A TELEMETRIC STUDY OF HOMING AND HOME RANGE OF FLATHEAD CATFISH, *PYLODICTIS OLIVARIS* (RAFINESQUE), IN A 850 HECTARE OKLAHOMA RESERVOIR

By

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OKLAHOMA RESERVOIR

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PREFACE

Few in situ observations of fish movements in reservoirs have been described because heretofore methods for tracking free-ranging fish were not available. The objectives of this study were to apply telemetric tracking techniques to investigate movements of flathead catfish in a reservoir. Twenty-eight flathead catfish were tracked for an average 18.66 days. I would hope this study would not only enlighten fishery scientists and managers of behavioral aspects of flathead catfish, but inspire them to apply telemetric techniques to other fishes as well.

I would like to express my sincere appreciation to Dr. Robert C. Summerfelt, Leader of the Oklahoma Cooperative Fishery Unit, for serving as my committee chairman and advisor. His persistent enthusiasm throughout the field work and during preparation of this manuscript resulted in not only the successful completion of this project but establishment of a lasting friendship as well. I also wish to thank Dr. Austin K. Andrews, Assistant Leader of the Oklahoma Cooperative Fishery Unit, and Dr. Ronald W. McNew, Statistics Department, for serving on my advisory committee and for their constructive criticism of this manuscript.

I would also like to thank all those who collected data with special consideration to Mr. Paul Turner, Mr. Phillip Keasling, Mr. Robert Tafanelli, Mr. Ronald Boyer and Mr. Raymond Harrison. The assistance of Mrs. Helen Murray, Unit Secretary, and Mrs. Cathy

McNabb in typing and plotting data is appreciated.

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Special recognition is due my wife, Patricia, for her patience and understanding during the many nights I was "on the lake, chasing a darned old catfish."

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CHAPTER I

INTRODUCTION

Movements of fishes have intrigued man for at least the last half-century. A naturalist once remarked that, among the many riddles of nature, not the least mysterious is the migration of fishes (Hasler 1966). Mark-and-recapture methods used to study fish movements were developed as early as the late 1800's (Jones 1968). Migration routes of salmon and eels have been described by recapture of fish marked by the traditional tagging methods.

Investigations of the movements of fishes other than catadromous and anadromous species began on a large scale in the 1930's, usually as a secondary result of mark-and-recapture studies of harvest, mortality and population estimates. Recapture data indicated homing ability in twenty-one species of fishes in diverse taxonomic groups (Gerking 1959). Return of a displaced fish to a site formerly occupied implies that the fish has delineated a portion of its habitat as a home range. Gunning (1959) defined homing as a return to a home range, and thirty-four species of fish have been recognized as having restricted movements (a home range) (Gerking 1959). Undoubtedly many other fishes have homing ability and associated home range behavior.

Knowledge of homing ability and home range is of practical importance to fishermen, fishery biologists and biological scientists. Both sport and commercial fishermen can use data on characteristics of the home range to select productive fishing sites. Home range dimensions can aid in a commercial fisherman's prognosis of fishing success in a heavily fished portion of a reservoir or river. Homing ability and home range dimensions are essential conceptualizations needed to obtain adequate population sampling and to measure population distribution. The latter is needed to assess the effects of heavy fishing pressure on part of a body of water and for determining some of the factors affecting dense populations as might be found in fish culture ponds. Biological scientists could use such data in bioenergetic investigations and ecosystem modeling.

Homing and home range of flathead catfish, *Pylodictis olivaris* (Rafinesque), are described in this report from telemetric observations of 28 flathead catfish in Lake Carl Blackwell, Oklahoma. Homing ability and home range are described from 1190 telemetric observations of 22 flathead catfish captured from and tracked in Lake Carl Blackwell and from an additional 456 observations of 6 flathead catfish captured from Boomer Lake but released in Lake Carl Blackwell. The Boomer Lake fish were introduced for comparison with native Lake Carl Blackwell fish. Restricted movements of tagged flathead catfish in Missouri streams reported by Funk (1955) suggest a home range tendency, but home range size was not ascertained and homing ability was not investigated. Flathead catfish captured from the Missouri River in Nebraska were equipped with ultrasonic transmitters, but attempts to follow the fish were unsuccessful (Morris 1968).

CHAPTER II

HOMING BEHAVIOR OF FLATHEAD CATFISH, *PYLODICTIS OLIVARIS* (RAFINESQUE), TAGGED WITH ULTRASONIC TRANSMITTERS

Introduction

Observations on behavior of displaced fish show that many fish recognize a home area and have the sensory capability to traverse great distances of presumably unknown area to return to their home (Hasler 1966). Mark-and-recapture procedures generally provide insufficient observations to adequately describe the movements of a free-ranging fish without prodigious effort to obtain recaptures. Where frequent recaptures are possible, as in small streams, behavior of a fish may be altered due to trauma associated with methods of capture. Development of transmitters applicable to placement in or on fish, i.e., ultrasonic-transmitter-equipped fish, provides an opportunity for continuous surveillance without the disturbance of recapture. Telemetry tracking can make a significant contribution to accurate study of homing, home range, activity levels, habitat preference, and correlations between movements and environmental variables.

Movements of flathead catfish in Missouri streams have been observed by mark-and-recapture techniques but homing behavior was not investigated (Funk 1955). Efforts to follow movements of flathead catfish carrying ultrasonic tags in the Missouri River, bordering Nebraska-Iowa, were unsuccessful (Morris 1968). Thus, mark-and-recapture techniques and ultrasonic tracking procedures heretofore applied to studies on flathead catfish in streams have not ascertained the existence of homing ability. In the present study in Lake Carl Blackwell, Oklahoma, ultrasonic telemetry methods were used to track displaced flathead catfish to their previous home area. Behavior of non-displaced fish was also observed for comparison. Homing is described from 1190 telemetric observations of site locations of 22 flathead catfish and observations on 4 of 18 displaced flathead catfish recaptured after tagging with butt-end and anchor tags.

Description of Study Area

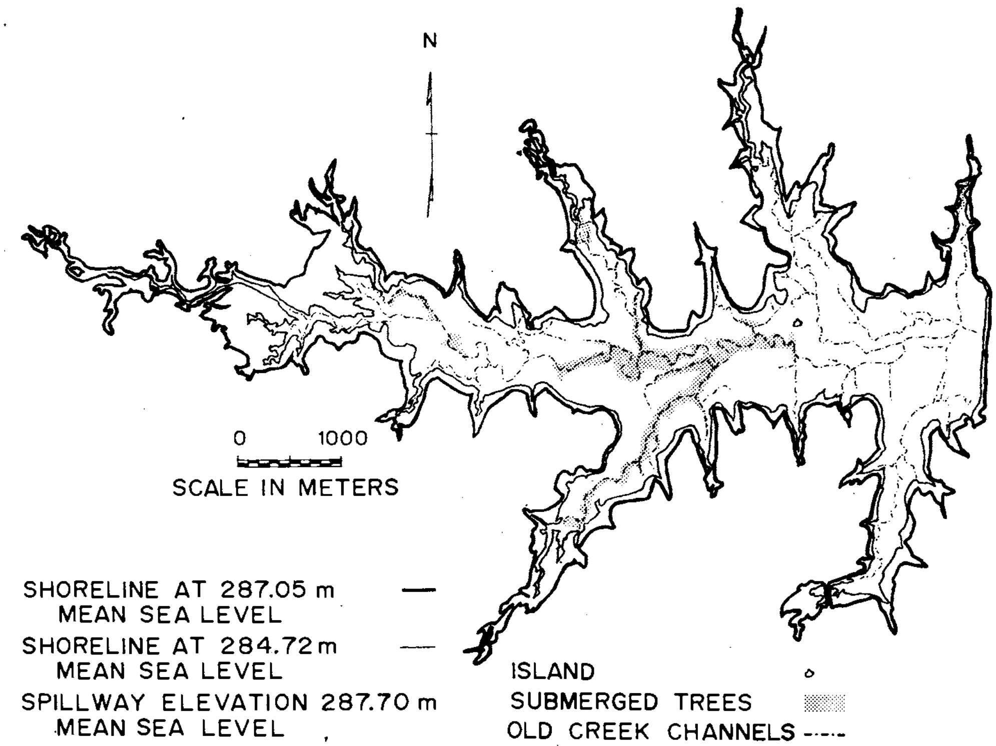
Lake Carl Blackwell (Figure 1), located 12.8 km west of Stillwater, Oklahoma, is an impoundment of Stillwater Creek. The reservoir lies in Payne County, north-central Oklahoma, in the Permian red-beds physiographic region. At the time of the study, with the lake surface 3.4 m below spillway elevation (284 m above mean sea level), the main east-west axis was 5.3 km long, with several arms extending north and south. At this lake elevation, the surface area was approximately 850 ha, the volume was 33.9 million cubic meters, and the average depth was 4.0 m.

Methods and Materials

Equipment

Ultrasonic transmitters and receiving equipment were purchased from a commercial source (Smith-Root Electronics, Seattle, Washington).

FIGURE 1. Location of creek channels and distribution of submerged trees in the Lake Carl Blackwell basin.


N
0 1000
SCALE IN METERS
SHORELINE AT 287.05 m MEAN SEA LEVEL
SHORELINE AT 284.72 m MEAN SEA LEVEL
SPILLWAY ELEVATION 287.70 m MEAN SEA LEVEL
ISLAND
SUBMERGED TREES
OLD CREEK CHANNELS

The 74 kHz/second ultrasonic transmitters were cylindrical in shape, 90 mm long by 19 mm in diameter; after paraffin coating and with battery they weighed 29.5 g in water; they had a specific gravity of 1.09. The transmitter weight comprised 0.6% of the average weight (5.13 kg) of all 22 flathead catfish. The receiver measured 178 mm long by 165 mm wide by 102 mm high and weighed 1.5 kg (not 6.6 kg as was erroneously reported by Summerfelt and Hart 1972). The hydrophone weighed 2 kg and consisted of a hydrophone cone (maximum diameter 145 mm) positioned on the end of a 156 cm submersible shaft. The performance of this equipment in Lake Carl Blackwell has been described by Summerfelt and Hart (1972).

