Monitoring and Assessment of Juvenile Steelhead on Toppenish National Wildlife Refuge

Quick Response Project for 2001

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Introduction and Background

Toppenish National Wildlife Refuge (TNWR) in south central Washington was established in 1964 to provide an important link in the chain of feeding and resting areas for waterfowl and other migratory birds using the Pacific Flyway. Wetlands on TNWR include both natural floodplain wetlands along Toppenish Creek and man-made impoundments designed to mimic natural floodplain processes. Wetland improvement projects were completed between 1995-1998 to restore wetland habitat conditions and eliminate monotypic stands of invasive reed canary grass. Habitat improvements boosted fall/winter use from 2,000 to 50,000 waterfowl, and increased overall use by many species of water birds, shorebirds, and other migratory birds. Increased use by bald eagles, peregrine falcons, and willow flycatchers has also been recorded.

Wetlands at TNWR are often inundated by natural flooding events in winter or spring when water overtops the dikes. As floodwaters recede in spring, water control structures with flashboard risers allow the managers to retain water in selected units. Water is held in the wetlands at 6"-18" depth to prevent the growth of invasive reed canarygrass. Wetlands are then “drawn-down” or de-watered sometime between April 1 through June 15. During the dewatering process, wetland water is maintained at shallow depths 2-6" to encourage growth of invertebrate food sources for nesting waterfowl, waterbirds, and other wetland bird species.

Mid-Columbia River steelhead (*Oncorhynchus mykiss*) were listed as threatened in 1999 (Federal Register 1999), and steelhead of this stock spawn in Toppenish Creek, a tributary of the Yakima River. Steelhead adults and smolts in Toppenish Creek migrate through TNWR. Toppenish Creek steelhead have been identified as a genetically distinct population within the Yakima River stock (BPA 1996). The steelhead run in Toppenish Creek averages less than 100 adults, down from an estimated 1,000 adults in the 1950’s. Steelhead parr and smolt rear and migrate in Toppenish Creek, a portion of which runs through the TNWR. During spring flooding of Toppenish Creek, juvenile steelhead may be entering the wetland management units of TNWR, perhaps becoming stranded and vulnerable to avian predators. Steelhead juveniles trapped in wetland units could also suffer mortality from desiccation or warm summer temperatures.

In order to satisfy their responsibilities under Section 7 of the Endangered Species Act, managers of TNWR must consult with National Marine Fisheries Service on the potential impact of Refuge operations on threatened steelhead. There are currently no data on whether steelhead occur on refuge lands, which makes development of the Section 7 document problematic. Refuge managers need information about the occurrence of juvenile steelhead in wetland units, whether juvenile fish survive movements into wetlands, and how well the current wetland management practices for waterfowl work to assure fish migration and survival.

This report is part of a "Quick Response" project developed by the U.S. Geological Survey (USGS) and the U.S. Fish and Wildlife Service (USFWS) to address data needs at Toppenish National Wildlife Refuge. The objective was to test sampling strategies, begin monitoring use of wetland habitat by juvenile steelhead, and begin monitoring temperature on TNWR. Data collection was conducted during the spring of 2001. The work reported here is a collaborative effort between USGS and USFWS.

Study Area

TNWR covers 1,978 acres of floodplain along Toppenish Creek, a tributary of the lower Yakima River. Toppenish Creek flows west to east from the east slope of the Cascade Mountains through the arid shrub-steppe ecosystem and into the intensive agricultural area in the lowlands of the Yakima valley. Precipitation in the Toppenish Creek watershed occurs mainly as snow in the headwaters area. The Refuge is managed with the intent of benefiting waterfowl and other migratory birds and controlling invasive vegetation. Natural and man-made wetland habitats along the creek (Figure 1) are managed to mimic natural flood-plain processes as much as possible.

Figure 1. Flooded and dewatered wetland units at the Toppenish National Wildlife Refuge.

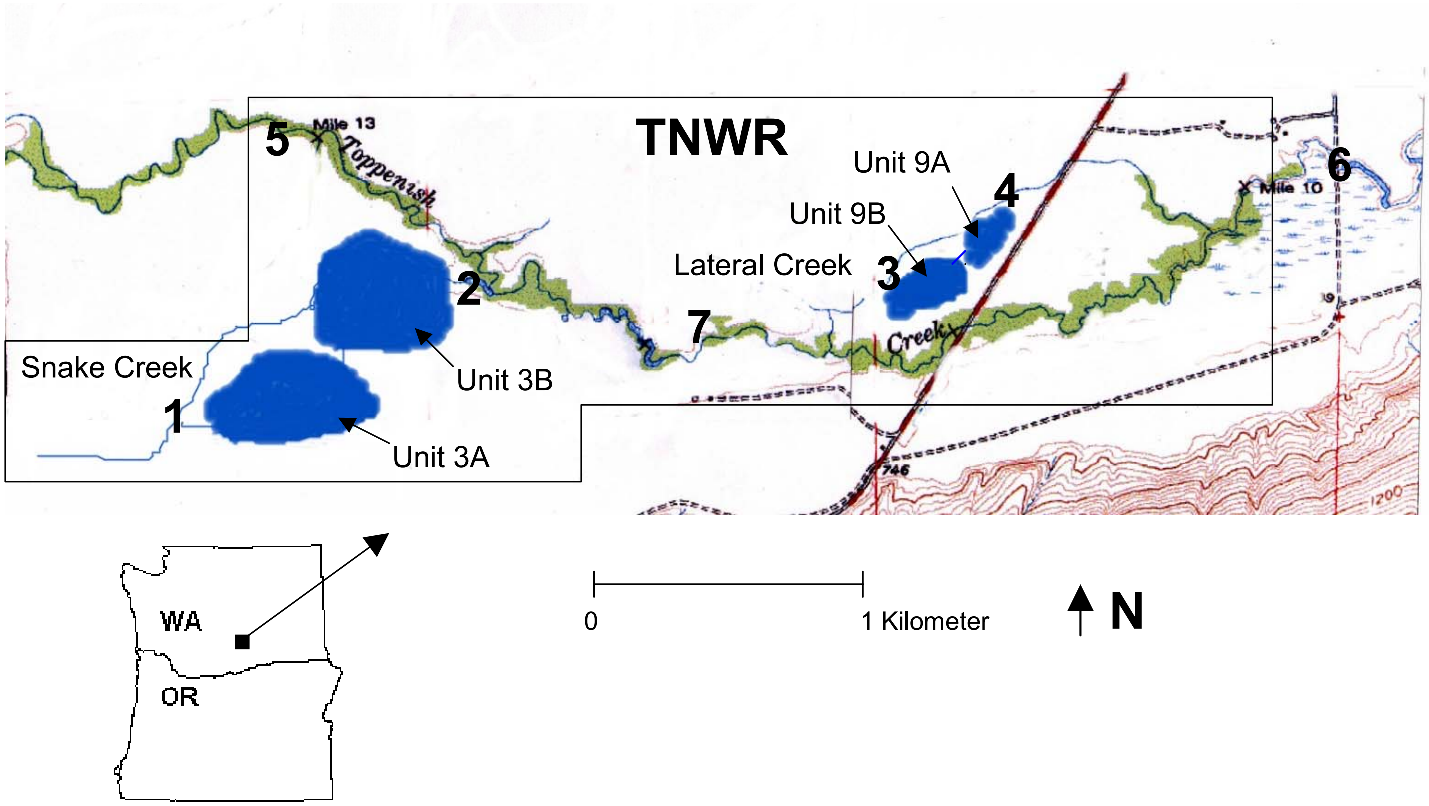

Figure 2. Toppenish National Wildlife Refuge. Numbers indicate locations of; 1) Upper Snake Cr. fyke net, thermograph, and flow site, 2) Lower Snake Cr. fyke net and flow site, 3) Upper Lateral Cr. fyke net, 4) Lower Lateral Cr. fyke net, 5) Upper Toppenish Cr. thermograph site, 6) Lower Toppenish Cr. thermograph site, 7) Toppenish Cr. flow site.

