Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Dispersal of Radio-Tagged Razorback Suckers Released into the Lower Colorado River

August 2007

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Lower Colorado River
Multi-Species Conservation Program

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Lower Colorado River
Multi-Species Conservation Program Office
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Boulder City, Nevada
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SUMMARY

Stocking is a major component of the conservation and management strategy of the highly endangered razorback sucker (*Xyrauchen texanus*). Little information on post-stocking behavior exists of razorback sucker released into the lower Colorado River, and few studies indicate how stocking should be conducted to maximize survival. In this study, dispersal was compared between two groups of fish released in winter-spring 2005 into the lower Colorado River near Blythe, CA.

Twenty-four fish were radio-tagged and released in two groups on February 4, 2005: 12 in a backwater with direct connectivity to the main channel (A-7 backwater) and 12 in a backwater that was connected to the main channel via metal culverts, and often isolated by low water levels (A-10 backwater). Fish were located every two weeks for a 12-week period ending May 7, 2005. Dispersal from A-7 backwater was rapid, with some fish dispersing 10-50 km during the first week post-release. No fish that dispersed from A-7 backwater were found in other backwaters along the Colorado River. Dispersal from A-10 backwater was not detected, and movements within this backwater were less compared to fish movements within A-7 backwater. Water movement within A-7 backwater may mimic natural flushing regimes and discourage fish from remaining near the stocking site. The striking difference in behavior between the two groups of fish suggests there may be a difference in survival between fish stocked at the two locations. Further studies using passive-integrated transponder tags and longer-lasting telemetry tags are suggested to evaluate this differential survival and its potential causes.

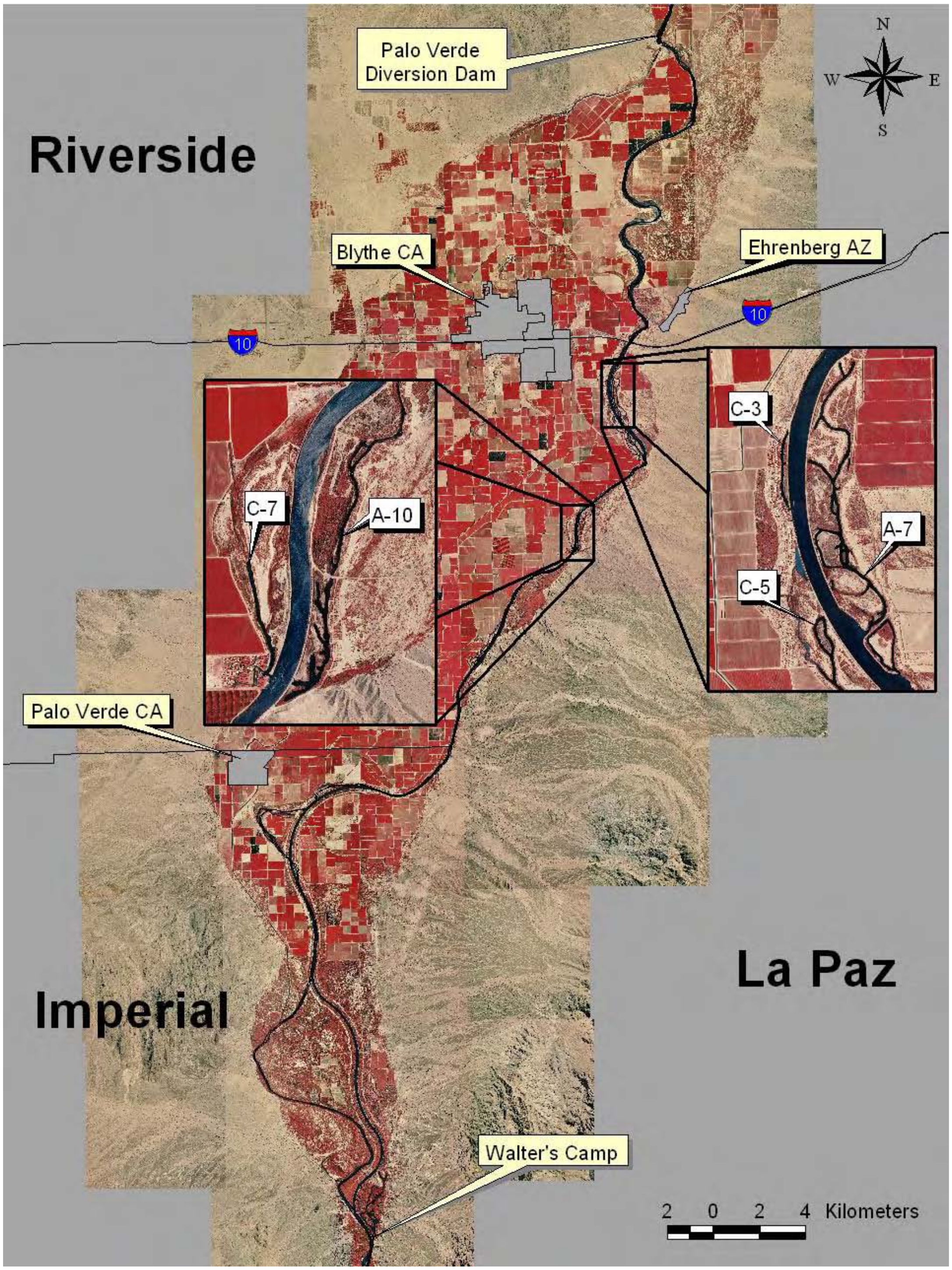
INTRODUCTION

The razorback sucker *Xyrauchen texanus* is a highly endangered Catostomid fish endemic to the Colorado River basin of the western United States. Razorback sucker once ranged throughout the West, from Wyoming to northwestern Mexico (Holden 1980; Minckley et al. 1986). Historical populations of razorback sucker were estimated to be in the hundreds of thousands (Minckley et al. 2003), and the species at one time was plentiful enough to be used for fertilizer along the fields of the Colorado River (Miller 1961). Razorback sucker populations throughout the Colorado River basin declined following the construction of mainstream dams, the large-scale diversion of water, modification of river channels, and the introduction of non-native fishes (Minckley et al. 1991; USFWS 1998).

Razorback sucker populations currently exist only as a small remnant population in the upper Colorado River basin and scattered individuals in the lower basin, except for a population of approximately 2000 wild-plus-repatriated fish in Lake Mohave, a Colorado River impoundment on the Arizona-Nevada border (Marsh et al. 2003; Marsh et al. 2005; Minckley 1983; Minckley et al. 1991). The population in Lake Mohave is declining and is being supplemented by the stocking of wild-born, hatchery-reared fish (Marsh et al. 2003, Mueller 1995). Though razorback suckers spawn in the wild, recruitment is rarely detected (Minckley 1983, Marsh and Minckley 1989). This low recruitment rate is considered the result of overwhelming predation on larvae by introduced fishes (Marsh and Langhorst 1988).

The U.S. Fish and Wildlife Service listed the razorback sucker as endangered in 1991 (56 FR 54957), and a recovery plan was implemented in 1998. The recovery plan emphasizes stocking as a means to circumvent the problem of poor natural recruitment in extant populations and to re-establish populations where they have been extirpated (USFWS 1998). Currently, in the lower basin, razorback sucker larvae, either wild caught or artificially spawned, are reared in hatchery ponds or other grow out facilities to a length of approximately 30 cm and released in a number of locations, including the lower Colorado River near Blythe, CA (Figure 1) (Schooley and Marsh, in press). Specifically, stocking efforts in the lower Colorado River have been focused on A-7 backwater, just downriver of Ehrenberg, AZ. Arizona Game and Fish Department (AZGFD) stocked 47,907 fish ≥ 25 cm into A-7 backwater between March 2000 and June 2005 (Schooley, unpubl. data). Since intensive sampling of the lower Colorado River by the Arizona State University (ASU) Native Fish Lab began in January 2003, through December 31, 2005, 6,385 minutes of electrofishing and 896 trammel net sets have been completed in the main channel and backwaters between Parker Dam and Imperial Dam. The result of this sampling is a remarkably low capture of 516 razorback suckers, the majority of which were captured near their release site within 2 months of release (ASU Native Fish Lab unpublished data). This low capture rate advances questions related to the stocking program in the lower Colorado River. For example, are there any aspects to razorback sucker behavior immediately after stocking that would explain this low capture rate? If the low detection rate is the result of poor survival of stocked fish, would survival increase with the use of a better stocking site?

Figure 1. Study Area. The upstream (northern) boundary is the Palo Verde Diversion Dam, and the downstream (southern) boundary is the confluence of the Colorado River and the Palo Verde Outfall Drain at Walter's Camp. A-7 and A-10 backwaters are shown in the insets.



We hypothesized that fish stocked into A-7 backwater left the study area soon after stocking, either through predation or downstream movement, as has occurred elsewhere (Mueller et al. 2003). We also hypothesized that using a different stocking site could affect survival and dispersal. The A-10 backwater (Figure 1) was chosen as an alternate stocking location because it is deeper, has a steeper bank profile, and is connected to the main channel by a series of 61 cm and 91 cm culverts, which isolate the backwater from the main channel at low flows. It was thought that rapid dispersal of stocked fish would be facilitated by the full access of A-7 backwater to the main channel, whereas stocking fish in a backwater with intermittent connectivity to the main channel (A-10 backwater) would slow this rapid dispersal. Because A-7 backwater is directly open to the main channel, it experiences flushing and filling on a regular basis, and water levels in A-7 backwater mirror those on the main channel. In contrast, A-10 backwater has more stable water levels, because the entire volume must enter or exit through relatively small culverts. This difference in flow dynamics may affect the behavior of a fish species that evolved in an environment where water levels changed frequently. Perhaps the rapidly changing water levels in A-7 trigger a response in razorback suckers whereby they seek deeper water or the main channel. An additional quality of A-10 backwater is that the greater depth and steeper banks could result in fewer losses due to avian predation. We tested the first hypothesis by releasing 12 radio-tagged fish into A-7 backwater and tracking them during February-May 2005. We tested the second hypothesis by using a “control” group of 12 radio tagged fish stocked into the upper section of A-10 backwater and comparing their movements to the fish stocked into A-7 backwater.

METHODS

Study Area--Boundaries of the study area were the Colorado River main channel and all backwaters between Palo Verde Diversion Dam and the confluence of the Colorado River with Palo Verde Outfall Drain 72.8 km downstream at Walter's Camp (Figure 1). Significant backwaters included CA-124 backwater (on the California side of the river 2 km upstream of the I-10 bridge), C-3 backwater, A-7 backwater (this backwater is separated by a levee into a larger upstream area and a smaller downstream area), C-5 backwater, A-10 backwater, C-7 backwater, Sandy Cove, and the Palo Verde Outfall Drain. Daily mean discharges from Palo Verde Diversion Dam ranged from 2,000 cfs in February to 11,000 cfs in April and May. Discharges fluctuated hourly, with flows occasionally changing by as much as 9,000 cfs during a 24-h period. Main channel depth averaged 2-3 m with numerous sand bars (up to 1 m deep during high discharges, exposed during low discharges) and a few deep (5-6 m) holes. Most backwaters were dredged and averaged 3 m deep. Bottom substrate throughout most of the study area was silty-sand with some areas of fine to medium cobble, while bankline substrate was typically riprap. During the first half of the study, water clarity was poor, with visibility about 0.25 m. Water later cleared and visibility was about 1 m. Riparian vegetation was sparse and characterized by tamarisk (*Tamarisk* spp.), mesquite (*Prosopis* spp.), and saltbush (*Atriplex* spp.). Backwaters often had emergent stands of tule (*Scirpus* spp.) and cattail (*Typha* spp.), but submergent vegetation such as *Najas* and *Potamogeton* was sparse-to-absent among backwaters during the study. Electrical conductivity of water in the main channel and most backwaters averaged approximately 1200 µS/cm while water in Palo Verde Outfall Drain averaged about 2400 µS/cm (this high conductivity limited radio-tag detection there). Water temperatures ranged from 16º C during February to 21º C during early May, with a daily fluctuation of 1-2º C.

Two backwaters of particular interest are A-7 and A-10 backwaters. A-7 backwater is located at RM 114, La Paz Co., AZ and was designated as the primary stocking site for razorback suckers released into the lower Colorado River below Parker Dam. This backwater is approximately 17 ha with braided channels of varying depths. It is directly open to the main channel at its downstream end and connected by a culvert at its upstream end. Bank profiles are gradual with numerous exposed sandy beaches and shallow pools that are occasionally isolated during periods of low water. Shore habitat and cover, in the form of emergent vegetation and woody debris, are exposed by low river levels. These characteristics may contribute to increased levels of bird and fish predation of recently stocked razorback suckers.

A-10 backwater, located approximately 8 km downstream of A-7 backwater, is a potentially more suitable site for stocking razorback suckers. This backwater is approximately 8 ha and fairly linear except for one island and three small coves. Depth is relatively uniform at 3 m during normal river flows and shallow areas are restricted to isolated, dead end coves. It is connected to the river at the upstream and downstream ends by 61 cm and 91 cm culverts, respectively. A road also bisects A-10 backwater and a 61 cm culvert joins the upper and lower ends. Bank profiles are steeper compared to A-7 backwater and emergent vegetation covers most of the shoreline. Because there is no direct connectivity to the main channel (the connection being via culverts), A-10 backwater is isolated from the main channel during extended low flow periods. During the study, it appeared that it took discharges of approximately 7,000 cfs to raise the river level enough to maintain a connection between A-10 backwater and the main channel. That did not occur until the first week of March 2005, and after that time the A-10 backwater was frequently isolated for several hours at a time while discharges were low. The isolated nature of this backwater would presumably allow fish an acclimation period before they entered the main channel.

Telemetry--All fish were tagged with externally-mounted radio tags (ATS, Inc., Isanti MN; model F-2020). Transmitters each emitted a unique frequency in the 40-41 MHz range, weighed 8.6 g in water, were cylindrical in shape with dimensions of 12 x 39 mm, had trailing whip antennae 24-cm long and had a nominal life expectancy of 80-d. Detection range varied with depth and water conductivity, from 50 m in shallow (1-2 m) water to 0 m in water >5m deep. On February 4, 2005, transmitters were externally attached (Mueller et al. 2003) after fish were anesthetized in a solution of 125 mg/L tricaine methane sulfonate. Tagged fish were acquired from Arizona Game and Fish Department's Bubbling Ponds State Fish Hatchery. Tagged fish total length (TL) averaged 395 mm (range: 371-436 mm). Twelve radio-tagged fish were released within cohorts of 500 untagged razorback suckers into both A-7 and A-10 backwaters on February 4, 2005. Tracking began immediately and continued through May 7, 2005. We attempted to find each fish at least once every other week by thoroughly covering the main channel and all backwaters while listening for radio signals with a scanning receiver (ATS model R2100) and omni-directional antenna. When a signal was detected, a precise location was obtained by homing in on the signal with a hand-held, octagonal directional antenna. Locations were recorded with a global positioning system receiver (Garmin GPS 12). As an additional aid to monitor fish movements, two fixed listening stations were constructed. One was located at the entrance to C-7 backwater and the other near a bridge 22 km upstream of the lower boundary of the study area. These listening stations consisted of an octagonal directional antenna, an ATS model R2100 receiver, and an ATS Data Collection Computer. All fish locations were imported into a geographic information system (ArcView, Redlands, CA) and overlaid on a digital ortho quarter quad coverage of the study area for analysis using the extension Animal Movement Analysis Version 2.0 (Hooge et al. 1999).

RESULTS AND DISCUSSION

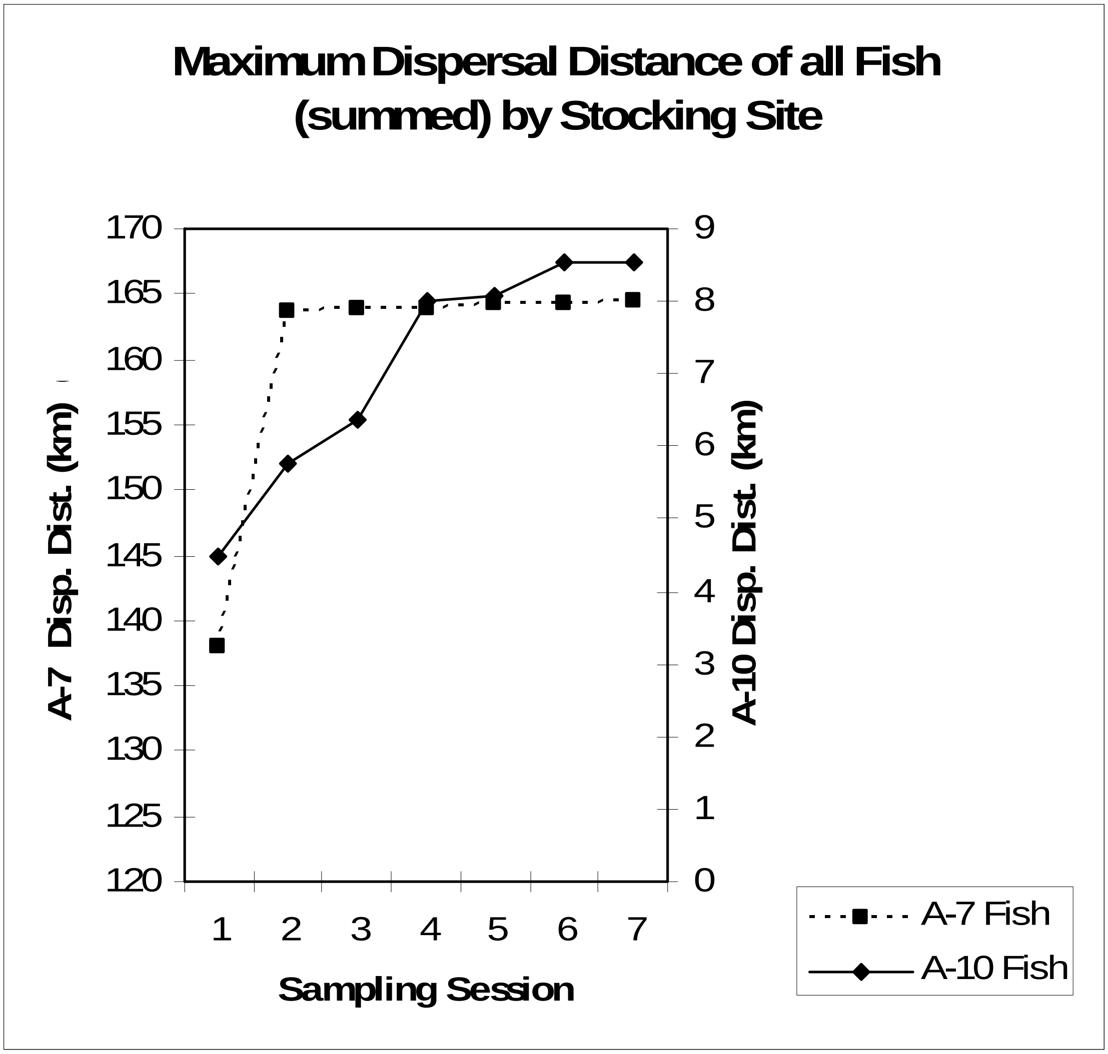
One hundred ninety three locations were obtained on 24 razorback suckers. Nine of 12 fish left A-7 backwater, all within 7 d of the release date. One fish moved upstream, seven fish moved downstream, and one fish was lost after it (presumably) left A-7 backwater. Eight fish were tracked throughout most of the study (Table 1). Three fish likely dispersed well downstream of the study area soon after release and were not again contacted, and a fourth was lost by day 54. A SCUBA-equipped diver determined that two fish lost their tags, most likely through mortality. The remaining six fish dispersed varying distances and maintained fidelity to a particular site. The greatest amount of movement occurred during the first 2 weeks after release (Figure 2). All 12 of the fish released into A-10 were located there through day 58 of the study. By day 72 of the study, four fish were missing and not found anywhere in the study area.

