesota. Loon 47(2):58-61.

Fuller, M. R. 1975. A technique for holding and handling raptors. J. Wildl. Manage. 39(4):824-825.

Fuller, M. R., T. H. Nichols, and J. R. Tester. 1974. Rapter conservation and management applications of bio-telemetry studies from Cedar Creek Natural History Area. *In*: Hamerstrom, F. N., *et al*. (eds.), Management of Raptors. Proceedings of the Conf. on Raptor Conservation Techniques, 1973 (Part 4).

Fuller, M. R., P. T. Redig, and G. E. Duke. 1973. Raptor rehabilitation and conservation in Minnesota. Loon 45(2):50-55.

Fuller, M. R. and J. R. Tester. 1974. An automatic radio tracking system for biotelemetry. Raptor Res. 7(3/4):103-104.

Gilmer, D. S., I. J. Ball, L. M. Cowardin, J. E. Mathisen, and J. H. Riechman. 1978. Natural cavities used by wood ducks in north-central Minnesota. J. Wildl. Manage. 42(2):288-298.

Gilmer, D. S., I. J. Ball, L. M. Cowardin, and J. H. Riechmann. 1974. Effect of radio packages on ducks. J. Wildl. Manage. 38(2):243-252.

Gilmer, D. S., I. J. Ball, L. M. Cowardin, J. R. Riechmann, and J. R. Tester. 1975. Habitat use and home range of mallards breeding in Minnesota. J. Wildl. Manage. 39(4):781-789.

Gilmer, D. S., R. E. Kirby, I. J. Ball, and J. H. Riechmann. 1977. Post-breeding activities of mallards and wood ducks in north-central Minnesota. J. Wildl. Manage. 41(3):345-359.

Gilmer, D. S., S. E. Miller, and L. M. Cowardin. 1973. Analysis of radio-tracking data using digitized habitat maps. J. Wildl. Manage. 37(3):404-409.

Graul, W. D., S. R. Derrickson, and D. W. Mock. 1977. The evolution of avian polyandry. Amer. Nat. 3(980):812-816.

Gray, R. H., and J. M. Haynes. 1977. Depth distribution of adult chinook salmon (Oncorhynchus tshawytscha) in relation to season and gas-super-saturated water. Trans. Am. Fish. Soc. 106(6):617-620.

Gray, R. H. and J. M. Haynes. 1979. Spawning migration of adult chinook salmon carrying external and internal radio transmitters. J. Fish. Res. Board Can. 36:1060-1064.

Haynes, J. M. 1978. Movement and habitat studies of chinook salmon and white sturgeon. Pacific N.W. Lab., Richland, WA. PNL-2471, 65 pp.

Haynes, J. M., R. H. Gray, and J. C. Montgomery. 1978. Seasonal movements of white sturgeon (Acipenser transmontanus) in the mid-Columbia River. Trans. Am. Fish. Soc. 107(2):275-280.

Heezen, K. L., and J. R. Tester. 1967. Evaluation of radio-tracking by triangulation with special reference to deer movements. J. Wildl. Manage. 31(1):124-141.

Hessler, E., J. R. Tester, D. B. Siniff, and M. M. Nelson. 1970. A bio-telemetry study of survival of pen-reared pheasants released in selected habitats. J. Wildl. Manage. 34(2):267-274.

Hoskinson, R., J. R. Tester, R. Autenrieth, and O. D. Markhan. 1975. Antelope migrations in and near the INEL site. In: Markham, O. E. (ed.), Summaries of the Idaho National Engineering Laboratory Site Ecological Information Meeting, July 10, 11, 1975. Idaho Natl. Eng. Lab., IDO-12079, pp. 3-4.

Hoskinson, R. L., and J. R. Tester. 1980. Migration behavior of pronghorn antelope in southeastern Idaho. J. Wildl. Manage. 44(1):132-144.

Houseknecht, C. R. 1969. Denning habits of the striped skunk and the exposure potential for disease. Bull. Wildl. Disease Assoc. 5:302-306.

Houseknecht, C. R. 1970. Biotelemetry as a technique in disease ecology studies. J. Wildl. Diseases 6:414-417.

Houseknecht, C. R., and R. A. Huempfner. 1970. A red fox-striped skunk encounter. Amer. Midl. Naturalist 83(1):304-306.

Houseknecht, C. R., and J. R. Tester. 1978. Denning habits of striped skunks (*Mephitis mephitis*). Amer. Midl. Naturalist 100(2):424-430.

