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ABSTRACT

Northern pike *Esox lucius* movements and distributions in relation to various habitat characteristics during and after spawning were investigated during 1991 in Volkmar Lake, a remote 273 hectare water body in interior Alaska. Fourteen mature fish were fitted with externally-attached radio transmitters, and concurrent with mark and recapture experiments for population abundance and composition estimation, were located three times per day for a 25 day period, and once a day for an additional eight days. Northern pike (six males and eight females) were located a total of 770 times, from the onset of the open water period in mid-May to early August. Minimum rate of movement (meters per hour) between tracking periods was greatest during the 11 days following breakup, with males being generally more active than females. Minimum rates of movement for both sexes declined over the study, and both males and females showed a significant preference for nearshore waters (less than 100 meters from shore) during the initial study period. Following spawning, males preceded females in becoming distributed in deeper waters. Both males and females displayed preferences for vegetated habitat throughout the study. Based upon movements of radio-tagged fish, improvements in sampling techniques for the estimation of population abundance and composition are described.

KEY WORDS: Northern pike, *Esox lucius*, Volkmar Lake, fish distribution, movements, mark-recapture experiments, radio-telemetry.

INTRODUCTION

Volkmar Lake (64°07'N, 145°11'W), is a remote 273 ha (675 ac) lake located approximately 25 km northeast of the town of Delta Junction in interior Alaska. The lake is accessible during the open water season by float-equipped aircraft. Snowmachines and ski-equipped aircraft provide access during the winter. Volkmar Lake lies at an elevation of 326 m and has a maximum depth of 12.8 m. The lake has two small inlets and an ill-defined outlet that drains westerly through wetlands toward the Goodpaster River. Inshore waters are shallow with beds of aquatic vegetation providing spawning and rearing substrate for northern pike *Esox lucius*. Emergent vegetation is prevalent to depths of approximately 3 m in Volkmar Lake. Volkmar Lake is typically ice-free from mid-May (19 May in 1991) to early October, and spawning activity of northern pike generally coincides with the beginning of the ice-free period around the 10th of May, when ice initially melts next to the shoreline, and continues for up to three weeks through breakup into late May (Pearse 1991). Other fish species present in the lake include humpback whitefish *Coregonus pidschian*, least cisco *C. sardinella*, and slimy sculpin *Cottus cognatus*.

Sport fishing effort in Volkmar Lake from 1981 to 1989 averaged 1.7 angler-days/ha (range 0.7 to 2.6), and annual harvest of northern pike has averaged 1.7 fish per ha (range 0.7 to 2.8) during the same interval (Pearse 1991). Volkmar Lake is a popular sport fishery because of land disposals around the lake by the State, improved winter access from new snow machine trails and roads in the Delta Agricultural Project, and increased summer and winter use by cabin owners around the lake and on the nearby Goodpaster River.

Research on northern pike in Volkmar Lake, and nearby area waters began in 1985 with efforts focused on obtaining estimates of abundance and composition (Peckham 1986). In 1986, several gear types and deployment techniques were evaluated to identify a non-lethal, efficient sampling method for the capture of northern pike. Seines proved to be the most effective non-selective capture method of those gears evaluated (gill nets, various trap and fyke nets, and seines) for study of northern pike (Peckham and Bernard 1987). Studies to estimate the abundance, recruitment, survival, and composition of northern pike in Volkmar Lake during the spring have been reported by Clark and Gregory (1988), Timmons and Pearse (1989), and Pearse (1991). Sampling of the northern pike population in Volkmar Lake has proven troublesome. For example, despite use of the most non-selective gear available (seines), and attempts to distribute sampling effort randomly within and uniformly between lake areas (see Pearse 1991 for a description of the methodology), size selectivity was detected during sampling in 1985-1988, and again in 1990 and 1991. Catch rates (fish per seine haul) declined during the within-season sampling event in 1988 and were again disappointing in 1989, therefore two-season Petersen estimates of abundance (with the Robson and Flick (1965) correction applied) were developed for those years. Estimates of abundance and composition were stratified by length to compensate for the sampling selectivity. Selectivity may have resulted from mechanically selective fishing gear or differential behavior of small versus large sized fish during sampling. While compensation for size selectivity is possible, parameter estimates tend to be less precise. Declining or consistently low catch rates likely reflected the lack of availability of northern pike in inshore (within

100 m of shore) and shallow (no deeper than 3 m) lake areas where seine gear can be effectively fished. A desire to more fully understand the behavior and movements of northern pike during the spring prompted this study.

Other investigators have met with varying degrees of success in using radio telemetry to describe movement patterns of northern pike over time and to describe distribution of northern pike in relation to various habitat characteristics (hereafter referred to as habitat preferences). These studies include Chapman and Mackay (1984a, 1984b), Cook and Bergersen (1988), Diana (1980), Diana et al. (1977), Malinin (1969, 1970, 1971), Poddubnyi et al. (1970), and Ross and Winter (1981). In Alaska, previous telemetry studies involving northern pike have been limited to the Minto Flats and Tanana River areas west of Fairbanks (Hallberg 1984, Holmes and Burkholder 1988, and Burkholder 1991). This study is the first attempt by the Alaska Department of Fish and Game (ADF&G) to describe movements of lacustrine populations of northern pike in Alaska.

The objective of this study was to describe the movements and distributions of six male and six female radio-tagged northern pike in Volkmar Lake from mid-May to mid-June 1991, in relation to time of day, depth, and lake section. Our intent was to relate distribution and movements of these 12 radio-tagged northern pike during and immediately after spawning to sampling methods presently being used to estimate northern pike population composition and abundance. It was believed that a better understanding of northern pike movements in Volkmar Lake could assist ADF&G staff in designing more accurate and more cost-effective mark and recapture experiments.

METHODS

Description of Radio Tags and Tagging Methodology

Between 20 May and 22 May, 1991, 12 radio-transmitters were externally attached to six male and six female northern pike captured with a beach seine, 100 m long by 3 m deep with 25 mm square mesh, set from a boat and retrieved by hand to shore. Because two of the original six females shed their transmitters inadvertently during recapture with the seine, another two female northern pike were tagged for a total of 14 individual fish used in the study. Of the two northern pike that shed their transmitters, one 655 mm fish carried the tag for one day (21 to 22 May), and the other, a 918 mm northern pike, was tracked for 10 days (20 to 30 May). One of the replacement females (855 mm) was recaptured a day after initial tagging (23 to 24 May) which also resulted in the shedding of its transmitter. The transmitter was reattached (24 May), and the fish was held for observation and subsequently released on 26 May. Northern pike used in the telemetry study were examined for evidence of prior marking applied during 1984-1990 mark-recapture experiments (Floy tags, fin clips and/or opercle punches). Of the 14 fish radio tagged, one (female) had been marked with a Floy tag in 1984, three (two males and a female) were marked in 1987, one (female) was tagged in 1988, and one (female) was tagged in 1989. Northern pike released with an attached radio transmitter were also marked with a Floy FD-68 internal anchor tag inserted posteriorly at the left base of the dorsal fin. In addition, a partial dorsal fin-clip was applied.

The sex of each fish was determined by the presence of sex products; all tagged fish were mature. Northern pike less than 500 mm fork length (FL), in an unhealthy condition, or for which sex could not be determined were not used in this study.

A nylon electrical tie, through which a 10 cm Petersen disc needle was pushed, was placed and tightened around the individual transmitter, and the whole assembly secured with epoxy glue. The exposed needle was then passed through the dorsal musculature of each study fish immediately posterior to the insertion of the dorsal fin, and attached to an individually numbered Petersen disc on the opposite side of the fish. The average size of the six tagged males was 570 mm FL (range, 540-624 mm), and the average size of the eight tagged females was 758 mm (range, 604-918 mm). Weight was not recorded. The radio-transmitters (hereafter referred to as tags) were 2.5 cm long by 1.1 cm wide by 0.6 cm thick, and weighed 4.5 g with an external 26 cm antenna (model CHP-1P transmitter with a TA-5LT antenna, manufactured by Telonics, Inc., Mesa, Arizona). The transmitter operational life exceeded three months at a pulse rate of approximately 30 signals per min, and transmitted in the frequency band between 150.45 and 150.65 Mhz. The receiving equipment (also from Telonics, Inc.) consisted of a TR-2 receiver mated to a TS-1 scanner-programmer, which were fed by a RA-4B directional eight-element "Yagi" antenna with 11.8 dB of forward gain. The antenna and receiving equipment were mounted in an inflatable motor propelled raft. Reception distances ranged from a maximum of 2 km at a transmitter depth of 1 m to a minimum of 200 m at a depth of 3.3 m. The effect of transmitter signal attenuation caused by vegetation, thermocline development, or water conductivity was not examined.

Tracking of Radio Tagged Fish

Locations of radio-tagged fish were monitored intermittently from 20 May to 5 August. This time frame was chosen because it was thought to encompass the time of spawning, and because Pearse (1991) found that peak capture rates occurred in May and June as opposed to July through September. Radio tagged fish were tracked three times a day (between 0800-1100 h - hereafter called mornings; 1400-1700 h - hereafter called afternoons; and, 2000-2300 h - hereafter called evenings) from 21-31 May, 3-7 June, and 10-14 June. At least 3 h elapsed between trackings to allow northern pike to move at normal swimming velocities (Chapman and Mackay 1984). Radio tagged fish were tracked once a day (between 1400-1700 h, afternoons) during 24-27 June and on 5 August.

Tracking consisted of programming frequencies of all deployed transmitters into the receiver/scanner (occasional frequency drift did occur, but did not interfere with adjacent transmitters), and motoring to the last location of the respective fish. The individual fish was approached at slow speed, and the receiver's audio output/sensitivity continually reduced to aid in pinpointing the location. Due to the high forward gain of the receiving antenna, fish passage was accompanied by an immediate reduction (null) in signal strength followed by a slight increase in strength as the rear of the antenna sensed the position of the fish aft of the boat. Whenever possible, visual confirmation of fish presence accompanied the electronic location

procedure. If substantial movement occurred between relocations, then the scanner was used to locate individual northern pike while motoring around the lake. Due to apparent signal attenuation, it occasionally took several trips around the lake to locate fish positioned in dense vegetation or at depth.

Each time a relocation was made, the following data were recorded: date, time of day, depth of the water column, surface temperature, vegetation (none, submergent, or emergent), bottom characteristics (if visible), fish activity (at the time of observation), visual confirmation of fish, wind direction, wave height, and recent weather conditions. Water depth was determined with an electric fathometer. Depth of the relocated fish was not verified, but visual observations of northern pike indicated they were in the mid to lower portion of the water column. Temperature profiles were taken at an established station in mid-lake with standard techniques (Welch 1948). Water temperatures were taken with a calibrated electrical-resistance thermometer. Vegetation presence (none, submergent, or emergent) was determined visually; distribution of fully emergent vegetation was estimated from aerial photographs taken of the lake's surface in late July. Fish were determined to be active during the relocation if there was a marked change in location or directed movement during the brief period of observation. Locations of individual northern pike determined during a given sampling period were field-plotted on bathymetric maps (1:13,333 scale) that featured prominent terrain and in-lake markers (buoys). The lake map was developed from a USGS 1:63,360 map, which was enlarged proportionally with the aid of a photocopier. Depth contours, previously determined from values recorded on tape along established transects with the use of an electronic fathometer, were plotted on the lake map prior to sampling. A new map with fish locations was developed for each observation interval. Specific locations of tagged fish were determined by visual triangulation to known shore landmarks and buoys placed in known fixed locations around the lake's perimeter and across an established transect line bisecting the lake, and with depths from the lake contour map. An accurate LORAN receiver was used to confirm landmark/buoy/depth locations. Radio signals, occasionally degraded by unexpected sunspot activity, precluded daily usage of the LORAN receiver to further confirm fish locations. Precision of northern pike locations is considered logarithmic, and was estimated to be plus or minus 15 m within 300 m of shore, increasing to about 50 m in the center of the lake.

Data Analysis

Data on lake shape, depth contour intervals, fish locations, and direction and distance between relocations were entered on a digitized replica of the field sampling maps using Freelance software (Lotus Development Corp; Appendices A1-A14). Data were partitioned into time periods corresponding to the first sampling event in the mark-recapture experiment (20 to 25 May; Period 1), the hiatus or mixing period (26 to 27 May; Period 2), the recapture event in the mark-recapture experiment (28 to 31 May; Period 3), and weekly sampling periods that followed (3 to 7 June, Period 4; 10 to 14 June; Period 5, and 20 June to 5 August; Period 6), or up to whatever date the fish ceased to be a part of the movement study because of loss or malfunction of the transmitter. A series of clear overlay maps were developed as a means to segment Volkmar Lake into a set of alternative zones and these maps depicting: (a) offshore

distance intervals (100 m each); (b) zones of shallow (less than 3 m) and deep water; (c) mark-recapture experiment sampling areas; and, (d) zones of emergent vegetation. These clear maps were then overlaid on top of the relocation maps (Appendices A1-A14) and used as an aid in the tallying of the number of times radio tagged fish were relocated in each segment or lake zone of Volkmar Lake. The surface area of each lake segment or zone was estimated with the use of a software program linked to a CALCOMP 9100 digitizing table, and then converted to the percentage of total lake surface area.

The proportions of the 12 radio tagged northern pike in each zone (inshore versus offshore; shallow water versus deep water; vegetated versus unvegetated; and, mark-recapture sampling areas) of Volkmar Lake during each of the 60 relocation periods were calculated and compared to the proportion of the surface area of the lake that is within each zone to determine if northern pike preferred inshore, shallow, vegetated, or one of the mark-recapture sampling zones. The null hypothesis is that the distribution of tagged fish was skewed to one zone just as often as to the other:

$$H_o: Prob[q_i > q_o] = 0.50 \quad (1)$$

where:

q_i = the proportion of radio tagged fish located in inshore shallow, vegetated, or Area 4; and,

q_o = the proportion of the surface area of the lake represented by that zone (0.23 for inshore; 0.45 for shallow water; 0.25 for vegetated; and, 0.55 for Area 4 used in the mark-recapture experiment).

The number of times that $q_i > q_o$ during each sampling period was tallied and compared to a binomial distribution table ($p = 0.05$) to draw statistical inferences concerning northern pike distribution patterns.

Movements between relocation observations were calculated as straight line distances between successive relocations. These estimated distances moved by study fish are considered to be minimum distances actually moved because fish likely did not move unidirectionally between relocations.

To project expected minimum movement distances of northern pike over various potential mixing periods (nights) within the period encompassing the mark-recapture experiment (20 to 30 May), estimates were developed from the observed distance moved by the radio tagged fish. Distances moved by the study fish were apportioned into the following proportions of movements made by all tagged fish over the course of the study: 0.10, 0.25, 0.50, 0.75, and 0.90. To permit comparison of observed movements between non-uniform times, estimated movement distances (m) of individual northern pike were converted to estimates of minimum rates of movement, for sex and time period categories. Time intervals (h) were determined by defining the difference in hours between the mid-point of the respective sequential observation periods (09:30 for mornings; 15:30 for afternoons; and, 21:30 for evenings).

Rates of movement of individual study fish were calculated as follows:

$$\bar{v}_i = \frac{\sum_{j=1}^{k_i} \frac{m_{ij}}{h_{ij}}}{k_i} \quad (2)$$

where: k_i = numbers of intervals of time between locations of the ith fish;

h_{ij} = duration of the jth interval in hours for the ith fish; and,

m_{ij} = distance between locations for the ith fish over the jth interval.

The average rate of movement for all study fish of a sex during a sampling period was calculated from the individual rates (v_i) as follows:

$$\bar{v} = \frac{\sum_{i=1}^{f} \bar{v}_i}{f} \quad (3)$$

where: f = number of females (or males) tagged.

The variance of $\bar{v}$ was calculated as:

$$V[\bar{v}] = \frac{\sum_{i=1}^{f} (\bar{v}_i - \bar{v})^2}{f\,(f-1)} \quad (4)$$

Minimum rates so estimated assumed that movements between observations occurred as bouts of continuous straight line swimming.

RESULTS AND DISCUSSION

The 14 radio-tagged northern pike (12 transmitters) were located 770 times during the study. Two of the northern pike (a 570 mm male, and a 610 mm female) were tracked for the entire course of the study (20 May to 5 August). Four northern pike shed their transmitters, which were visually located on the lake bottom in beds of emergent vegetation; two of the shed transmitters were recovered. One shed transmitter (from a 540 mm male) was located on 21 June, 30 d after attachment, two were located on 27 June (from a 653 mm female and a 548 mm male) 38 and 36 d after attachment, respectively, and the last (from a

569 mm male) was located on 5 August (77 d after being released). The remaining transmitters were presumed to be attached throughout the study, as movement occurred between all northern pike relocations except for those that were shed. The loss of tags coincided, and was probably due to, the emergence of dense aquatic vegetation. This emphasizes the risk associated with externally attached rigid devices on a species that frequents vegetated areas where they may be entangled and torn off. Coelomic (Diana 1980, Ross 1982), or stomach implantation (Diana et al. 1977) is deemed preferable for long-term studies in the presence of emergent vegetation. However, there is a potential for fish inactivity of up to 5 d after radio tag implantation (Diana 1980), and because of this phenomenon, we chose external tags for our study. All externally-attached transmitters functioned normally throughout this study, reception distance appeared consistent with depth of the associated water column, and frequency drift was acceptable.

Effects of capture, handling, and the attachment of external transmitters on the subsequent locations and movements of the 14 study fish were not investigated. We assumed these handling factors had no effect on subsequent movements of the study fish. There was no observed avoidance of the approaching boat by tagged northern pike.

The spawning period, as determined by the extrusion of sexual products from a sample of 1,009 individual northern pike captured during the mark-recapture experiment (Pearse 1991), commenced prior to ice-melt and was concluded by the end of the recapture event on 31 May. No female northern pike were captured at the onset of sampling (20 May) in either a pre-spawning (tight eggs) or spent condition. Female northern pike captured after 31 May were spent. Therefore, some ripening and the majority of spawning occurred in the 11-d interval between 20 May and 31 May. This time interval is similar to that for northern pike investigated by Fabricius (1950) in Lake Vojmsjo. Thus, movements of the 14 study fish relative to the time interval beginning 20 May and ending 31 May (Periods 1-3) likely includes behavior associated with a combination of both spawning and post-spawning activity; whereas, after 31 May (Periods 4-6) movements do not include behavior associated with spawning.

Movements

Visual examination of individual locations and movements of the 14 study fish suggests that fish were rarely sedentary (Appendices A1-A14). Radio tagged northern pike were mobile immediately upon release. These 14 radio tagged northern pike frequented all areas of the lake. Gross linear movements between consecutive observations ranged from no apparent movement to a maximum of 2,224 m. Based upon the lake's size and shape, maximum possible movement in a straight line would be approximately 2,600 m.

Minimum distances moved between relocations were converted to m/hr to permit comparisons over non-uniform times. These rates of minimum distances moved are hereafter referred to as velocity.

Mean velocities of individual northern pike between periods ranged from 120 m/hr to about 2 m/hr, generally declining after Period 2 (Figure 1). Obvious correlations of the velocities of the 14 radio tagged northern pike with fish

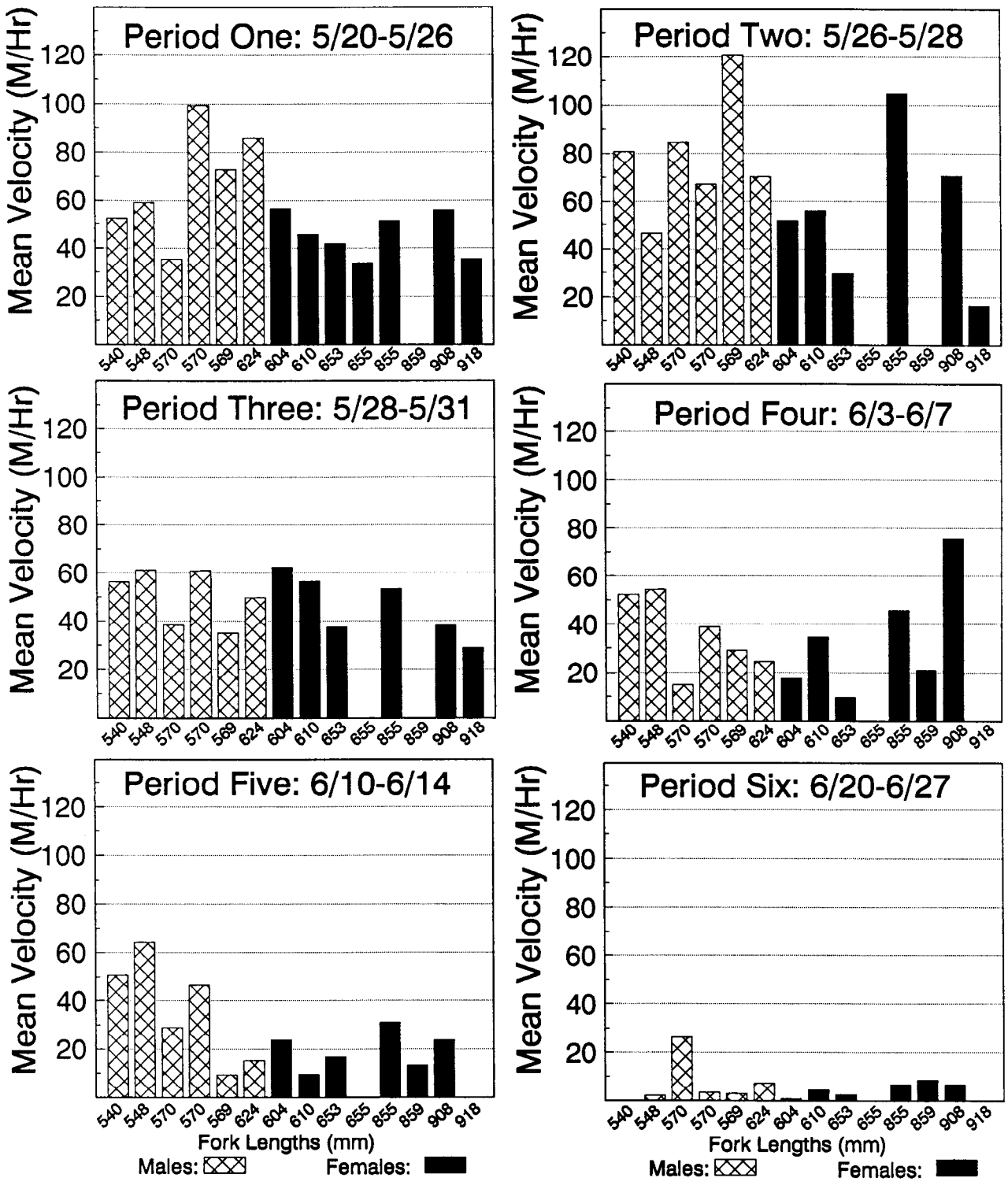

Figure 1. Mean velocities of individual radio-tagged northern pike during sampling Periods 1 to 6 in Volkmar Lake, 1991.

size or sex during the periods examined were not apparent. The most active northern pike observed was a 569 mm male during Period 2.

Velocity detected immediately after breakup during Period 1 declined by Period 4 for males, and by Period 5 for females and sexes combined. Velocity of males ranged from 78.3 m/hr (SE = 9.2) during Period 2 to 8.6 m/hr (SE = 4.1) during Period 6, and averaged 47.1 m/hr (SE = 4.8) for all periods. Velocity of females ranged from 54.8 m/hr (SE = 11.6) during Period 2 to 5.2 m/hr (SE = 1.0) during Period 6, averaging 34.9 m/hr (SE = 3.9) for all periods. The velocity range for all fish varied from 66.6 m/hr (SE = 8.2) during Period 2 to 6.7 m/hr (SE = 2.0) during Period 6 and averaged 40.8 m/hr (SE = 3.14) for all periods. Mean velocities between evenings and mornings (Night), mornings and afternoons (Morning) and afternoons and evenings (Afternoon) varied but no pattern to this variation is visually obvious (Figures 2 and 3).

The literature is relatively void of quantitative references to movements and velocities of northern pike during and immediately after the spawning period. Several authors have indicated elevated activity related to spawning and post-spawning feeding in lakes and reservoirs (Miller 1948, Moen and Henegar 1971, Casselman 1975 and 1978, Priegel and Krohn 1975, Diana 1979, Cook and Bergersen 1988). None specifically discuss sex-dependent movement and velocity, but Cook and Bergersen (1988) observed that activity (percentage of fish that moved between relocations) of radio-tagged northern pike was greatest during the spawning period in April and May (approximately 75%), and declined by more than half (approximately 30%) by July. They observed that there was no significant difference in activity between daily time intervals, similar to our observations. They also noted that approximately 50% of the fish monitored moved from 0 to 8 m/hr during the summer period following spawning. This velocity is similar to our estimate for Period 6 (Figure 2) of 6.7 m/hr (SE = 1.99). They reported activity peaks associated with the morning and evening twilight hours; such crepuscular activity has also been noted by Malinin (1970, 1971) and Casselman (1978). Diana (1980) reported northern pike to be most active by day. During May and June in interior Alaska, daylight is nearly continuous. Decreases in activity in late summer were observed by Diana et al. (1977). These studies add support to our observation that velocities are greatest during spawning, later decline through the summer but do not vary significantly by sex nor by time of day during the nearly continuous photo period experienced in interior Alaska from May through July.

Distribution of Radio Tagged Fish in Various Lake Segments and Zones

Inskip (1982) provides a general literature review of habitat preferences and proposed habitat suitability models for northern pike.

Shore Proximity:

The proportions of time that radio-tagged northern pike were located in various 100 m incremental distances from shore were determined for males and females and for sexes combined (Figure 4). An estimated 23% of the surface area of the lake is within 100 m of shore (zone 1), and 21%, 18%, 15%, 11%,

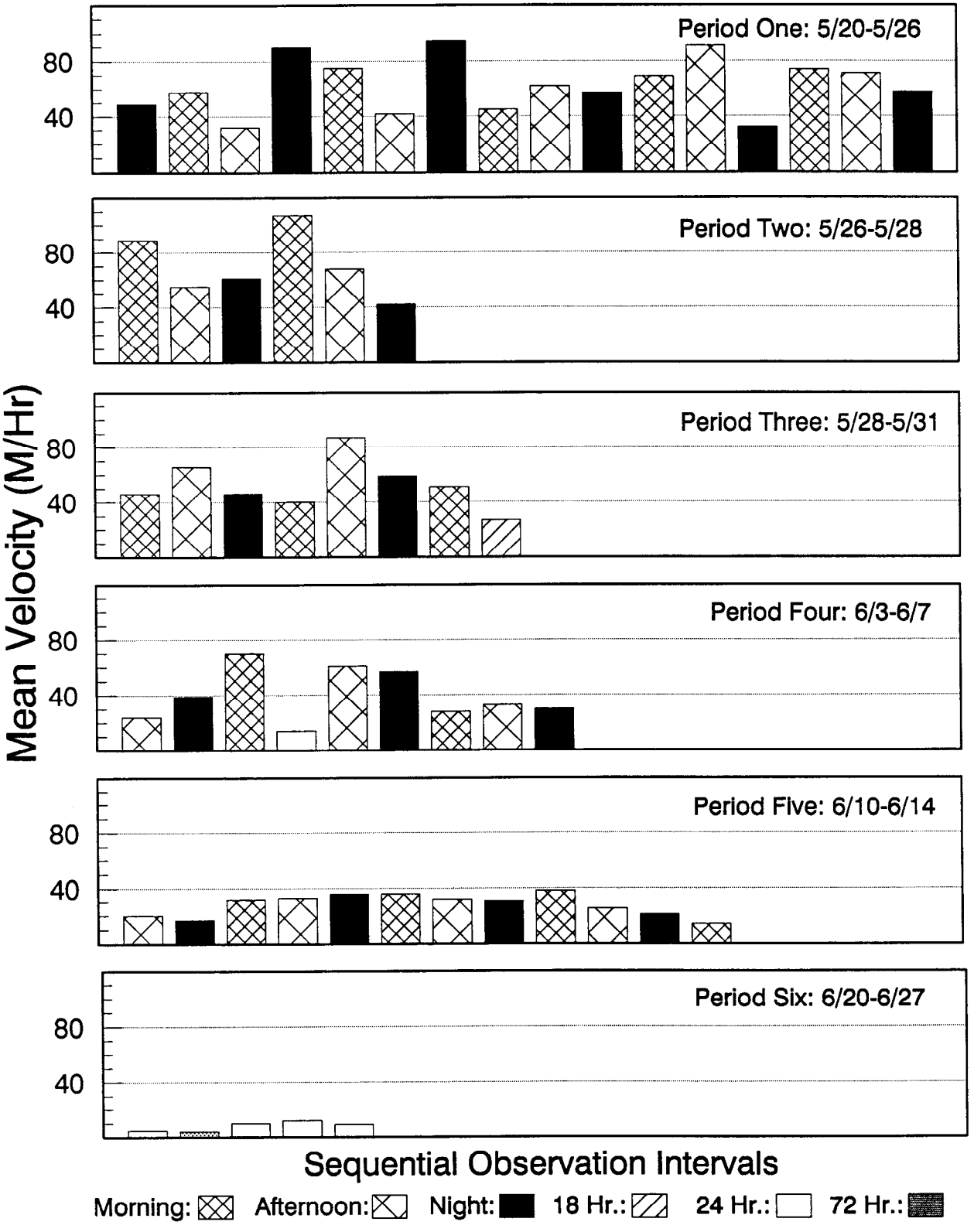

Figure 2. Mean velocities of radio-tagged northern pike (sexes combined) during morning, afternoon, and evening sequential observation intervals in Volkmar Lake, 1991.

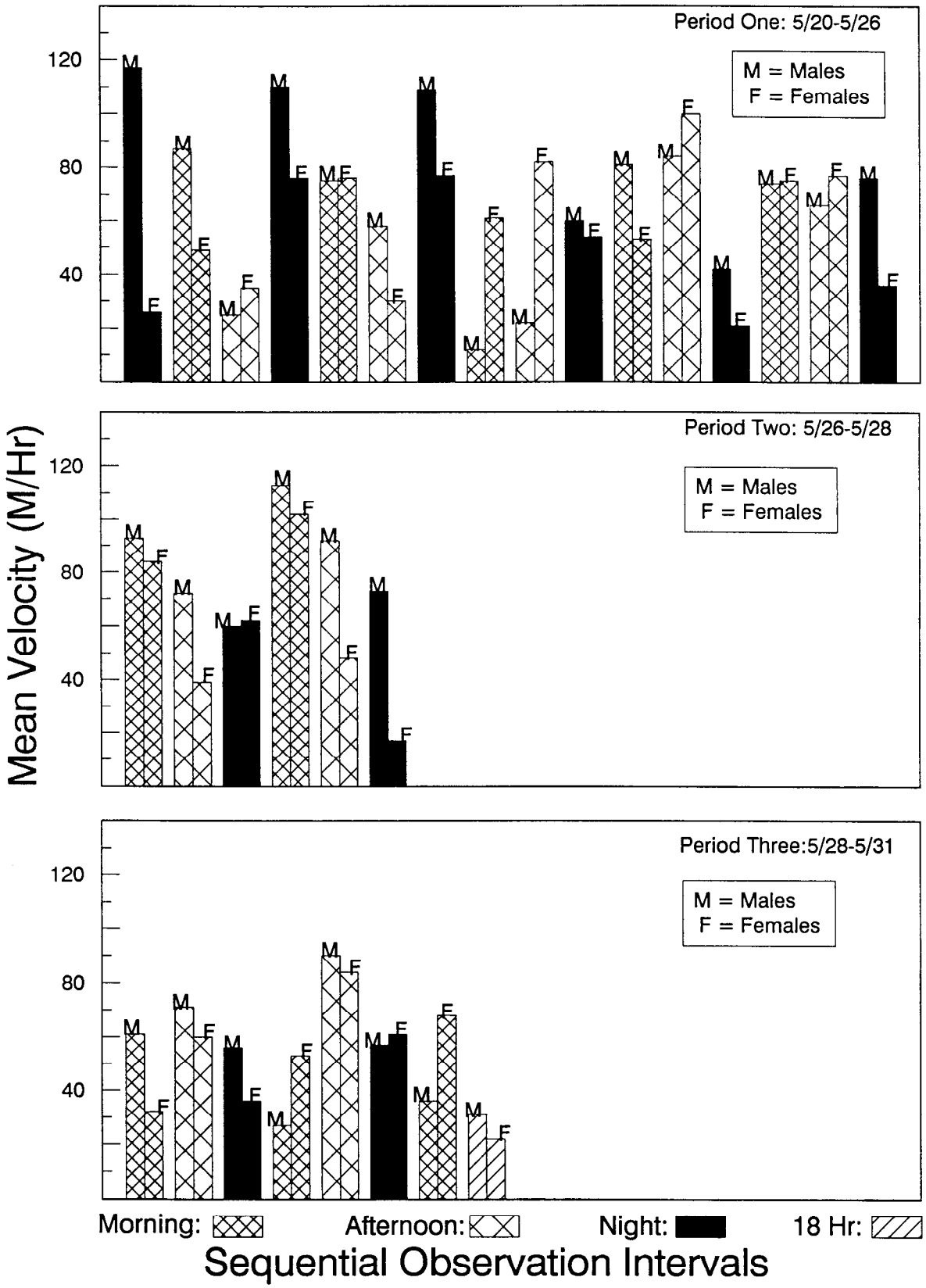

Figure 3. Mean velocities of radio-tagged male and female northern pike during morning, afternoon, and evening sequential observation intervals in sampling Periods 1, 2, and 3 in Volkmar Lake, 1991.

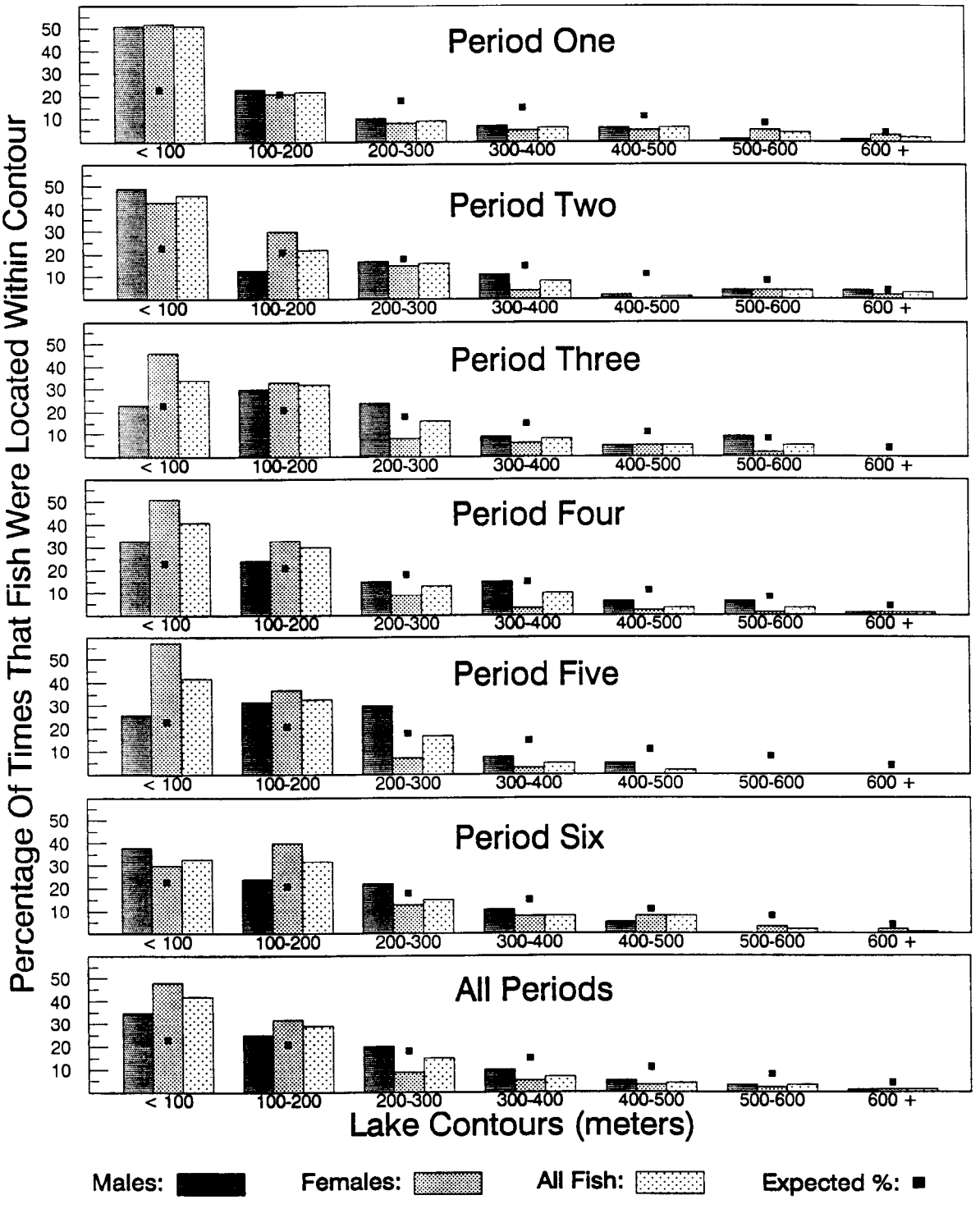

Figure 4. Percentage of time that radio-tagged northern pike were found in various zones at 100 m incremental distances from shore in Volkmar Lake, 1991.

8%, and 4% of the lake is within zones 2 through 7, respectively, located in sequential 100 m offshore intervals.

Radio tagged northern pike tended to inhabit shoreward zones both during the spawning period and shortly thereafter. Sampling Periods 1 through 3 coincide with the spawning event; Periods 4 through 6 coincide with the post spawning and summer intervals, respectively.

Inshore-Offshore Distribution:

Data on relocations relative to the shore-proximity intervals described above were collapsed into "inshore" (within 100 m of shore) and "offshore" (>100 m) (Table 1 and Figure 5). Radio-tagged male northern pike preferred the inshore zone during Periods 1, 2, and 4. Female northern pike with radio tags preferred inshore waters during Periods 1, 3, 4 and 5. When sexes were combined, northern pike preferred inshore waters during sampling Periods 1 - 5. The apparent preference by northern pike for waters within 100 m of shore during Periods 1-5 is likely related to spawning. The reason that distribution of male radio-tagged northern pike changed sooner than did the distribution of females is uncertain; however, Priegel and Krohn (1975) observed that males moved into and out of the spawning area faster than females. No other studies citing observations of measured preference for shore proximity during spawning, given other choices, could be located.

A portion of the above data was examined to determine whether the inshore preference of northern pike (males, females and sexes combined) varied during mornings, afternoons, or evenings during the mark-recapture experiment (Periods 1-3). No obvious trends were apparent (Figure 6).

Water Depth:

Depths of the water column itself at locations where radio-tagged northern pike were relocated during the study were determined (Table 2; Figure 7). During Period 1, northern pike tended to be located in shallower water during the afternoon observation interval than during the morning or afternoon observation intervals. During Period 2 northern pike tended to be located in deeper water during the morning observation interval than during either the afternoon or evening observation intervals. During Period 3, northern pike tended to be in deeper water during the afternoon than was the case during either the mornings or evenings. No obvious trends occurred during Periods 4-6. When observations concerning the depth of the water at locations where radio tagged northern pike were relocated were grouped (morning afternoon and evening observations taken together) by period (Table 2) the average depths for females by period were all shallower than were the average depths for males. The percentage of times that radio-tagged northern pike were located in shallow water (less than 3 m) were determined for males, females, and for sexes combined (Table 3). Males showed a statistical preference for the shallow water zone during Periods 1, 4, and 5; females showed a statistical preference for the shallow water zone during Periods 1-5; and when sexes were combined, northern pike showed a statistical preference for the shallow water zone during Periods 1, 3, 4, and 5.

Table 1. Number and percentage of times that radio-tagged northern pike were located in inshore (within 100 m of shore) and offshore waters of Volkmar Lake, 1991.

Sampling Period	Date & Time	Males				Females				All Fish			
		Inshore		Offshore		Inshore		Offshore		Inshore		Offshore	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	5/21:M[a]	1	100	0	0	3	100	0	0	4	100	0	0
1	5/21:A[a]	1	100	0	0	2	67	1	33	3	75	1	25
1	5/21:E[a]	1	33	2	67	4	67	2	33	5	56	4	44
1	5/22:M	3	75	1	25	2	33	4	67	5	50	5	50
1	5/22:A	4	100	0	0	2	40	3	60	6	67	3	33
1	5/22:E	3	75	1	25	2	40	3	60	5	56	4	44
1	5/23:M	1	17	5	83	2	40	3	60	3	27	8	73
1	5/23:A	1	100	0	0	1	50	1	50	2	67	1	33
1	5/23:E	3	50	3	50	3	60	2	40	6	55	5	45
1	5/24:M	2	33	4	67	2	33	4	67	4	33	8	67
1	5/24:A	4	67	2	33	4	80	1	20	8	73	3	27
1	5/24:E	3	50	3	50	4	80	1	20	7	64	4	36
1	5/25:M	2	33	4	67	3	60	2	40	5	45	6	55
1	5/25:A	4	80	1	20	4	80	1	20	8	80	2	20
1	5/25:E	3	50	3	50	4	80	1	20	7	64	4	36
Probabilities:[b]		*1 of 15; P = 0.0005*				*0 of 15; P = 0.0000*				*0 of 15; P = 0.0000*			
2	5/26:M	2	33	4	67	3	60	2	40	5	45	6	55
2	5/26:A	2	33	4	67	2	33	4	67	4	33	8	67
2	5/26:E	2	33	4	67	2	33	4	67	4	33	8	67
2	5/27:M	2	33	4	67	1	17	5	83	3	25	9	75
2	5/27:A	4	67	2	33	3	50	3	50	7	58	5	42
2	5/27:E	4	67	2	33	2	33	4	67	6	50	6	50
Probabilities:		*0 of 6; P = 0.0156*				*1 of 6; P = 0.1094*				*0 of 6; P = 0.0156*			
3	5/28:M	2	33	4	67	4	67	2	33	6	50	6	50
3	5/28:A	1	17	5	83	3	50	3	50	4	33	8	67
3	5/28:E	1	17	5	83	4	67	2	33	5	42	7	58
3	5/29:M	2	33	4	67	3	50	3	50	5	42	7	58
3	5/29:A	1	17	5	83	4	67	2	33	5	42	7	58
3	5/29:E	1	17	5	83	4	67	2	33	5	42	7	58
3	5/30:M	1	17	5	83	4	67	2	33	5	42	7	58
3	5/30:A	0	0	6	100	1	20	4	80	1	9	10	91
3	5/31:M	0	0	6	100	3	60	2	40	3	27	8	73
Probabilities:		*7 of 9; P = 0.9102*				*1 of 9; P = 0.0195*				*1 of 9; P = 0.0195*			

- continued -

Table 1. (Page 2 of 2).

Sampling Period	Date & Time	Males				Females				All Fish			
		Inshore		Offshore		Inshore		Offshore		Inshore		Offshore	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
4	6/3:A	3	50	3	50	2	33	4	66	5	42	7	58
4	6/3:E	3	50	3	50	3	50	3	50	6	50	6	50
4	6/4:M	2	33	4	67	3	50	3	50	5	42	7	58
4	6/4:A	3	33	4	67	4	67	2	33	6	50	6	50
4	6/4:E	4	67	2	33	4	67	2	33	8	67	4	33
4	6/5:E	3	50	3	50	4	67	2	33	7	58	5	42
4	6/6:M	2	33	4	67	2	33	4	67	4	33	8	67
4	6/6:A	2	33	4	67	3	50	3	50	5	42	7	58
4	6/6:E	2	33	4	67	3	50	3	50	5	42	7	58
4	6/7:M	3	50	3	50	1	17	5	83	4	33	8	67
Probabilities:		*0 of 10; P = 0.0010*				*1 of 10; P = 0.0107*				*0 of 10; P = 0.0010*			
5	6/10:A	2	33	4	67	3	50	3	50	5	42	7	58
5	6/10:E	3	50	3	50	2	33	4	67	5	42	7	58
5	6/11:M	1	17	5	83	2	33	4	67	3	25	9	75
5	6/11:A	1	17	5	83	2	33	4	67	3	25	9	75
5	6/11:E	1	17	5	83	2	33	4	67	3	25	9	75
5	6/12:M	1	17	5	83	2	33	4	67	3	25	9	75
5	6/12:A	1	17	5	83	3	50	3	50	4	33	8	67
5	6/12:E	1	17	5	83	5	83	1	17	6	50	6	50
5	6/13:M	4	67	2	33	5	83	1	17	9	75	3	25
5	6/13:A	2	33	4	67	4	67	2	33	6	50	6	50
5	6/13:E	4	67	2	33	4	67	2	33	8	67	4	33
5	6/14:M	2	40	3	60	5	83	1	17	7	64	4	36
5	6/14:A	2	40	3	60	4	67	2	33	6	55	5	45
Probabilities:		*6 of 13; P = 0.5000*				*0 of 13; P = 0.0001*				*0 of 13; P = 0.0001*			
6	6/20:A	3	60	2	40	5	83	1	17	8	73	3	27
6	6/21:A	3	60	2	40	4	67	2	33	7	64	5	36
6	6/24:A	2	40	3	60	1	17	5	83	3	27	8	73
6	6/25:A	3	60	2	40	0	0	6	100	3	27	8	73
6	6/26:A	3	60	2	40	1	17	5	83	4	37	7	63
6	6/27:A	0	0	4	100	1	20	4	80	1	11	8	89
6	8/5:A	1	33	2	67	0	0	5	100	1	13	7	87
Probabilities:		*1 of 7; P = 0.0625*				*5 of 7; P = 0.7734*				*2 of 7; P = 0.2266*			
All Periods		*15 of 60*				*8 of 60*				*4 of 60*			

[a] M = mornings, A = afternoons, and E = evenings.

[b] The proportion of the lake that is composed of inshore waters is 23%. Probabilities provided (listed *P* values) are based upon the binomial distribution ($p = 0.5$) with the hypothesis test being that the proportion of observations of the distributions of northern pike in inshore waters exceeding 23% is due to chance alone.