Table 1. Dispersal distances (km) from stocking site. For each fish, the distance found from the stocking site during each sampling session is shown. The maximum distance is reported, i.e., if a fish was found closer to the stocking location in subsequent sessions the previous, maximum distance is retained in the table. Distances in regular text indicate lost fish, distances in bold italics represent censored fish (tags from which a signal was detected but was later determined to have been separated from the fish) and distances in regular italics represent missing observations (fish were not found during that sampling session).

ID	**Session 1** 2/4-2/12	**Session 2** 2/21-2/25	**Session 3** 3/7-3/11	**Session 4** 3/21-3/25	**Session 5** 4/2-4/6	**Session 6** 4/18-4/22	**Session 7** 5/3-5/7	**Notes***
A-7 Backwater								
11	**35.4**	**54.4**	**54.4**	**54.4**	**54.4**	**54.4**	**54.4**	
21	**3.2**	**3.2**	**3.2**	**3.2**	***3.2***	***3.2***	***3.2***	1
31	**5.5**	5.5	5.5	5.5	5.5	5.5	5.5	2
41	**6.1**	**6.4**	**6.5**	**6.5**	**6.5**	**6.5**	**6.7**	
51	**3.2**	**3.2**	***3.2***	***3.2***	***3.2***	***3.2***	***3.2***	1
61	**54.9**	**54.9**	**54.9**	**54.9**	**54.9**	**54.9**	**54.9**	
71	**3.3**	**3.4**	***3.4***	***3.4***	***3.4***	***3.4***	***3.4***	1
81	**1.7**	1.7	1.7	1.7	1.7	1.7	1.7	2
91	**17.6**	17.6	17.6	17.6	17.6	17.6	17.6	2
101	**3.7**	**3.7**	**3.8**	3.8	3.8	3.8	3.8	2
111	**0.29**	**6.6**	*6.6*	*6.6*	**6.9**	**6.9**	**7**	
121	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**	
Sum	**137.99**	**163.7**	**163.9**	**163.9**	**164.2**	**164.2**	**164.5**	
A-10 Backwater								
141	**0.16**	**0.32**	**0.32**	**0.65**	**0.65**	**0.65**	**0.65**	
151	**0.57**	**0.57**	**0.90**	**0.90**	**0.90**	0.90	0.90	2
601	**0.85**	**0.90**	**0.90**	**0.90**	**0.90**	0.90	0.90	2
611	**0.30**	**0.60**	**0.60**	**0.60**	**0.60**	**0.60**	**0.60**	
621	**0.16**	**0.21**	**0.23**	**0.23**	**0.23**	**0.23**	**0.23**	
631	**0.18**	**0.46**	**0.46**	**0.87**	**0.87**	**1.03**	**1.03**	
641	**0.15**	**0.30**	**0.42**	**0.42**	**0.42**	0.42	0.42	2
651	**1.00**	**1.00**	**1.00**	***1.00***	***1.00***	***1.00***	***1.00***	1
661	**0.17**	**0.48**	***0.48***	***0.48***	***0.48***	***0.48***	***0.48***	3
671	**0.63**	**0.63**	**0.63**	**0.63**	**0.69**	**1.00**	1.00	2
681	**0.16**	**0.16**	**0.28**	**0.72**	**0.72**	0.72	0.72	2
691	**0.15**	**0.15**	**0.15**	**0.61**	**0.61**	**0.61**	**0.61**	
Sum	**4.48**	**5.78**	**6.37**	**8.01**	**8.07**	**8.54**	**8.54**	

*Notes: 1 = died or lost tag, 2= lost, 3= tag detached

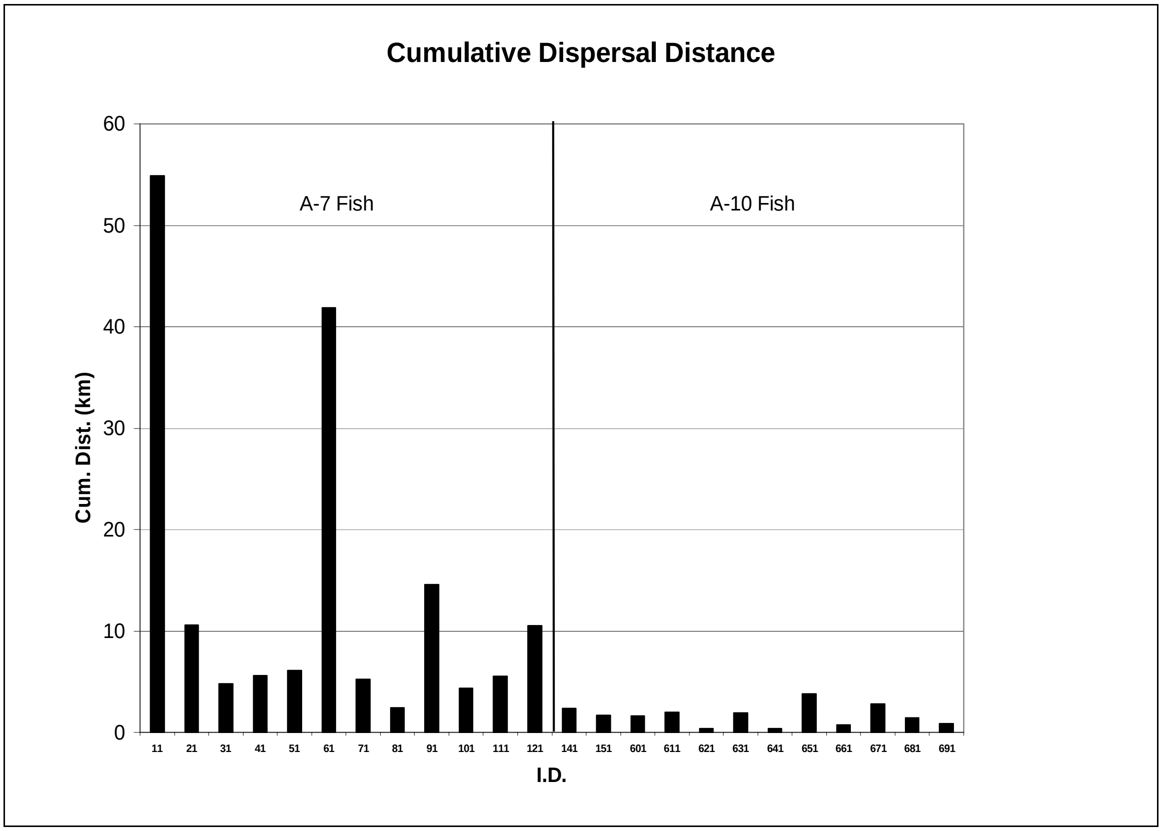
Figure 2. Maximum Dispersal Distance of all Fish (Summed) by Stocking Site. For each sampling session, the distance from the stocking site for each group of fish (A-7 vs. A-10) is plotted. Maximum dispersal distance as defined in Table 1 is reported. Dates for each sampling session are provided in Table 1.



Another fish was censored (removed from the study because the tag fell out when it was caught in a trammel net) on day 17 of the study. A sixth fish was lost on day 86 of the study. Whether the missing fish actually left A-10 backwater, the fish died, or their tags were lost is a matter of speculation. The main channel and adjacent backwaters downstream and upstream of A-10 backwater were searched thoroughly for these fish, but it is still possible that they rapidly dispersed downstream of the study area. It is just as likely, though, that the fish died or lost their tags and the tags, lying on the bottom of A-10 backwater, were too deep for a signal to be detected at the surface.

Distances dispersed were significantly shorter for A-10 fish than A-7 fish ($\alpha<0.001$, Mann-Whitney statistic=144, Wilcoxon two-sample statistic=144). This is because A-10 backwater fish never left that backwater, which likely was due to the small connection between the upper and lower parts of A-10 backwater and the intermittent connectivity of A-10 backwater to the main channel. However, even fish that never left A-7 backwater ranged farther than A-10 fish (Figure 3). This may be due to the presence of some stimulus in A-7 backwater that was absent in A-10 backwater, for example, water movement, selected predators, thermal mixing, habitat complexity, disturbance, or water level change. Or, this observation may simply reflect the fact that A-7 is physically larger (17 ha) than A-10 (8 ha), and fish thus had more space to move around in the larger site. Some generalities of fish behavior were observed. Interestingly, of all of the fish that dispersed from the A-7 backwater, none were found in backwater habitats, that is, out of 12 fish, three of them established home ranges (home range is defined as the area that a fish traverses during its normal activities) within the A-7 backwater, one was located once within A-7 and then never again, and eight were located outside A-7 in the main channel, but not within any other backwaters.

Figure 3. Cumulative Distances Following Release. Distances between successive locations were summed over the duration of the study. Distances recorded are straight-line between successive observations and do not account for sinuosity of fish movements or river/backwater channel. Distances for A-7 fish (IDs 11-121) were substantially greater than for A-10 fish (IDs 141-691). Even fish that never left the A-7 backwater (21, 51, and 121) ranged farther than all of the A-10 fish.



Several fish were detected near entrances to backwaters C-5 and C-7, but did not establish home ranges there. This observation has obvious implication for future studies on razorback sucker in the lower Colorado River. For example, if many of the stocked razorback suckers are selecting main channel habitats, they will be difficult to detect, especially if sampling efforts are focused on backwater areas, and both post-stocking abundance and survival will be underestimated.

Another interesting observation is that fish dispersed rapidly from A-7 backwater and slowly, or not at all, from A-10. Post-stocking mortality could be elevated due to exposure of naïve fish to numerous predators such as flathead catfish (*Pylodictis olivaris*) and striped bass (*Morone saxatilis*), which are know to occupy the main channel. Additionally, apparent mortality of fish could be the result of fish “lost” from the study area by rapid downstream travel before they acclimate to life in strong currents. Conversely, fish that disperse slowly from a backwater like A-10 might reap the benefits of a soft release (Bright and Morris 1994) -a release in which translocated or reintroduced animals are given an opportunity to acclimate to the area in which they are released. These benefits might not mean a larger population of razorback suckers in the lower Colorado River if fish do not disperse at all from A-10 backwater, however. A follow-up study with long-life sonar tags and/or large numbers of fish tagged with passive integrated transponders (PIT) would give more useful information on the benefits of releasing fish in A-10 backwater vs. A-7 backwater.

A third generalization is that while there is a wide variety of behaviors exhibited by razorback suckers in terms of post-release dispersal, dispersal happens within 1 or 2 weeks of release after which fish exhibit a fairly high degree of fidelity to a particular area. An interesting future research question is whether this apparent site fidelity can be related to survival. It is possible that of the fish that were not found after they dispersed, some ended up in backwater habitats, which are numerous downstream of the study area. A few attempts were made to locate fish downstream of the study area, but the large area of potential habitat and the limited range (2-40 m depending on depth of the tag) of the radio-tags made this a difficult task. Longer range sonar tags would possibly provide the means to track fish that disperse farther than the downstream boundary of the area defined in this study, and longer lasting tags would provide more survival information.

MANAGEMENT AND RESEARCH IMPLICATIONS

Some fish apparently dispersed far downstream from the release site, but most remained in the general area and chose main channel habitats. This contrasts to other studies of razorback sucker (Mueller et al. 2003, Slaughter et al. 2002) where backwater habitats were selected after release. It is possible that, with the exception of A-10 backwater, backwaters on this part of the lower Colorado River represent low-quality razorback sucker habitat. Fish generally dispersed rapidly from A-7 to the main channel. If further studies indicate that rapid dispersal is inversely related to survival, this can be interpreted to mean that A-7 is a poor stocking site.

Limited range and life of radio-tags used in this study limits the certainty with which differential survival between the two backwaters can be inferred. Information is lacking on fish dispersing from A-10 and without this information it is not possible to determine which stocking site would be more conducive to razorback sucker population maintenance in the lower Colorado River. The dramatic difference in behaviors between fish stocked at the two sites encourages future research, with longer-ranging, longer-lived telemetry tags and/or PIT tags.

It is obvious that fish were hesitant to leave the A-10 backwater. In fact, no radio-tagged fish were found to have moved from upper to lower parts of A-10. Other studies have indicated that razorback sucker are able to find and exploit small openings while dispersing (Mueller and Marsh 1998, Mueller et al. 2003, Arizona State University Native Fish Lab Unpublished Data), so it is unlikely that these fish simply could not find their way out of the backwater. Therefore, it is possible that A-10 backwater fish found optimal food, cover, and water characteristics in A-10 backwater and were not pressured to leave. Stable water levels in A-10 backwater compared to A-7 backwater also might have influenced their site fidelity. A longer-term study comparing survival and dispersal of fish stocked in A-10 compared to A-7 could determine whether this is actually the case, and if so characteristics of A-10 backwater could be compared to other areas within the range of the razorback sucker to identify other suitable stocking areas.

LITERATURE CITED

Bright, P.W. and P.A. Morris. 1994. Animal translocation for conservation: performance of dormice in relation to release methods, origin, and season. Journal of Applied Ecology 31(4):699-708.

Holden, P. B. 1980. *Xyrauchen texanus* (Abbott). Pages 435 *in* D. S. Lee, and coeditors, editors. Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History, Raleigh.

Hooge, P.N., W. Eichenlaub, and E. Solomon. 1999. The Animal Movement Program. USGS, Alaska Biological Science Center, Glacier Bay Field Station.

Marsh, P. C., and D. R. Langhorst. 1988. Feeding and fate of wild larval razorback sucker. Environmental Biology of Fishes 21:59-67.

Marsh, P.C. and W.L. Minckley. 1989. Observations on recruitment and ecology of razorback sucker: lower Colorado River, Arizona-California-Nevada. Great Basin Naturalist 49(1)71-78.

Marsh, P. C., C. A. Pacey, and B. R. Kesner. 2003. Decline of the razorback sucker in Lake Mohave, Colorado River, Arizona and Nevada. Transactions of the American Fisheries Society 132:1251-1265.

Marsh, P.C., B.K. Kesner, and C.A. Pacey. 2005. Repatriation as a management strategy to conserve a critically imperiled fish species. North American Journal of Fisheries Management 25:547-556.

Miller, R.R. 1961. Man and the changing fish fauna of the American Southwest. Papers of the Michigan Academy of Science, Arts, and Letters 46: 365-404,

Minckley, W. L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the lower Colorado River basin. The Southwestern Naturalist 28:165-187.

Minckley, W. L., D. A. Hendrickson, and C. E. Bond. 1986. Geography of western North American freshwater fishes: Description and relations to intracontinental tectonism. Pages 519-613 *in* C. H. Hocutt, and E. O. Wiley, editors. The Zoogeography of North American Freshwater Fishes. John Wiley and Sons, NY.

Minckley, W. L., P. C. Marsh, J. E. Brooks, J. E. Johnson, and B. L. Jensen. 1991. Management toward recovery of the razorback sucker. Pages 303-357 *in* W. L. Minckley and J. E. Deacon, editors. Battle Against Extinction. The University of Arizona Press, Tucson.

Minckley, W.L., P.C. Marsh, J.E. Deacon, T.E. Dowling, P.W. Hedrick, W.J. Matthews, and G. Mueller. 2003. A conservation plan for native fishes of the lower Colorado River. BioScience 53:219-234.

Mueller, G. 1995. A program for maintaining the razorback sucker in Lake Mohave. American Fisheries Society Symposium 15:127-135.

Mueller, G.A., and P.C. Marsh. 1998. Post-stocking dispersal, habitat use, and behavioral acclimation of juvenile razorback suckers (*Xyrauchen texanus*) in two Colorado River reservoirs. Open-File Report 98-301. U.S. Geological Survey, Denver, CO.

Mueller, G. A., P. C. Marsh, D. Foster, M. Ulibarri, and T. Burke. 2003. Factors influencing poststocking dispersal of razorback sucker. North American Journal of Fisheries Management 23:270-275.

Schooley, J. D. and P. C. Marsh. In press. An examination of 30 years of razorback sucker stocking in the lower Colorado River basin: 1974-2004. North American Journal of Fisheries Management.

Slaughter, J.E. IV, S.D. Gurtin, J.A. Falke, S.J. Sampson, and R.H. Bradford. 2002. Habitat selection and use by hatchery-reared adult razorback sucker and flathead catfish and the response of razorback sucker to off-channel habitat restoration activities within the Imperial Division, lower Colorado River. Contract Report No. 05, Arizona Game and Fish Department, Phoenix.

USFWS. 1998. Razorback sucker (*Xyrauchen texanus*) Recovery Plan. USFWS, Denver.

APPENDIX I. Summary of Movements of Individual Radio-tagged Razorback Suckers

Fish ID- 11
TL- 420 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- 2/8/05
Last Contact Date- 5/6/05

No. 11 rapidly dispersed from A-7 backwater downstream to the confluence of Palo Verde Outfall Drain, 54.4 km downstream from the release site. It was located several times in the main channel before it was found just upstream of Palo Verde Outfall Drain, where it was consistently located from late February through the end of the study in May. It developed a strong affinity to a nondescript area of the river along a riprapped bank with little bottom structure.