Capture, Selection and Tagging of Fish

Flathead catfish were captured from Lake Carl Blackwell in hobbled gill nets. At the time of capture, each fish was tagged for individual recognition with an anchor and a butt-end tag (Summerfelt et al. 1972). The anchor tag was placed through an operculum and the butt-end tag was clamped around the base of a pectoral spine. Fish used for mark-and-recapture observations of homing were displaced to another part of the reservoir for immediate release.

Fish used for transmitter tracking were selected from fish which lacked gill net lesions or other visible injury. These fish were sexually mature and averaged 720 mm total length and 5.13 kg total weight. Fish to be used for telemetry were transported to our laboratory at Oklahoma State University where they were placed in 610 liter tanks with a continuous flow (about one liter/minute) of dechlorinated tap water from Lake Carl Blackwell. Ultrasonic transmitters were surgically implanted according to procedures described by Hart and Summerfelt (1974). Fish were anesthetized twice, first during surgery and second during the return trip to the lake. Elapsed time between capture and release was as much as 10 days, averaging 4.4 days for the first 10 fish and 2 days for the last 12 fish. Surgical implantation of transmitters into the peritoneal cavity proved to be a desirable technique for tagging flathead catfish with transmitters (Summerfelt et al. 1972).

Releasing and Tracking Methods

Fish were transported from the laboratory to the lake in a semi-anesthetized condition (12 ppm quinaldine), released at a predetermined location and tracked continuously for at least one hour. Fish were released along the shoreline or, when released offshore, they were held in a submersed plastic basket until completely recovered from the anesthetic. Ten fish (designated non-displaced fish) were released near the closest shore to the site of capture. The distance from site of capture to release point averaged 289 meters. Fish were released near shore rather than at the site of capture because visual observation of the released fish during the initial recovery period was facilitated in shallow water. Twelve fish (designated displaced fish) were moved a minimum water distance of 1.3 to 2.7 km (mean 1.9 km) from the site of capture to ascertain homing ability. The first 8 of the displaced fish were tracked continuously for 48 hours; then their location was checked once every 6 hours. Due to the high cost of continuous surveillance, the last 14 fish were checked once every 6 hours after tracking continuously for the first hour.

In tracking an ultrasonic-transmitter-equipped fish, the last location (fix) noted from the previous check was used as a point to begin searching and a search was made in the apparent direction of travel, as suggested from previous map locations. When a fish was not located near the site of a previous fix, then a systematic check was made of other habitats where flathead catfish were frequently found. When both procedures failed to locate the fish, then a systematic transect survey was made for one or two hours daily for a week or more, depending on the probability of the transmitter still functioning.

The transmitter signal was sought by lowering the hydrophone cone about 60 cm beneath the water surface and rotating it 360^{o} while listening for the signal with the aid of earphones. After obtaining a signal, the boat was driven closer to the assumed location, then the hydrophone lowered and the signal sought again. The procedure was repeated until a maximum signal was obtained directly below the boat. In some cases, it was not necessary to obtain direct positioning over the fish to obtain a location because, after obtaining alignment from several positions around the fish, the location became obvious. In rare instances, fish appeared to move away from the boat if approached too closely; thereafter, location of that fish was approximated within the center of a 25 m^2 block rather than from positioning directly over the fish. After the fish was located, the map location was obtained in one of the following ways: (1) locating the fish directly on the map in reference to transect lines, using a dot to represent the site; (2) estimating distance and direction from a permanent reference site; (3) by triangulation from permanent reference sites and transect lines.

The number of fixes obtained for each fish was a function of the longevity of the transmitter and ability of the personnel to find the fish. During continuous surveillance, the search and location procedure gave as many fixes as needed to record the movement of the fish. When monitoring was reduced to four daily checks, a search was maintained until a fix was obtained; then the observer searched for the next fish. When a fish was moving, however, the observer stayed with the fish for up to an hour, giving additional fixes.

Using observations at six-hour intervals, 1565 fixes would have been the maximum number obtained on the 22 fish, considering the average longevity of the transmitters. Not all scheduled checks were made because fish were occasionally lost and inclement weather or equipment malfunction eliminated 25% of the scheduled checks. The quarterly tracking procedure did yield 1190 fixes for 22 fish which was 75% of the maximum number.

Average tracking time for a fish was 18.66 days--7.55 days less than expected transmitting life determined in a performance evaluation of the transmitters (Summerfelt and Hart 1972), and 41.34 days less than the manufacturer's advertised "useful life." The discrepancy between the length of time the fish were followed and the expected transmitting life indicated that most fish were lost before the transmitter ceased to function. This could have occurred if a fish got beneath stumps or logs or beneath a deep, narrow, submerged creek channel, causing attenuation or blockage of signal transmission.

Precision of Techniques

The precision of map locations representing the travels of a fish under study was influenced by discrepancy between true and apparent location of the fish and precision of the observer in reconnoitering and transposing a fix to a map point. Based on observations of the azimuth deviation in ponds (Summerfelt and Hart 1972) and observations in ponds on movement of transmitter-tagged flathead catfish which also had a bobber-tag, we assumed a linear precision on the reservoir within 5 meters, making location precision an area of 25 m^2. This is a minimal precision influenced somewhat by wave action and signal echoes, however, the dot size on the map (scale = 15.81 m/mm, or ca 250 m^2 per mm^2) was about 0.7 - 1.0 mm diameter, which covered 96 to 196 m^2 lake area. The slight error in locating fish in the reservoir was only 13 to 26% of the map area occupied by the dot representing a fix; therefore, actual location error in the reservoir appears inconsequential in comparison to the error in transposing the observed location to the map.

A reasonable estimate of the error in transposing lake locations to the map may have been as much as two mm (ca 32 mm) on the map for a single transposition. In subsequent locations within 300 m of a previous map location, the transposition error would appear to be less than one mm (15.81m) map distance because the new map location was referenced in relation to the previous map location.

Determination of Homing

Determination of homing of fishes has been assessed in several ways. Homing of stream fishes has been assessed by recapturing the fish in a "home pool." Anadromous fish are usually considered to have homed when recaptured in a stream where they had been captured prior to seaward migration. Homing of lake and reservoir fishes has often been associated with recapturing a fish in the same cove or along the same shoreline as originally captured. Using telemetric tracking of a displaced fish, a decision on whether a fish has homed depends on how close the fish must come to its original capture location to be considered a homed fish. Gunning's (1959) definition of homing as the return of a fish to its original home range seemed more rational than requiring return to an exact recapture point. Gunning's definition, however, requires knowledge of the fish's home range prior to displacement, which is usually unavailable, or an assumption that an average home range for the same species in the same habitat is an appropriate approximation.

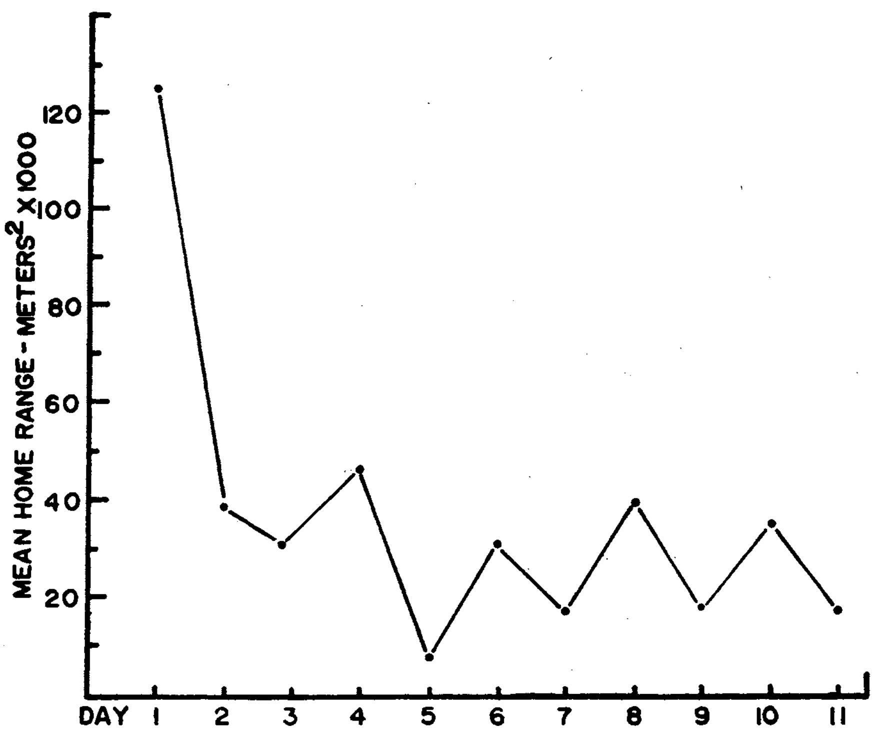
The original home range was estimated by a circular home range procedure based on recapture radii computed by the methods of Dice and Clark (1953) and Calhoun and Casby (1958). Recapture radii were determined by first giving each fix a Cartesian coordinate (x and y value). Then all x and y values were averaged to yield a mean x and y location, the center of activity. Finally, the recapture radii were determined by calculating the distance between each fix to the center of activity. All recapture radii for a single fish were then arranged in ascending order and a radius of sufficient length selected which contained 95% of all radii for that fish. The mean 95% recapture radius was 494 meters, and a fish was considered to have homed if it was located within 494 m of the original capture location.

Results

Adjustment Period

Daily home ranges in the first 1.5 days after release were abnormally large (Figure 2), indicating movements within the first 1.5 days constitute an adjustment period when behavior appears atypical.

FIGURE 2. Mean daily home range of Lake Carl Blackwell flathead catfish during the first 11 days after release.


MEAN HOME RANGE - METERS² X 1000
120
100
80
60
40
20
DAY 1 2 3 4 5 6 7 8 9 10 11

Shepherd's (1973) reports on behavior of transmitter-bearing rainbow trout released in tanks suggest they also have an adjustment period of approximately one day. In the present study, movements in the 1.5 day adjustment period are not included in determinations of homing or home range.

Homing

Most of 22 ultrasonic-transmitter-equipped fish accurately homed while mark-and-recapture observations of 18 displaced fish gave no indication of homing. Eight (67%) of the 12 displaced fish and 8 (80%) of the 10 non-displaced fish homed (Table 1). The average homing accuracy, the distance from the original capture location to the closest fix, was within 182 m for displaced fish and 588 m for non-displaced fish. Using conventional mark-and-recapture techniques, only 4 of 18 displaced fish were recaptured and none exhibited homing behavior. Although a major gill netting effort was underway during the period of study to estimate flathead catfish population density by mark-and-recapture methods, only 1 of 12 displaced transmitter-tagged fish was recaptured during this study.

