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Migration and Passage of Redband Trout in the Donner und Blitzen River, 2007-2009

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Contents

ABSTRACT

Movement of redband trout (*Oncorhynchus mykiss gairdneri*) was tracked between March 2007 and June 2009 in the Donner und Blitzen River (Blitzen River). We had three primary study objectives: 1) examine redband trout spawning locations and spawning migration timing, 2) evaluate redband trout passage at diversion dams, and 3) investigate seasonal migration patterns of redband trout as they relate to stream temperature dynamics. We tagged 96 redband trout with radio transmitters and 706 with PIT tags. Radio tracking included both mobile and fixed station detections. We established PIT tag readers at Cato Bridge (Rkm 1), Busse Dam (Rkm 35), Grain Camp Dam (Rkm 48), and Page Dam (Rkm 76) for additional data on large-scale movement patterns. With the PIT antennas at the three diversion dams, we placed one antenna below the dam and one at the upstream exit of the fish ladders to evaluate the passage delays at each dam. Stream temperature was recorded at 10 locations in the Blitzen River throughout the study. Scales of 257 migratory trout were interpreted for age and spawning history. Our results indicated that the majority of Blitzen redband trout migrated upstream of Page Dam to spawn and that most trout spawned in the mainstem and not the tributaries. Upstream trout migration occurred from March to July, but the peak migration occurred during late April and early May. Passage problems were recorded at two of the three dams evaluated. Trout were delayed longest at Busse Dam and 44% of radio-tagged trout that approached the dam were never able to pass. Trout experienced less delay at Grain Camp Dam and only 8% of radio-tagged trout failed to pass the dam. At Page Dam, which has a recently upgraded fish ladder, trout delays were short and only 5% of trout that approached the dam were unable to pass. Potentially stressful or lethal temperatures (>24.3°C) were recorded at all monitoring locations downstream of Fish Creek, except at the site just below Page Springs. The migratory population ranged in age from 1+ to 5+, but only age 3+ and older trout were reproductively mature. This suggests that the spring upstream migration includes both adult trout seeking suitable spawning habitats and immature trout making a seasonal habitat shift for thermal refuge. A fraction of the PIT-tagged fish were observed to make two or three migrations from below Busse Dam to above Page Dam in the spring and returning back to the lower river in the fall. We recommend prioritizing fish passage at the Busse Dam and Grain Camp Dam for conservation and enhancement efforts.

INTRODUCTION

Redband trout (*Oncorhynchus mykiss gairdneri*), the inland subspecies of rainbow trout, are distributed from northern British Columbia in the north to northern California and Nevada in the south and from the Cascade Divide into eastern Idaho and Montana (Behnke 1992). Redband trout have adapted to a wide variety of habitats across their range and have developed a diversity of life history strategies in order to adapt to local conditions. The species is notable for its plasticity and opportunistic approach in finding and exploiting niches (Northcote 1997). Some trout are able to complete their life-cycle within a single stream reach, but others make long-distance movements to utilize habitats that optimize their growth, survival, and reproduction (Northcote 1997). When such long-distance movement patterns become well-established and involve a large fraction of the population that move at regular periods and return to their natal habitats to spawn, it is considered a migration (Northcote 1997). Rainbow trout populations can be entirely migratory, partially migratory, or entirely resident (Northcote 1997). Redband trout migrations involve moving into the ocean (anadromous), into lakes (lacustrine-adfluvial), or within streams (fluvial) (Dedual and Jowett 1999; Meka et al. 2003; Mellina et al. 2005; Zimmerman and Reeves 2000).

Diversity in the migratory life-histories exhibited by a population of trout can improve the productivity and stability of the population (Rieman and Dunham 2000). Instead of relying on a single habitat for all ontogenetic life stages, migratory trout transition to habitats that are specifically suited to a given stage of development and move once the habitat no longer meets those needs. As a result, migratory redband trout often grow larger than residents (Kunkel 1976, Messmer and Smith 2007). Large size can infer advantages for trout in terms of foraging status, mate selection, and increased fecundity (Kunkel 1976). Populations with both migratory and resident trout are likely to be more resilient to catastrophic disturbance and to temporal variability in habitat conditions that favor one life-history group over another (Rieman and Dunham 2000).

Although migratory behavior has the ability to optimize spatially or temporally heterogeneous habitat for redband trout, there are also costs and risks associated with migrations. Salmonids unable to return to spawning habitat at the correct time may fail to reproduce (Caudill et al. 2007; Naughton et al. 2005). Long-distance migrations are energetically costly (Rand and Hinch 1998) and transitional habitats may be unproductive or increase the risk of predation. Because of these costs and risks, the time in transit may influence growth and survival rates of stream fishes moving between habitat patches (Schlosser 1995). The risks of migration increase on streams that are used for irrigation. Impoundments for irrigation diversion can delay or prevent fish from migrating between habitats. Additionally, diversion canals can lead downstream migrants into sink habitats, isolated from the main channel.

Human activities have dramatically altered both stream habitat quality and connectivity which have led to dramatic declines of redband trout populations. Thurow et al. (2007) summarize how fragmentation has impacted redband trout populations:

> *Many systems that support redband trout remain as remnants of what were larger, more complex, diverse, and connected systems… Where watershed disturbances such as construction of dams, irrigation diversions, or other migration barriers result in loss of connectivity, remaining redband trout populations have been progressively isolated into smaller and smaller patches of habitat. Corridors that provide habitat for migration, rearing, and overwintering*

> *may be critical…The loss of spatial diversity in population structure and of the full expression of life-history pattern may lead to a loss of productivity and stability important to long term persistence.*

Fragmentation of river systems is one of the most serious problems facing redband trout populations, but restoring connectivity by providing passage is often one of the most cost-effective methods of restoration.

The Donner und Blitzen River (Blitzen River) has a relatively abundant migratory population of redband trout that is unique in the Great Basin region of the Western United States. In 2000, the U.S. Congress designated parts of the Blitzen River as the nation's first trout reserve and stated that it would be managed "in a manner that conserves the unique population of redband trout native to the Donner und Blitzen River" (Steens Mountain Cooperative Management and Protection Act of 2000). Despite the national recognition of the value of Blitzen redband trout, little is known about the spawning migrations, seasonal movement patterns, or life-history diversity of the population.

Redband trout likely first occupied the Malheur Lakes Basin 50,000 years ago and have been largely isolated from Columbia Basin populations since the Voltage lava flows of approximately 18,000 years ago blocked the Malheur Gap between the present day Malheur Lake and Malheur River (Behnke 2007; Bisson and Bond 1971). Although hatchery strains of coastal rainbow trout were historically stocked in the Blitzen River, genetic and meristic evidence suggests that genetic introgression has been limited (Behnke 2007; Currens 1990; Phelps et al. 1996). Differences in both fish community composition and intra-species morphology and genetics indicate that there has been little connectivity between the Blitzen River, Silvies River and Silver Creek, the three major drainages in Harney Basin (Bisson and Bond 1971; Currens 1990).

A number of historical changes in the Blitzen River have impacted the redband trout population. Although historical data of redband trout abundance is limited, anecdotal accounts indicate that Blitzen River population, particularly the migratory component, has declined over the last century (Hosford and Pribyl 1983). Extensive channelization of the river and construction of diversion ditches throughout the valley occurred principally between 1910 and 1915. Although some diversion dams were likely constructed during this early period, the current diversion structures were constructed in the 1930s by the Civilian Conservation Corps (Hosford and Pribyl 1983). These dams had fish passage provisions, but the efficiency of the passage structures was likely poor, based on historical reports of trout attempting passage stacking up below the dams (Hosford and Pribyl 1983). The introduction of carp (*Cyprinus carpio*) to Malheur Lake is thought to be an important factor in the decline of the large migratory redband trout and utilization of Malheur Lake (Bowers et al. 1999). The incredibly abundant carp populations may affect the trout population through food-chain interactions and by increasing turbidity in the lake, reducing the ability of the sight-foraging trout to find food (Bowers et al. 1999). Numerous efforts to reduce the carp populations including chemical treatments, physical barriers, and even dynamite have had only short-term success.

Despite the many challenges facing the Blitzen River redband trout, there remains a strong population with diverse life-histories. The Malheur Lakes Basin redband trout population has been estimated at over 400,000 trout age 1+ or greater, accounting for about 44% of the entire Great Basin population (Dambacher et al. 2001). Within the Malheur Lakes Basin, only the Blitzen River population has a migratory life-history expression.

Although migratory redband have been documented in other Great Basin rivers, the loss of the migratory life-history from these basins may be more common (Bowers et al. 1999; Tinniswood 2007). The migratory movements of redband trout in the Blitzen River have not been extensively studied. A telemetry project conducted by U.S. Fish and Wildlife Service and Oregon Department of Fish and Wildlife in which 17 fish were radio-tagged indicated that there were migratory redband in 2000, but only a small percentage of those fish passed all diversion dams (USFWS unpublished data). Evidence for the persistence of a migratory population was bolstered by a trapping and tagging effort in 1999 and 2000 in which fish were caught in traps at the diversion dams after swimming up through the fish ladders (USFWS unpublished data).

This study was initiated to investigate the movement patterns and life-history of the Blitzen River redband trout, but it quickly became apparent that the details of the migration were inextricably connected to the fish passage conditions in the river. We collected field data from March 2007 to June 2009, which involved tracking redband trout movement using both radio telemetry and Passive Integrated Transponder (PIT) tags, monitoring of stream temperature and stream discharge, and interpreted age and spawning history of migratory fish through scale analysis. The goal of the project was to describe the movement patterns of migratory redband trout in the Blitzen River and to evaluate the impact of passage barriers. Specific objectives were to:

1. Examine redband trout spawning locations and spawning migration timing,

2. Evaluate redband trout passage at the diversion dams,

3. Investigate seasonal migration patterns of redband trout as they relate to stream temperature dynamics.

STUDY SYSTEM

This study was conducted in the Donner und Blitzen River, which is located in the high desert region of south-eastern Oregon (Figure 1). The Blitzen River drains into Malheur Lake and has no further outlet to the ocean. This basin has an area of 2,045 km^2 and a drainage density of 0.33 km/km^2. Its elevation ranges from 1,248 m at Malheur Lake to 2,967 m at the top of the Steens Mountain. The Blitzen River mainstem is 128 kilometers long. The tributaries, most of which drain the west slope of the Steens Mountain, flow through deep, glacially-carved valleys of basalt and andesite bedrock, and have a parallel drainage pattern. Major tributaries included in the study were Indian, Fish, and Bridge creeks and the Little Blitzen River (Figure 1). Mean annual precipitation in the basin ranges from less than 40 cm at lower elevations to over 100 cm at the higher mountain elevations (Taylor 2005). Most precipitation falls as snow during the winter months and most runoff occurs as snow melt during the spring.

The Blitzen River Basin has five vegetation zones: 1) the alpine bunchgrass/ tundra zone, 2) the aspen/ upper sagebrush/ grass zone, 3) the juniper zone, 4) the sagebrush zone, and 5) and the shadscale/marsh zone (Mansfield 2000). Land management in the Blitzen River Basin includes: 61.1% Bureau of Land Management as Steens Mountain Wilderness, Wilderness Study Area, or O&C Lands, 12.7% United States Fish and Wildlife Service as the Malheur National Wildlife Refuge, 23.8% private, and 2.3% Oregon Department of State Lands.

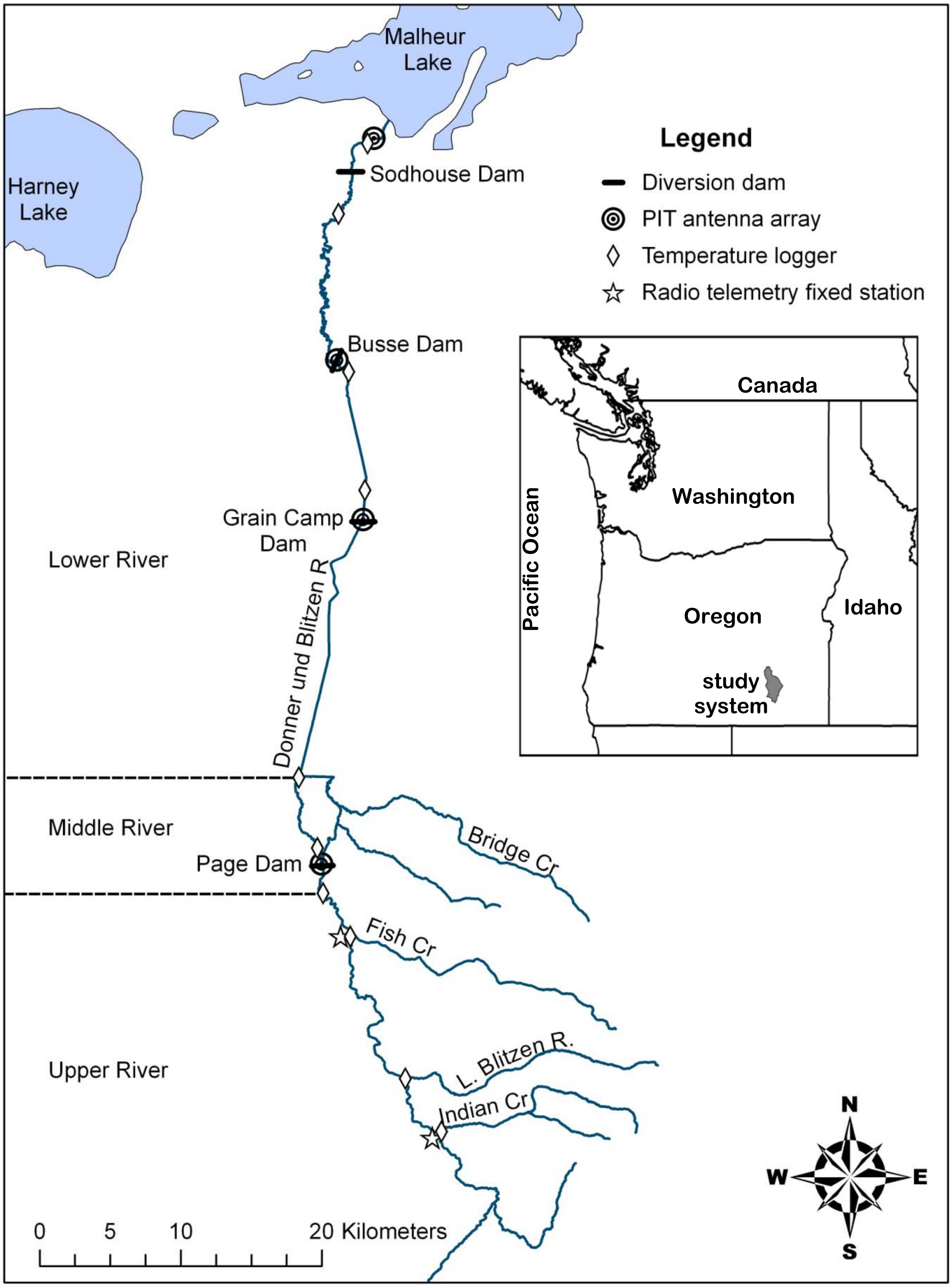

Figure 1. Map of the study site illustrating the locations of diversion dams, PIT tag readers, temperature loggers, and radio telemetry fixed stations.

For the purposes of this study, we divided the Blitzen River into three sections (lower, middle, and upper river) based on general changes in stream morphology. The lower river covers the area from the mouth of the Blitzen River to the confluence with Bridge Creek at river km 67. This stream section consists of low-gradient and a highly sinuous channel, except where artificially straightened, with predominantly sand and silt bedload. Because there is little gravel in this segment, it is not likely to provide trout spawning habitat. The middle river extends from Bridge Creek up to the Page Springs Weir at river km 79. The middle river is characterized by a low-gradient, unconstrained channel with pool-riffle habitat and gravel as the primary substrate type. The upper river, above the Page Spring Weir, is constrained by steep canyon walls and is characterized by boulder-strewn rapids interspersed with pockets of gravel.

The Malheur National Wildlife Refuge (MNWR) has four primary diversion dams on the Blitzen River that are operated primarily during the spring snowmelt period to maintain wetland habitat for breeding waterfowl. Three of those dams (Sodhouse, Busse, and Grain Camp) are located in the lower river segment and the fourth (Page) is located in the middle river segment (**Appendix A**). Additionally, a meter high concrete gaging station weir (Page Spring Weir) is located approximately 1.5 km upstream of the southern boundary of the MNWR. Sodhouse, Busse, and Page dams have Denil fish ladders and Grain Camp dam has a jump-pool fish ladder. The Page Spring Weir has no passage facility but is low enough to allow some fish passage.

METHODS

Redband trout were caught in fish traps located at the upstream end of fish ladders at Sodhouse, Busse, and Page dams and by angling in the vicinity of the dams. Traps were set 4 to 7 days a week from late March to early June of 2007, 2008 and 2009. Angling with artificial flies or lures was employed below the dams in April and May each year in order to increase the number of trout sampled. Additionally, trout were sampled by angling for three days in late March 2008 to catch middle river fish before migrants began moving upstream from the lower river. With the exception of the March 2008 angling effort, sampling methods specifically targeted migratory fish. Total weight (g) and fork length (FL mm) were recorded for each trout captured. Scales were taken from a subset of trout. Sexual maturity was assessed for radio-tagged fish based on external characteristics and by examining gonads during the tagging surgery. The sex of the trout was recorded for mature individuals.

We tagged all redband trout over 35 g with PIT tags and 96 of the larger trout with Lotek Wireless® radio telemetry transmitters. Texas Instrumnets® PIT tags, 23 mm in length and 1 g in weight, were inserted into the body cavity of smaller trout (FL < 300 mm) and the dorsal sinus of the larger trout (FL ≥ 300 mm). Trout were selected for radio tagging based on minimum size criteria and seasonal timing in an attempted to deploy tags throughout the migration season. Trout were radio tagged regardless of condition except in the case of severe injury. In 2007, we used 36 MCFT-3A (16 g) and 10 MCFT-3FM (11 g) tags. In 2008, we used 4 MCFT-3A (16 g), 2 MCFT-3FM (11 g), and 16 NTC-6-2 (4.5 g) tags. In 2009, we used 2 MCFT-3A (16 g), 2 MCFT-3FM (11 g), and 15 NTC-6-2 (4.5 g) tags. Tag weight averaged 1.4% of the body weight of the fish and ranged from 0.5% to 2.5%. All surgeries were conducted on site at the capture location. Trout were anesthetized in an aerated holding tank with approximately 100 mg/l tricane methanesulphonate (MS-222) solution with 120 mg/l of bicarbonate buffer.

Anesthesia typically occurred in 2-4 minutes. For the surgery, trout were placed ventral side up in a wet, foam cradle. The gills of the fish were irrigated with anesthetic solution or stream water during the surgery. A 1.5-2.5 cm long incision, just wide enough to accommodate the transmitter, was made on the fish anterior to the pelvic girdle of the fish, offset 2 cm from the mid-ventral line. A cannula shielded with plastic tubing was used to guide the transmitter antenna to the exit location posterior to the pelvic fin (Ross and Kleiner 1982). After placing the transmitter in the body cavity, the incision was closed with 2 to 3 sutures of monofilament absorbable material with a simple interrupted 3-2-1 surgical pattern (Wagner et al. 2000). All surgical equipment was disinfected between uses with Benz-all®. Trout were allowed to recover in a covered tank with cool stream water for at least 15 minutes and until they were fully responsive before being released at the capture location. Trout caught in the traps were released upstream of the dam.