Fish ID- 21
TL- 415 mm
Release Location- A-7 backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- never contacted outside A-7 backwater
Last Contact Date- 5/3/05 (censored 3/8/05 due to tag loss)

No. 21 was contacted several times in A-7 backwater during the first month of the study. Within 1 day of release, it was located at the confluence of A-7 backwater and the main channel but was never located outside A-7 backwater. All four contacts after 3/7/05 were at the same location and this fish was assumed to have died or shed its tag. Signal strength did not vary, which indicated the tag was not moving. The tag was determined to be on the bottom because a signal was only detected when water level was relatively low.

Fish ID- 31
TL- 399 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- 2/5/05
Last Contact Date- 2/10/05

No. 31 was detected once in A-7 backwater the day after release. On 2/8/05 and 2/10/05 it was contacted in the main channel, adjacent to the confluence with C-5 backwater. It was never contacted after that.

Fish ID- 41
TL- 385 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- 2/4/05
Last Contact Date- 5/7/05

No. 41 was contacted once in A-7 backwater the day it was released. On 2/8/05 it was contacted approximately 3 km downriver from the confluence of A-7 backwater and the main channel. It moved a few hundred meters downstream over the next few weeks, eventually becoming associated with an area of the river below a deep (5 m) hole and a sandbar. It continued to be contacted there though the end of the study.

Fish ID- 51
TL-391 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-7 backwater
Last Contact Date- 5/7/05 (censored 3/21/05)

No. 51 was contacted several times in A-7 backwater during the first week of the study. Like 21, it was contacted at the confluence of A-7 backwater and the main channel on the day it was released, but was never contacted outside A-7 backwater. All detections after 3/21/05 were in the same location. Signal strength did not vary and the signal was undetectable during high water, characteristic of a tag on the bottom. Therefore, the fish was assumed to have lost its tag due to mortality or shedding.

Fish ID- 61
TL- 405 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- 2/4/05
Last Contact Date- 2/8/05

No. 61 was contacted once in A-7 backwater on the day it was released. On 2/7/05, it was detected by the listening station located at C-7 backwater. On 2/8/05 it was located at just upstream of the confluence of the main channel and Palo Verde Outfall Drain, approximately 54 km downstream of A-7 backwater. This fish was never contacted again, and was assumed to have dispersed downstream of the study area.

Fish ID- 71
TL-391 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- 2/5/05
Last Contact Date- 5/7/05 (censored 2/24/05)

No. 71 was contacted twice in A-7 backwater during the first two days following release. On 2/10/05 it was contacted in the middle of the main channel just outside of A-7 backwater. Subsequent detections were along the riprapped bank just downstream the confluence of A-7 backwater and the main channel. A SCUBA diver determined this fish had lost its tag through shedding or mortality around 2/24/05.

Fish ID- 81
TL- 385 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-7 backwater
Last Contact Date- 2/10/05

No. 81 was contacted four times in A-7 backwater by 2/10/05. After that date, it was never contacted again. A-7 backwater was covered thoroughly many times during the study and it is unlikely this fish died or shed its tag in the backwater, and it is assumed that 81 dispersed from the backwater early in the study.

Fish ID- 91
TL- 371 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- 2/5/05
Last Contact Date- 5/4/05

No. 91 was contacted once in A-7 backwater on 2/5/05. On 2/10/05 it was contacted 17.6 km upriver from A-7 backwater. This is the only fish that dispersed upriver. On 2/22/05 it was contacted 3.5 km downstream of the 2/10/05 location. For the rest of the study all locations were within 100 m of each other, adjacent to a mid-channel sandbar with scattered large woody debris.

Fish ID- 101
TL- 381 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- 2/4/05
Last Contact Date- 3/21/05

No. 101 was contacted at the confluence of A-7 backwater and the main channel on the release day. The next day it was contacted in the main channel outside A-7 backwater. It was contacted several times on both sides of the main channel in a reach approximately 300 m long just downstream of the confluence of A-7 backwater and the main channel. This fish exhibited the most movement within a home range of all those that were regularly contacted in the main channel.

Fish ID- 111
TL- 375 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- 2/5/05
Last Contact Date- 5/5/05

No. 111 was contacted once in A-7 backwater on 2/5/05. It was contacted on 2/24/05 approximately 3 km downstream of A-7 backwater. It was not contacted during the next two sampling sessions, but was contacted 250 m downstream of the 2/24/05 location on 4/4/05. This fish was contacted in this general area for the rest of the study, in the vicinity of no. 41 just downstream of a deep hole and sandbar.

Fish ID- 121
TL-376 mm
Release Location- A-7 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-7 backwater
Last Contact Date- 5/3/05

No. 121 was located throughout A-7 backwater during the entire study and was never contacted outside A-7 backwater.

Fish ID- 141
TL 403 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 5/3/05

No. 141 was contacted during the entire study in the upper section of A-10 backwater.

Fish ID- 151
TL 387 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 4/2/05

No. 151 was contacted several times in the upper section of A-10 backwater. It was not contacted after 4/2/05. Because the next sampling session occurred after tags had been in operation for more than the 80-day warrantee life, tag failure was a possible cause of non-detection.

Fish ID- 601
TL- 400 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 4/2/05

No. 601 was contacted several times in the upper section of A-10 backwater. It was not contacted after 4/2/05. Because the next sampling session occurred after tags had been in operation for more than the 80-day warrantee life, tag failure was a possible cause of non-detection.

Fish ID- 611
TL- 406 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 5/3/05

No. 611 was contacted throughout the duration of the study in the upper section of A-10 backwater.

Fish ID- 621
TL- 621 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 5/4/05

No. 621 was contacted throughout the duration of the study in the upper section of A-10 backwater. On 3/21 it was contacted in shallow water (approximately 1 m deep) adjacent to a stand of cattail. All subsequent locations were in this area. It was thought that the fish may have lost its tag or died here, but a SCUBA diver determined that the tag was not stationary. This fish maintained a high fidelity to a particular site for several weeks.

Fish ID- 631
TL- 400 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 5/3/05

No. 631 was contacted throughout the duration of the study in the upper section of A-10 backwater.

Fish ID- 641
TL- 379 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 4/2/05

No. 641 was contacted several times in a small area of the upper section of A-10 backwater. It was not contacted after 4/2/05. Because the next sampling session occurred after tags had been in operation for more than the 80-day warrantee life, tag failure was a possible cause of non-detection.

Fish ID- 651
TL 389 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 5/3/05 (censored 4/2/05)

No. 651 was contacted in the upper section of A-10 backwater throughout the duration of the study. After 4/2/05 it was contacted at the same location and a SCUBA diver was able to recover a tag from this location.

Fish ID- 661
TL 436 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 2/21/05

No. 661 was contacted three times in the upper section of A-10 backwater through 2/21/05, after which it lost its tag when it was captured in a trammel net.

Fish ID- 671
TL- 410 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 4/18/05

No. 671 was contacted several times in the upper section of A-10 backwater. It was not contacted after 4/18/05. Because the next sampling session occurred after tags had been in operation for more than the 80-day warrantee life, tag failure was a possible cause of non-detection.

Fish ID- 681
TL- 405 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 4/2/05

No. 681 was contacted several times in the upper section of A-10 backwater. It was not contacted after 4/2/05. Because the next sampling session occurred after tags had been in operation for more than the 80-day warrantee life, tag failure was a possible cause of non-detection.

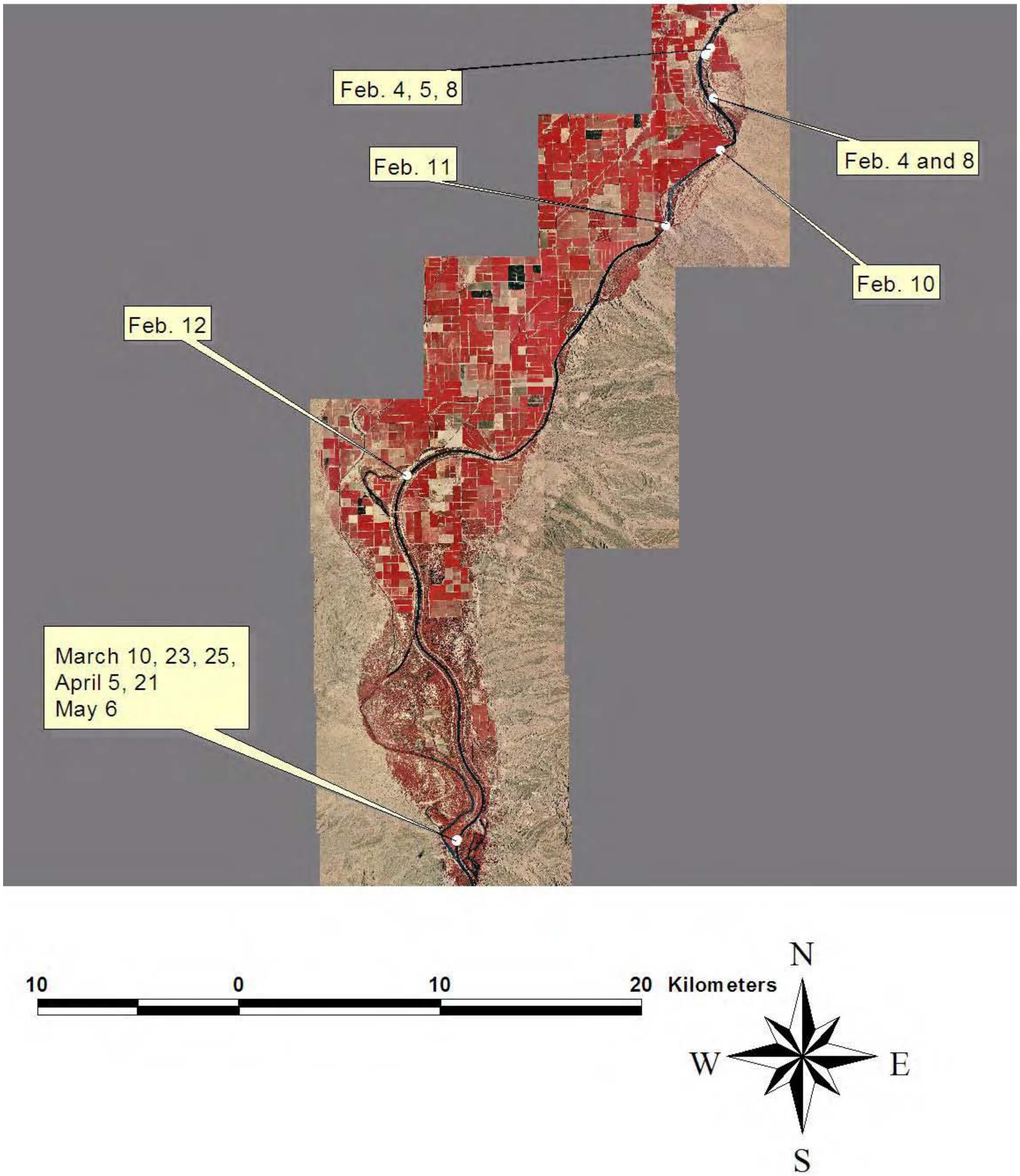
Fish ID- 691
TL- 691 mm
Release Location- A-10 Backwater
Release Date- 2/4/05
Earliest possible dispersal date from backwater- Never contacted outside A-10 backwater
Last Contact Date- 5/3/05

No. 691 was contacted in the upper section of A-10 backwater several times during the study. All locations after 3/21 were in the same general area.

APPENDIX II. Maps of Radio-tagged Fish Movements

For each fish, a map of telemetry locations is provided. The number at the top of each map is the fish ID (tag) number. Because of the extensive movements of fish No. 11, an overview map and multiple larger scale maps are provided.

11 Overview


Feb. 4, 5, 8
Feb. 4 and 8
Feb. 11
Feb. 10
Feb. 12
March 10, 23, 25,
April 5, 21
May 6
10
0
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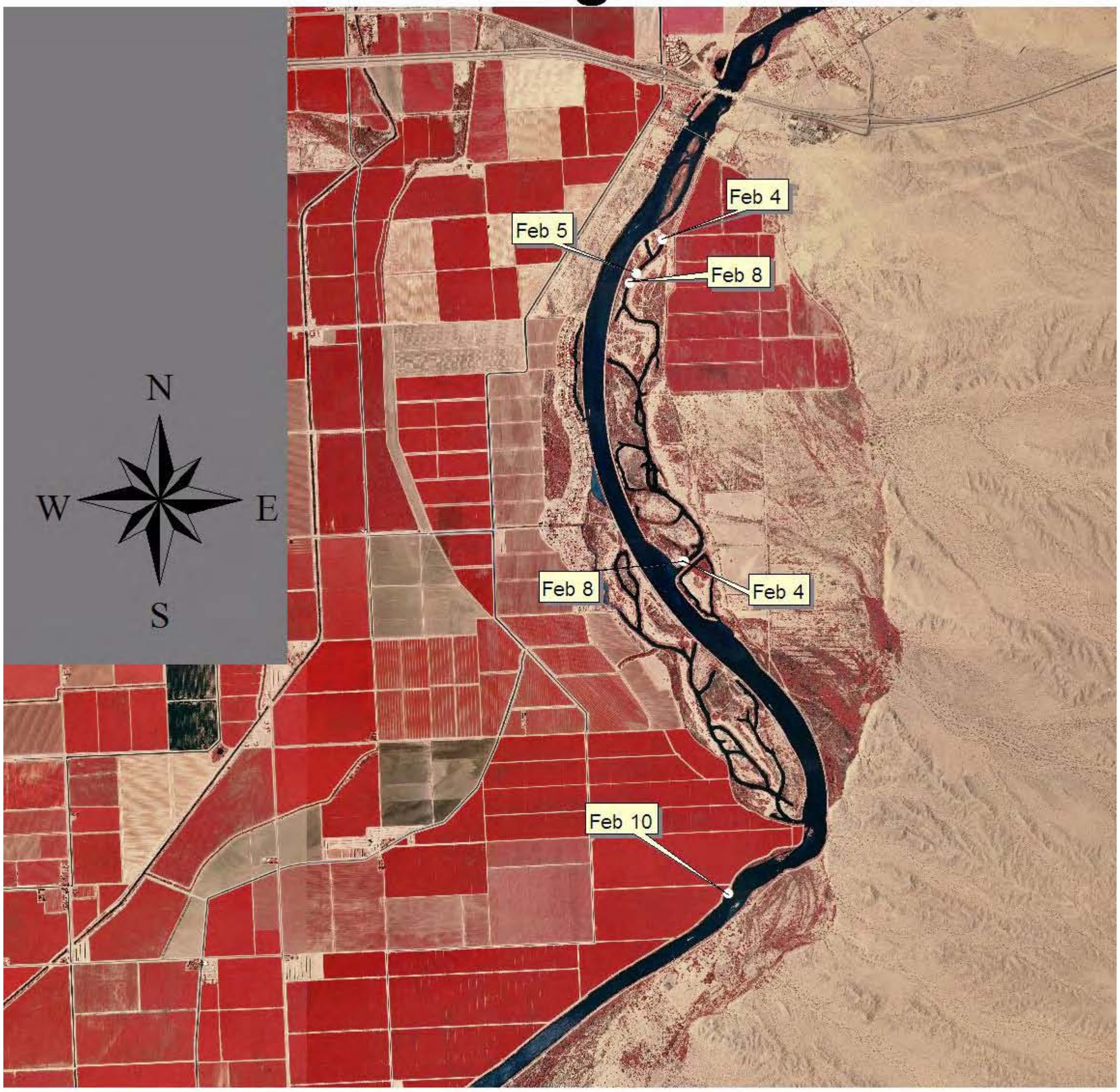
20 Kilometers
N
W
E
S