A good characterization of homing ability was demonstrated by a female flathead catfish, code 226, which returned to the capture site (Figure 3). Displaced a distance of not less than 1817 m, it homed a distance of 2316 m within 39.5 hours of release. It came within 47 m of the initial recapture site within only 16.7 hours, but passed about 174 m beyond it. In its homing journey the fish selected the deeper (3 m) but longer passage around the outside of an island rather than a shorter route through shallow water (0.5 m). Observations on depth

TABLE 1. Homing behavior, displacement distance and homing accuracy (the linear distance from the original capture location to the closest fix) of displaced and non-displaced Lake Carl Blackwell flathead catfish.

Displaced fish							Non-displaced fish					
Code	Sex	Homing behavior	Behavior pattern	Displacement distance (m)	Homing Accuracy (m)	Tracking time (days)	Code	Sex	Homing behavior	Behavior pattern	Closest fix (m)	Tracking time (days)
211	M	yes	3	2237	316	26.1	311	M	no	3	1249	11.1
212	M	yes	3	1960	24	16.8	312	M	yes	2	134	7.4
213	M	yes	4	1739	494	22.9	313	M	yes	1	55	15.7
221	F	no	3	1407	1091	7.7	314	M	yes	1	308	10.4
222	F	no	5	1289	648	25.8	321	F	yes	2	340	8.0
223	F	yes	4	2174	117	5.4	322	F	no	3	3241	26.9
224	F	no	3	1858	822	35.1	323	F	yes	2	63	33.5
225	F	yes	4	1700	71	23.9	324	F	yes	1	190	26.3
226*	F	yes	3	1817	0	1.9	325	F	yes	5	206	7.8
227	F	yes	4	1858	277	19.8	326	F	yes	1	95	9.5
228	F	yes	3	2672	126	6.4						
231	?	no	4	1486	783	19.3						

*Fish 226 was sacrificed after injuring itself in a gill net 1.9 days after release.

FIGURE 3. Homing of a displaced female flathead catfish (fish code 226). Numbers represent days after release.


Release site
.1
.3
.4
Capture and
recapture site
1.7
.7
1.0
N
500 meters

distribution indicate that flathead catfish in Lake Carl Blackwell rarely travel into water of less than 3.5 m.

Major Behavior Patterns

Behavior patterns of ultrasonic-transmitter-equipped fish were categorized as follows: (1) behavior pattern 1 (Figure 4)--established a small home range close to the release site and stayed within the home range; (2) behavior pattern 2 (Figure 5)--as in behavior pattern 1, but made sallies (defined by Burt 1943) outside the home range; (3) behavior pattern 3 (Figure 6)--left the release area, traveled extensively, then established a small home range and stayed within the home range; (4) behavior pattern 4 (Figure 7)--as in behavior pattern 3, but made sallies outside the home range; and (5) behavior pattern 5 (Figure 8)--established a large home range and made widely extended movements within it. All displaced fish, regardless of whether or not they homed, moved away from their release site before establishing a home range, thus exhibiting behavior patterns 3, 4 and 5 (Table 2). Most non-displaced fish (70%) exhibited behavior patterns 1 or 2, indicating a preference for the release site. The behavior of non-displaced fish suggests familiarity with environmental stimuli of the release area as those of their previous home range, thus preference for establishment of their home range in the same area. The type 3 and 4 behavior of displaced fish suggests a searching behavior of fish seeking their previous home or other suitable habitat.

Site Recognition

Another type of homing behavior occurred when a fish spontaneously left its home range (made a sally) then returned. This is homing in

FIGURE 4. Behavior pattern category 1, illustrated by fish code 326, where the fish established a home range near site of release and stayed within the home range.

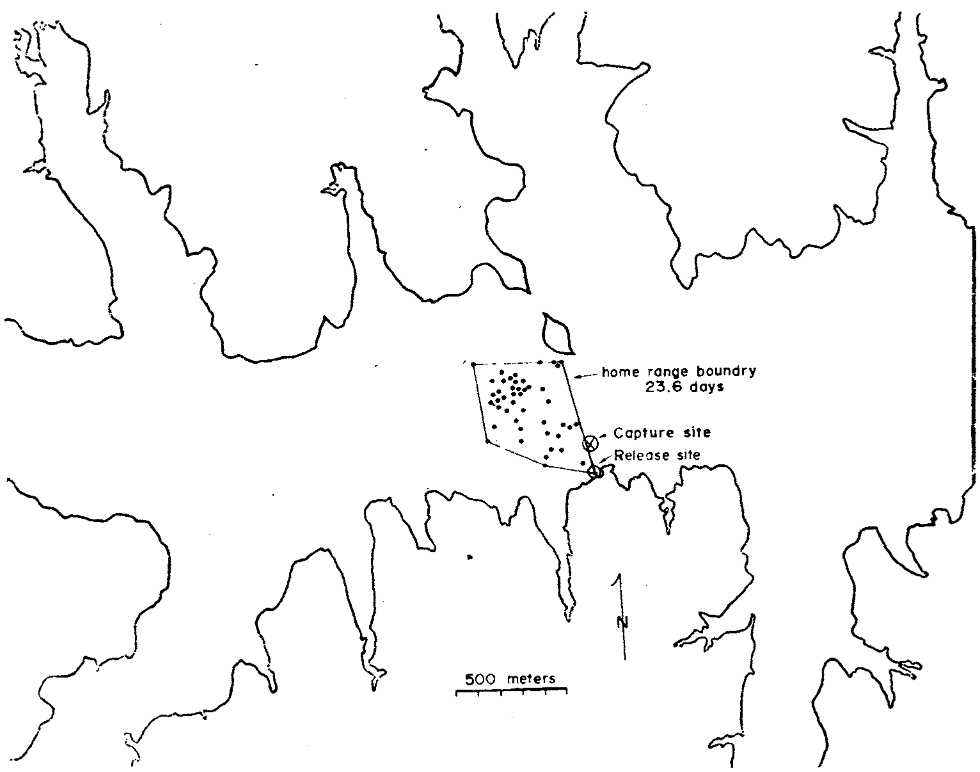

home range boundry
23.6 days
Capture site
Release site
N
500 meters

FIGURE 5. Behavior pattern category 2, illustrated by fish code 312, where the fish established a home range near site of release but made sallies. The fish spent 74% of tracking time within the home range boundary. Release site represented by "x" and original capture location represented by "⊕".

FIGURE 6. Behavior pattern category 3, illustrated by fish code 212, where the fish traveled from release site and established a home range which included the original capture site. Four of eight fish which were placed in this category homed. Release site represented by "x" and original capture location represented by "⊕".

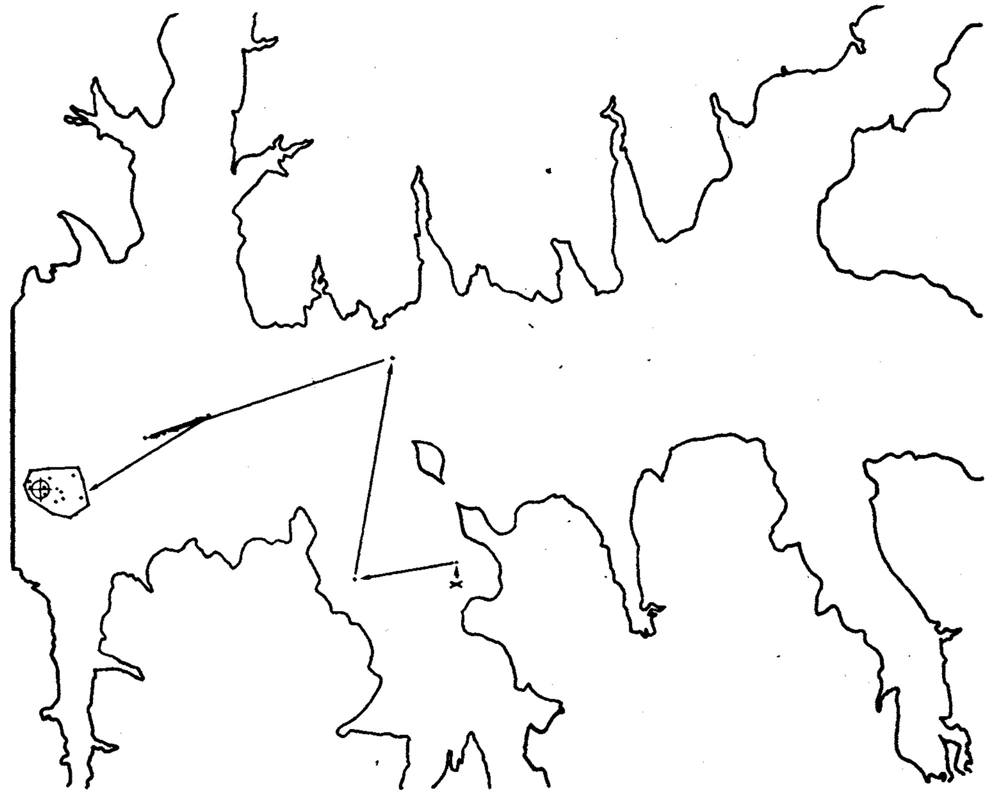


FIGURE 7. Behavior pattern category 4, illustrated by fish code 213, where the fish left the release site, established a home range, but made lengthy sallies. Numbers represent days after release.