Radio-tagged trout were located using Lotek Wireless® SRX 400 receivers and their positions recorded with a hand-held GPS unit. Fish tracking was done on foot, from a pick-up truck, from the air with a small plane, and with fixed stations. Tracking intensity was the highest during the spring spawning migration (March to June) with average fish relocations of 1.5 times per week in 2007, 1.7 times per week in 2008, and 2.5 times per week in 2009. During summer, fall, and winter, trout were tracked at approximately monthly intervals. Two telemetry fixed-stations were installed in the upper Blitzen River (Figure 1) to ensure migrating trout would be detected if long-distance movements took place between scheduled tracking. Fish detection precision ranged from 40 m when tracking was carried out on foot and triangulation was possible, to 100 m if done from a vehicle. Aerial tracking precision was estimated at about 160 m based on what was reported in similar aquatic aerial telemetry studies (Roberts and Rahel 2005). Due to high water and high turbidity during the snowmelt period, it was rarely possible to confirm the spawning location of individual trout. Most radio-tagged fish were confirmed to be sexually mature during the tagging process. Direct spawning observations were limited to tracking radio-tagged trout to spawning aggregations on two occasions, and observing a female trout with a telemetry antenna near her redd on one occasion. Although spawning location could not often be confirmed, most trout were redetected multiple times near the upstream-most site. Passage at diversion dams was evaluated using radio telemetry for any trout that approached a dam at least 10 km upstream of the tagging location. Since the exact passage time could not always be determined, we calculated the minimum passage delay as the number of days from the time the trout was first detected within 0.5km below the dam until it was detected above the dam. Trout that moved at least 10 km upstream to a dam, but were never detected above the dam, we considered to have failed passage.

Trout location coordinates from radio telemetry and PIT tag antenna detections were imported into ESRI ArcGIS®. Detection locations were related to a 1:24:000 BLM stream layer rectified to aerial photographs. The coordinates of each trout position were then located along the stream route to determine the relative location from the river mouth in river kilometers (Rkm). Individual movement histories of trout were constructed by plotting the position (Rkm) against the date and time of all detections.

We determined the large-scale movements and passage rates of PIT-tagged fish with stationary, swim-through antennae and by scanning recaptured fish with hand-held detectors. PIT tag antennae arrays (Figure 1) were installed in April 2007 at Page Dam and in June 2007 at Busse Dam, Grain Camp Dam, and Cato Bridge. In March 2009, the Cato Bridge reader was moved to Sodhouse Dam. At each of the three dams, one antenna was located 30 to 50 m downstream of the dam, a second antenna was set in the downstream entrance of the fish ladder, and a third antenna was placed near the upstream exit of the ladder. The antennas below the ladders spanned the entire river channel (10 to 15 m wide). The bottom of the antennas followed the contours of the channel, and the top of the antenna was a maximum of

0.7 m above the bottom. During most flows, the detection field filled the entire wetted channel, and at high flows, only the upper portion of the water column was outside the detection field. Antennas at the fish ladders were rigid and rectangular with dimensions that matched those of the ladder. Cato Bridge had two 0.7 m by 7 m semi-rigid rectangular antennas with detection fields that filled most of the channel except the area near each bank. Detection efficiency varied between antennas and through time due to interference of multiple tagged fish entering detection field simultaneously, tag angle within the antenna field, or equipment failures. The antenna read-ranges were checked weekly during the high-flow spring season and monthly the rest of the year. The Busse antennae had periodic power failures in the summer of 2007 and the Grain Camp antenna was damaged from ice formation and was not functioning from November 2007 through February 2008. Passage time was calculated as the time between a trout's first detection at the PIT antenna below the dam and the first detection at the PIT antenna at the ladder exit.

Large-scale movement patterns of trout were summarized for trout that were PIT-tagged in the first year of the study and continued to be redetected in subsequent years of the study. Individual movement histories were recreated based on the sequence of movement directions detected by the PIT antennas. Time, location, and direction of these detections were summarized in monthly time-steps for comparison with seasonal changes in temperature and discharge conditions.

Trout scales were interpreted for age and occurrence of prior spawning events. Scales were collected from 257 redband trout. In preparation, scales were cleaned, mounted on a gum card, and impressions were made on plastic sheets using a heat press. The scale impressions were viewed on a microfiche reader. Growth annuli and spawning checks were interpreted independently by two readers, and any scales that were interpreted differently were removed from the sample. We used the information from the scales to determine age distribution of the migratory portion of the population, age at which fish spawned, and whether or not repeat spawning occurred in the population.

We recorded water temperature data at 30-minute intervals at 10 locations on the Blitzen River using Onset Hobo® temperature loggers. In 2007, one temperature logger was damaged and one was exposed to air, while in 2008, one temperature logger was exposed to air; therefore, data recorded by these units were not included in any of the analyses. We summarized stream temperatures for both summer and winter. For each temperature logger, a 7-day moving average was calculated from the maximum temperature recorded each day. The U.S. Geological Survey collected river discharge data at 15-minute intervals at the Page Springs Weir gaging station, located immediately upstream of the Malheur Nation Wildlife Refuge boundary.

RESULTS

During the study, we caught 711 redband trout; 91 were tagged with both a radio tag and a PIT tag, 615 were tagged only with a PIT tag, and 5 were tagged only with a radio tag. In all three years, trout were caught in the traps from March to June with a peak migration in late April/ early May (Figure 2). Substantially more trout were caught in 2007 than in either 2008 or 2009 though the trapping and angling effort was equivalent in each of the years (Table 1). Also, there was a smaller proportion of large fish caught in the second and third year of the study. The median fork length was 345 in 2007, 285 in 2008, and 266 in 2009 (Figure 3). Age and spawning history interpretation conducted on trout caught in 2007 and 2008 indicated that the migratory trout ranged in age from 1+ to 5+. No spawning checks were detected prior to the age-3 annulus on any scale. Scales of age 4+ trout indicated a 51% (26 of 50 scales) occurrence of prior spawning. Out of 6 age 5+ trout, 3 had spawned once before, 2 had spawned twice before, and one had not previously spawned.

Table 1. Number of trout caught in traps at each dam and by angling in each year of the study.

	2007		2008		2009	
Location	Trap	Angling	Trap	Angling	Trap	Angling
Sodhouse Dam	81	2	6	1	15	4
Busse Dam	221	12	39	13	19	14
Grain Camp Dam	-	29	-	2	-	0
Page Dam	164	2	15	5	34	1
Other	10	2	0	14	0	1
Total	473	47	60	35	69	21

The majority of the radio-tagged trout migrated upstream from the tagging location to spawn. In most cases, sexual maturity was confirmed for radio-tagged trout during the tagging surgery. All radio-tagged trout were believed to be ready to spawn except 4 immature, 6 unknown, and 3 that had already spawned. Of the 96 trout radio-tagged during the study, 74 migrated at least one km upstream of their tagging locations (**Appendix B and C**). Of the trout that migrated, 43 were tagged in the lower river and 31 were tagged in the middle river. The longest migration recorded was 91 km. Over the course of the study, one radio-tagged trout migrated to the upper Blitzen River past the confluence with Indian Creek, one migrated into Indian Creek, six migrated into the Little Blitzen River, and one migrated into Fish Creek. The percentage of radio-tagged trout that migrated at least as far upstream as the confluence of Fish Creek was 21% (10 of 46) in 2007, 52% (16 of 31) in 2008, and 42% (8 of 19) in 2009. The percentage that migrated to the reach between Page Dam and Fish Creek was 24% (11of 46) in 2007, 19% (6 of 31) in 2008, and 21% (4 of 19) in 2009. Except for the few trout detected in tributaries, most probably used spawning habitats located in the mainstem of the Blitzen River. Out of the 43 trout tagged in the lower river that made an upstream migration, 14 never reached spawning habitats, which likely only occur upstream of the confluence with Bridge Creek.

Most trout captured first in the lower river segment subsequently migrated upstream. Of the trout tagged in the lower river, 51% and 60% were redetected at least 10 km upstream in 2007 and 2008, respectively. Over the course of the study, 15% of trout PIT-tagged in the lower river moved at least as far as Page Dam. Twenty-four of the trout PIT-tagged in 2007 were detected during subsequent years of the study, providing information about long-term migration patterns (Figure 4). These trout moved upstream during the spring high-flow period from March to June, did not make long-distance movements in the summer months as indicated by the lack of detections at the PIT readers, and tended to move downstream into the lower river during fall and early winter period. In 2008, the fish repeated the migration pattern, moving upstream in the spring and downstream in the fall. Four trout made a third upstream migration in the spring of 2009. The individual movement histories of the four trout tracked for three spring migrations illustrate the pattern of repeat migration (Figure 5).

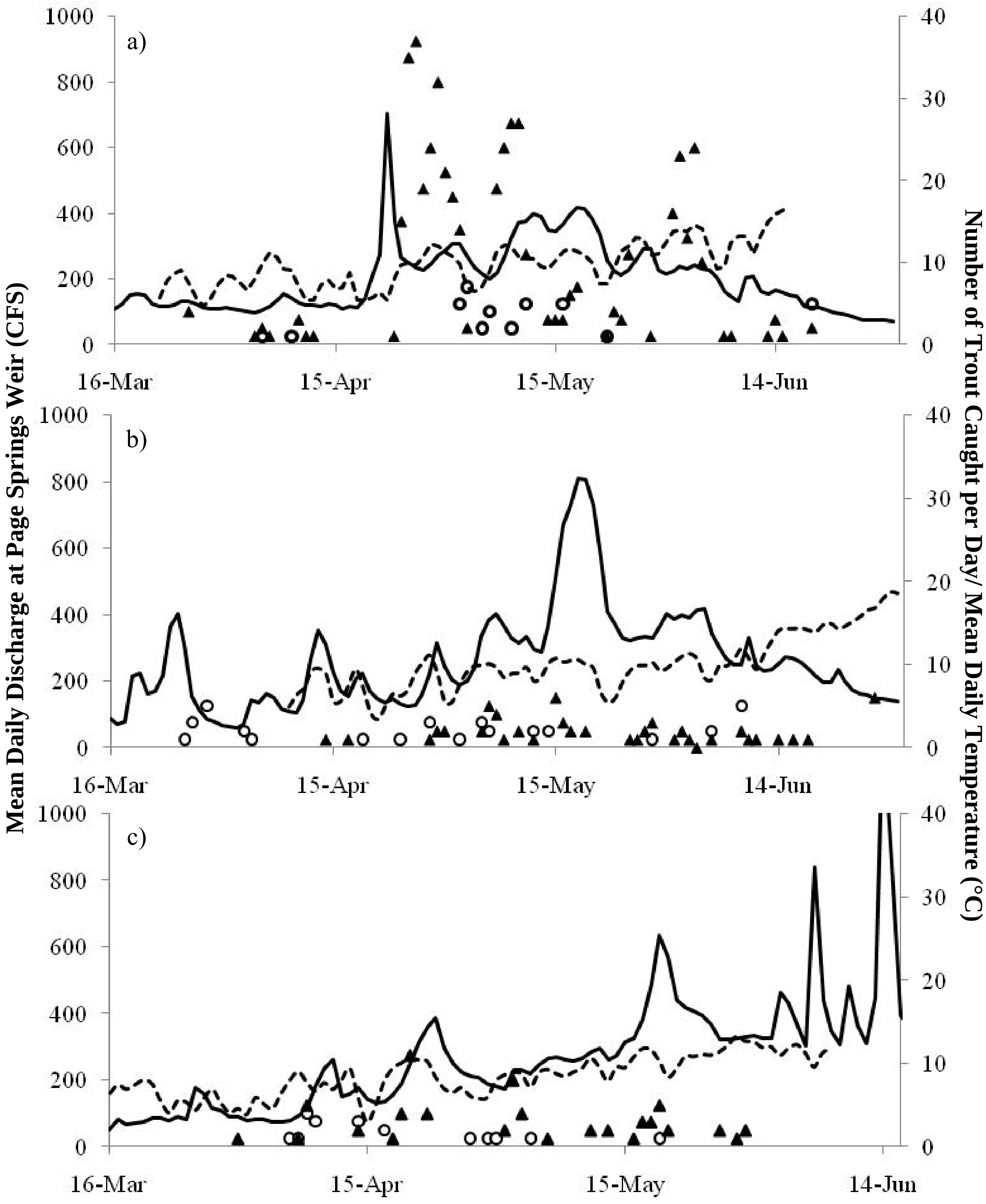

Figure 2. Number of fish captured in traps (triangles) and by angling (circles) daily during the spring of a) 2007, b) 2008 and c) 2009. The solid line depicts the mean daily discharge at the Page Spring weir and the dashed line shows the mean daily temperature above the confluence with Bridge Creek.

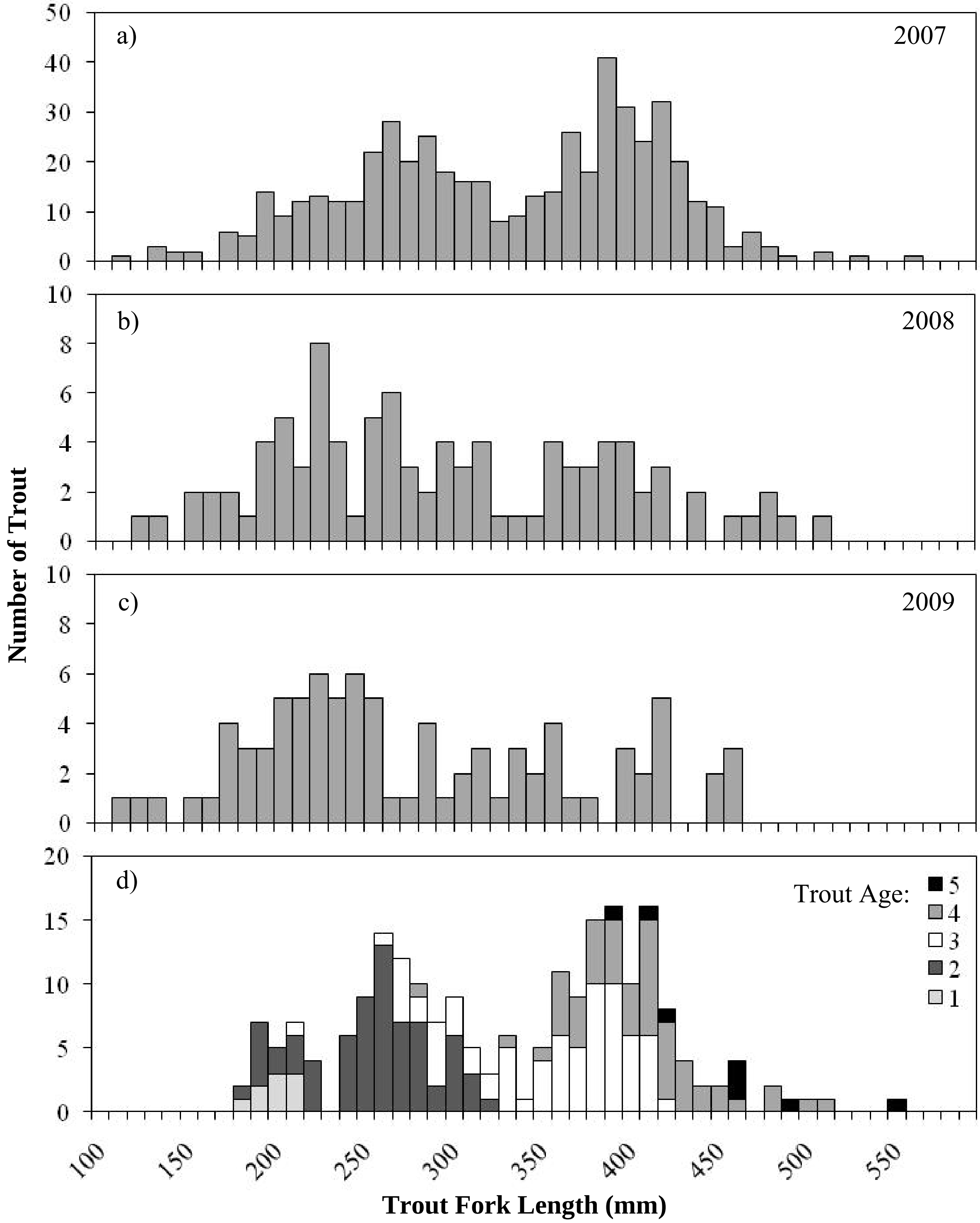

Figure 3. Histogram of redband trout lengths a) for all trout captured in 2007, b) for all trout captured in 2008, c) all trout captured in 2009, and d) for the subset of fish from 2007 and 2008 that had ages interpreted from scale samples. Note different vertical axes.

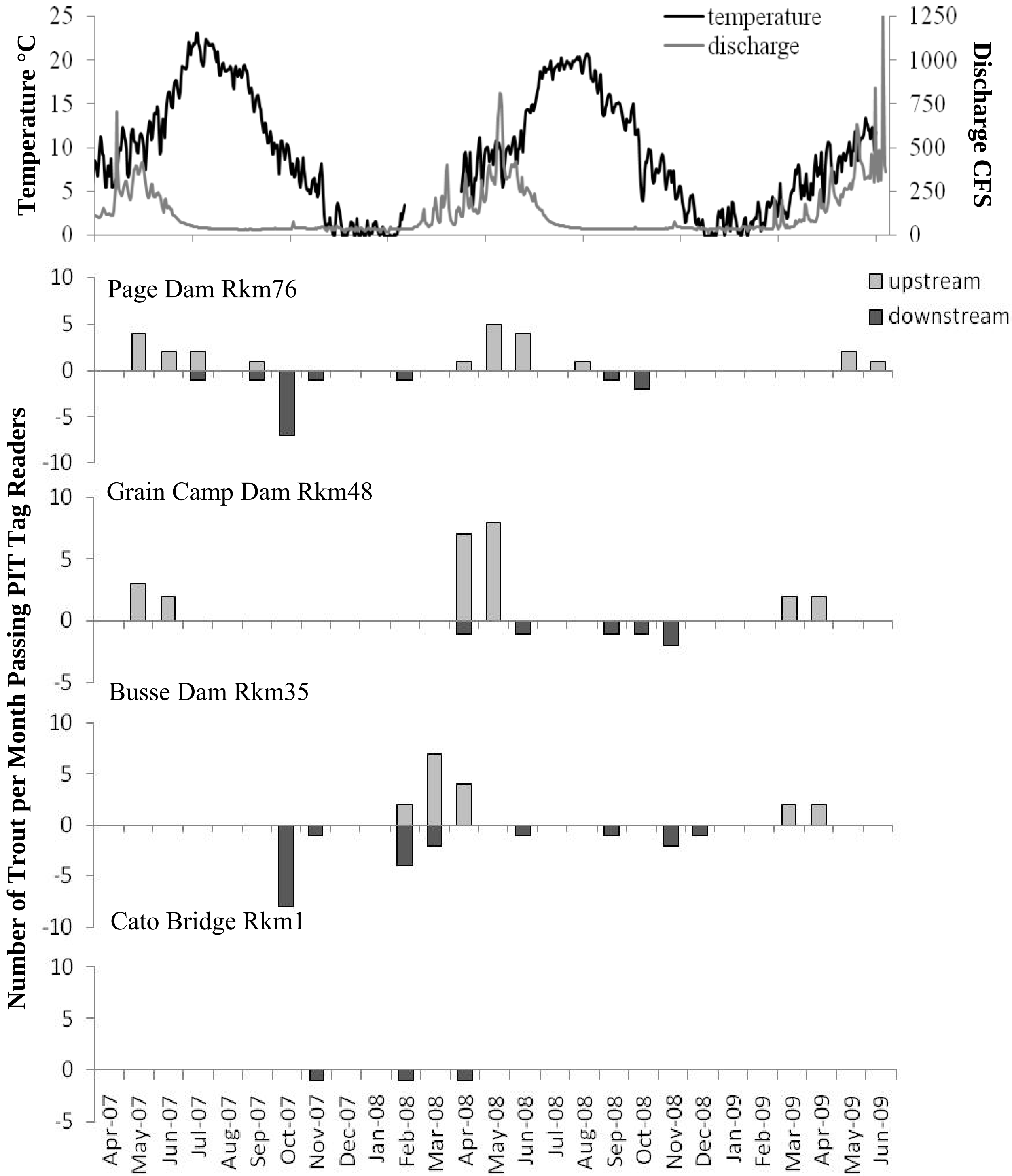

Figure 4. Top panel: Mean daily temperature recorded upstream of Bridge Creek and the mean daily discharge at the Page Springs Weir. Bottom panel: Directional movements of 24 redband trout PIT-tagged in 2007 with PIT tag detections in subsequent years. The vertical axis depicts the number of fish detected at each PIT antenna each month where negative numbers represent downstream moving trout and positive numbers represent upstream moving trout. The horizontal axis shows a common date for both panels.