11- Pg. 1



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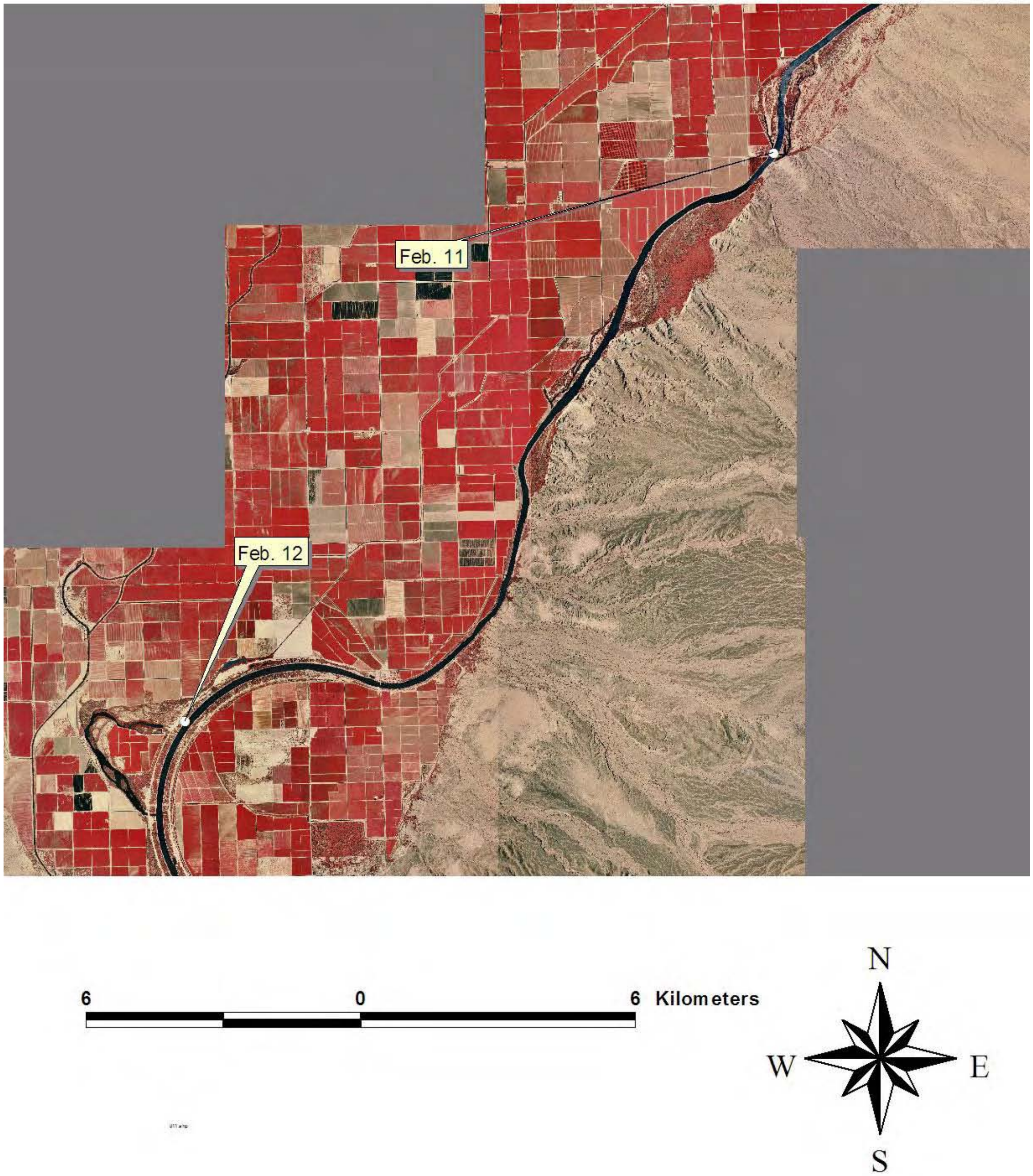
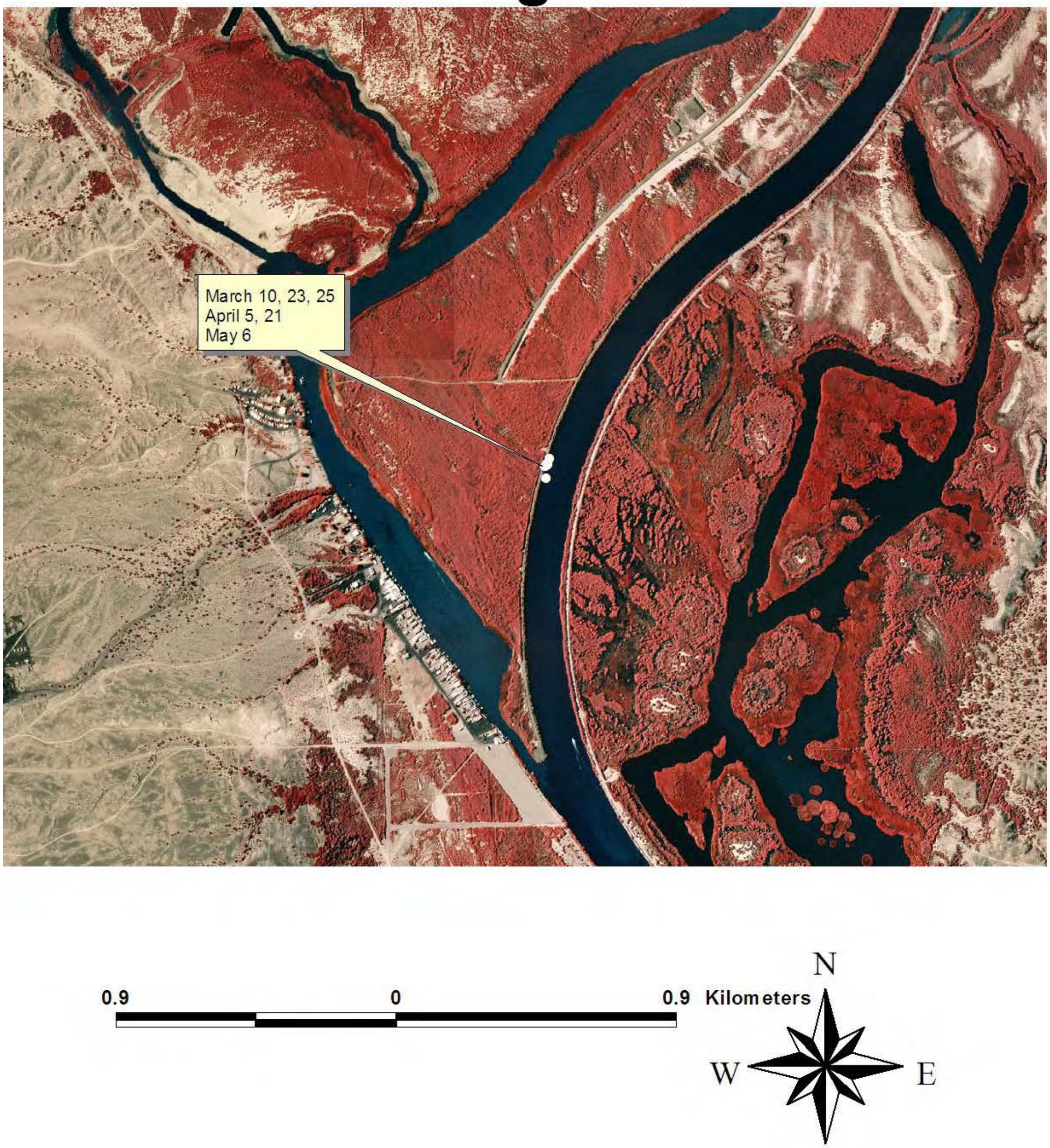


11 Pg. 3



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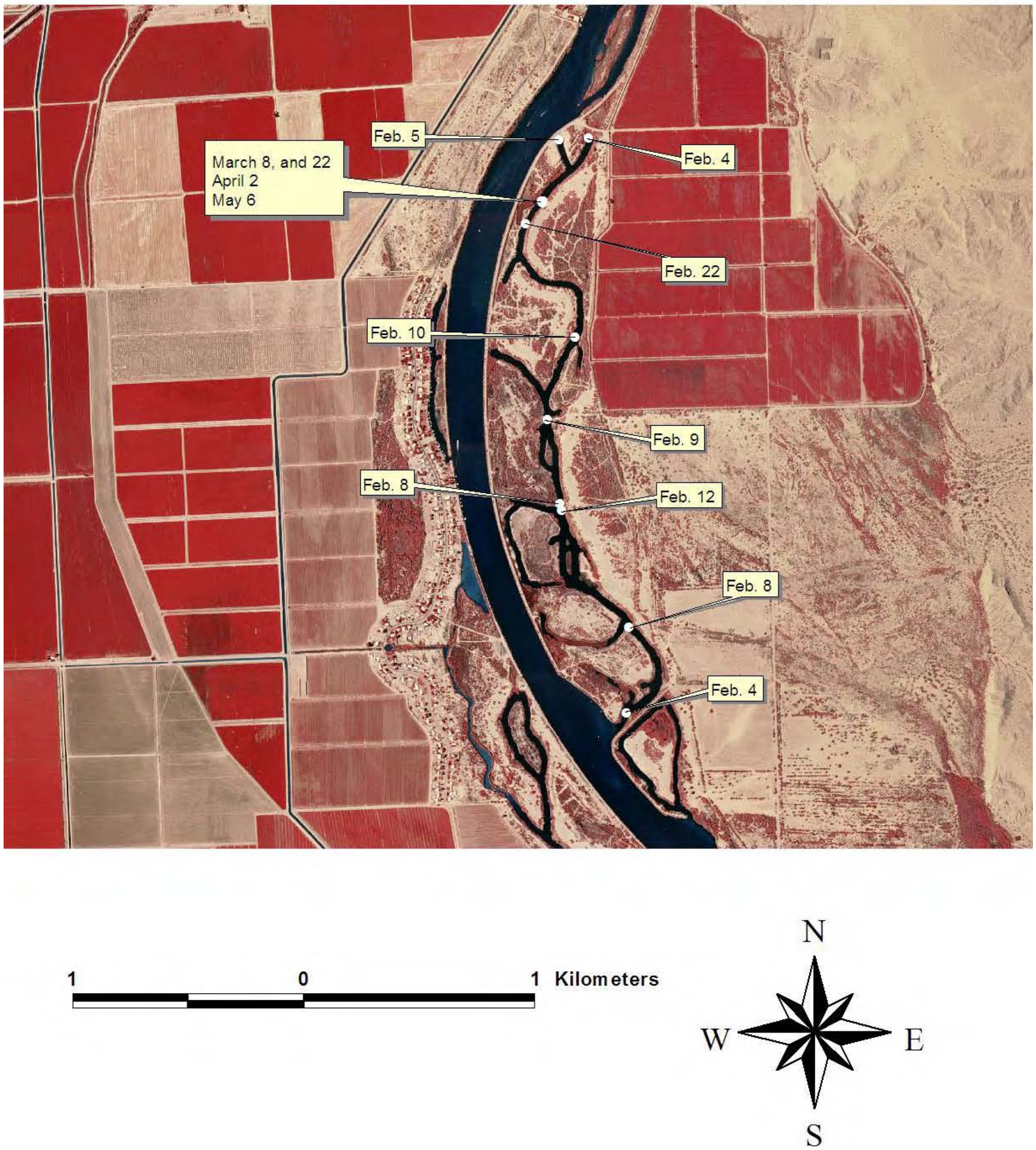
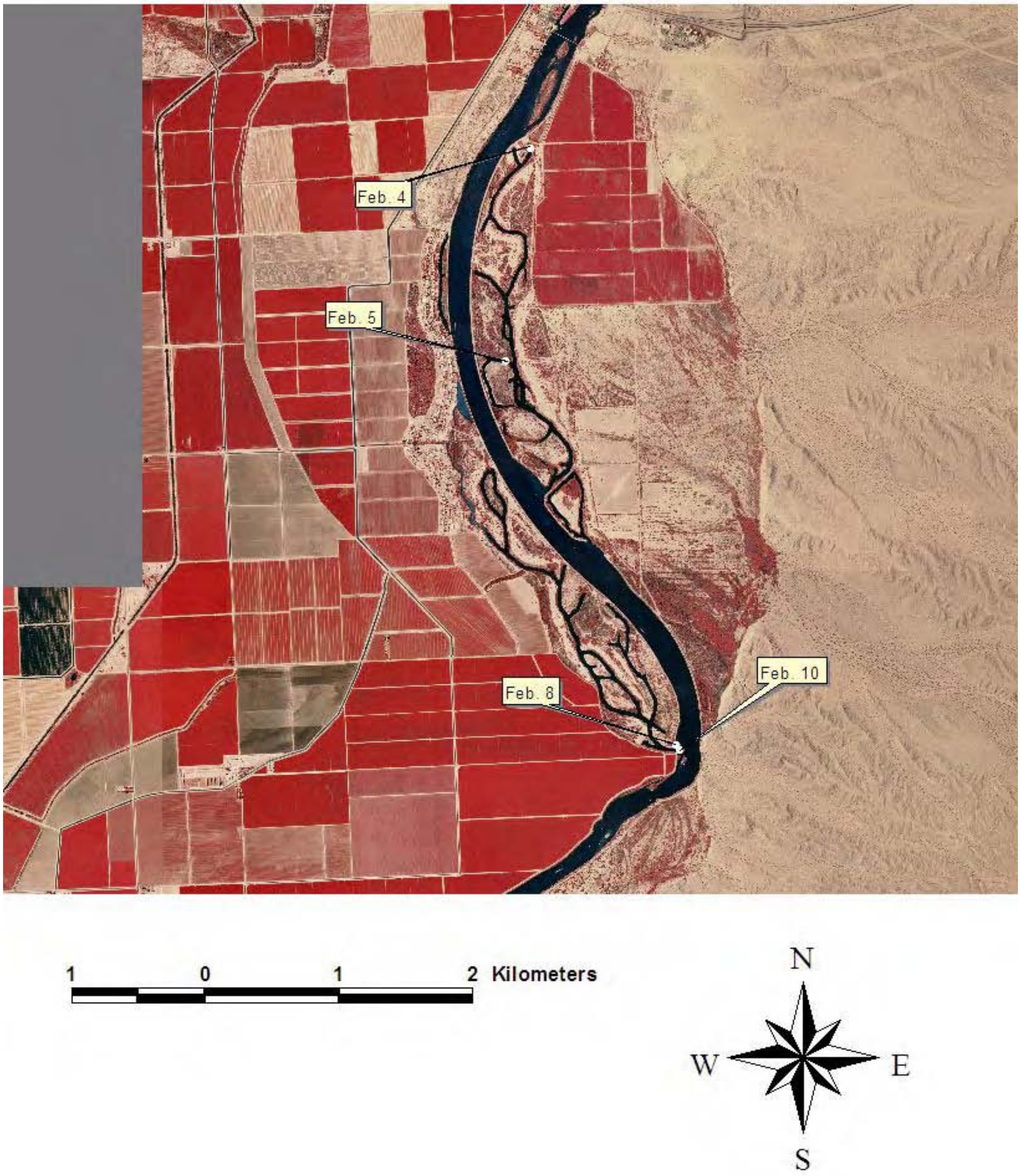


Feb. 5
Feb. 4
March 8, and 22
April 2
May 6
Feb. 22
Feb. 10
Feb. 9
Feb. 8
Feb. 12
Feb. 8
Feb. 4
1 0 1 Kilometers
N
W
E
S

31



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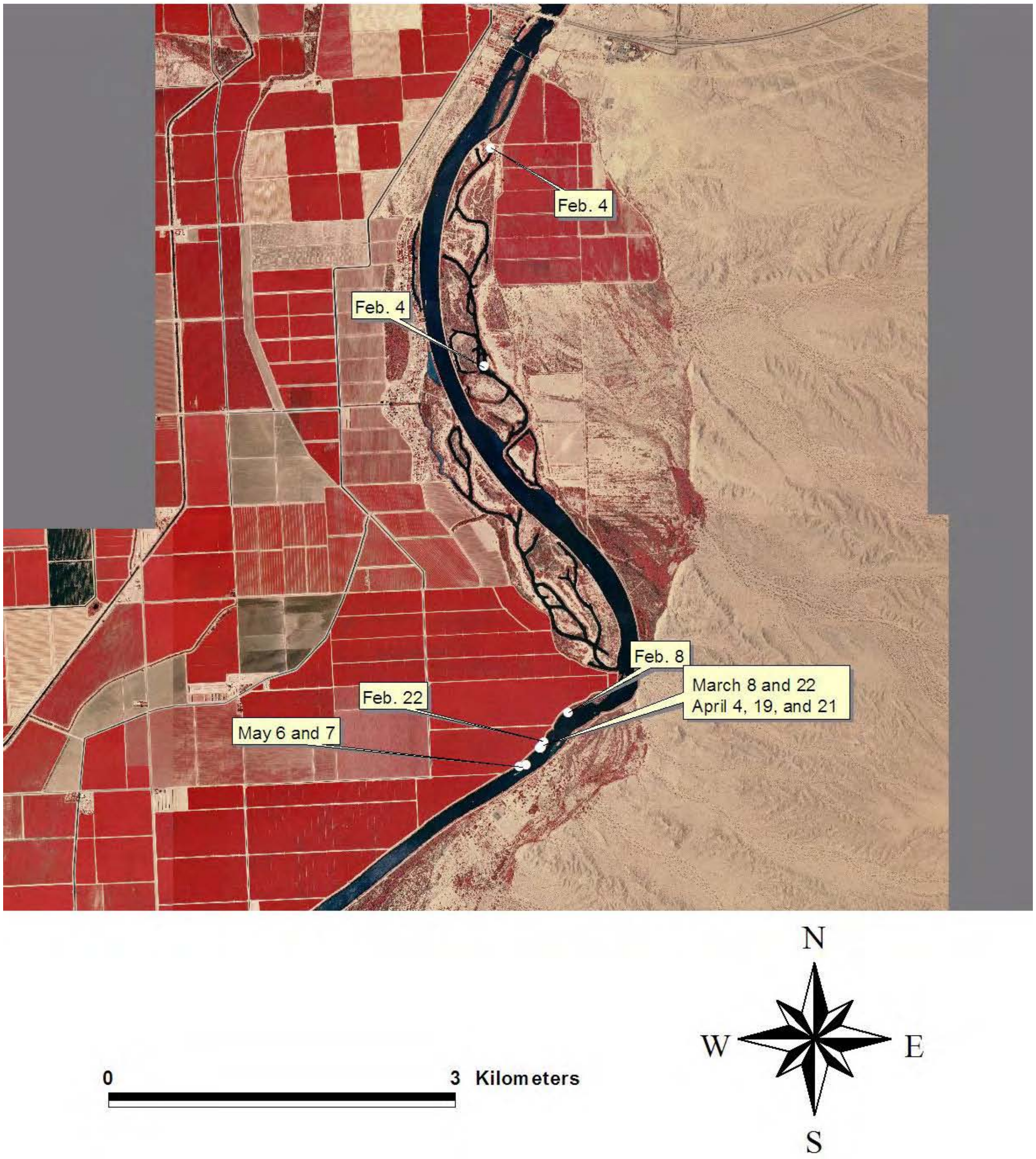
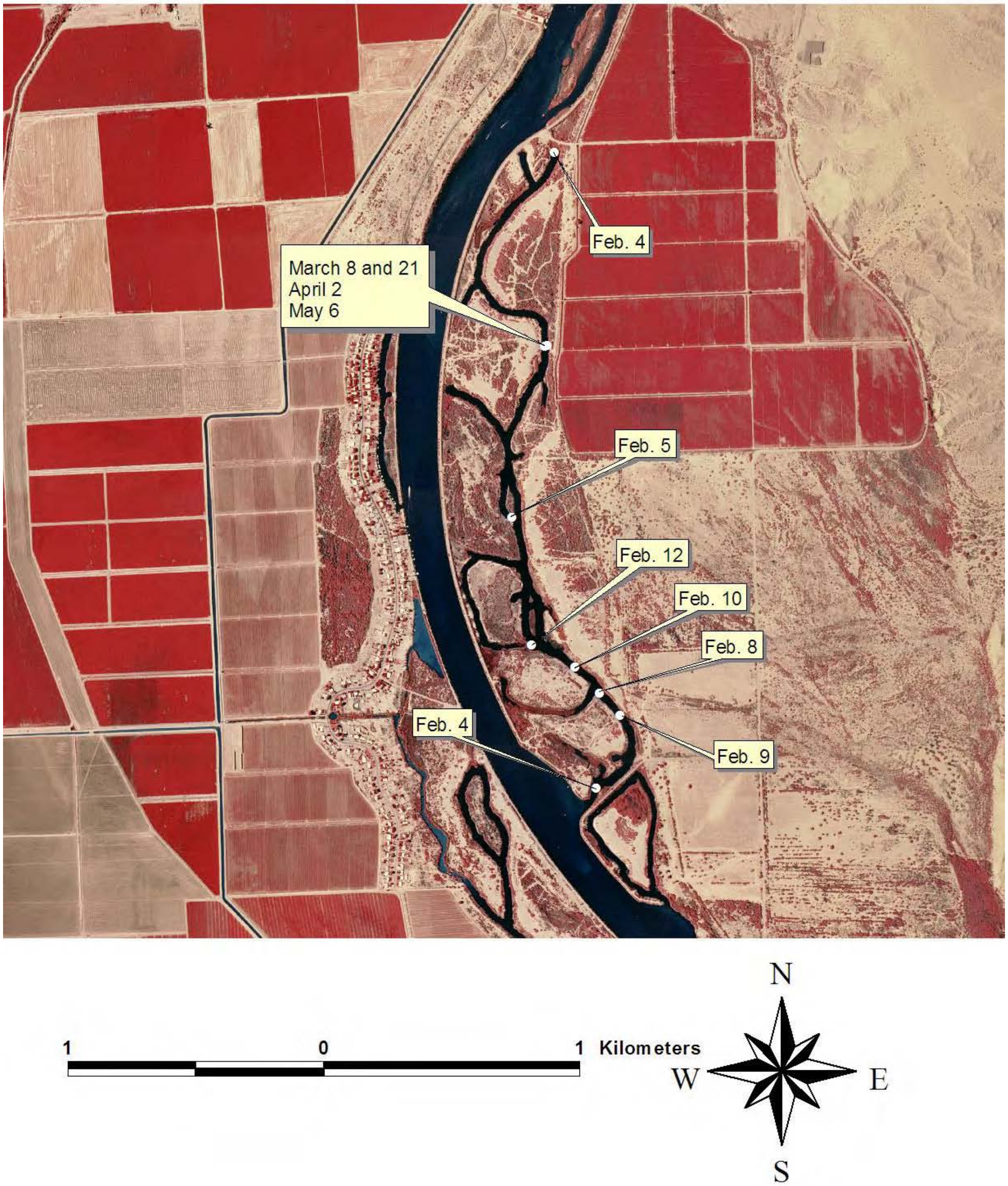
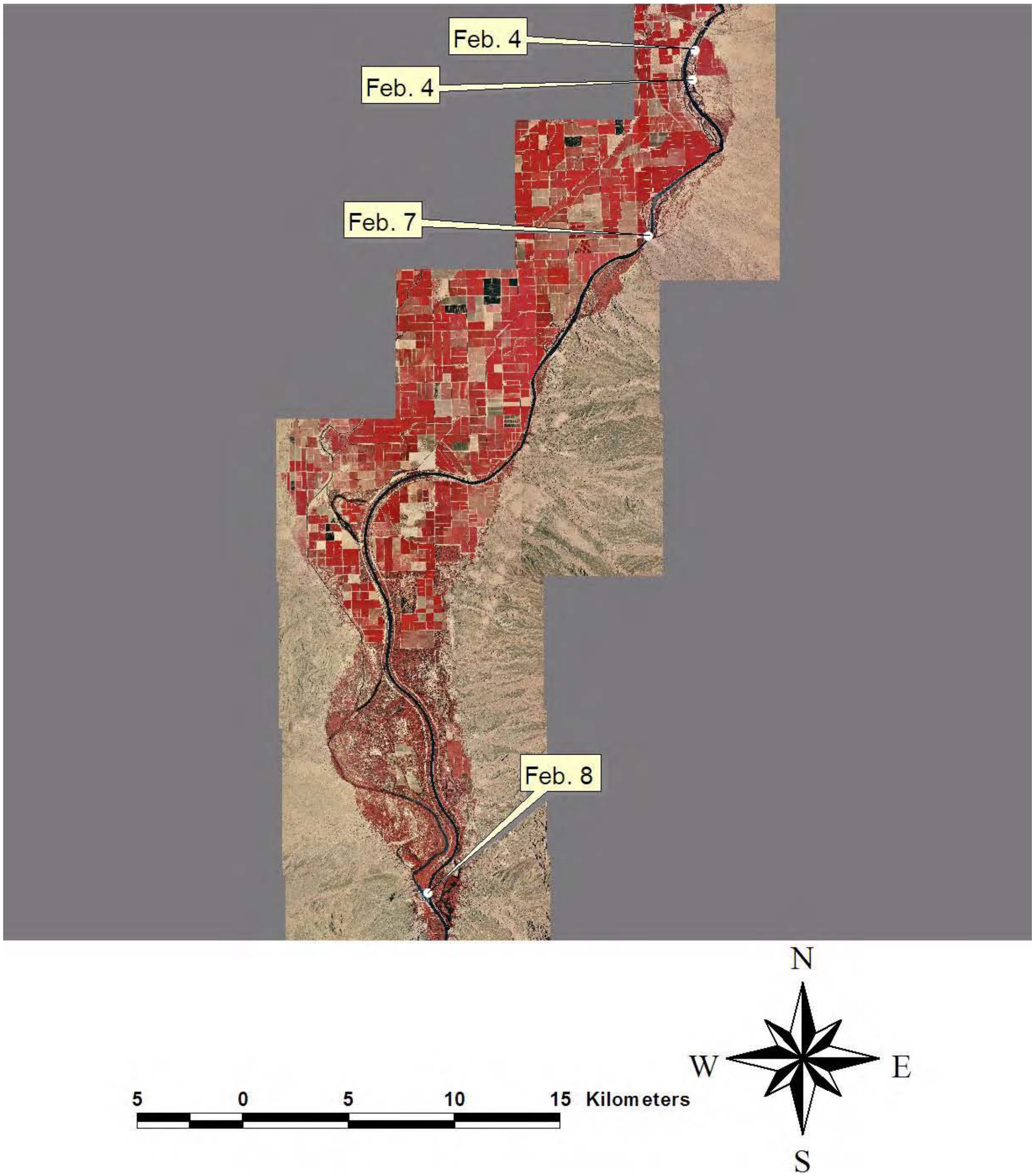