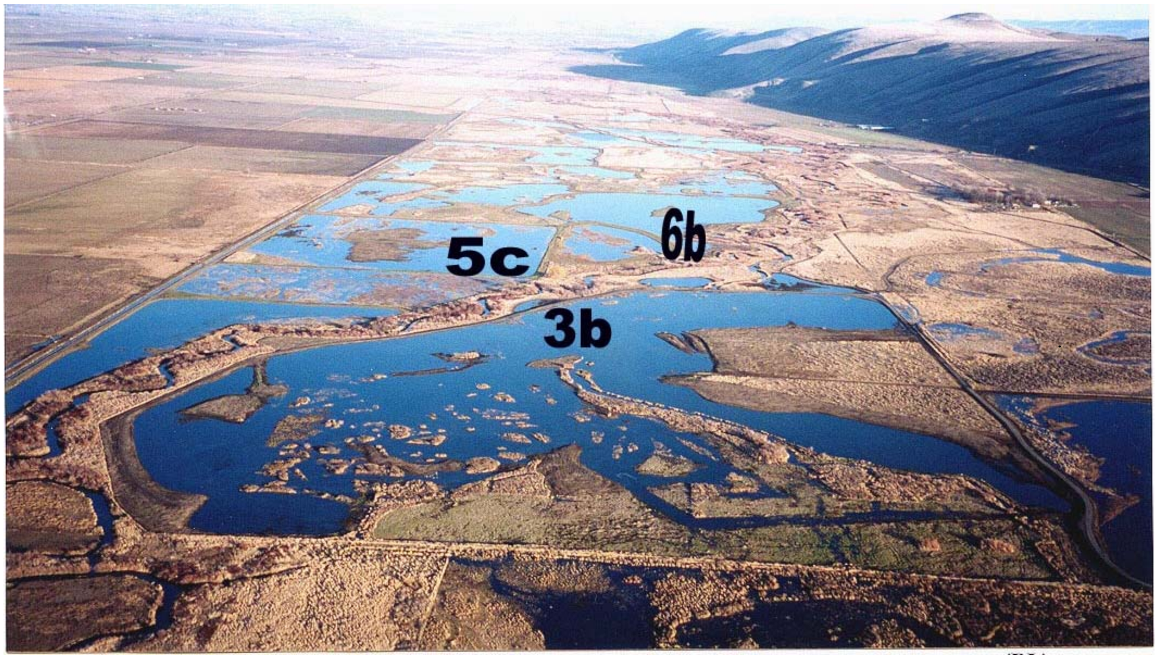

Figure 3. Aerial view of Toppenish National Wildlife Refuge looking east. The complete refuge is not shown. Toppenish Creek enters TNWR at the lower left and flows eastward. Snake Creek enters unit 3B in the lower right corner of the photograph. Three units are labeled (3B, 5C, and 6B).

Methods

Fish Sampling

We sampled two off-channel areas on TNWR for the presence of steelhead smolts and other fishes. Fish-sampling sites were located on Snake Creek and Lateral Creek (Figure 2 and Table 1). Snake and Lateral creeks flow into wetland units where steelhead smolts could potentially encounter impediments to migration including disorientation, predation, and thermal challenge. Snake Creek is a side channel to Toppenish Creek that originates approximately 4 kilometers above the Refuge. Lateral Creek is a channel on the Refuge into which water is diverted through an unscreened pipe from Toppenish Creek. We placed fyke nets (mesh size 0.25 in) at culverts located at water control structures to capture fishes moving through the areas (Figure 4). We sampled at both the entrance to the wetland units and the exit of the units to attempt to estimate survival and travel time through the units. The Lateral Creek traps were fished for 4 days only, after which the flow of water to Lateral Creek was stopped by the TNWR managers. The upper Lateral Creek trap was placed in the entrance culvert to Unit 9B. Unit 9B flows into Unit 9A then back into Lateral Creek. The lower Lateral Creek trap was placed in the exit culvert from Unit 9A. The Snake Creek traps were fished for 32 days before sampling was stopped due to high water temperature (Table 1). The upper Snake Creek trap was placed in the entrance culvert to Unit 3B. The lower Snake Creek trap was placed in the exit culvert to Unit 3B. There is approximately 0.8 kilometers of stream channel between the upper Snake Creek trap and the wetland that constitutes Unit 3B.

Captured steelhead were anesthetized, weighed to the nearest 0.1 g, measured for fork length to the nearest mm, and released below the net in which they were captured. Fins of steelhead captured at each wetland unit entrance were marked with a unique mark for each day. Fins were marked with Alcian Blue dye applied with a Madajet innoculator following the recommendations of Thedinga and Johnson (1995). Steelhead captured at the exit nets were inspected for marks. Fishes other than steelhead were identified and enumerated. A sub-sample of each species was weighed and measured for fork length. “Gee” style minnow traps baited with salmon eggs were fished overnight on two occasions in the wetland units and in Toppenish Creek to gauge their effectiveness at capturing steelhead. Condition factors were computed for captured steelhead as $K = mass / (length)^3$ (Bagenal and Tesch 1978).

Figure 4. Deployment of fyke net at the lower Snake Creek site on Toppenish National Wildlife Refuge, 2001.

Temperature

We deployed four thermographs (Optic StowAway; Onset Computer Corporation) on the Refuge (Table 1 and Figure 2). Water temperature was recorded every hour. The thermographs were located in Toppenish Creek where it enters the Refuge, and where it leaves the Refuge, in Snake Creek adjacent to the upper fyke net, and in Unit 6A. Unit 6A was dewatered toward the end of the study and the thermograph was moved to Toppenish Creek below the Unit 3B outlet. The thermograph from Unit 6A had not been downloaded at the time of this report.

Flow

We took flow measurements in Toppenish Creek and Snake Creek on two occasions during the course of the study (Figure 2). The Toppenish Creek flow site was immediately upstream of the maintenance-road bridge over Toppenish Creek on the Refuge. The upper Snake Creek flow site was at the upper fyke net (entrance to Unit 3B). The lower Snake Creek flow site was immediately downstream of the lower fyke net (exit of Unit 3B). Flows were taken with a Marsh-McBirney flow meter following Gallagher and Stevenson (1999).