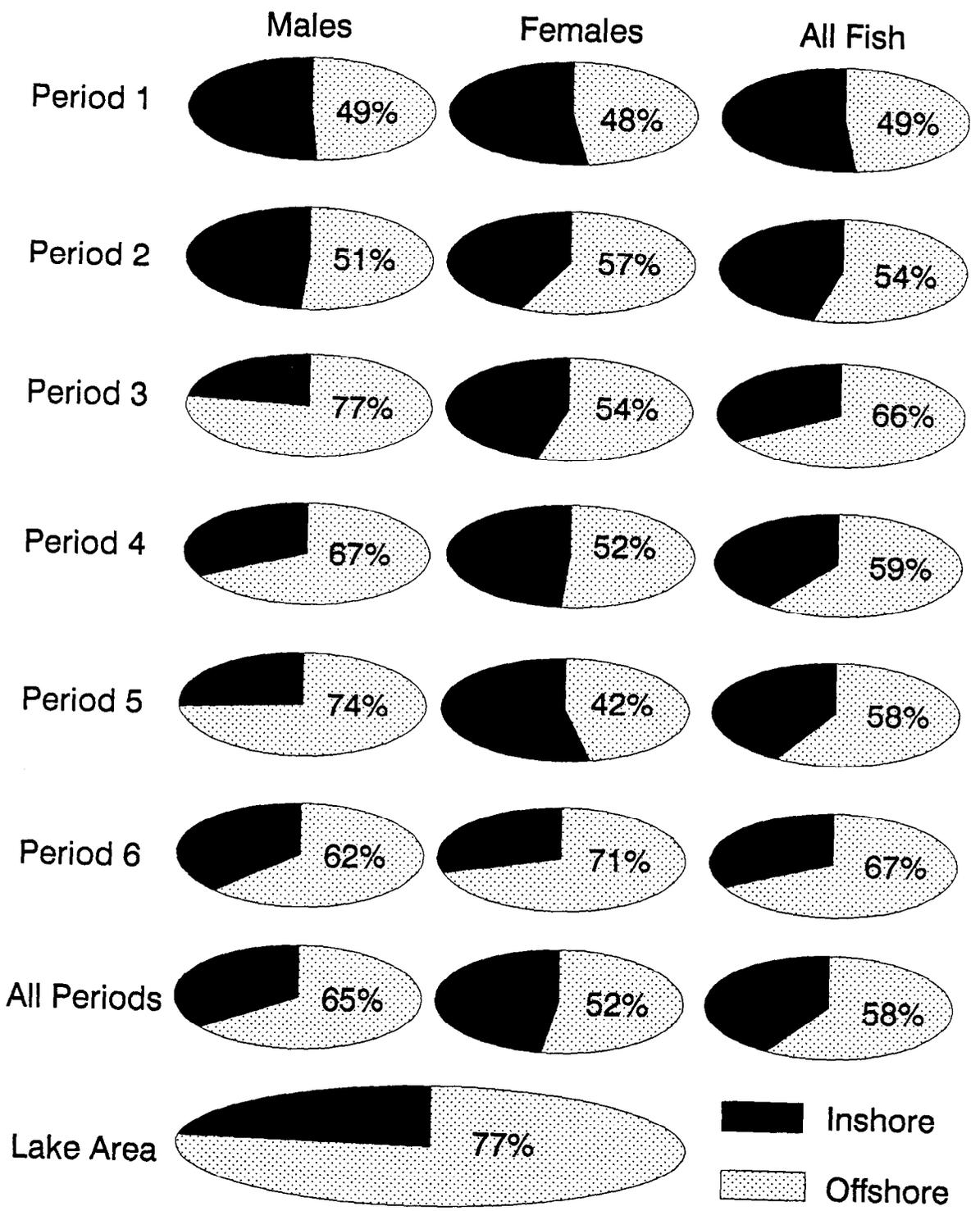

Figure 5. Percentage of time that radio-tagged northern pike were located in inshore (<100 m of shore) and offshore (>100 m) waters in Volkmar Lake, 1991.

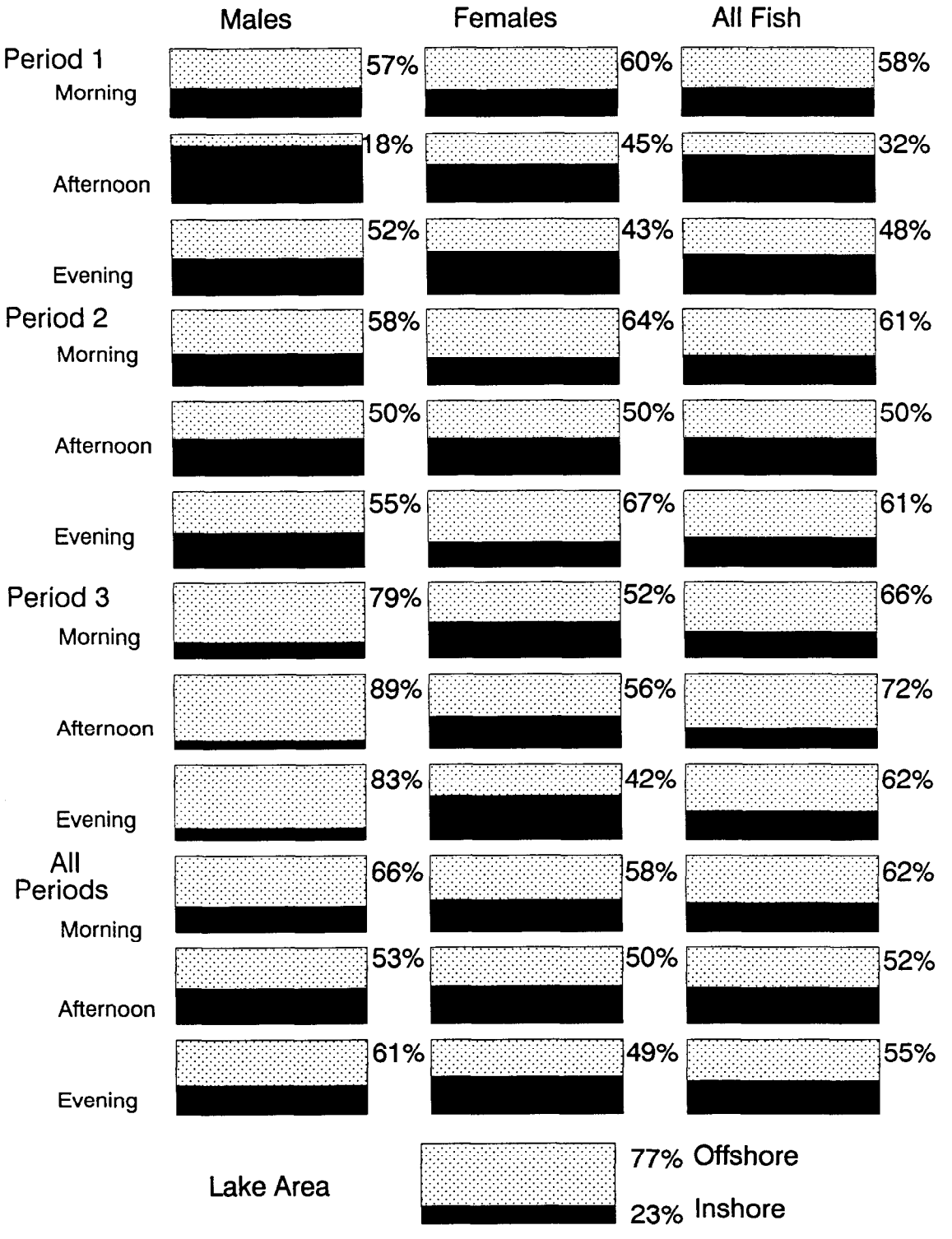

Figure 6. Percentage of time that radio-tagged northern pike were located in inshore and offshore waters of Volkmar Lake during mornings (M), afternoons (A), and evenings (E) for sampling Periods 1, 2, and 3, 1991.

Table 2. Mean water depths where radio-tagged northern pike were located in Volkmar Lake, 1991.

Sampling Period	Dates	Water Depths (M) Where Fish were Located: Males Sample Size	Males Mean	Males SE	Females Sample Size	Females Mean	Females SE	All Fish Sample Size	All Fish Mean	All Fish SE
1	5/21-5/25	63	2.7	0.3	68	2.6	0.3	131	2.6	0.2
2	5/26-5/27	40	4.4	0.5	29	2.4	0.6	69	3.6	0.4
3	5/28-5/31	63	4.4	0.4	43	1.8	0.2	106	3.4	0.3
4	6/3-6/7	70	3.3	0.4	50	2.4	0.2	120	2.9	0.2
5	6/10-6/14	76	3.8	0.4	78	2.1	0.1	154	3.0	0.2
6	6/20-8/5	31	3.0	0.9	39	3.3	0.4	70	3.2	0.3
All	5/21-8/5	343	3.6	0.2	307	2.4	0.1	650	3.0	0.1

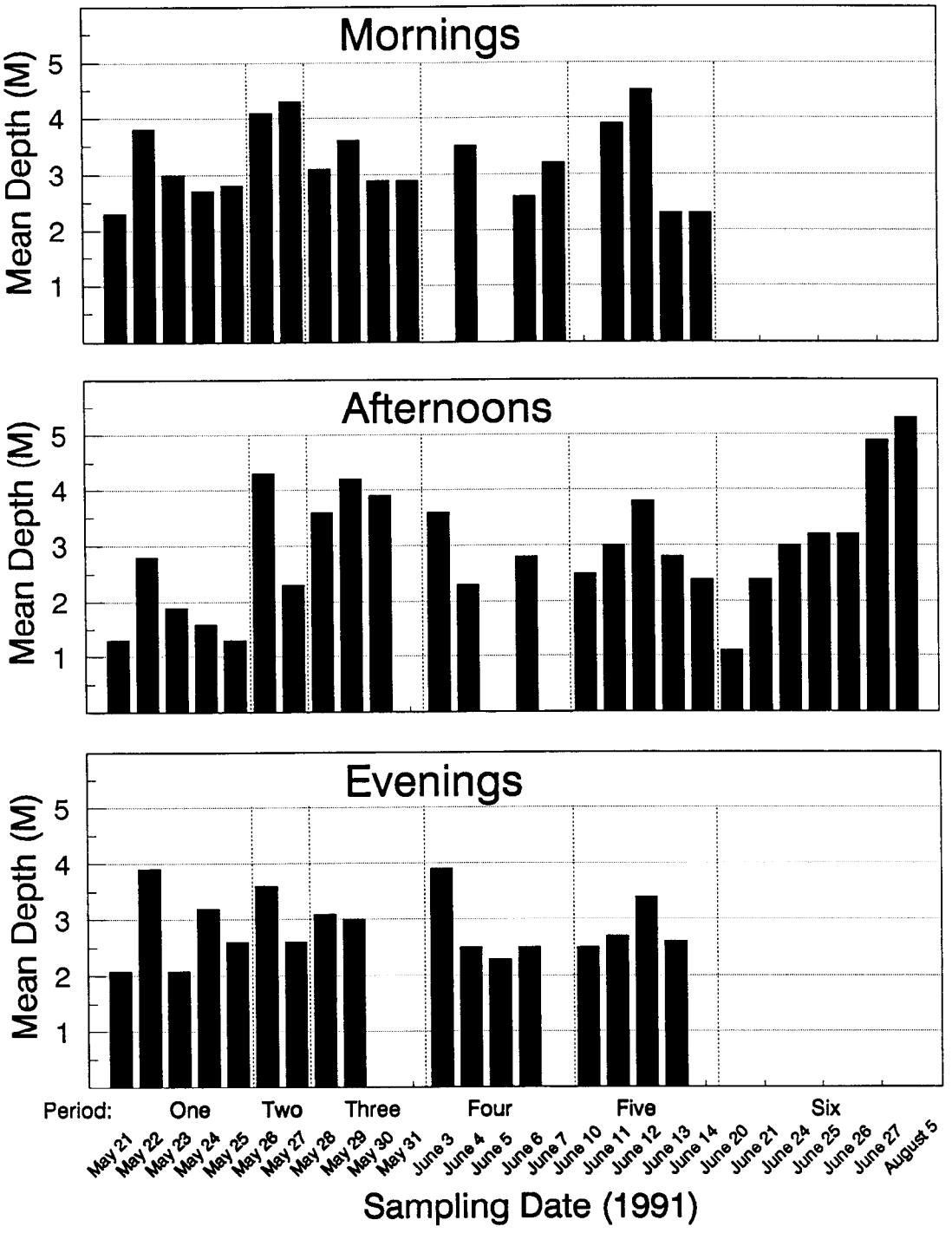

Figure 7. Mean depths at which radio-tagged northern pike were located during mornings (A), afternoons (B), and evenings (C) by sampling date, Volkmar Lake, 1991.

Table 3. Number and percentage of times that radio-tagged northern pike were located in waters less than 3 meters and in waters more than 3 meters in Volkmar Lake, 1991.

Sampling Period	Date & Time	Males				Females				All Fish			
		0-3 M		3 M Plus		0-3 M		3 M Plus		0-3 M		3 M Plus	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	5/21:M[a]	0	0	1	100	3	100	0	0	3	75	1	25
1	5/21:A[a]	1	100	0	0	3	100	0	0	4	100	0	0
1	5/21:E[a]	1	33	2	67	6	100	0	0	7	78	2	22
1	5/22:M	4	100	0	0	3	50	3	50	7	70	3	30
1	5/22:A	4	100	0	0	3	60	2	40	7	78	2	22
1	5/22:E	3	75	1	25	3	60	2	40	6	67	3	33
1	5/23:M	5	83	1	17	4	80	1	20	9	82	2	18
1	5/23:A	1	100	0	0	3	100	0	0	3	100	0	0
1	5/23:E	5	83	1	17	5	100	0	0	10	91	1	1
1	5/24:M	4	67	2	33	5	83	1	17	9	75	3	25
1	5/24:A	6	100	0	0	5	100	0	0	11	100	0	100
1	5/24:E	4	67	2	33	5	100	0	0	9	82	2	18
1	5/25:M	4	67	2	33	4	80	1	20	8	73	3	27
1	5/25:A	5	100	0	0	5	100	0	0	10	100	0	0
1	5/25:E	4	67	2	33	3	60	2	40	7	64	4	36
Probabilities:[b]		*2 of 15; P = 0.0037*				*0 of 15; P = 0.0000*				*0 of 15; P = 0.0000*			
2	5/26:M	2	33	4	67	3	60	2	40	5	45	6	55
2	5/26:A	3	50	3	50	3	50	3	50	6	50	6	50
2	5/26:E	4	67	2	33	5	83	1	17	9	75	3	25
2	5/27:M	3	50	3	50	3	50	3	50	6	50	6	50
2	5/27:A	5	83	1	17	6	100	0	0	11	91	1	9
2	5/27:E	6	100	0	0	4	67	2	33	10	83	2	17
Probabilities:		*1 of 6; P = 0.1094*				*0 of 6; P = 0.0156*				*1 of 6; P = 0.1094*			
3	5/28:M	4	67	2	33	5	83	1	17	9	75	3	25
3	5/28:A	4	67	2	33	4	67	2	33	8	67	4	33
3	5/28:E	2	33	4	67	5	83	1	17	7	58	5	42
3	5/29:M	2	33	4	67	6	100	0	0	8	67	4	33
3	5/29:A	2	33	4	67	6	100	0	0	8	67	4	33
3	5/29:E	2	33	4	67	6	100	0	0	8	67	4	33
3	5/30:M	3	50	3	50	6	100	0	0	9	75	3	25
3	5/30:A	2	33	4	67	5	100	0	0	7	64	4	36
3	5/31:M	3	50	3	50	5	100	0	0	8	73	3	27
Probabilities:		*5 of 9; P = 0.5000*				*0 of 9; P = 0.0020*				*0 of 9; P = 0.0020*			

- continued -

Table 3. (Page 2 of 2).

Sampling Period	Date & Time	Males 0-3 M No.	Males 0-3 M %	Males 3 M Plus No.	Males 3 M Plus %	Females 0-3 M No.	Females 0-3 M %	Females 3 M Plus No.	Females 3 M Plus %	All Fish 0-3 M No.	All Fish 0-3 M %	All Fish 3 M Plus No.	All Fish 3 M Plus %
4	6/3:A	3	50	3	50	4	67	2	33	7	58	5	42
4	6/3:E	3	50	3	50	3	50	3	50	6	50	6	50
4	6/4:M	3	50	3	50	6	100	0	0	9	75	3	25
4	6/4:A	5	83	1	17	6	100	0	0	11	91	1	9
4	6/4:E	4	67	2	33	5	83	1	17	9	75	3	25
4	6/5:E	4	67	2	33	6	100	0	0	10	83	2	17
4	6/6:M	5	83	1	17	5	83	1	17	10	83	2	17
4	6/6:A	5	83	1	17	5	83	1	17	10	83	2	17
4	6/6:E	5	83	1	17	6	100	0	0	11	91	1	9
4	6/7:M	5	83	1	17	4	67	2	33	9	75	3	25
Probabilities:		*0 of 10; P = 0.0010*				*0 of 10; P = 0.0010*				*0 of 10; P = 0.0010*			
5	6/10:A	5	83	1	17	6	100	0	0	11	91	1	9
5	6/10:E	4	67	2	33	6	100	0	0	10	83	2	17
5	6/11:M	4	67	2	33	3	50	3	50	7	58	5	42
5	6/11:A	4	67	2	33	5	83	1	17	9	75	3	25
5	6/11:E	4	67	2	33	6	100	0	0	10	83	2	17
5	6/12:M	3	50	3	50	4	67	2	33	7	58	5	42
5	6/12:A	3	50	3	50	5	83	1	17	8	67	4	33
5	6/12:E	3	50	3	50	5	83	1	17	8	67	4	33
5	6/13:M	5	83	1	17	6	100	0	0	11	91	1	9
5	6/13:A	4	67	2	33	6	100	0	0	10	83	2	17
5	6/13:E	4	67	2	33	6	100	0	0	10	83	2	17
5	6/14:M	4	80	1	20	6	100	0	0	10	91	1	9
5	6/14:A	4	80	1	20	6	100	0	0	10	91	1	9
Probabilities:		*0 of 13; P = 0.0001*				*0 of 13; P = 0.0001*				*0 of 13; P = 0.0001*			
6	6/20:A	4	80	1	20	6	100	0	0	10	91	1	9
6	6/21:A	4	80	1	20	5	83	1	17	9	82	2	18
6	6/24:A	4	80	1	20	4	67	2	33	8	73	3	27
6	6/25:A	4	80	1	20	4	67	2	33	8	73	3	27
6	6/26:A	4	80	1	20	4	67	2	33	8	73	3	27
6	6/27:A	3	75	1	25	1	20	4	80	4	44	5	56
6	8/5:A	1	33	2	67	2	40	3	60	3	37	5	63
Probabilities:		*1 of 7; P = 0.0625*				*2 of 7; P = 0.2266*				*2 of 7; P = 0.2266*			
All Periods		*9 of 60*				*2 of 60*				*3 of 60*			

[a] M = mornings, A = afternoons, and E = evenings.

[b] The proportion of the lake that is less than 3 M is 45%. Probabilities provided (listed *P* values) are based upon the binomial distribution ($p = 0.5$) with the hypothesis test being that the proportion of observations of the distributions of northern pike in waters less than 3 M exceeding 45% is due to chance alone.

The depth distribution of mature northern pike during the spawning period has received limited description in the available literature. Frost and Kipling (1967) noted in Lake Windermere, England that spawning occurred in depths from 15 cm to 3.5 m. However, considerable data is available regarding later summer depth distribution and preferences. Diana et al. (1977) found that in summer, 52% of the northern pike studied occupied depths less than 2 m, and 95% were found in water less than 4 m. Chapman and Mackay (1984a) found that 67% of the fish examined selected depths less than 2 m. Cook and Bergersen (1988) in describing summer depth preferences, noted tagged northern pike displayed daily depth distribution patterns with monitored fish occupying comparatively shallower water during late afternoon and early evening, and deeper water at night. Average depth of all relocations was 3.14 m, with 48.1% in water less than 1.9 m. Male northern pike occupied average depths of 2.8 m; female fish averaged depths of 4.0 m. These data appear to contradict those we determined for Volkmar Lake, but are averaged over an entire summer as opposed to our observations which were limited after 27 June. These authors felt tagged northern pike were located in significantly deeper water on sunny than cloudy days, but not farther than shore. In their study, Cook and Bergersen also found northern pike to be significantly farther from shore on windy days than on calm days, but not significantly deeper. Chapman and Mackay (1984b) felt northern pike behaved similarly on windy days, presumably due to inhibited sight feeding ability caused by the increased turbidity generated by wave action. Unlike Cook and Bergersen, these authors felt northern pike selected shallow water close to shore during sunny periods in May and June.

Emergent Vegetation:

The proportions of times that radio-tagged northern pike were located in vegetated areas of Volkmar Lake were determined for males, females and for sexes combined (Table 4; Figure 8). Males showed a statistical preference for vegetated access during Periods 1, 4, and 5. Female northern pike only showed a statistical preference for vegetated areas of Volkmar Lake during Period 5. When sexes were combined, northern pike showed a statistical preference for vegetated areas of Volkmar Lake during Periods 1, 4, and 5.

Diana et al. (1977) reported that 92% of northern pike relocations occurred in vegetated habitat during summer. Chapman and Mackay (1984b) reported that northern pike were found associated with aquatic macrophytes significantly more than would have been expected if they were choosing habitats randomly; they were not necessarily strongly tied to shallow vegetated areas and were associated with non-vegetated lake zones for up to 10 d intervals. Cook and Bergersen (1988) determined that 90% of male and 71% of female northern pike relocations occurred in vegetated areas. The total percent use of vegetated areas by both sexes combined (74%) was significant and only 35% of the water body studied was vegetated. They found that females were relocated in unvegetated areas nearly three time more often than males, and logically assumed that the larger females also inhabited deeper habitats in summer than males as mentioned previously. Our observation that female northern pike seemingly preferred shallower, vegetated habitats closer to shore than males reflects data relative to our monitoring period in early summer. Our observations of these preferences may be an artifact of the time frame of our

Table 4. Number and percentage of times that radio-tagged northern pike were located in vegetated and unvegetated areas of Volkmar Lake, 1991.

Sampling Period	Date & Time	Males				Females				All Fish			
		Veget.		Unveget.		Veget.		Unveget.		Veget.		Unveget.	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	5/21:M[a]	0	0	1	100	2	67	1	33	2	50	2	50
1	5/21:A[a]	0	0	1	100	2	67	1	33	2	50	2	50
1	5/21:E[a]	1	33	2	67	3	50	3	50	4	44	5	56
1	5/22:M	2	50	2	50	1	17	5	83	3	30	7	70
1	5/22:A	3	75	1	25	2	40	3	60	5	56	4	44
1	5/22:E	3	75	1	25	1	20	4	80	4	44	5	56
1	5/23:M	2	33	4	67	1	20	4	80	3	27	8	73
1	5/23:A	1	100	0	100	0	0	2	100	1	33	2	67
1	5/23:E	4	67	2	33	3	60	2	40	7	64	4	36
1	5/24:M	2	33	4	67	3	50	3	50	5	42	7	58
1	5/24:A	3	50	3	50	4	80	1	20	7	64	4	36
1	5/24:E	2	33	4	67	3	60	2	40	5	45	6	55
1	5/25:M	3	50	3	50	3	60	2	40	6	55	5	45
1	5/25:A	4	80	1	20	4	80	1	20	8	80	2	20
1	5/25:E	2	33	4	67	2	40	3	60	4	36	7	64
Probabilities:[b]		*2 of 15; P = 0.0037*				*4 of 15; P = 0.0592*				*0 of 15; P = 0.0000*			
2	5/26:M	1	17	5	83	3	60	2	40	4	36	7	64
2	5/26:A	1	17	5	83	1	17	5	83	2	17	10	83
2	5/26:E	2	33	4	67	2	33	4	67	4	33	8	67
2	5/27:M	2	33	4	67	2	33	4	67	4	33	8	67
2	5/27:A	2	33	4	67	3	50	3	50	5	42	7	58
2	5/27:E	4	67	2	33	2	33	4	67	6	50	6	50
Probabilities:		*2 of 6; P = 0.3438*				*1 of 6; P = 0.1094*				*1 of 6; P = 0.1094*			
3	5/28:M	1	17	5	83	3	50	3	50	4	33	8	67
3	5/28:A	0	0	6	100	1	17	5	83	1	8	11	92
3	5/28:E	0	0	6	100	0	0	6	100	0	0	12	100
3	5/29:M	2	33	4	67	3	50	3	50	5	42	7	58
3	5/29:A	1	17	5	83	5	83	1	17	6	50	6	50
3	5/29:E	1	17	5	83	5	83	1	17	6	50	6	50
3	5/30:M	3	50	3	50	4	67	2	33	7	58	5	42
3	5/30:A	1	17	5	83	3	60	2	40	4	36	7	64
3	5/31:M	2	33	4	67	1	20	4	80	3	27	8	73
Probabilities:		*6 of 9; P = 0.7461*				*3 of 9; P = 0.2539*				*2 of 9; P = 0.0898*			

- continued -

Table 4. (Page 2 of 2).

Sampling Period	Date & Time	Males				Females				All Fish			
		Veget.		Unveget.		Veget.		Unveget.		Veget.		Unveget.	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
4	6/3:A	2	33	4	67	4	67	2	33	6	50	6	50
4	6/3:E	3	50	3	50	3	50	3	50	6	50	6	50
4	6/4:M	3	50	3	50	4	67	2	33	7	58	5	42
4	6/4:A	4	67	2	33	3	50	3	50	7	58	5	58
4	6/4:E	2	33	4	67	1	17	5	83	3	25	9	75
4	6/5:E	5	83	1	17	4	67	2	33	9	75	3	25
4	6/6:M	3	50	3	50	1	17	5	83	4	33	8	67
4	6/6:A	2	33	4	67	4	67	2	33	6	50	6	50
4	6/6:E	3	50	3	50	4	67	2	33	7	58	5	42
4	6/7:M	4	67	2	33	2	33	4	67	6	50	6	50
Probabilities:		*0 of 10; P = 0.0010*				*2 of 10; P = 0.0547*				*1 of 10; P = 0.0107*			
5	6/10:A	2	33	4	67	5	83	1	17	7	58	5	42
5	6/10:E	5	83	1	17	4	67	2	33	9	75	3	25
5	6/11:M	2	33	4	67	2	33	4	67	4	33	8	67
5	6/11:A	2	33	4	67	5	83	1	17	7	58	5	42
5	6/11:E	3	50	3	50	4	67	2	33	7	58	5	42
5	6/12:M	2	33	4	67	3	50	3	50	5	42	7	58
5	6/12:A	1	17	5	83	5	83	1	17	6	50	6	50
5	6/12:E	2	33	4	67	5	83	1	17	7	58	5	42
5	6/13:M	4	67	2	33	6	100	0	0	10	83	2	17
5	6/13:A	4	67	2	33	5	83	1	17	9	75	3	25
5	6/13:E	2	33	4	67	5	83	1	17	7	58	5	42
5	6/14:M	4	80	1	20	5	83	1	17	9	82	2	18
5	6/14:A	4	80	1	20	5	83	1	17	9	82	2	18
Probabilities:		*1 of 13; P = 0.0017*				*0 of 13; P = 0.0001*				*0 of 13; P = 0.0001*			
6	6/20:A	4	80	1	20	5	83	1	17	9	82	2	18
6	6/21:A	4	80	1	20	5	83	1	17	9	82	2	18
6	6/24:A	3	60	2	40	4	67	2	33	7	64	4	36
6	6/25:A	3	60	2	40	3	50	3	50	6	55	5	45
6	6/26:A	4	80	1	20	3	50	3	50	7	64	5	36
6	6/27:A	1	20	4	80	2	40	3	60	3	33	6	67
6	8/5:A	1	33	2	67	1	20	4	80	2	25	6	75
Probabilities:		*1 of 7; P = 0.0625*				*1 of 7; P = 0.0625*				*1 of 7; P = 0.0625*			
All Periods		*12 of 60*				*11 of 60*				*5 of 60*			

[a] M = mornings, A = afternoons, and E = evenings.

[b] The proportion of the lake bottom that was covered with vegetation was 25%. Probabilities provided (listed *P* values) are based upon the binomial distribution ($p = 0.5$) with the hypothesis test being that the proportion of observations of the distributions of northern pike in vegetated areas exceeding 25% is due to chance alone.

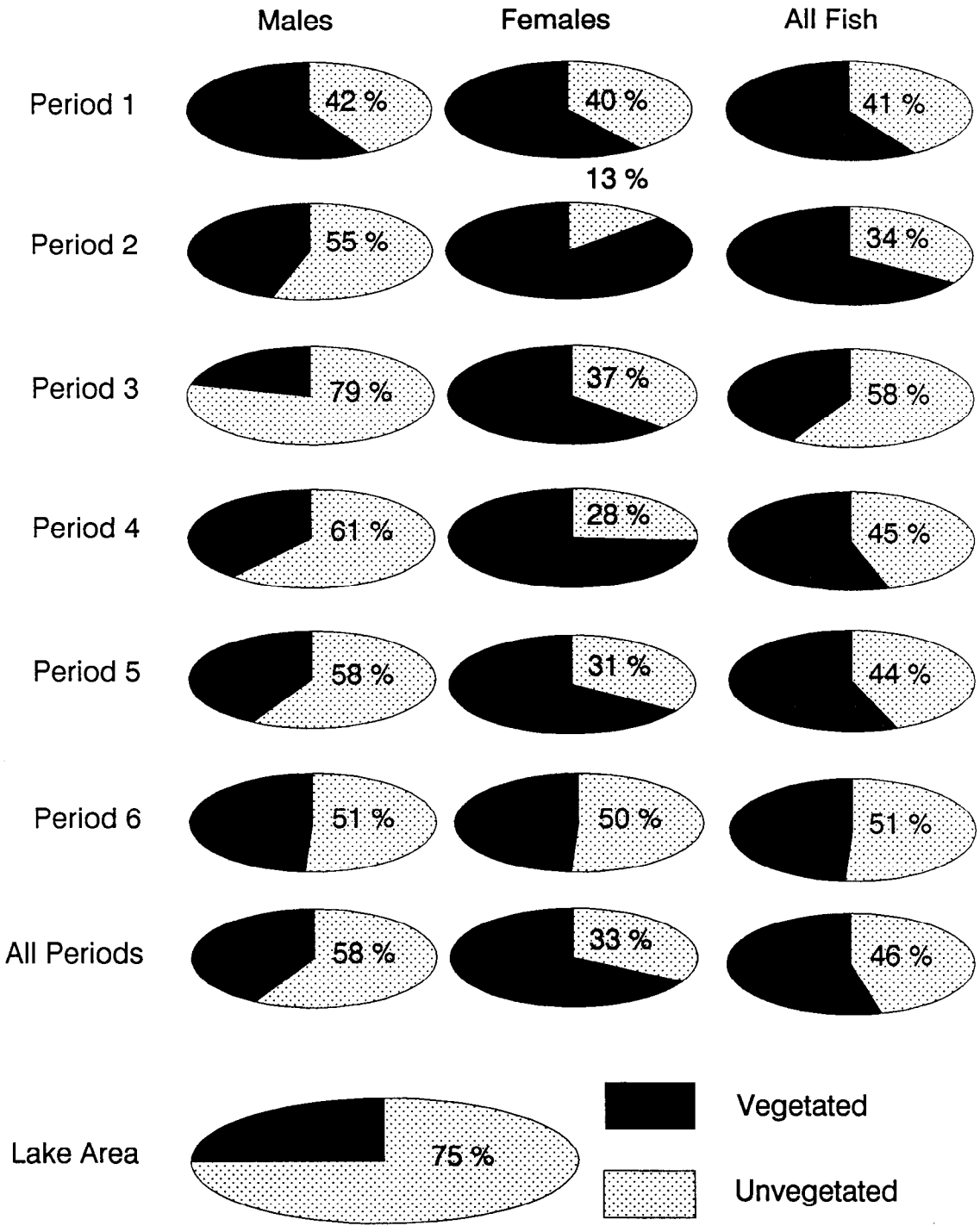

Figure 8. Percentage of time that radio-tagged northern pike were located in vegetated zones of Volkmar Lake, 1991.

study. We lack data for the remainder of the summer; none of the available literature provided information relative to the time frame of our study.

Mark-Recapture Sampling Areas:

From 1985 through 1990, Volkmar Lake was arbitrarily divided into sampling Areas 1 (24% of lake area), 2 (42% of lake area), and 3 (34% of lake area). These areas were based upon easily recognizable geographic features, and facilitated tests to determine if mixing occurred between the mark and recapture sampling events (Pearse 1991). For the 1991 stock assessment project, the lake was divided into two sampling areas (Area 4 representing 55% of the lake area and Area 5 representing 45% of the lake area), primarily to minimize problems associated with poor recapture probabilities experienced in Area 3 of the previous sampling design (Pearse 1991).

The proportions of times that radio-tagged northern pike were located in Areas 4 and 5 of Volkmar Lake were determined for males, females, and for sexes combined (Table 5; Figure 9). Males showed a statistical preference for Area 4 during Periods 3, 4, and 5 whereas females showed such a preference during Periods 2-6. When sexes were combined, northern pike showed a statistical preference for Area 4 of Volkmar Lake during Periods 1-5.

Water Temperatures

Volkmar Lake was thermally mixed prior to 26 May, when slight stratification (> 1 degree C change/m) was observed at the recording station (Figure 10). Surface temperatures taken at the recording station did not differ from those taken at locations of tagged fish. Surface water temperatures were 8 C at the onset of the study, and fell within the range reported as optimum for northern pike spawning activity (4.4 - 11.1 C, Scott and Crossman 1973; 6 C, Frost and Kipling 1967; 10 - 17.8 C, Priegel and Krohn 1975).

Sampling Implications and Recommendations

During the 1991 mark-recapture experiment, Pearse (1991) determined that either the fish marked during the first event (both sexes combined) mixed completely between events, or that capture probabilities during the marking event (Period 1) were the same throughout the lake. This assumption was based upon the fact that fractions of northern pike with marks captured during the second event (the R/C ratio) were not significantly different between lake Areas 4 and 5. Comparison of marking area versus recapture area also indicated sufficient mixing between areas had occurred. However, as in previous abundance estimates for Volkmar Lake, significant size selectivity was detected. In 1991, only composition data (length-age-sex) from the marking event was used to characterize the population, as tests of cumulative length distributions between events (the Kolmogorov-Smirnov two-sample test) indicated significant size selectivity occurred during the recapture event (Pearse 1991).

The northern pike used in this telemetry study did not include the entire size range of both sexes (> 300 mm FL) as was the case in the mark-recapture experiment. Movements and distributions determined from the telemetry data

Table 5. Number and percentage of times that radio-tagged northern pike were located in Areas 4 and 5 of Volkmar Lake, 1991.

Sampling Period	Date & Time	Males Area 4 No.	Males Area 4 %	Males Area 5 No.	Males Area 5 %	Females Area 4 No.	Females Area 4 %	Females Area 5 No.	Females Area 5 %	All Fish Area 4 No.	All Fish Area 4 %	All Fish Area 5 No.	All Fish Area 5 %
1	5/21:M[a]	1	100	0	0	1	33	2	67	3	75	1	25
1	5/21:A[a]	1	100	0	0	1	33	2	67	3	75	1	25
1	5/21:E[a]	3	100	0	0	3	50	3	50	8	88	1	12
1	5/22:M	2	50	2	50	2	33	4	67	7	70	3	30
1	5/22:A	2	50	2	50	2	40	3	60	6	67	3	33
1	5/22:E	2	50	2	50	2	40	3	60	5	56	4	44
1	5/23:M	2	33	4	67	2	40	3	60	7	64	4	36
1	5/23:A	1	100	0	0	1	50	1	50	3	100	0	0
1	5/23:E	4	67	2	33	4	80	1	20	8	73	3	27
1	5/24:M	6	100	0	0	6	100	0	0	12	100	0	0
1	5/24:A	5	83	1	17	5	100	0	0	10	91	1	9
1	5/24:E	3	50	3	50	3	60	2	40	7	64	4	36
1	5/25:M	2	33	4	67	4	80	1	20	8	73	3	27
1	5/25:A	4	80	1	20	4	80	1	20	7	70	3	30
1	5/25:E	5	83	1	17	5	100	0	0	8	73	3	27
Probabilities:[b]		*6 of 15; P = 0.3036*				*8 of 15; P = 0.5000*				*0 of 15; P = 0.0000*			
2	5/26:M	5	83	1	17	3	60	2	40	8	73	3	27
2	5/26:A	4	67	2	33	4	67	2	33	8	67	4	33
2	5/26:E	3	50	3	50	4	67	2	33	7	58	5	42
2	5/27:M	6	100	0	0	5	83	1	17	11	91	1	9
2	5/27:A	4	67	2	33	6	100	0	0	10	83	2	17
2	5/27:E	3	50	3	50	6	100	0	0	9	75	3	25
Probabilities:		*2 of 6; P = 0.3438*				*0 of 6; P = 0.0156*				*0 of 6; P = 0.0156*			
3	5/28:M	4	67	2	33	6	100	0	0	10	83	2	17
3	5/28:A	4	67	2	33	6	100	0	0	10	83	2	17
3	5/28:E	5	83	1	17	4	67	2	33	9	75	3	25
3	5/29:M	5	83	1	17	5	83	1	17	10	83	2	17
3	5/29:A	5	83	1	17	4	67	2	33	9	75	3	25
3	5/29:E	3	50	3	50	4	67	2	33	7	58	5	42
3	5/30:M	4	67	2	33	5	83	1	17	9	75	3	25
3	5/30:A	4	67	2	33	4	80	1	20	8	73	3	27
3	5/31:M	5	83	1	17	4	80	1	20	9	82	2	18
Probabilities:		*1 of 9; P = 0.0195*				*0 of 9; P = 0.0020*				*0 of 9; P = 0.0020*			

- continued -

Table 5. (Page 2 of 2).

Sampling Period	Date & Time	Males Area 4 No.	Males Area 4 %	Males Area 5 No.	Males Area 5 %	Females Area 4 No.	Females Area 4 %	Females Area 5 No.	Females Area 5 %	All Fish Area 4 No.	All Fish Area 4 %	All Fish Area 5 No.	All Fish Area 5 %
4	6/3:A	4	67	2	33	4	67	2	33	8	67	4	33
4	6/3:E	4	67	2	33	4	67	2	33	8	67	4	33
4	6/4:M	4	67	2	33	5	83	1	17	9	75	3	25
4	6/4:A	4	67	2	33	5	83	1	17	9	75	3	25
4	6/4:E	3	50	3	50	5	83	1	17	8	67	4	33
4	6/5:E	4	67	2	33	5	83	1	17	9	75	3	25
4	6/6:M	4	67	2	33	5	83	1	17	9	75	3	25
4	6/6:A	4	67	2	33	5	83	1	17	9	75	3	25
4	6/6:E	4	67	2	33	5	83	1	17	9	75	3	25
4	6/7:M	4	67	2	33	5	83	1	17	9	75	3	25
Probabilities:		*1 of 10;*	*P = 0.0107*			*0 of 10;*	*P = 0.0010*			*0 of 10;*	*P = 0.0010*		
5	6/10:A	3	50	3	50	5	83	1	17	8	67	4	33
5	6/10:E	4	67	2	33	5	83	1	17	9	75	3	25
5	6/11:M	5	83	1	17	5	83	1	17	10	83	2	17
5	6/11:A	6	100	0	0	5	83	1	17	11	91	1	9
5	6/11:E	5	83	1	17	5	83	1	17	10	83	2	17
5	6/12:M	4	67	2	33	5	83	1	17	9	75	3	25
5	6/12:A	4	67	2	33	5	83	1	17	9	75	3	25
5	6/12:E	4	67	2	33	5	83	1	17	9	75	3	25
5	6/13:M	2	33	4	67	4	67	2	33	6	50	6	50
5	6/13:A	2	33	4	67	4	67	2	33	6	50	6	50
5	6/13:E	4	67	2	33	4	67	2	33	8	67	4	33
5	6/14:M	4	80	1	20	4	67	2	33	8	73	3	27
5	6/14:A	3	60	2	40	4	67	2	33	7	64	4	36
Probabilities:		*3 of 13;*	*P = 0.0461*			*0 of 13;*	*P = 0.0001*			*2 of 13;*	*P = 0.0112*		
6	6/20:A	2	40	3	60	4	67	2	33	6	55	5	45
6	6/21:A	2	40	3	60	4	67	2	33	6	55	5	45
6	6/24:A	3	60	2	40	4	67	2	33	7	64	4	36
6	6/25:A	3	60	2	40	4	67	2	33	7	64	4	36
6	6/26:A	2	40	3	60	4	67	2	33	6	55	5	45
6	6/27:A	3	75	1	25	3	60	2	40	6	67	3	33
6	8/5:A	2	67	1	33	4	80	1	20	6	75	2	25
Probabilities:		*3 of 7; P = 0.5000*				*0 of 7;*	*P = 0.0078*			*3 of 7; P = 0.5000*			
All Periods		*16 of 60*				*8 of 60*				*5 of 60*			

[a] M = mornings, A = afternoons, and E = evenings.

[b] The proportion of the lake that is comprised of area 4 is 55%. Probabilities provided (listed *P* values) are based upon the binomial distribution ($p = 0.5$) with the hypothesis test being that the proportion of observations of the distributions of northern pike in area 4 exceeding 55% is due to chance alone.

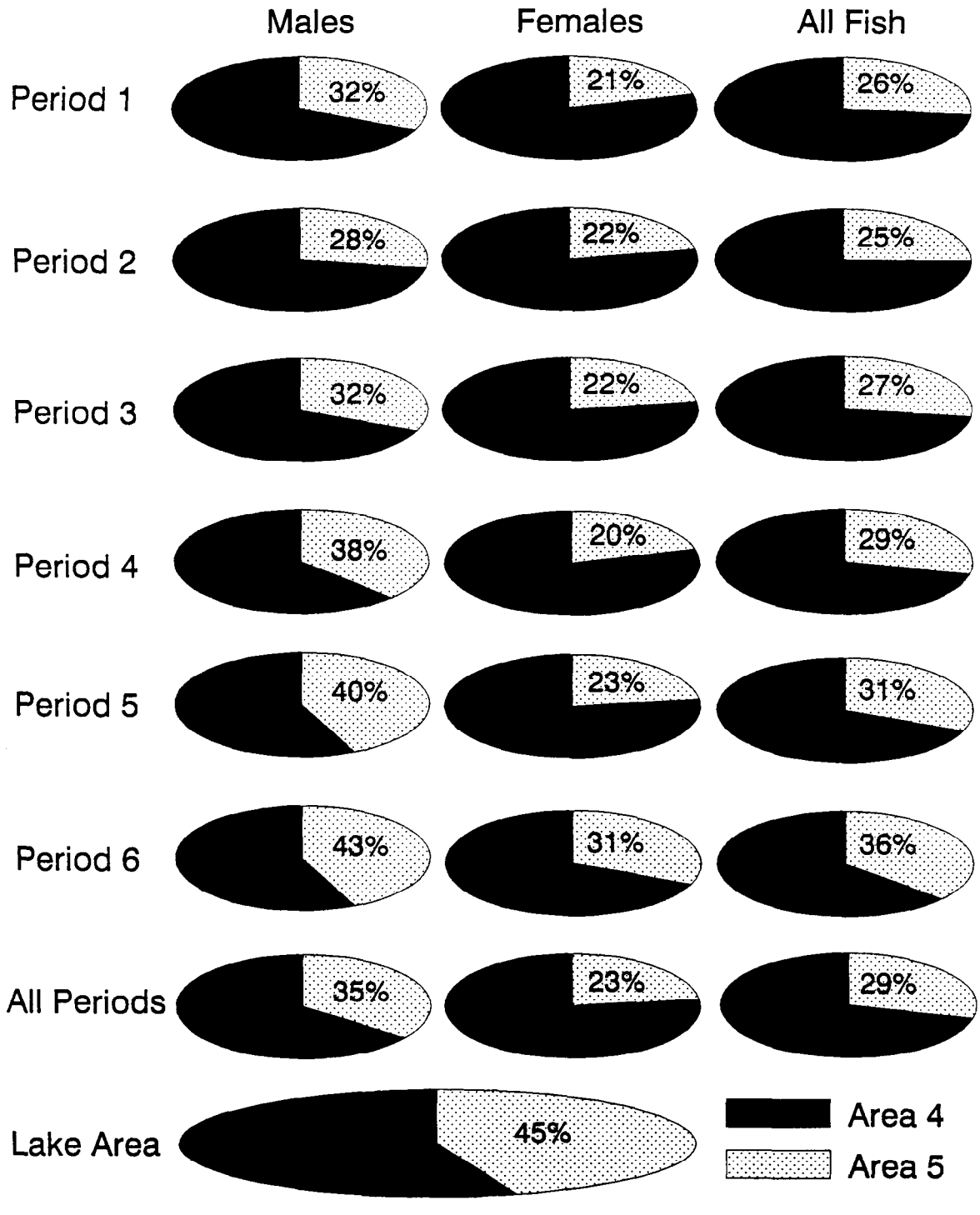

Figure 9. Percentage of time that radio-tagged northern pike were located in Areas 4 and 5 of Volkmar Lake, 1991.

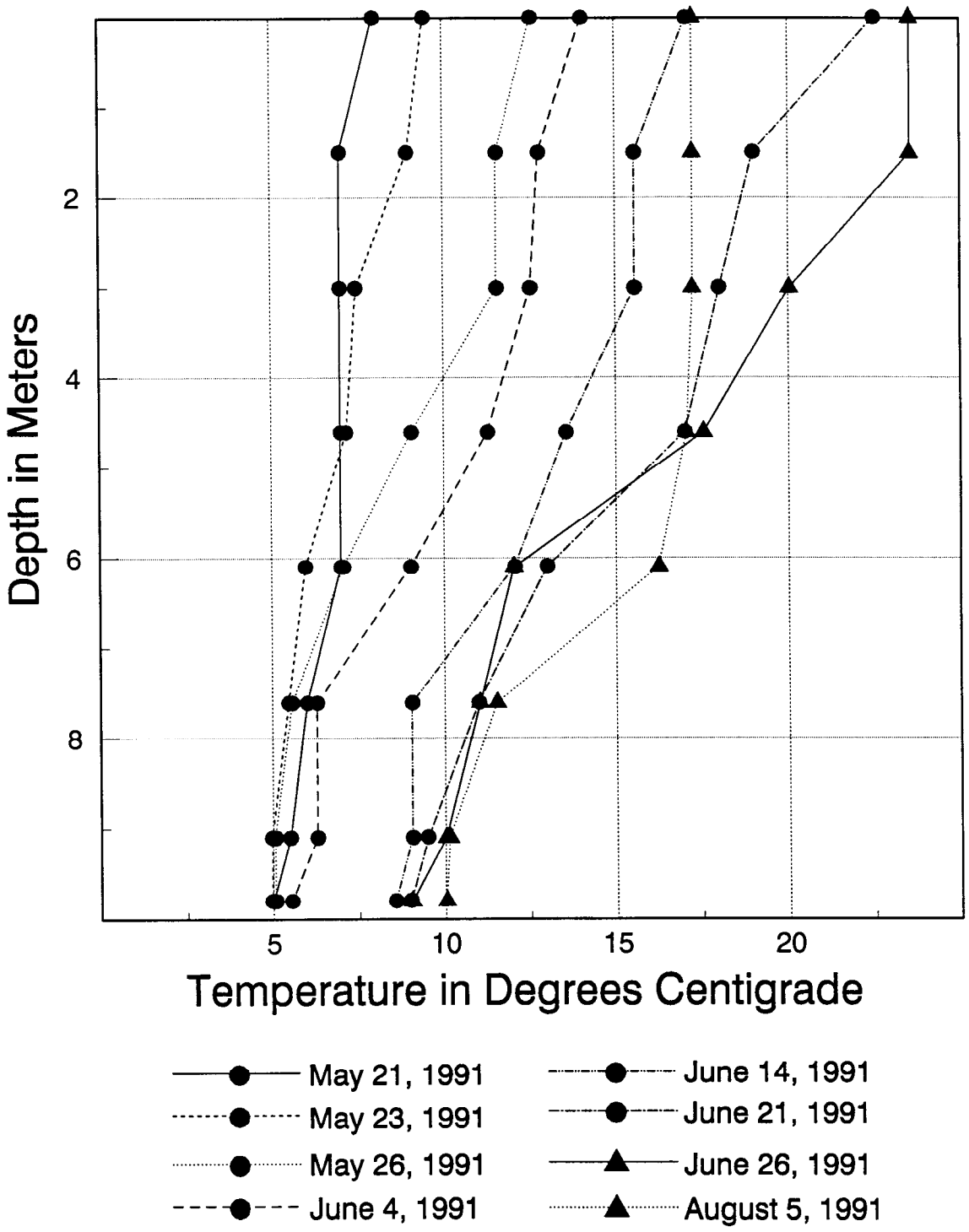

Figure 10. Temperature profiles of Volkmar Lake, 1991.

may not apply to all northern pike in the population. However, results from the telemetry study may be helpful in planning future stock assessments of the northern pike population of Volkmar Lake.

As previously discussed, the proportion of male northern pike in offshore waters (Figure 5) increased from about 50% during Periods 1 and 2 (the marking event and hiatus period of the mark-recapture experiment) to 77% during Period 3 (the recapture event of the mark-recapture experiment). In addition, male northern pike were relocated in somewhat deeper water than where females were found during between 20-23 May and this was particularly so during Period 3 (Table 2); and, these deeper waters are more difficult to effectively seine. Also, distributions of radio-tagged northern pike relative to area of the lake (Areas 4 and 5; Figure 9) were typically different than what would be expected by chance alone. If the mature northern pike population of Volkmar Lake behaves similar to the radio tagged study fish, then these observations of radio-tagged fish emphasize the need to sample as much of the inshore zone as possible during the short time frame immediately after breakup, when mature fish of both sexes (and hence sizes) are available in locations where seine gear can be effectively fished.