Feb. 4
Feb. 4
Feb. 8
March 8 and 22
April 4, 19, and 21
Feb. 22
May 6 and 7
0
3 Kilometers
N
W
E
S

51


Feb. 4
March 8 and 21
April 2
May 6
Feb. 5
Feb. 12
Feb. 10
Feb. 8
Feb. 4
Feb. 9
1
0
1
Kilometers
N
W
E
S

61



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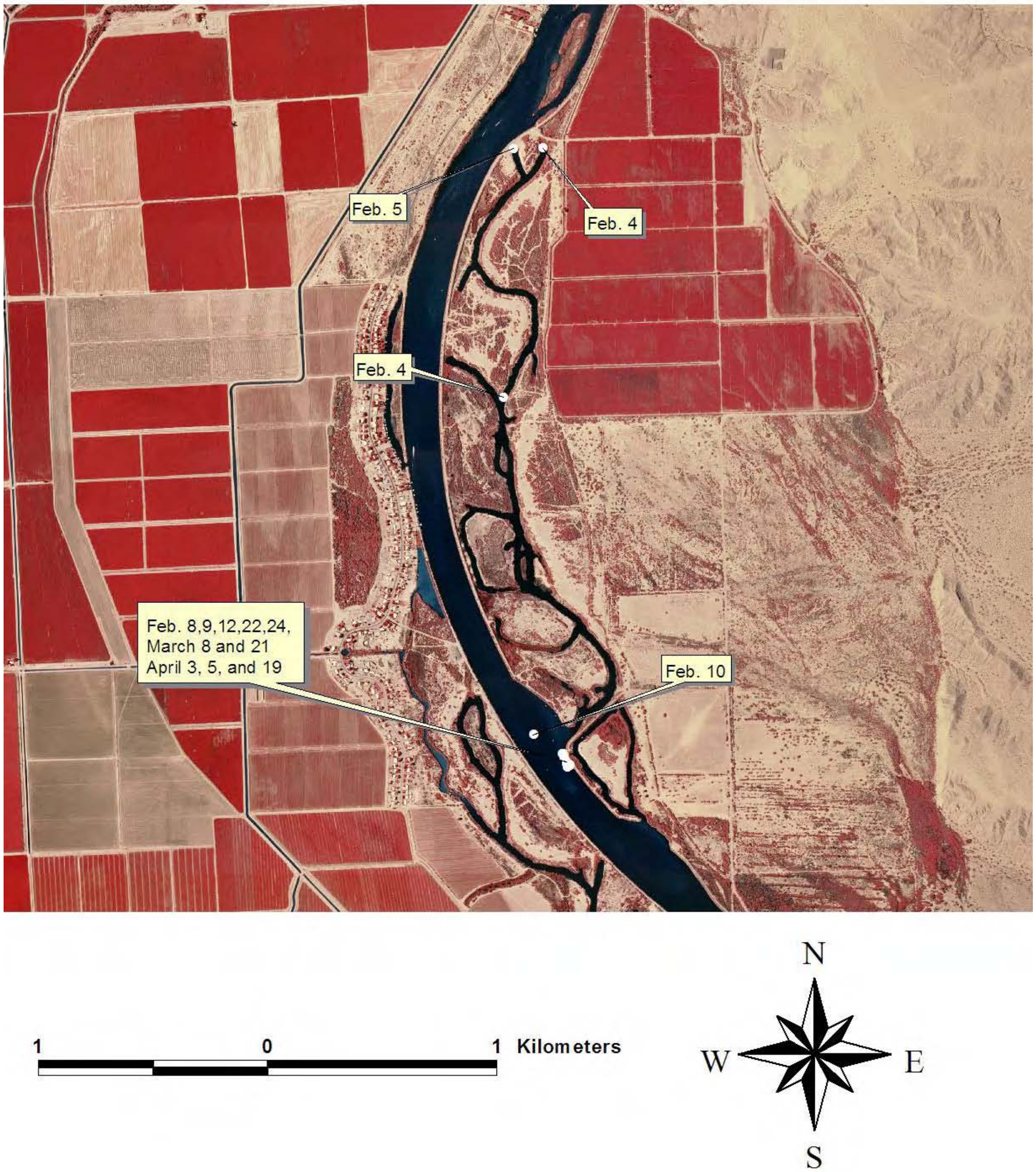
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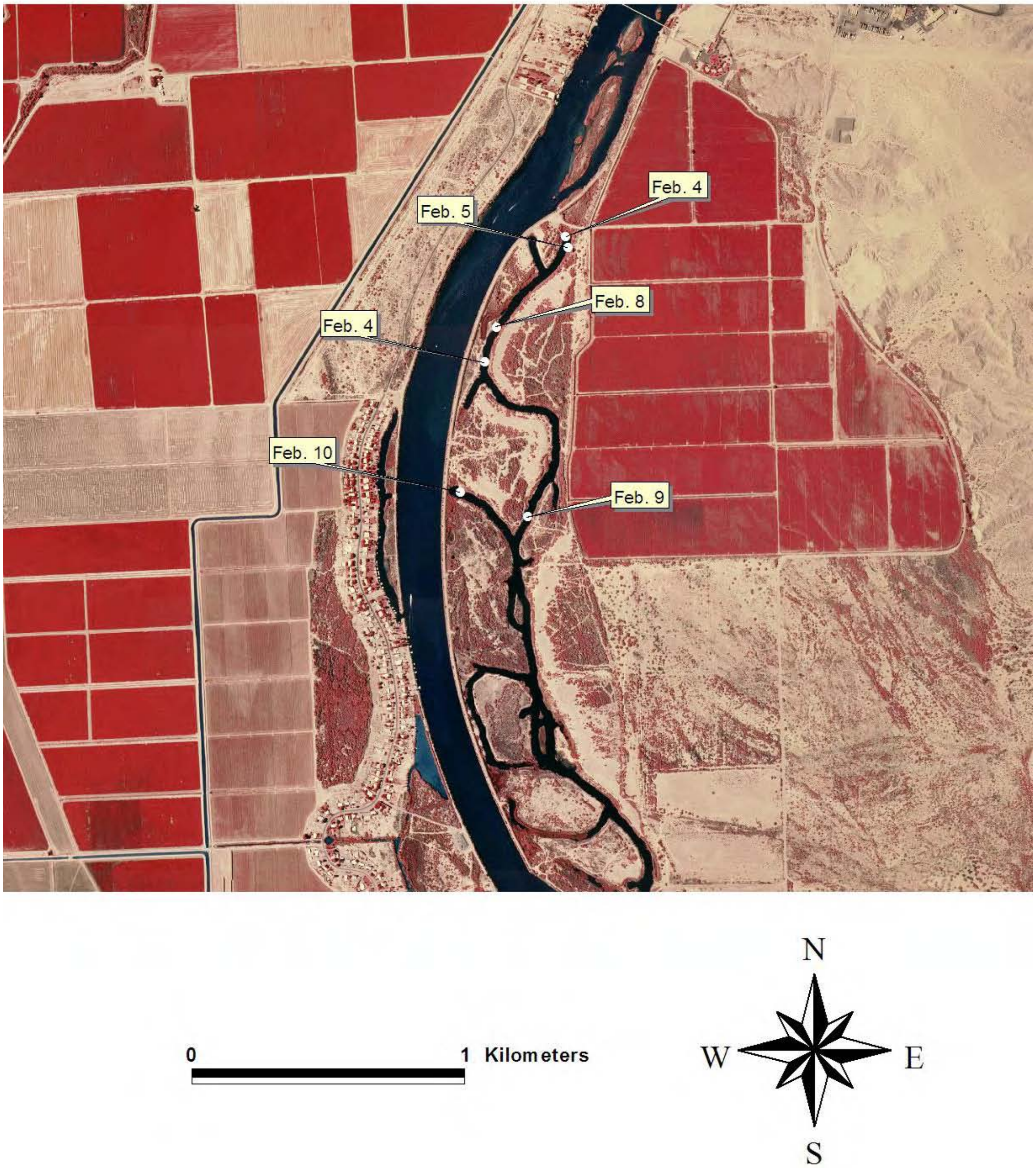
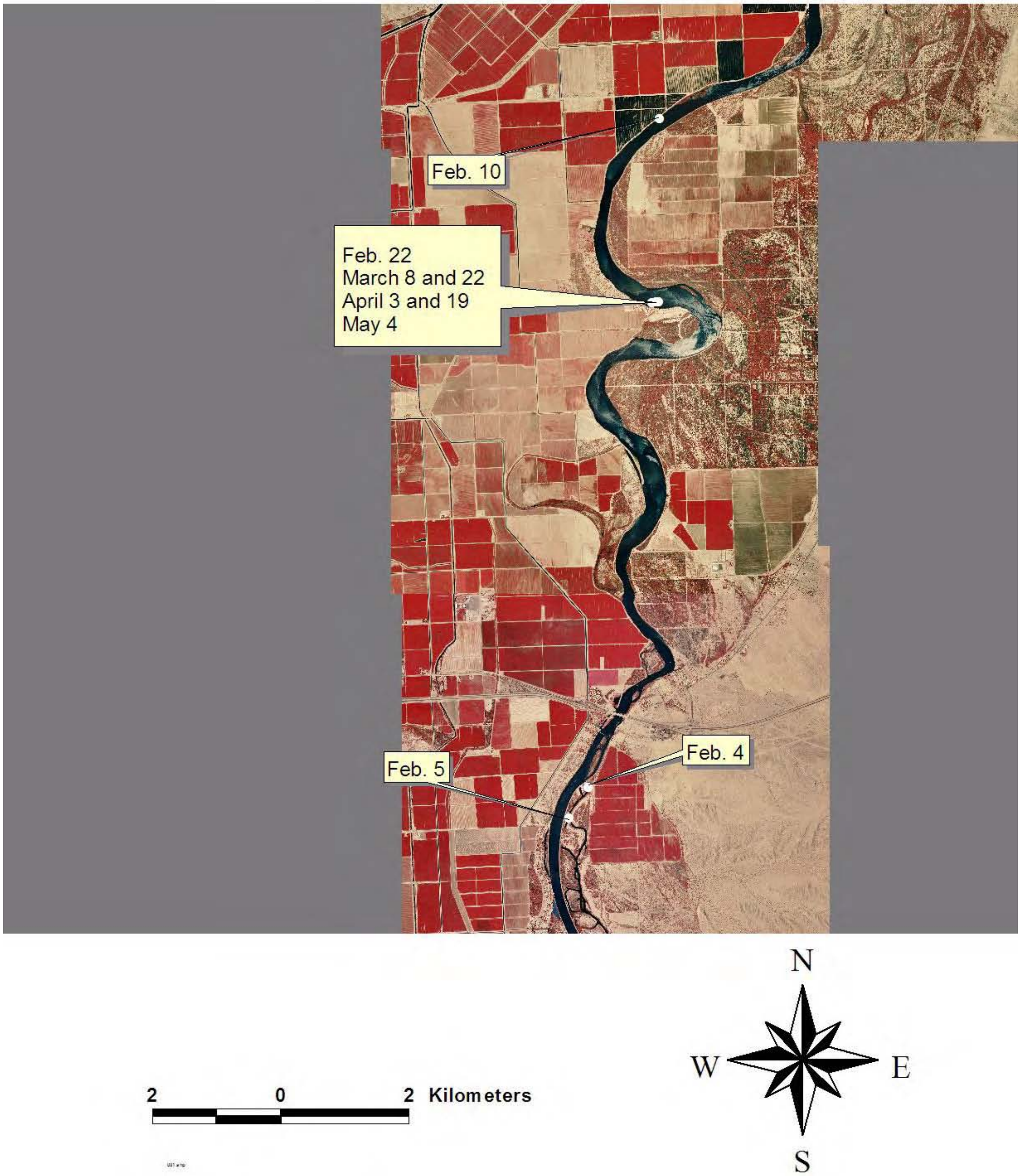
Feb. 4
Feb. 4
Feb. 8,9,12,22,24,
March 8 and 21
April 3, 5, and 19
Feb. 10
1 0 1 Kilometers
N
W
E
S