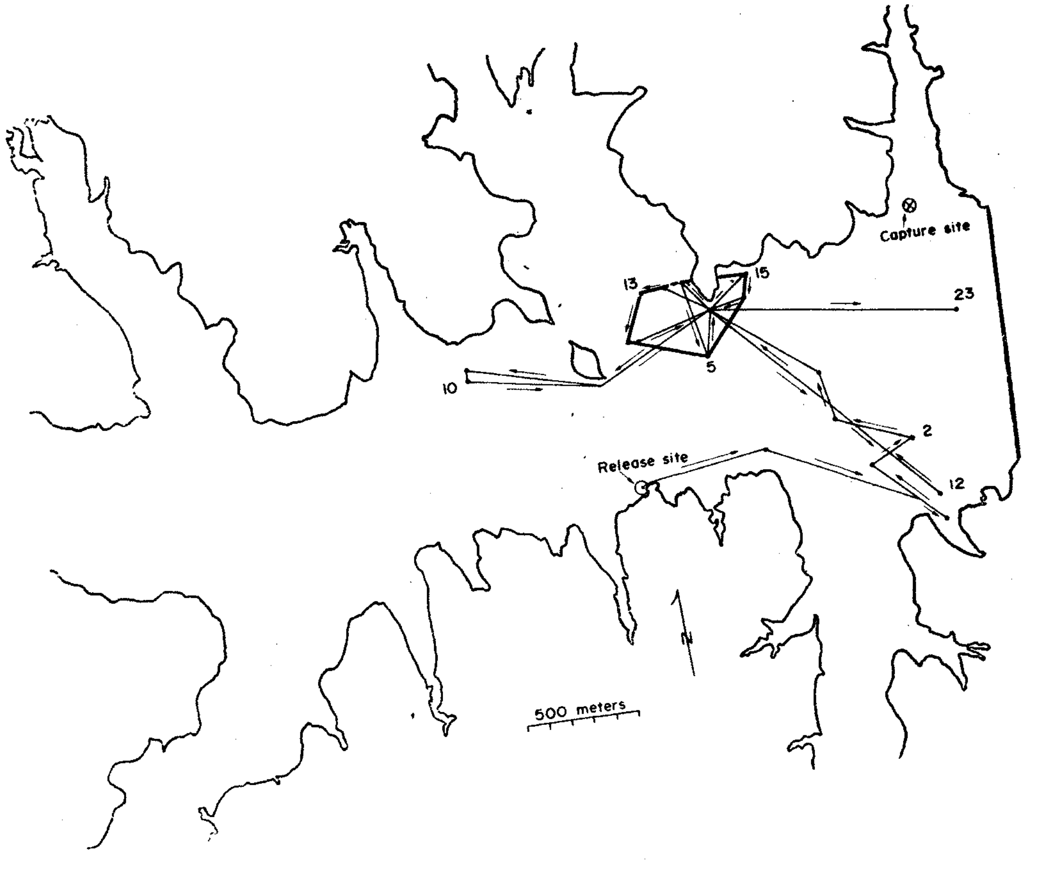

Capture site
13
15
23
5
10
2
Release site
12
N
500 meters

FIGURE 8. Behavior pattern category 5, illustrated by fish code 222, where the fish established a large home range and made extensive movements within the home range. Release site represented by "x" and original capture location represented by "⊕".

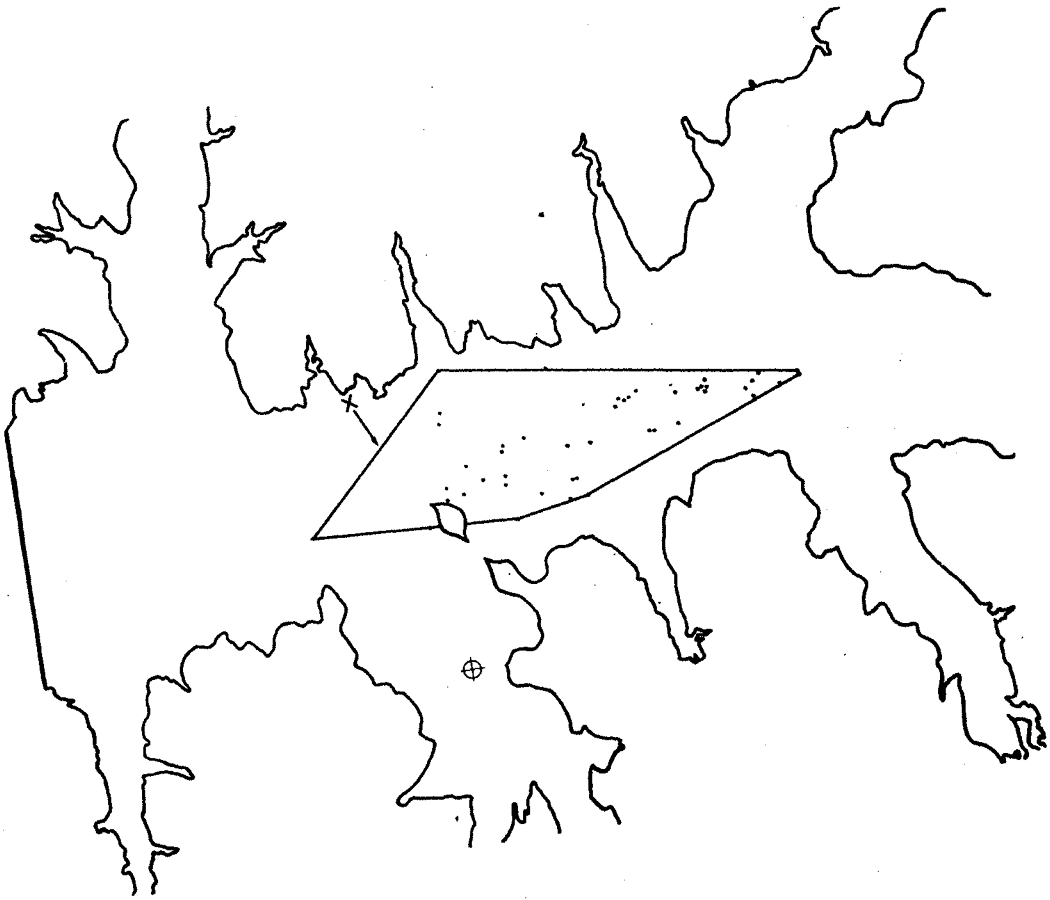


TABLE 2. Number of fish in each stratified group exhibiting one of five major behavior patterns (behavior patterns described in text); the number of fish that homed is given in parenthesis.

Description of behavior pattern	Behavior category	Displaced fish	Non-displaced fish
Remained near release site			
Restricted movements	1	0	4(4)
Took sallies	2	0	3(3)
Departed from release site			
Restricted movements	3	6(4)	2(0)
Took sallies	4	5(4)	0
Extended movements	5	1(0)	1(1)

the sense that a fish goes beyond its home range then returns to it. Another case of homing occurred when a fish returned or reused a previously used site within its home range. These trips obviously required memory of environmental cues since the fish returned to exactly the same location, within our precision of 25 m^2, after excursions (sallies) up to 1.4 km linear distance. Nineteen of 22 fish exhibited this type of homing behavior. Fish code 213 (Figure 7), a displaced male, appeared to have established a second home range in an area not including its original capture site; it took sallies outside this home range and also reused sites within its home range.

Discussion

The inability to continuously track a fish was the greatest obstacle restricting accurate homing studies, but this problem has largely been solved with the development of ultrasonic transmitters (Trefethen 1956), albiet longer life transmitters (at least 12 months) are needed to track fish through annual activity cycles. Provided the method of transmitter attachment and tracking is suitable, ultrasonic transmitters present the opportunity for continuous surveillance from a remote location thus allowing the fish to behave normally.

Gunning (1959) defined homing as returning to a home range; for reservoir or lake fishes this is more realistic than limiting homing only to those displaced fish which returned to the original capture site. Ideally, the home range of each fish should be known before displacement, but knowledge of average home range dimensions of the species in a given environment will usually have to be substituted because of the difficulty in the sequence: determining the home range of a fish, then recapturing and displacing it to determine its homing ability. Homing is best defined as the return of a displaced fish to an area within a specified radius of its original capture site. In the present study, this radius was defined as the average recapture radius containing 95% of all observations for all fish studied in this reservoir. In many previous studies, homing was assessed when a fish returned to a home pool, stream or spawning ground without knowing the home range dimensions of the species under investigation.

Homing ability of flathead catfish was demonstrated after being removed from the lake for at least two days. The elapsed time between capture and release ranged from 2 to 10 days with an average of 3 days for all 22 fish. During the time interval the fish were removed from the lake, they were anesthetized twice, hauled in covered containers in trucks and boats twice and held in two different tanks. Even after these experiences, most displaced fish exhibited homing after an initial adjustment or reorientation period of 1.5 days. Eight of 10 non-displaced fish demonstrated recognition of their previous home area by re-establishing a home range in the area of their release and, consequently, the area of their previous home range. All of 12 displaced fish left the release area before establishing a home range, apparently indicating an attempt to locate the original home range.

Most displaced and non-displaced flathead catfish which established a home range returned to a given site within that home range more than once. Reuse of a specific site within the home range suggests a highly developed sense of environmental recognition and occurrence of preferred use areas. Of the three fish that did not show this behavior, two homed in the sense they returned to within 494 m of their original capture site. Therefore, 21 of 22 fish showed some type of homing behavior.

CHAPTER III

HOME RANGE OF FLATHEAD CATFISH, *PYLODICTIS OLIVARIS*, IN AN OKLAHOMA RESERVOIR AS DESCRIBED BY ULTRASONIC TRACKING

Introduction

Large-scale investigations of the movements of fishes began between 1890 and 1900 coincident with the implementation of mark-and-recapture techniques (Jones 1968). Gerking (1959) reported restricted movements for at least 34 species from an extensive review of movement studies reported by 1958. In this study, home range is defined as an area within which a fish restricts its movements when a larger area is available. Although all definitions of home range specifically point out that it is an area and Gerking's review leaves little doubt many fish have restricted movements, home range in the specific sense of an areal measurement has not been reported. The lack of quantification of fish home range area reflects the inability of conventional mark-and-recapture methods to yield sufficient locations to mark off home range boundaries.

Ultrasonic-transmitter-equipped fish allow continuous tracking of their movements, providing opportunity to define boundaries of the home range. Ultrasonic transmitters and receiving equipment used in fisheries research, first developed by the U. S. Fish and Wildlife Service in 1955 (Trefethen 1956), have been improved to the point they are now a useful research tool (Hasler and Henderson 1963, Bass and Rascovich 1965, Henderson et al. 1966, Lonsdale and Baxter 1968). Tracking of fish bearing ultrasonic transmitters has provided measurement of travel speeds, distance traveled, migration routes, direction of travel, movements in relation to structures and homing (Stasko 1971a and 1971b). Malinin (1971), whose work was done in Ryabinsk Reservoir, USSR, appears to be the only investigator to use telemetric techniques to study home range of fish, but no areal measurements of home range were given.