Results

Fish sampling

We found a total of 12 fish species on TNWR during the spring 2001 sampling period (Table 2). Steelhead trout *Oncorhynchus mykiss*, western brook lamprey *Lampetra richardsoni*, black bullhead *Ictalurus melas*, carp *Cyprinus carpio*, chiselmouth *Acrocheilus alutaceus*, goldfish *Carassius auratus*, largemouth bass *Micropterus salmoides*, redside shiner *Richardsonius balteatus*, longnose sucker *Catostomus catostomus*, longnose dace *Rhinichthys cataractae*, northern pikeminnow *Ptychocheilus oregonensis*, and pumkinseed *Lepomis gibbosus*. Goldfish were the most common species with 1,514 individuals captured, while western brook lamprey was the least common species with 4 individuals captured.

Black bullhead, carp, goldfish, largemouth bass, and pumpkinseed are exotic species.

Table 1. Sampling locations and types of data collected at Toppenish National Wildlife Refuge, 2001. See Figure 2 for locations. NA = Not available at present.

Sample method Location name	GPS reading		Dates sampled (mm / dd)
	Longitude	Latitude	
Fish / Fyke nets			
Snake Creek – upper	46^{O} 18.315’	120^{O} 22.255’	4/23 – 5/24
Snake Creek – lower	46^{O} 18.708’	120^{O} 21.355’	4/24 – 5/24
Lateral Creek – upper	46^{O} 18.648’	120^{O} 20.036’	4/23 – 4/27
Lateral Creek – lower	46^{O} 18.823’	120^{O} 19.635’	4/23 – 4/27
Temperature			
Toppenish Cr. – upper	46^{O} 19.034’	120^{O} 21.897’	4/24 – ongoing
Toppenish Cr. – lower	46^{O} 18.870’	120^{O} 18.828’	4/25 – ongoing
Snake Cr.	46^{O} 18.315’	120^{O} 22.255’	4/25 – 5/30
Unit 6A	46^{O} 18.857’	120^{O} 20.657’	4/25 – 5/15
Flow			
Toppenish Cr.	46^{O} 18.519’	120^{O} 20.711’	4/26, 5/2
Snake Creek – upper	46^{O} 18.315’	120^{O} 22.255’	4/26, 5/2
Snake Creek – lower	46^{O} 18.708’	120^{O} 22.355’	5/2

We found steelhead in Snake Creek but not in Lateral Creek. A total of 159 steelhead were captured in the upper Snake Creek trap (entrance to unit 3B). Dye marks were given to 153 of these steelhead, 3 were released unmarked, and 3 were mortalities. We captured a total of 81steelhead in the lower Snake Creek trap of which 38 had dye marks (Figure 5 and Appendix 2). The recapture rate for marked steelhead from the upper to lower Snake Creek traps was 24.8%. Median travel time from the upper Snake Creek trap for the 38 marked fish captured in the lower Snake Creek trap was 2 days (Figure 6). Only three fish took over five days to negotiate Unit 3B, while ten fish traversed the unit in one day. Some fish may have been lost through holes in the nets during the middle period of sampling, perhaps causing the “bimodal” pattern in Figure 45.

The minnow traps, deployed and baited with salmon eggs, failed to capture any steelhead in the wetland units or in the mainstem of Toppenish Creek. Three traps were fished on two separate nights.

Table 2. Fish species and number of individuals captured at four sites on Toppenish National Wildlife Refuge during spring of 2001. Sites are: upper Snake Creek (U.Snake), lower Snake Creek (L.Snake), upper Lateral Creek (U.Lat), lower Lateral Creek (L.Lat). Steelhead numbers are shown in Table 3.

	Site				
Species	U.Snake (entrance)	L.Snake (exit)	U.Lat (entrance)	L.Lat (exit)	Total
Western brook lamprey	3	1	0	0	4
Black bullhead	4	42	0	0	46
Carp	0	90	0	0	90
Chiselmouth	5	4	0	0	9
Goldfish	0	56	0	1,458	1,514
Largemouth bass	0	0	0	5	5
Redside shiner	137	227	4	25	393
Longnose sucker	123	69	0	0	192
Longnose dace	16	8	0	0	24
Northern pikeminnow	25	5	0	0	30
Pumpkinseed	91	753	1	380	1,225

Table 3. Number of steelhead captured at the upper and lower Snake Creek traps. The upper trap was located above Unit 3B and the lower trap was located at the Unit 3B exit. Traps were checked daily.

Upper Snake Creek			Lower Snake Creek		
Total STH	STH released		Total STH	STH released	
captured	marked	not marked	captured	with mark	unmarked
159[a]	153	3	81[b]	38	43

[a] Includes three mortalities found in the trap.
[b] Includes two fish whose mark status was not determined.