Huempfner, R. A., S. J. Maxson, G. J. Erickson, and R. J. Schuster. 1975. Recapturing radio-tagged ruffed grouse by nightlighting and snow-burrow netting. J. Wildl. Manage. 39(4):821-823.

Kirby, R. E. 1978. Roosting of passerines over open water at night. N. Amer. Bird Bander 3(3):104-105.

Kirby, R. E., J. H. Riechmann, and M. E. Shough. 1976. A preliminary report on Minnesota's innovative 1973 waterfowl season. Wildl. Soc. Bull. 4(2):44-63.

Kuechle, V. B. 1967. Batteries for biotelemetry and other applications. BioInstrumentation Advisory Council, Amer. Inst. Biol. Sci., Washington, D.C., Info. Module M10. 15 pp.

Kuechle, V. B., D. P. DeMaster, and D. B. Siniff. 1979. State of the art in needs of the earth platform for animal location systems. 13th Symp. on Remote Sensing, Ann Arbor, MI. 15 pp.

Kuechle, V. B., R. A. Reichle, K. E. Zinnel, and M. J. Ross. 1979. Use of a microprocessor to locate fish in experimental channels. Second Intl. Conf. Wildl. Biotelemetry, Laramie, Wyoming. pp. 33-39.

Maxson, S. J. 1977. Activity patterns of female ruffed grouse during the breeding season. Wilson Bull. 89(3):439-455.

Maxson, S. J. 1978. Evidence of brood adoption by ruffed grouse. Wilson Bull 90(1):132-133.

Maxson, S. J. 1978. Spring home range and habitat use by female ruffed grouse. J. Wildl. Manage. 42(1):61-71.

Maxson, S. J. 1978. Growth and behavior of ruffed grouse chicks. Loon 50(2):106-112.

Maxson, S. J. 1978. Ruffed grouse use of supraorbital combs in displays. Condor 80:240.

McColl, J. G., and S. J. Maxson. Phenological and nutrient studies of trembling aspen: a prime food source of ruffed grouse. Submitted, Ecology.

McKinney, F. 1965. The displays of the American Green-winged Teal. Wilson Bull. 77(2):112-121.

McKinney, F. 1965. An analysis of pair-formation in Anas crecca carolinensis. Bull. Ecol. Soc. Amer. 46(3):110-111 (Abstract).

McKinney, F. 1967. Breeding behavior of captive Shovelers. Wildfowl Trust, Ann. Rept. 18:108-121.

McKinney, F. 1968. Nest building movements performed by male ducks. Wildfowl Trust, Ann. Rept. 19:64-66.

McKinney, F. 1970. Displays of four species of blue-winged ducks. The Living Bird 9:29-64.

McKinney, F. 1972. Ecoethological aspects of reproduction. In: Breeding Biology of Birds. Natl. Acad. of Science. Washington, D.C.

McKinney, F. 1974. The evolution of duck displays. In: Evolutionary Aspects of Behaviour. Niko Tinbergen Festschrift. Clarendon Press, Oxford.

Mech, L. D. 1965. Sodium pentabarditol as an anesthetic for raccoons. J. Mammal. 46(2):343-344.

Mech, L. D. 1965. A critical evaluation of the concept of home range. Bull. Ecol. Soc. Amer. 46(3):121 (Abstract).

Mech, L. D., and N. V. Anderson. 1965. Renal hypoplasia and compensatory hypertrophy in a raccoon. J. Mammal. 47(1):128-129.

Mech, L. D., D. M. Barnes, and J. R. Tester. 1968. Seasonal weight changes, mortality, and population structure of raccoons in Minnesota. J. Mammal. 49(1):63-73.

Mech, L. D., K. L. Heezen, and D. B. Siniff. 1966. Onset and cessation of activity in cottontail rabbits and snowshoe hares in relation to sunset and sunrise. Animal Behavior 14(4):410-413.

Mech, L. D., V. B. Kuechle, D. W. Warner, and J. R. Tester. 1965. A collar for attaching radio transmitters to rabbits, hares, and raccoons. J. Wildl. Manage. 29:898-902.

Mech, L. D., and J. R. Tester. 1965. Biological, behavioral, and physical factors affecting home ranges of snowshoe hares, raccoons, and white-tailed deer under natural conditions. Minn. Mus. Nat. Hist. Tech. Rept. 9, 11 pp. mimeo.

Mech, L. D., J. R. Tester and D. W. Warner. 1966. Fall daytime resting habits of raccoons as determined by telemetry. J. Mammal. 47(3):450-466.

Mech, L. D., and F. Turkowski. 1966. Twenty-three raccoons in one winter den. J. Mammal. 47(3):529-530.