In impounded waters of the south-central United States, flathead catfish attain a large size (45 kg), are highly piscivorous and are capable of using forage fishes too large for most other predators. They are an important component of the Mississippi River commercial fishery. Flathead catfish in Oklahoma reservoirs have been under intensive investigation by the Oklahoma Cooperative Fishery Unit to delineate the ecological significance of the fish in Southern reservoirs (Turner 1971, Turner and Summerfelt 1971a, 1971b and 1971c). Study of the home range of flathead catfish was undertaken because home range size of flathead catfish has not previously been described. Funk (1955) reported data indicating a home range tendency for flathead catfish in Missouri rivers. Flathead catfish have previously been equipped with ultrasonic transmitters in a study in the Missouri River in Nebraska, but attempts to follow the fish were unsuccessful (Morris 1968). In Lake Carl Blackwell, of fish tagged with anchor or butt-end tags, multiple recaptutes were too infrequent to determine home range size of flathead catfish. Availability of telemetry equipment for tracking fish prompted the present study of flathead catfish home range using ultrasonic transmitters.

As no areal measurements of fish home range have been reported, no definitive procedures for estimating home range size for fish have been described. Therefore, four procedures heretofore applied to describing home range of mammals will be used to describe the daily and total home range of flathead catfish. Two of the procedures describe a circular home range, one an elliptical home range and another, called the minimum home range procedure, uses the area of a polygon. The present report compares these methods for describing home range size of flathead catfish based on 1646 telemetric observations of 28 flathead catfish in Lake Carl Blackwell, Oklahoma.

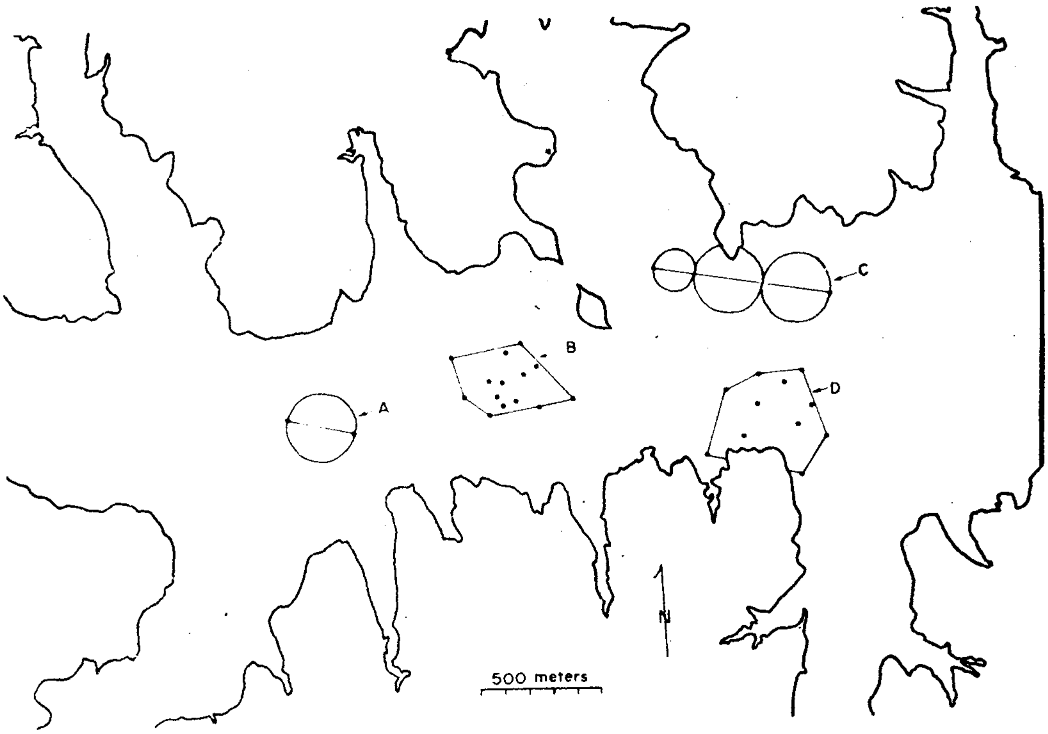
Methods and Materials

Equipment used to determine the home range of flathead catfish, field methods associated with the study and a description of Lake Carl Blackwell are described in Chapter II. Twenty-two fish were captured from Lake Carl Blackwell, but six fish were captured from Boomer Lake and released in Lake Carl Blackwell. Boomer Lake, which impounds Boomer Creek, is a shallow (2.98 m mean depth), 102 ha turbid reservoir located 11.3 km east of Lake Carl Blackwell.

Methods for Determining Daily Home Range

Observations at six-hour intervals provided four fixes daily from which a polygon was drawn by connecting the outer boundary points with straight lines (Figure 9B). The daily home range area was attained by measurement of the polygon area with a planimeter. If the boundary intersected the shoreline, the terrestrial section was not included in the area (Figure 9D). When all fixes in a day occurred in a straight

FIGURE 9. Lake Carl Blackwell showing examples of procedures (described in text) used for outlining the daily home range of flathead catfish.


A
B
C
D
N
500 meters

line, or when only two fixes were plotted in a day, home range was equated to the area of a circle having a diameter equal to the distance between the two most distant daily fixes (Figure 9A). When only two locations were available for an interval of several days, the daily home range was calculated by proportioning the linear distance traveled by the number of days and using the proportioned segments as diameters of circles (Figure 9C). The area of the circles was used as the daily home range for those days. If a circle intersected the shoreline, only the aquatic section was considered the daily home range (Figure 9C). Circles have been used to compute daily home range of mammals from live-trapping (Hayne 1949). Of a total 378 daily home range determinations, 201 were derived from polygons and 177 were derived from circles (Table 3). Areas derived from circles averaged 10,713 m^2 larger than areas of polygons, but, because the number of observations and the variance were large, the two methods were not significantly different (t test, $P > .20$).

Total Home Range by the Minimum Home Range Method

Total home range is the area measurement for the entire interval in which the fish was tracked; thus, the total home range is based on all location determinations for each fish. Total home range estimated by the minimum home range method described by Mohr (1947) and Hayne (1949) is the total area of a polygon formed by connecting the most extreme perimeter fixes. Consistency is assured by turning the maximum angle possible from the preceding line and still pass through a fix (Figure 9B and D). Minimum home range encloses an area within which the fish was known to have been present, albeit the fish may concentrate

TABLE 3. Mean, standard deviation of mean and range of daily home range size by polygon and circle methods.

	Polygon method	Circle method
Number of observations	201	177
Mean size	18,679 m^2	29,392 m^2
Standard deviation of mean	2,813 m^2	8,727 m^2
Range - lower	57 m^2	16 m^2
- upper	392,290 m^2	1,360,554 m^2

its time in only a small part of the entire area. The area of the polygon, exclusive of terrestrial areas within the home range boundary, was determined with a planimeter.

Once the home range polygon has been determined by this method, the major and minor axes of the polygon have comparative value as descriptive of the dimensional features of the home range. Major and minor axes were determined for the minimum home range of each fish. The major axis is a line segment formed by connecting the two fixes that are the greatest distance apart. The minor axis is a line segment perpendicular to the major axis and connecting the boundaries of the minimum home range at its widest point.

Circular Home Range from Activity Radii

Hayne (1949) was first to present a method using a mathematical center of activity and activity radii to quantitate the relative frequency of usage of portions of a home range by an animal. With Hayne's method, each fix was given a Cartesian coordinate ($\underline{x}$ and $\underline{y}$ value). To assign Cartesian coordinates to each location, $\underline{x}$ and $\underline{y}$ axes were positioned such that the $\underline{x}$ axis always paralleled the prominent submerged creek channel in the area where the fish established a home range. This was done so the effect of submerged creek channels on the linearity of the home range could be investigated. All $\underline{x}$ and $\underline{y}$ values were averaged to yield a mean $\underline{x}$ ($\bar{x}$) and mean $\underline{y}$ ($\bar{y}$) location, termed the apparent center of activity. The center of activity is the mean coordinate point. The center of activity is not necessarily the true center of activity of the fish and may never have been occupied by the fish. After the center of activity has been ascertained, the linear distance from each fix to the center of activity, the activity radius (r_{ij}), may be determined by the formula given by Calhoun and Casby (1958):

$$r_{ij} = \left[(x_{ij} - \overline{x}_i)^2 + (y_{ij} - \overline{y}_i)^2\right]^{\frac{1}{2}}$$

Other authors postulated methods for calculating home range size from activity radii (Dice and Clark 1953, Harrison 1958, Calhoun and Casby 1958, White 1964, Jennrich and Turner 1969). The advantage of this mathematical technique over minimum home range procedures is that some allowance is made for fixes where a fish is located more than once.

Calhoun and Casby (1958) made a notable contribution to understanding home range by expressing home range as a density function, a mathematical expression representing the probability of an animal being present in some arbitrarily small area. To use ideas and formulas postulated by Calhoun and Casby, three assumptions are made: (1) the home range is stationary, or time independent; (2) there is a true center of activity although the apparent center of activity may deviate from it; and (3) the probability of an animal being in a unit of area decreases with increasing distance from the true center of activity. The second and third assumptions suggest a bivariate normal distribution of the density function. A set of activity radii were calculated for each flathead catfish by Calhoun and Casby's formula. Flathead catfish total home range was calculated from Calhoun and Casby's formula for circular home range:

$$A = (9\pi) \frac{1}{n-1} \sum_{i=1}^{n} r^2{}_{ij}$$

where A equals the area of the home range and r_{ij} is an activity radius for the _i_th fish. The generated circle accounts for at least 95% of the fish's utilization of its habitat. Detailed explanations and justification of the above formula are given by Calhoun and Casby (1958).