When this study was initiated, we hoped that telemetry data could be used to develop a better, more cost effective, and time efficient method of assessing the abundance and composition of northern pike in Volkmar Lake. To address this possibility, relocations and movements of radio tagged northern pike during the 1991 mark-recapture event (sampling Periods 1 through 3) were organized to project expected distances of minimum straight-line movements over a range of from one to nine mixing periods (nights between sampling events; Table 6 and Figure 11). Values reflecting the range of from 10 to 90% of the ranked individual movements were determined, and indicated for example, that 25% of the northern pike studied moved at least 1,045 m, while 50% and 75% moved 642 and 299 m, respectively, over a single night interval (n = 106). Mean distances moved and associated velocities are provided as footnotes in Table 6. Cumulative movement generally increased over successive nightly intervals, indicating a non-sedentary trend during sampling Periods 1 through 3 of the study. Estimates of the cumulative distance moved for selected proportions of the tagged population, which diverged with time (Figure 11), reflect the range of variability. The range of male northern pike velocity, over all daily relocation intervals, was somewhat higher than that determined for females (Figure 1). Mean male velocity likely exceeds that of females over nightly sequential observation intervals, and therefore this sexually-dimorphic behavior likely contributes somewhat to the movement ranges depicted in Figure 11.

Considering these movement data in light of the apparent time-limited behavior noted, the following sampling design is recommended for the 1992 mark-recapture experiment at Volkmar Lake. An intensive sampling strategy employing the multiple-marking Schnabel estimator (Ricker 1975; Seber 1982) is recommended to help shorten the required time frame for sampling (no multiple day hiatus period). This ratio estimator involves simultaneous mark and recapture events. The entire series of releases and recaptures can be conducted within a shorter time frame (compared to the two-sample Petersen estimate presently used) to help minimize the potential effect of apparent

Table 6. Projected minimum distances that northern pike of Volkmar Lake would be expected to move during various potential mixing periods within mark-recapture experiments conducted during the last two weeks of May, 1991.

Days Between Sampling Events[a]	Expected Distances (m) of Minimum Movements[b] for the following Proportions of the Northern Pike Population: 0.90	0.75	0.50	0.25	0.10
1[c]	119	299	642	1,045	1,388
2[d]	881	1,432	2,299	2,896	3,417
3[e]	1,792	2,478	3,671	4,477	6,075
4[f]	2,612	3,850	5,829	6,778	7,566
5[g]	3,597	4,583	6,105	8,628	9,417
6[h]	4,612	5,942	7,298	11,433	12,970
7[i]	5,195	7,211	9,495	12,479	14,671
8[j]	5,405	8,628	10,627	12,896	16,194
9[k]	5,764	7,943	12,585	16,507	17,776

[a] Days between sampling events are defined as the number of nights (n) elapsed between the evening of day 1 (D_1) and the morning of D_{1+n}.

[b] Expected distances were based upon the actual distribution of movements observed wherein the distance associated with 0.50 for instance, was the median distance moved for fish in a given category.

[c] Summary statistics for fish located one evening and relocated the next morning: sample size = 106; mean distance moved = 708 m (SD = 472 m); mean velocity = 59 m/hr (SD = 39 m/hr).

[d] Summary statistics for fish located one evening and relocated two mornings later: sample size = 50; mean distance moved = 2,223 m (SD = 968 m); mean velocity = 62 m/hr (SD = 27 m/hr).

[e] Summary statistics for fish located one evening and relocated three mornings later: sample size = 32; mean distance moved = 3,692 m (SD = 1,449 m); mean velocity = 62 m/hr (SD = 24 m/hr).

[f] Summary statistics for fish located one evening and relocated four mornings later: sample size = 23; mean distance moved = 5,340 m (SD = 1,704 m); mean velocity = 64 m/hr (SD = 20 m/hr).

[g] Summary statistics for fish located one evening and relocated five mornings later: sample size = 15; mean distance moved = 6,387 m (SD = 2,292 m); mean velocity = 59 m/hr (SD = 21 m/hr).

[h] Summary statistics for fish located one evening and relocated six mornings later: sample size = 11; mean distance moved = 8,503 m (SD = 2,882 m); mean velocity = 64 m/hr (SD = 22 m/hr).

[i] Summary statistics for fish located one evening and relocated seven mornings later: sample size = 11; mean distance moved = 9,853 m (SD = 2,999 m); mean velocity = 63 m/hr (SD = 19 m/hr).

[j] Summary statistics for fish located one evening and relocated eight mornings later: sample size = 10; mean distance moved = 10,841 m (SD = 3,321 m); mean velocity = 60 m/hr (SD = 18 m/hr).

[k] Summary statistics for fish located one evening and relocated nine mornings later: sample size = 9; mean distance moved = 12,176 m (SD = 3,917 m); mean velocity = 60 m/hr (SD = 19 m/hr).

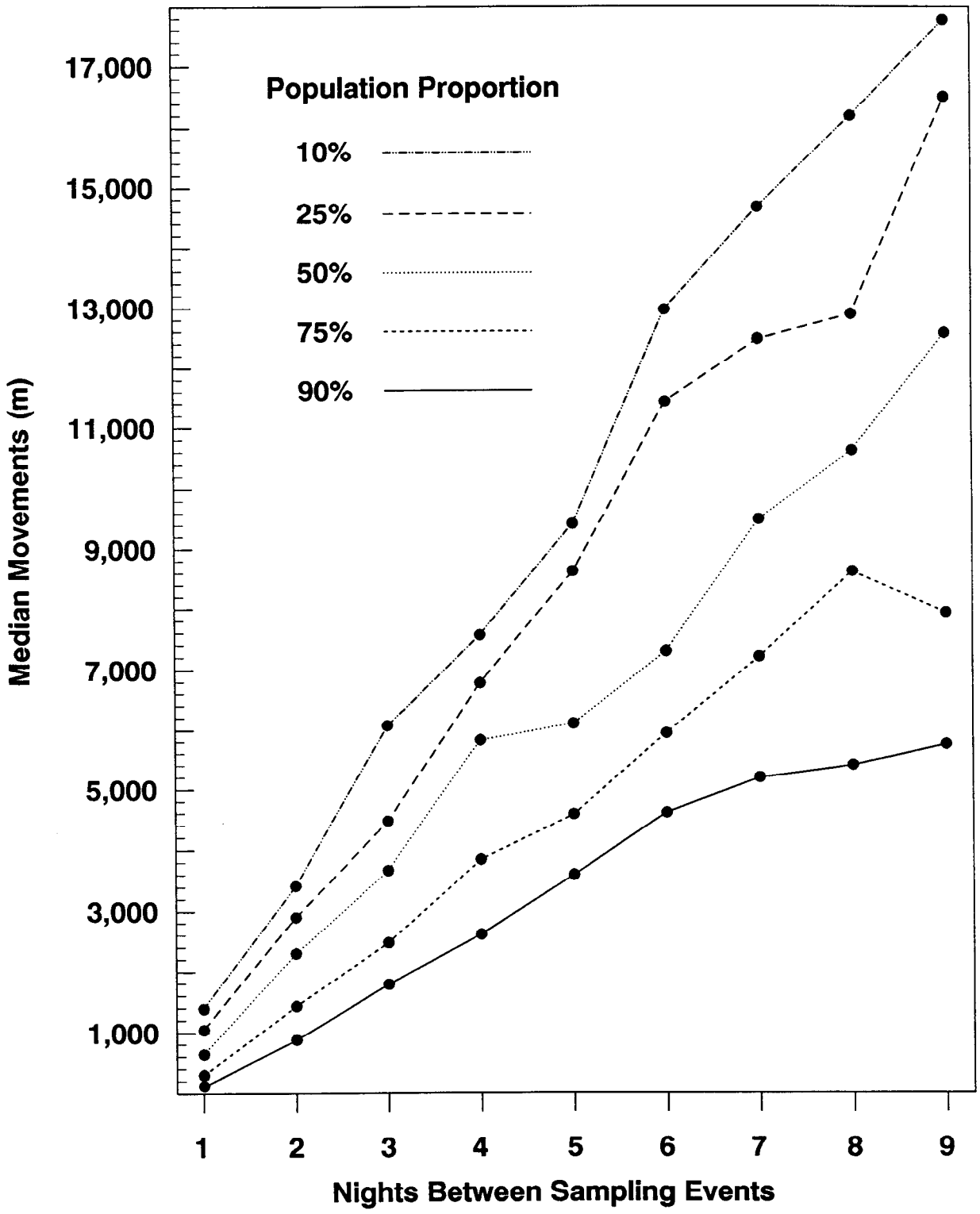

Figure 11. Projected minimum distances that northern pike of Volkmar Lake would be expected to move during potential mixing periods within mark-recapture experiments conducted during the last two weeks of May.

time-dependent fish availability while maximizing mixing probabilities due to spawning-related behavior. To reduce the effect of location preference by sex, and promote adequate mixing, the sampling should proceed in a systematic manner. The lake should be divided into sampling zones (pie slices), the inshore-length of which should not exceed 650 m (the minimum distance moved by 50% of the fish over a one night period; Table 6). Each of these sampling zones should be seined each day during the mark-recapture experiment.

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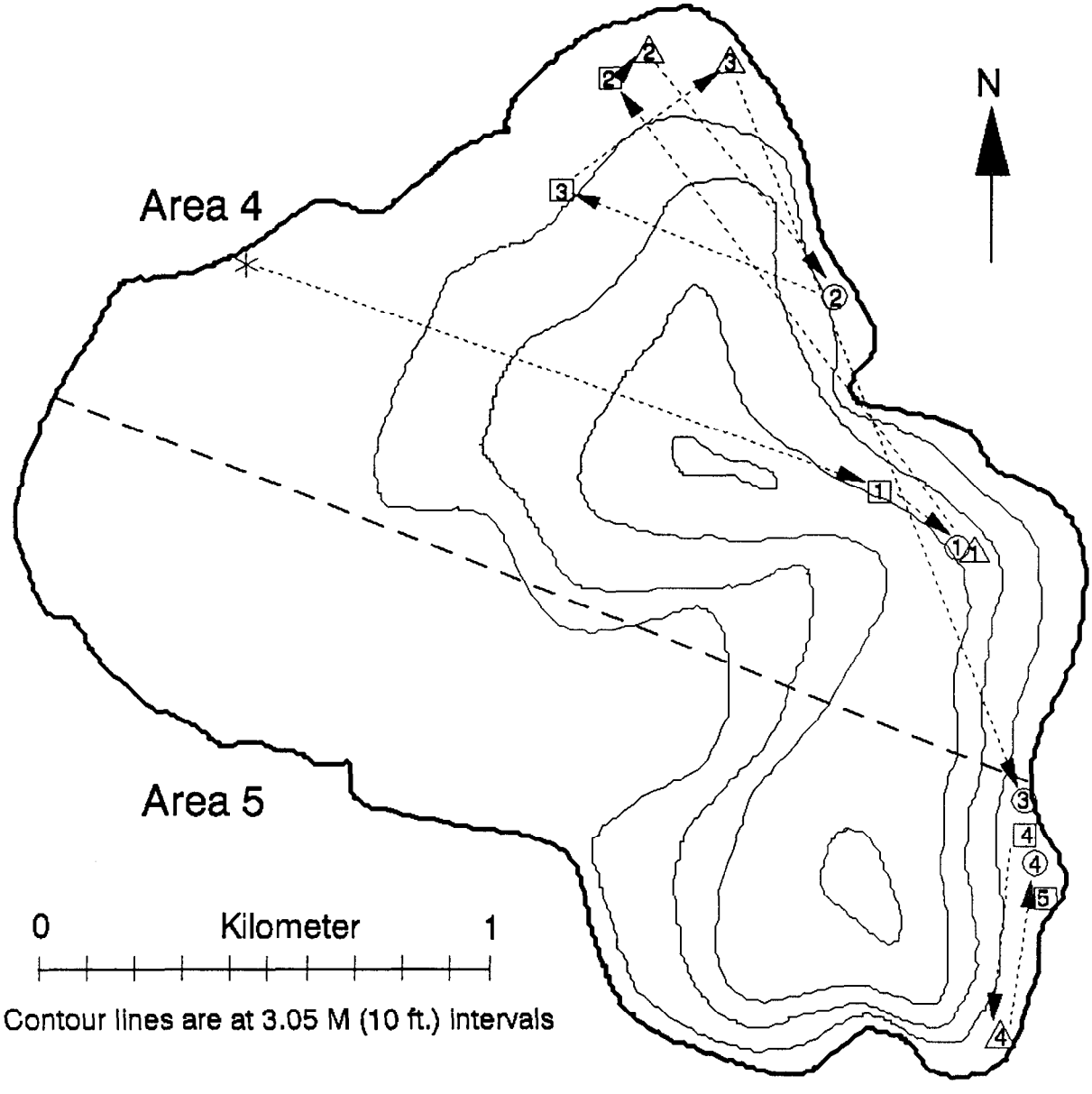
APPENDIX A

Appendix A1. Locations of a female pike (tag 1; 908 mm) between 5/21/91 and 8/5/91.

Tag #1 - 908 mm female released 5/21/91 at 16:00



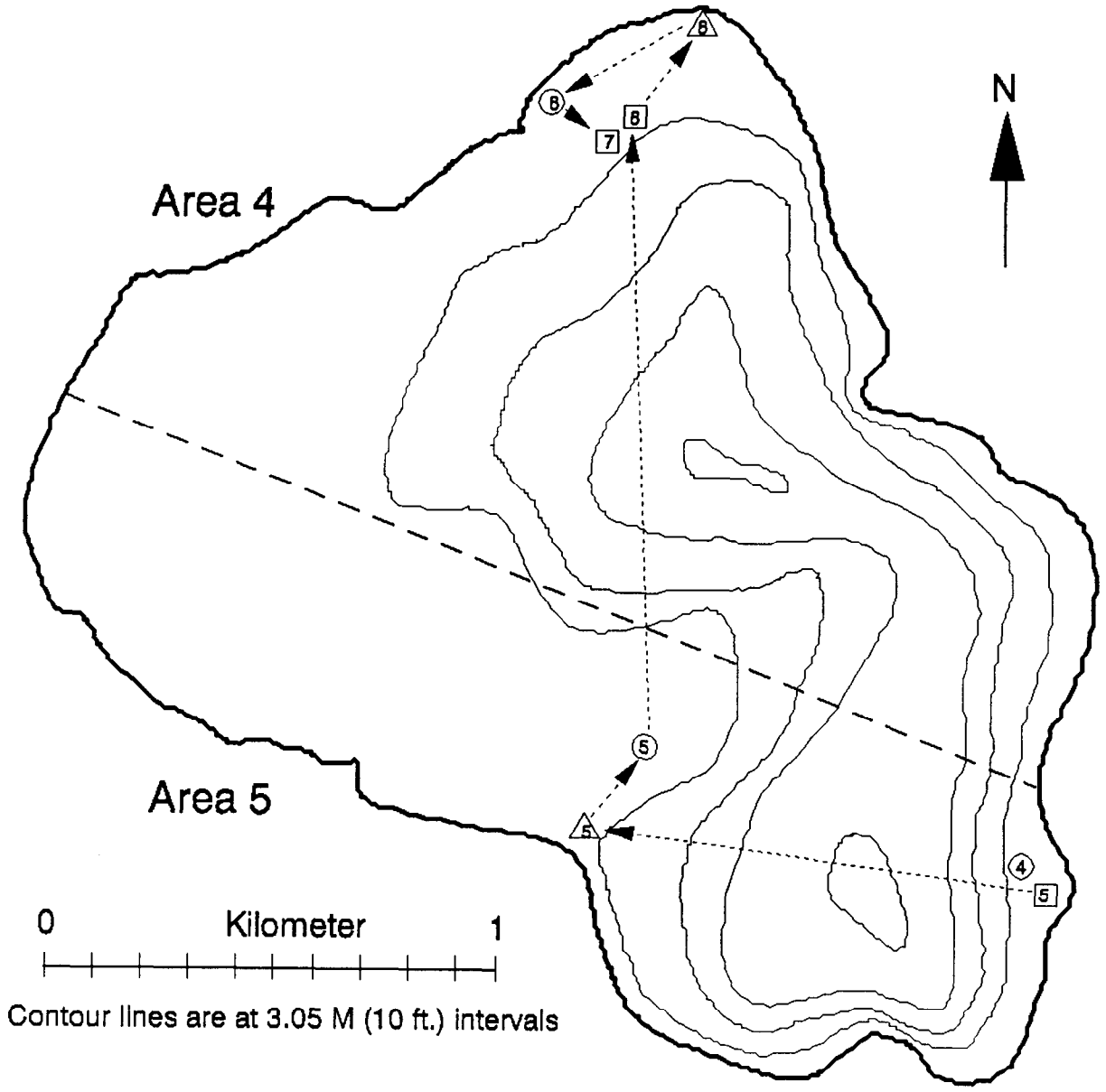
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00
- ✳ Indicates location where fish was originally released

Period 1 - 5/21/91 through 5/25/91.

-continued-

Tag #1 - 908 mm female released 5/21/91 at 16:00



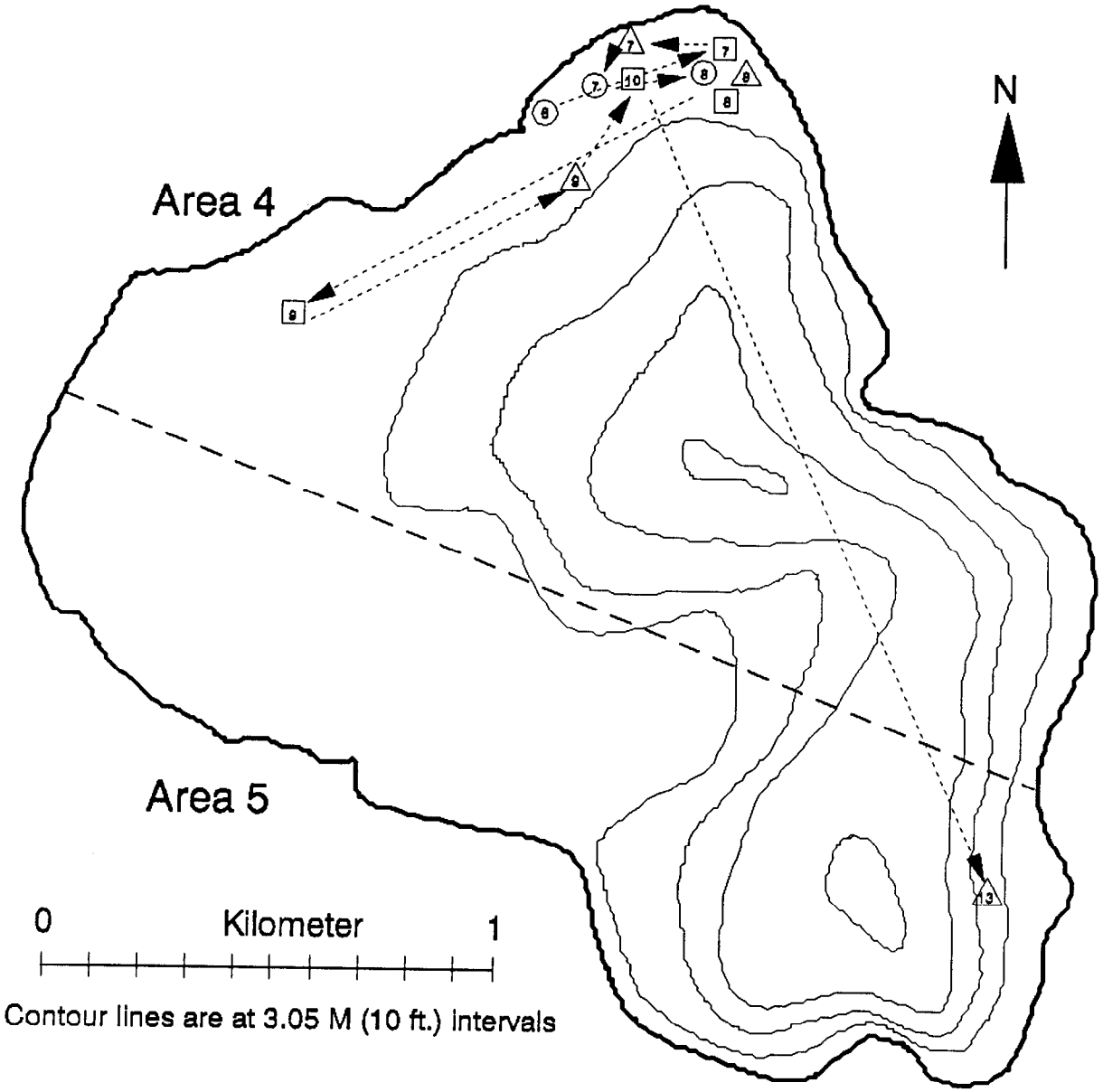
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #1 - 908 mm female released 5/21/91 at 16:00



Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

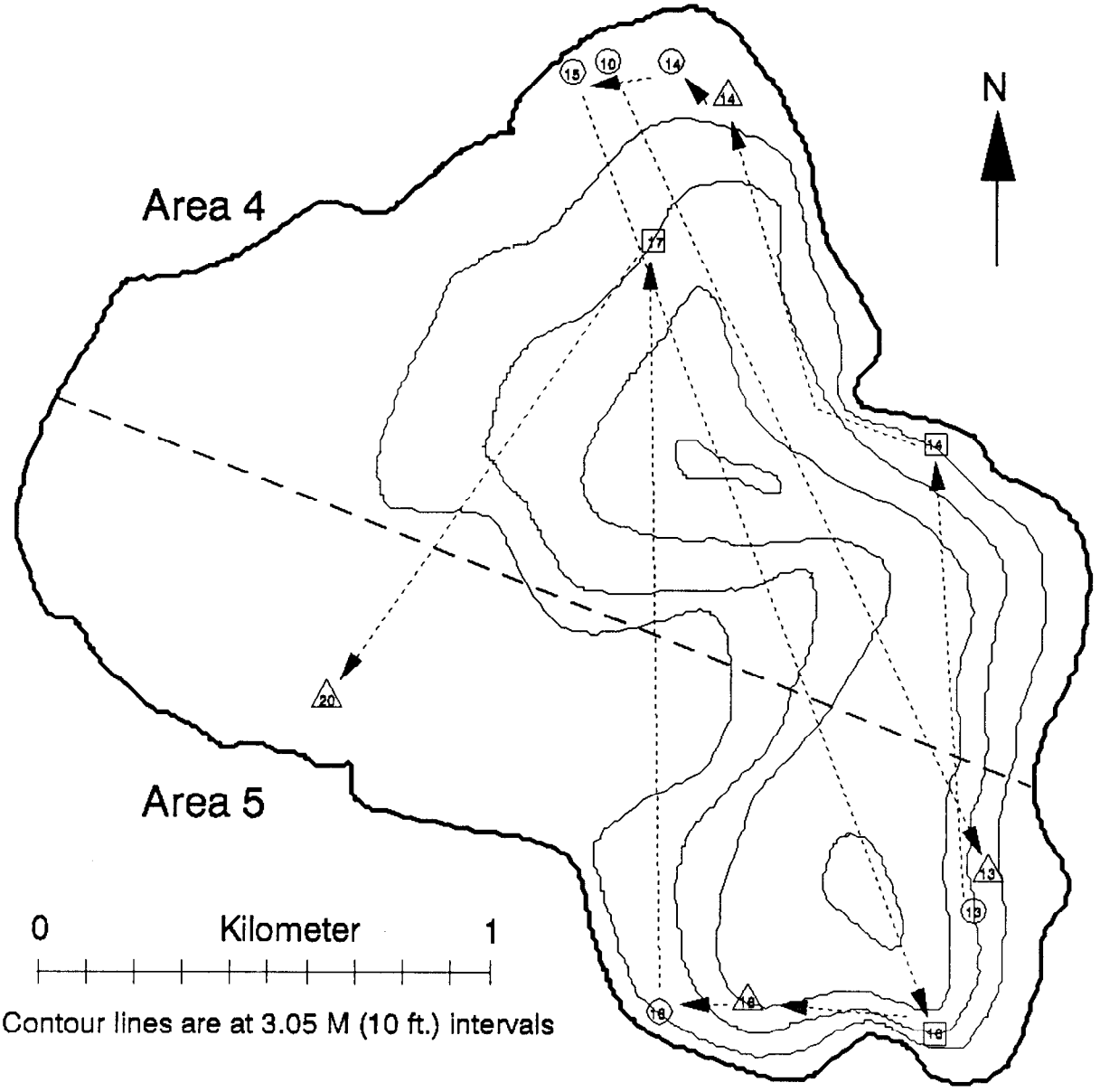
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #1 - 908 mm female released 5/21/91 at 16:00



Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

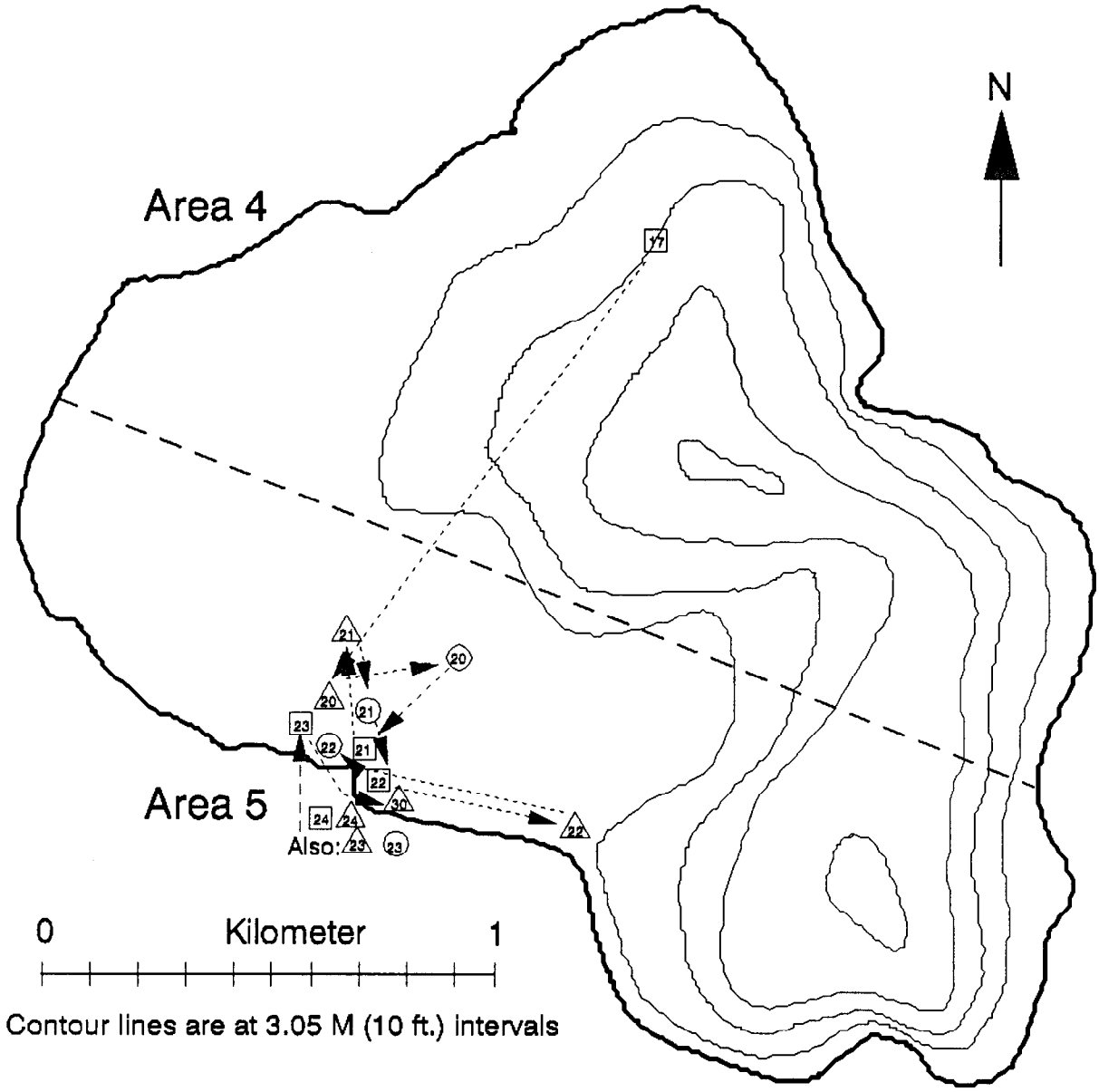
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #1 - 908 mm female released 5/21/91 at 16:00



Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

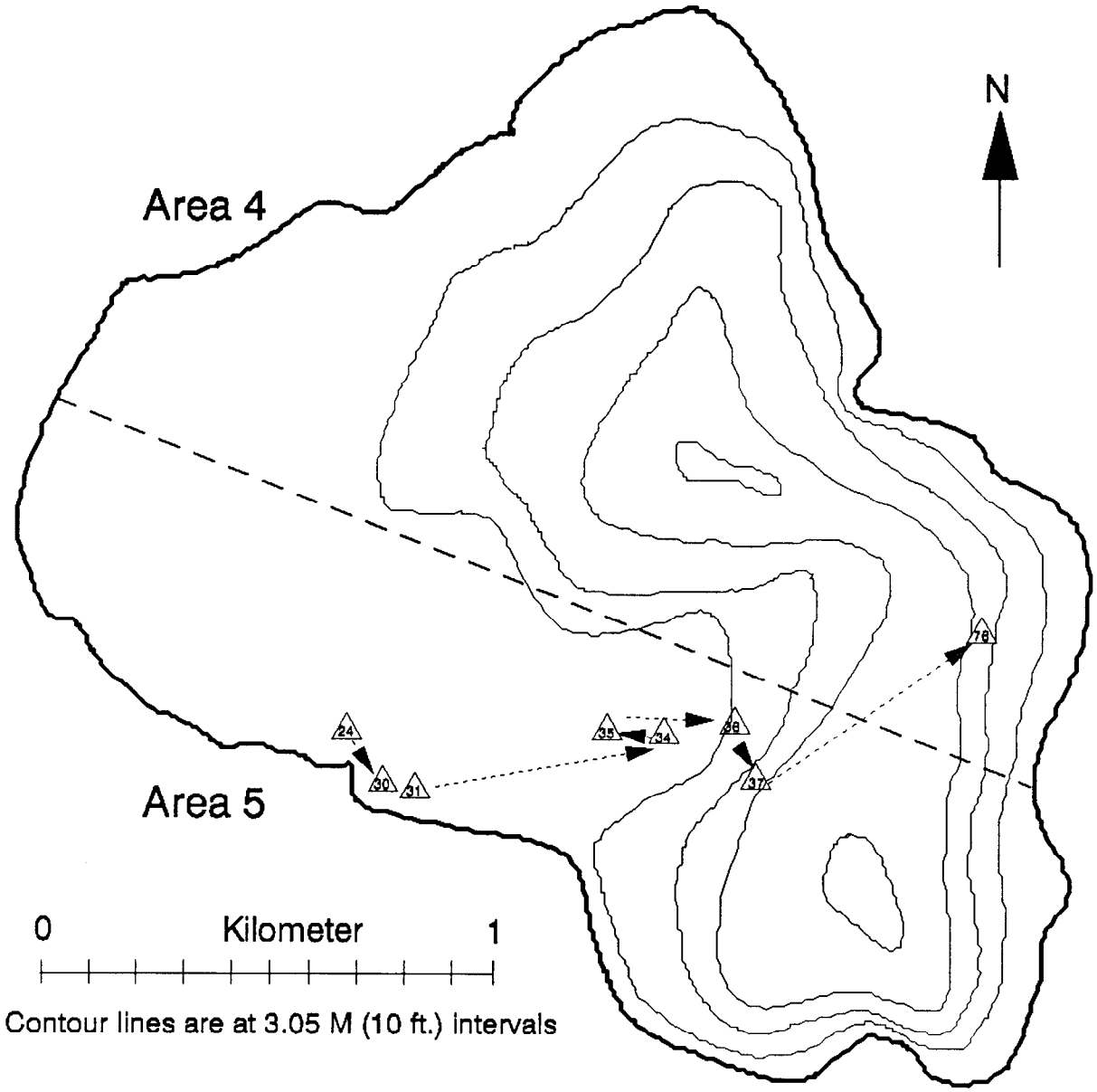
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #1 - 908 mm female released 5/21/91 at 16:00

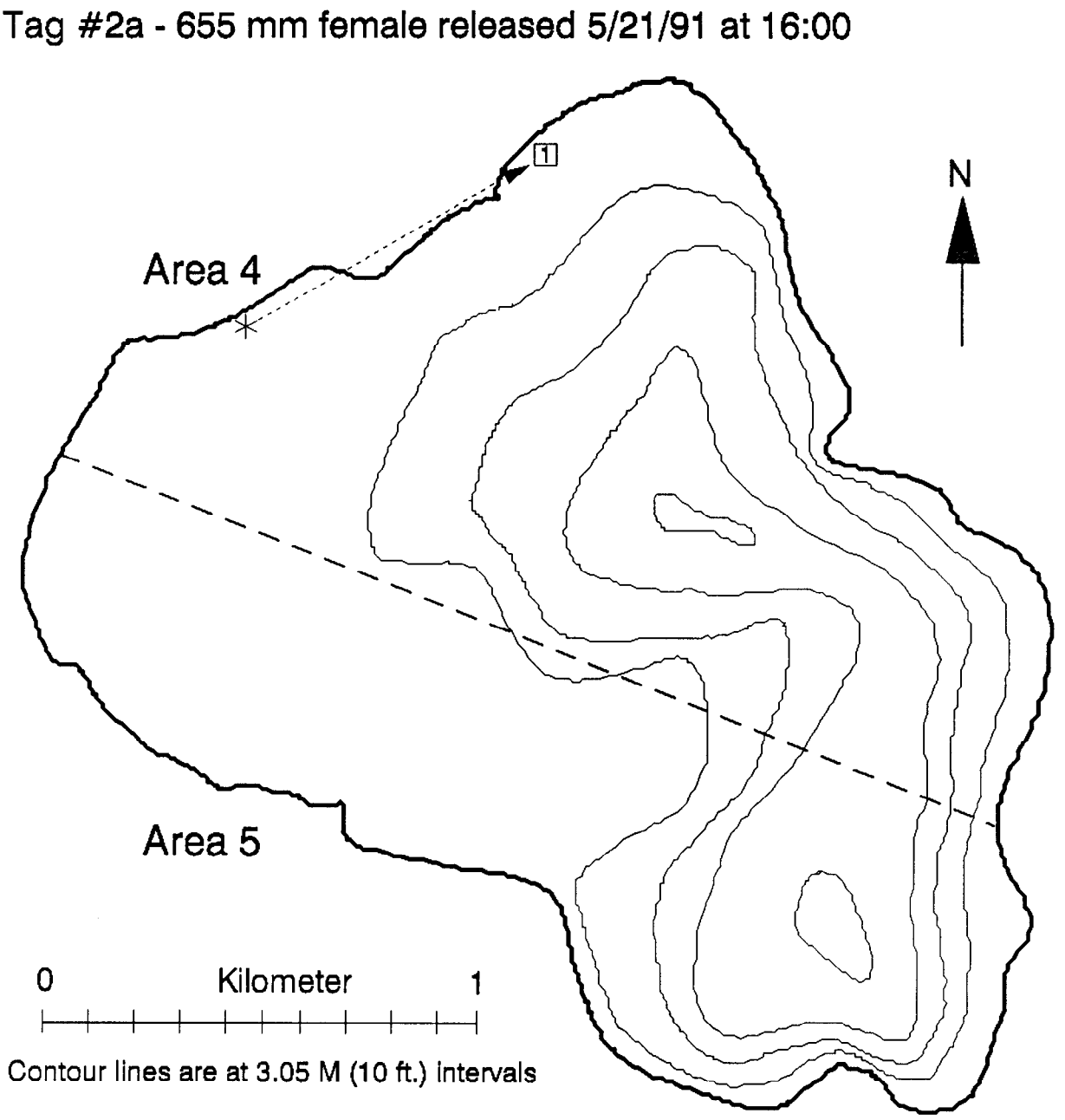


Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

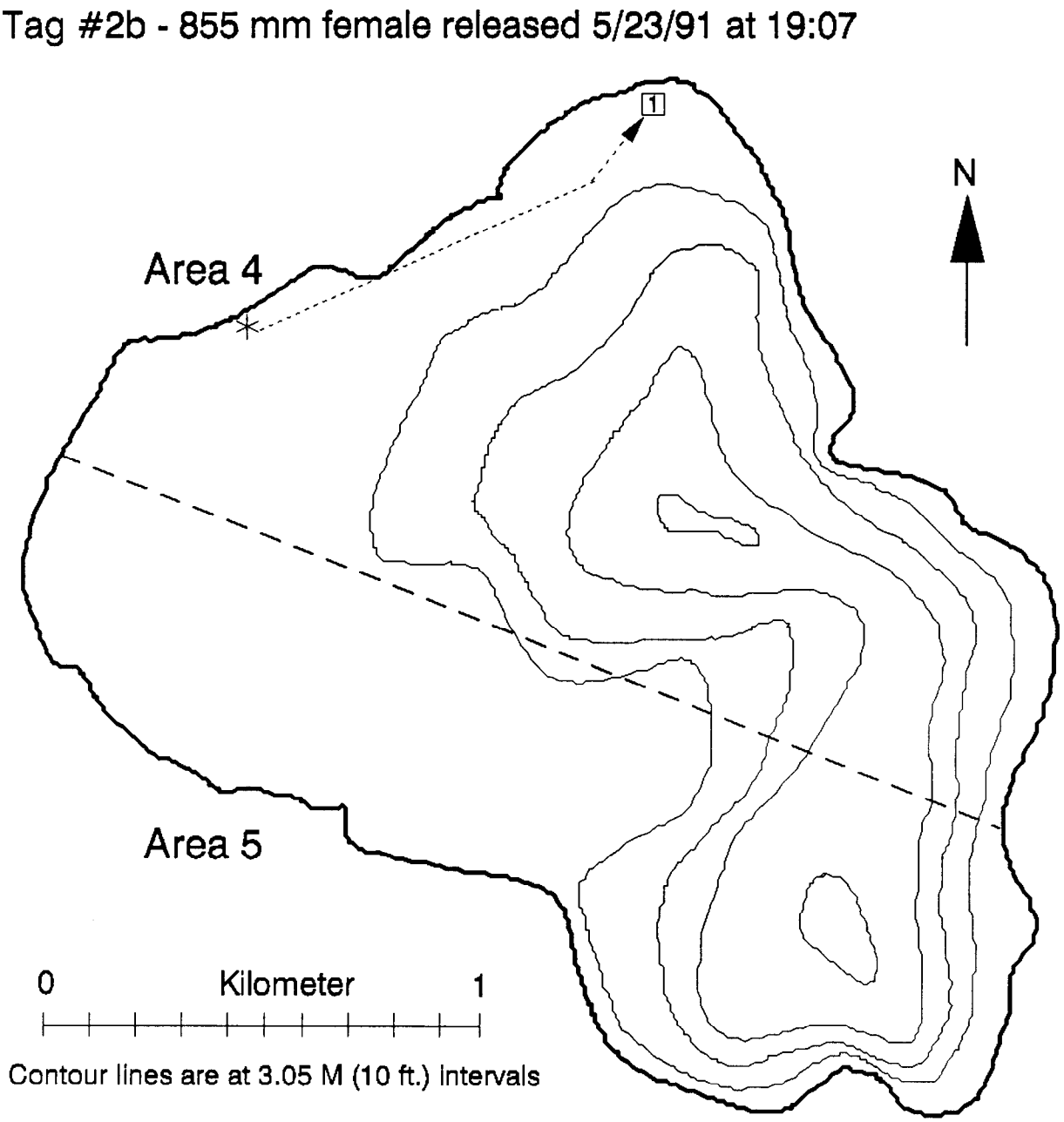
Period 6 - 6/20/91 through 8/5/91.

Appendix A2. Locations of a female northern pike (tag 2a; 655 mm) between 5/21/91 and 5/22/91.



Period 1 - 5/21/91 through 5/22/91.

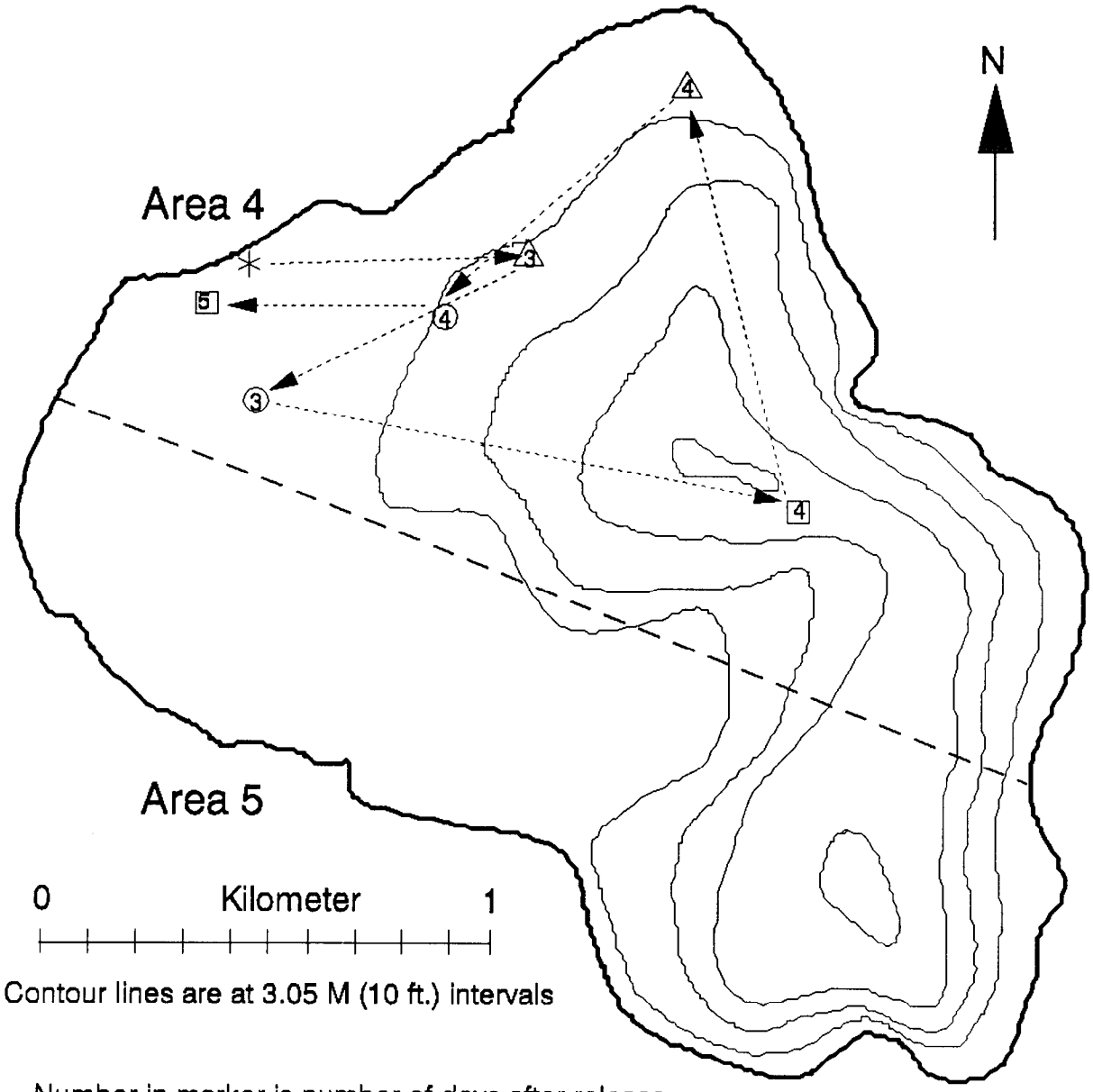
Appendix A3. Locations of a female northern pike (tag 2b; 855 mm) between 5/23/91 and 8/5/91.



Period 1 - 5/23/91 through 5/24/91.