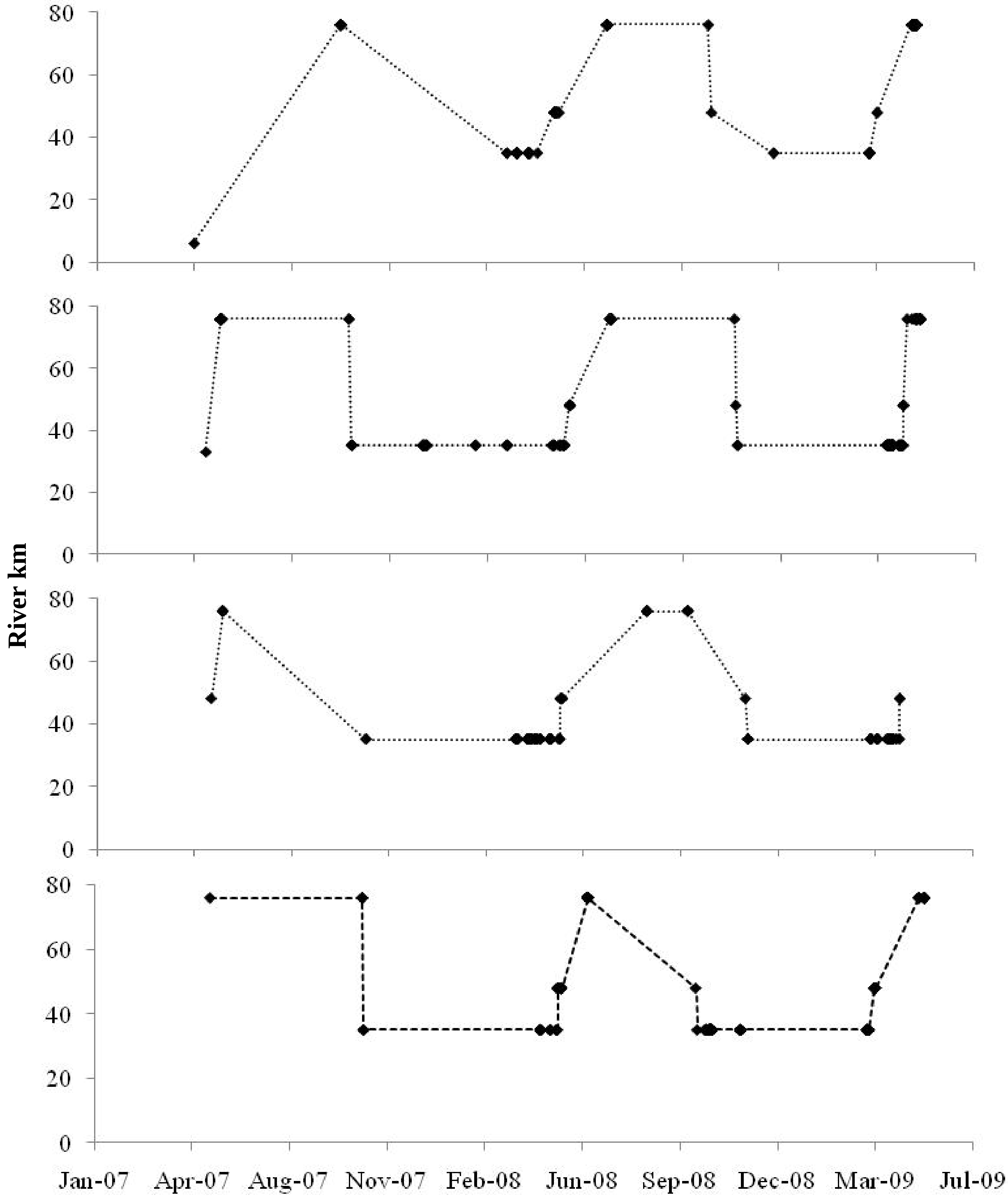

Figure 5. Movement patterns of four redband trout that were tagged in 2007 and tracked with PIT tag readers located at Rkm 1, 35, 48, and 76 for 27 months. The vertical axis indicates the detection location in Rkm, and the horizontal axis indicates the detection date. Dotted lines connect the nodes for clarity but do not indicate known trout locations between successive detections.

The Blitzen River had extreme water temperatures in both the summer and winter periods. The maximum values from the moving average were compared to both the ultimate upper incipient lethal temperature (UUILT), the maximum temperature a fish can tolerate over a prolonged period, and the critical maximum temperature (CMT), the temperature at which a fish loses equilibrium. We used the UUILT of 24.3°C (Bear et al. 2007) specific to rainbow trout, and the CMT of 29.1°C (Rodnick et al. 2004) specific to Great Basin redband trout. Maximum 7-day mean of maximum daily temperatures (7-day max) exceeded the UUILT for rainbow trout at all of the lower river temperature loggers in 2007 and at the two temperature loggers that were farthest downstream in 2008 (Figure 6). The temperature logger located at the Page Springs Weir also recorded 7-day max that exceeded the UUILT during both years of the study. The hottest temperatures occurred between July 14th and August 1st in 2007 and between July 7th and August 16th in 2008. Water temperatures in the Blitzen River generally warmed from upstream to downstream, but cooled notably at Page Springs, where the 7-day max never reached the UUILT. Maximum 7-day mean of maximum daily temperatures (7-day max) did not exceed CMT at any of the monitoring sites. Summer thermal refuge, where the 7-day max did not exceed the UUILT, occurred near Page Springs and above Fish Creek. Winter temperatures were low throughout the river during December and January (Figure 7). The temperature was slightly warmer in the upper river and Page Springs appeared to have a warming influence, but the winter temperatures did not average more than 3°C at any monitoring station. Summer temperatures were not recorded in 2009.

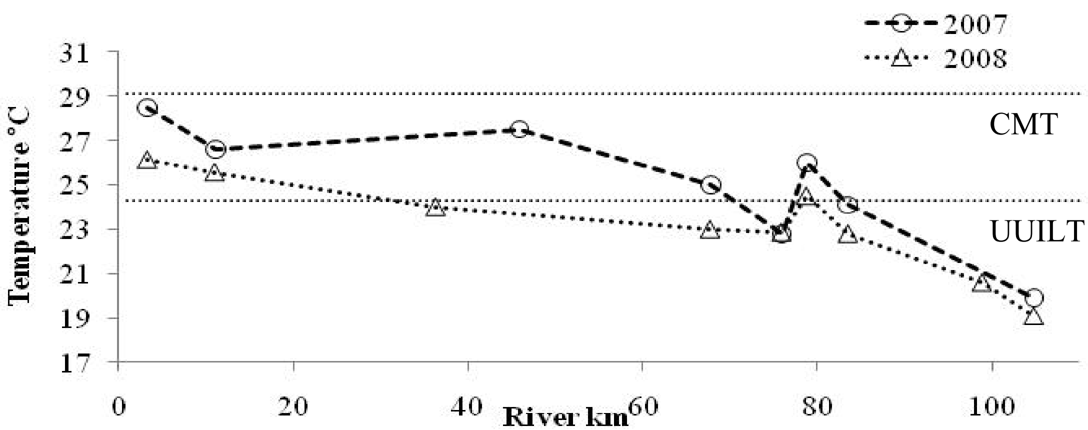

Figure 6. Maximum 7-day mean of maximum daily temperatures for the 2007 and 2008 at 10 locations in the Blitzen River. The ultimate upper incipient lethal temperature (UUILT) and critical maximum temperature (CMT) for redband trout are shown for context.

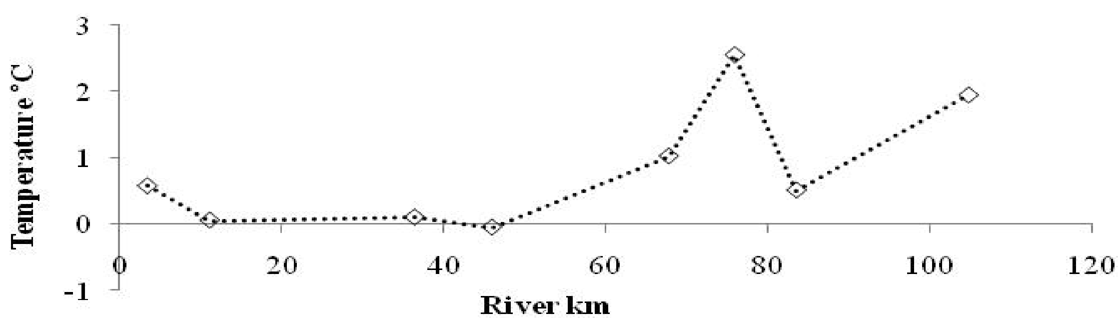

Figure 7. Mean temperature during December 2007 and January 2008 at eight locations in the Blitzen River.

Redband trout passage delays were evaluated at three dams on the Blitzen River using PIT tag antennas in 2008 and 2009 (Figure 8). Kaplan-Meyers curves (Allison 1995; Castro-Santos and Haro 2003) show the rate of passage as the proportion of individuals available to pass a given dam. Trout were considered available to pass as soon as they were detected at the PIT antenna downstream from the dam. The proportion of trout available to pass was the number waiting to pass out of the total number that arrived at the base of each dam. When an individual trout successfully passed the fish ladder (indicated by a vertical drop of the line in the graph), the proportion of trout available to pass decreased. If we lost track of a fish and never recorded a successful passage, that individual was censored and removed from the sample population (noted by the circles in the graph).

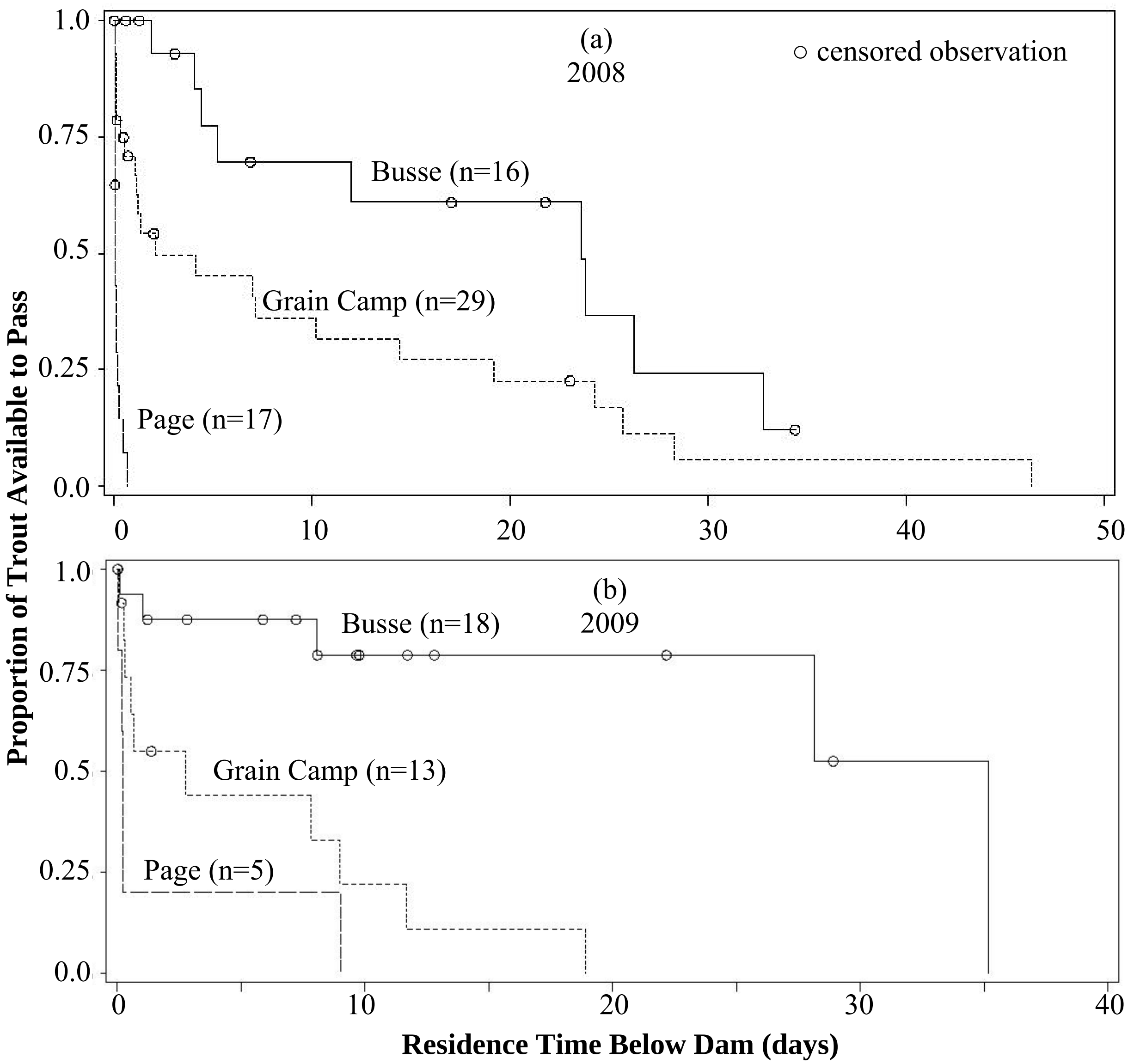

Figure 8. Kaplan-Meier curves depicting the rate of fish passage in days at Busse, Grain Camp, and Page dams during a) 2008 and b) 2009. Trout became available to pass when initial detected below the dam and the proportion available decreased each time a trout successfully passed. Circles indicate censoring times of individuals that were not detected passing and were no longer detected below the dam.

Censoring could be the result of trout failing to pass or an undetected passage event, but trout were considered to be delayed by the structure as long as they continued to be detected below the dam. Upon a passage event following censoring, the proportion was calculated from a smaller population, thus the vertical drop is greater following censoring of individuals. In both years, migrating trout were delayed longest below Busse Dam followed by Grain Camp Dam. Passage delays were relatively brief at Page Dam during both years. The high number of censored cases at Busse Dam, especially in 2009, could have been caused either by trout that failed to pass or by trout passing via an alternative route not monitored by PIT antennas. The Denil ladder at Busse was built into the previous jump-pool ladder and it is likely that some fish used the remnants of the jump-pool structure to pass.

Differences in fish passage among the three dams were also apparent from radio telemetry data. Fish passage was evaluated during 2007, 2008, and 2009 based on 16 trout at Busse Dam, 26 trout at Grain Camp Dam, and 19 trout at Page Dam (Table 2). At Busse Dam, 9 of the 16 trout that approached the dam were unable to pass. The trout that passed Busse Dam experienced a mean minimum delay of 9.9 days. Out of 26 trout that approached Grain Camp Dam, 24 were able to pass the dam. Trout experienced a mean minimum delay of 3.0 days at Grain Camp Dam. At Page Dam, 18 out of 19 trout that approached the dam were able to pass, and those that passed experienced a mean minimum delay of 1.1 days. Although the passage delays from the radio telemetry data are shorter than those calculated from the PIT tags, it was not possible to determine exactly when the trout arrived at the dam or exactly when they passed, therefore these data likely underestimate the total duration of delays. The radio telemetry assessment of passage was consistent with the finding of the PIT tag assessment and also provided information about the proportion of the trout that were not able to pass the dams at all. Although post-tagging mortality of migrating trout could have confounded the passage results, we feel that it is unlikely since the fish had to move over 10 km upstream from the tagging location be included in the analysis and the passage delay results were highly consistent with the PIT tag data.

Table 2. Percent of trout able to pass and the mean minimum delay (days) at Busse, Grain Camp and Page dams based on radio telemetry tracking

	2007		2008		2009		Total	
Dam	Percent Passing	Mean Delay	Percent Passing	Mean Delay	Percent Passing	Mean Delay	Percent Passing	Mean Delay
Busse	50%	5.5	100%	14.0	50%	28.0	56%	9.9
Grain Camp	92%	2.9	90%	2.8	100%	3.7	92%	3.0
Page	91%	1.1	100%	0.0	100%	4.5	95%	1.1

DISCUSSION

There is a highly mobile fraction of the redband trout population in the Blitzen River that utilizes an extensive portion of the watershed to complete their life cycle. Effective conservation of that migratory group will best be achieved by improving fish passage. This redband trout population has adapted a unique migratory pattern that involves annual, long-distance migrations to seasonally suitable habitats. In the fall, trout move into the lower river, and when available, into Malheur Lake. This portion of the watershed not only provides winter refuge habitat but a rich forage base that provides high growth potential. Trout captured in this portion of the watershed were substantially larger than trout captured from tributary streams in the Blitzen watershed. Results from a concurrent study that sampled the watershed upstream from Page Dam captured no trout larger than 250 mm in Blitzen River tributaries (http://oregonstate.edu/dept/ODFW/NativeFish/GreatBasinRedband.htm). In contrast, the overwhelming majority of fish captured from the lower and middle river portions of the mainstem exceeded 250 mm in length. In the summer, water temperatures approach critical maxima in the lower portion of the watershed. This occurs because of natural thermal regimes and water diversion. In response to these high temperatures, trout migrate upstream to reaches with cooler temperatures. Additionally, mature fish must migrate upstream to access gravel substrates and well-oxygenated water necessary for spawning. Because these habitats are spatially segregated, successful completion of this life cycle is partially dependent on successful passage around diversion dams. A trout that makes an annual migration may encounter each of these dams many times within its lifespan. Long delays below the dams can have negative repercussions on a trout seeking different habitats and can increase the risk of predation. For spawning trout, timing is of paramount importance: over-ripening of eggs can lead to reduced fertility, eggs must be deposited early enough to avoid dewatering as flows diminish through the late spring, and offspring may gain a competitive advantage by emerging earlier and growing larger than others in their cohort.