Elliptical Home Range from Activity Radii

Jennrich and Turner (1969) reviewed the conceptualizations and procedures for determining minimum home range, one type of modified minimum home range, and a circular home range derived from centers of activity and activity radii. They found that minimum home range is biased by sample size, circular home range is biased if the animal's home range is not circular, and modified minimum home range procedures have never been clearly defined. They also suggested Calhoun and Casby (1958) should have used the constant 6π instead of 9π. Jennrich and Turner introduced a new elliptical home range procedure using the determinant of the covariance matrix of the x and y values for fixes for each animal. Accordingly, home range (A) is estimated by the formula:

$$A = 6\pi(|S|)^{\frac{1}{2}}$$

where S equals the determinant of the fix covariance matrix:

$$\begin{pmatrix} S_{xx} & S_{xy} \\ S_{yx} & S_{yy} \end{pmatrix}$$

defined by the equations:

$$S_{xx} = \frac{1}{n-2} \sum_{i=1}^{n} (x_{ij} - \bar{x}_i)^2$$

$$S_{yy} = \frac{1}{n-2} \sum_{i=1}^{n} (y_{ij} - \bar{y}_i)^2$$

$$S_{xy} = S_{yx} = \frac{1}{n-2} \sum_{i=1}^{n} (x_{ij} - \overline{x}_i)\ (y_{ij} - \overline{y}_i)$$

With this formula for area, the only required assumption is that the intensity with which an animal utilizes each point in its habitat is expressed by a bivariate normal distribution.

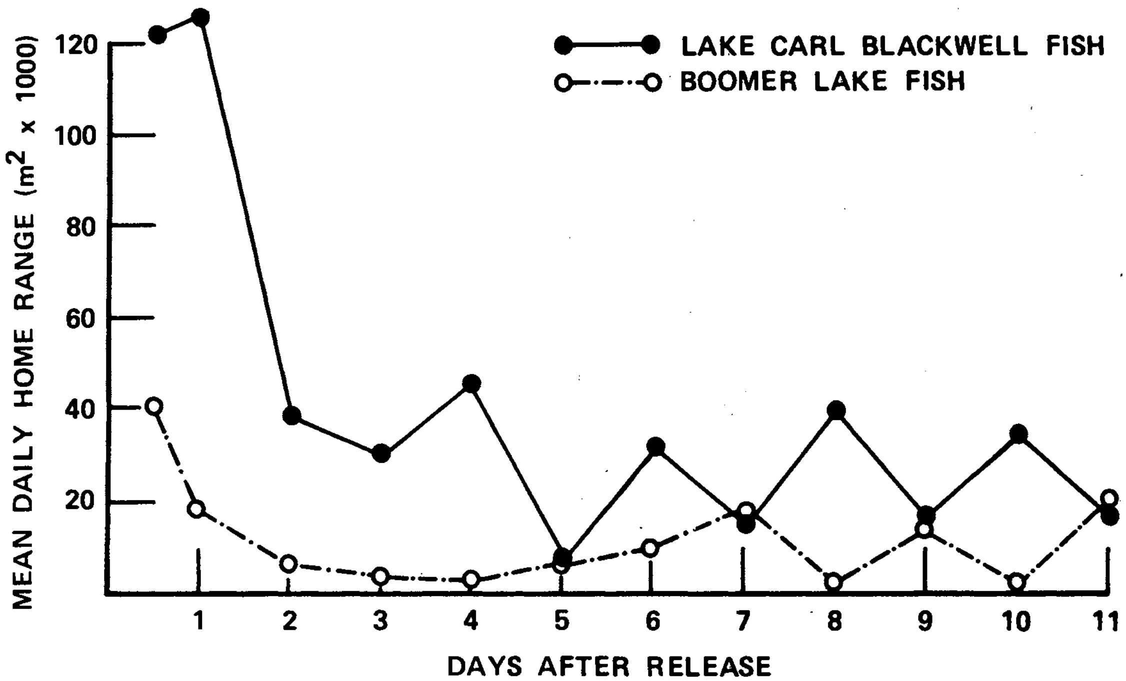
Jennrich and Turner's procedure yields the area of the smallest region which accounts for 95% of an animal's utilization of its habitat. Their technique will yield a circle if the data analyzed is from an animal with a circular home range.

Results

Adjustment Period

The daily home range of transmitter-bearing fish from either Lake Carl Blackwell or Boomer Lake was abnormally large during the first 1.5 days after release as ascertained from home range of the same fish during the first 11 days after release (Figure 10). The very rapid movements and expansive nature of the home range within the first 1.5 days after release apparently constitute an adjustment period. Shepherd (1973) evaluated transmitter attachment and fish behavior and reported data which suggests rainbow trout released in tanks have an adjustment period of approximately one day. In later field studies, Shepherd released tagged rainbow trout 48 hours prior to tracking to eliminate the adjustment period. These observations suggest taking a skeptical view of short duration (i.e. less than 48 hours) telemetric tracking studies of fishes. Movements in the first 1.5 days after release are not included in computations of home range in this report.

FIGURE 10. Mean daily home range of Lake Carl Blackwell and Boomer Lake flathead catfish during the first 11 days after release.


LAKE CARL BLACKWELL FISH
BOOMER LAKE FISH
MEAN DAILY HOME RANGE (m2 x 1000)
120
100
80
60
40
20
1
2
3
4
5
6
7
8
9
10
11
DAYS AFTER RELEASE

Fish Code 224 had an extended adjustment period, spending 5.66 days near the release site, then traveling 2.11 km westward to establish a home range during the last 29.47 days of observation. Four other fish (code numbers 311, 223, 322 and 228) exhibited similar behavior but had left the dam area and begun to establish their home ranges within the adjustment period. The movement of fish 224 to another area after 5.66 days could be considered a shift in home range, but since its behavior so closely resembled the other 4 fish released in the same area, it was considered to have an extended adjustment period. For fish 224, only the last 29.47 days of observations are included in computations of total home range.

Daily Home Range

The mean daily home range of 22 Lake Carl Blackwell fish was 2.76 ha compared with 1.00 ha for 6 fish introduced from Boomer Lake. A *t* test of the difference in the two means was significant ($P < .05$, Table 4). The smaller home range of Boomer Lake fish displaced to Lake Carl Blackwell could be related to lack of familiarity with the environment, a maturity or size factor (Boomer Lake fish were smaller and females sexually immature), or a pre-conditioning due to some unknown factor. The size of the daily home range was negatively correlated with the length of the fish for Lake Carl Blackwell fish but not for Boomer Lake fish (Table 4).

Differences in size of daily home range due to displacement or the sex of Lake Carl Blackwell flathead catfish were not significant. The average daily home range of 12 Lake Carl Blackwell fish released an average 1.9 km from their site of capture (displaced fish) was 3.01 ha.

TABLE 4. Correlation coefficients for home range size and fish length, and results of *t* tests between stratified groups of flathead catfish for daily home range and three types of total home range.

Group	Daily home range	Minimum home range	Circular home range	Elliptical home range
	t tests			
Lake Carl Blackwell - Boomer Lake	P>.001*	.40>P>.20	.40>P>.20	.40>P>.20
All males - all females	P>.50	.40>P>.20	P>.50	.40>P>.20
Lake Carl Blackwell males - Lake Carl Blackwell females	P>.50	P>.50	P>.50	P>.50
Boomer Lake males - Boomer Lake females	.40>P>.20	.10>P>.05	.40>P>.20	.40>P>.20
Boomer Lake males - Lake Carl Blackwell males	.50>P>.40	P>.50	P>.50	P>.50
Boomer Lake females - Lake Carl Blackwell females	.20>P>.10	.20>P>.10	P>.50	.10>P>.05
Displaced Lake Carl Blackwell - Non-displaced Lake Carl Blackwell	P>.50	P>.50	.50>P>.40	P>.50
	Correlations			
Lake Carl Blackwell fish	r = -0.5385	r = -0.5383	r = -0.3922	r = -0.3807
Home range and length	.05>P>.01	.05>P>.01	.10>P>.05	.10>P>.05
Boomer Lake fish	r = 0.2305	r = 0.7084	r = 0.4939	r = 0.5033
Home range and length	P>.10	P>.10	P>.10	P>.10

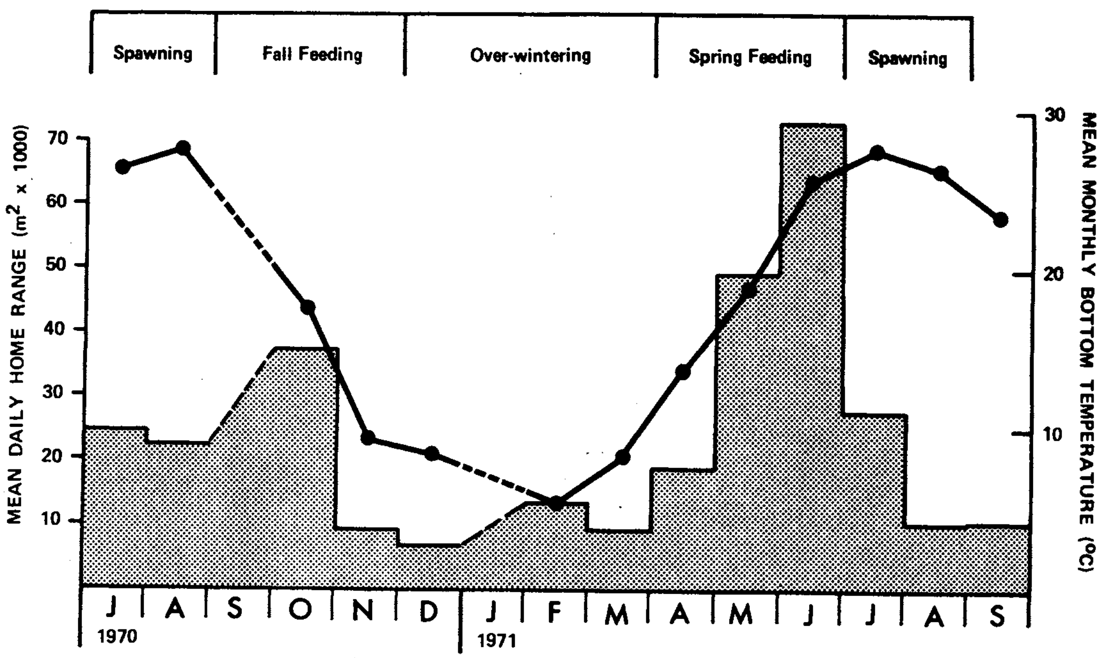
*Underscored values denote significance at 10% level (P <.10).