-continued-

Tag #2b - 855 mm female re-released 5/26/91 at 12:30



Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

△ Indicates fish was located between 14:00 and 17:00

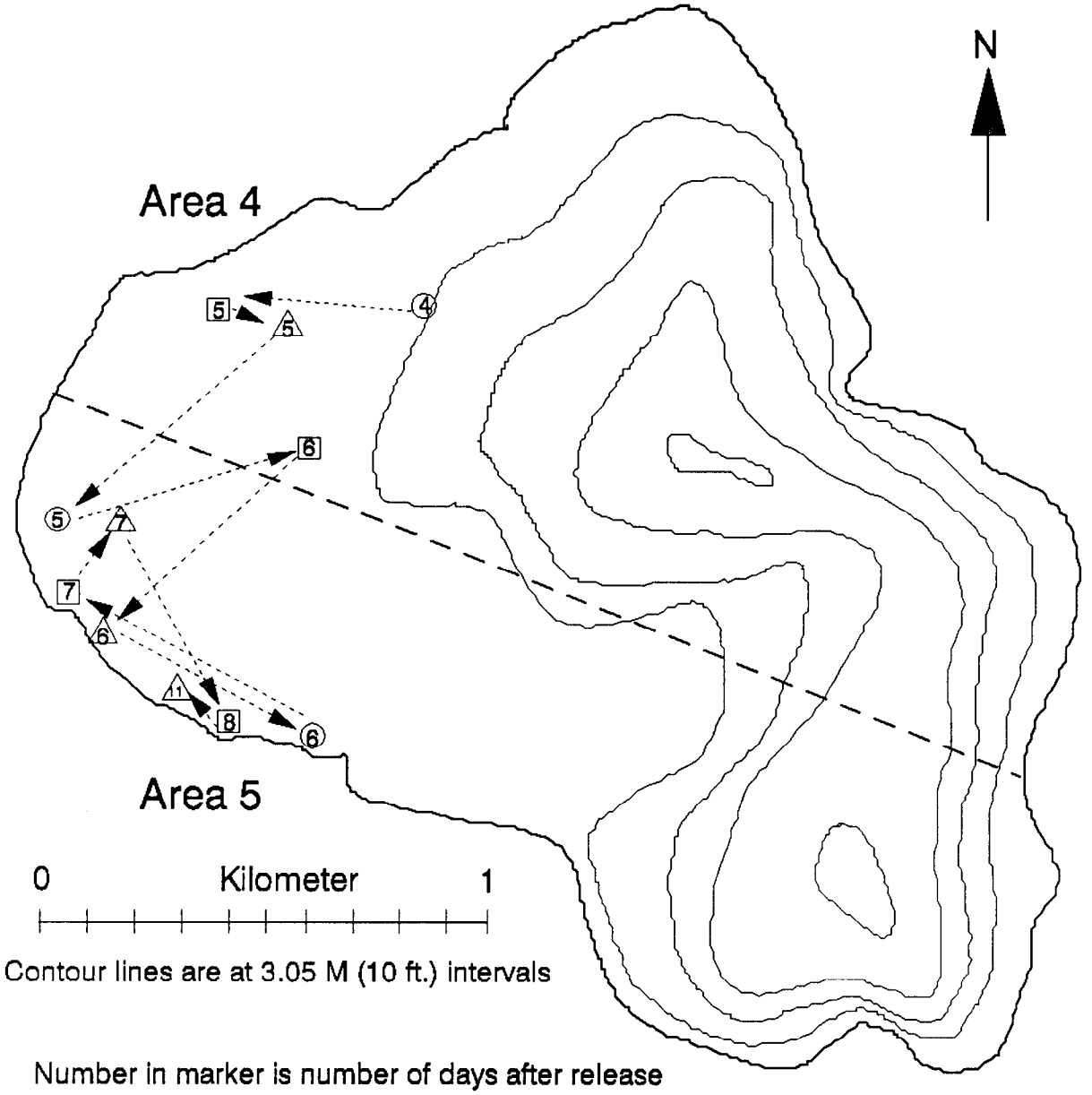
○ Indicates fish was located between 20:00 and 23:00

✳ Indicates location where fish was originally released

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #2b - 855 mm female re-released 5/26/91 at 12:30



Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

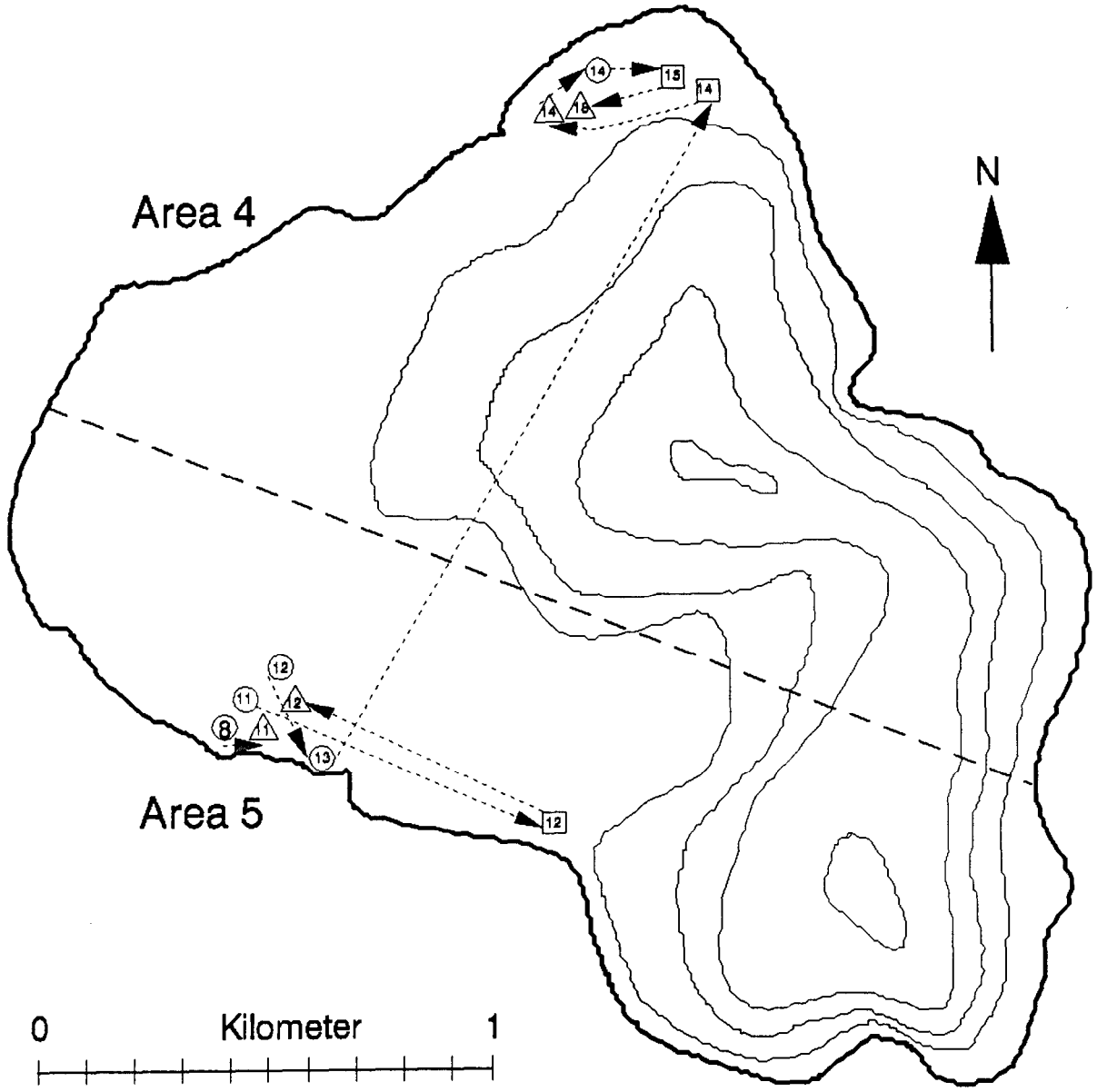
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #2b - 855 mm female re-released 5/26/91 at 12:30



Contour lines are at 3.05 M (10 ft.) intervals

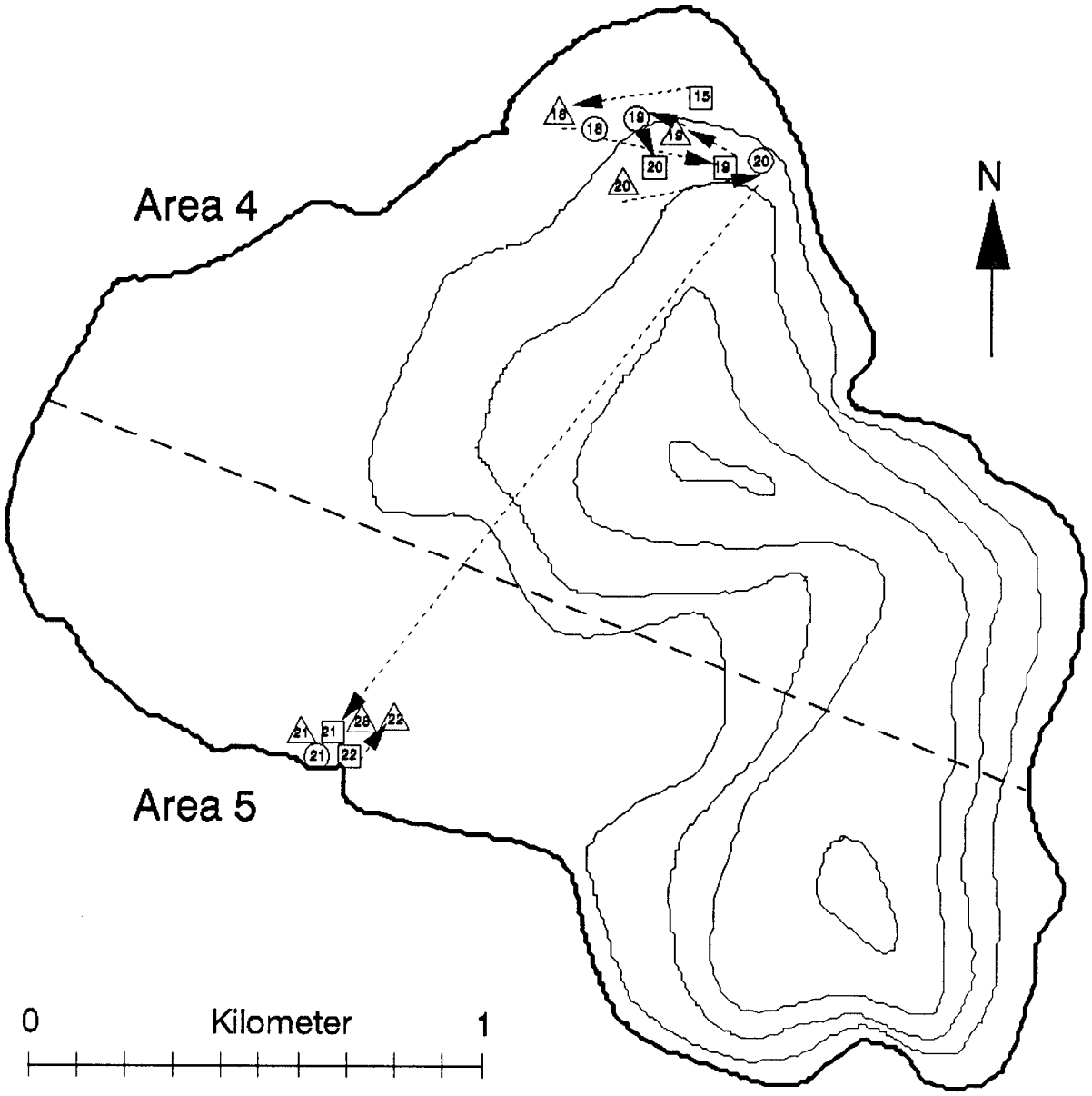
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #2b - 855 mm female re-released 5/26/91 at 12:30



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

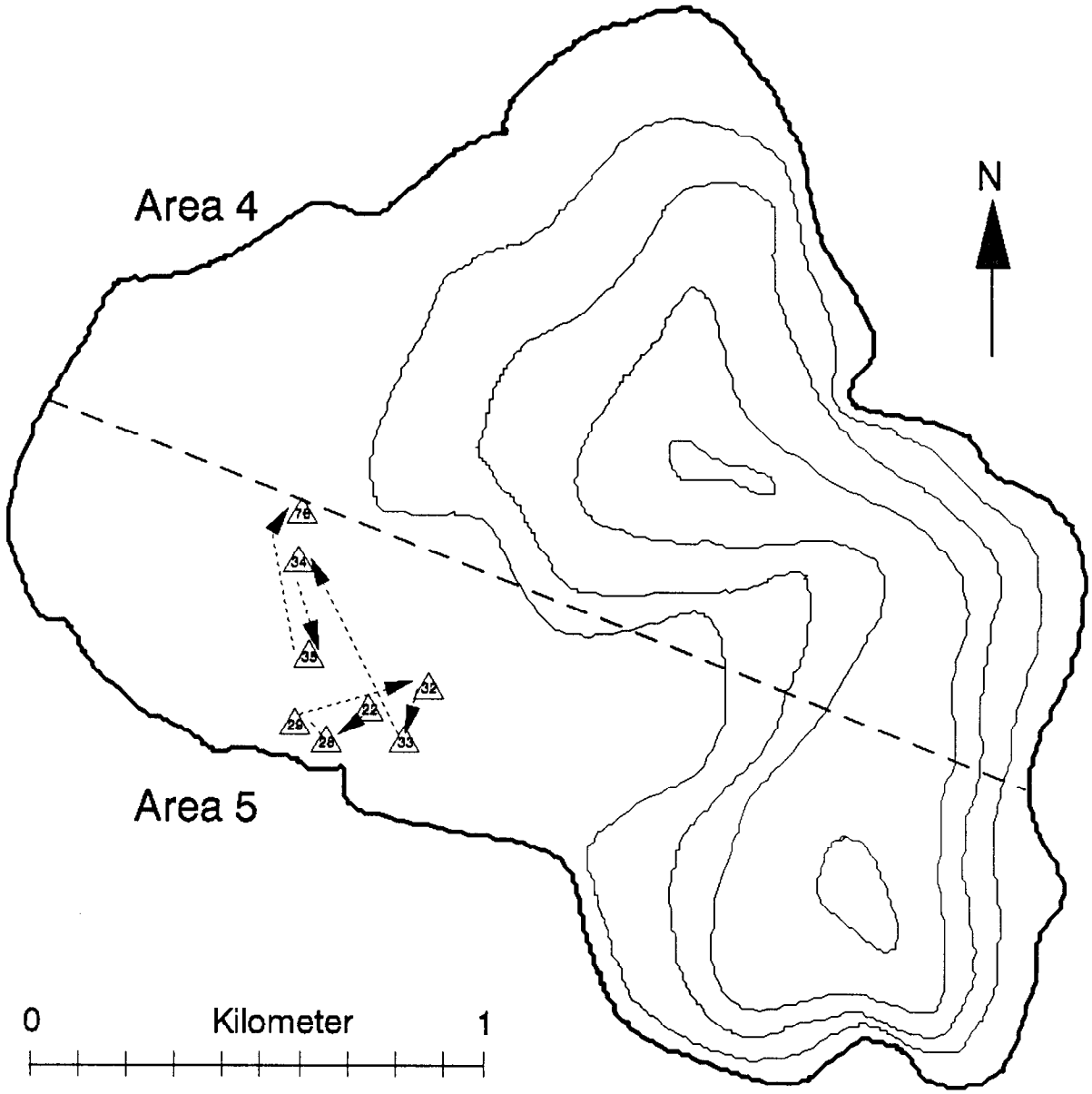
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #2b - 855 mm female re-released 5/26/91 at 12:30



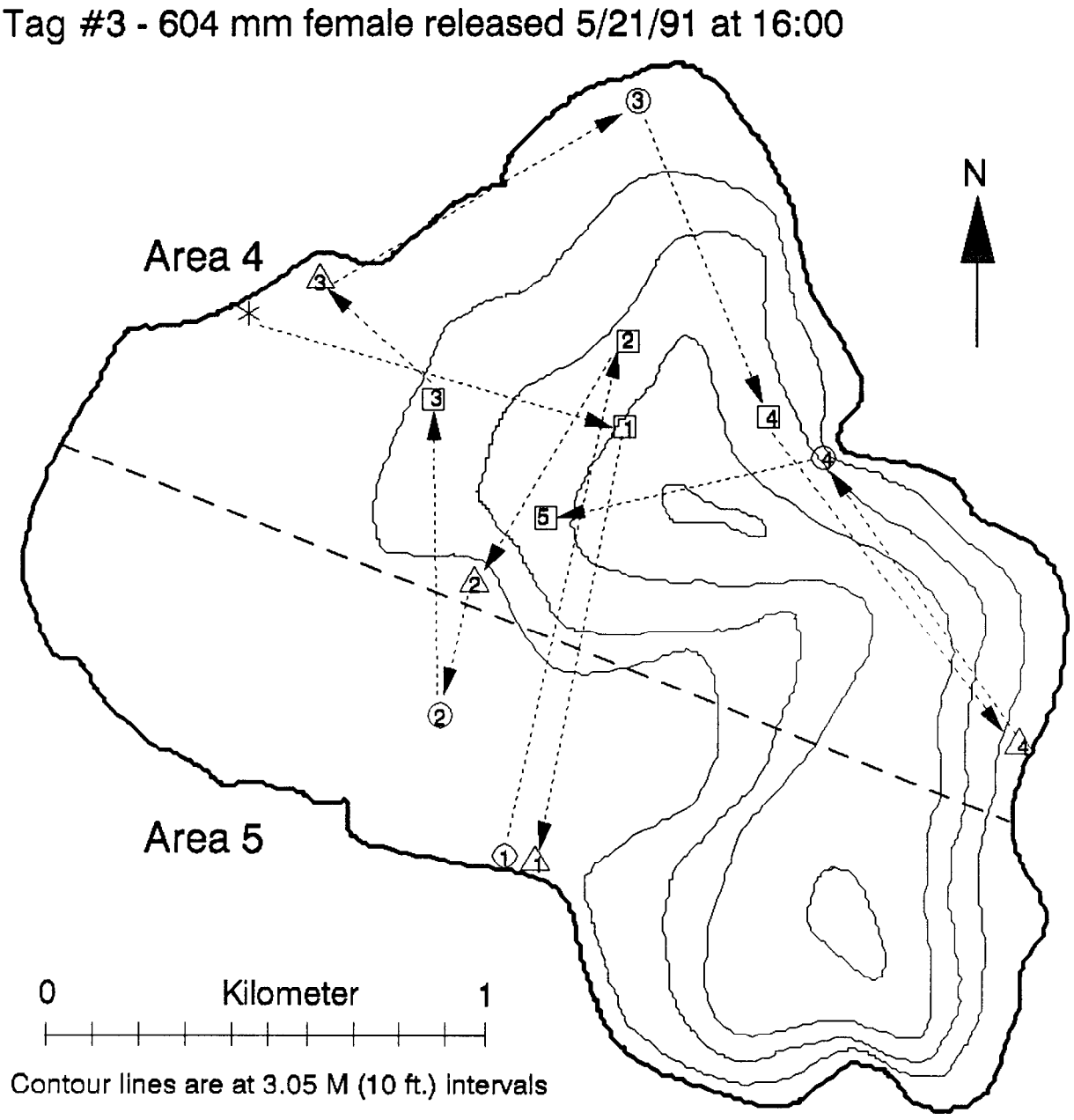
Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

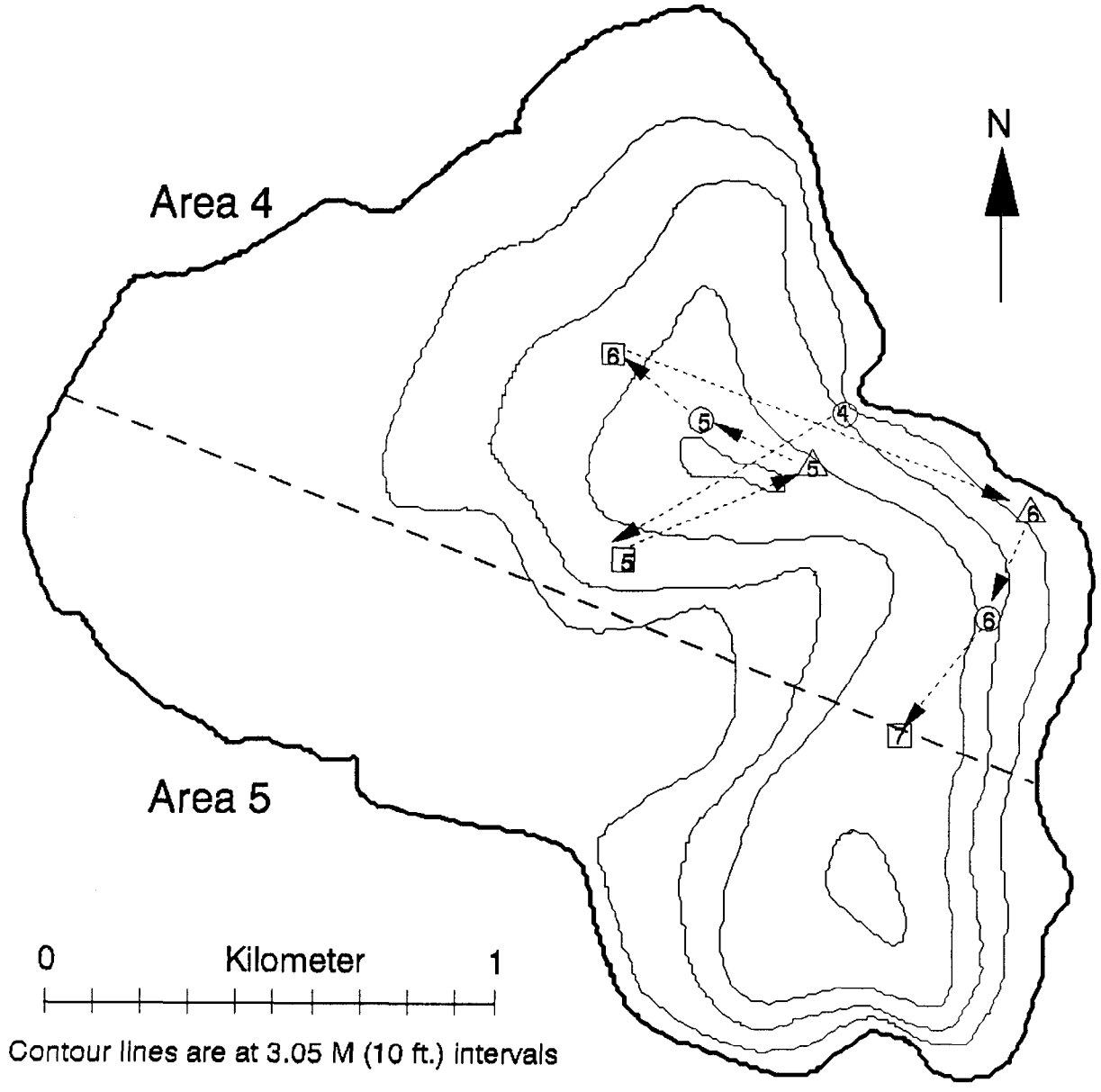
Period 6 - 6/17/91 through 8/5/91.

Appendix A4. Locations of a female northern pike (tag 3; 604 mm) between 5/21/91 and 8/5/91.



-continued-

Tag #3 - 604 mm female released 5/21/91 at 16:00



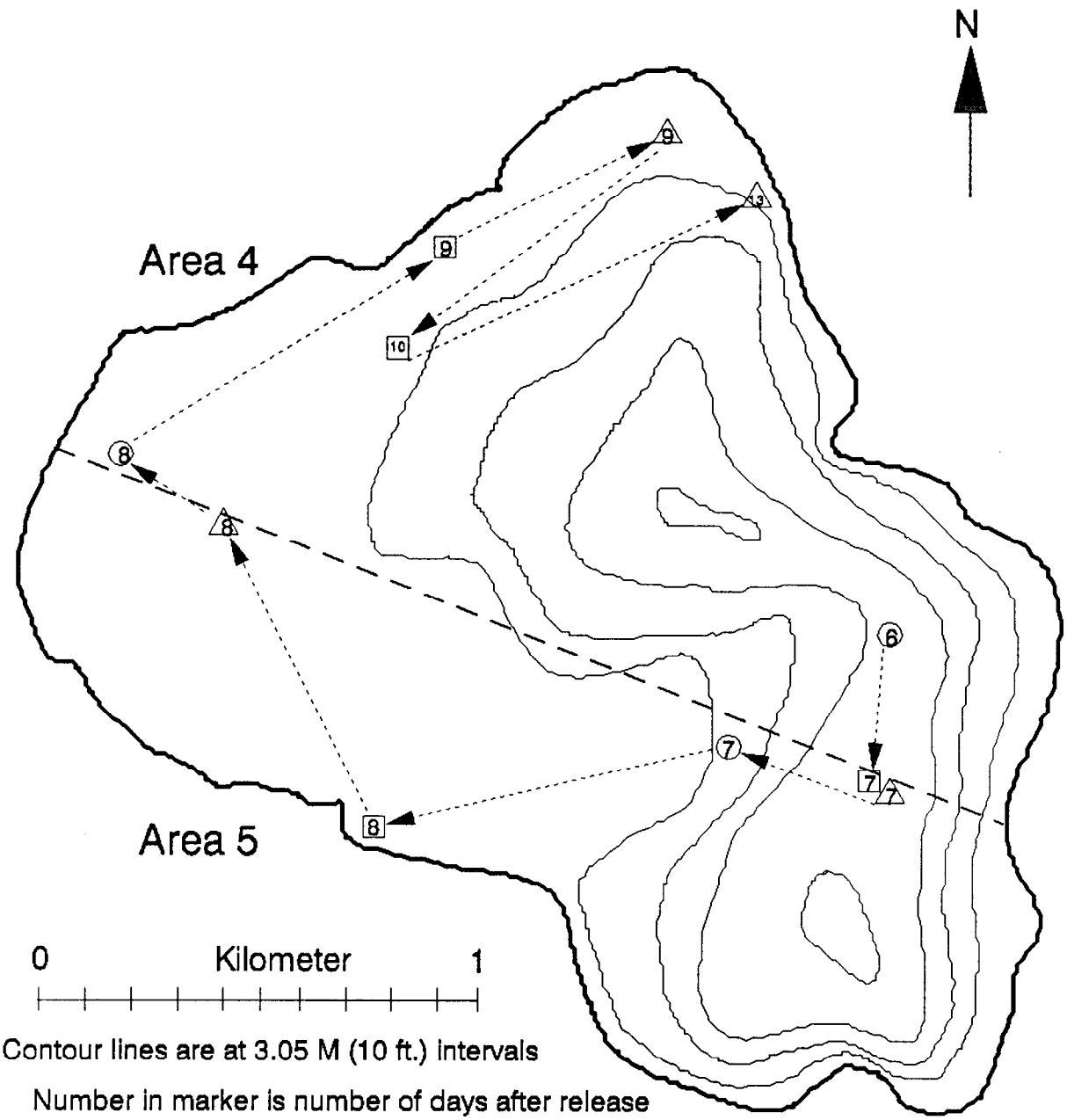
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #3 - 604 mm female released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

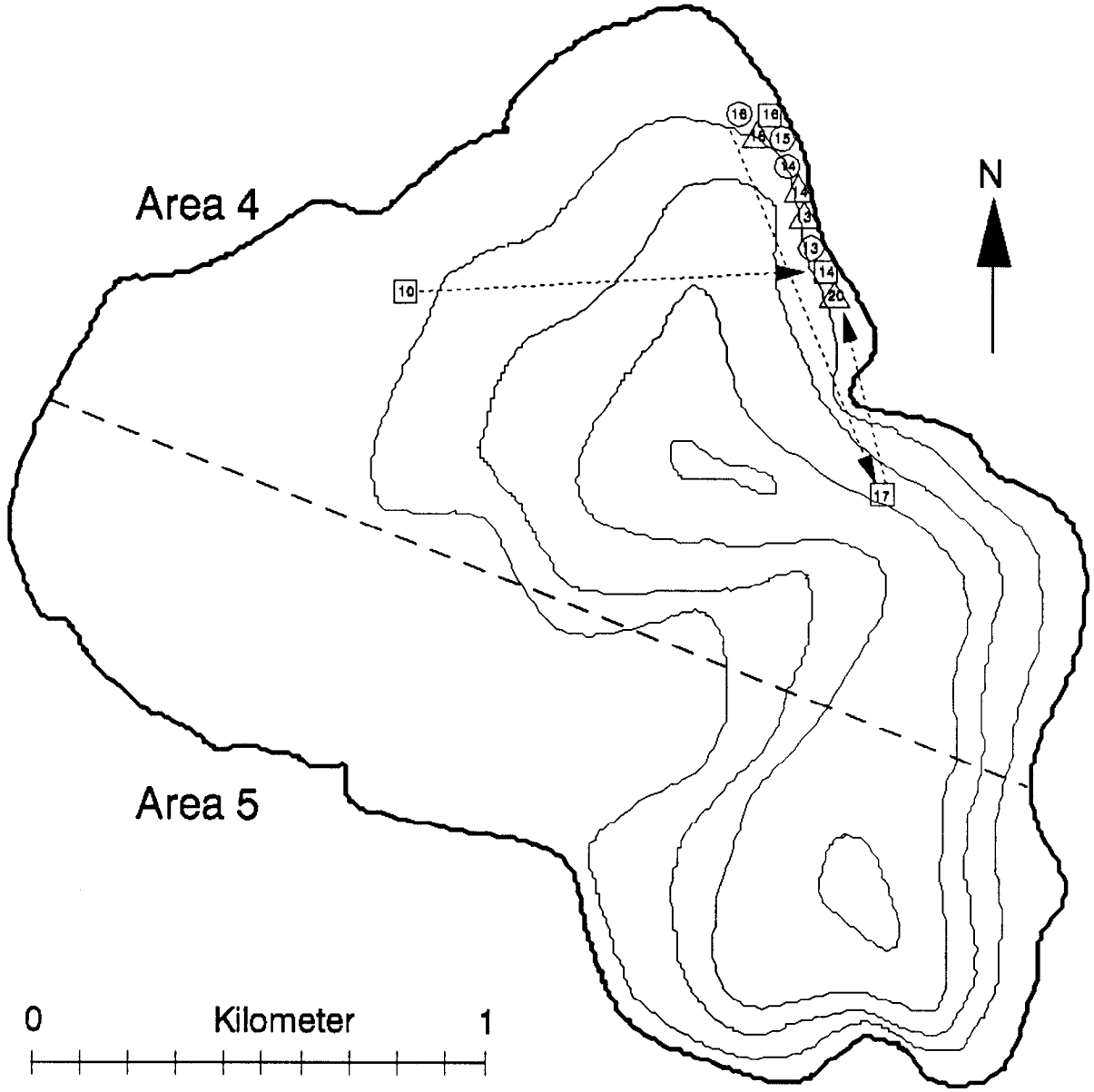
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #3 - 604 mm female released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

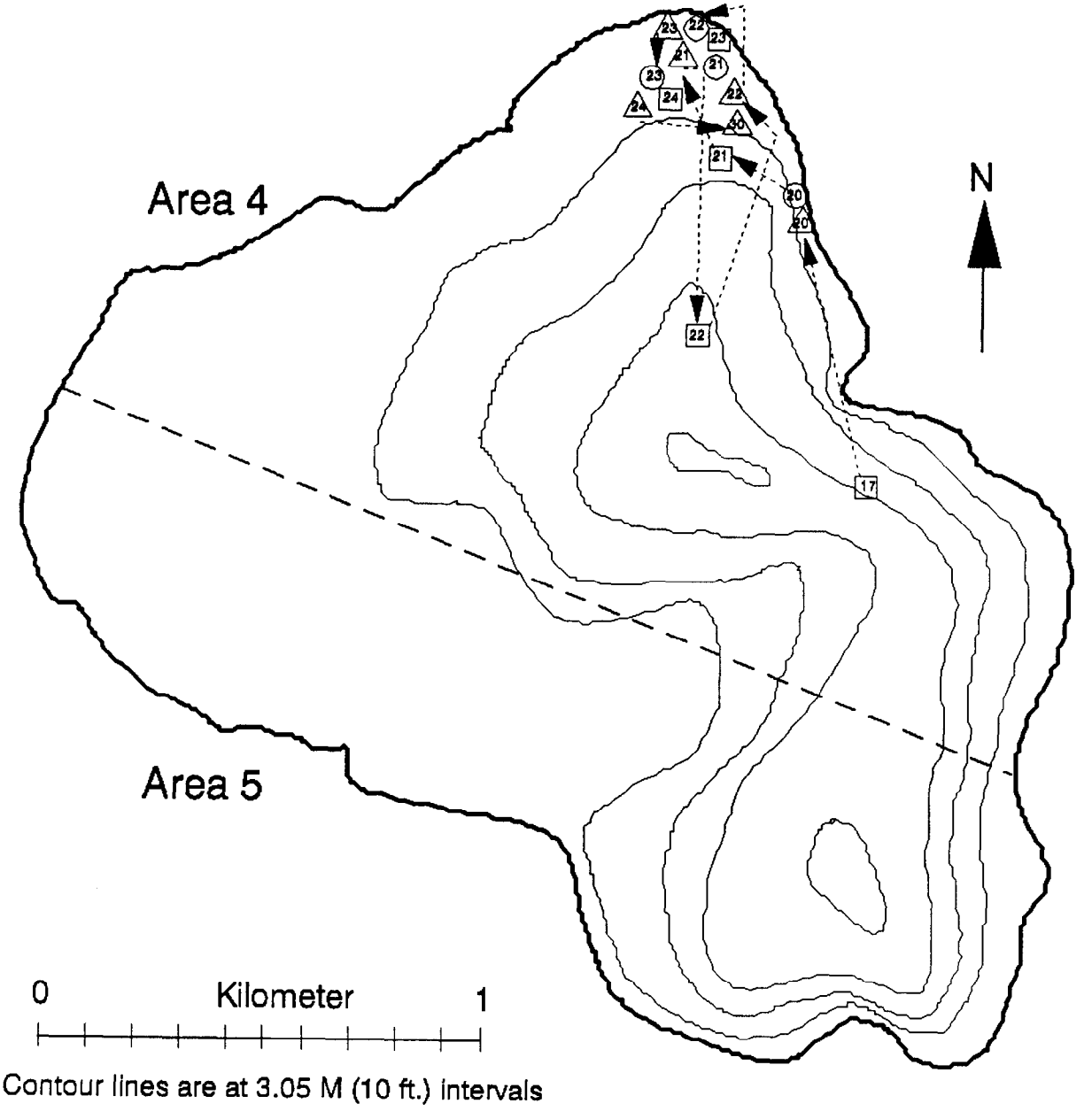
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #3 - 604 mm female released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

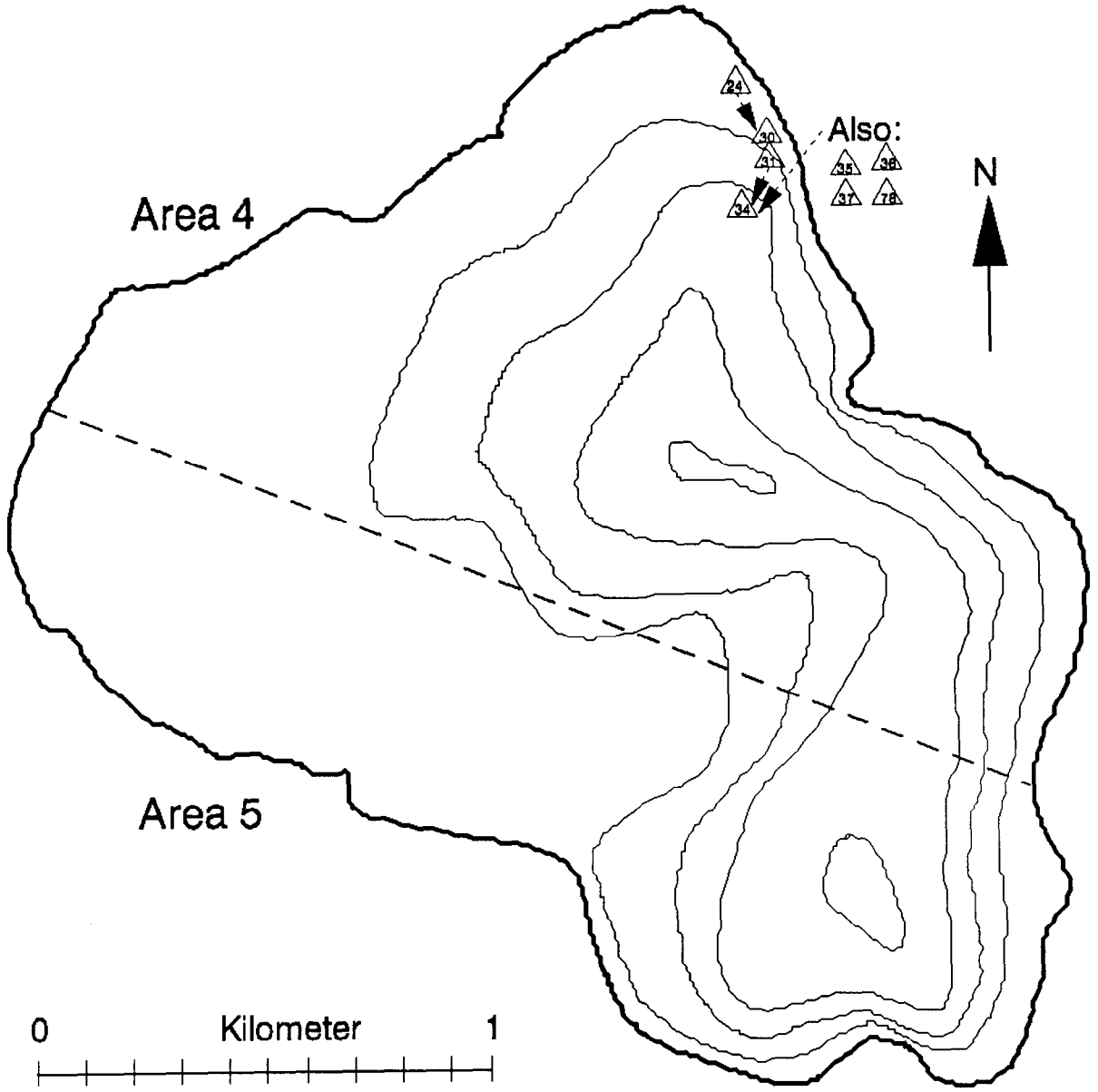
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #3 - 604 mm female released 5/21/91 at 16:00



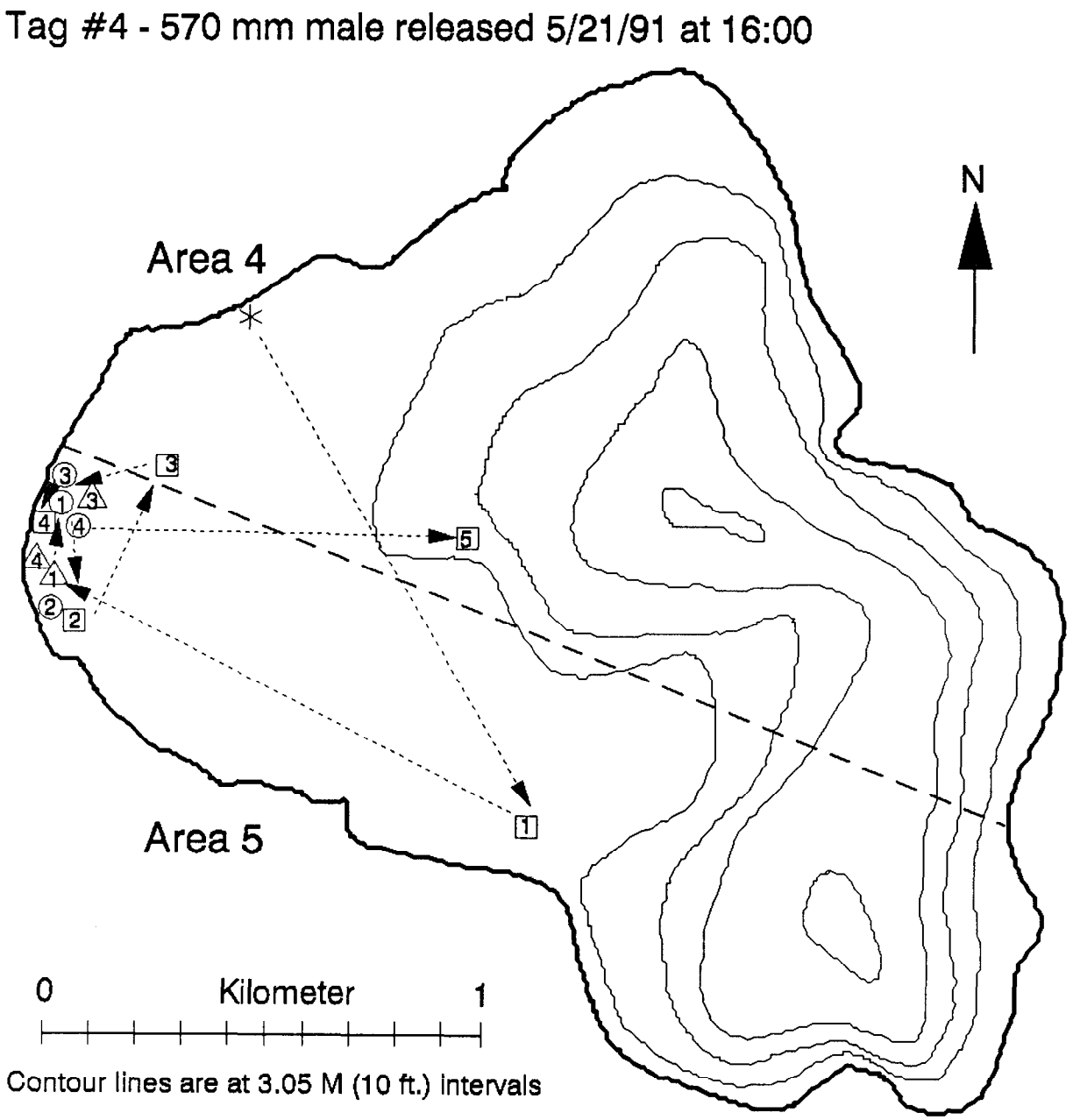
Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

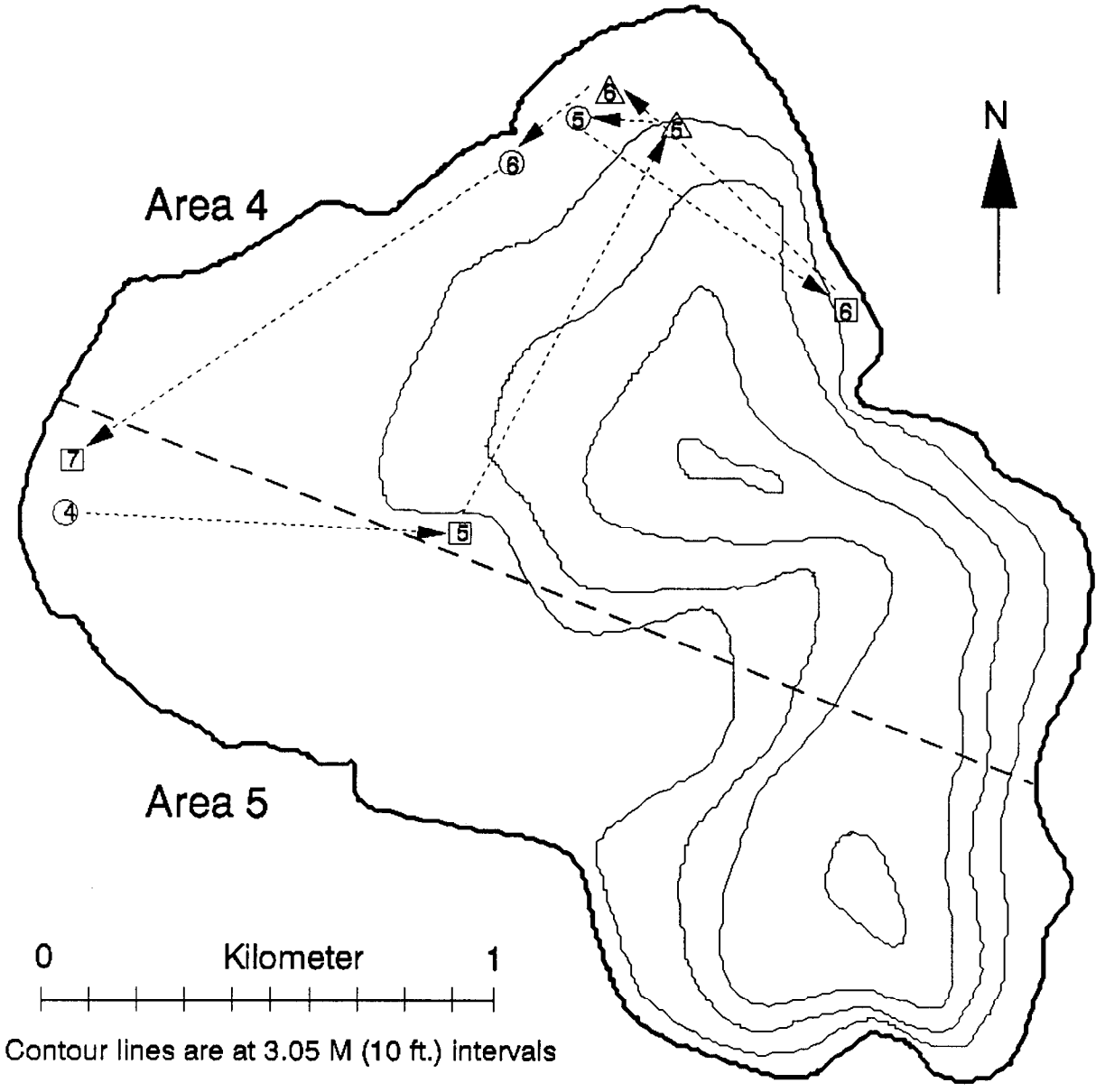
Period 6 - 6/20/91 through 8/5/91.

Appendix A5. Locations of a male northern pike (tag 4; 570 mm) between 5/21/91 and 8/5/91.