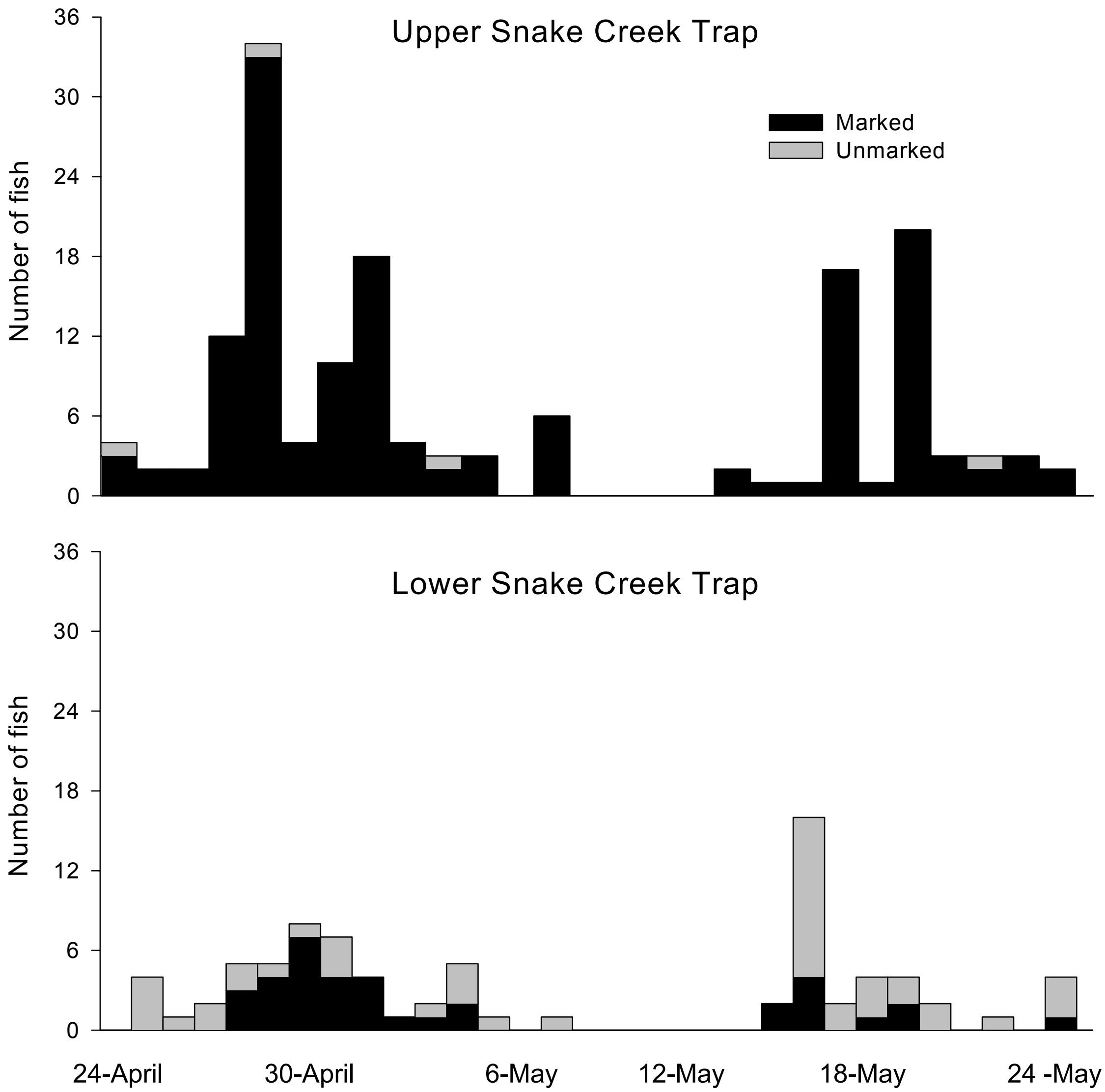

Figure 5. Number and timing of steelhead captured at the Snake Creek trap sites on Toppenish National Wildlife Refuge, 2001. Steelhead captured at the upper trap were given a dye mark unique to each day.

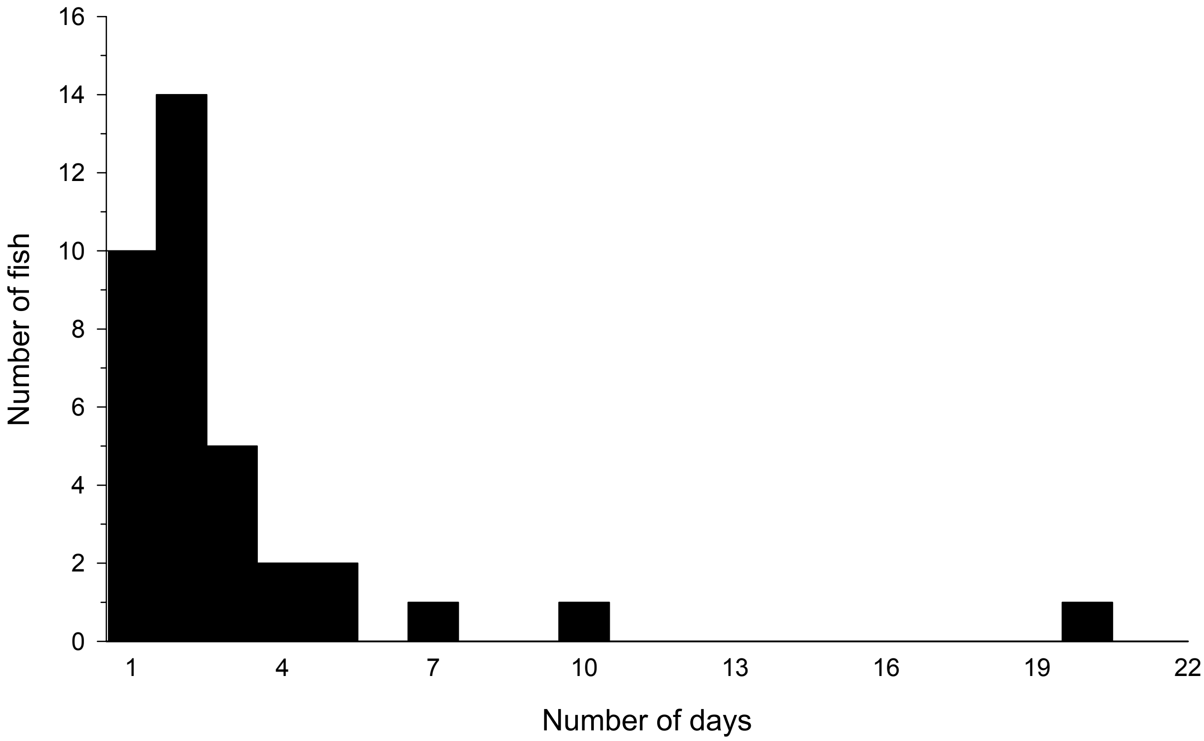

Figure 6. Travel time of dye-marked steelhead on Toppenish National Wildlife Refuge from the upper Snake Creek trap, through Unit 3B to the lower Snake Creek trap during 24 April to 24 May, 2001. Median passage was 2 d (N = 38).

Individual data on juvenile steelhead are provided in Appendix 2. The average length of all fish entering the TNWR was 171 mm FL (range 121-275 mm), having an average mass of 50.0 g (range 15.2 – 171.4 g; Table 4). The overall condition of steelhead was 0.979 (Table 4). Although unmarked fish captured at the exit of unit 3B tended to be larger (Table 4), there was no statistical difference in the length, size, or condition of marked (recaptured) versus unmarked steelhead collected at the lower Snake Creek trap (t-tests, $\log_e$ transformed data; all $P > 0.17$). Since there was no difference, we pooled marked and unmarked fish from the exit trap for remaining analyses.

The average length of all steelhead entering the upper Snake Creek trap declined slightly over the sample period (linear regression; $P<0.05$), but size did not change with time at the lower Snake Creek trap. Because of the bimodal nature of the passage data at the two traps, we compared size of fish collected during two periods: 24-April to 10-May (days of year 114-130) and 11-May to 24-May (days of year 131-144). During the early period, juvenile steelhead length and mass were significantly larger at the exit than at the entrance to unit 3B (t-tests; $P<0.06$; Table 5). During the late period, fish exiting the unit were not different in size or condition that fish entering the unit (t-tests; $P>0.13$; Table 5). Length-frequency distribution suggested that larger fish (>220 mm) may have been slightly more successful at transiting unit 3B than smaller fish, although we did not test this hypothesis statistically because of the relatively small number of fish in this size class.

Table 4. Average size and condition of juvenile steelhead collected at two traps on Toppenish National Wildlife Refuge during 2001. Upper Snake Creek is the entrance to unit 3B and lower Snake Creek is the exit from this unit.

	Fork length (mm)		
	Average	SD	*N*
Upper Snake Creek	168	20	156
Lower Snake Creek	176	31	79
Marked	171	19	38
Not marked	181	39	41
All individuals	171	25	235

	Mass (g)		
	Average	SD	*N*
Upper Snake Creek	48.3	20.2	154
Lower Snake Creek	54.9	29.5	54
Marked	47.8	11.4	25
Not marked	61.0	38.2	29
All individuals	50.0	23.1	208

	Condition (K)		
	Average	SD	*N*
Upper Snake Creek	0.979	0.091	154
Lower Snake Creek	0.977	0.071	54
Marked	0.963	0.067	25
Not marked	0.990	0.074	29
All individuals	0.979	0.086	208

Table 5. Average size of juvenile steelhead during early and late migration periods at Toppenish National Wildlife Refuge, 2001. Entrance is the upper Snake Creek trap and Exit is the lower Snake Creek trap. Numbers in parentheses are SD.