Montgomery, G. G. 1974. Communication in red fox dyads: a computer similation study. Smithsonian Contributions to Zoology, Smithsonian Institution Press, Washington 187:1-30.

Montgomery, G. G., J. W. Lang, and M. E. Sunquist. 1970. A raccoon moves her young. J. Mammal. 51(1):202-203.

Nicholls, T. H., and D. W. Warner. 1972. Barred owl habitat use as determined by radio telemetry. J. Wildl. Manage. 36(2):213-224.

Phillips, R. L., R. D. Andrews, G. L. Storm, and R. A. Bishop. 1972. Dispersal and mortality of red foxes. J. Wildl. Manage. 36(2):237-248.

Preston, E. M. 1973. Computer simulated dynamics of a rabies-controlled fox population. J. Wildl. Manage. 37(4):501-512.

Redig, P. T., M. R. Fuller, and D. Evans. 1974. Techniques for determining some biomedical parameters of migrating raptors. Pp. 151-154. In: The Proceedings of the North American Hawk Migration Conference. Michael Harwood, ed. Hawk Migration Association of N. American, Washington, Connecticut. 165 pp.

Rongstad, O. 1969. A bull snake encounter with young ground squirrels. Minn. Acad. Sci. 35(2-3):95-96.

Rongstad, O. J., and J. R. Tester. 1969. Movements and habitat use of white-tailed deer in Minnesota. J. Wildl. Manage. 33(2):366-379.

Rongstad, O. J., and J. R. Tester. 1971. Behavior and maternal relations of young snowshoe hares. J. Wildl. Manage. 35(2):338-346.

Ross, M. J., V. B. Kuechle, R. A. Reichle, and D. B. Siniff. 1979. Automatic radio telemetry recording of fish temperature and depth. Second Intl. Conf. Wildl. Biotelemetry, Larmie, Wyoming. pp. 238-247.

Sanderson, G. C., L. D. Mech, and J. H. Schnell. 1971. A contribution to a bibliography of the raccoon (Procyon lotor). U.S. Atomic Energy Commission, Division of Tech. Info., 82 pp.

Schladweiler, J. L., and I. J. Ball. 1968. Telemetry bibliography emphasizing studies of wild animals under natural conditions. Bell Mus. Nat. Hist. Tech. Rept. 15, 31 pp. Mimeo.

Schneider, D. G., L. D. Mech, and J. R. Tester. 1966. An eight-month radio-tracking study of raccoon families. Bull. Ecol. Soc. Amer. 47(3):149-150 (Abstract).

Schnell, J. H. 1970. Rest site selection by radio-tagged raccoons. J. Minn. Acad. of Science 36(2-3):83-88.

Seal, U. S., and R. L. Hoskinson. 1978. Metabolic indicators of habitat condition and capture stress in pronghorns. J. Wildl. Manage. 42(4):755-763.

Siniff, D. B., D. P. DeMaster, R. J. Hofman, and L. L. Eberhardt. 1977. An analysis of the dynamics of a Weddell seal population. Ecological Mono. 47(3):319-335.

Siniff, D. B. 1966. Computer programs for analyzing radio-tracking data. Minn. Mus. Nat. Hist., Tech. Rept. 12, 10 pp. Mimeo.

Siniff, D. B., and J. R. Tester. 1965. Computer analysis of animal movement data obtained by telemetry. BioScience 15(2):104-108.

Siniff, D. B., and C. R. Jessen. 1969. A simulation model of animal movement patterns. Advances Ecological Res. 6:185-219.

Storm, G. L., R. D. Andrews, R. L. Phillips, R. A. Biship, D. B. Siniff, and J. R. Tester. 1976. Morphology, reproduction, dispersal, and mortality of midwestern red fox populations. Wildlife Mono. 49:1-82.

Storm, G. L., and G. G. Montgomery. 1975. Dispersal and social contract among red foxes: results from telemetry and computer simulation. <u>In</u>: Fox, M. W. (ed.), The Wild Canids, Van Nostrand Reinhold Co., New York, pp. 237-246.

Sunquist, M. E. 1967. Effects of fire on raccoon behavior. J. Mammal. 49(4):673-674.

Sunquist, M. E. 1975. Winter activity of striped skunks (<u>Memphitis memphitis</u>) in east-central Minnesota. Amer. Midl. Naturalist 92(2):434-446.

Sunquist, M. E., G. G. Montgomery, and G. L. Storm. 1969. Movements of a blind raccoon. J. Mammal. 50(1):145-147.

Swanson, G. Q., V. B. Kuechle, and A. B. Sargeant. 1976. A telemetry technique for monitoring diel waterfowl activity. J. Wildl. Manage. 40(1):187-190.