-continued-

Tag #4 - 570 mm male released 5/21/91 at 16:00



Number in marker is number of days after release

☐ Indicates fish was located between 08:00 and 11:00

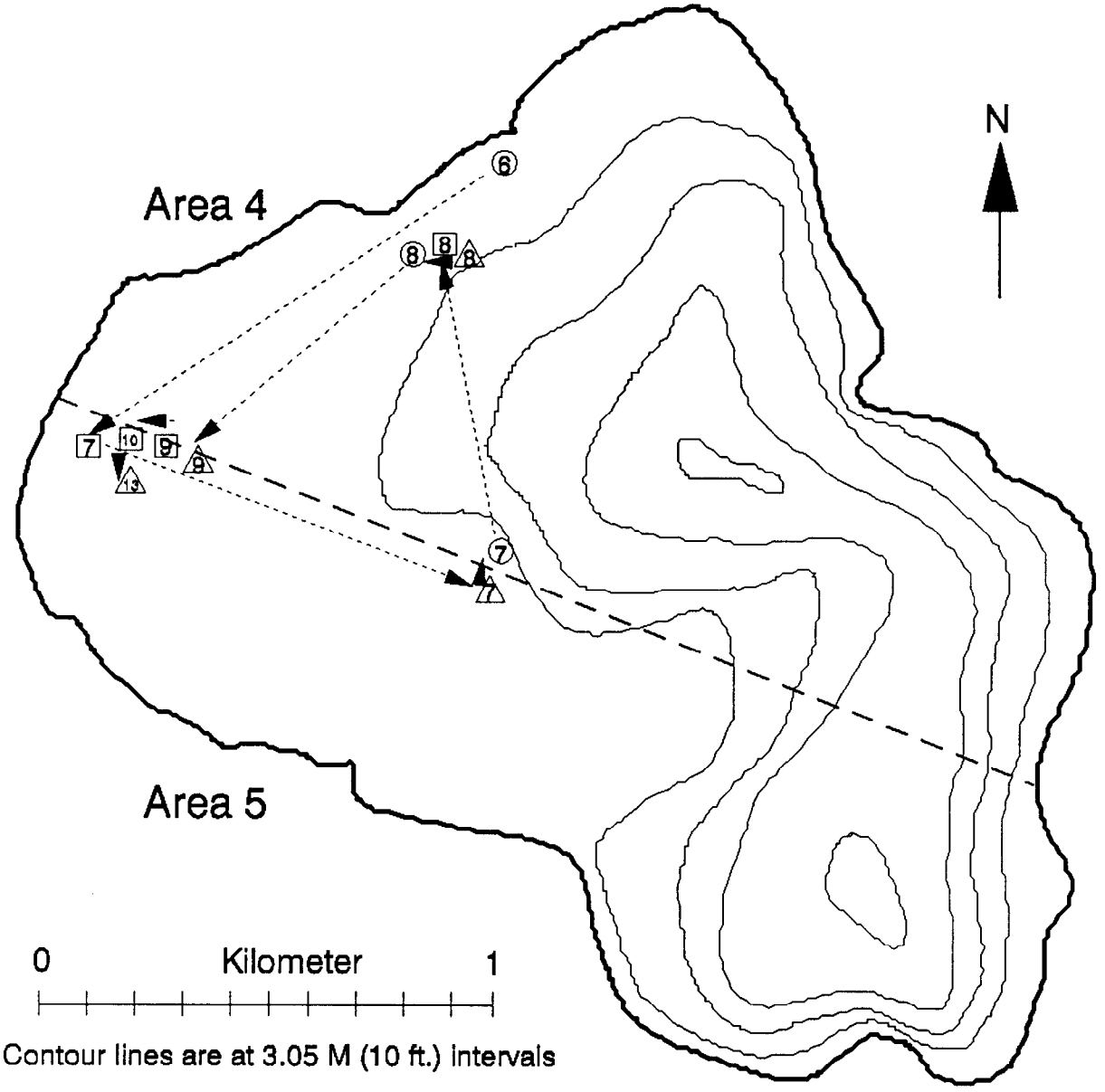
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #4 - 570 mm male released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

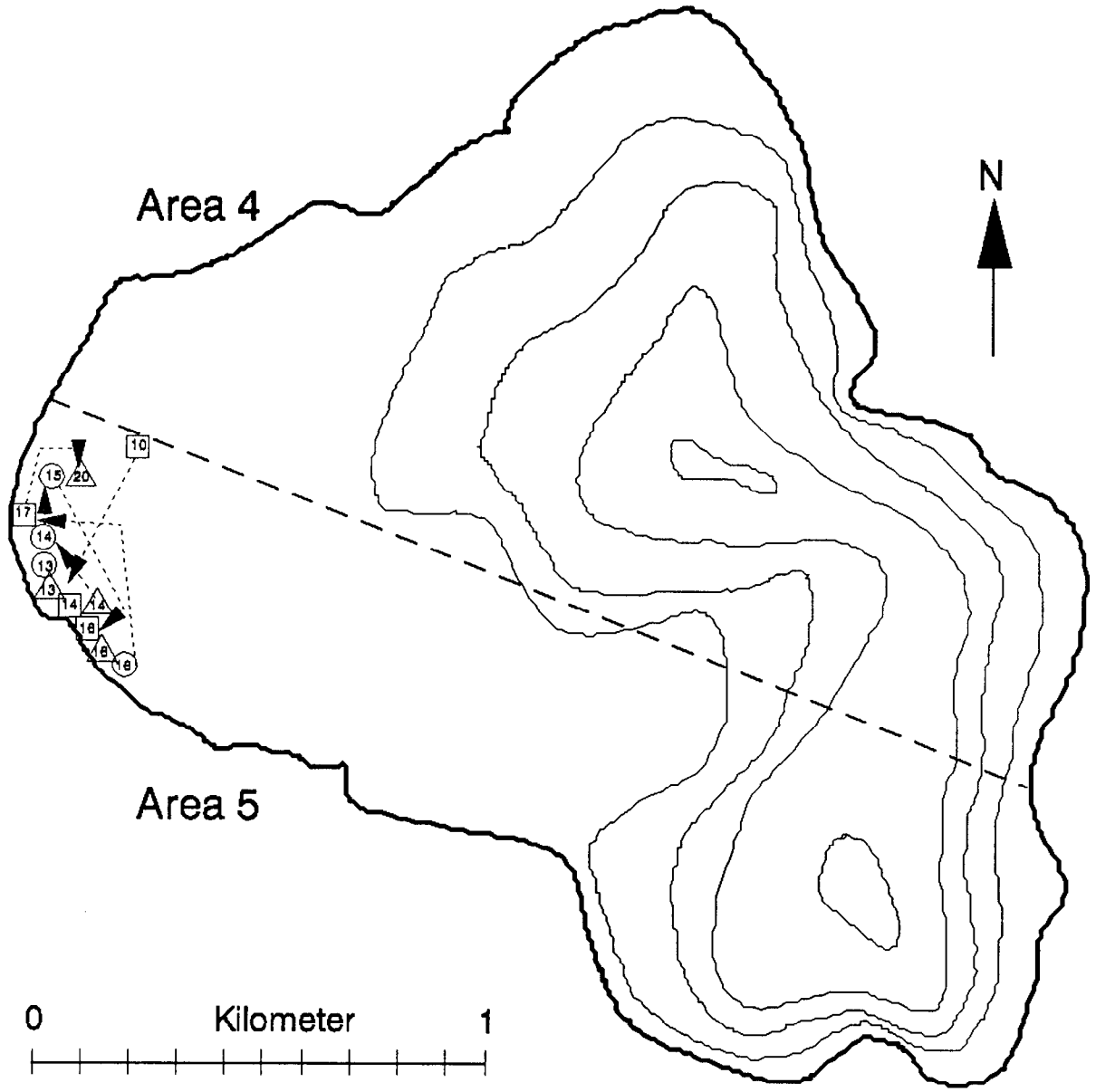
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #4 - 570 mm male released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

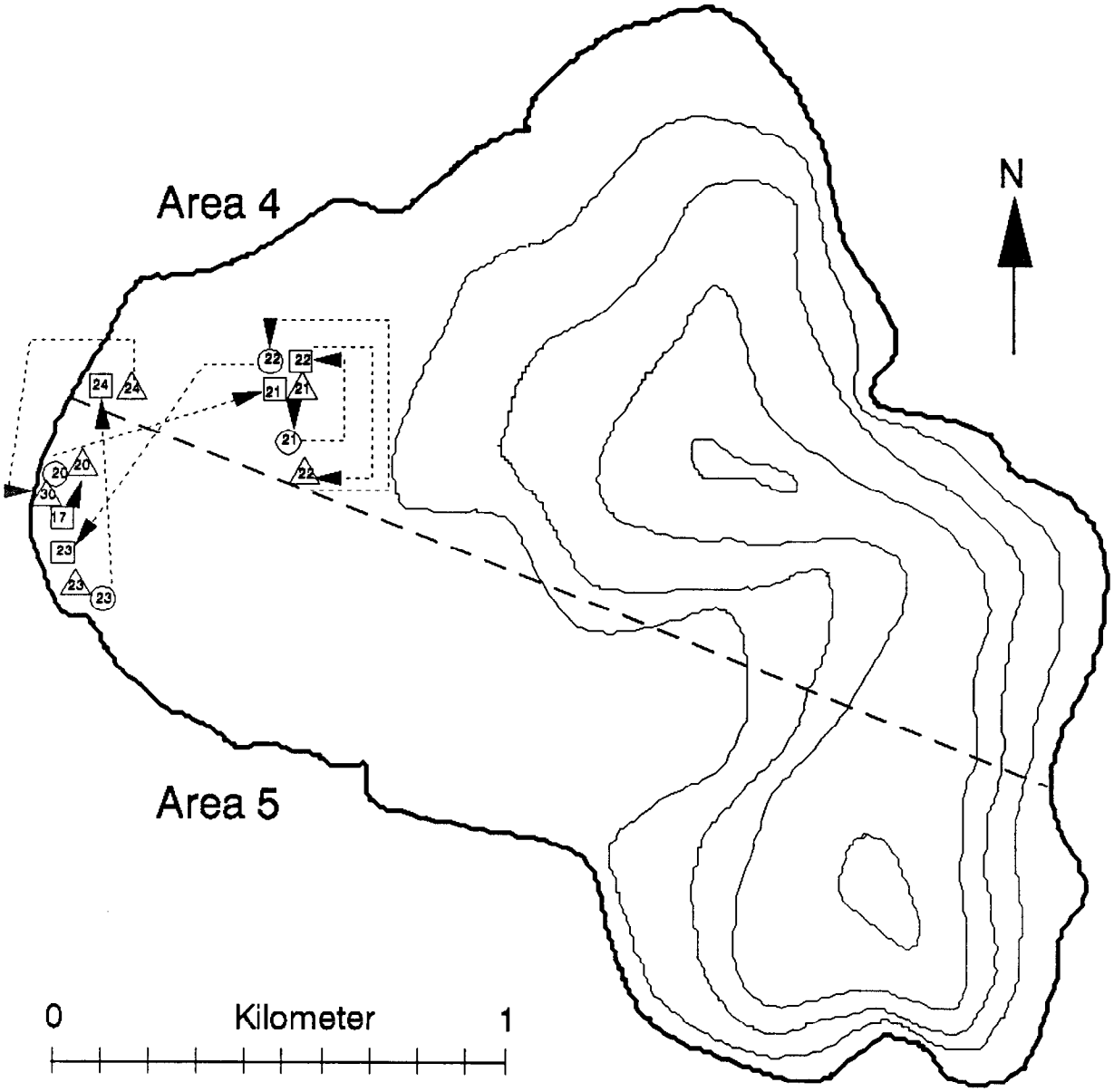
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #4 - 570 mm male released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

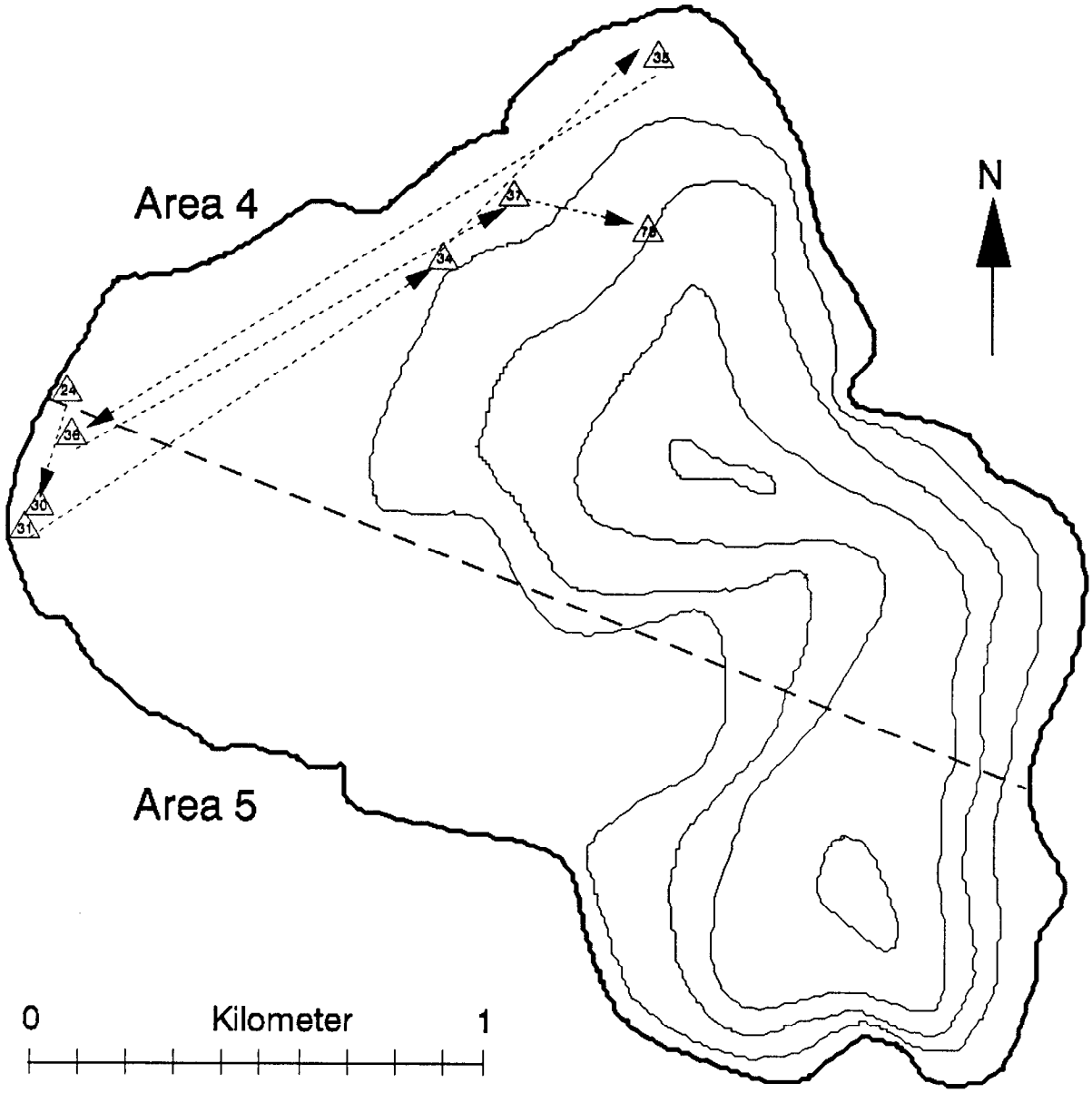
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #4 - 570 mm male released 5/21/91 at 16:00



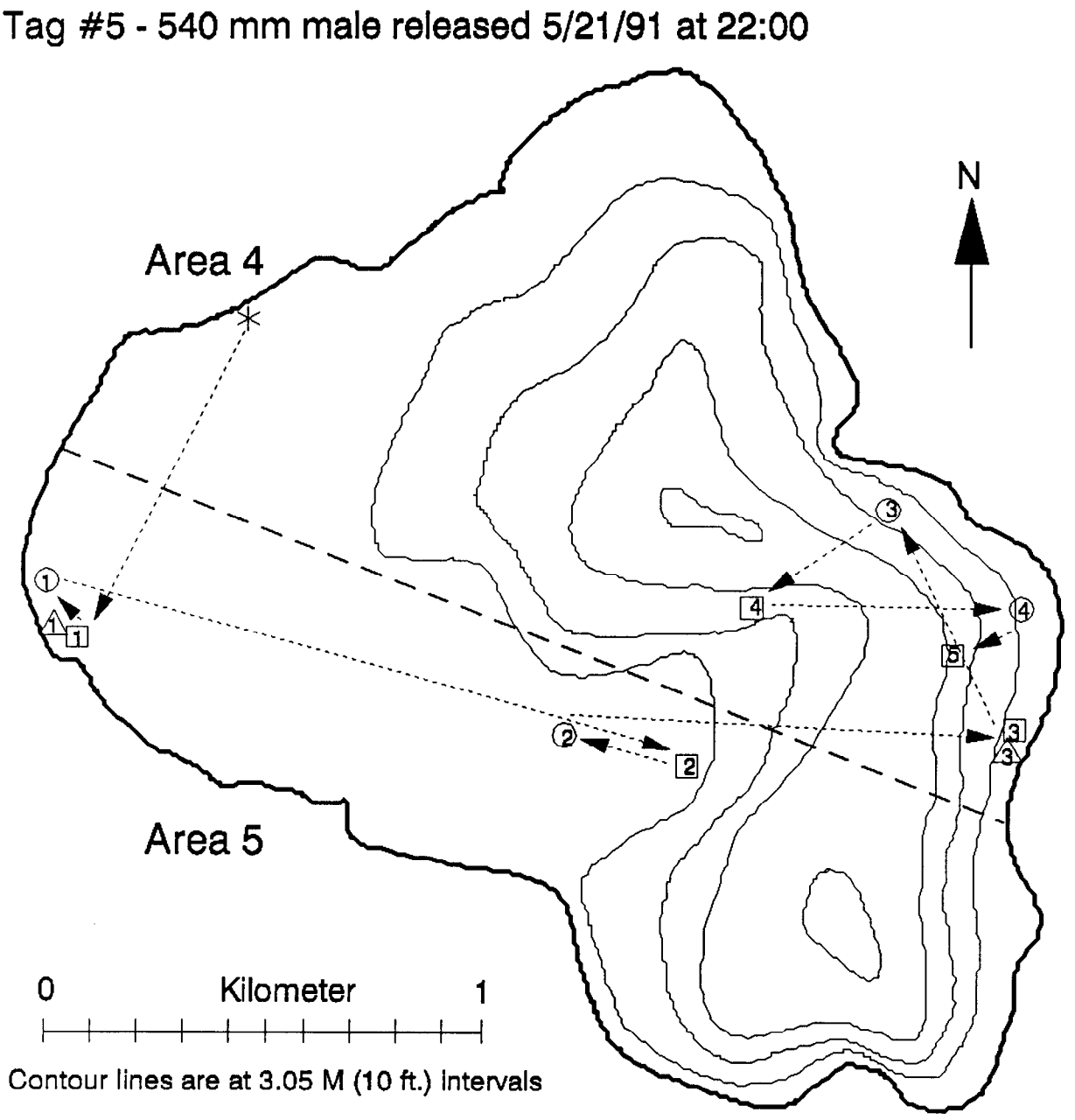
Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

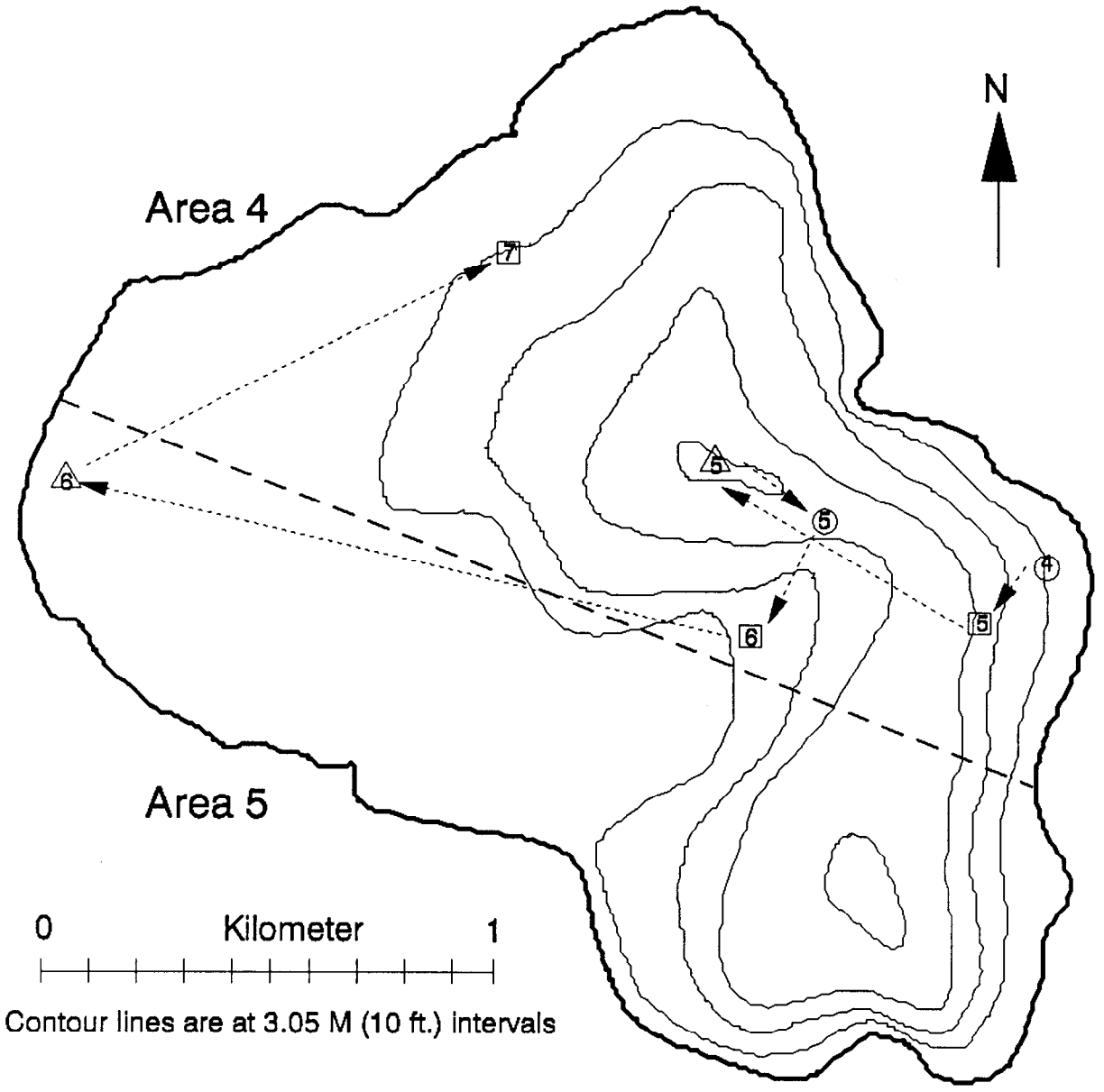
Period 6 - 6/20/91 through 8/5/91.

Appendix A6. Locations of a male northern pike (tag 5; 540 mm) between 5/21/91 and 6/13/91.



-continued-

Tag #5 - 540 mm male released 5/21/91 at 22:00



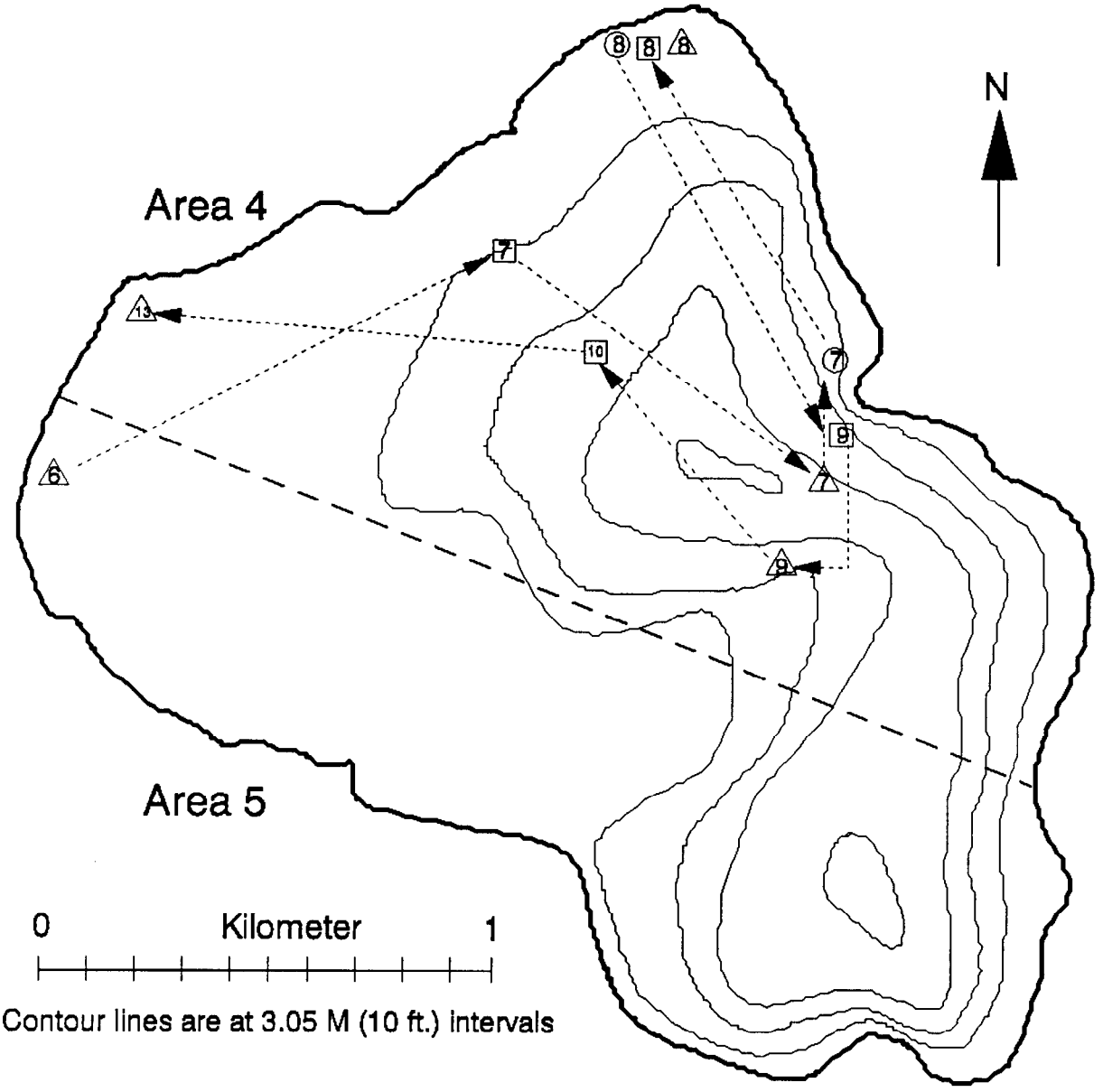
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #5 - 540 mm male released 5/21/91 at 22:00



Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

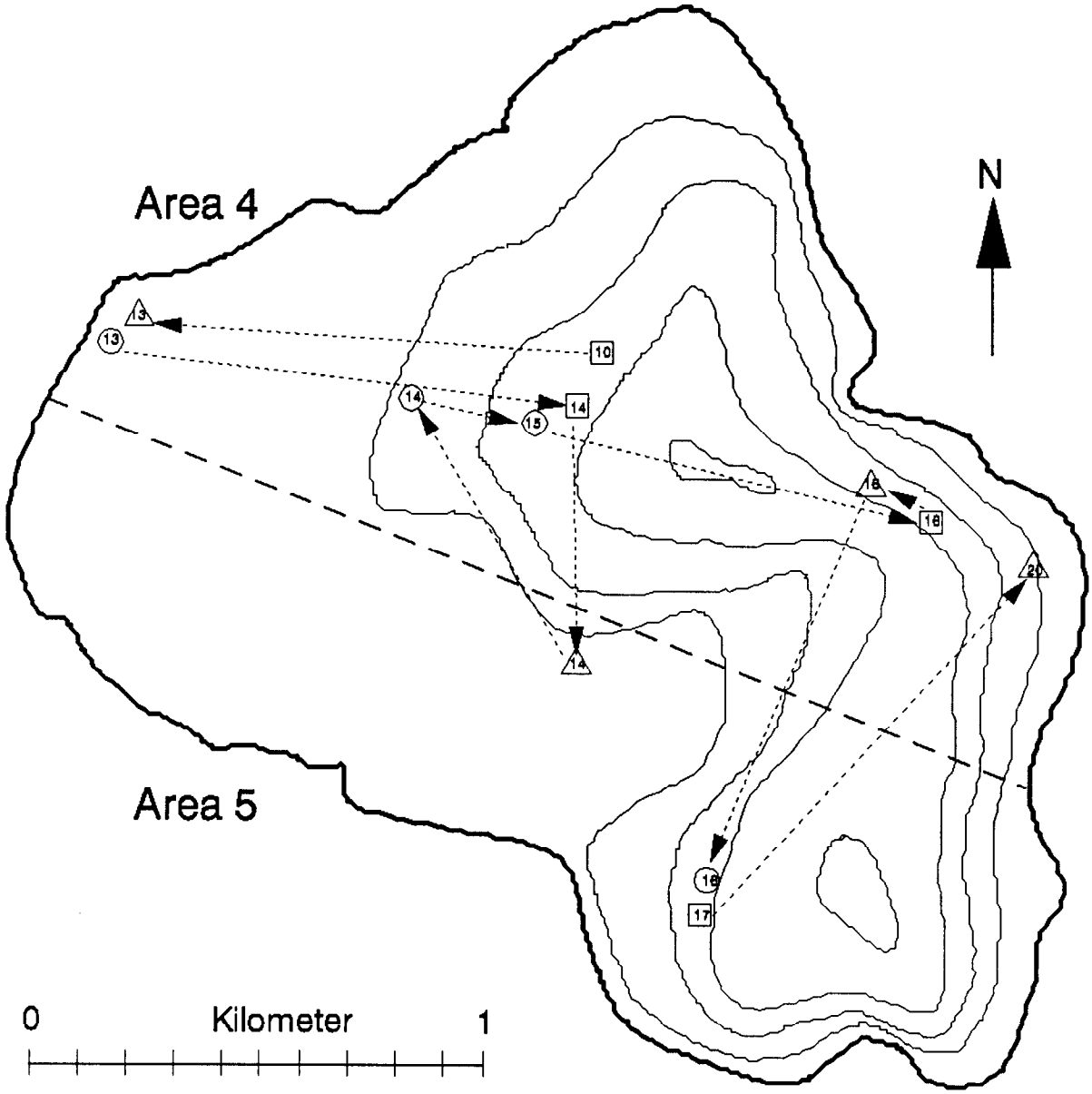
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #5 - 540 mm male released 5/21/91 at 22:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

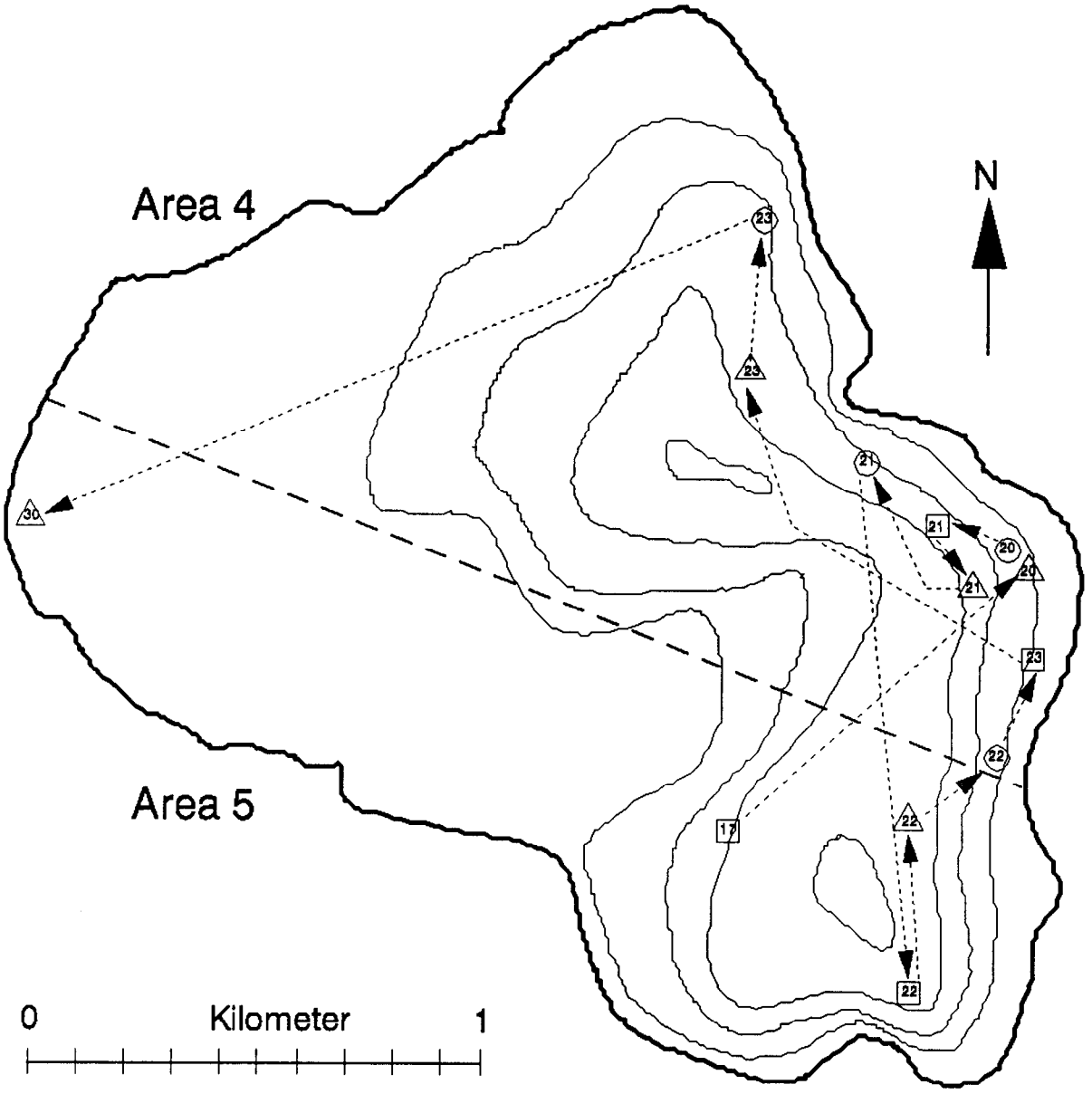
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #5 - 540 mm male released 5/21/91 at 22:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

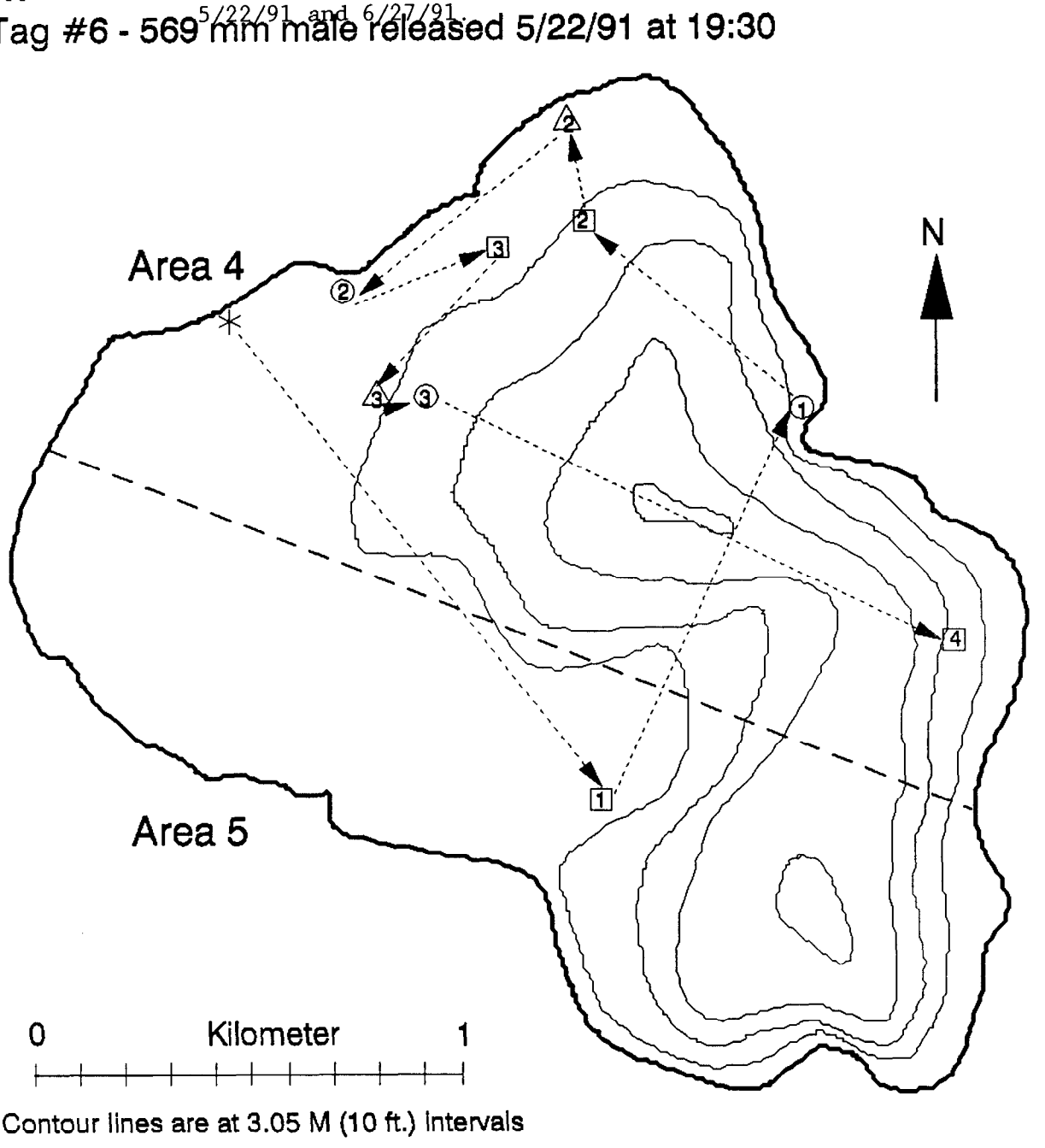
□ Indicates fish was located between 08:00 and 11:00

△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

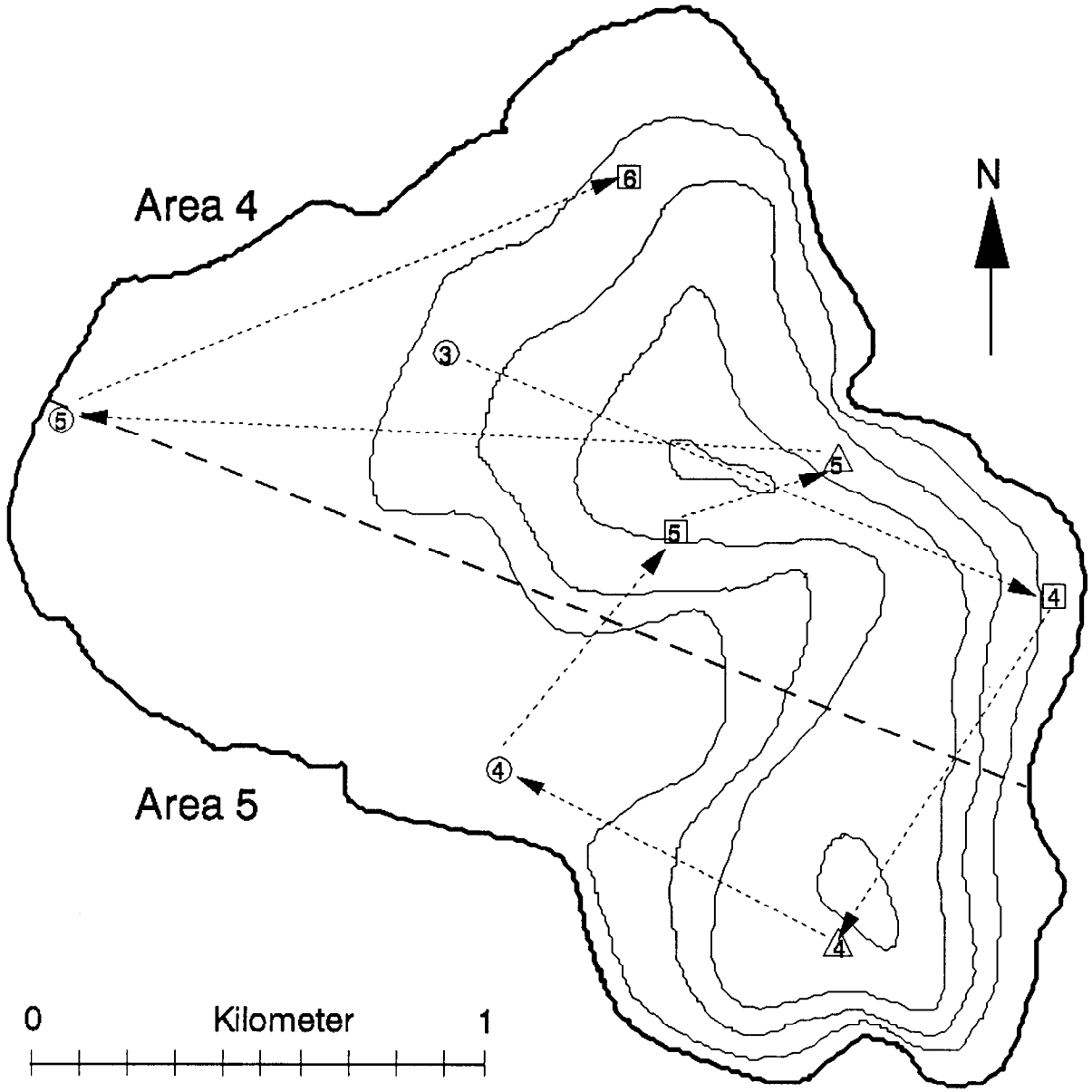
Period 5 - 6/10/91 through 6/14/91.

Appendix A7. Locations of a male northern pike (tag 6; 567 mm) between 5/22/91 and 6/27/91.



-continued-

Tag #6 - 569 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

☐ Indicates fish was located between 08:00 and 11:00

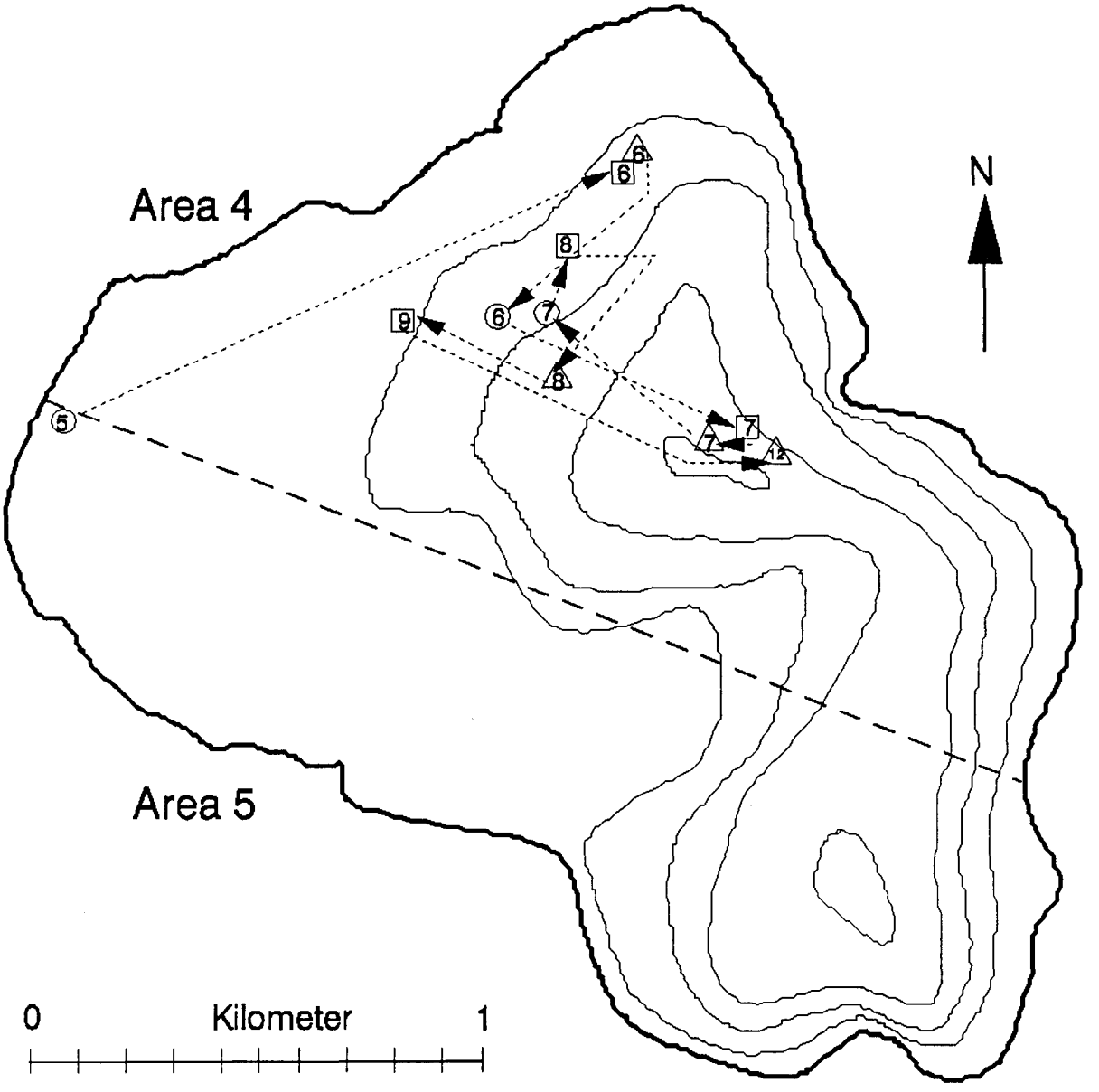
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #6 - 569 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) Intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

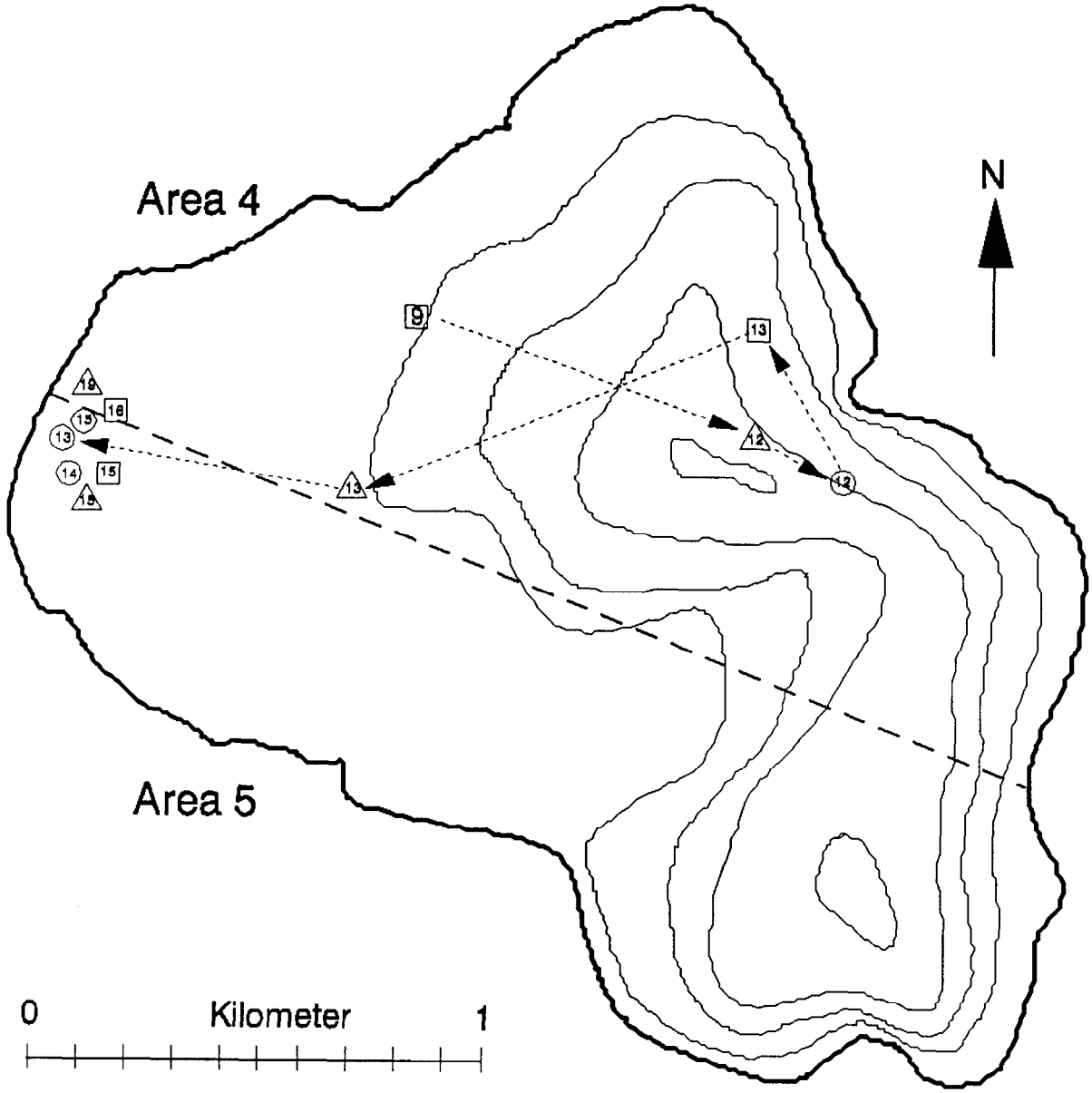
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #6 - 569 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

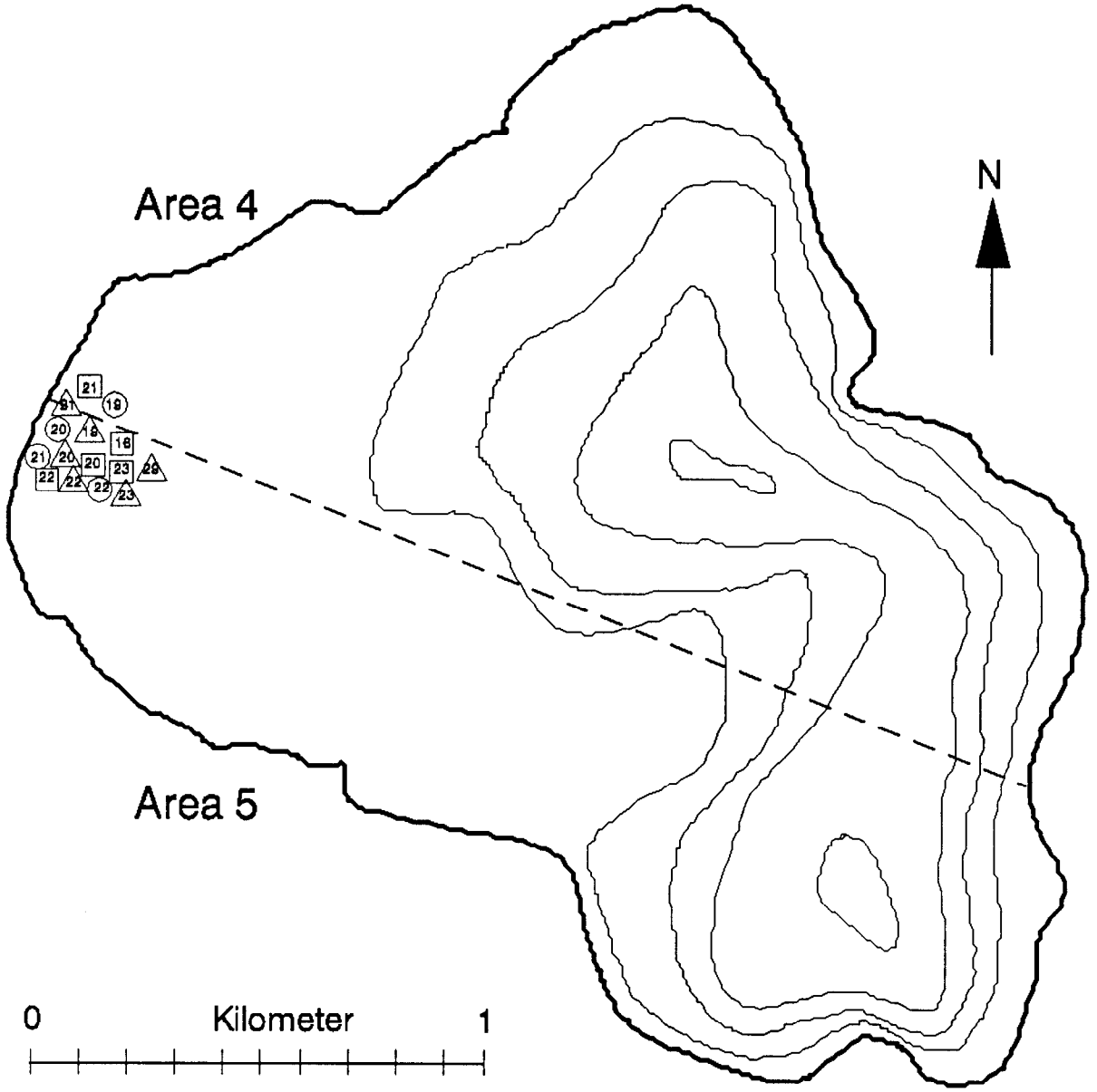
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #6 - 569 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