	Fork length (mm)	N	Mass (g)	N
Early period (April 24 – May 10)				
Entrance	171 (20)	101	50.3 (19.4)	101
Exit	179 (28)	46	62.1 (33.9)	35
Late period (May 11 – May 24)				
Entrance	163 (19)	55	44.4 (21.4)	53
Exit	172 (34)	33	41.5 (10.1)	19

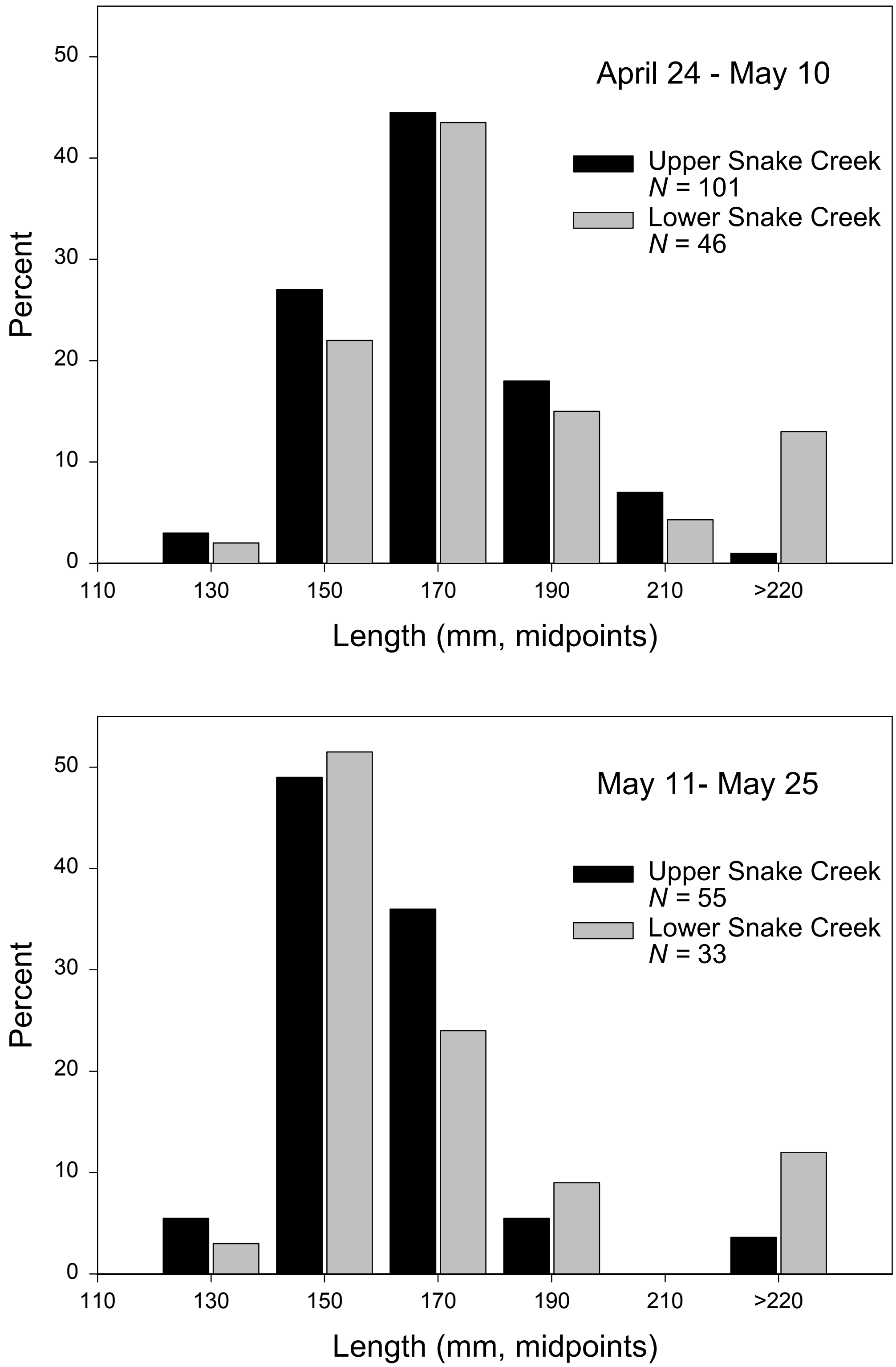

Figure 7. Length-frequency distributions of juvenile steelhead entering (Upper Snake Creek) and exiting (Lower Snake Creek) Unit 3B on Toppenish National Wildlife Refuge, 2001. Data are divided into two periods (top and bottom panels).

Temperature

The minimum water temperature we recorded at TNWR during our spring 2001 fish sampling period was 9.8 ºC in Snake Creek and the maximum temperature recorded was 28.7 ºC, also in Snake Creek (Table 6). The Washington Department of Ecology has set a 16 ºC limit for surface waters as an indicator of stream health (Washington Department of Ecology, November 18 1997, Chapter 173-201A, Water Quality Standards for the Surface Waters of the State of Washington). Maximum water temperatures exceeded 16 ºC on 30 days at upper Toppenish Creek, 26 days at lower Toppenish Creek, and 31 days at Snake Creek. Snake Creek was the warmest site with an hourly mean temperature of 17.6 ºC. Toppenish Creek had a mean daily temperature of 16.8 ºC at the upper site and 16.6 ºC at the lower site (Table 6).

The daily average, maximum, and minimum temperatures varied considerably during the study period (Figure 8). Temperatures generally increased through May, but there were three periods of declining temperature that were likely associated with increased flows caused by rain events. Mean daily temperature was generally highest in Snake Creek and similar at the Toppenish Creek sites.

Average temperature differences were computed between thermographs on each day of sampling (day of year 118 – 156; Figure 9). On most days, water entering unit 3B in Snake Creek was warmer than water at either the upper or the lower Toppenish Creek sites (Figure 9 A and B). On 27 of 39 days monitored (69%), the difference in average daily water temperature between Snake Creek and lower Toppenish Creek was significantly greater than zero (P <0.01; t-test). Water temperature at the two Toppenish Creek monitoring sites was generally similar except during the last 10 days of the sampling period when temperature was about 1 °C higher at the upper Toppenish Creek location (Figure 9 C). Average hourly temperature in Snake Creek was warmer than water in lower Toppenish Creek (mean difference +0.9 °C; SE 0.1; N = 911; P <0.001 for t-test equal to zero) and was also warmer than water in the upper Toppenish Creek site (mean difference +0.6 °C; SE 0.1; N = 924; P < 0.001). Hourly water temperature at the upper Toppenish Creek site was warmer on average than water at the lower Toppenish

Creek site (mean difference +0.3 °C; SE 0.01; N =910; $P < 0.001$), although most of this difference appears to have occurred during the latter part of the sample period.