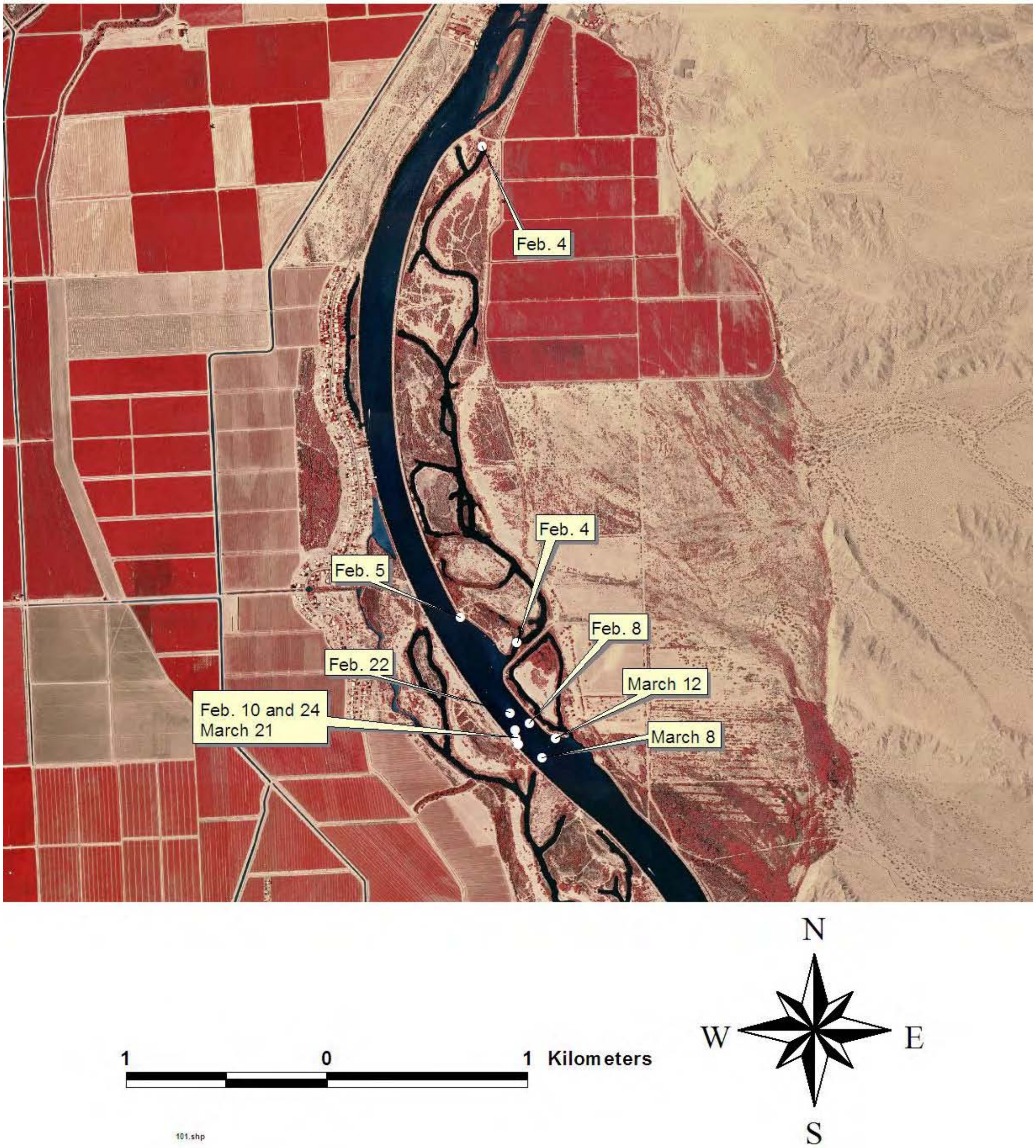
81



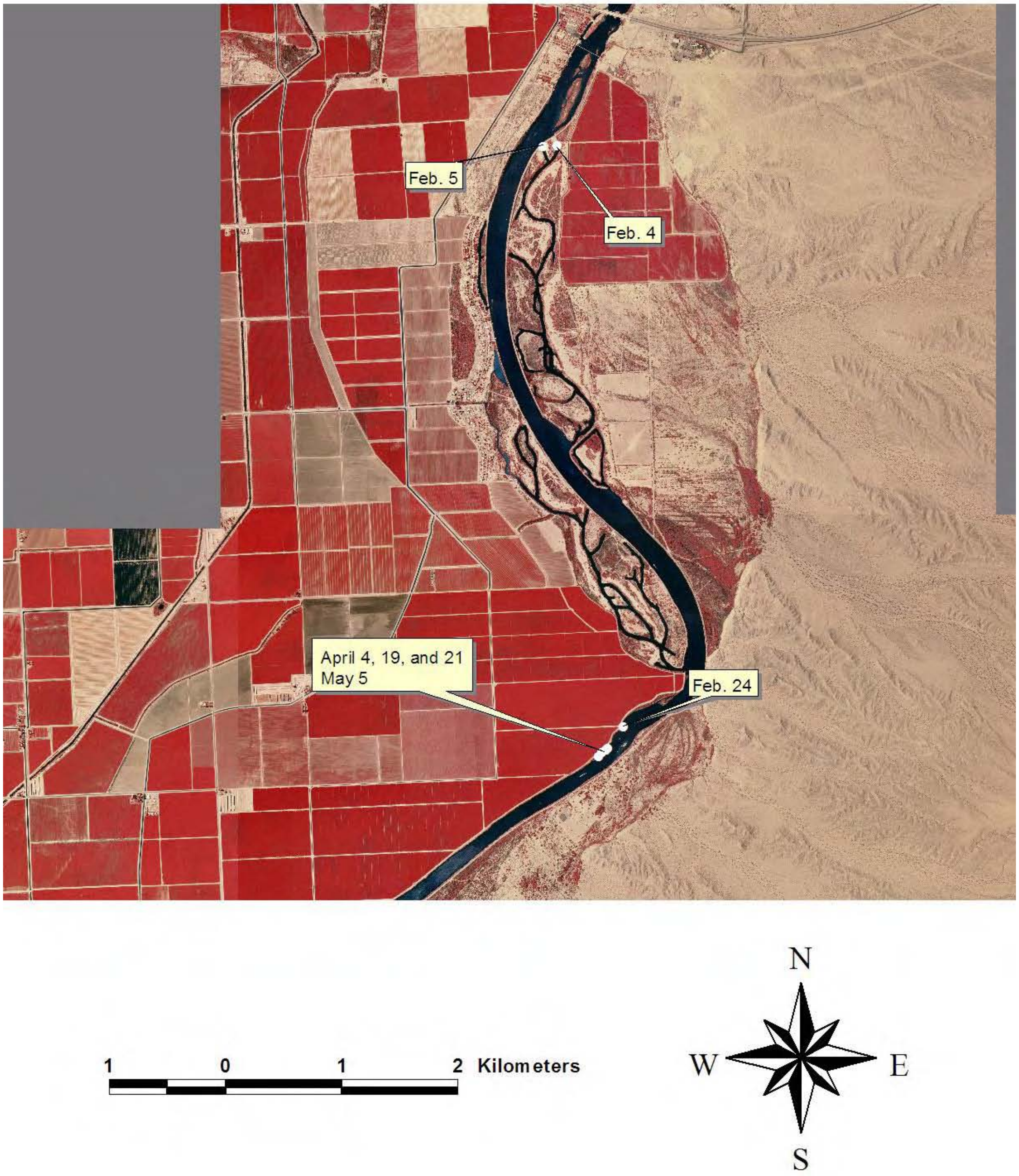
91


Feb. 10
Feb. 22
March 8 and 22
April 3 and 19
May 4
Feb. 4
Feb. 5
N
W
E
S
2
0
2 Kilometers

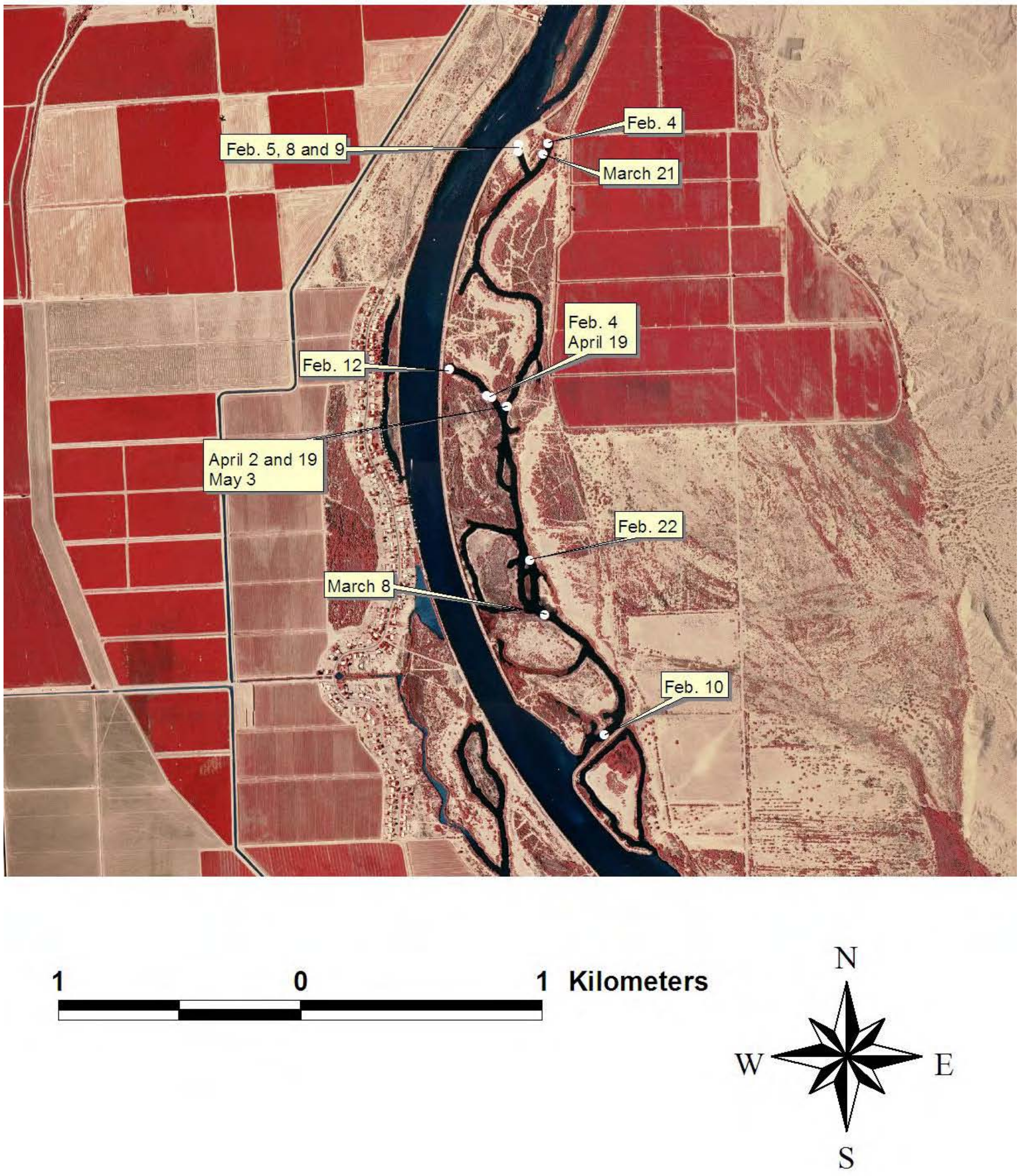
101


Feb. 4
Feb. 4
Feb. 5
Feb. 8
Feb. 22
March 12
Feb. 10 and 24
March 21
March 8
1
0
1 Kilometers
101.shp
N
W
E
S

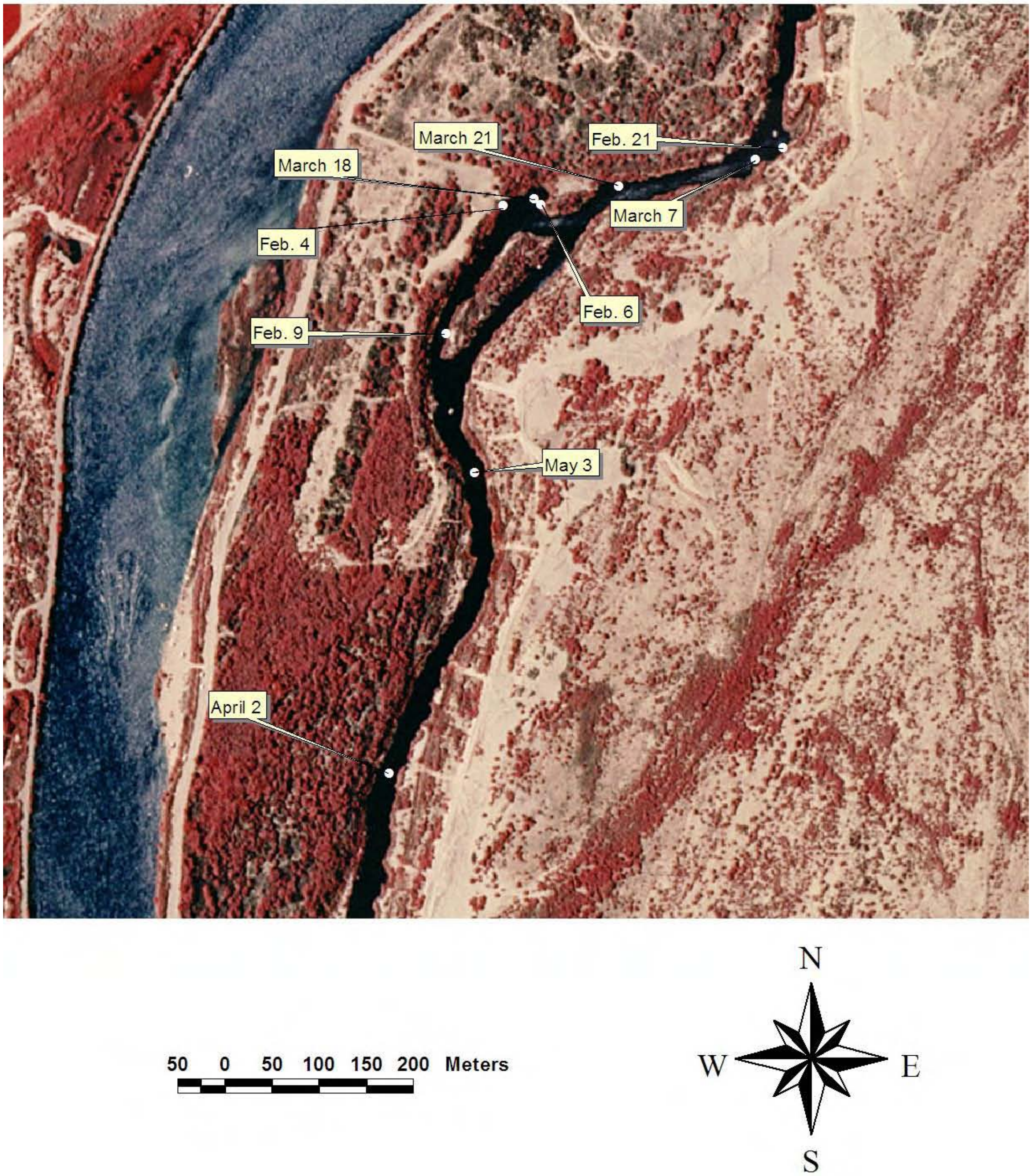
111



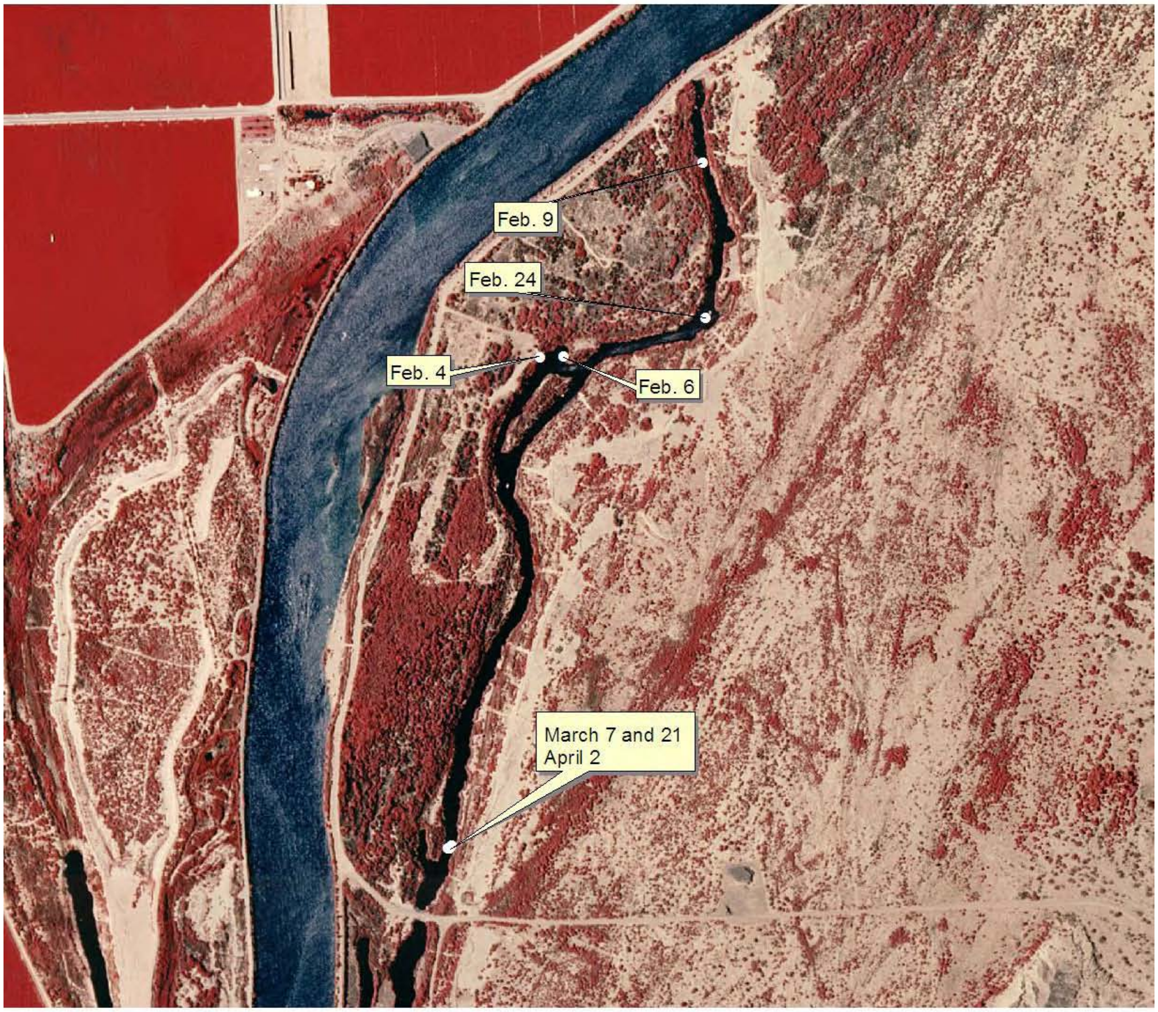
121


Feb. 4
Feb. 5, 8 and 9
March 21
Feb. 4
April 19
Feb. 12
April 2 and 19
May 3
Feb. 22
March 8
Feb. 10
1
0
1 Kilometers
N
W
E
S