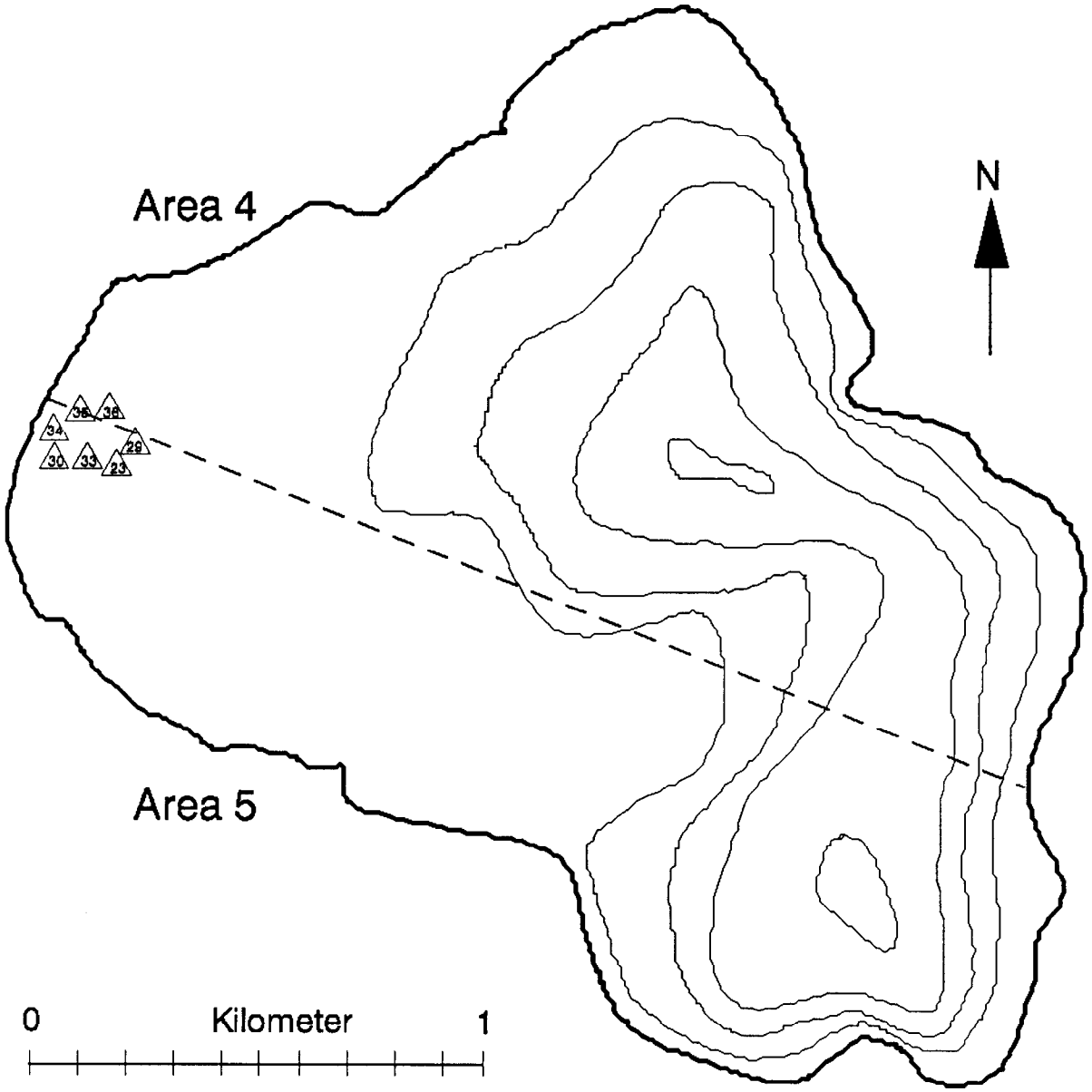
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #6 - 569 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

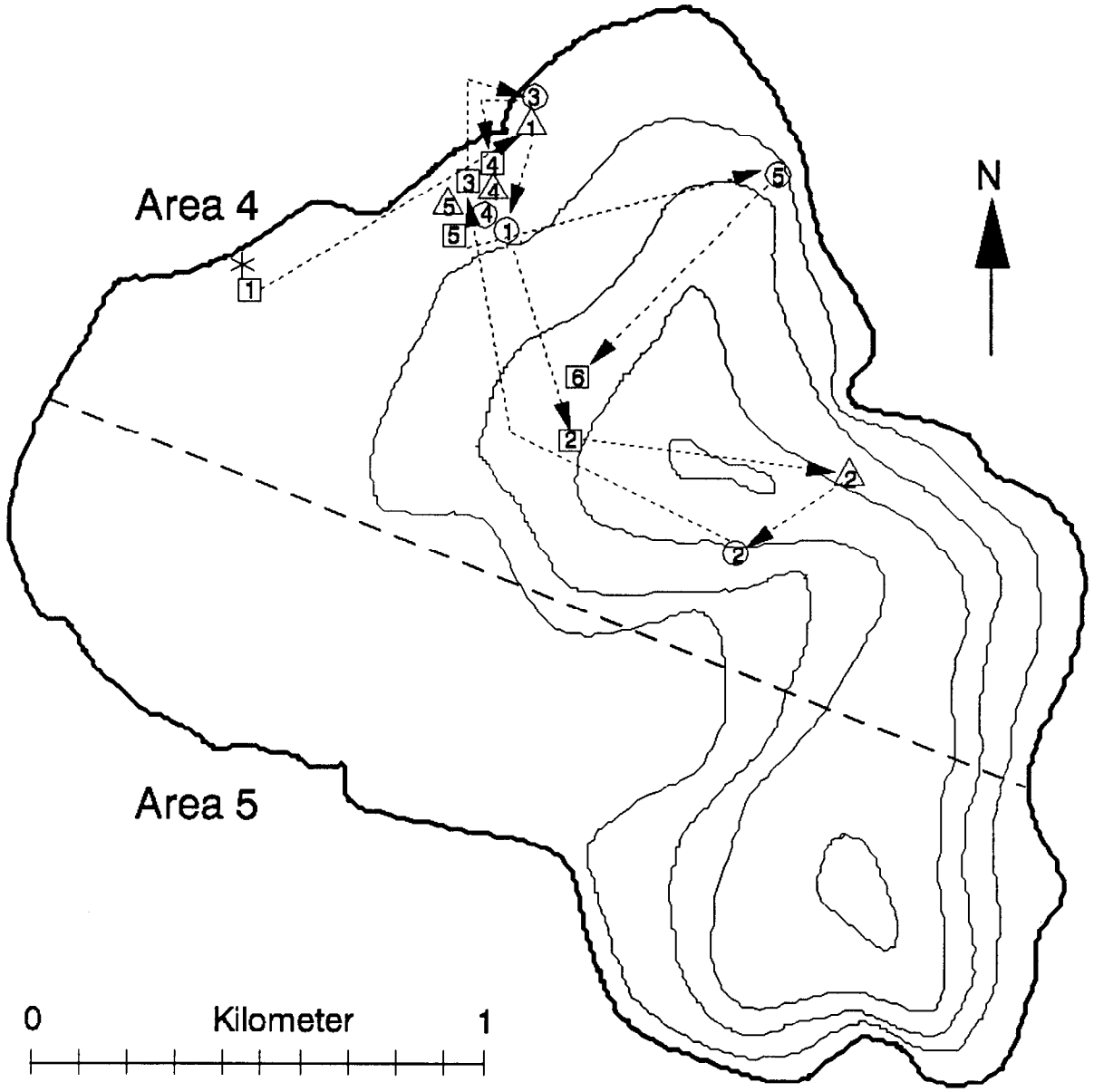
Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

Period 6 - 6/20/91 through 6/27/91.

Appendix A8. Locations of a female northern pike (tag 7; 653 mm) between 5/20/91 and 6/26/91.

Tag #7 - 653 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

△ Indicates fish was located between 14:00 and 17:00

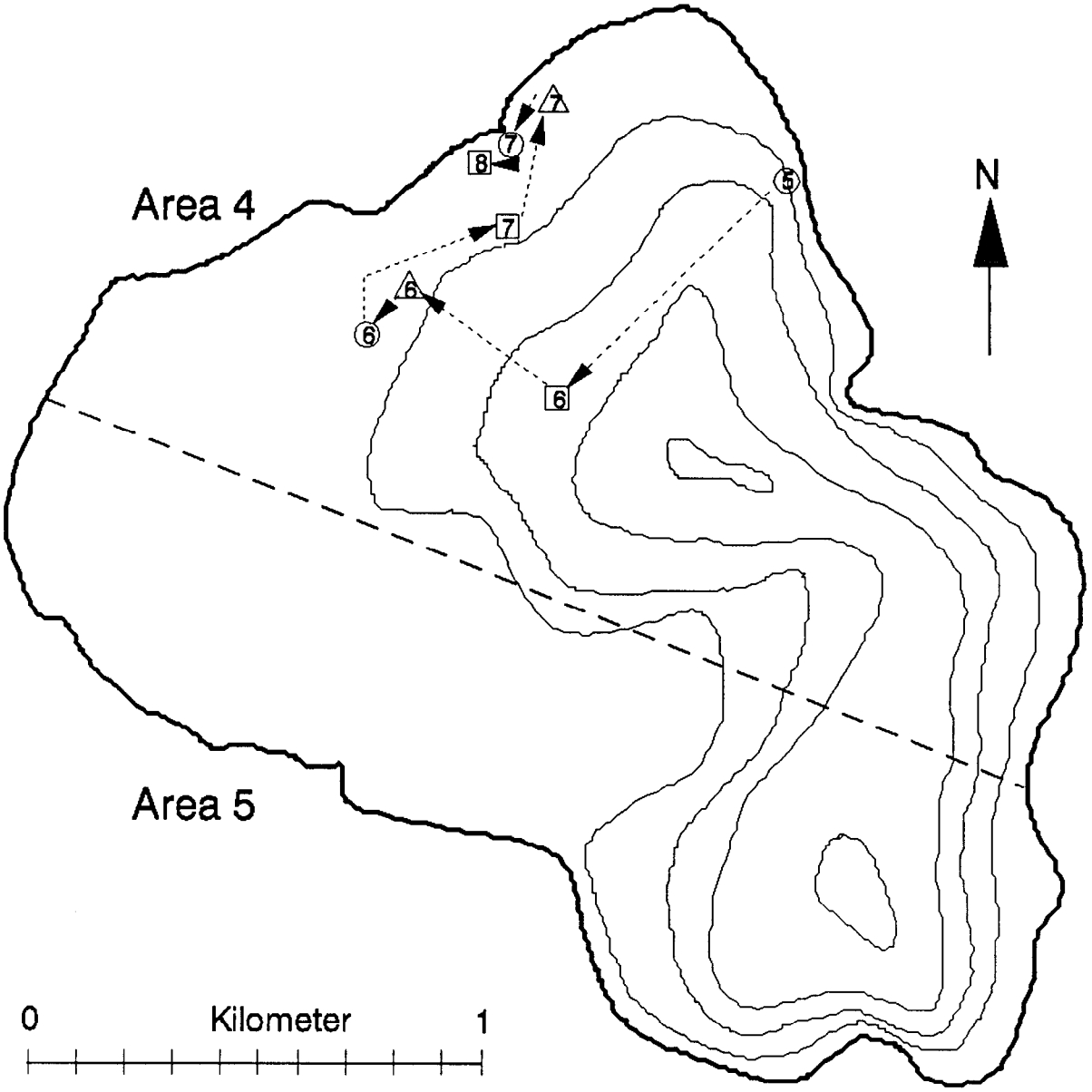
○ Indicates fish was located between 20:00 and 23:00

✳ Indicates location where fish was originally released

Period 1 - 5/20/91 through 5/25/91.

-continued-

Tag #7 - 653 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

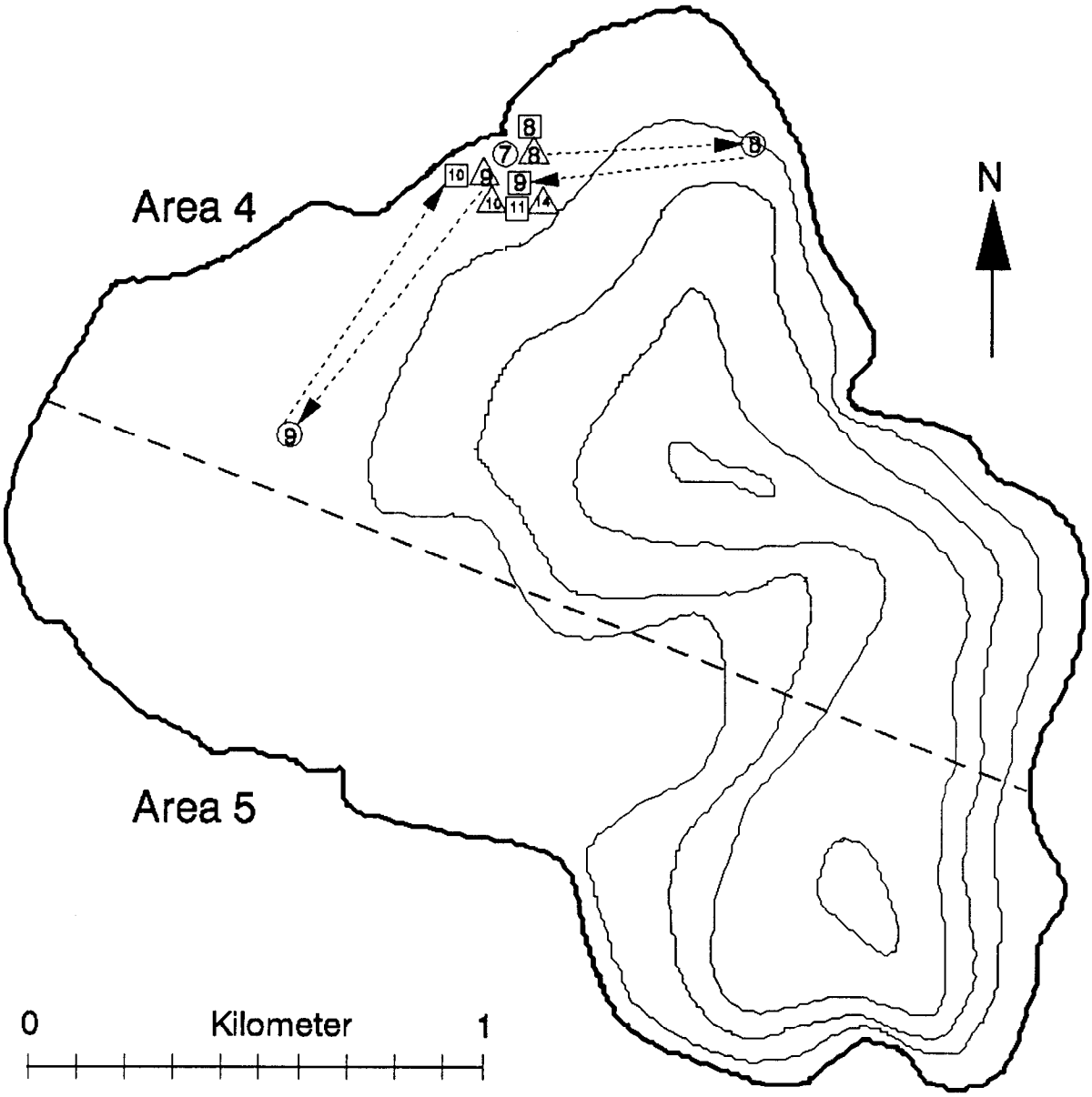
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #7 - 653 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

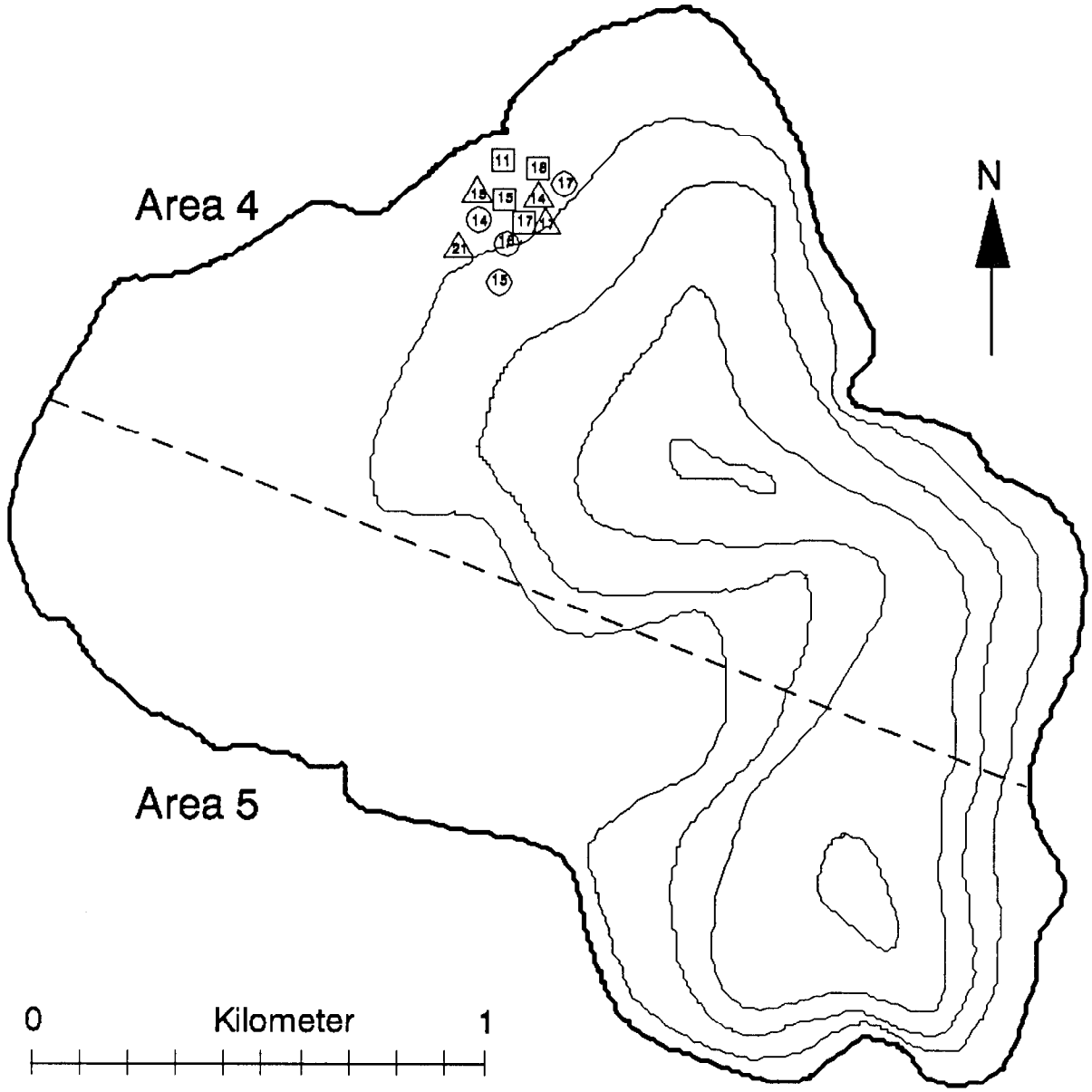
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #7 - 653 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

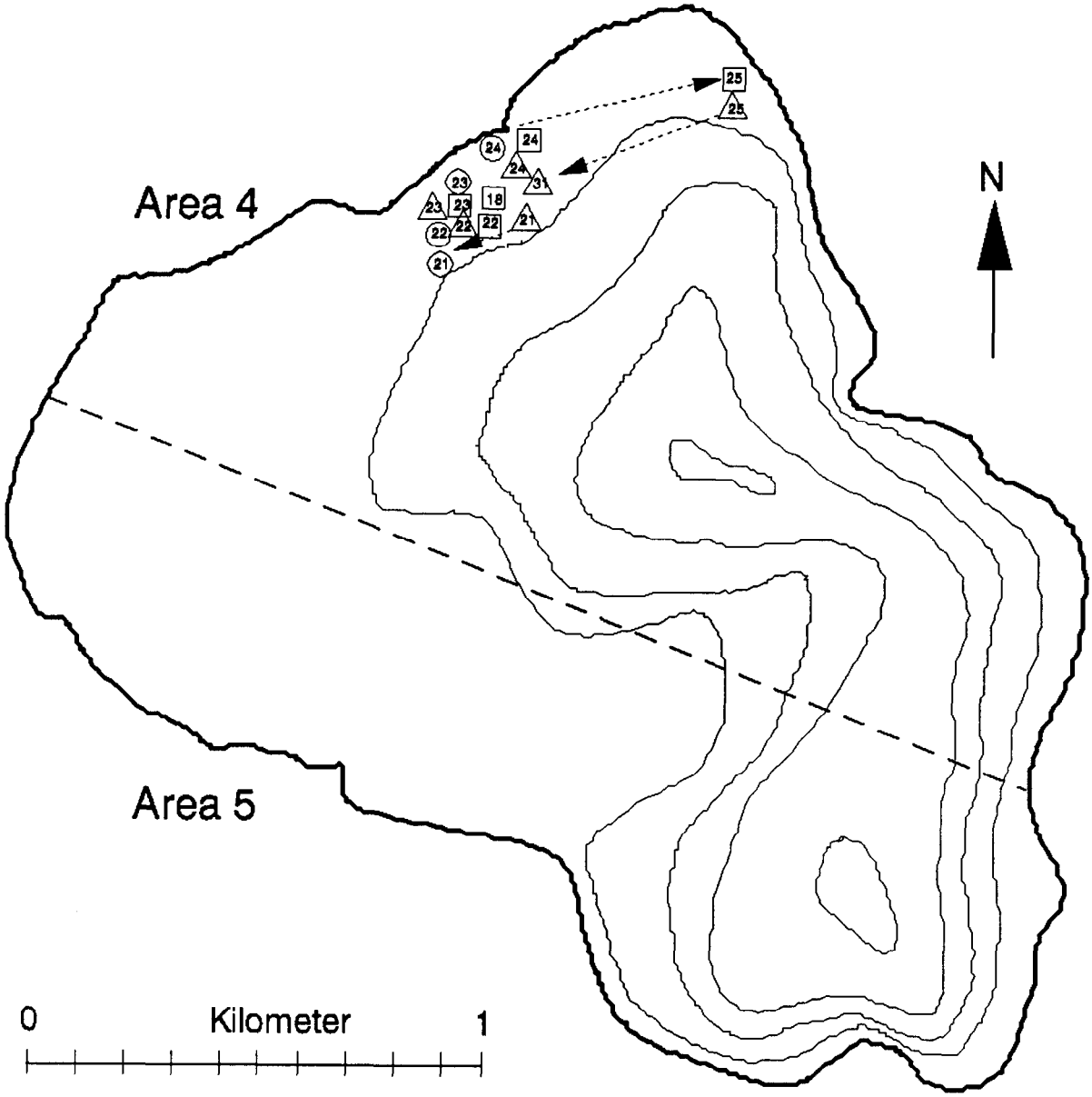
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #7 - 653 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

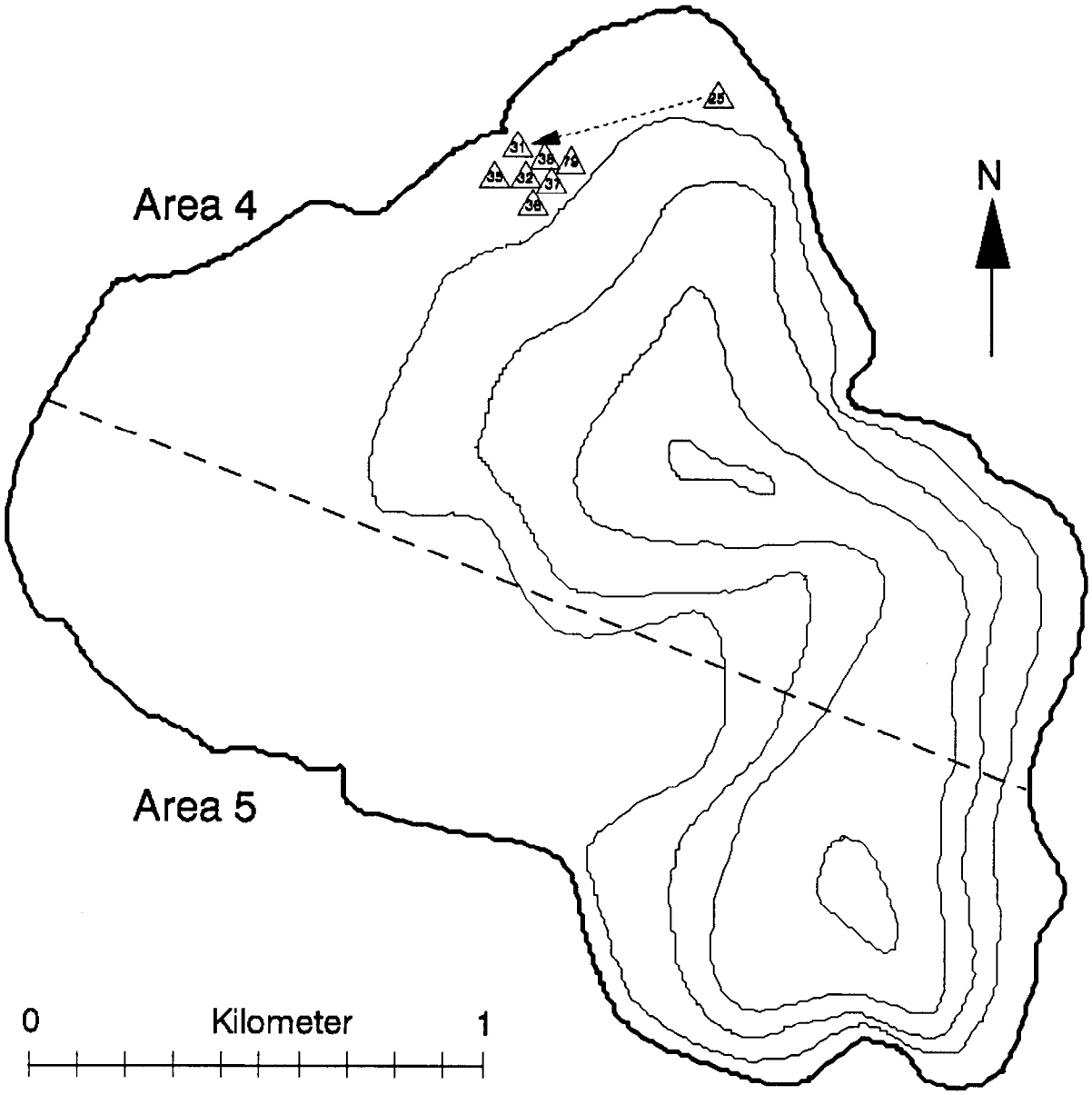
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #7 - 653 mm female released 5/20/91 at 23:00

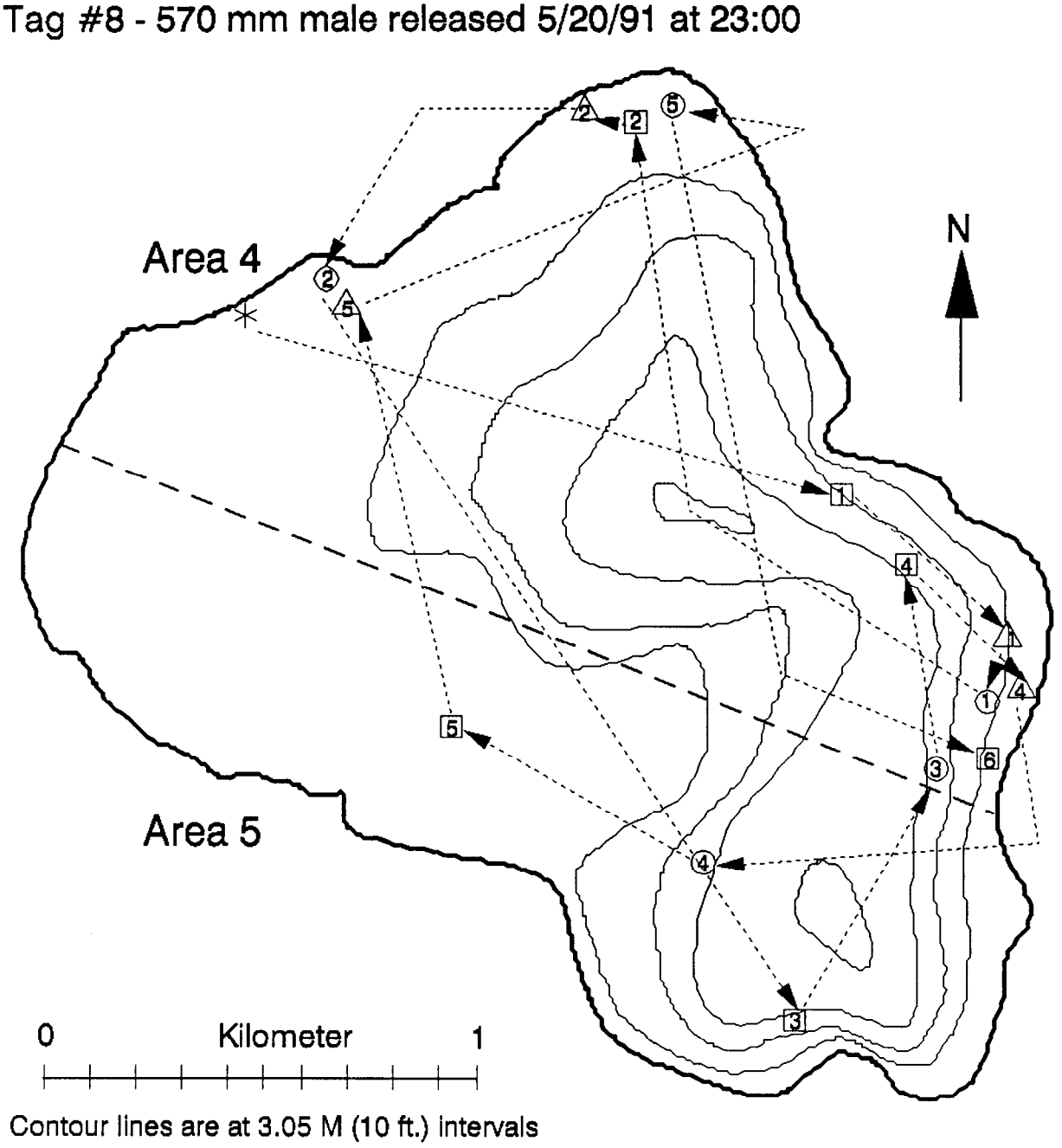


Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release
△ Indicates fish was located between 14:00 and 17:00

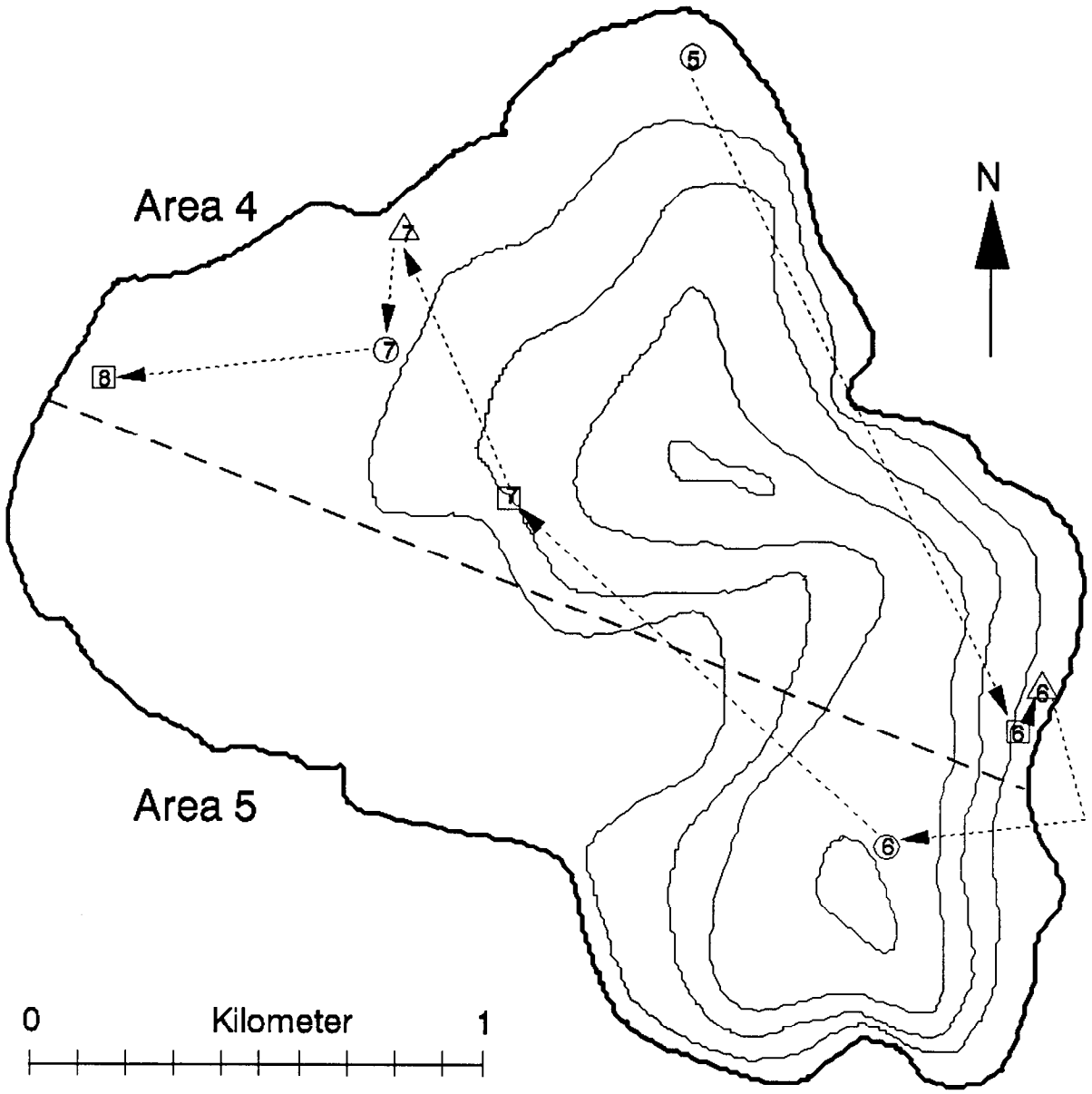
Period 6 - 6/20/91 through 6/26/91.

Appendix A9. Locations of a female northern pike (tag 8; 570 mm) between 5/20/91 and 8/5/91.



-continued-

Tag #8 - 570 mm male released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

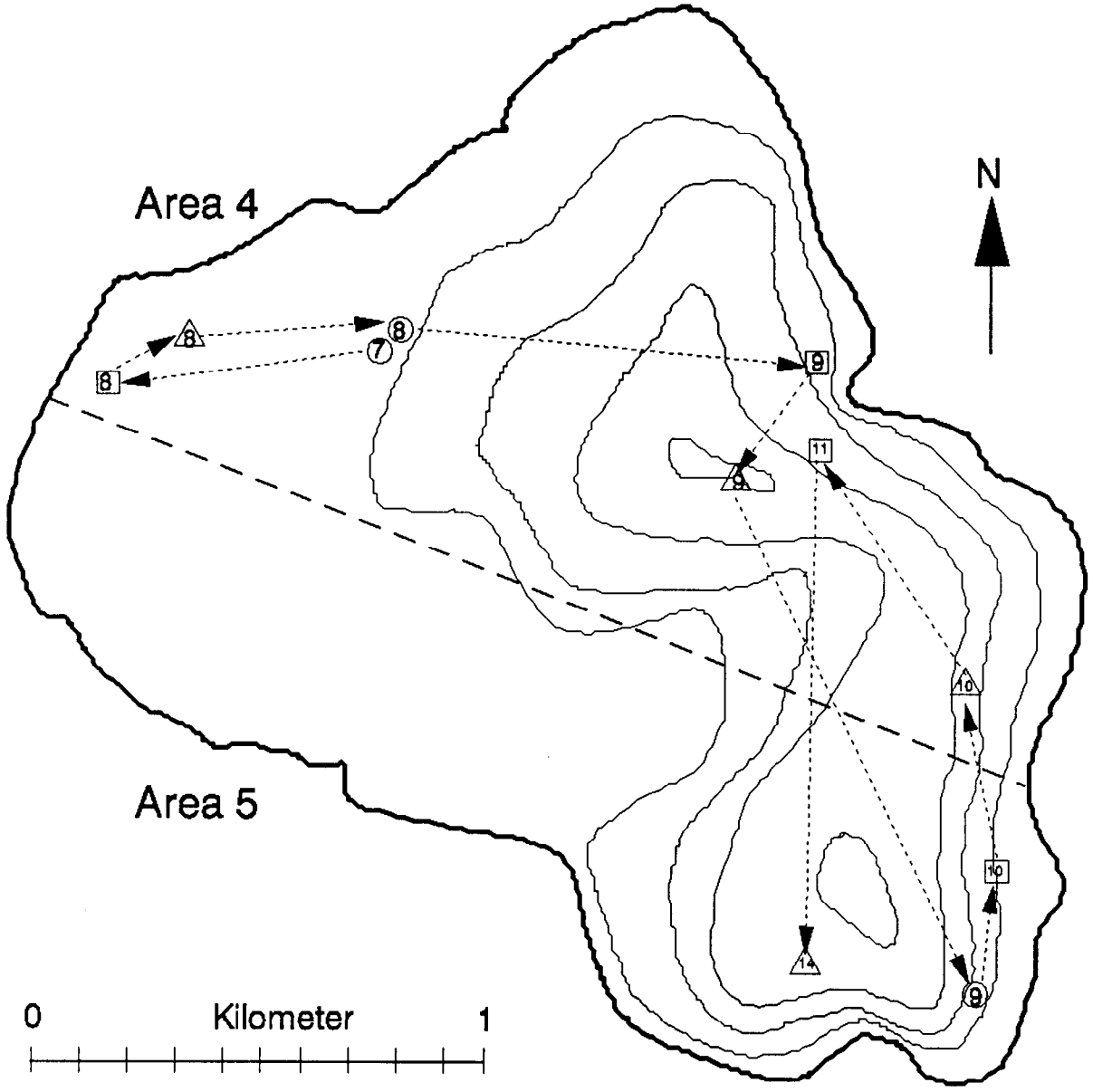
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #8 - 570 mm male released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

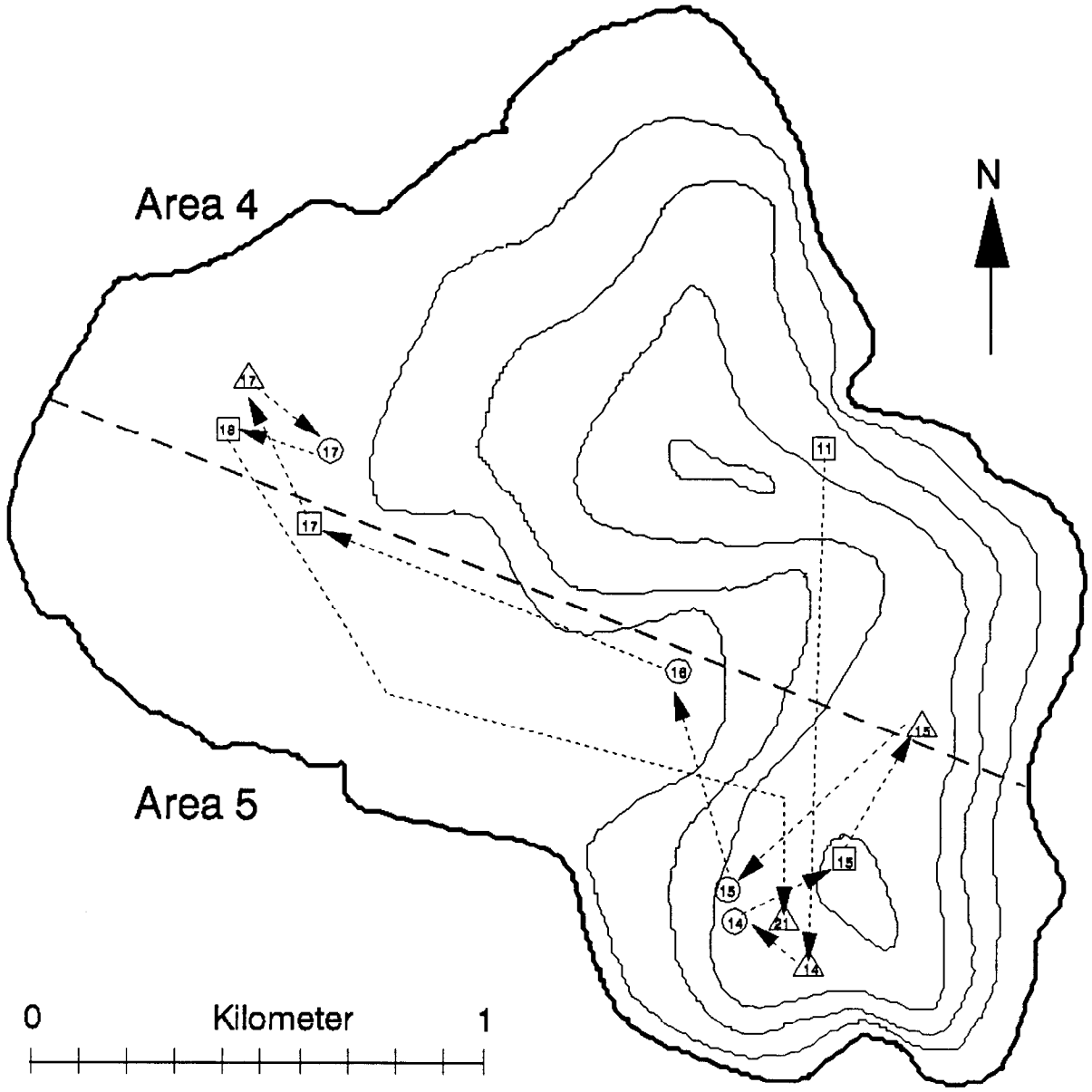
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #8 - 570 mm male released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

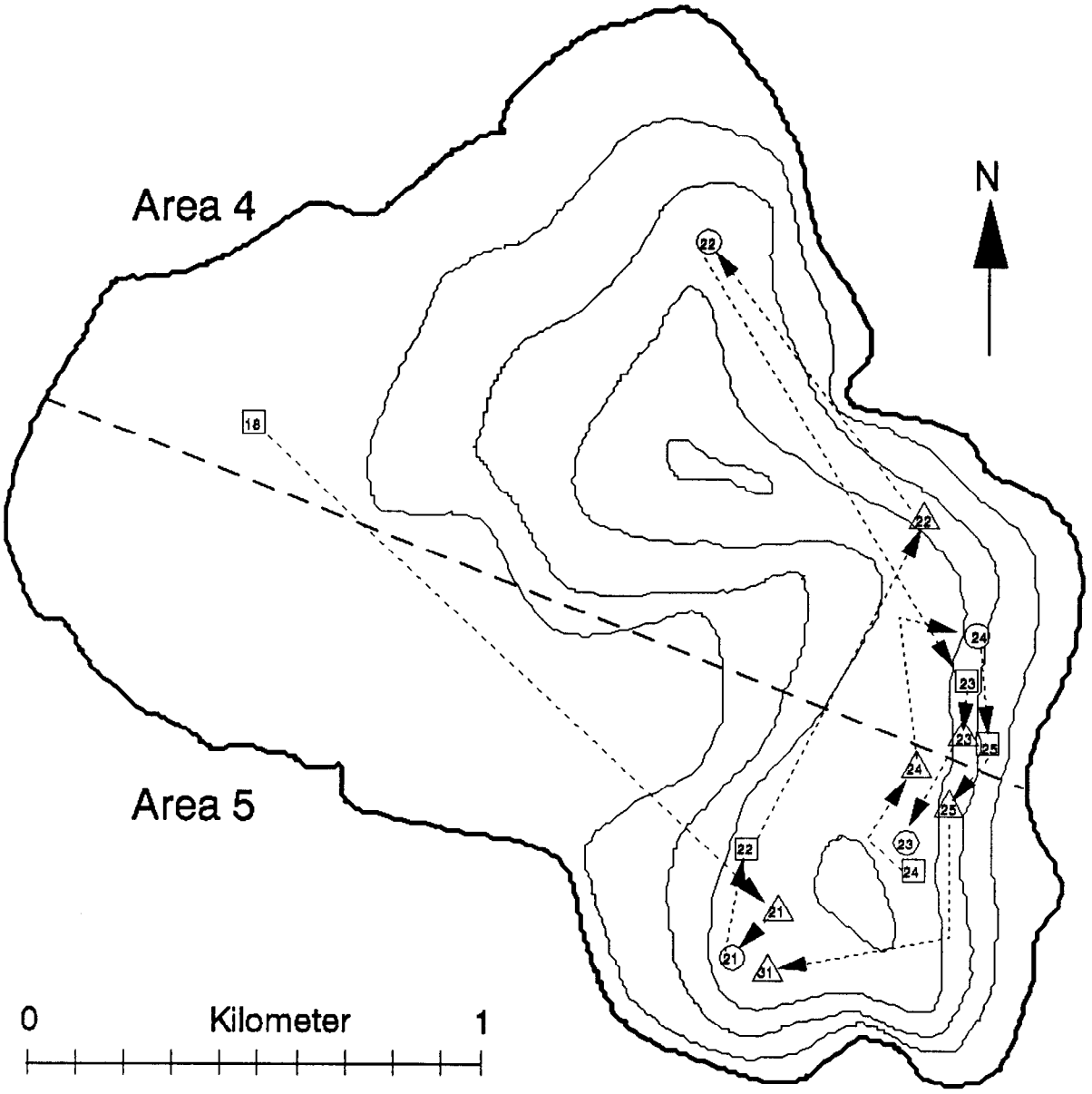
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #8 - 570 mm male released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