The average daily home range of 10 non-displaced fish was 2.37 ha. The difference in mean home range of displaced and non-displaced fish was not significant ($P > .50$, Table 4). The mean of the daily home range means for all 7 male Lake Carl Blackwell fish (displaced and non-displaced) was 3.21 ha which was not significantly different from the 2.58 ha average for all 14 female Lake Carl Blackwell fish ($P > .50$, Table 4). The difference in average daily home range of 3 male (1.29 ha) and 3 female (0.46 ha) flathead catfish introduced from Boomer Lake was non-significant ($.20 < P < .40$, Table 4).

Variation in monthly means of daily home ranges was related to the seasonal activities of flathead catfish in Lake Carl Blackwell and to water temperature (Figure 11). The significant correlation between size of monthly means of daily home range and monthly mean near-bottom water temperature was positive ($r = .53$, $.05 < P < .10$). The correlation of water temperature and the size of the daily home range could be an indirect result of the seasonal activity patterns of flathead catfish.

A hypothetical annual activity cycle of flathead catfish in Lake Carl Blackwell was prepared from previous studies on the reservoir using relationships of food habits, gonadal-body weight relationships, catch rate, and capture location (Summerfelt 1970, Figure 12). From December through March, flathead catfish were located in deepest portions of the central pool (10 m), or in deep portions of certain arms of the reservoir. These locations are referenced as their winter grounds (Figure 12). The water temperature at the beginning of the winter period was about 10^{o} C; it declined to near freezing with occasional ice-cover during colder periods of the winter, then returned to

FIGURE 11. Seasonal means of daily home range of Lake Carl Blackwell flathead catfish (histogram) and mean monthly bottom temperatures (line).



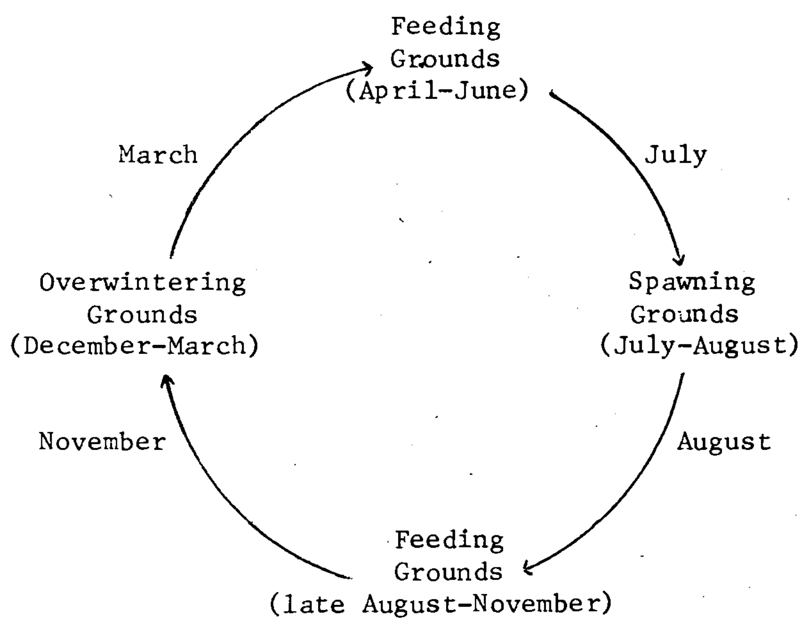
Spawning
Fall Feeding
Over-wintering
Spring Feeding
Spawning
MEAN DAILY HOME RANGE (m^2 x 1000)
70
60
50
40
30
20
10
MEAN MONTHLY BOTTOM TEMPERATURE (°C)
30
20
10
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
1970
1971

near 10° in late March. The fish were relatively inactive during the winter period as indicated by poor catch rate in gill nets and infrequent feeding (Turner and Summerfelt 1971a). The average monthly means of daily home range was comparatively small during this period (0.99 ha).

Flathead catfish began a period of intensive feeding in April when the water temperature rose from 10° C (Turner and Summerfelt 1971a). Spring feeding continued until June when water temperatures reached 22° C. Relative gonadal weight increased sharply around May 1 (Turner and Summerfelt 1971b). The average home range increased with each successive month in this period to a maximum (7.29 ha) in June. The average of monthly means of daily home range during spring feeding was 4.71 ha. The spawning period of flathead catfish generally coincides with maximum temperatures (24 - 28° C) occurring in late July and throughout August (Turner and Summerfelt 1971b). Spawning is apparently in inshore areas of rock out-cropping or in areas with an abundance of submerged timber. Average daily home range decreased sharply during the spawning period (average of monthly means 2.12 ha) from maximum values obtained near the end of spring feeding.

September through November is a period of fall feeding. Fall feeding began just after spawning, at about 24° C, and continued until water temperatures fell to about 10° C in late November. Average daily home range increased during fall feeding from low values obtained during spawning (average of monthly means 2.31 ha). When water temperatures decline to less than 10° C, flathead catfish return to their winter grounds and the annual migration cycle is completed.

FIGURE 12. Seasonal activity cycle of Lake Carl Blackwell flathead catfish.


Feeding
Grounds
(April-June)
July
Spawning
Grounds
(July-August)
August
Feeding
Grounds
(late August-November)
November
Overwintering
Grounds
(December-March)
March

Minimum Home Range

Of 28 fish released for tracking, 27 established minimum home ranges. One fish (code number 226) injured itself in the gill net where it was originally captured after homing a distance of 2316 m in no more than 39.5 hours (Figure 3). Fish 226 was not included in computations of total home range. The minimum home range of all 27 fish ranged from 0.02 to 133.65 ha, with a mean of 25.05 ha (Tables 5, 6 and 7). The average minimum home range for Lake Carl Blackwell fish was 23.97 ha and 15.64 ha for fish introduced from Boomer Lake. A t test for differences between the minimum home ranges of Lake Carl Blackwell fish and fish introduced from Boomer Lake was non-significant, as were differences between displaced and non-displaced Lake Carl Blackwell fish and all males and all females ($P > .20$, Table 4). Lack of significant differences between the groups was probably caused by large variation within each strata created by grouping mature and immature fish, fish of different lengths and fish tracked in different seasons. Boomer Lake males had home ranges significantly larger than Boomer Lake females--the difference probably caused by maturity, since only Boomer Lake females were considered immature (Table 4). A significant negative correlation existed between length of the fish and its minimum home range size for Lake Carl Blackwell fish but not for Boomer Lake fish (Table 4).

The size of the minimum home range corresponded with seasonal activities of flathead catfish in Lake Carl Blackwell. The largest average minimum home range (44.86 ha) was obtained for fish observed during spring feeding; however, fish observed during fall feeding had a much lower average (12.93 ha). The average minimum home range of

TABLE 5. Home ranges (hectares) for displaced Lake Carl Blackwell flathead catfish.

Code number	Length (mm)	Sex	Days tracked	Tracking season	Mean daily home range	Minimum home range	Circular home range	Elliptical home range
211	834	M	26.1	Over-winter	1.47	28.10	255.35	70.99
212	775	M	16.8	Spring feeding	0.88	11.29	139.82	30.87
213	575	M	22.9	Spring feeding	12.45	133.65	535.09	135.46
221	703	F	7.7	Spawning	0.26	0.44	19.08	1.39
222	753	F	25.8	Spawning	1.77	37.84	669.00	88.68
223	598	F	5.4	Spawning	7.44	38.95	238.23	64.80
224	888	F	35.1	Over-winter	0.59	15.05	116.77	25.41
225	616	F	23.9	Spring feeding	2.36	49.57	647.39	82.53
226	633	F	1.9	Spring feeding	0.34	-	-	-
227	665	F	19.8	Spawning	2.77	6.64	153.75	12.87
228	815	F	6.4	Fall feeding	4.51	2.66	91.49	19.10
231	?	?	19.3	Spawning	1.33	34.74	432.68	75.71

TABLE 6. Home ranges (hectares) for non-displaced Lake Carl Blackwell flathead catfish.

Code number	Length (mm)	Sex	Days tracked	Tracking season	Mean daily home range	Minimum home range	Circular home range	Elliptical home range
311	593	M	11.1	Spawning	1.72	19.25	140.24	39.59
312	810	M	7.4	Fall feeding	5.19	43.15	435.11	119.84
313	784	M	15.7	Spring feeding	0.01	0.02	0.32	0.09
314	850	M	10.4	Spawning	0.72	0.66	8.83	1.86
321	713	F	8.0	Spawning	4.89	25.23	591.91	91.97
322	783	F	26.9	Fall feeding	0.22	0.66	7.54	1.62
323	700	F	33.5	Spring feeding	1.43	49.79	260.97	70.09
324	741	F	26.3	Spring feeding	1.39	13.72	67.53	20.03
325	616	F	7.8	Spring feeding	5.37	55.98	548.68	121.52
326	666	F	9.5	Spawning	2.77	15.05	96.29	31.38

TABLE 7. Home ranges (hectares) for flathead catfish captured from Boomer Lake and tracked in Lake Carl Blackwell.

Code number	Length (mm)	Sex	Days tracked	Tracking season	Mean daily home range	Minimum home range	Circular home range	Elliptical home range
111	694	M	19.9	Spawning	1.52	49.12	582.07	115.74
112	699	M	40.2	Fall feeding	0.91	17.48	33.96	8.60
113	672	M	33.4	Fall feeding	1.44	17.26	64.30	15.79
121	668	F	33.4	Fall feeding	0.08	0.44	2.85	0.78
122	638	F	7.5	Spawning	1.23	0.66	23.82	4.04
123	661	F	17.3	Fall feeding	0.08	8.85	42.78	14.03

fish observed during the spawning season was 19.87 ha. The average minimum home range during over-wintering was 21.58 ha.

The general shape of the minimum home range was elongate with the average length 2.6 times the average width. The average major and minor axes of the minimum home range of all fish were 858 and 333 m respectively. The long axis of the minimum home range seemed to parallel a submerged creek channel for most fish.

Circular Home Range

Circular home range was defined as a circular area based on activity radii (described by Hayne 1949) containing 95% of all fixes for a fish. The total home range by the circular method ranged from 0.32 to 669.00 ha with a mean of 229.84 ha for all 27 flathead catfish (Tables 5, 6 and 7). The mean circular home range size for all 27 fish was 9.18 times larger than that derived by the minimum home range method. The mean home range size by the circular method for Lake Carl Blackwell fish (259.80 ha) was 134.84 ha larger than the mean home range size for fish introduced from Boomer Lake, but the difference was not significant (*t* test, $P > .20$, Table 4). Likewise, the home range did not differ as the result of sex or displacement (Table 4), suggesting the variation was caused by seasonal effects, some unknown factor or that the home range of flathead catfish is not adequately described by the circular method. Like the daily and the minimum home range, home range by the circular method was correlated with the seasonal activity cycle of flathead catfish in Lake Carl Blackwell and with the length of the fish (Table 4).