The majority of migratory redband trout in the Blitzen River appear to spawn on the mainstem upstream from Page Dam. Spawning trout were tracked as far as; the mainstem upstream of the confluence of Indian Creek, Indian Creek, the Little Blitzen River, and Fish Creek. Most of the trout ended their migrations on the mainstem below the confluence with the Little Blitzen River or in the lower part of the Little Blitzen River. No radio-tagged trout moved into the Little Blitzen gorge or Indian Creek gorge. There were also no trout tagged on the Blitzen River that moved into Bridge or Mud Creek even though passage was provided starting in 1999. However, three trout (one in 2008 and two in 2009) did move upstream into east canal, which captures the mouths of these two tributaries and is managed as fish habitat year-round. The movement patterns of these three fish indicate some connectivity is available within this portion of the Blitzen watershed.

Scale analysis indicated that there was some repeat spawning of migratory redband trout, but none of the radio-tagged trout were tracked through multiple spawning migrations. The scale samples can be used to estimate the proportion of trout at a given age that have spawned previously but not the frequency of post-spawning survival. The age distribution estimated from the scale interpretation suggests that post-spawning survival is not uncommon for age 3+ trout but is rare for age 4+ and 5+ spawners. In 2007, large radio tags (16g or 11g) were used so that the batteries would last through a second tracking season. The larger tags required that we tag only large and thus older trout, which may have reduced the likelihood that the trout would have survived to spawn naturally. We cannot rule out the possibility that the radio tagging reduced the post-spawning survival of the trout. In 2008, we primarily used smaller tags (4.5 g) but the tags only lasted 10 months, so we could not determine repeat spawning.

The abundance of migratory trout was higher in 2007 compared to 2008 and 2009. With similar trapping effort each year, there were over five times as many trout caught in 2007 than in either of the other years of the study. In addition, the migration included a smaller proportion of large spawners in 2008 and 2009. One possible explanation for the reduced number and size of trout is that the volume of Malheur Lake diminished notably over the course of the study. The PIT tag reader located at Cato Bridge (Rkm 1) indicated that very few of the trout tagged in the river moved into Malheur Lake during the study. However, 81 trout were captured in the trap at the Sodhouse Dam (Rkm 6) in 2007, compared to 6 trout in 2008 and 15 trout in 2009. This may indicate that trout were using the lake in the winter prior to the beginning of the study. Utilization of the lake may vary with lake volume and associated changes in water quality (Behnke 2007). Another cause for the short-term decline may be the combination of poor passage for migrating trout in the spring followed by high summer water temperatures in 2007. During 2007, in addition to the typical delays experienced at the ladders, maintenance problems at Grain Camp Dam prevented passage during most of May, June, and July, and water temperatures in the lower river during July reached potentially lethal levels.

MANAGEMENT RECOMMENDATIONS

Findings of this study strongly suggest that improvements in fish passage at Busse, Grain Camp, and Sodhouse Dams would benefit migratory redband trout in the Blitzen River. Findings about the movement patterns of redband trout and passage efficiency at the dams can be used to prioritize passage improvement projects. Based on our understanding of the life-history of this population, passage should be prioritized from upstream to downstream because migratory trout disperse from upstream summer habitat to downstream winter habitat. Based on both the location trout were trapped and the long-term PIT tag tracking, it appears that trout winter habitat is dispersed broadly through the lower river. In this portion of the river overwintering can occur between Grain Camp Dam (Rkm 46) and Malheur Lake. Passage improvements at Grain Camp Dam benefit all trout in the lower river, whereas passage improvements at Sodhouse Dam only benefit trout that move to the lowest 6 km of the river or into the lake. During low water years, when the migratory population is likely to be the smallest and most vulnerable, passage for trout rearing in the lower river may be more important than passage for trout rearing in Malheur Lake. However, Busse Dam consistently showed the lowest the passage efficiency. Passage at Sodhouse Dam was not evaluated in this study, but since the design is similar to Busse Dam passage, it probably has low passage efficiency. Based on both site location and passage efficiency, we recommend prioritizing dams for passage improvements in the order: 1) Busse, 2) Grain Camp, and 3) Sodhouse. Although not evaluated in this study, an additional critical step would include providing adequate screening to minimize entrainment of trout at diversions each of these dams.

Habitat improvements will also benefit the migratory redband trout population. Much of the Blitzen River was straightened and channelized early in the 20th Century (Beckham 1995) and the river has failed to reclaim the natural sinuosity that is apparent from historical aerial photographs. Radio-tagged trout generally spent little time in the straightened channel sections of the river. Opportunities to reconnect flood plains and historical channels through dike removal would benefit both the health of the river and the redband trout habitat. Rehabilitation of riparian vegetation has the potential improve many aspects of the habitat of the Blitzen River in the MNWR including moderating stream temperatures, providing cover, and contributing in-stream structure. Since trout are seeking summer temperature refuge in the P-Ranch to Page Springs reach, restoration efforts should focus in that segment first and expand downstream.

In recent years, the MNWR has been adding fish screens to diversion canals, and the current approach that prioritizes screening from upstream to downstream is supported by the trout movement patterns observed in this study. Trout in the study tended to move upstream during the spring and early summer during the irrigation season. Most of the downstream movements of PIT-tagged trout occurred in the fall when the irrigation canals were dewatered. The movements of juvenile trout were not evaluated, so we are unable to determine the impact of unscreened diversions on the early life-stage of redband trout. Each year of the study some radio-tagged trout moved downstream immediately after spawning in the spring either into the lower river or into unscreened diversions canals. None of those survived the summer in the river or in the diversion canals.

Future research of redband trout in the Blitzen River is needed to expand upon the information gained from this study. This study was limited to migratory trout caught in the spring that were large enough to tag with a 23mm PIT tag. We did not examine juvenile movement patterns, which would contribute to a full understanding of the life-history of migratory trout. Further, this study was conducted when Malheur Lake was relatively low. Replication of the study during a period of higher lake levels would be valuable to better understand the importance of the lake to the redband trout population. Finally, we recommend repeating the fish passage evaluation following future passage improvements to ensure that the dams no longer prevent passage or cause excessive delays. Passage should also be evaluated for other native fish species.

The migratory redband trout in the Blitzen River represent a unique life-history that was likely much more prevalent in the Great Basin region in the past. Some work indicates that salmonid populations with multiple life-history strategies are more resilient during changing environmental conditions (Rieman and Dunham 2000). Migratory redband trout tend to be larger and produce females with higher fecundity (Kunkel 1976). This life-history is responsible for many of the large redband trout that contribute to the valuable sport fishery on the Blitzen River. However, conservation of migratory redband trout provides numerous management challenges. Redband trout that utilize the lower river would greatly benefit from improvement to the efficiency of passage facilities at the dams.

ACKNOWLEDGEMENTS

We offer special thanks to Kelley Klopp, Matt Zarif, and Ryan Flaherty for their contributions to the field work. We also appreciate the field assistance of Tim Walters, Jon Gutcher, Bruce Miller, Katherine Nordholm, Bruce McIntosh, and Jay Nicholas of ODFW, Darren Brumback of the BLM, as well as Julie Anderson, Adela New, and Mark Villers who provided their personal time. The support and logistical assistance provided by the Malheur National Wildlife Refuge staff made the study possible. Thanks to OSP pilots Ken West and Andrew Menlow for providing valuable flight time. Bob Hooton, Tim Walters and Charlie Corrarino reviewed the manuscript.

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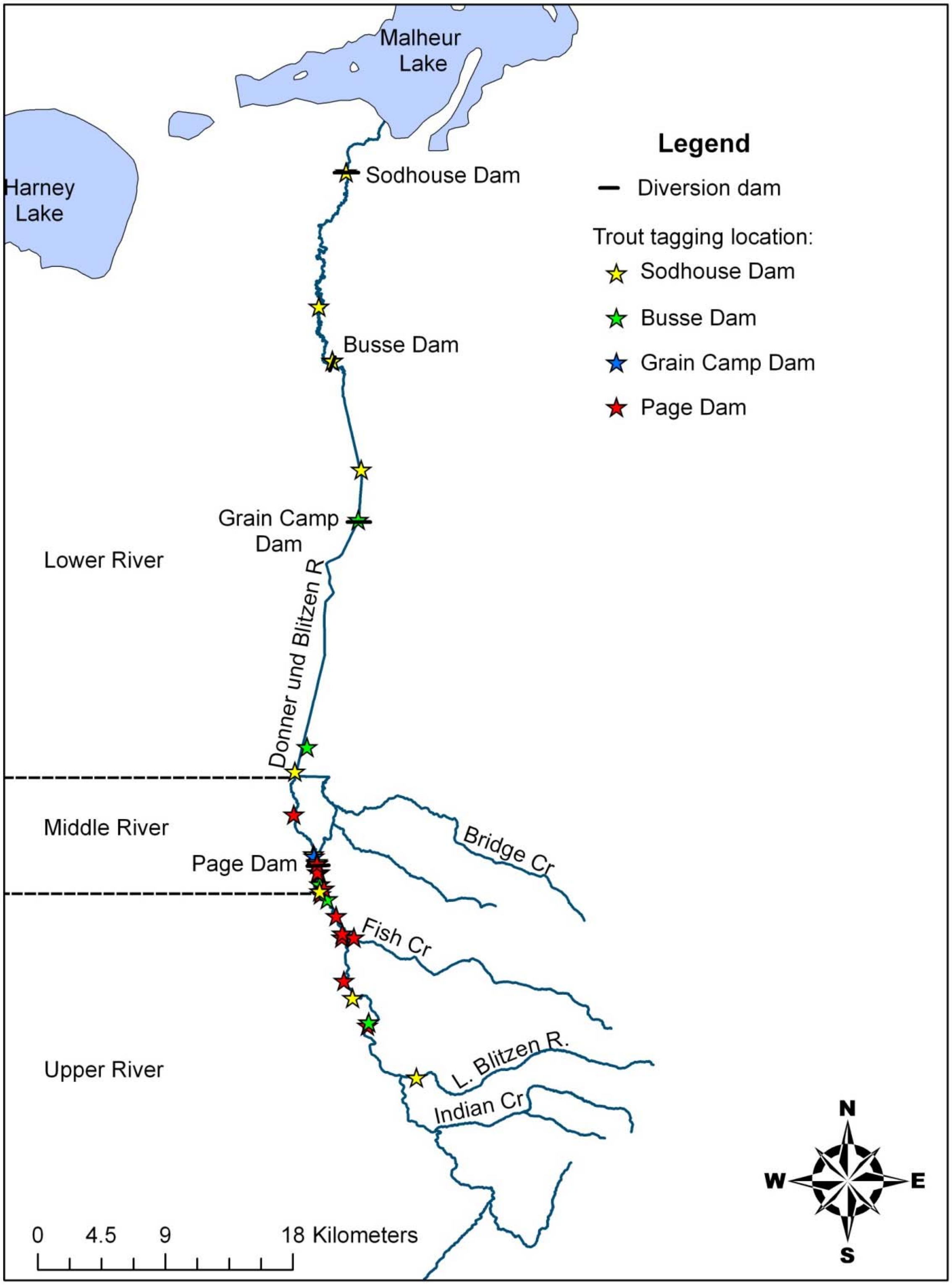
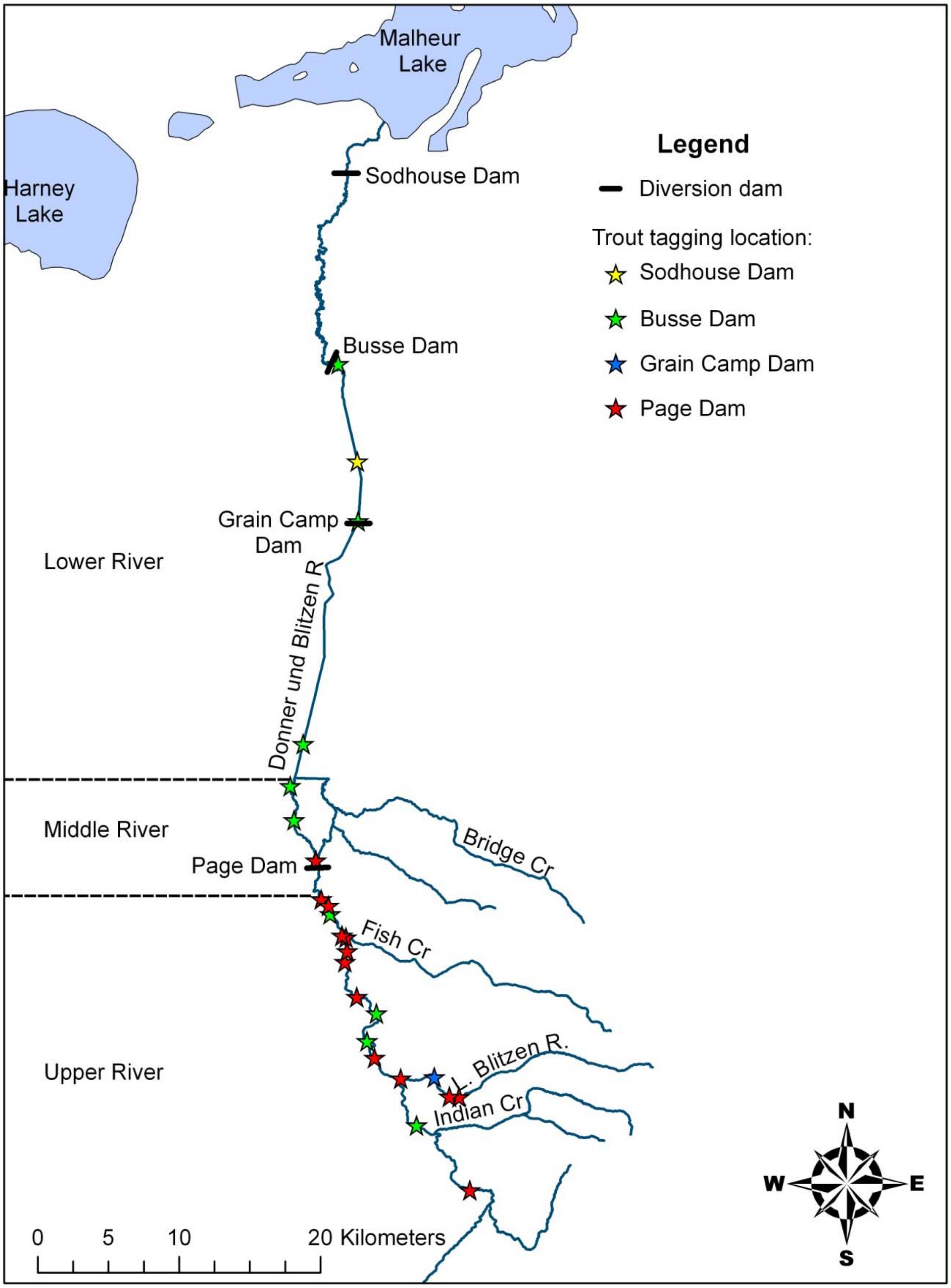
APPENDIX A. Photographs of four diversion dams on the Blitzen River. From top-left to bottom right: Sodhouse Dam, Busse Dam, Grain Camp Dam, and Page Dam.



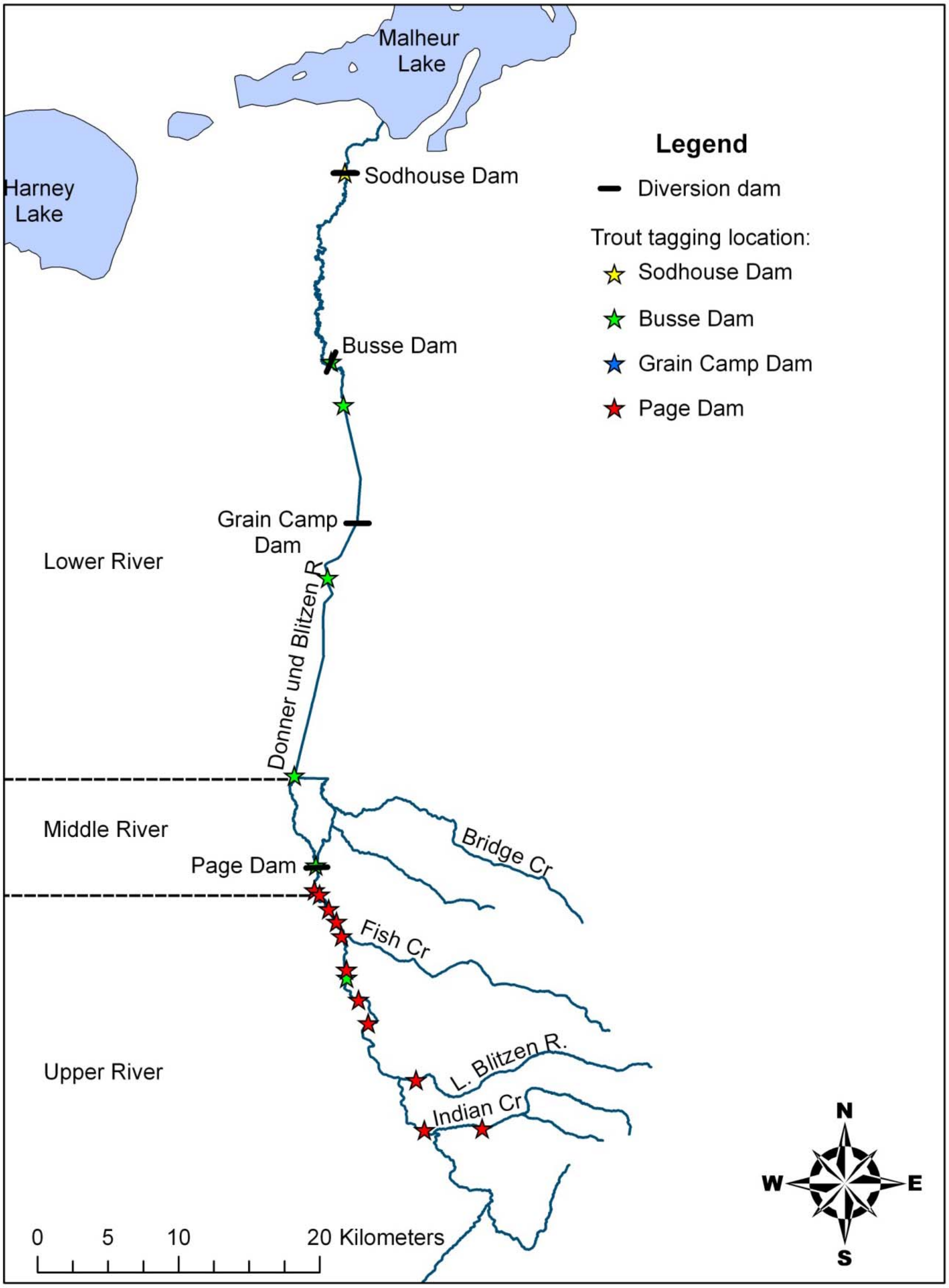

Appendix B. **ANNUAL UPSTREAM-MOST SITE OF RADIO-TAGGED REDBAND TROUT DURING SPRING 2007-2009.**



Upstream-most detection site (stars) for radio-tagged redband trout in 2007. The color indicates the location that the trout was tagged.