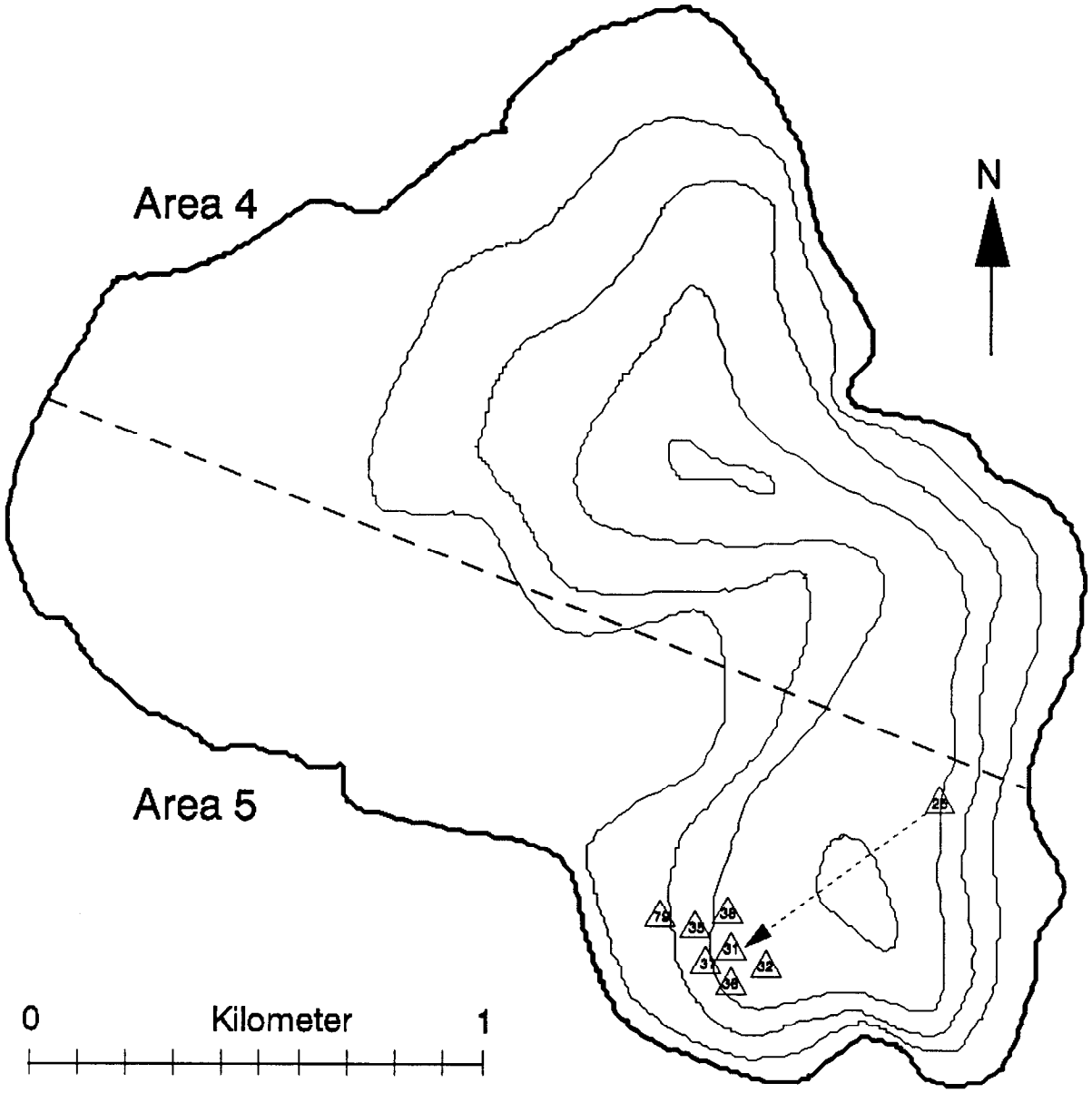
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #8 - 570 mm male released 5/20/91 at 23:00



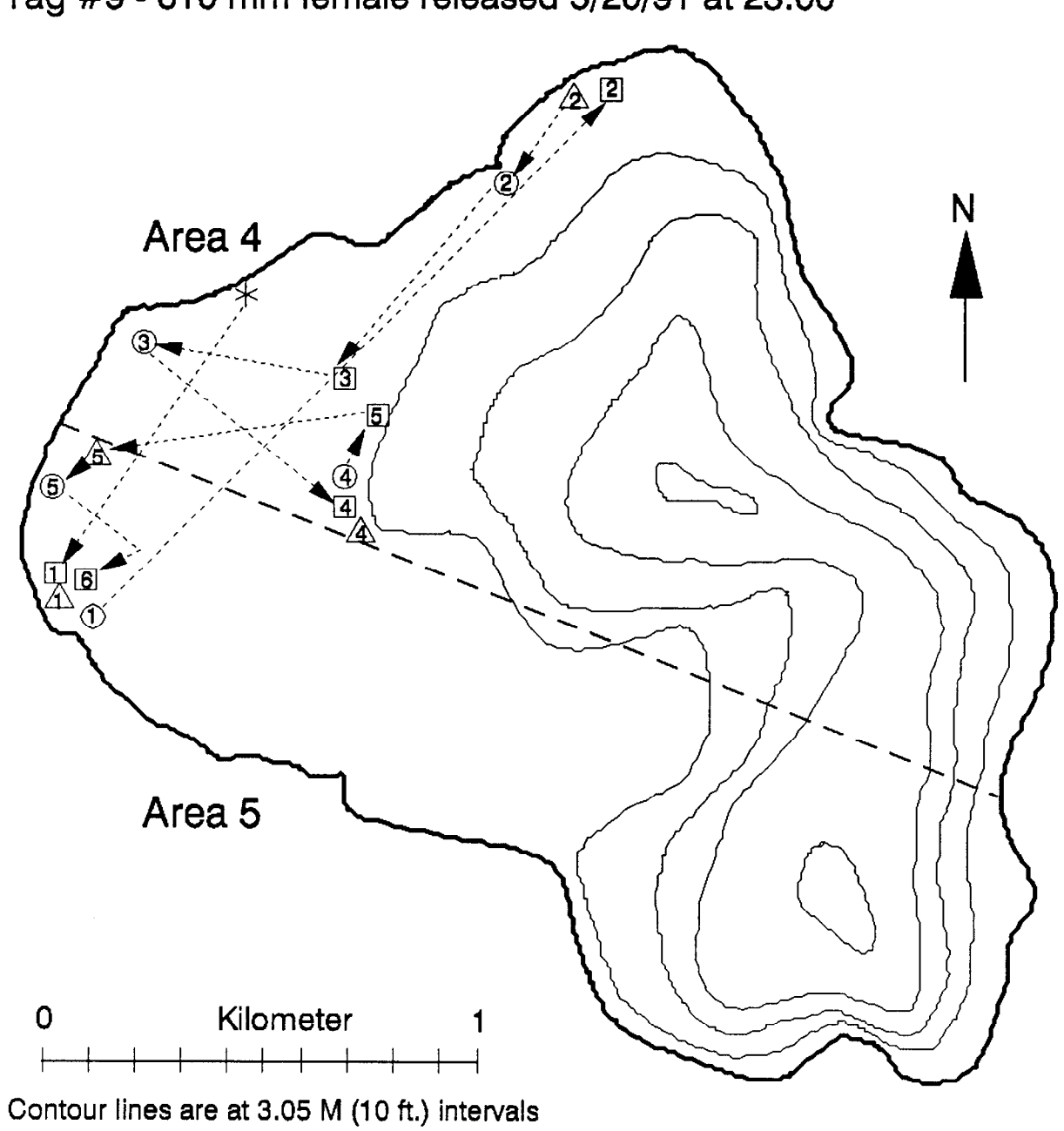
Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

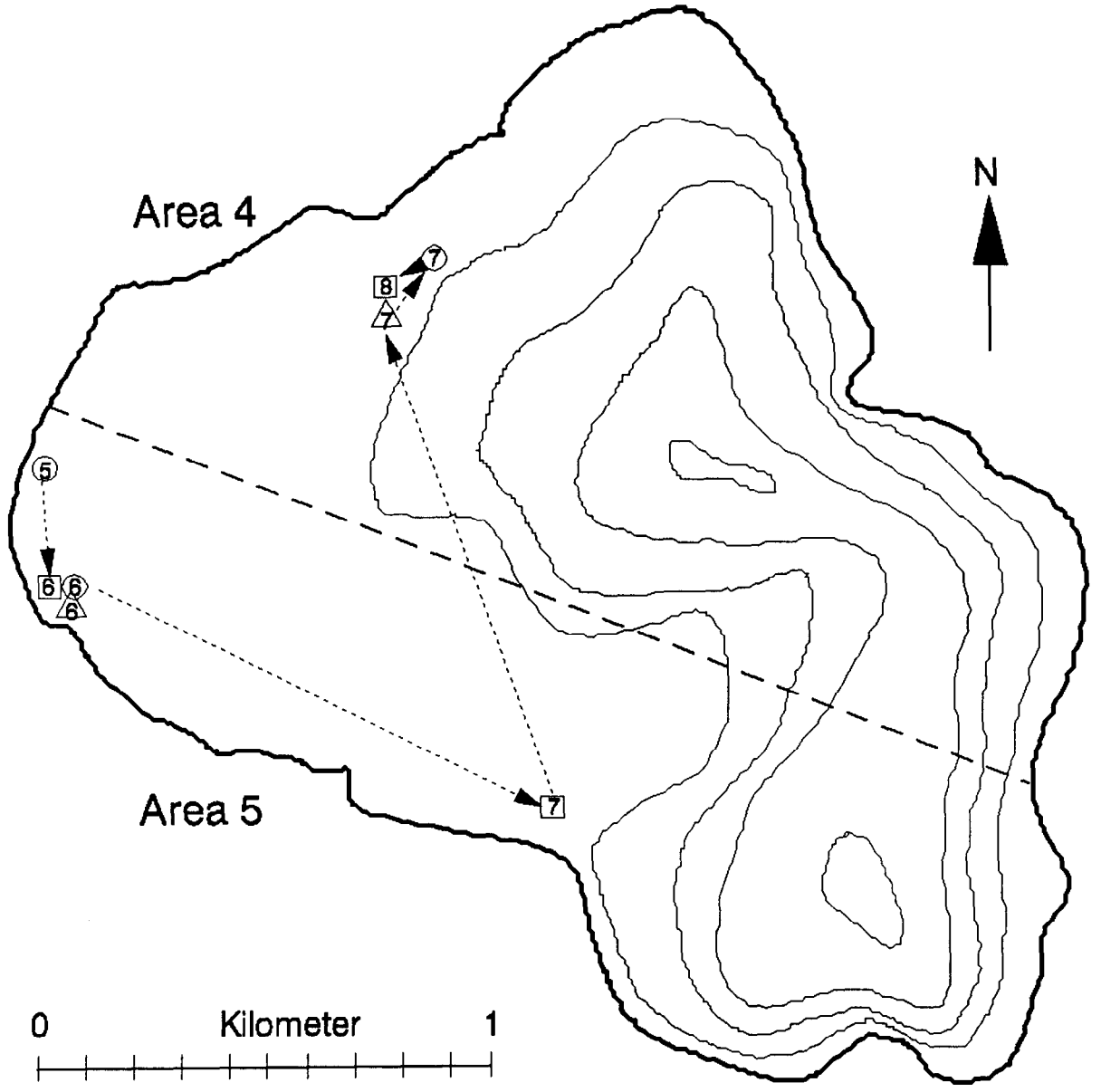
Period 6 - 6/20/91 through 8/5/91.

Appendix A10. Locations of a female northern pike (tag 9; 610 mm) between 5/20/91 and 8/5/91.



-continued-

Tag #9 - 610 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

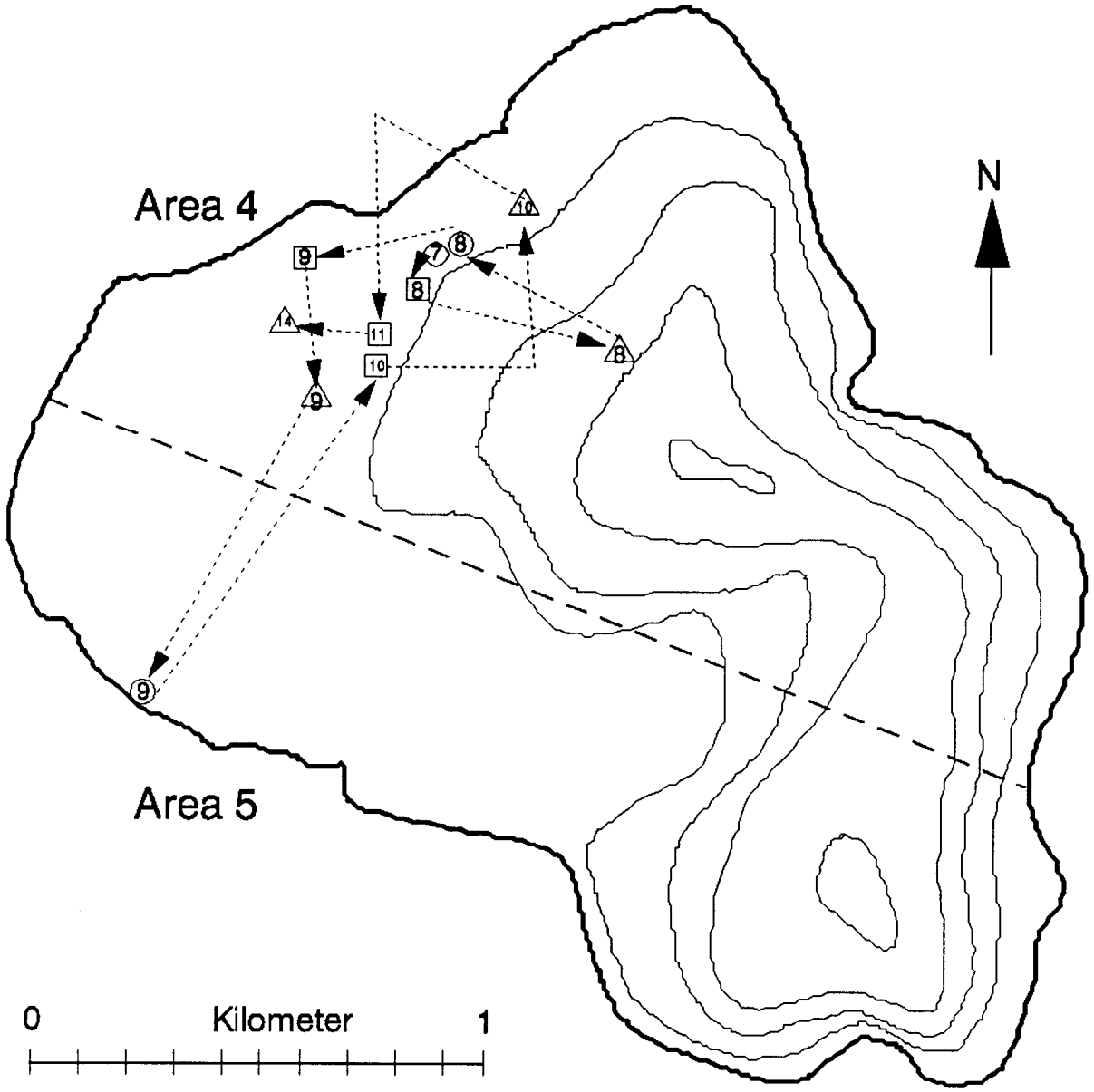
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #9 - 610 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

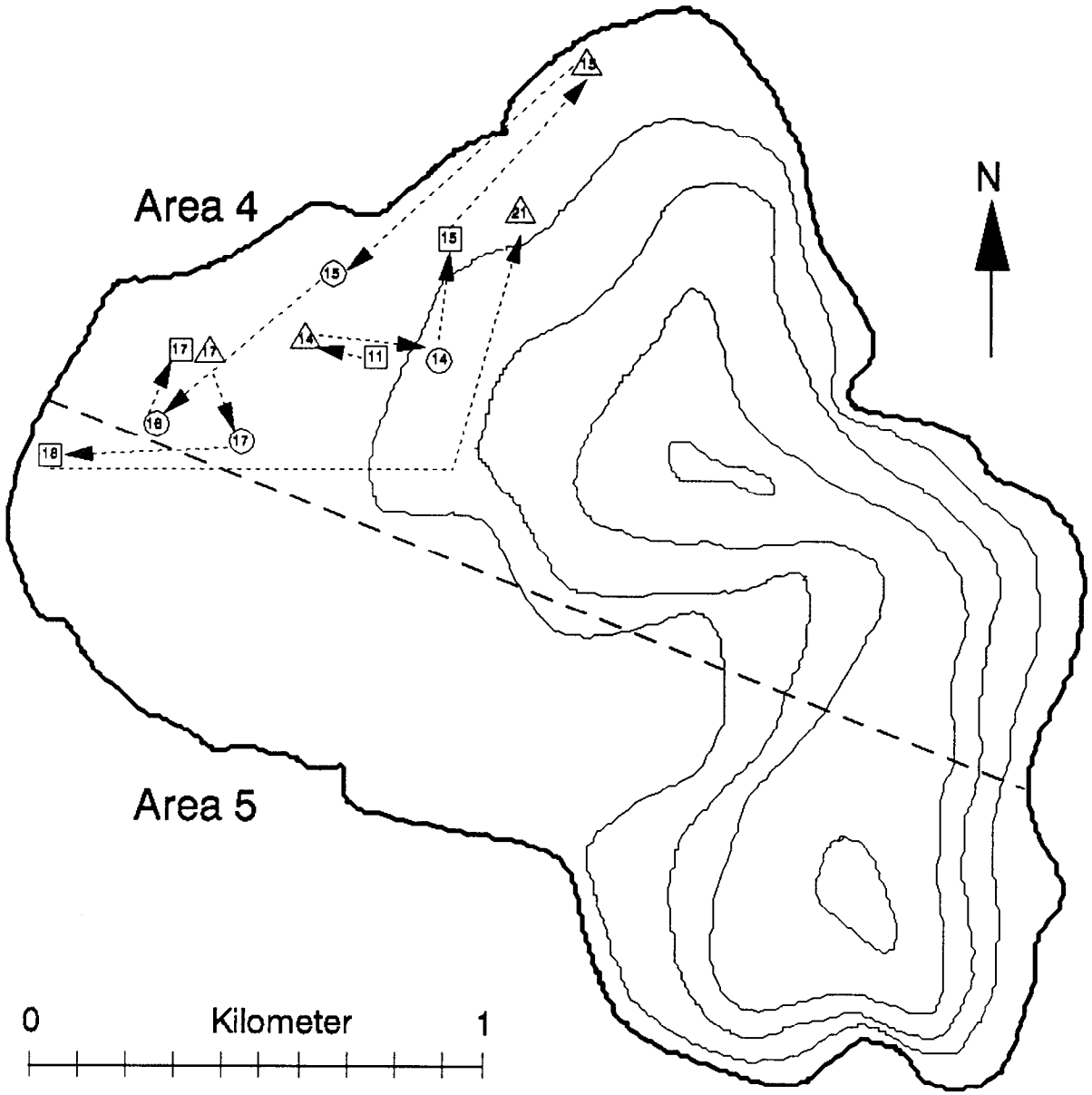
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #9 - 610 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

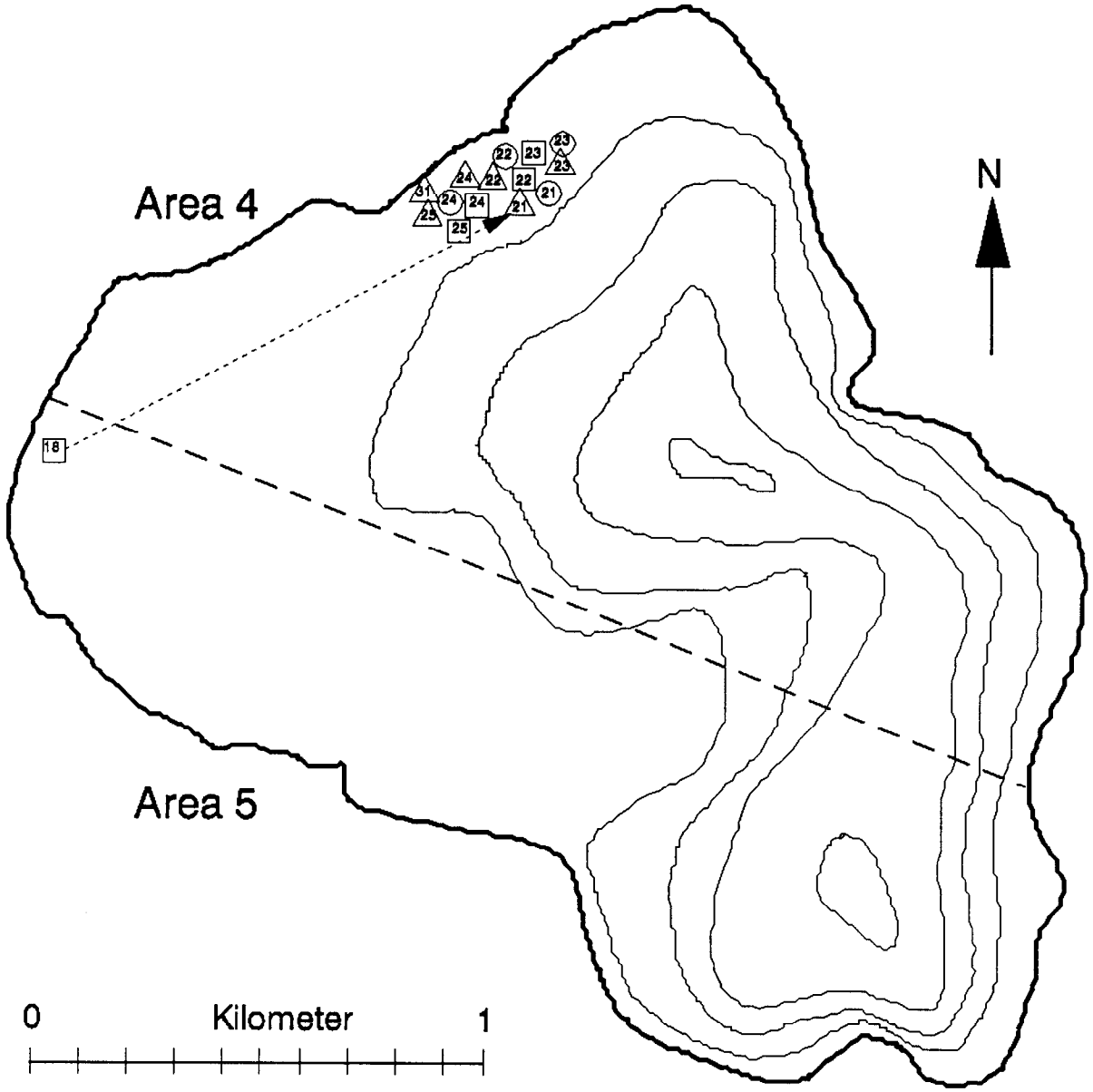
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #9 - 610 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

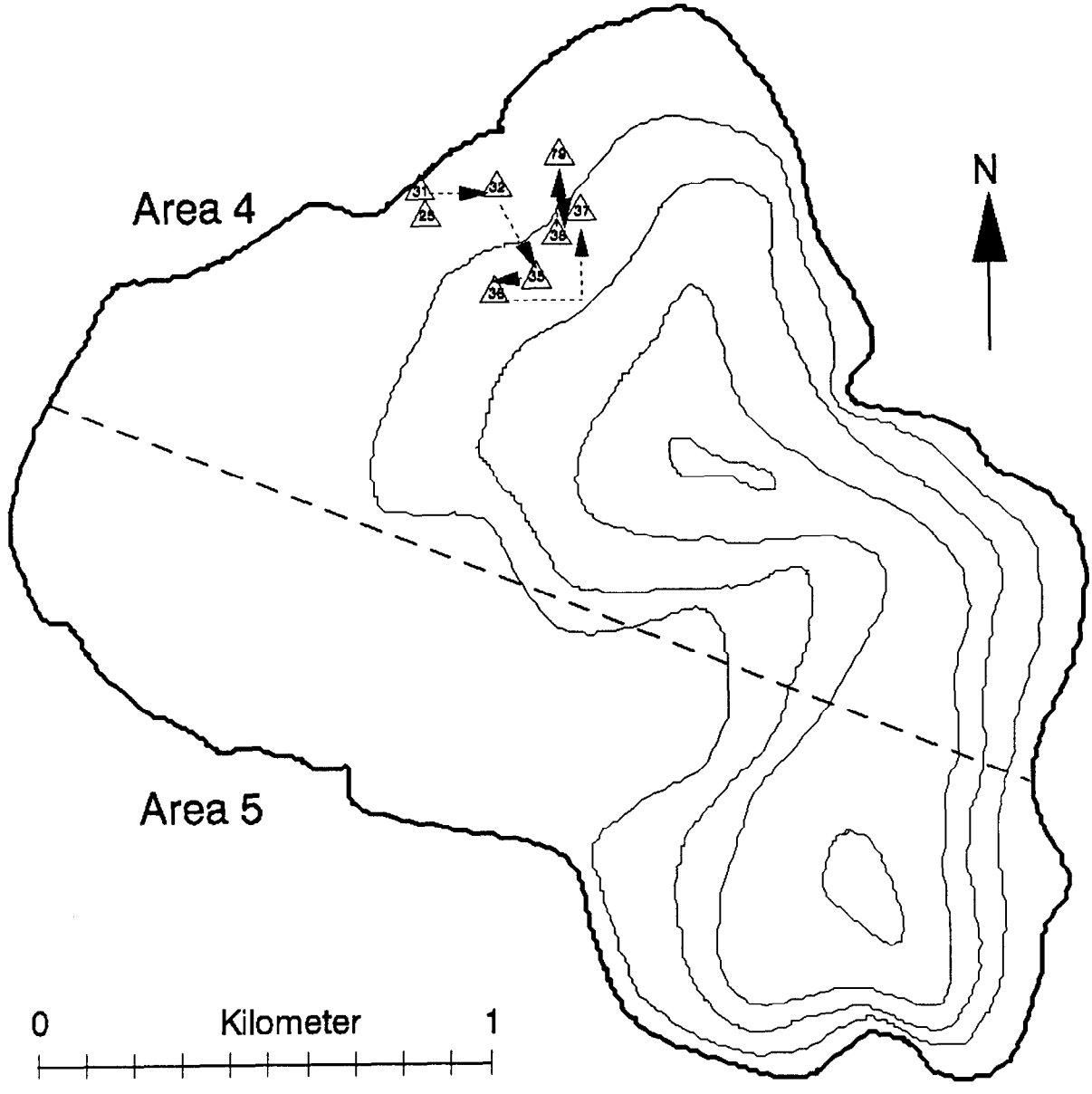
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #9 - 610 mm female released 5/20/91 at 23:00



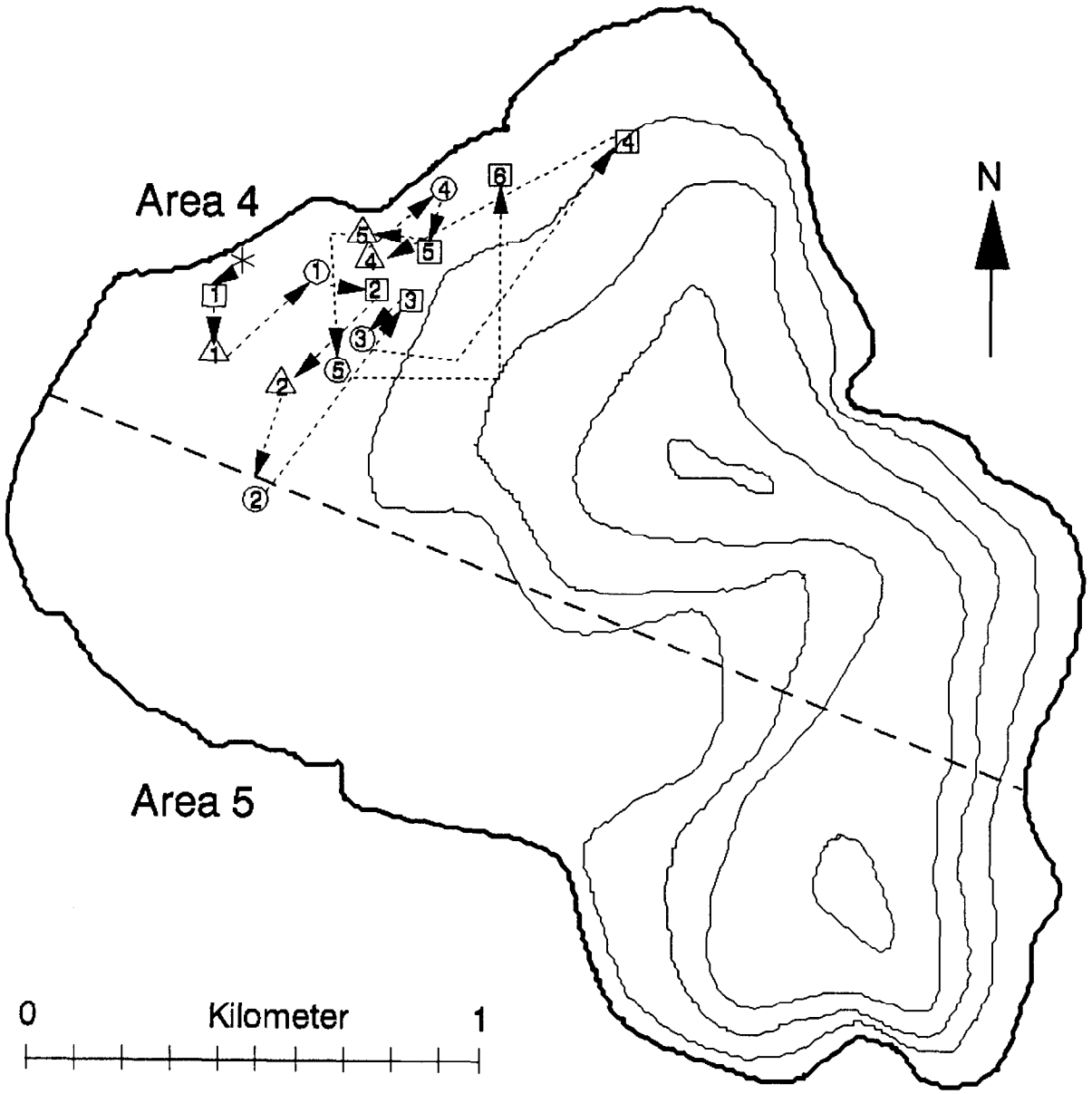
Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

Period 6 - 6/20/91 through 8/5/91.

Appendix A11. Locations of a female northern pike (tag 10a; 918 mm) between 5/20/91 and 5/30/91.

Tag #10a - 918 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

△ Indicates fish was located between 14:00 and 17:00

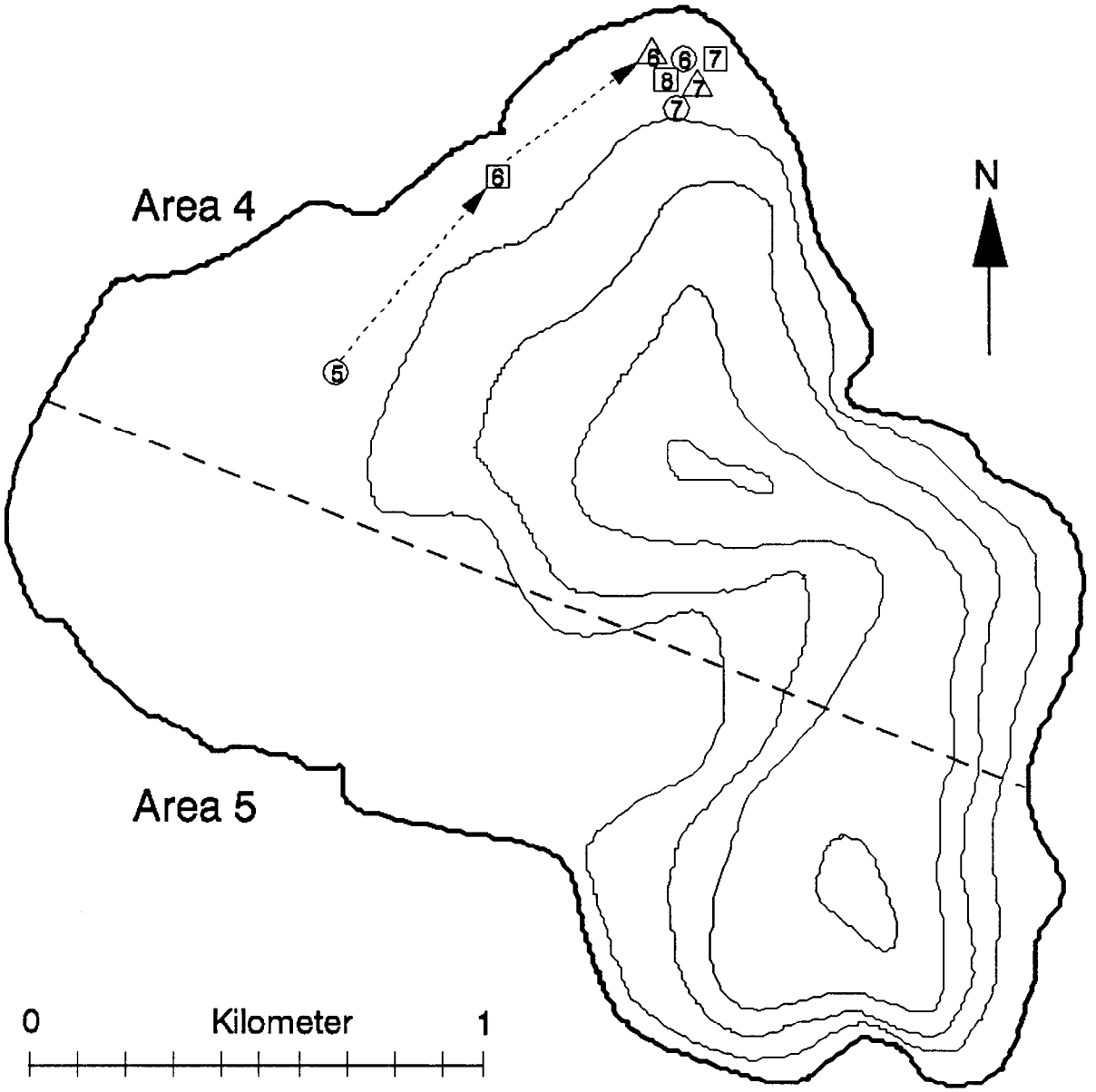
○ Indicates fish was located between 20:00 and 23:00

✳ Indicates location where fish was originally released

Period 1 - 5/20/91 through 5/25/91.

-continued-

Tag #10a - 918 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

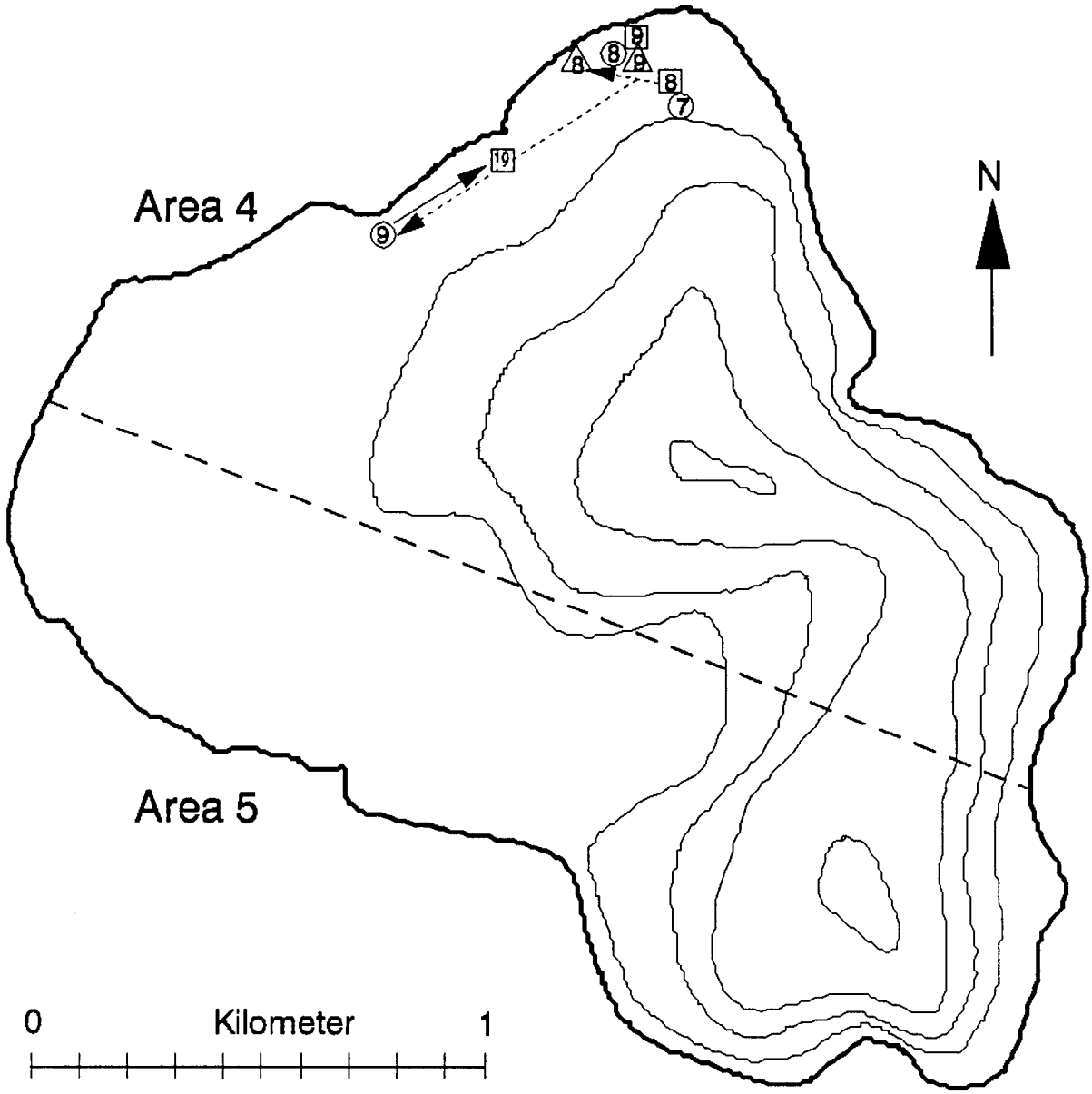
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #10a - 918 mm female released 5/20/91 at 23:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

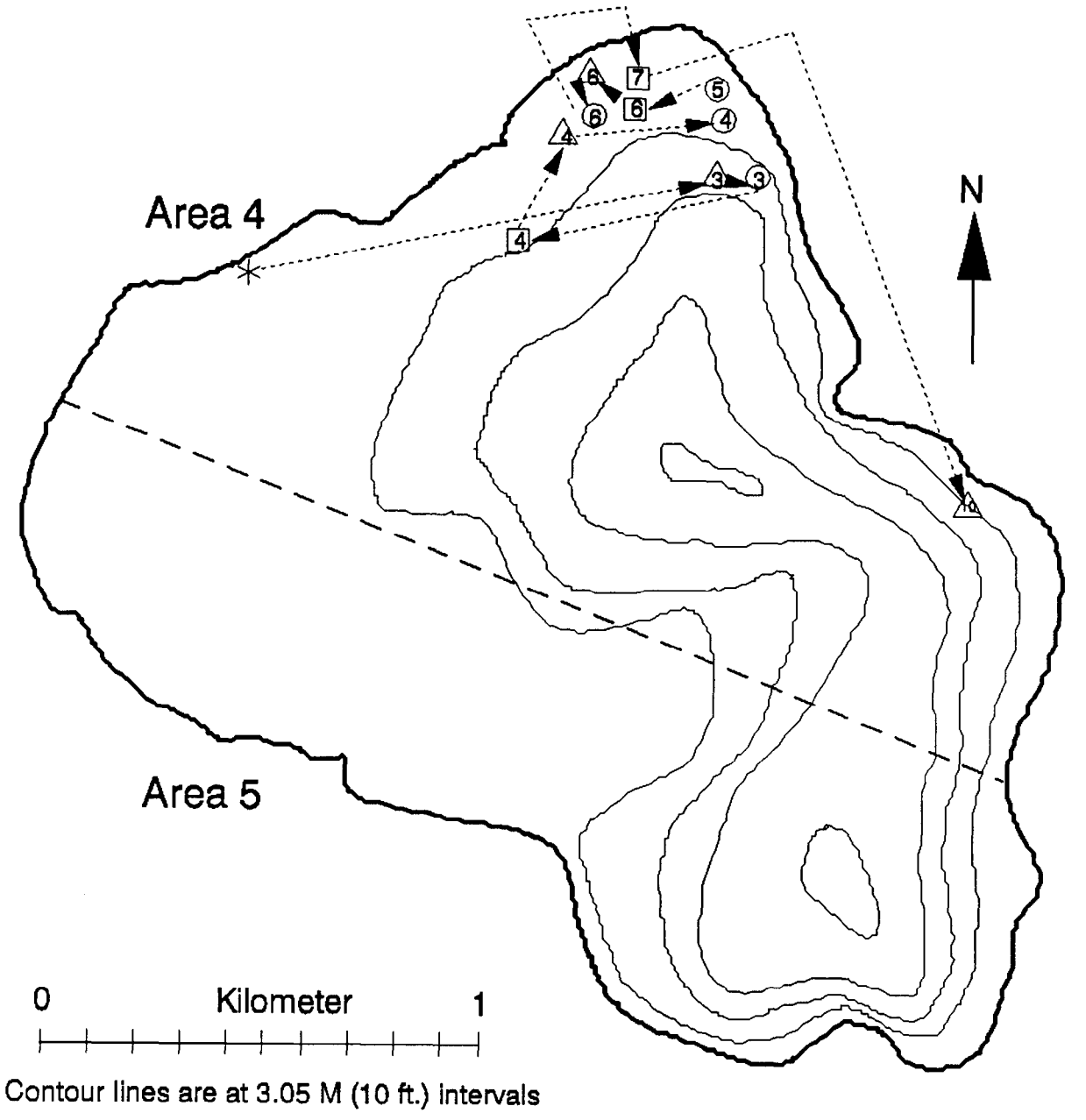
□ Indicates fish was located between 08:00 and 11:00

△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

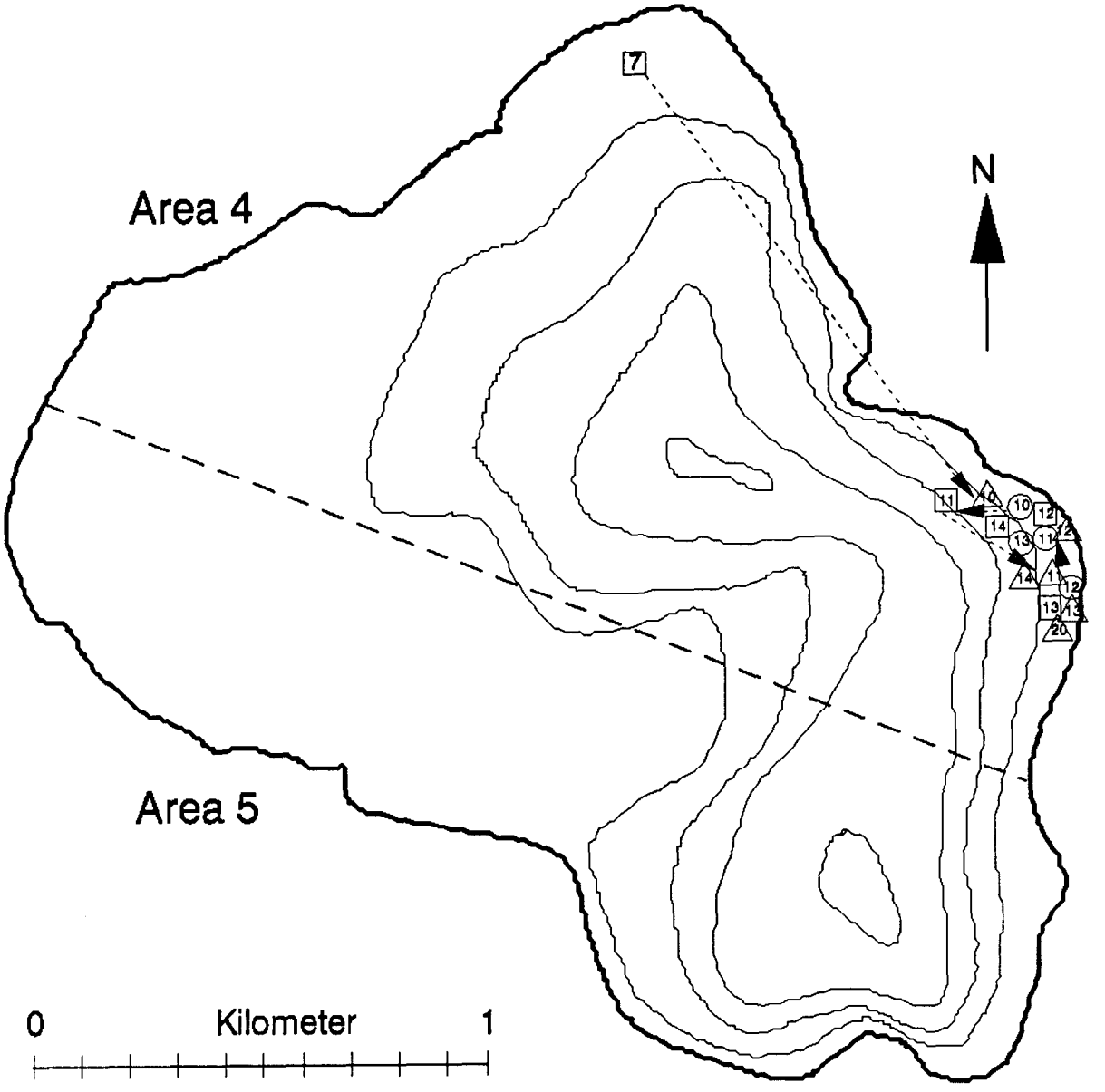
Period 3 - 5/28/91 through 5/30/91.

Appendix A12. Locations of a female northern pike (tag 10b; 859 mm) between 5/31/91 and 6/27/91.