The occasional declines in water temperature in Snake and Toppenish Creeks were likely caused by rain events and increased snowmelt that caused increased stream flows. Higher flow volumes probably tended to mix water and reduce overall temperatures and differences in temperature. Flow in the Yakima River at Kiona shows three peaks (Figure 9 D) that correspond fairly well with the declines in temperature and reduction in temperature differences between Snake Creek and Toppenish Creek (Figure 9 A and B). Kiona is downstream from TNWR, which may influence the temporal correspondence of these cooling events.

Diel temperatures were examined for three 3-d periods when temperature was relatively constant: a period early in May (days 131-133) with relatively high temperature, a period of low temperatures (days 136-138), and a period of very high temperatures in late May (days 144-146). For each of these periods we computed the average hourly temperature at each thermograph and plotted results in Figure 10. Water temperature showed a diel variation at all locations and periods, with highest temperature usually occurring about 18:00 and lowest temperature occurring at about 08:00. Water temperature from Snake Creek was warmer throughout the day during the first period (days 131-133; Figure 10 A), while the diel variation was greater at upper Toppenish Creek than at lower Toppenish Creek. There was little difference between the three thermographs during the cool-water period (Figure 10 B). During the warmest period that we analyzed, water in Snake Creek varied from ~18 ^{O}C to ~24.5 ^{O}C, while water at the lower Toppenish Creek site varied much less, from 20.8 ^{O}C to 23.5 ^{O}C.

Table 6. Mean, minimum, and maximum of hourly water temperatures at three sites on Toppenish National Wildlife Refuge during the period 25 April – 31 May.

Site	Temperature (ºC) Min	Mean	Max.
Upper Toppenish Creek	9.9	16.8	26.8
Lower Toppenish Creek	10.6	16.6	26.3
Snake Creek	9.8	17.6	28.7

Flow

We measured flow in Toppenish and Snake Creeks twice (Table 7). We measured flow in lower Snake Creek below the Unit 3B outlet once to compare with the upper Snake reading. Flow in Toppenish Creek varied from ~43 to ~75 cfs, while flow in Snake Creek was <2 cfs.

Table 7. Flow (cubic feet per second; cfs) readings taken during spring 2001 on Toppenish National Wildlife Refuge.

Site	Flow (cfs) 26 April	2 May
Toppenish Cr.	42.5	75.0
Snake Cr. – upper	1.6	1.6
Snake Cr. - lower	NT[a]	0.8

[a] NT = Not taken.

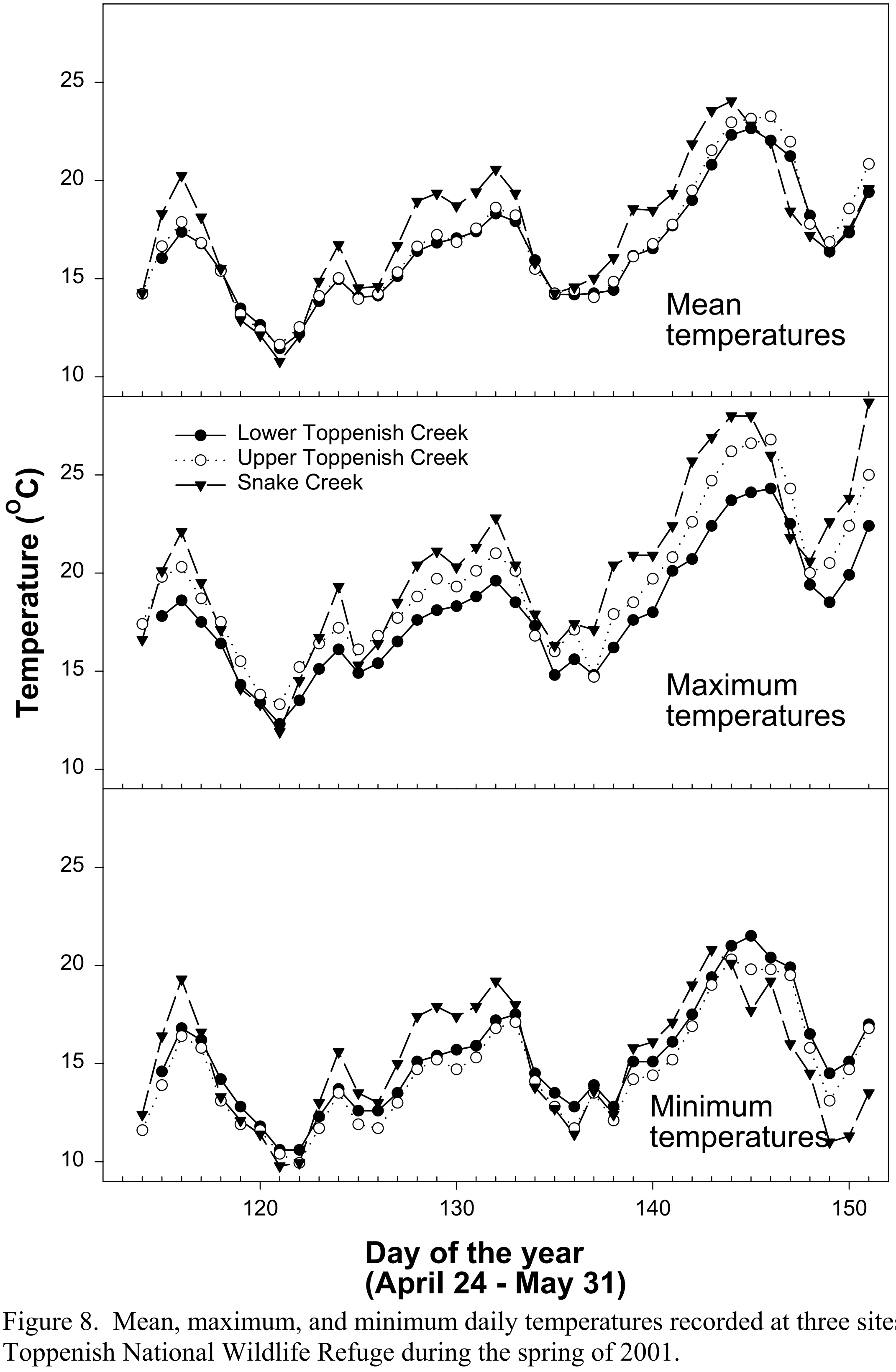

Figure 8. Mean, maximum, and minimum daily temperatures recorded at three sites on Toppenish National Wildlife Refuge during the spring of 2001.