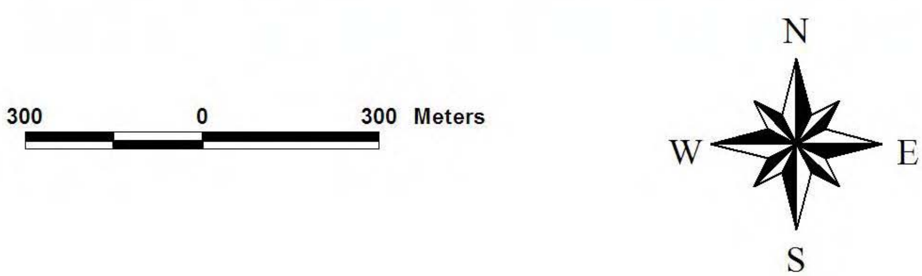
141


March 21
Feb. 21
March 18
March 7
Feb. 4
Feb. 6
Feb. 9
May 3
April 2
50 0 50 100 150 200 Meters
N
W
E
S

151

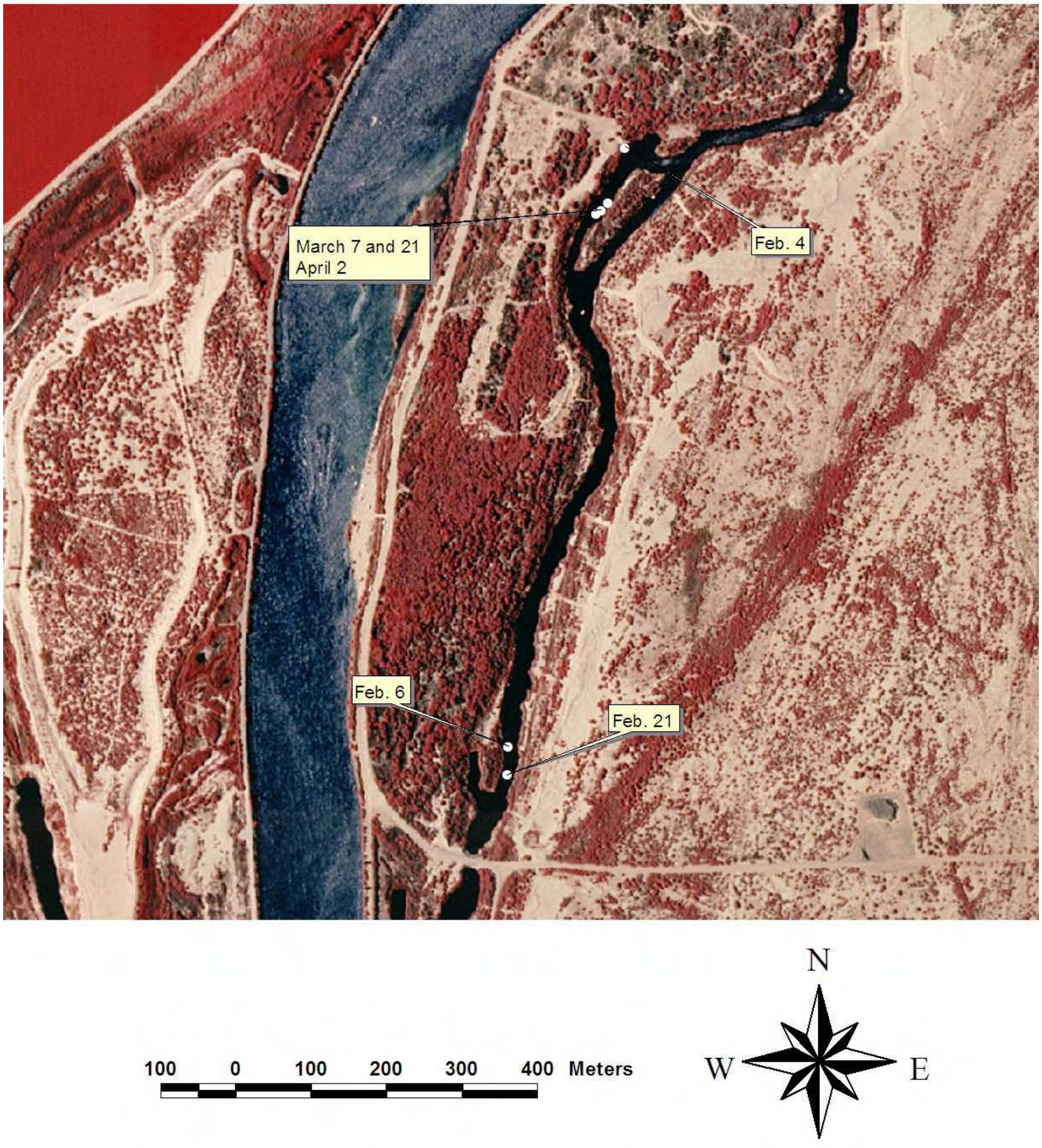


Feb. 9
Feb. 24
Feb. 4
Feb. 6
March 7 and 21
April 2

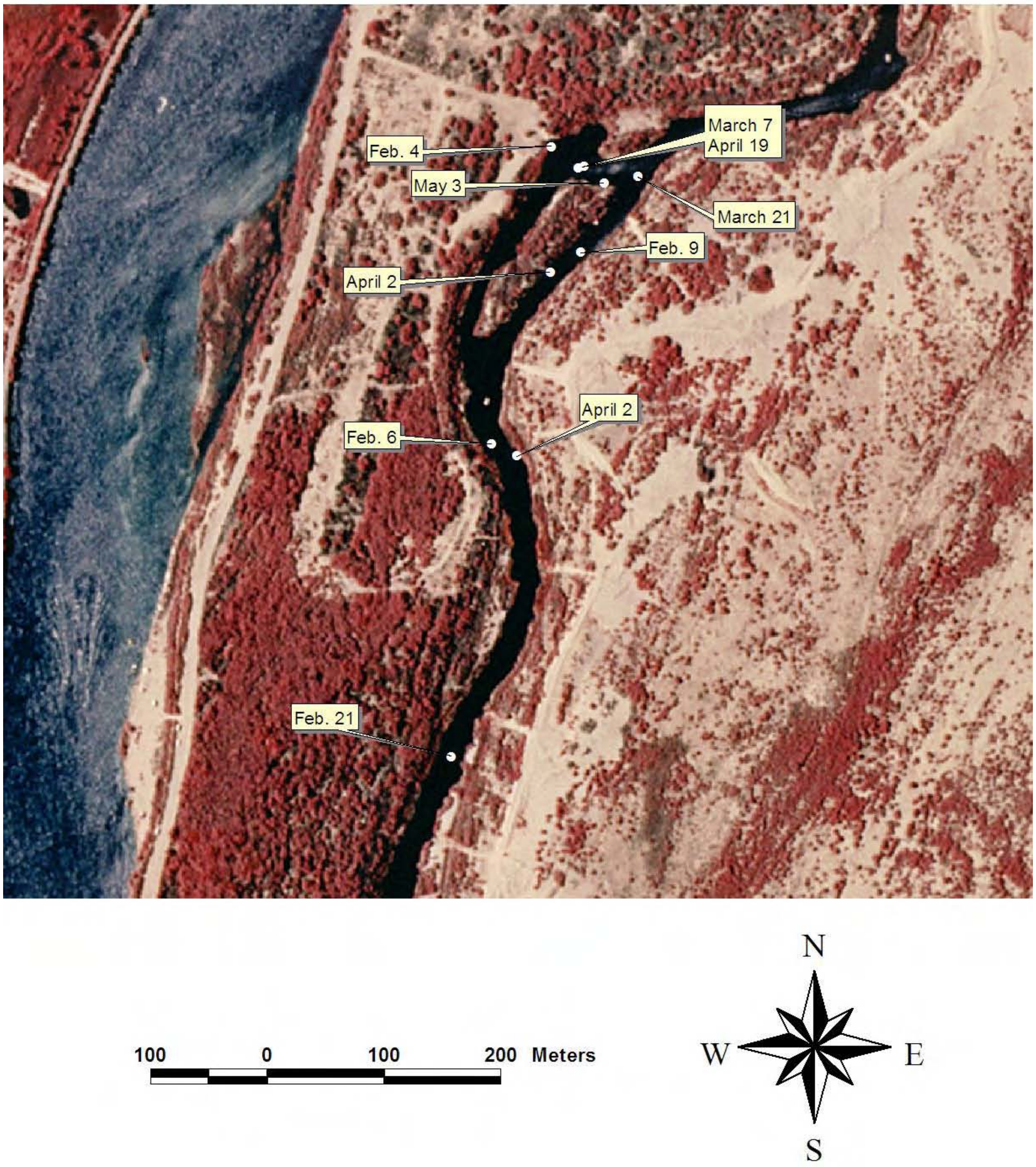


300
0
300 Meters
N
W
E
S

601

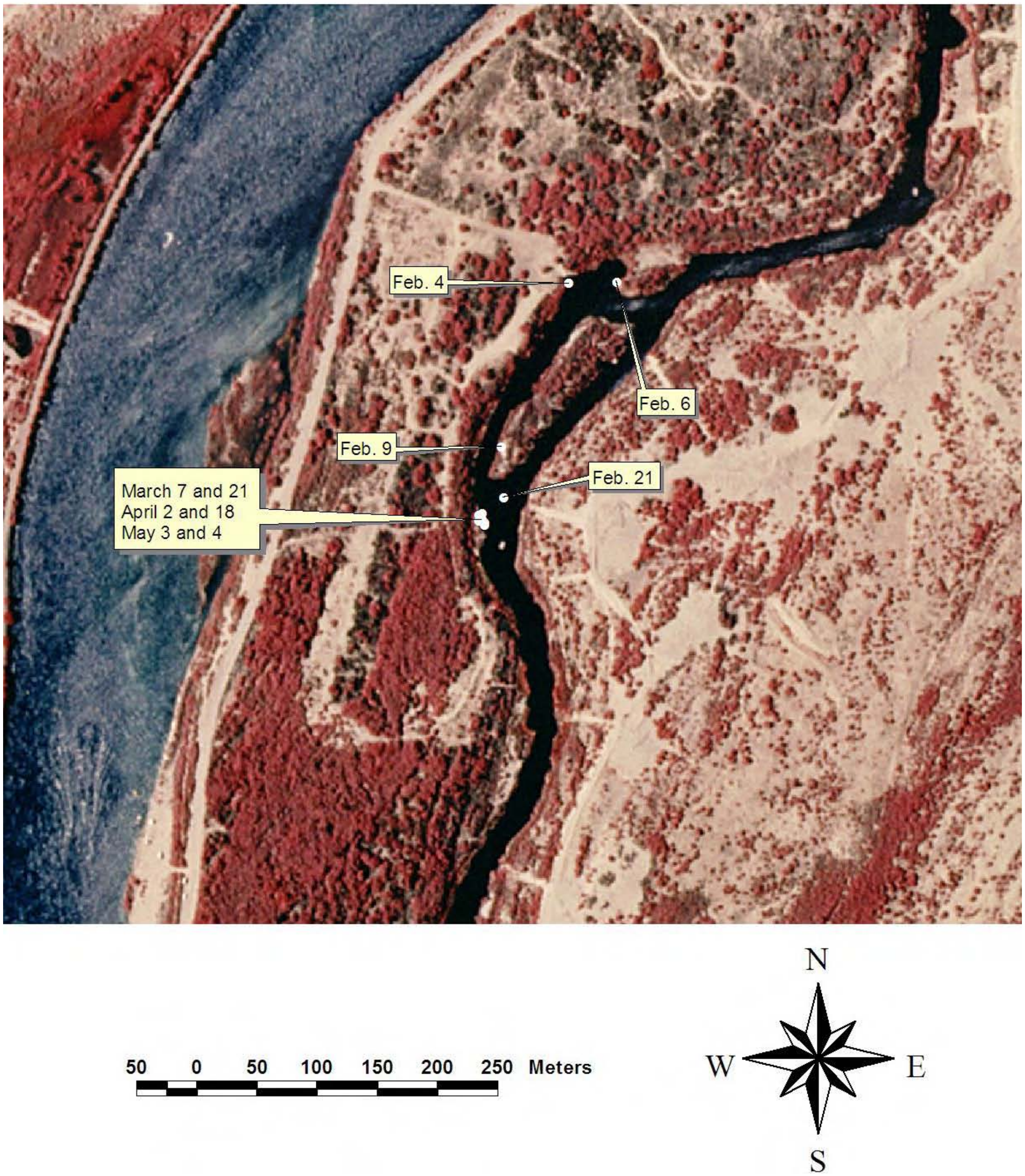

March 7 and 21
April 2
Feb. 4
Feb. 6
Feb. 21
100 0 100 200 300 400 Meters
N
W
E
S

611



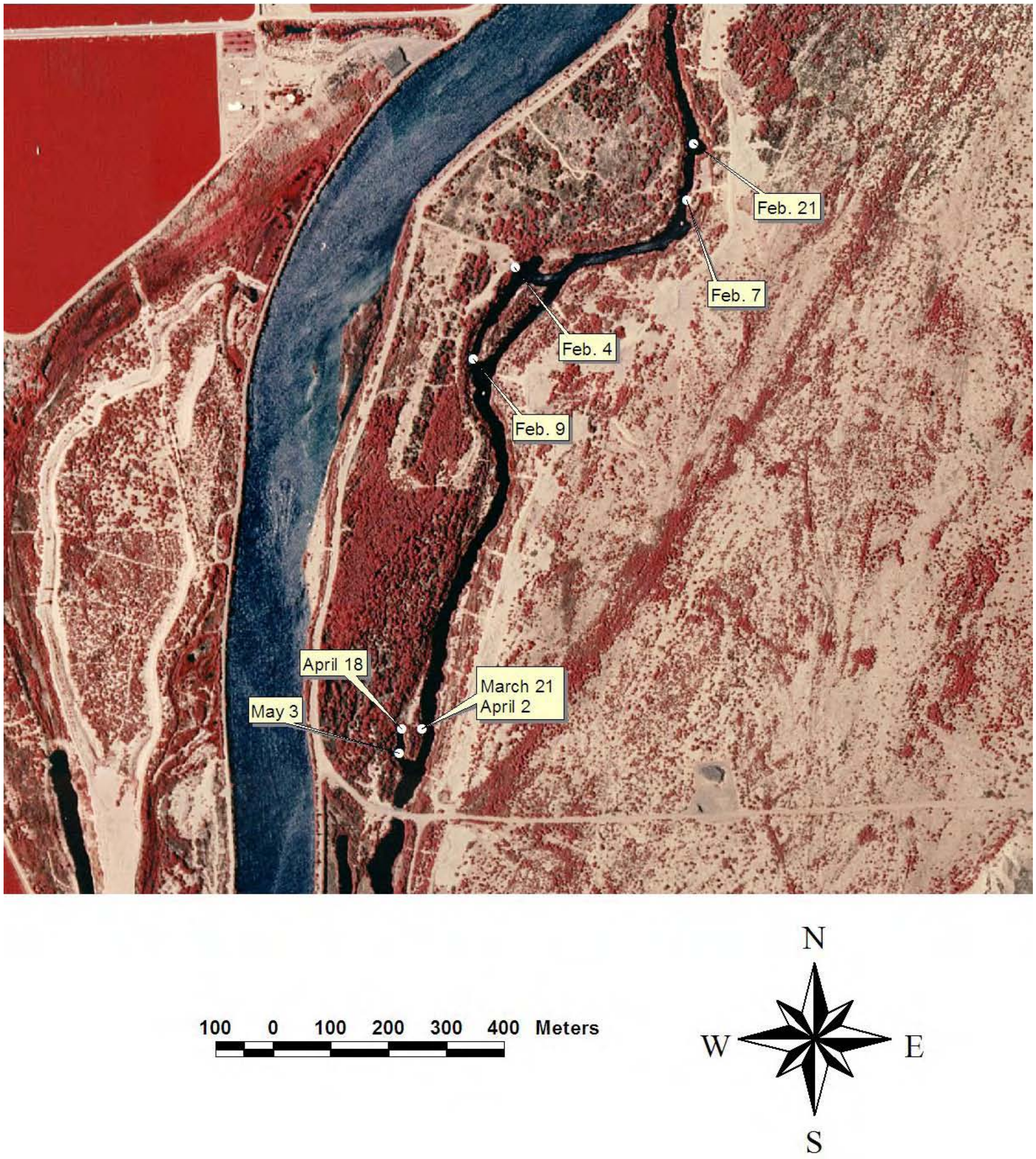
Feb. 4
March 7
April 19
May 3
March 21
Feb. 9
April 2
April 2
Feb. 6
Feb. 21
100 0 100 200 Meters
N
W
E
S