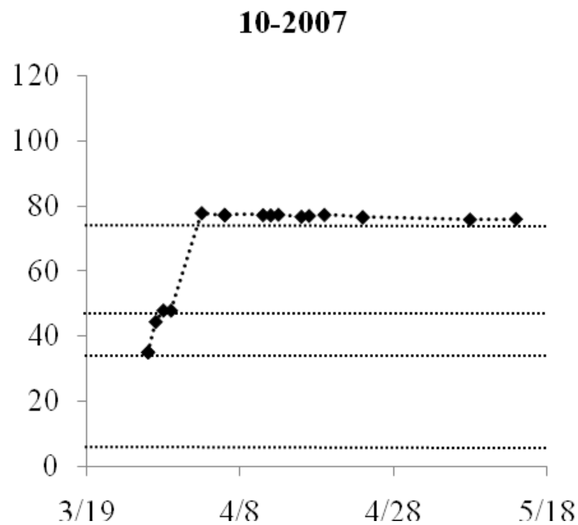


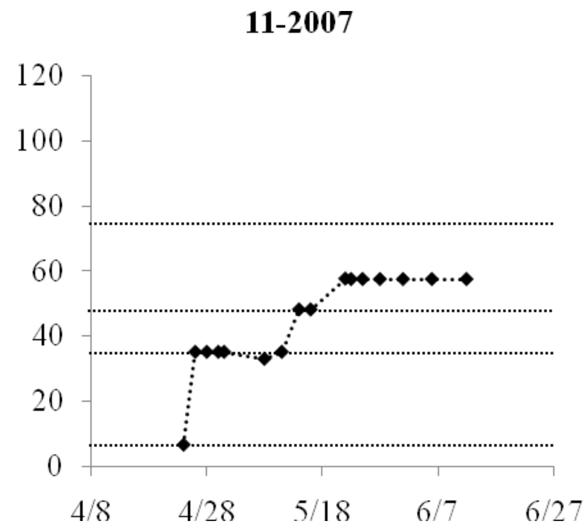
Upstream-most detection site (stars) for radio-tagged redband trout in 2008. The color indicates the location that the trout was tagged.

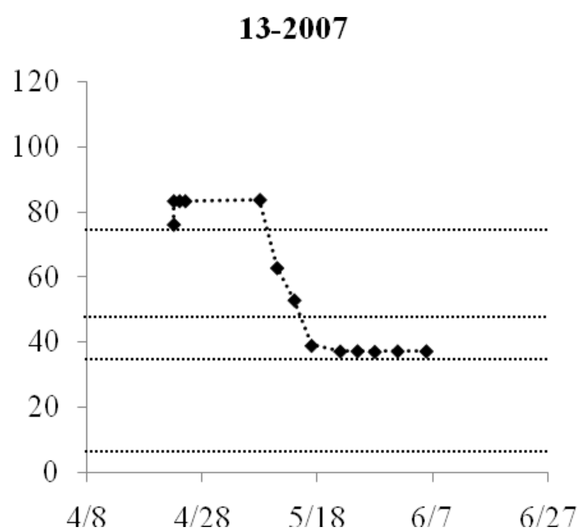


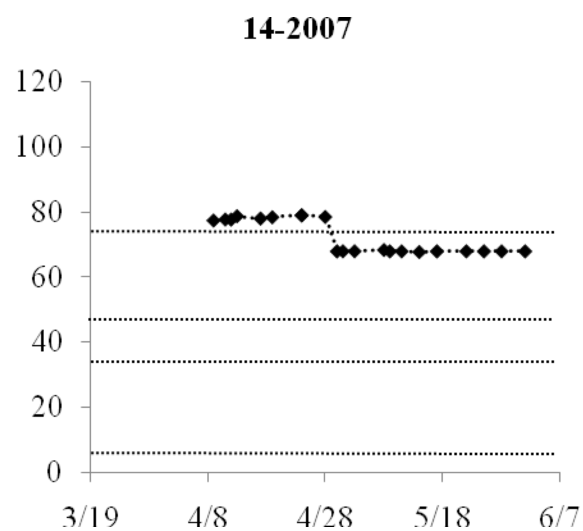
Upstream-most detection site (stars) for radio-tagged redband trout in 2009. The color indicates the location that the trout was tagged.

APPENDIX C. Individual movement histories reconstructed for 80 radio tagged trout. The vertical axis is river km and the horizontal axis is the date (MM/DD). The nodes indicate actual tag detection points which are connected by dotted lines for clarity. The horizontal lines depict the location of the four major dams: Sodhouse Dam (km 6), Busse Dam (km 35), Grain Camp Dam (km 48), and Page Dam (km 67). Titles indicate the unique radio tag number and the year the trout was initially tagged. Additional annotation has been added where necessary. Trout not illustrated include eight tagged in 2007 that showed no movement following radio tagging, seven in 2008 tagged too late in the season to provide sufficient movement information, and one in 2009 that suffered avian predation within days following tagging.

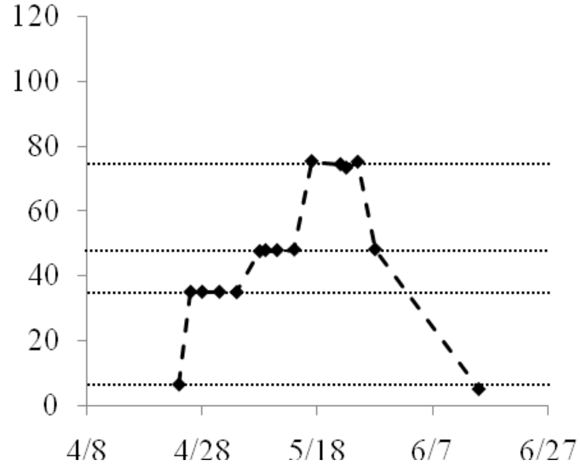




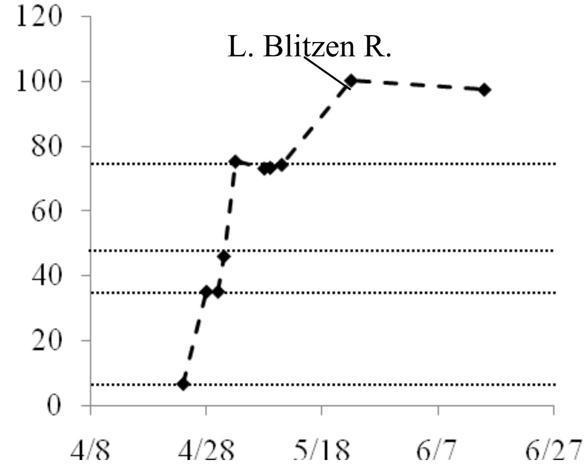




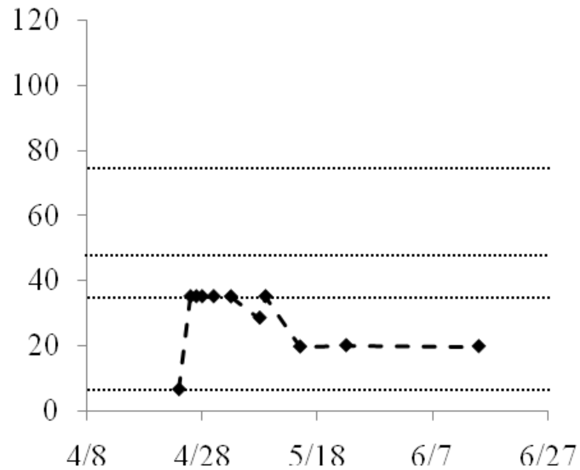
15-2007



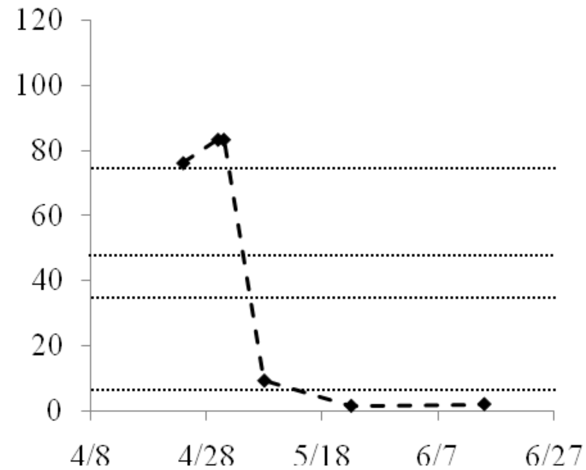
16-2007



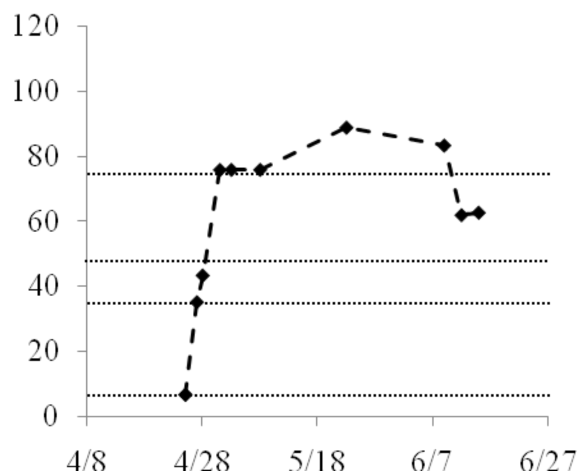
17-2007



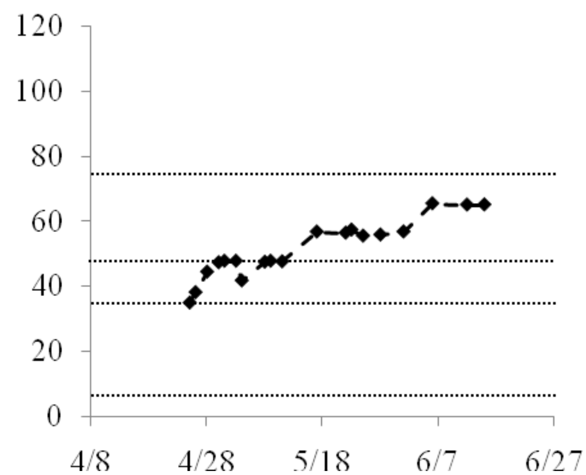
18-2007



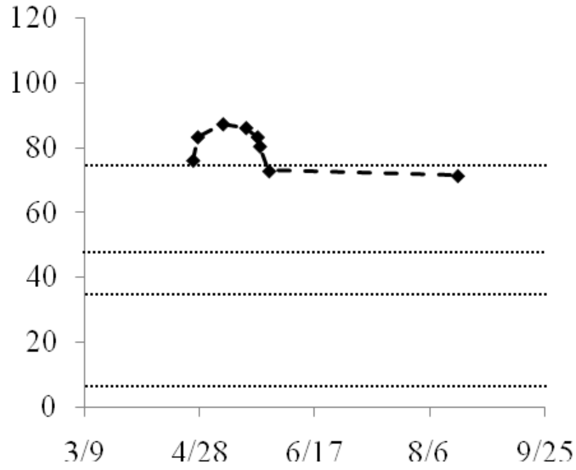
19-2007



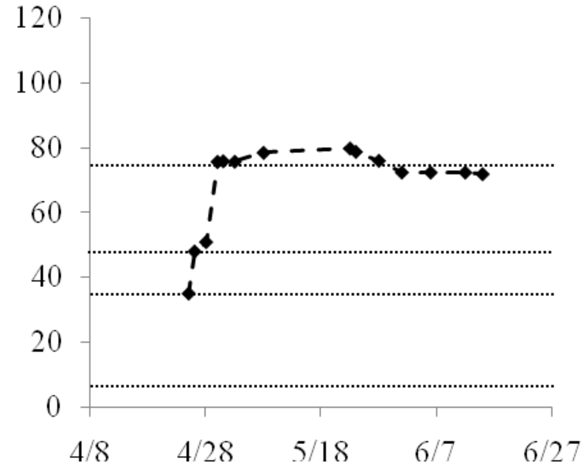
20-2007



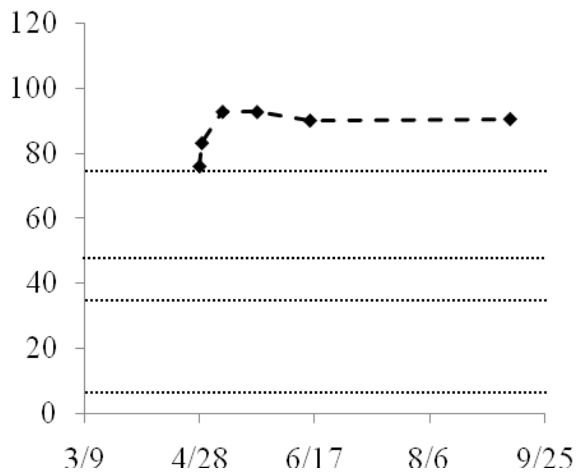
21-2007



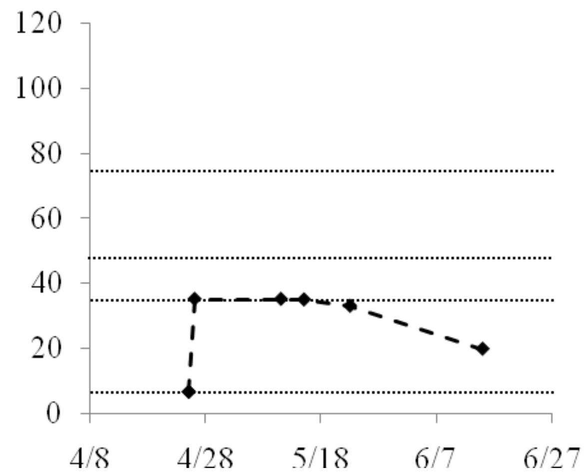
22-2007



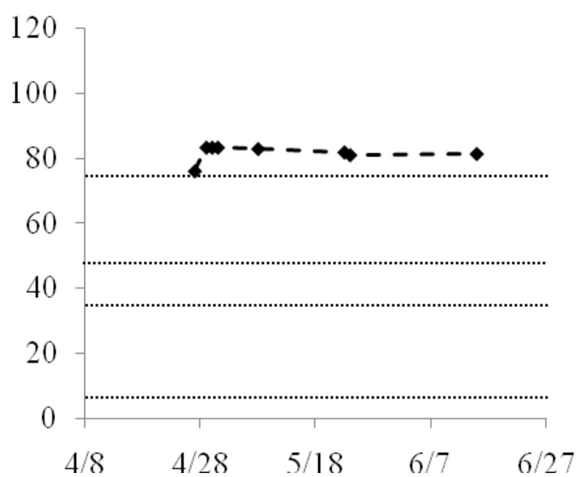
23-2007



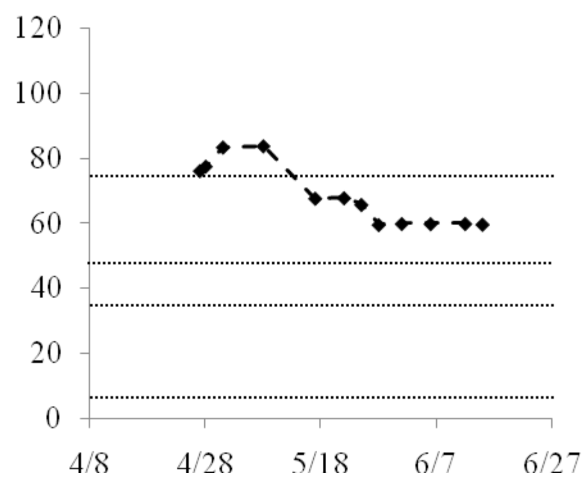
24-2007



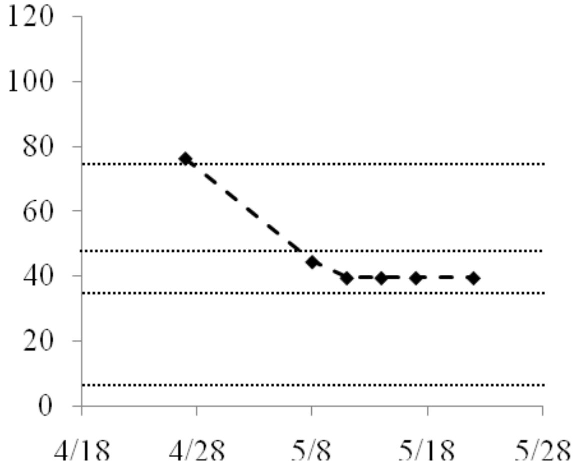
25-2007



26-2007



27-2007



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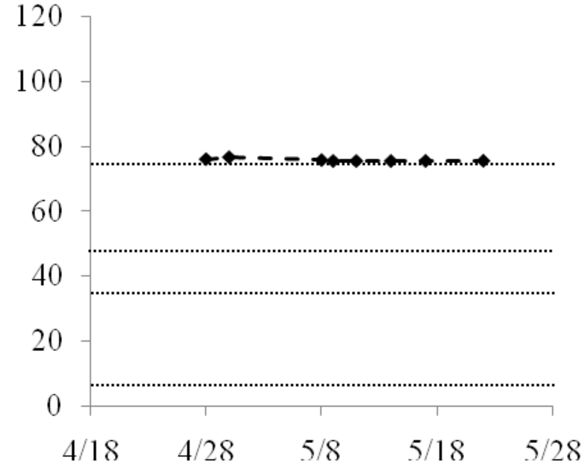

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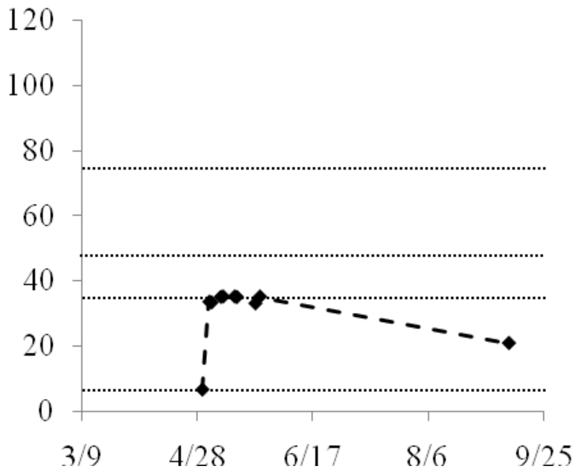