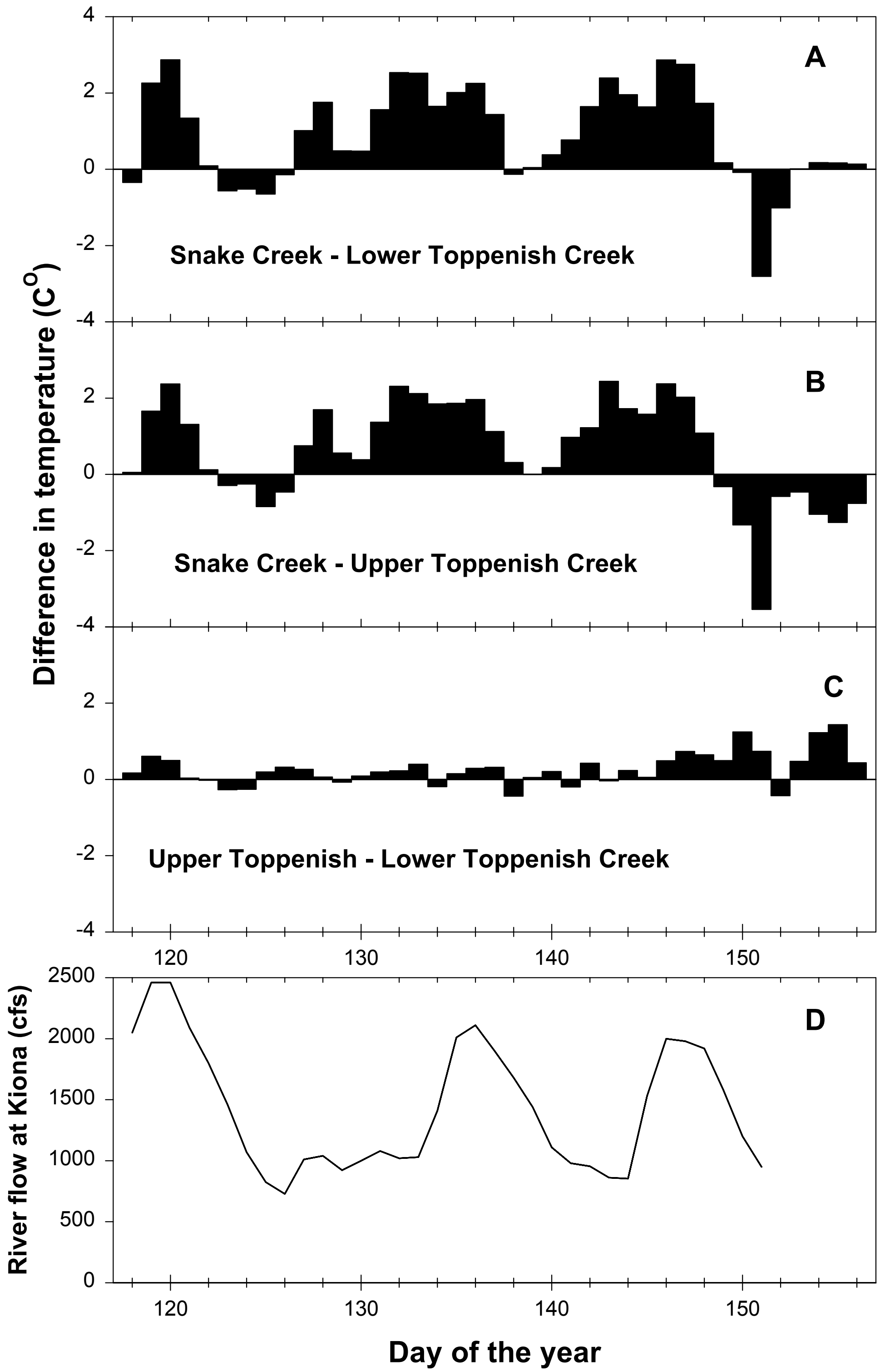

Figure 9. Difference in mean temperatures at three locations on the Toppenish National Wildlife Refuge (A-C), and flow measured at Kiona (USGS gage #12510500; panel D) on the lower Yakima River during May, 2001.

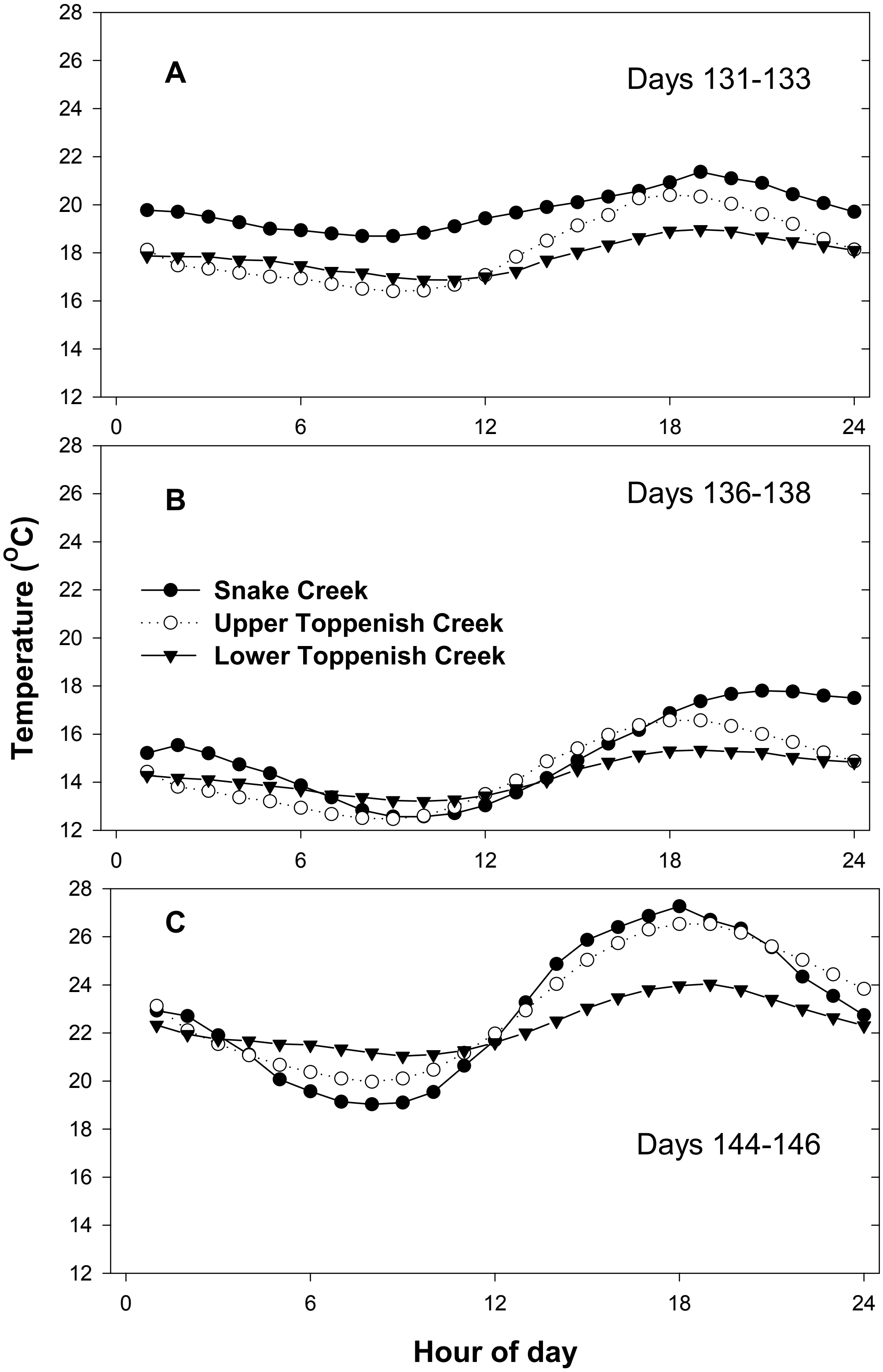

Figure 10. Diel patterns of temperature variation at Toppenish National Wildlife Refuge, spring 2001. Panels A-C represent three periods with relatively constant daily temperatures. Each point represents the mean of three days at the same hour of the day.