One of the assumptions of the circular home range method is that the animal has a circular home range (Jennrich and Turner 1969). The major and minor axes for flathead catfish indicate that its home range in Lake Carl Blackwell is somewhat linear (the length 2.6 times the width). To test this, all x and all y values for each fish were tested for unequal variances. The variances of the x and the y values were found to be significantly different ($P < .10$) for 24 of 27 fish. The test used was Calhoun and Casby's (1958) test III, with a Chi-square distribution. The home range of flathead catfish does not meet the basic assumption of circularity; therefore, total home range size was calculated instead by an elliptical method.

Elliptical Home Range

The elliptical home range method (Jennrich and Turner 1961) used to describe the total home range of flathead catfish accounted for 95% of all fixes for a fish. The home range of all 27 fish ranged from 0.09 to 135.46 ha (Tables 5, 6 and 7) with a mean of 46.84 ha. The size of the home range by the elliptical method was 20% of that derived by the circular method and 187% of that derived by the minimum home range procedure. The mean size of the elliptical home range was 52.66 ha for 21 Lake Carl Blackwell fish and 26.50 ha for the six Boomer Lake fish. A t test for difference between the mean home range size of Lake Carl Blackwell and Boomer Lake fish was not significant ($P > .20$, Table 4). The elliptical home range method, like the minimum home range method, indicated that some of the variation was related to the season, the length of the fish and its maturity. The three immature Boomer Lake females had home ranges significantly smaller than Lake

Carl Blackwell females (t test, P <.10). Tests for differences between sexes, other than the one just described, and displacement were not significant (t tests, P >.20, Table 4).

Discussion

Since few observations were made within a day, usually no more than four, estimation of daily home range size using both the minimum home range method and a circular home range method seemed adequate. Of the three methods reviewed here, the elliptical home range method appears to be the best for describing the total home range of flathead catfish in this habitat. The elliptical method gives a range of confidence over the minimum home range method, and both the shape and size of the home range varies to conform to the actual patterns plotted from observations of the fish. Also, the method easily lends itself to computer analysis. However, the procedure used here would probably be inappropriate for shoreline species since no allowance is made for excluding terrestrial areas in the home range boundary.

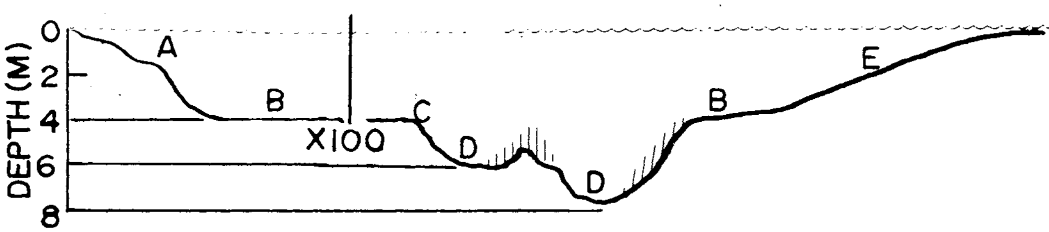
The mean home range size of mature Lake Carl Blackwell flathead catfish by the elliptical method, regardless of the season or length of the fish, was estimated to be 52.66 ha during the mean 18.66 day tracking interval. This estimate applies to only Lake Carl Blackwell flathead catfish. Significant statistical difference in daily home range and observed differences in total home range between Lake Carl Blackwell and Boomer Lake fish suggest that home range size of flathead catfish in other reservoirs may be quite different from that found in Lake Carl Blackwell.

Variation in home range size was related to the season in which the fish was tracked, maturity and length of the fish. Home range size is small during winter, probably as a result of the slowed metabolism caused by cold water temperatures. Larger home ranges during spring and fall feeding could be caused by searching behavior in quest of food. Home ranges during spring feeding, when temperatures were rising, were larger than home ranges during fall feeding when temperatures were declining and metabolism was slowing. Boomer Lake females had smaller home ranges than any other group, suggesting home range size may be associated with maturity, since only Boomer Lake females were immature. The length of Lake Carl Blackwell fish was negatively correlated with the size of the daily and total home range. With the exception of the immature female Boomer Lake fish, larger fish had smaller home ranges. The lack of a correlation between length of the fish and size of home range for Boomer Lake fish was probably caused by the small range in size of Boomer Lake fish in comparison to Lake Carl Blackwell fish (Tables 5, 6 and 7).

Home ranges of flathead catfish were usually associated with an old submerged creek channel or steep slope near shore (Figure 13). Based on observations of flathead catfish in tanks, echo soundings at known fish locations and successful gill-netting techniques, it was assumed that flathead catfish were on or near (within 30 cm) the bottom at each fix. Echo soundings were made at 138 known fish locations using a recording echo sounder. Of the 138 soundings, 84 (60.9%) fixes were within old submerged creek channels (Figure 13D), 52 (37.7%) were on a steep slope near shore (Figure 13A), and 2 (1.4%) were along the upper edge of an old submerged creek channel (Figure 13C).

Relationships between size of flathead catfish home range and estimated population numbers suggest that the home ranges of flathead catfish overlap in Lake Carl Blackwell. Dividing the 850 ha area of

FIGURE 13. Classification of the topographical features of the Lake Carl Blackwell basin. The vertical line between B and C indicates a distance equal to 100 times the relative horizontal scale, i.e., the largest category is the flat, former flood plain which was generally lacking trees. The small vertical lines in the creek channel represent inundated trees.



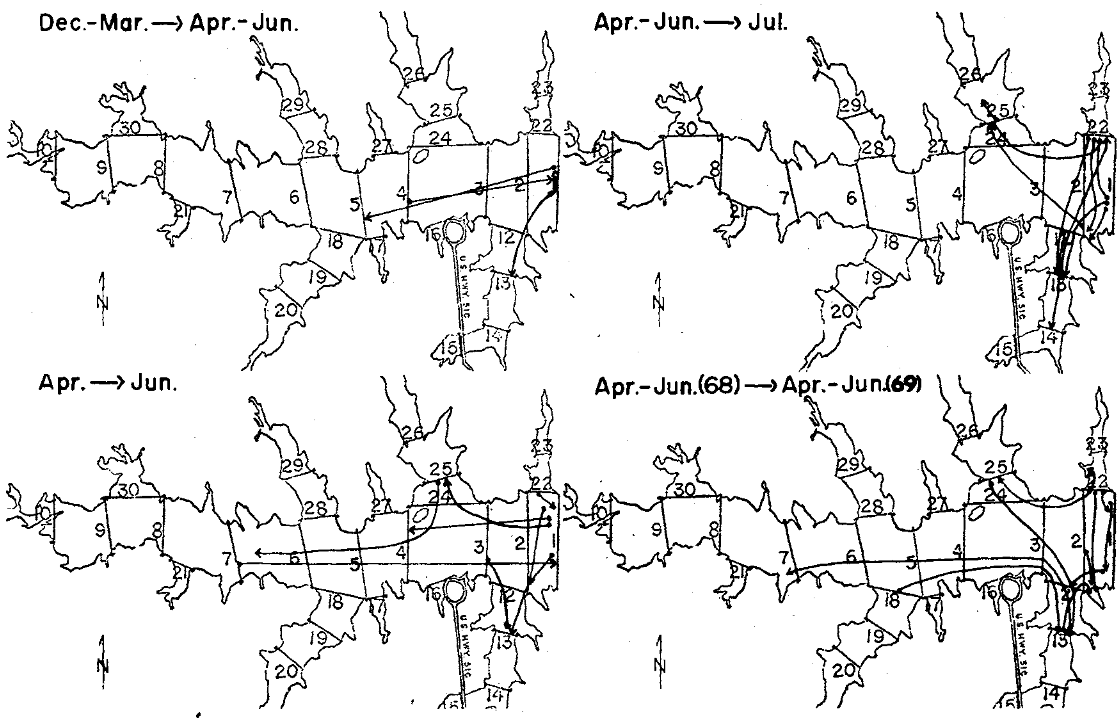
DEPTH (M)
0
2
4
6
8
A
B
X100
C
D
D
B
E

the reservoir by the mean home range size (52.66 ha), only 16 fish could share the reservoir without overlapping home ranges. A concurrent mark-and-recapture study of flathead catfish in Lake Carl Blackwell yielded an estimate of 870 fish in the size range used in this study. The product of the number of fish by the average home range size far exceeds the area of the lake; therefore, the home ranges of flathead catfish in Lake Carl Blackwell must overlap. This supposition is supported by actual observations of overlapping home ranges of Lake Carl Blackwell fish in the area of converging creek channels just south of the island (Figure 1).

The estimated size of the home range of flathead catfish would increase greatly if seasonal movements from one part of the reservoir to another were included in a single home range. This was not observed because the 18.66 day average tracking interval was too short to observe seasonal movements. Mark-and-recapture results show lengthy movements of some flathead catfish in Lake Carl Blackwell (Figure 14). Of particular interest are the movements of fish from April-June, 1968, to April-June, 1969. While 7 fish show somewhat restricted movements, 4 fish moved to spring feeding grounds over 2 km from their previous spring feeding grounds. Of 3 telemetry fish caught by fishermen after being at large for more than one year, 2 fish were caught within the minimum home range established during telemetric observation and one fish had displaced to another part of the reservoir.

Flathead catfish probably establish 3 or 4 home ranges annually as they make seasonal movements to spawning, fall feeding, over-wintering

FIGURE 14. Mark-and-recapture observations of seasonal movements of flathead catfish in Lake Carl Blackwell.


Dec.-Mar. ⟶ Apr.-Jun.
Apr.-Jun. ⟶ Jul.
Apr. ⟶ Jun.
Apr.-Jun.(68) ⟶ Apr.-Jun.(69)
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and spring feeding grounds. Our data indicate that some fish re-establish seasonal home ranges from year to year while others establish seasonal home ranges in other areas of the reservoir. An ultrasonic transmitter capable of functioning for at least 13 months would be desirable to follow seasonal movements.

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