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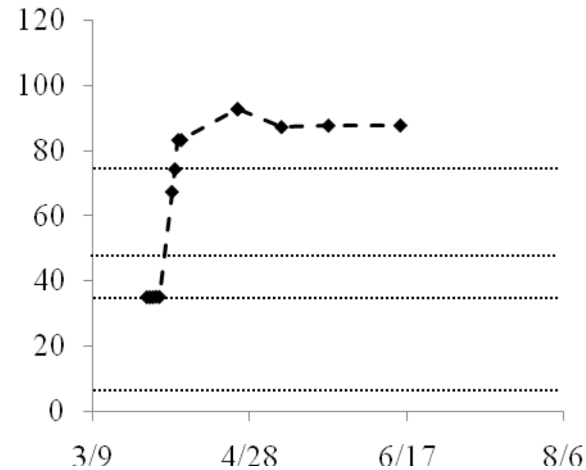
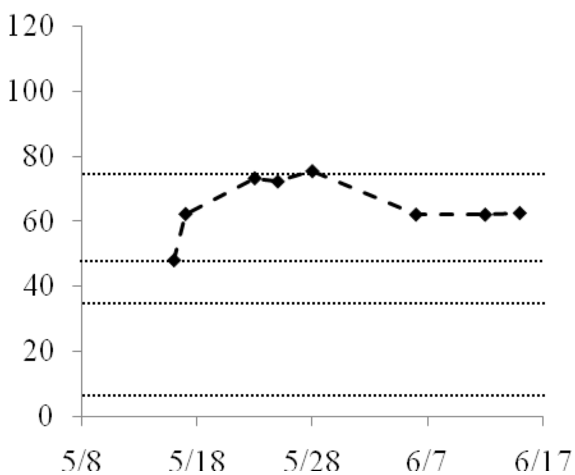


32-2007



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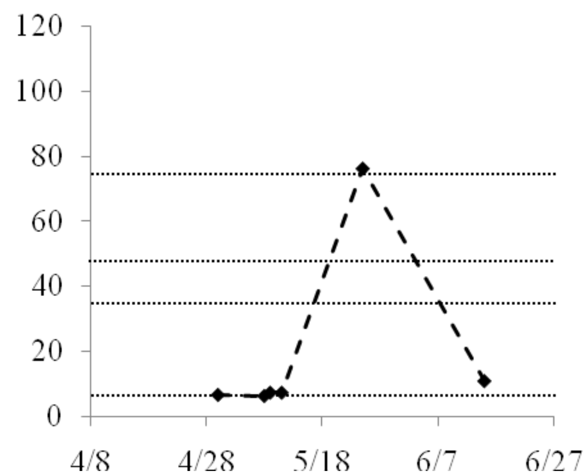

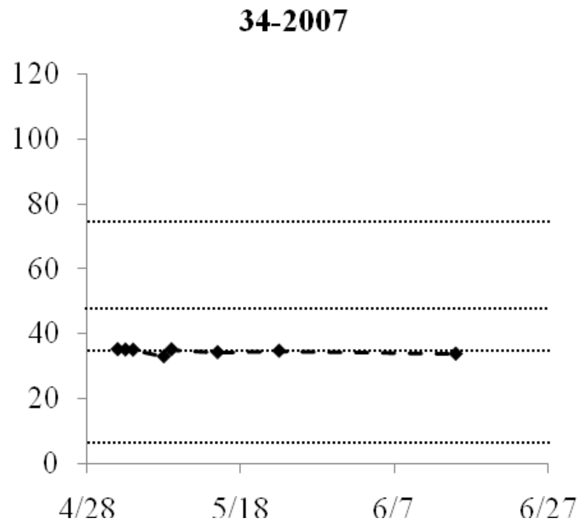
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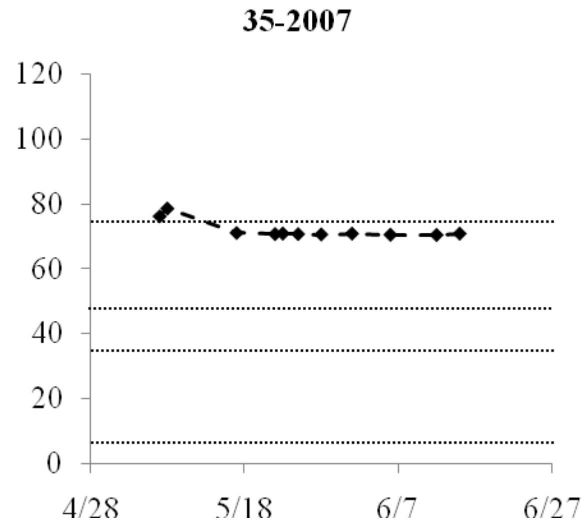
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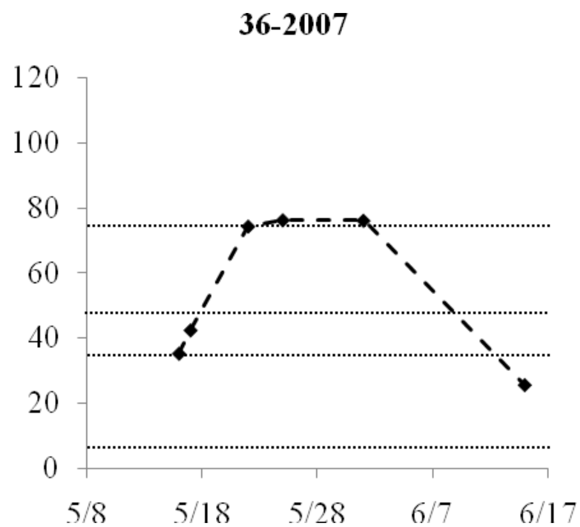
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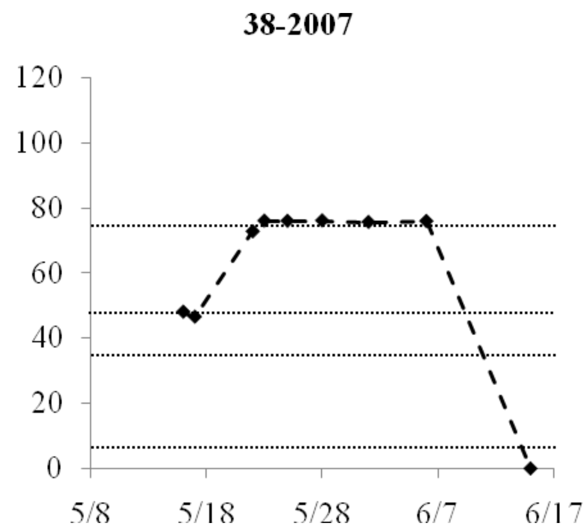
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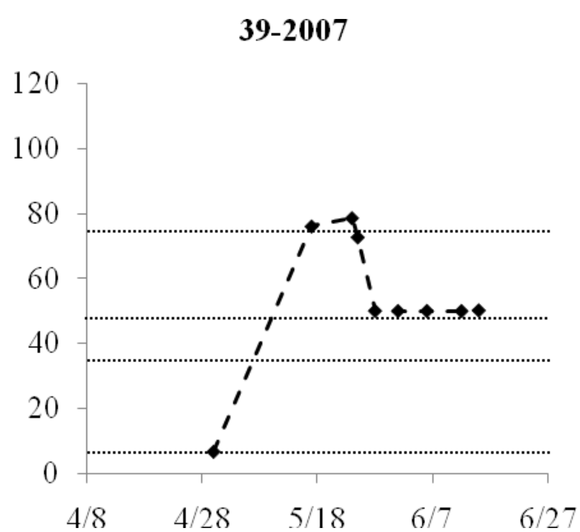
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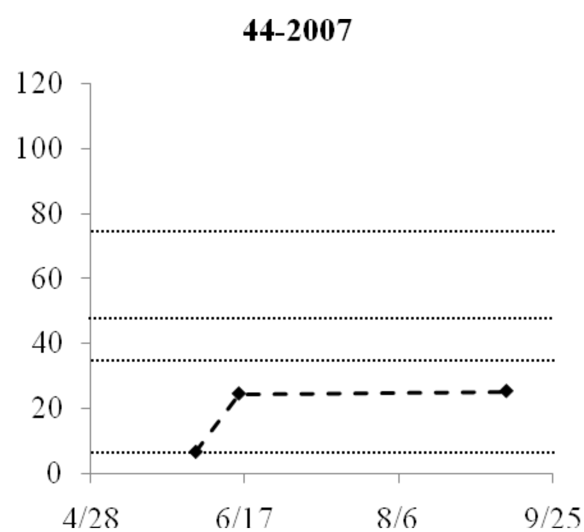
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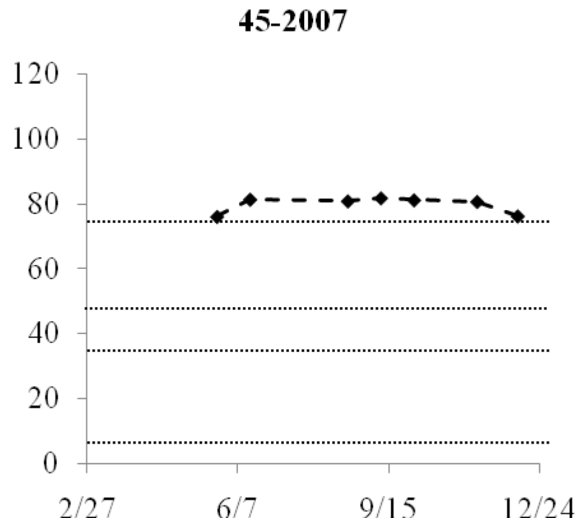
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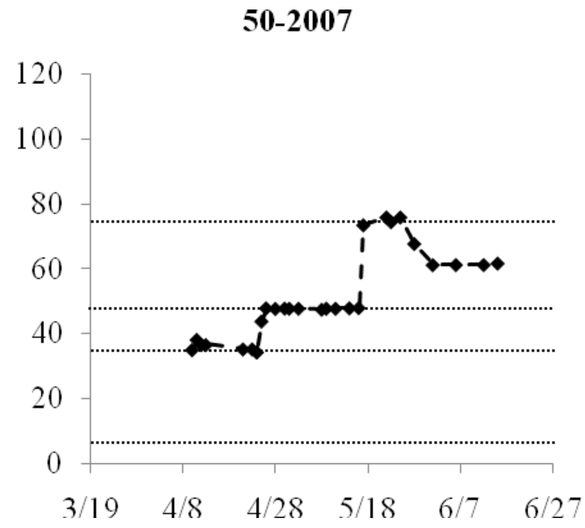
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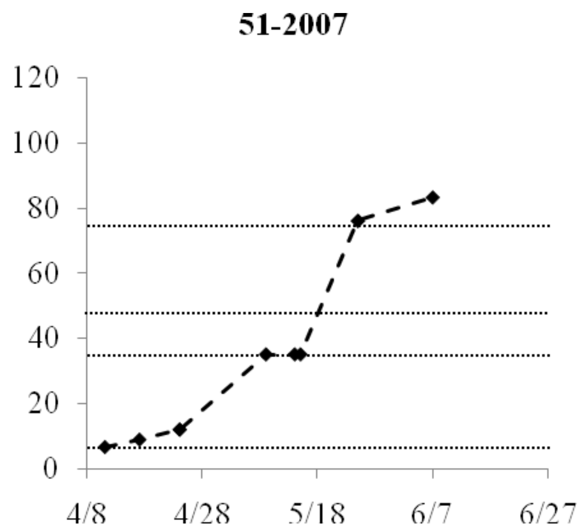
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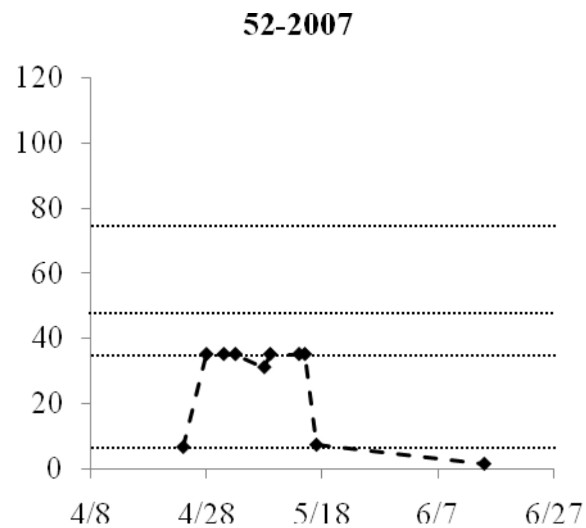
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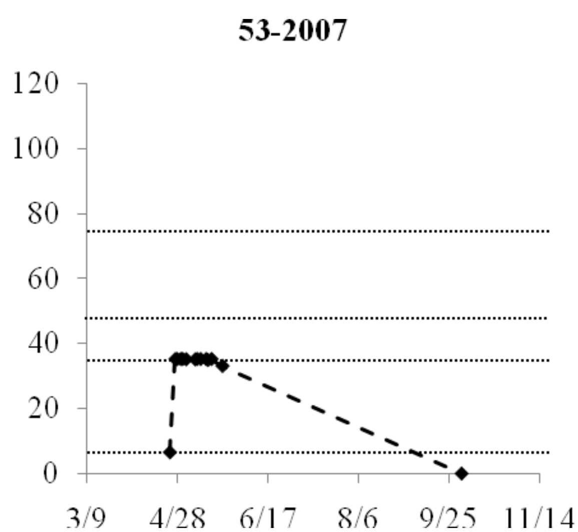
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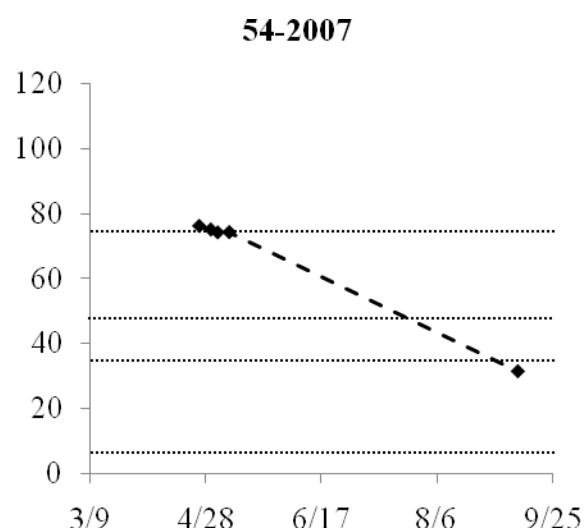
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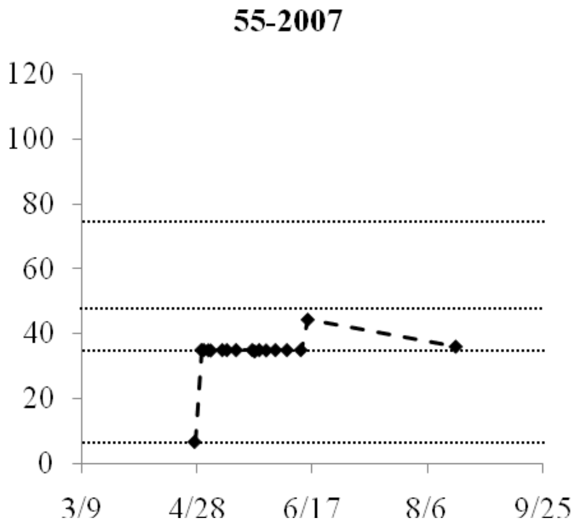
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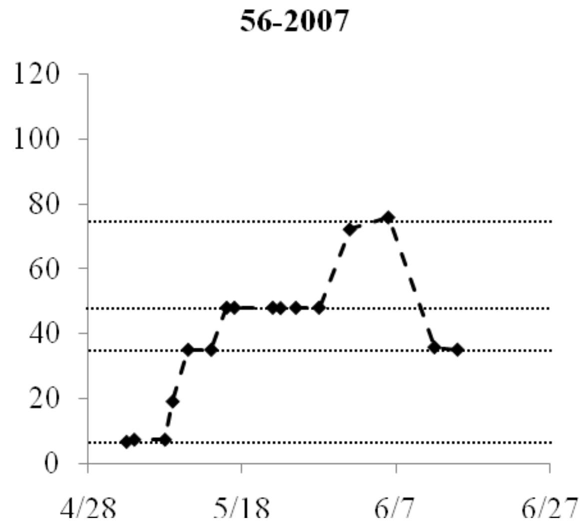
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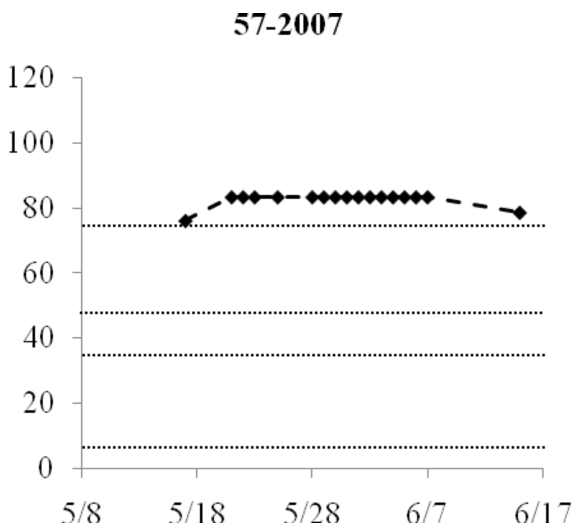
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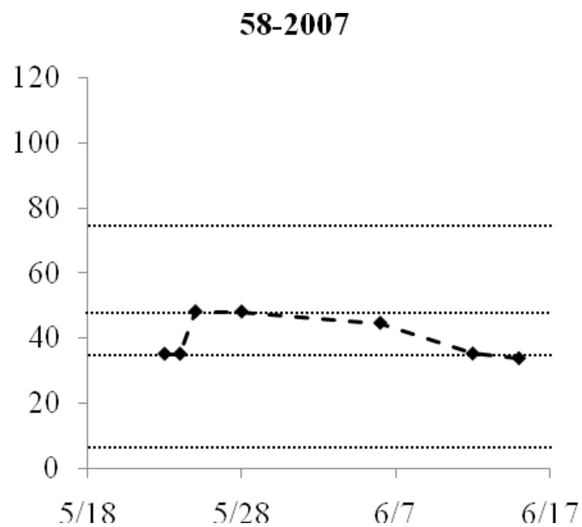
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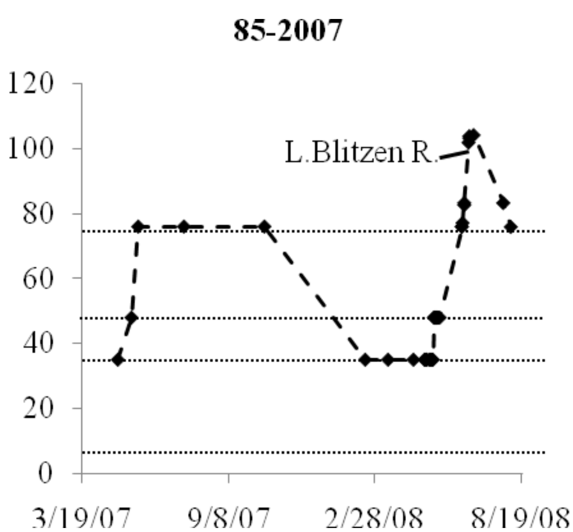
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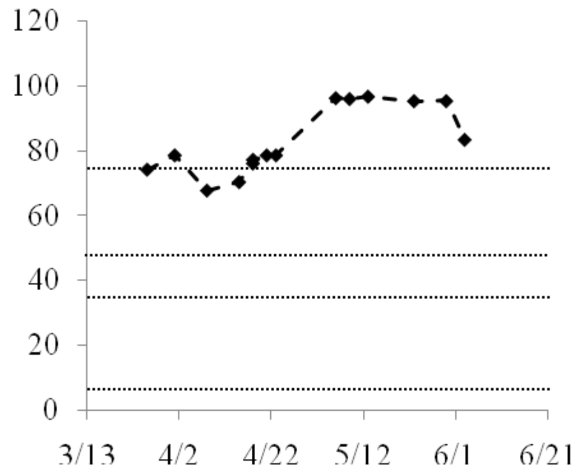
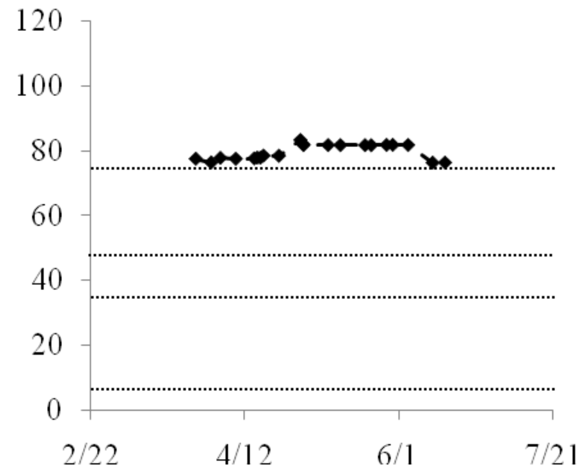
61-2008