Tester, J. R. 1965. Status and value of biotelemetry in studies of vertebrate ecology. Congress des Biol. du Gibier. 7:195-199.

Tester, J. R. 1966. Automatic radio-tracking system for studying animal movement and behavior (motion picture). Bull. Ecol. Soc. Amer. 47(3):156.

Tester, J. R. 1966. Potential of radio-tracking in studies of vertebrate behavior. Proc. Engineering in Medicine and Biol. 19:155 (Abstract)

Tester, J. R. 1971. Interpretation of ecological and behavioral data on wild animals obtained by telemetry with special reference to errors and uncertainties. In: Symp. on Biotelemetry, Pretoria, South Africa, November 1971, pp. 385-408.

Tester, J. R. 1978. Analysis of circadian rhythms of free-ranging mammals. Biotelemetry IV, Proc. 4th Intl. Symp. Biotelemetry, Garmisch-Parten-kirchen, Germany, pp. 167-170.

Tester, J. R., F. McKinney, and D. B. Siniff. 1968. Mortality of three species of ducks, Anas discors, A. crecca, and A. clypeata, exposed to ionizing radiation. Radiation Res. 33:364-370.

Tester, J. R., and J. C. Moulton. 1965. Movements and activity of pen-raised white-tailed deer (Odocoileus virginianus) after release in unfamiliar habitat. Bull. Ecol. Soc. Amer. 46(3):121 (Abstract).

Tester, J. R., and D. B. Siniff. 1965. Aspects of animal movement and home range data obtained by telemetry. Trans. N. Amer. Wildl. Conf. 30:379-392.

Tester, J. R., and D. B. Siniff. 1974. Relevance of home range concepts to game biology. Interl. Cong. of Game Biologists 11:287-296.

Tester, J. R., D. B. Siniff, and C. R. Jessen. 1969. Use of telemetry as a means of studying spacing and behavior of animals. In: Esser, A. H. (ed.), Behavior and Environment, The Use of Space by Animals and Men. Plenum Press, New York, pp. 117-120.

Tester, J. R., D. B. Siniff, and O. J. Rongstad. 1967. Effects of radiation on behavior of unconfined raccoons and snowshoe hares determined by telemetry. Amer. Zoologist 7(4):404 (Abstract).

Tester, J. R., J. W. Ternes, and D. B. Siniff. 1977. Behavior and mortality of free-ranging raccoons, snowshoe hares, and striped skunks after exposure to 300 R gamma radiation. Radiation Res. 69:500-512.

Thorkelson, J., and R. K. Maxwell. 1973. Design and testing of a heat transfer model of a raccoon (Procyon lotor) in a closed tree den. Ecology 55(1):29-39.

Turkowski, F., and L. D. Mech. 1968. An intensive analysis of the movements of a young male raccoon. J. Minn. Acad. Sci. 35(1):33-38.

Williams, T. D., and F. H. Kocher. 1978. A comparison of anesthetic agents in the sea otter. J. Am. Vet. Med. Assoc. 173:1127-1130.

Winter, J. D. 1977. Summer home range movements and habitat use by four largemouth bass in Mary Lake, Minnesota. Trans. Am. Fish. Soc. 106(4):323-330.

Winter, J. D., V. B. Kuechle, D. B. Siniff, and J. R. Tester. 1978. Equipment and methods for radio tracking freshwater fish. Univ. Minn. Agric. Exp. Sta., Misc. Rept. 152, 18 pp.

THESES

Abraham, R. L. 1971. An analysis of mallard vocalizations. Univ. Minn., M.S. Thesis.

Archibald, H. L. 1973. Spring drumming activity and space use of ruffed grouse. Univ. Minn., Ph.D. Thesis.

Ball, I. J. 1971. Movements, habitat use and behavior of wood duck (*Aix sponsa*) broods in north-central Minnesota as determined by radio tracking. Univ. Minn., M.S. Thesis.

Ball, I. J. 1973. Ecology of waterfowl broods in a forested region of north-central Minnesota. Univ. Minn., Ph.D. Thesis.

Barrett, Julie. 1973. Breeding behavior of captive mallards. Univ. Minn., M.S. Thesis.

Bland, M. E. 1977. Daily and seasonal activity patterns in the eastern gray squirrel. Univ. Minn., Ph.D. Thesis.

Fuller, M. R. 1979. Spatiotemporal ecology of four sympatric raptor species. Univ. Minn., Ph.D. Thesis.