621

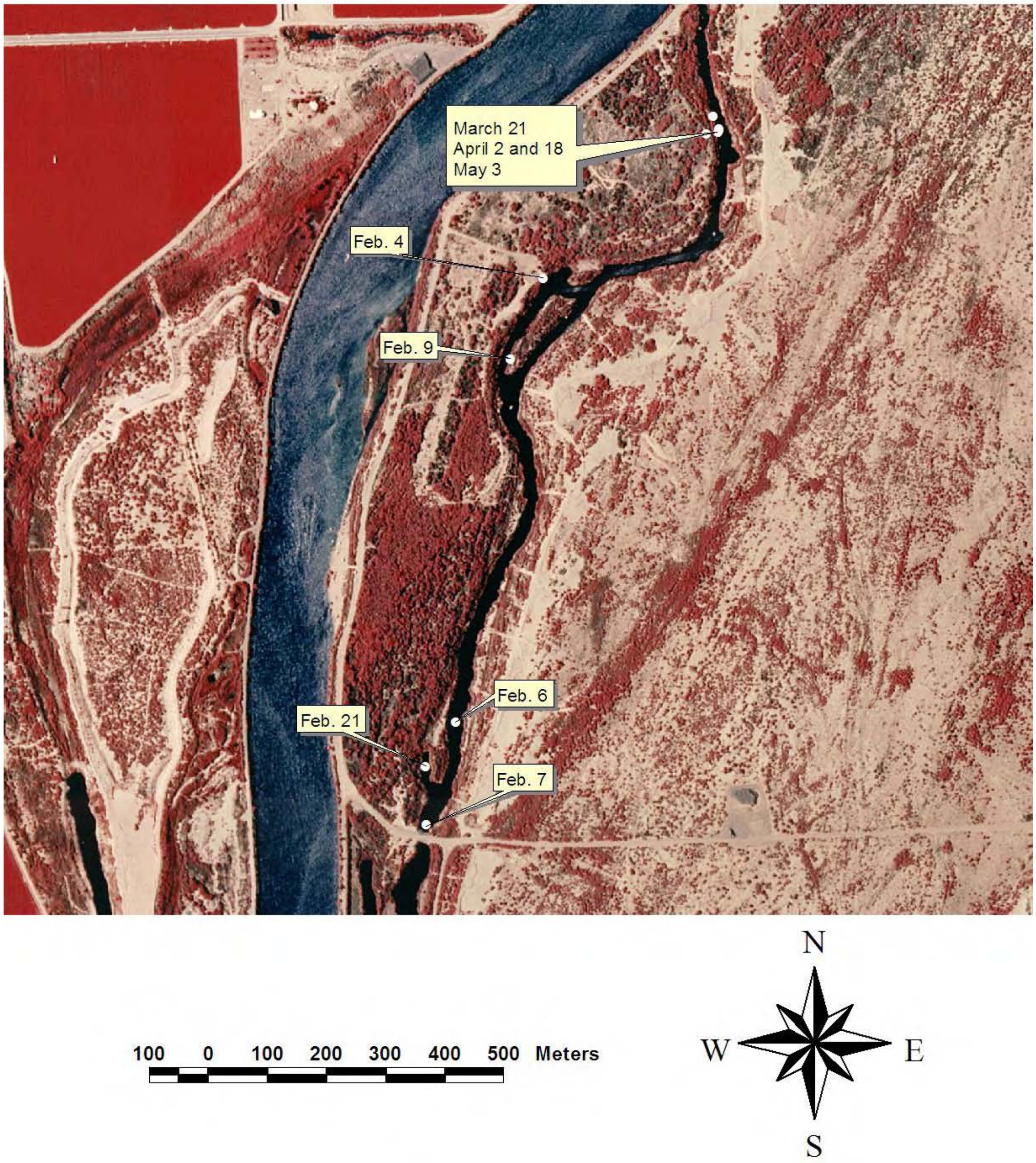


Feb. 4
Feb. 6
Feb. 9
Feb. 21
March 7 and 21
April 2 and 18
May 3 and 4
50 0 50 100 150 200 250 Meters
N
W
E
S

631

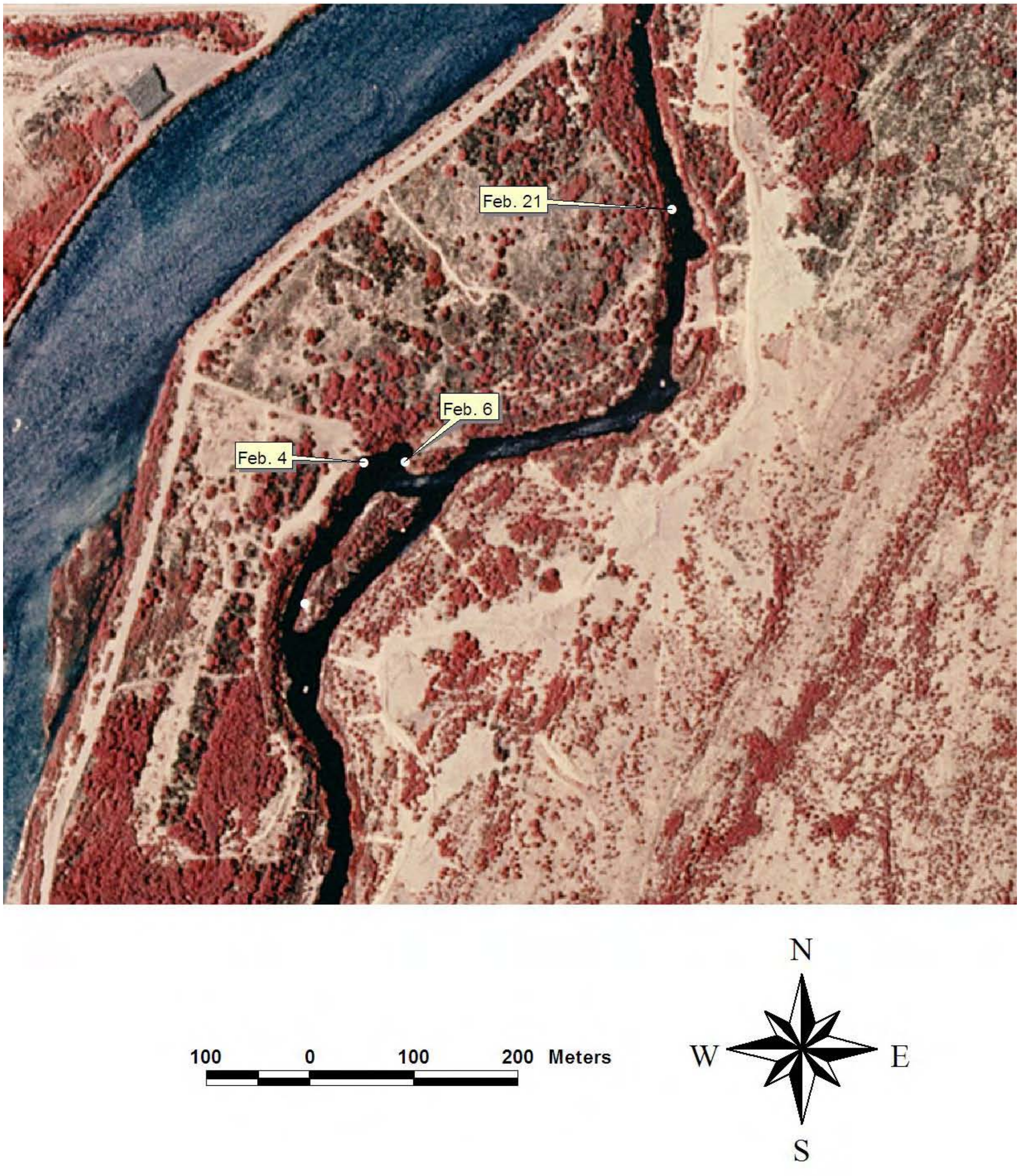

Feb. 21
Feb. 7
Feb. 4
Feb. 9
April 18
March 21
April 2
May 3
100 0 100 200 300 400 Meters
N
W
E
S

651



March 21
April 2 and 18
May 3
Feb. 4
Feb. 9
Feb. 6
Feb. 21
Feb. 7
100 0 100 200 300 400 500 Meters
N
W
E
S

661



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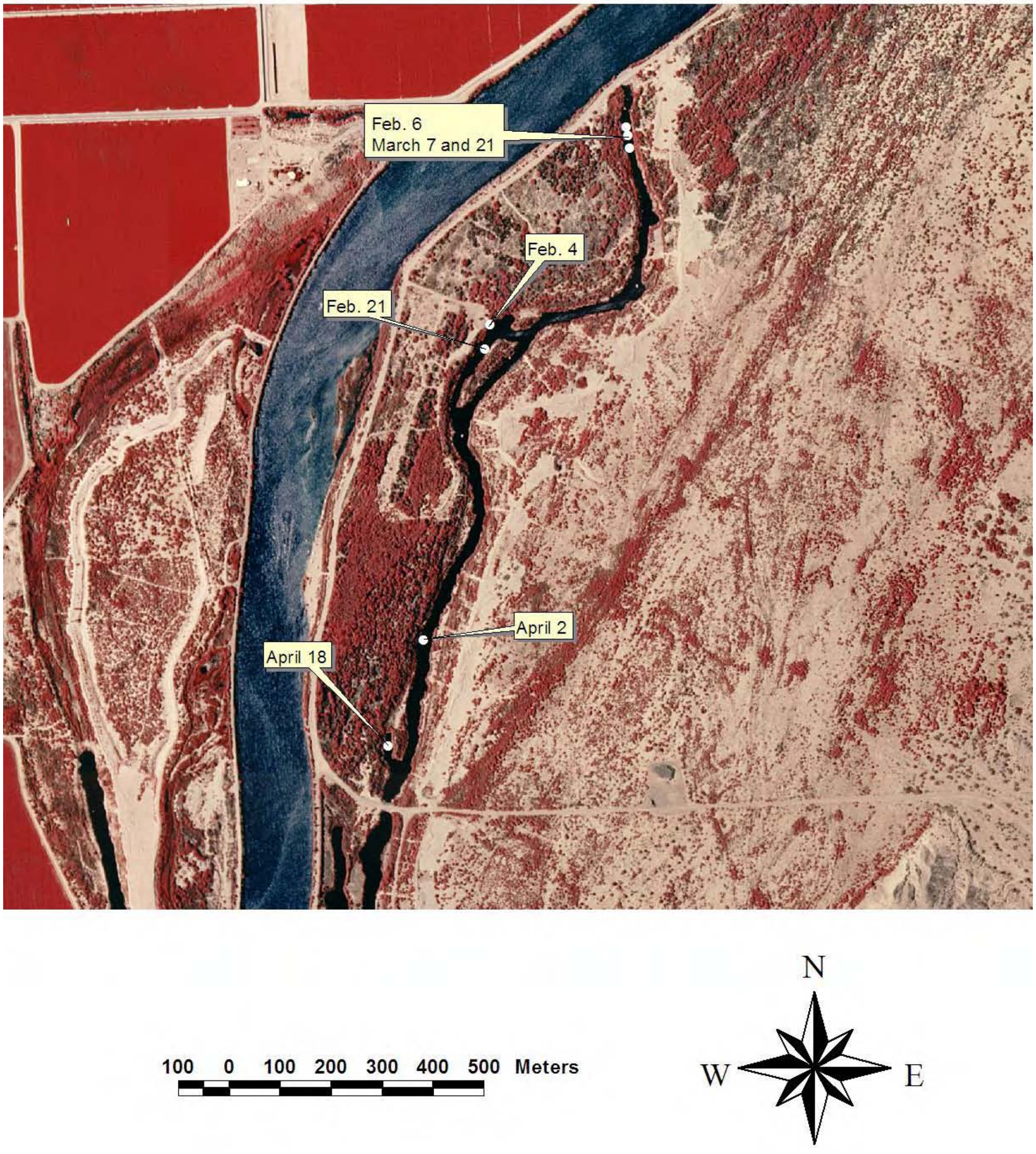
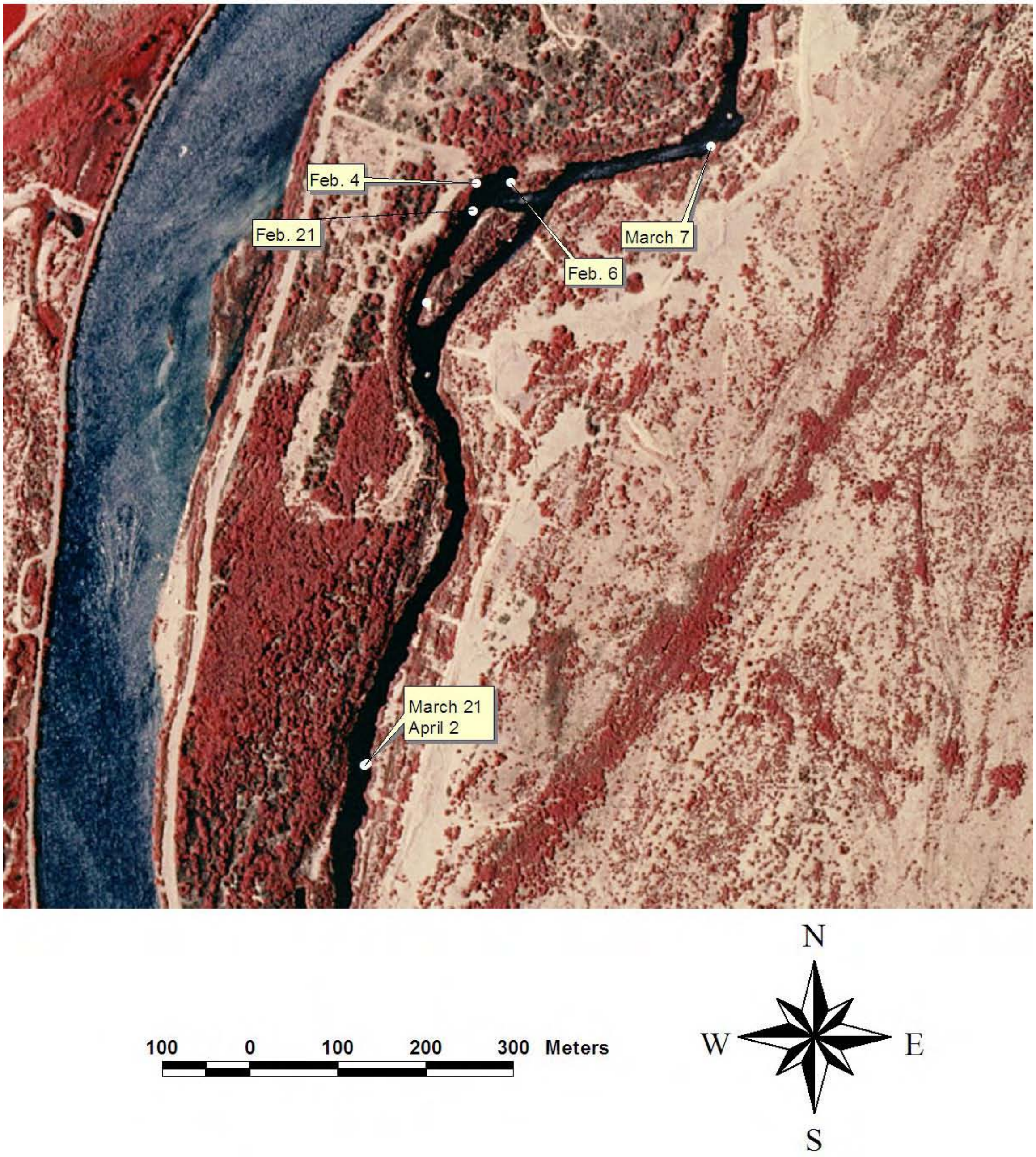
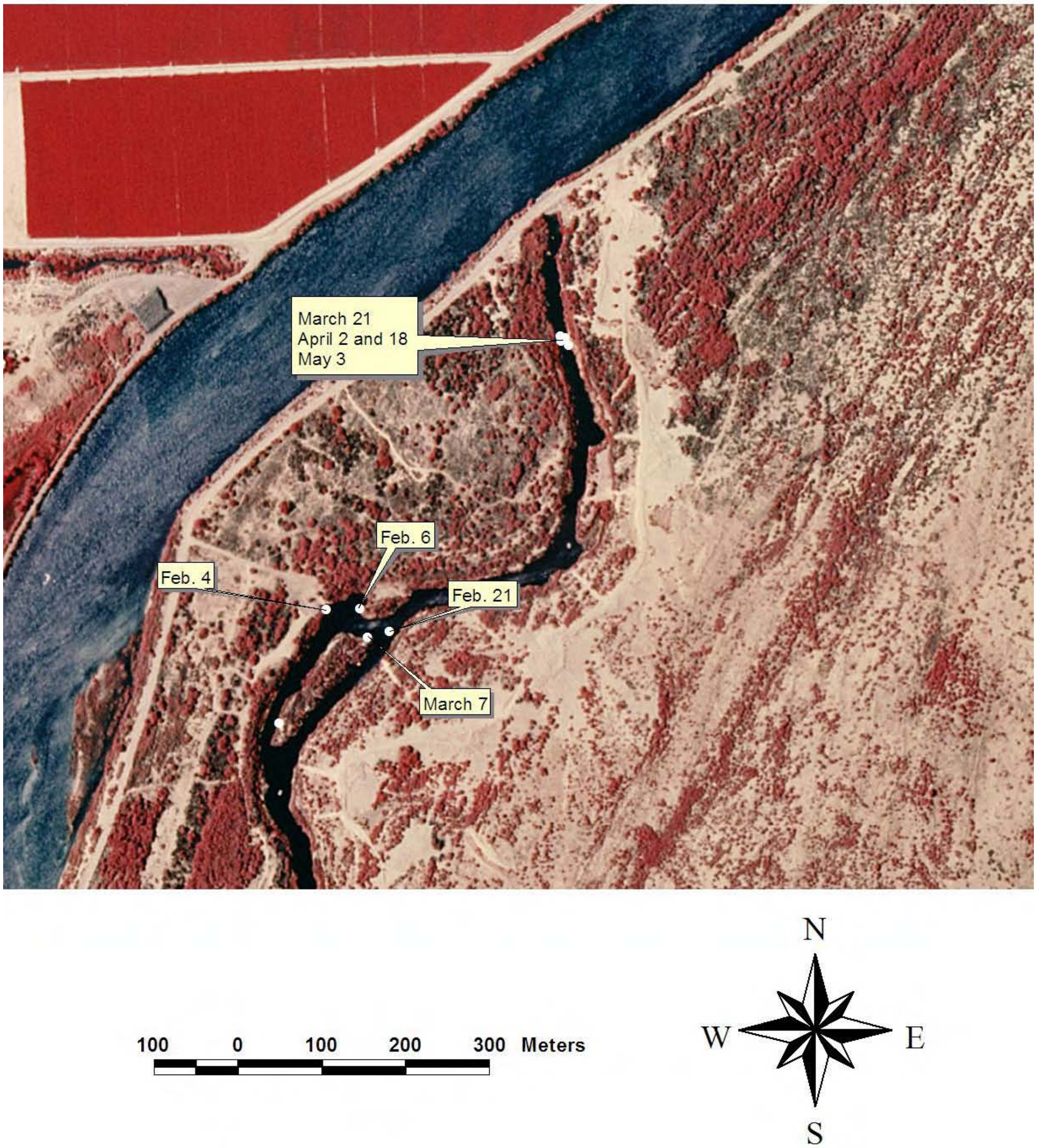

Feb. 6
March 7 and 21
Feb. 4
Feb. 21
April 2
April 18
100 0 100 200 300 400 500 Meters
N
W
E
S

681


Feb. 4
Feb. 21
Feb. 6
March 7
March 21
April 2
100 0 100 200 300 Meters
N
W
E
S

691



March 21
April 2 and 18
May 3
Feb. 6
Feb. 4
Feb. 21
March 7
100 0 100 200 300 Meters
N
W
E
S