62-2008



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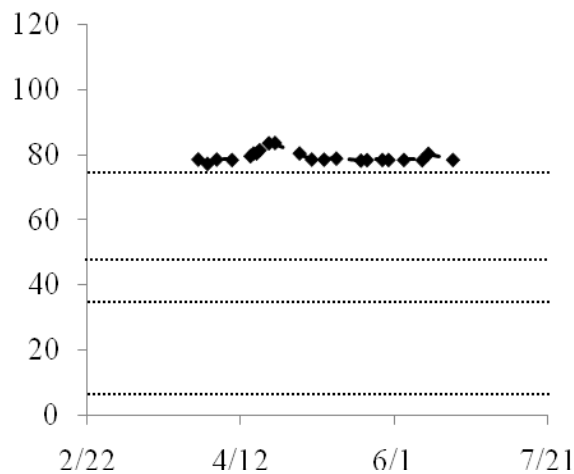

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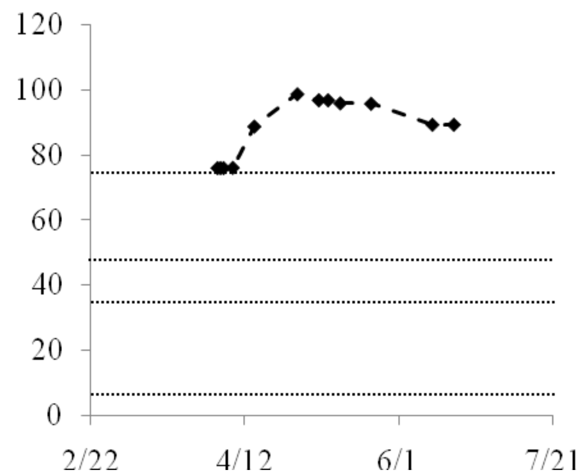

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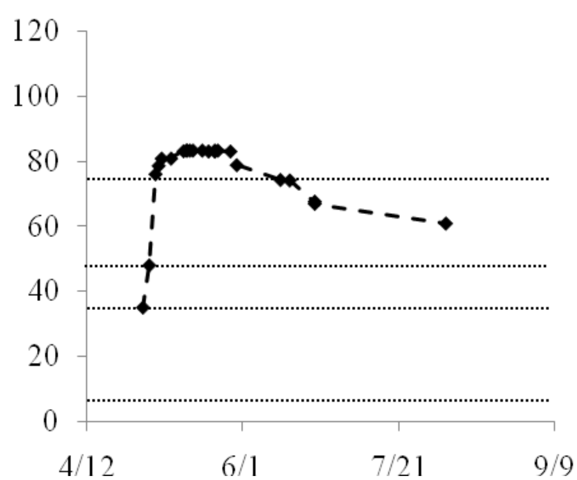

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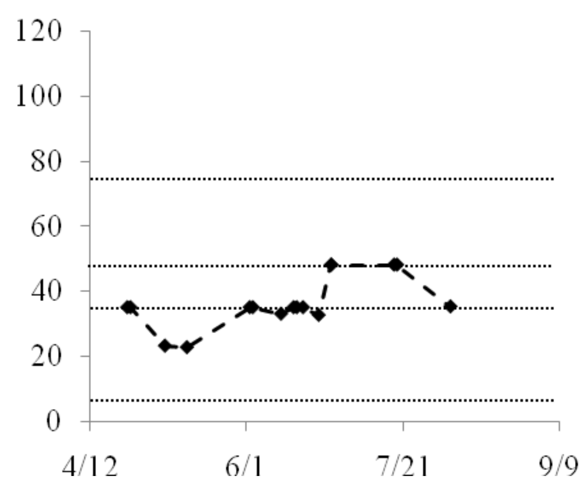

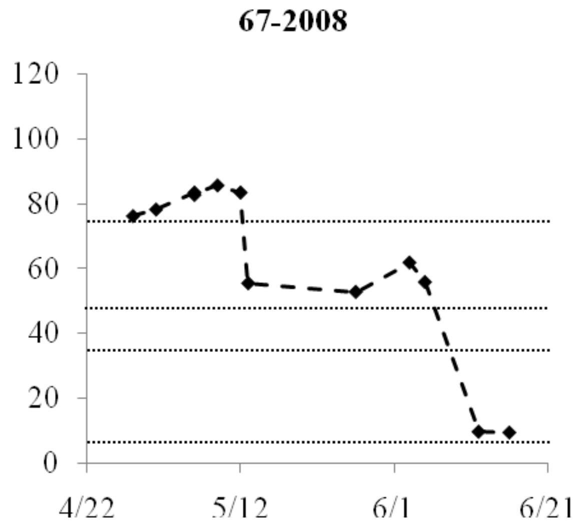
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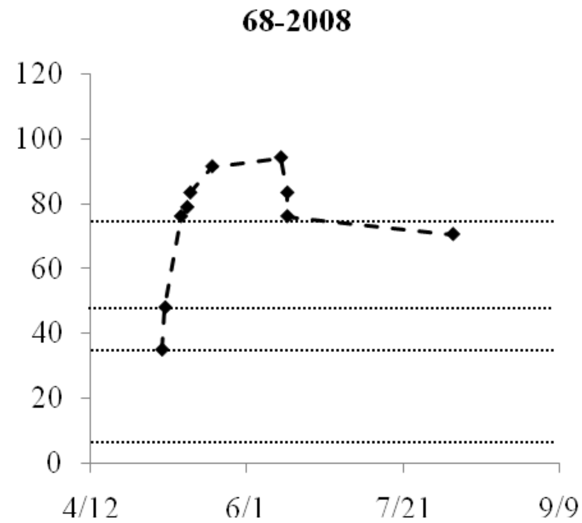
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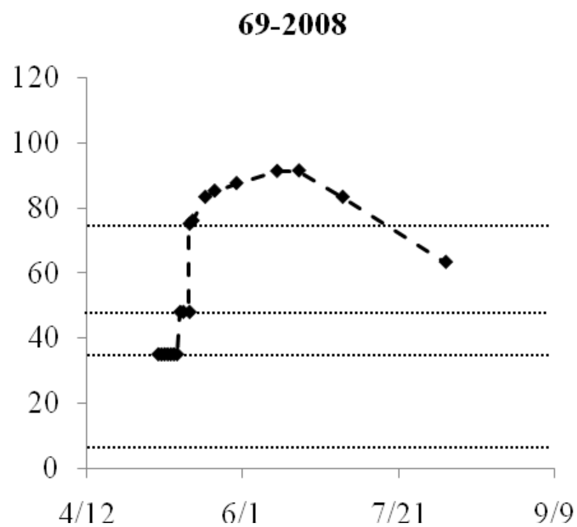
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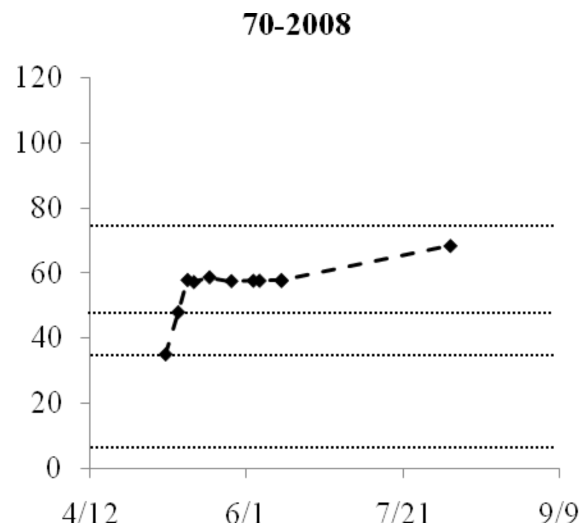
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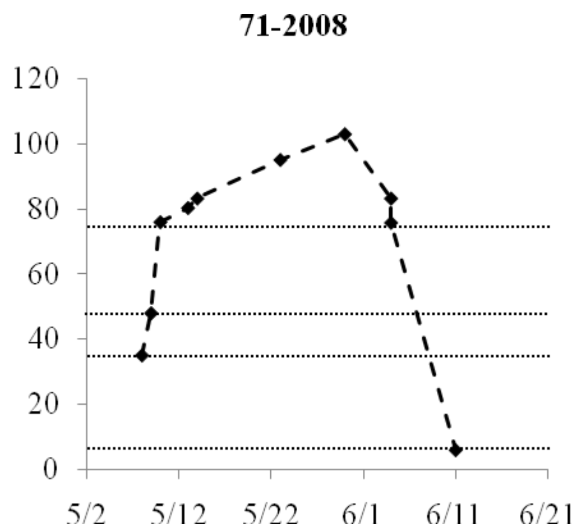
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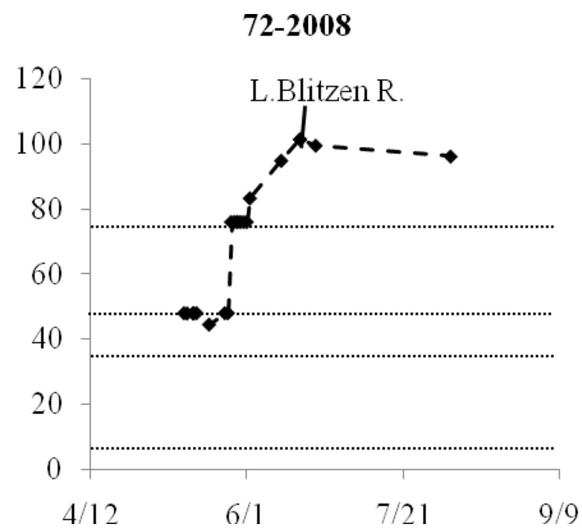
72-2008
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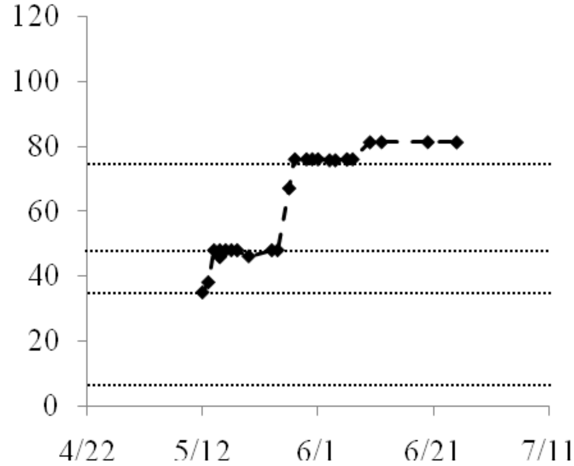
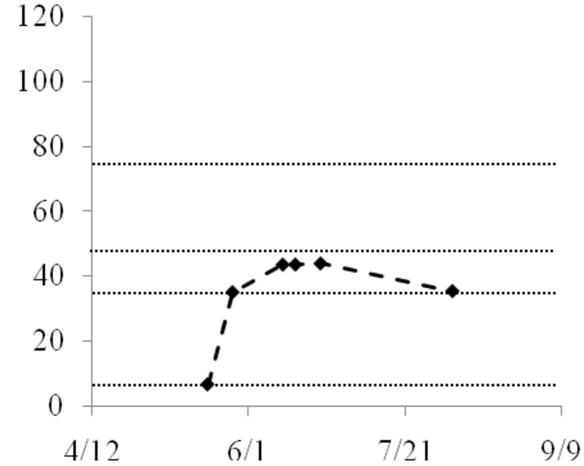
73-2008



74-2008



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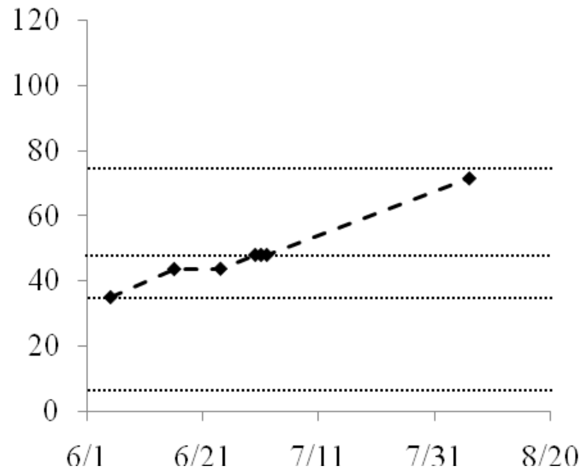

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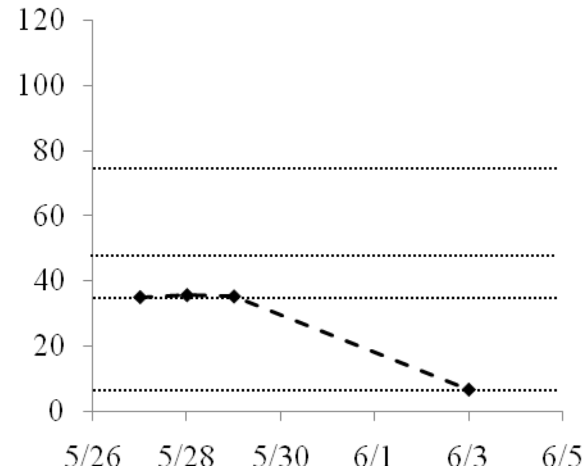

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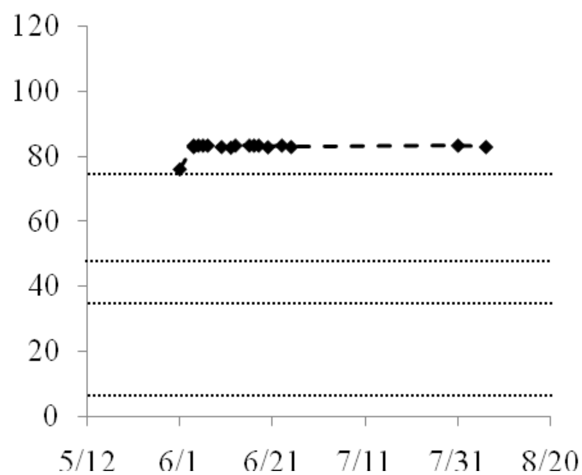

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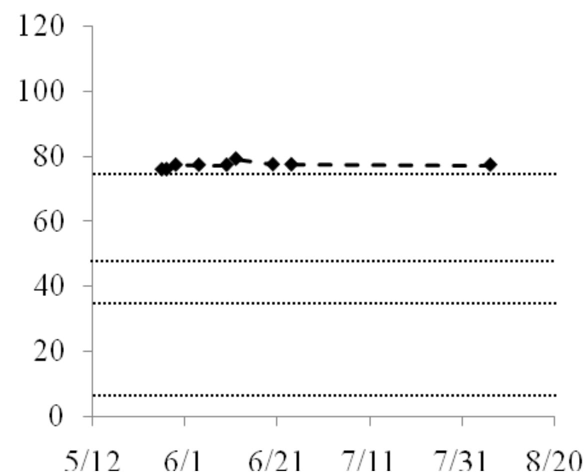