Gilmer, D. S. 1971. Home range and habitat use of breeding mallards (*Anas platyrhynchos*) and wood ducks (*Aix sponsa*) in north-central Minnesota as determined by radio tracking. Univ. Minn., Ph.D. Thesis.

Gull, J. 1977. Movement and dispersal patterns of immature gray squirrels (*Sciurus carolinensis*) in east-central Minnesota. Univ. Minn., M.S. Thesis.

Haynes, J. M. 1978. Movement and habitat studies of chinook salmon and white sturgeon. Univ. Minn., Ph.D. Thesis.

Heezen, K. L. 1965. Evaluation of animal-location data obtained by triangulation with observations on winter and spring movements of white-tailed deer in Minnesota. Univ. Minn., M.S. Thesis.

Hessler, E. W. 1968. Survival of ring-necked pheasants released in selected habitats in Minnesota. Univ. Minn., M.S. Thesis.

Hoskinson, R. L. 1977. Migration behavior of pronghorn antelope and summer movements and fall migration of pronghorn fawns in southeastern Idaho. Univ. Minn., Ph.D. Thesis.

Houseknecht, C. R. 1971. Movements, activity patterns and denning habits of striped skunks (*Mephitis mephitis*) and the exposure potential for disease. Univ. Minn., Ph.D. Thesis.

Kirby, R. E. 1976. Fall movements, behavior and habitat use of young waterfowl in north-central Minnesota. Univ. Minn., Ph.D. Thesis.

March, J. R. 1967. Dominance relations and territorial behavior in captive shovelers (Anas clypeata). Univ. Minn., M.S. Thesis.

Maxson, S. J. 1974. Acitivity, home range, and habitat usage of female ruffed grouse during the egg-laying, incubation, and early brood periods as determined by radio telemetry. Univ. Minn., M.S. Thesis.

Montgomery, G. G. 1973. Communication in red fox dyads: a computer simulation study. Univ. Minn., Ph.D. Thesis.

Moulton, J. C. 1966. Movement and activity of three white-tailed deer during the winter of 1964-1965 in east-central Minnesota determined by telemetry. Univ. Minn., M.S. Thesis.

Nicholls, T. H. 1973. Ecology of barred owls as determined by an automatic radio-tracking system. Univ. Minn., Ph.D. Thesis.

Riechmann, J. H. 1976. Factors affecting home range of mallard pairs. Univ. Minn., M.S. Thesis.

Stolen, P. D. 1974. Fall and winter movements and activity of muskrats in east-central Minnesota. Univ. Minn., M.S. Thsis.

Winter, J. D. 1976. Movements and behavior of largemouth bass (Micropterus salmoides) and steelhead (Salmo gairdneri) determined by radio telemetry. Univ. Minn., Ph.D. Thesis.

Zinnel, K. C. 1980. Behavior of walleye pike in experimental channels as monitored by a micro-computer utilizing radio telemetry. Univ. Minn., M.S. Thesis.

LIST OF THESES AND PUBLICATIONS SUBMITTED WITH THIS PROPOSAL

Gray, R. H. and J. M. Haynes 1979. Spawning migration of adult chinook salmon carrying external and internal radio transmitters. J. Fish. Res. Board Can. 36:1060-1064.

Hoskinson, R. L. and J. R. Tester 1980. Migration behavior of pronghorn in southeastern Idaho. J. Wildl. Manage. 44(1):132-144.

Kuechle, V. B., D. P. DeMaster and D. B. Siniff 1979. State of the art and needs of the earth platform. Proc. 13th Symp. Remote Sensing, Ann Arbor, Mich. 15 pp.

Kuechle, V. B., R. A. Reichle, K. E. Zinnel and M. J. Ross 1979. Use of a microprocessor to locate fish in experimental channels. Proc. Second Intl. Conf. Wildl. Biotelemetry, Laramie, Wyo. pp. 33-39.

Ross, M. J. V. B. Kuechle, R. A. Reichle and D. B. Siniff 1979. Automatic radio telemetry recording of fish temperature and depth. Proc. Second Intl. Conf. Wildl. Biotelemetry, Laramie, Wyo. pp. 238-247.

EFFORT REPORT

	Percent Effort Devoted to Project
Dr. J.R. Tester, Principal Investigator	
October 16, 1979 through June 15, 1978	33%
June 16, 1980 through October 15, 1980	42%
Dr. D.B. Siniff, Principal Investigator	
October 16, 1979 through June 15, 1980	9%
June 16, 1980 through October 15, 1980	37%
Mr. V.B. Kuechle	
October 16, 1979 through June 15, 1980	20%
June 16, 1980 through October 15, 1980	20%