-continued-

Tag #10b - 859 mm female released 5/31/91 at 12:00



Contour lines are at 3.05 M (10 ft.) intervals

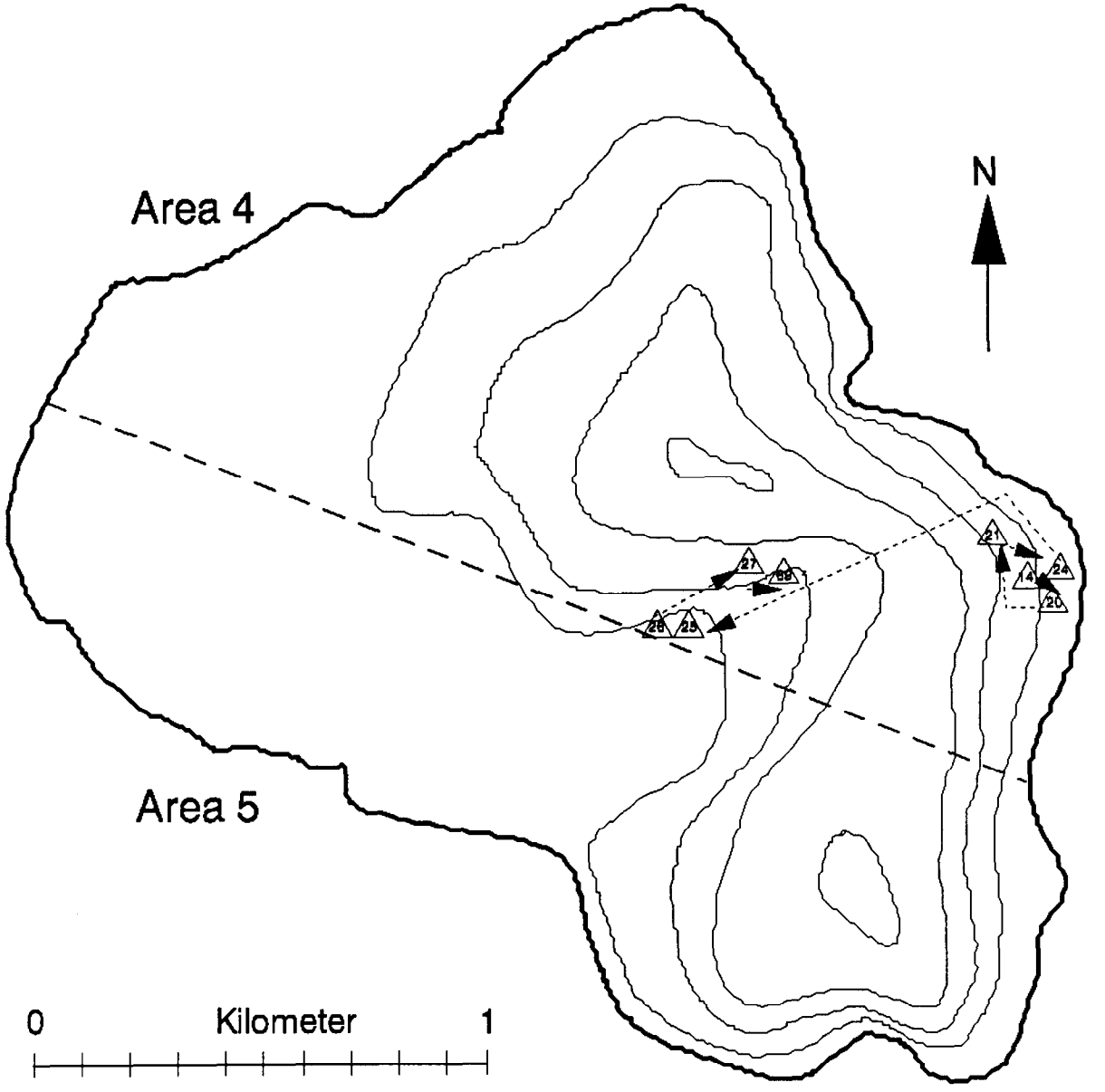
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #10b - 859 mm female released 5/31/91 at 12:00



Contour lines are at 3.05 M (10 ft.) intervals

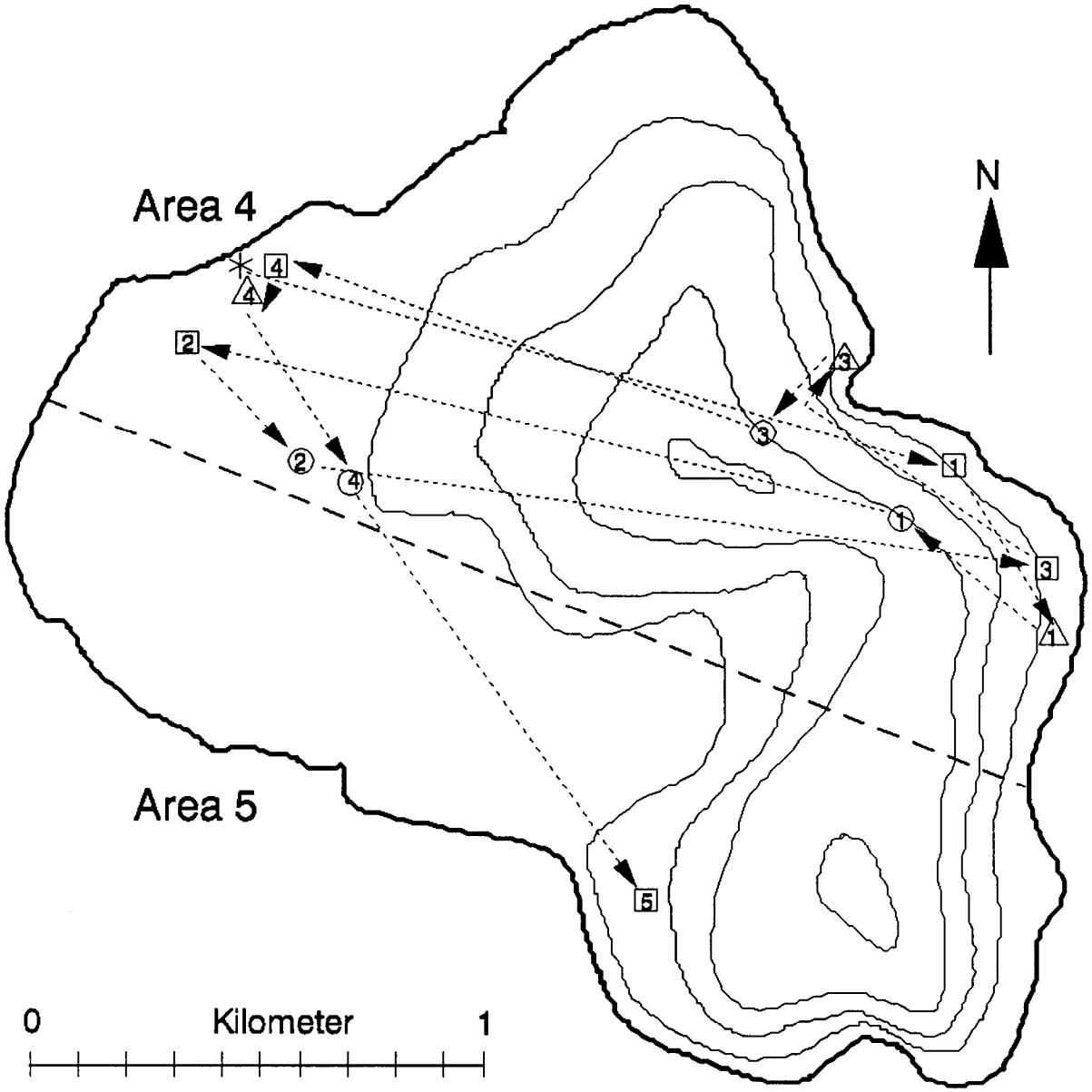
Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

Period 6 - 6/20/91 through 8/5/91.

Appendix A13. Locations of a male northern pike (tag 11; 624 mm) between 5/21/91 and 8/5/91.

Tag #11 - 624 mm male released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

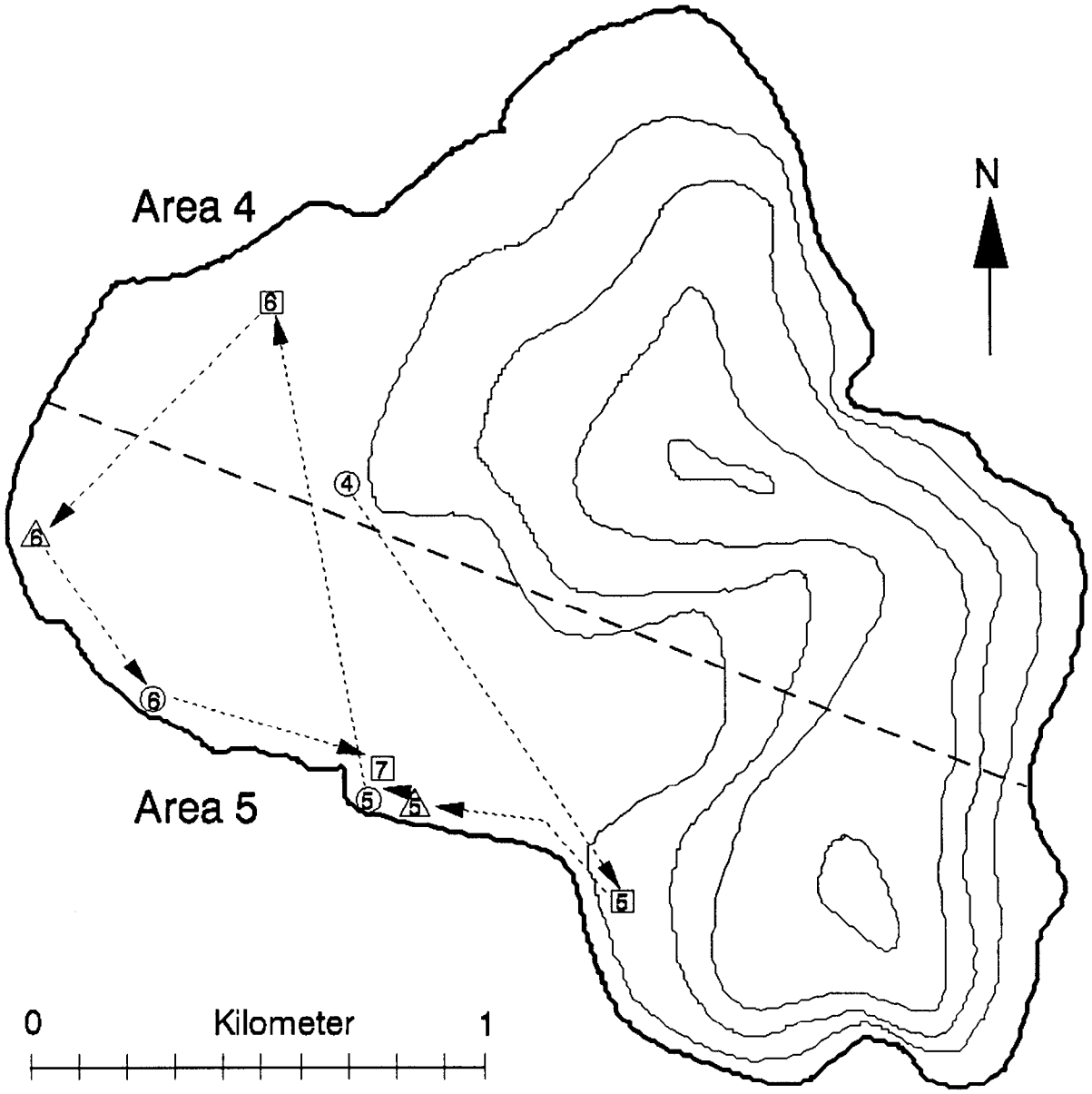
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00
- ✳ Indicates location where fish was originally released

Period 1 - 5/21/91 through 5/25/91.

-continued-

Tag #11 - 624 mm male released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) Intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

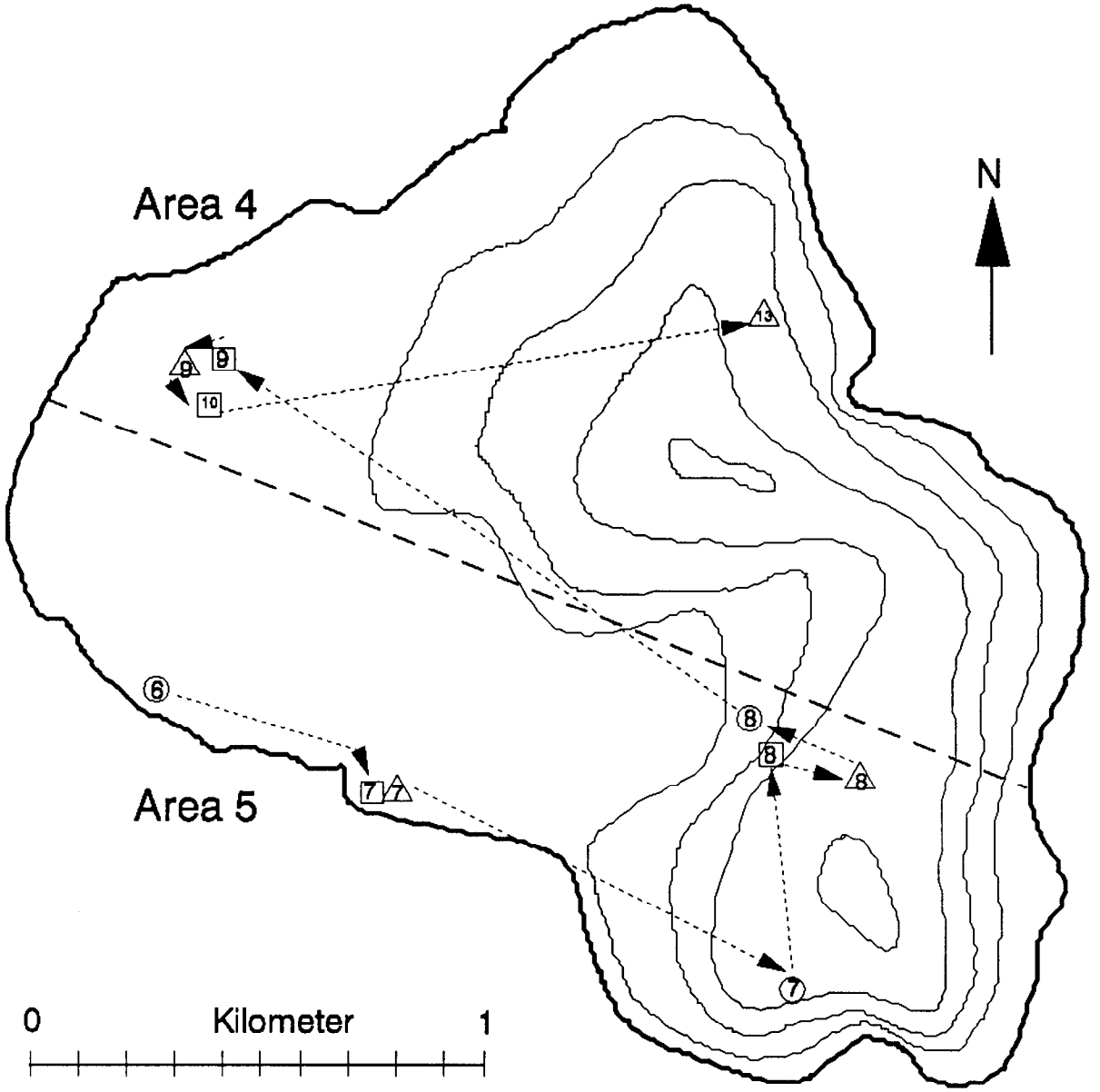
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #11 - 624 mm male released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

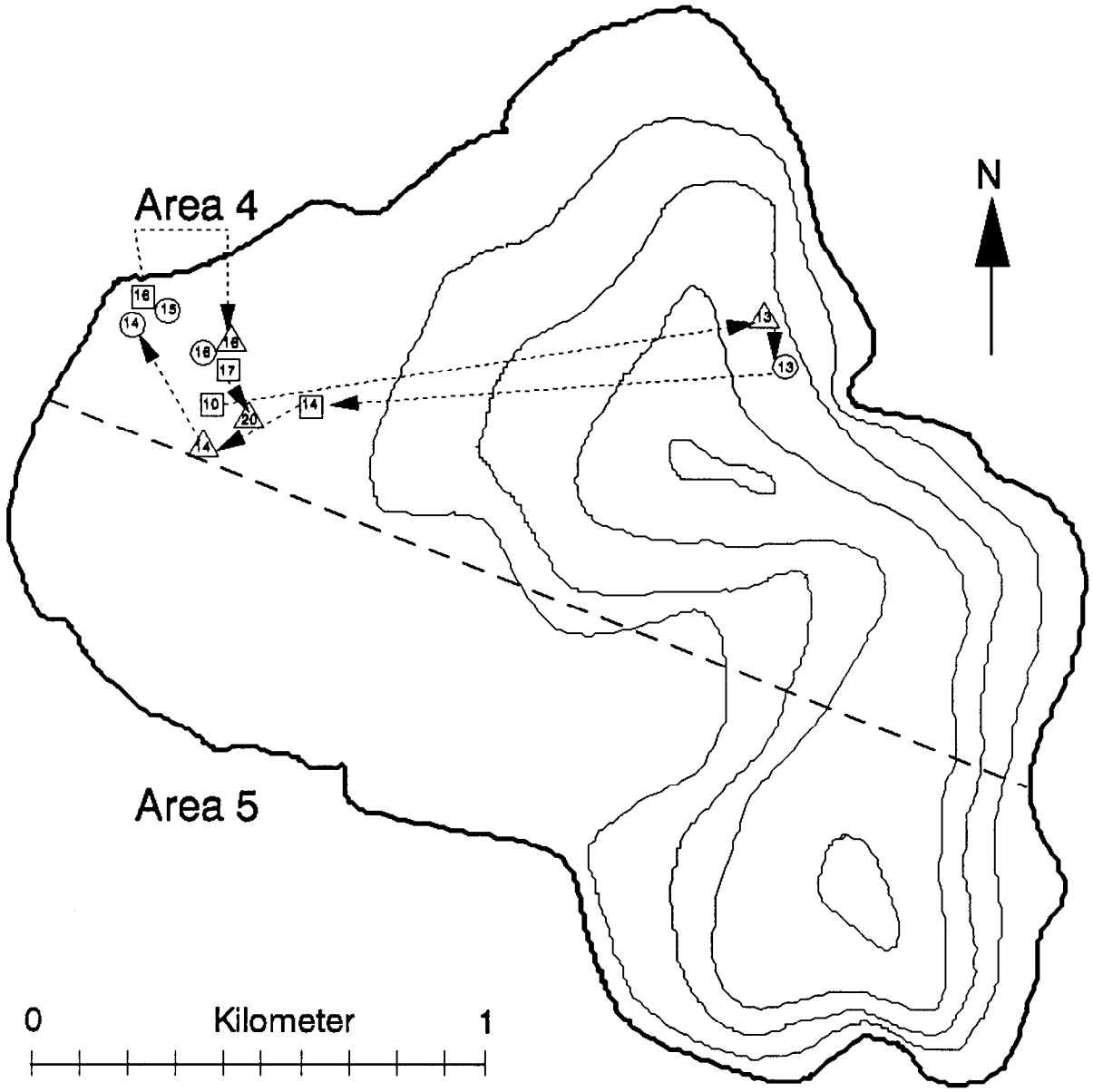
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #11 - 624 mm male released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

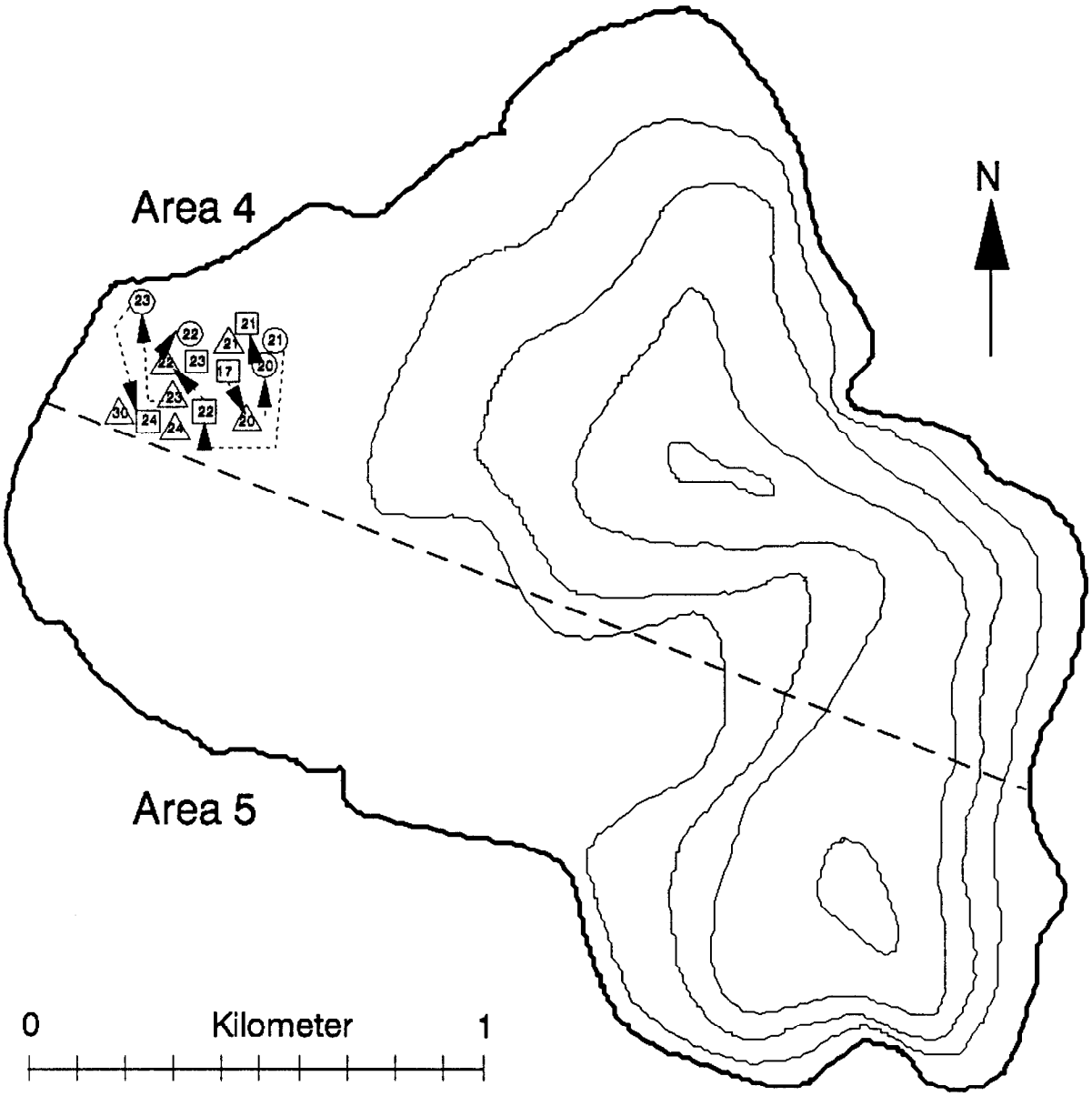
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #11 - 624 mm male released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

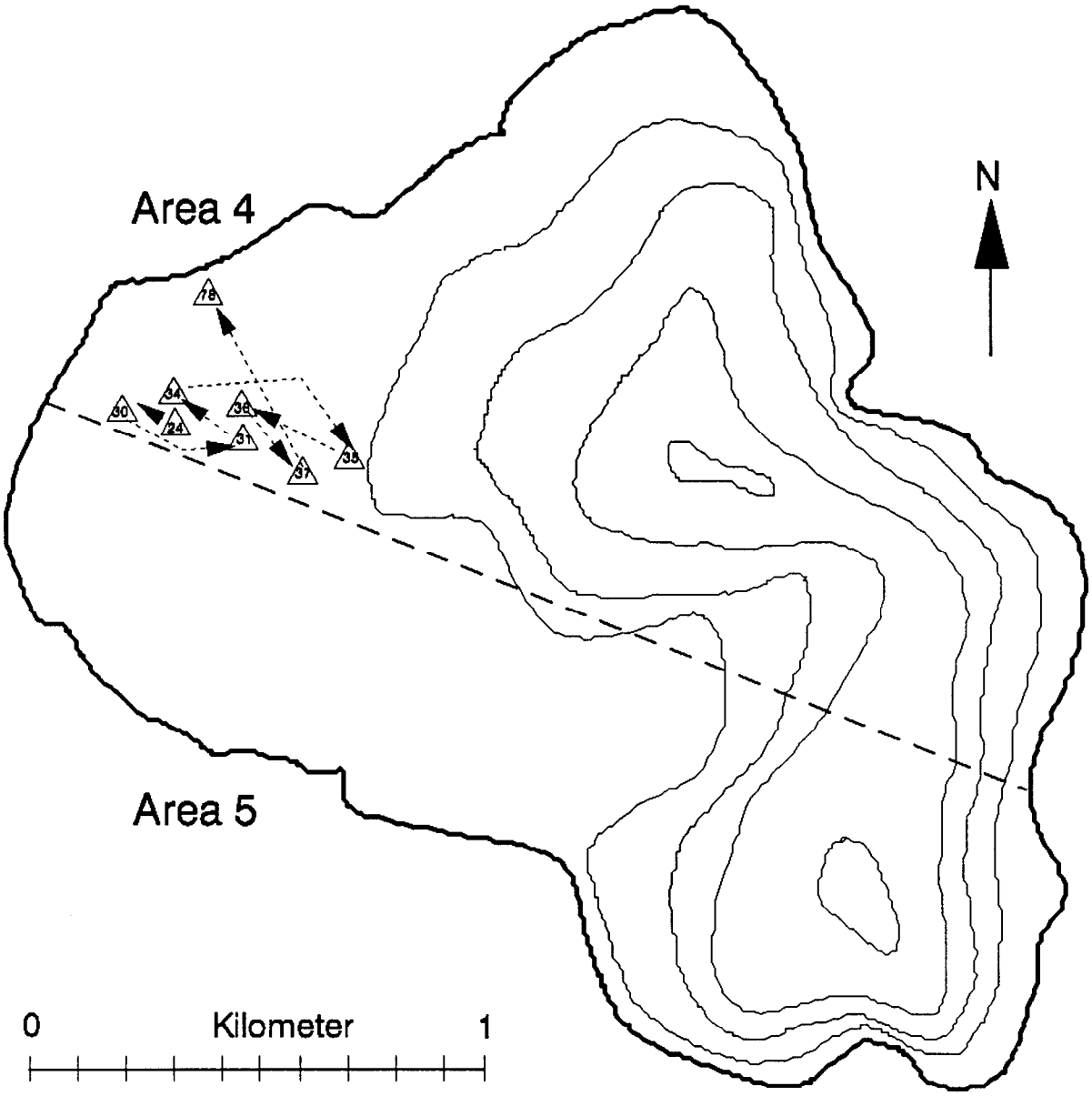
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #11 - 624 mm male released 5/21/91 at 16:00



Contour lines are at 3.05 M (10 ft.) intervals

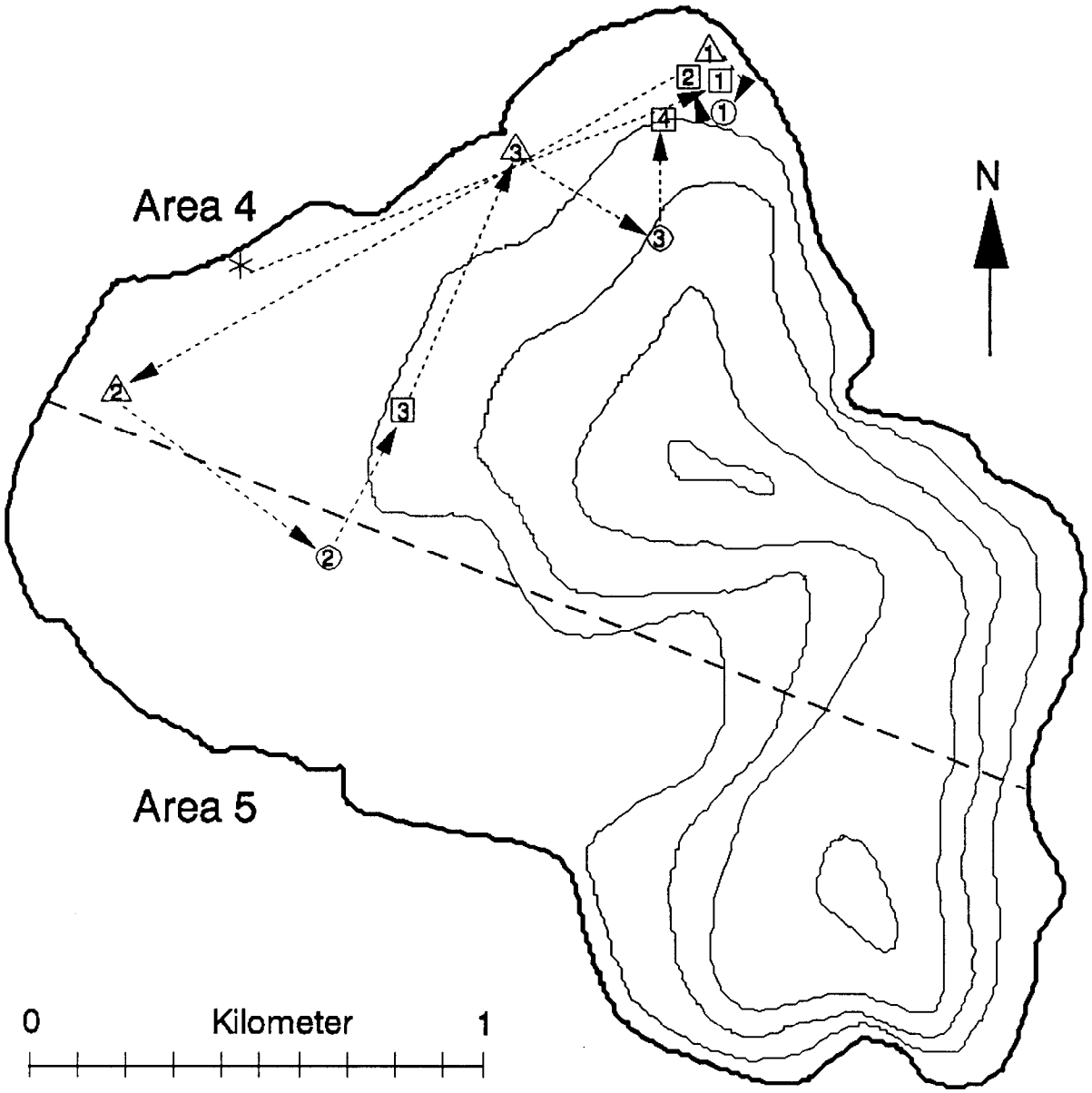
Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

Period 6 - 6/20/91 through 8/5/91.

Appendix A14. Locations of a male northern pike (tag 12; 548 mm) between 5/22/91 and 6/26/91.

Tag #12 - 548 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

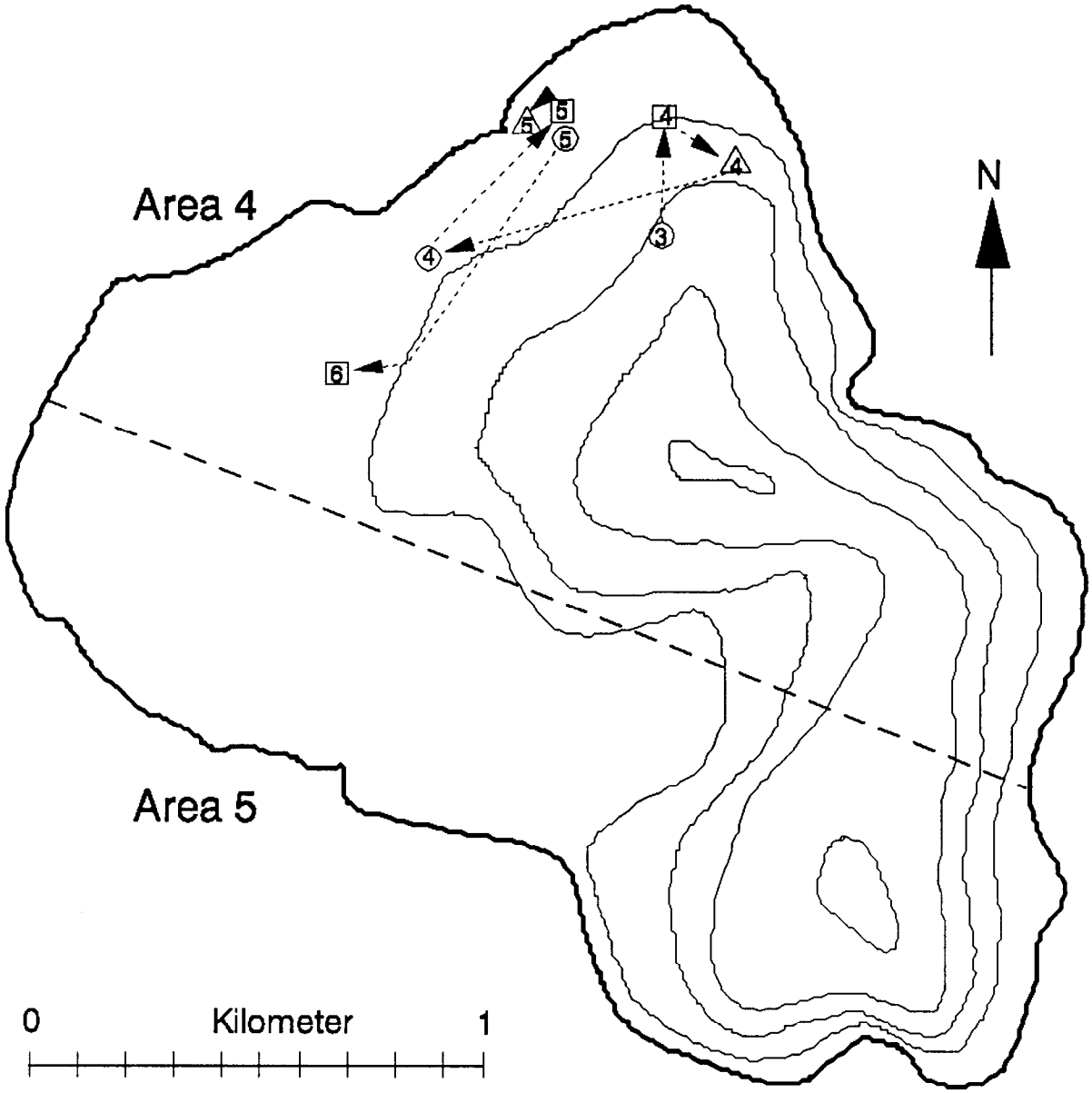
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00
- ✳ Indicates location where fish was originally released

Period 1 - 5/22/91 through 5/25/91.

-continued-

Tag #12 - 548 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

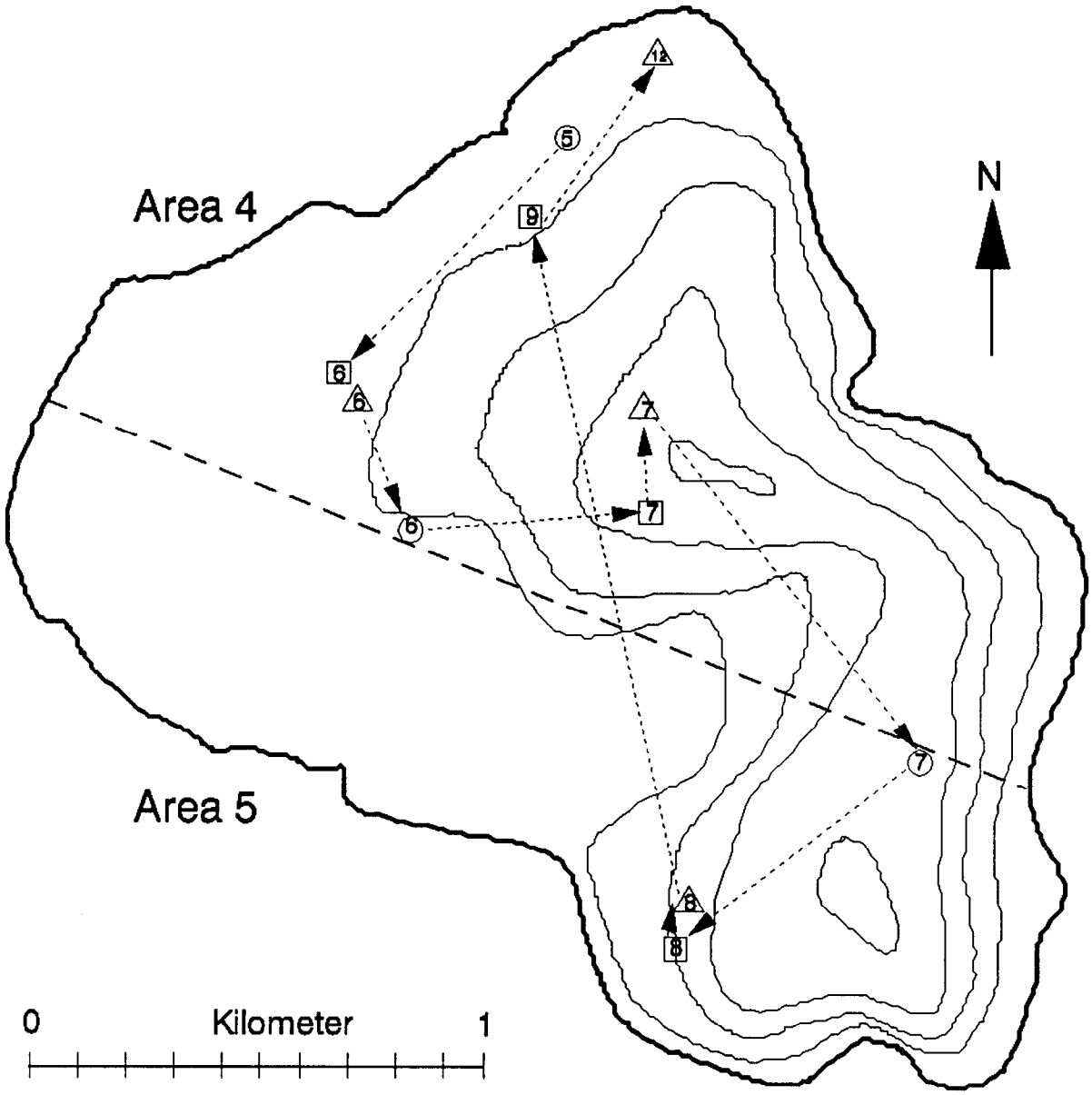
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 2 - 5/26/91 through 5/27/91.

-continued-

Tag #12 - 548 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

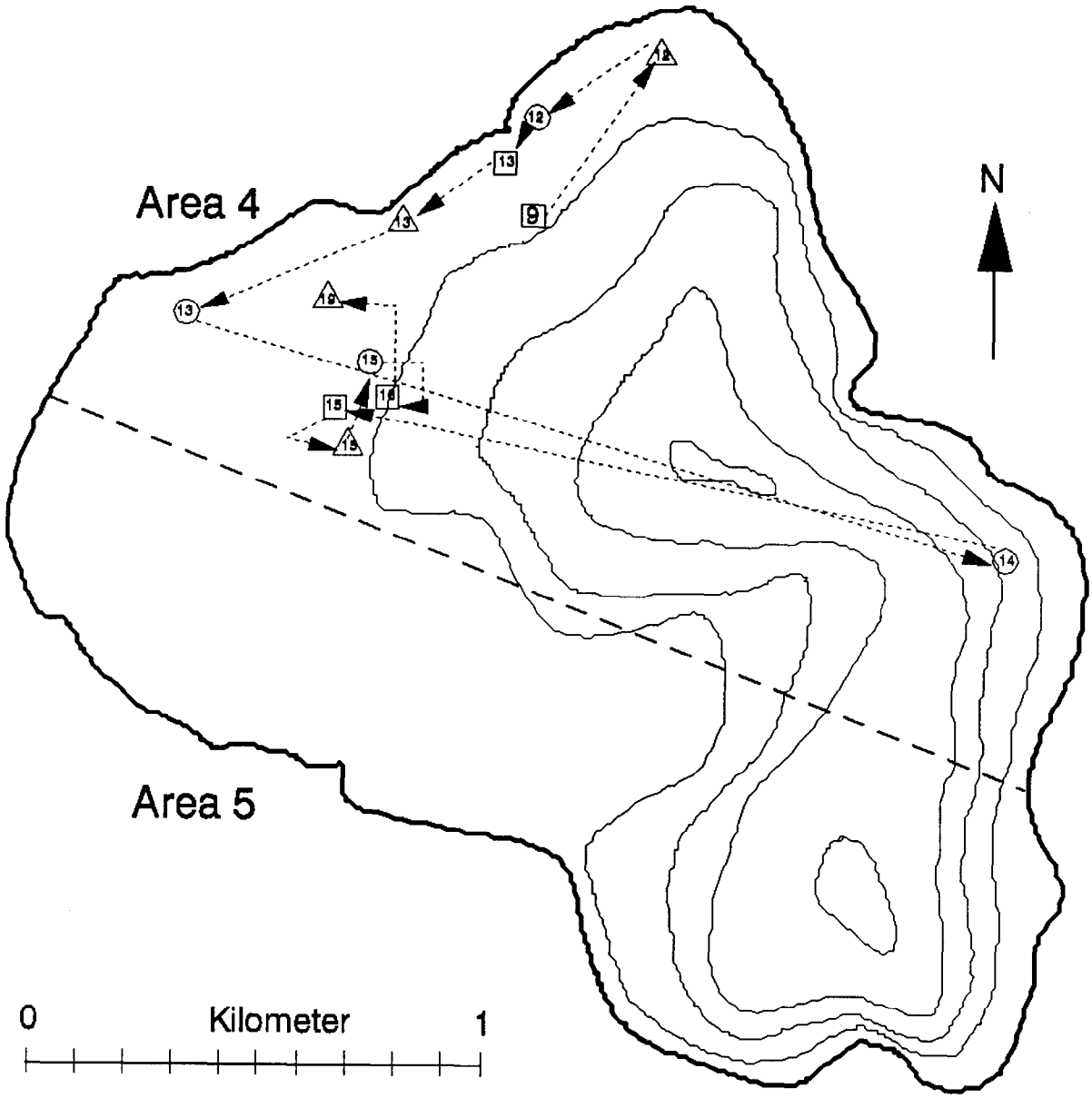
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00

Period 3 - 5/28/91 through 5/31/91.

-continued-

Tag #12 - 548 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

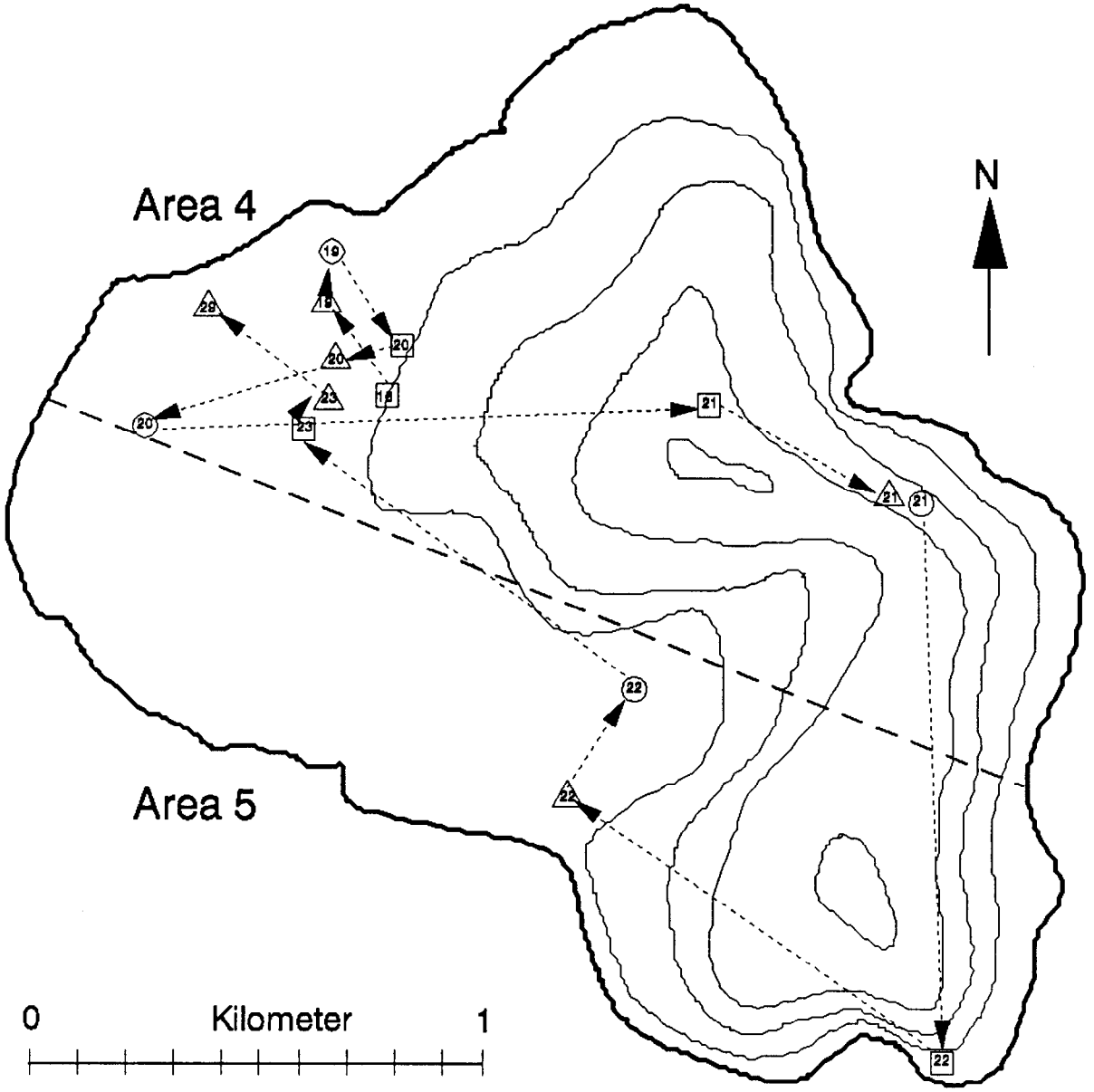
Number in marker is number of days after release

- □ Indicates fish was located between 08:00 and 11:00
- △ Indicates fish was located between 14:00 and 17:00
- ○ Indicates fish was located between 20:00 and 23:00

Period 4 - 6/3/91 through 6/7/91.

-continued-

Tag #12 - 548 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

□ Indicates fish was located between 08:00 and 11:00

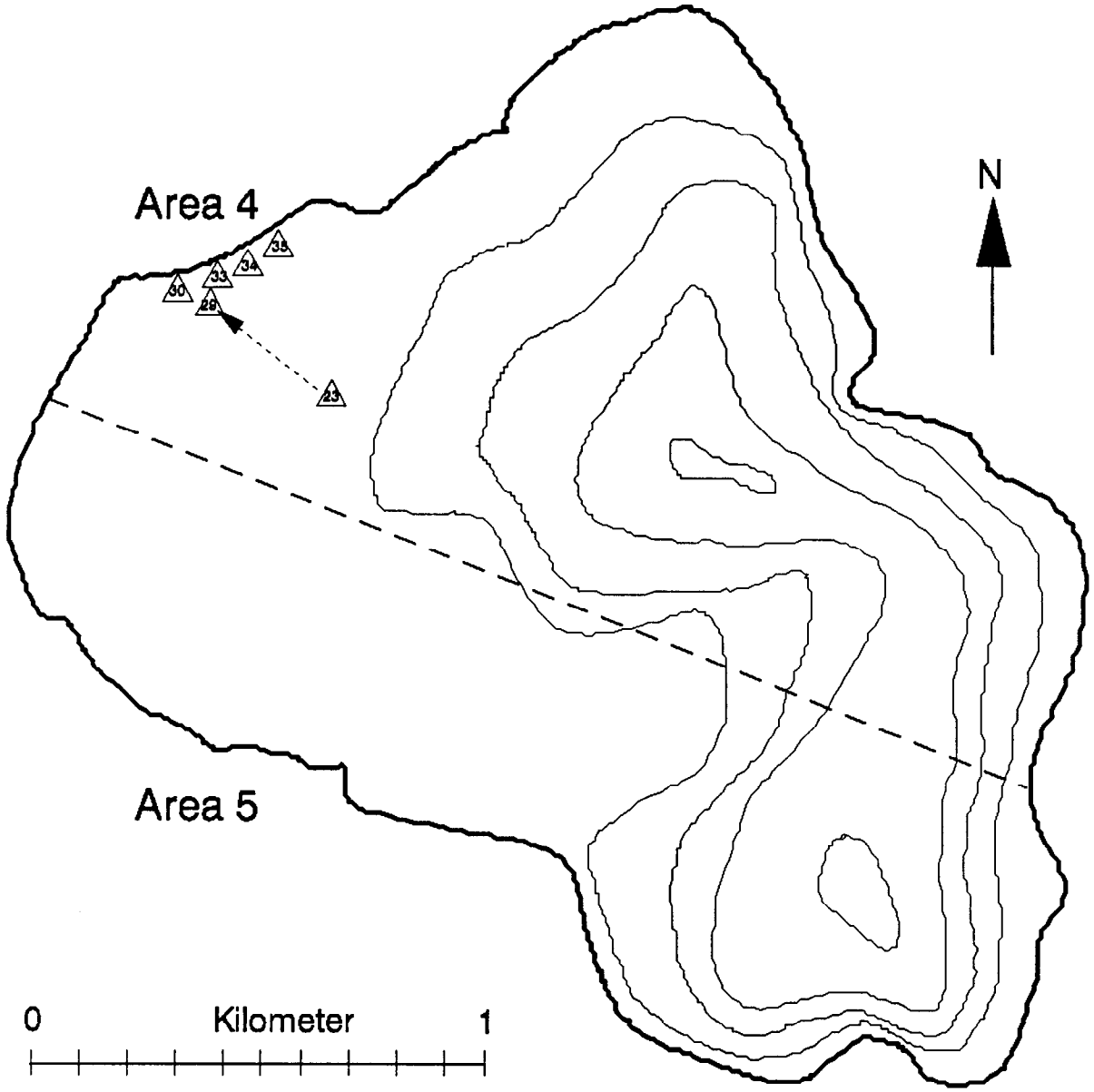
△ Indicates fish was located between 14:00 and 17:00

○ Indicates fish was located between 20:00 and 23:00

Period 5 - 6/10/91 through 6/14/91.

-continued-

Tag #12 - 548 mm male released 5/22/91 at 19:30



Contour lines are at 3.05 M (10 ft.) intervals

Number in marker is number of days after release

△ Indicates fish was located between 14:00 and 17:00

Period 6 - 6/20/91 through 6/26/91.