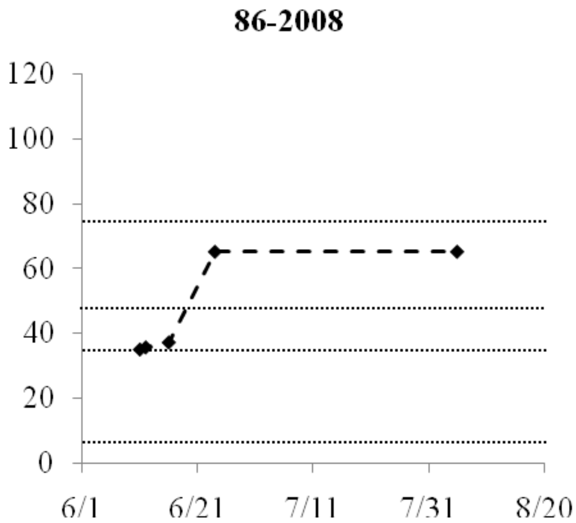
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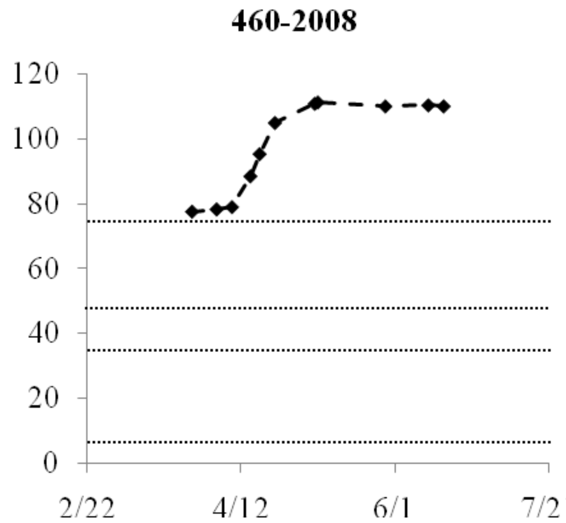
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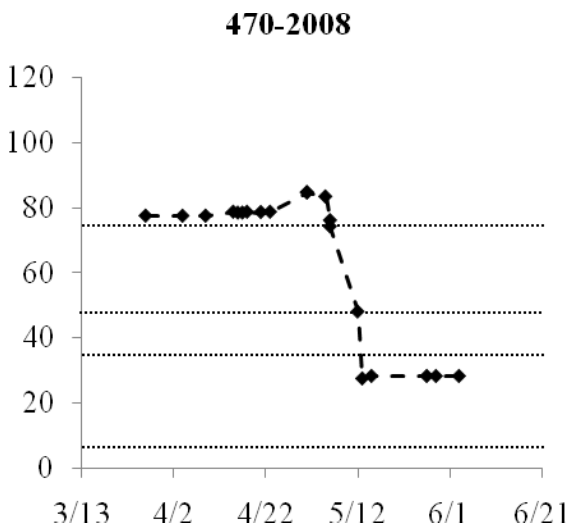
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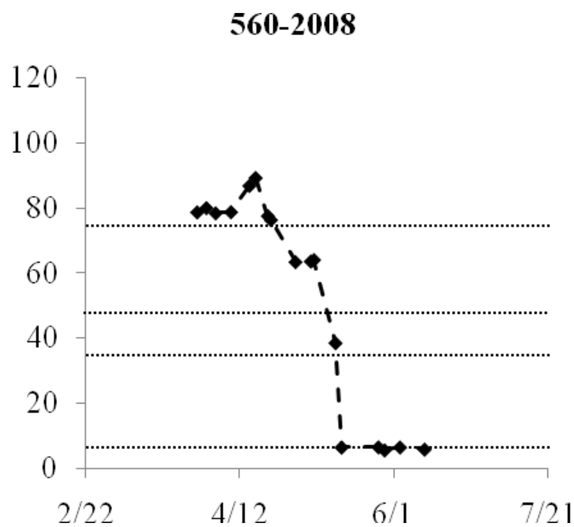
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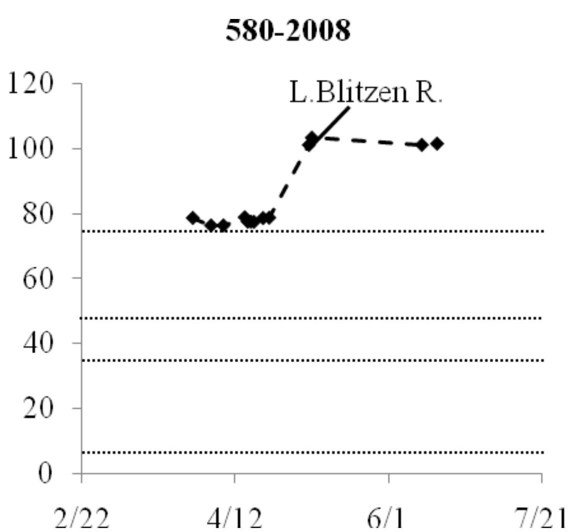
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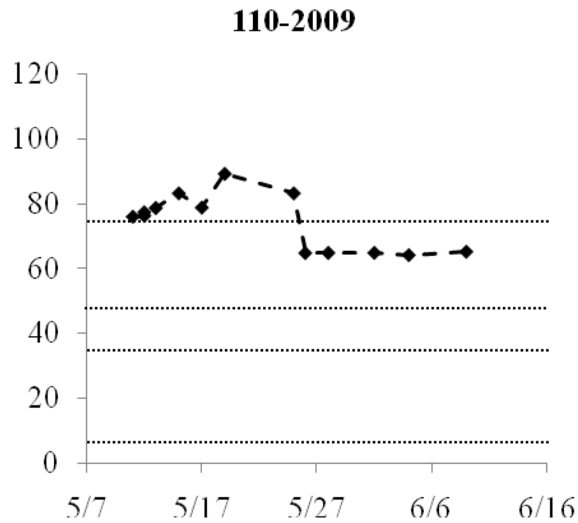
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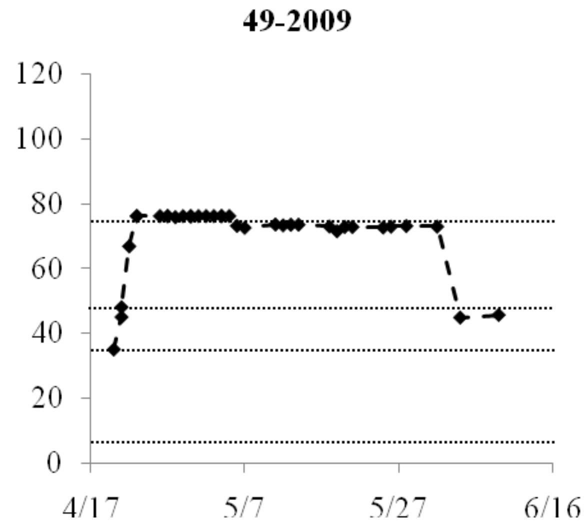
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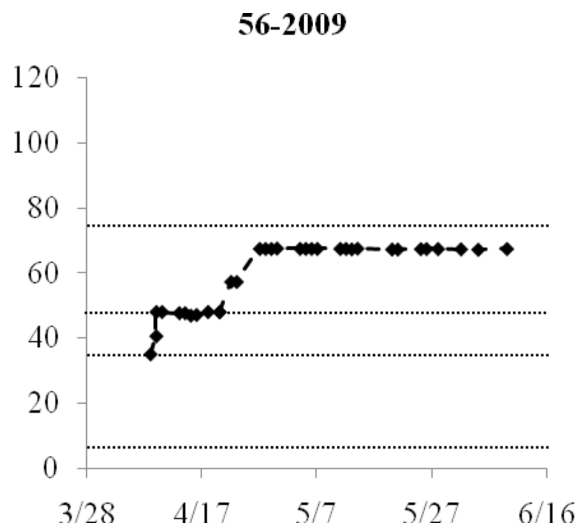
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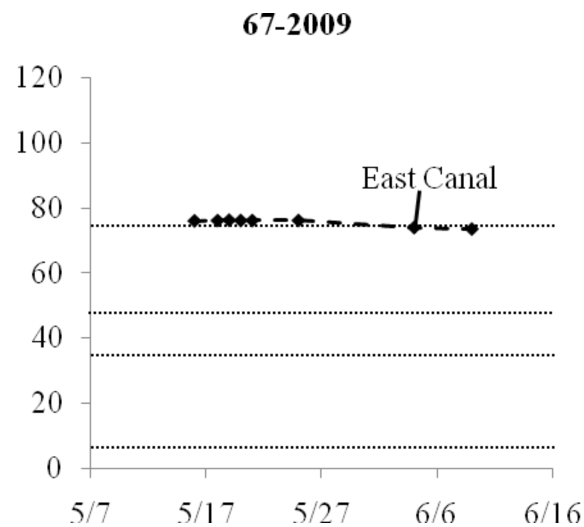
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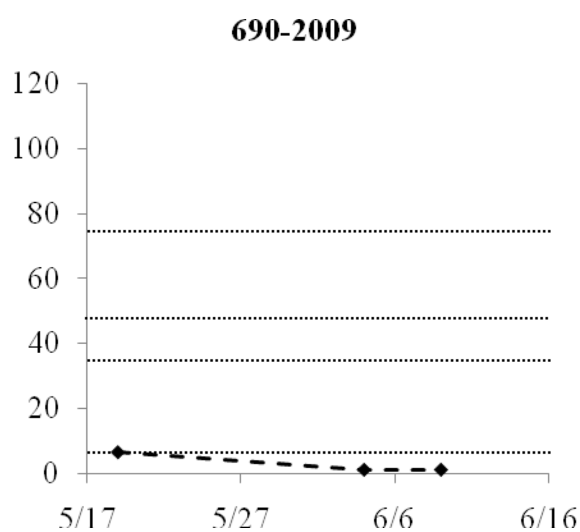
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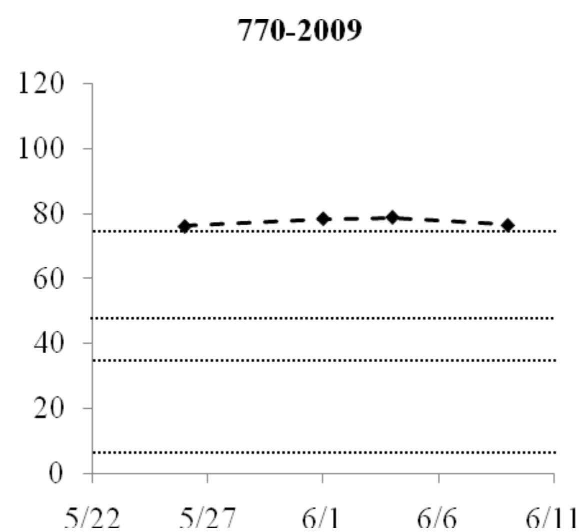
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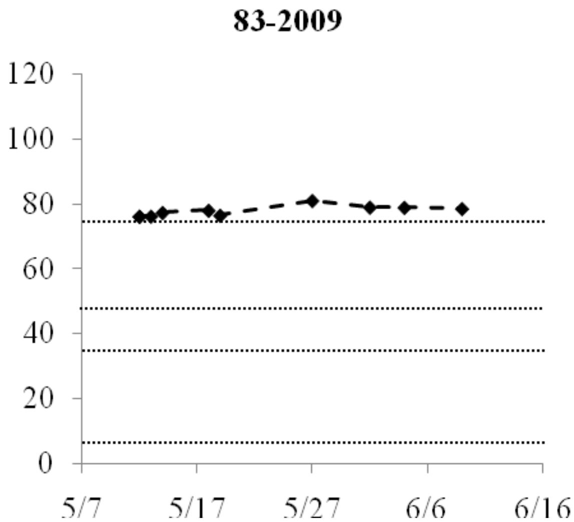
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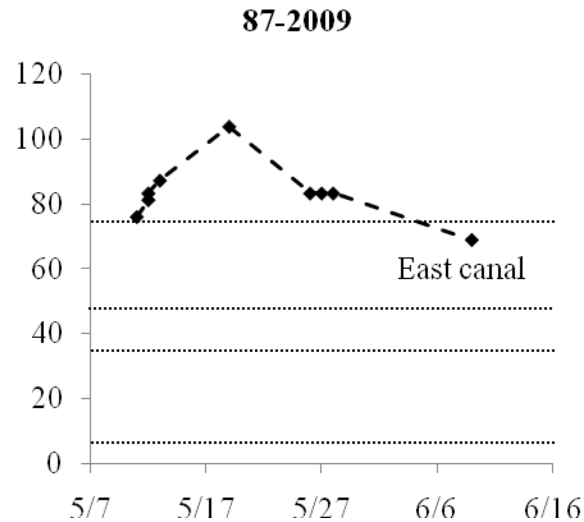
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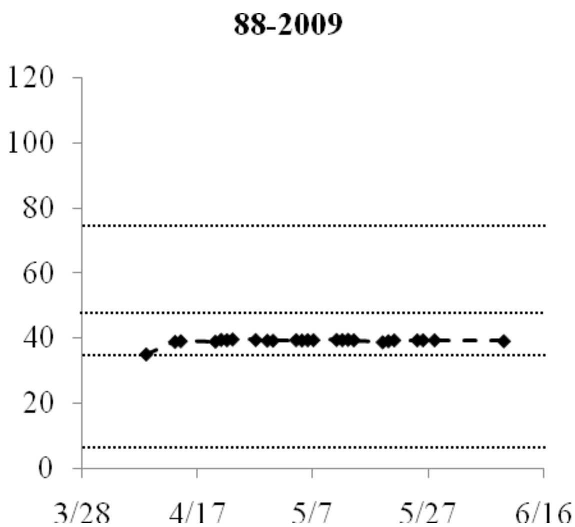
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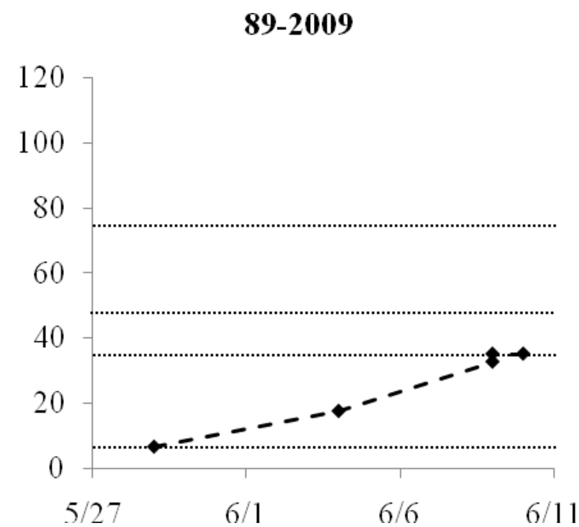
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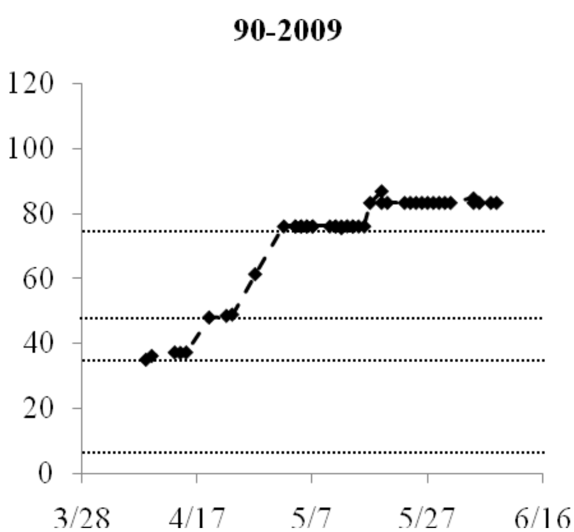
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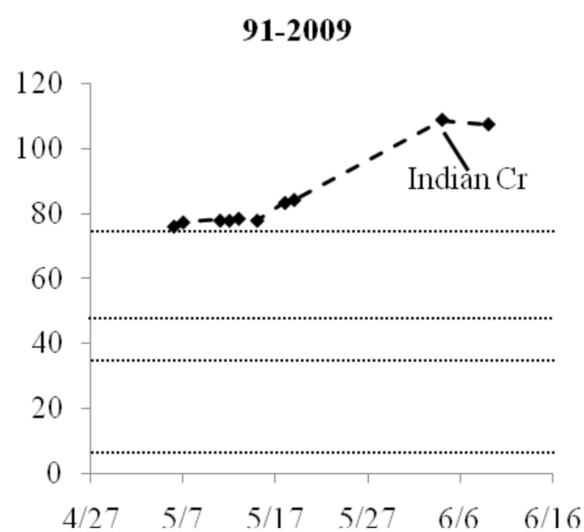
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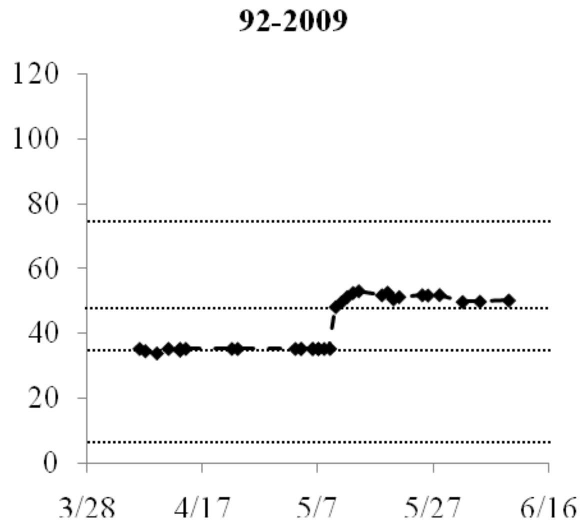
92-2009
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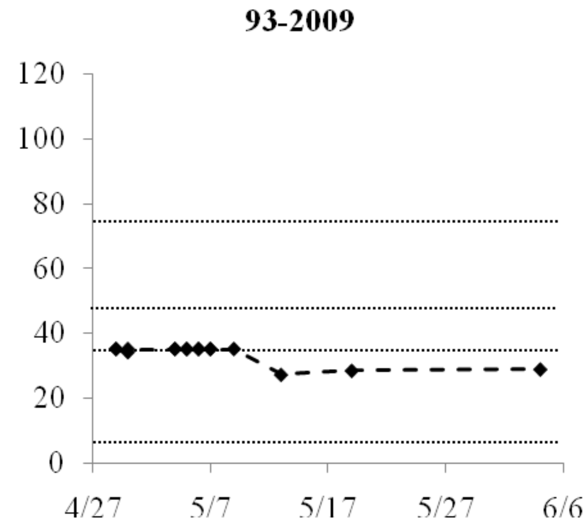
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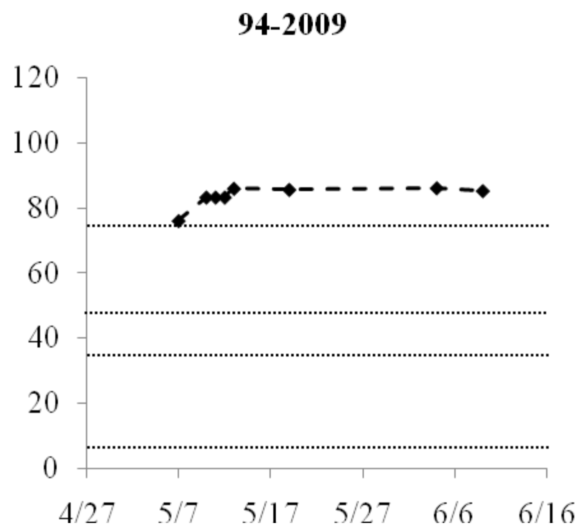
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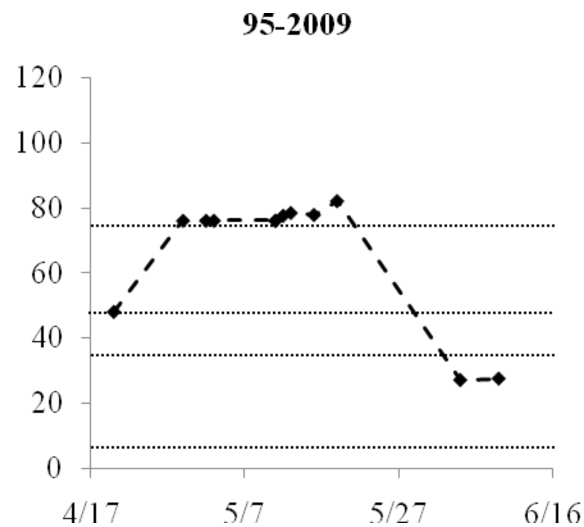
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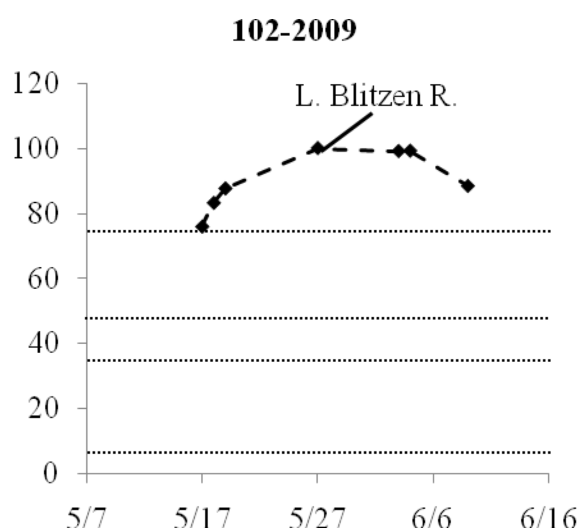
102-2009
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OREGON

Fish & Wildlife