Discussion

Fish sampling at TNWR during spring 2001 showed that juvenile steelhead use the Snake Creek channel of Toppenish Creek, and that steelhead enter and use habitat within the TNWR. Steelhead in the Snake Creek channel have to negotiate at least wetland Unit 3B and possibly other units on TNWR. We captured 202 individual steelhead in our Snake Creek traps during the period 23 April – 24 May. The steelhead we captured all exhibited smolt characteristics: silvery body color, streamlined shape, deciduous scales, and dark band on the caudal fin (Chrisp and Bjornn 1978; Loch et al. 1988). We captured no steelhead parr, suggesting that juvenile steelhead use Toppenish Creek on TNWR as a migration corridor. A variety of other species of fish were common on the refuge, including five introduced species (pumkinseed, carp, black bullhead, largemouth bass, and goldfish). The total biomass of fish on the refuge is likely quite high based on the observed numbers, although we did not attempt to estimate biomass.

We marked 153 steelhead at the upper Snake Creek trap and recaptured 38 of these fish at the lower Snake Creek trap after they had traversed Unit 3B. The 2-d median travel time from the upper to lower Snake Creek traps implies that steelhead have the ability to negotiate Unit 3B quickly. The fate of the marked fish that we did not re-capture is unknown, but may have included predation, starvation, retention on the unit past our sampling, or escape through an unsampled passageway. There is a small channel which leads from Snake Creek back to Toppenish Creek between the upper trap and Unit 3B. This channel could have provided an escape route for some fish, however, it was carrying less than 5% (visual estimation) of the flow and was choked with weeds and debris so we doubt that very many fish escaped via this channel. The steelhead in Unit 3B also could have become disoriented and eventually perished due to starvation or high water temperature.

Some potential piscivorous predators present on the refuge include great blue heron, black-crowned night heron, bald eagle, white pelican, river otter, northern pikeminnow, and largemouth bass. Northern pikeminnow (range 211-253 mm FL) and largemouth bass (range 66-76 mm FL) captured on the TNWR were generally too small to be effective predators on these large steelhead smolts (range 121 – 275 mm).

Great blue herons are abundant on the refuge during the spring period and many were observed feeding in wetland units and along the Snake Creek channel between the upper and lower traps by Refuge staff. A recent study of piscivorous birds in the Yakima Basin found fairly high densities of great blue heron along the middle reach of the Yakima River in April and May (Pearson et al. 2000). Great blue heron density increased to about 0.7 birds per km in May near Granger on the Yakima River, a short distance from TNWR (Pearson et al. 2000). The diet of herons was not determined by Pearson et al. (2000), but they "*frequently observed herons in fields and marshes*" (p. 93). Herons are considered to be significant predators of fish at hatcheries (Schaeffer 1992; Pitt and Conover 1996).

Our sampling had some limitations that should be considered. The peak of the smolt migration occurred before our sampling period, and smolts were captured upstream of the refuge as early as mid-January (pers. com. Rolf Eversen, Yakama Nation). Future studies of this type should be started at an earlier date to be sure that the peak migration is sampled. Several times during the course of sampling, holes were found in the nets from avian or mammalian predators. A portion of the unmarked fish captured at lower Snake Creek may have passed through the upper Snake Creek trap due to holes chewed in the net. The holes were repaired immediately upon discovery, and protective barriers were installed around the nets, which appeared to discourage the predators. We captured 43 steelhead in the lower Snake Creek trap that had no dye mark. A portion of the unmarked fish captured at lower Snake Creek may have been in Units 3A and 3B prior to our sampling (Unit 3A flows into 3B, flow to Unit 3A was stopped when we started sampling).

For some salmonids, larger fish migrate earlier in the season than smaller fish (e.g. Bohlin et al. 1996), which might be the reason we observed a larger average size in early May compared to late May. The slightly larger size of fish that we observed exiting unit 3B compared to those entering could have also been a result of larger fish migrating early if these larger fish were on unit 3B and 3A prior to the beginning of our sampling. Differences in size between fish entering and leaving the refuge could also be caused by differential mortality, such as smaller fish being more vulnerable to bird or fish predators.

Water temperatures observed at several of the thermographs approached the upper lethal limit for salmonids (McCullough et al. 2001). Four dead steelhead were reported in the lower Snake Creek trap on the final day of sampling, and sampling was stopped due to the high water temperatures. Temperatures regularly exceeded the preferred range for steelhead of 10-13 ºC (Bell 1986). Temperatures at upper Toppenish Creek and Snake Creek exceeded the lethal level for steelhead of 23.9 ºC (Bell 1986). Temperatures recorded in lower Toppenish Creek were similar to those in upper Toppenish Creek and were lower than temperatures in Snake Creek. Water on the TNWR is relatively shallow, slow-moving, and is often exposed to high air temperatures, so it was somewhat surprising that temperatures did not change significantly between the upper and lower Toppenish Creek sites. This suggests the possibility of groundwater input to Toppenish Creek, possibly through the wetland units.

The interaction between ground water and temperature on wetlands may be complex, with discharge and recharge zones occurring in the same wetland (Shedlock et al. 1993; Cole et al. 1997). In central Pennsylvania, for example, riparian depressions and slopes provided over 45% of the groundwater to a variety of wetlands (Cole et al. 1997). Wetlands may also be important zones of nutrient cycling since large numbers of waterfowl may move between surrounding agricultural areas and the wetlands on a diel cycle (Kitchell et al. 1999). Multidisciplinary studies with hydrologists, biologists, and geomorphologists may be needed to understand how specific wetlands function, and how they might benefit birds, fish, or other wildlife.

Low flow conditions as a result of the dry year likely contributed to the high water temperatures. The relatively high temperatures that occurred in Snake Creek and on TNWR suggest that steelhead could be exposed to near-lethal temperatures, or experience smoltification problems. High temperatures during the smolt phase can result in blockage of seaward migration, desmoltification, shifts in emigration timing, or other stresses detrimental to fitness (McCullough et al. 2001). Steelhead exhibit a variety of life history strategies, and such high temperatures might cause fish to remain in freshwater for an extra year.

The Pacific Northwest has been under a severe drought during 2001, and flow in Toppenish Creek during spring of 2001 was abnormally low. The winter of 2000/2001 was extremely dry in the Pacific Northwest. Snowpack in the lower Yakima River Basin was reported by the National Weather Service to be 36% of average. Normally during the spring runoff period, Toppenish Creek overflows the dikes that separate the wetland units from Toppenish Creek (pers. com. with Kevin Lamm, USFWS), however, this did not occur in spring 2001. Average daily historical flow during May at Kiona on the Yakima River was 5,830 cfs (annual range 902 to 13,930 cfs; period of record 1905 to 2000; USGS data). The average daily flow for May during 2001 at Kiona was 1,340 cfs, ~23% of normal. Although Kiona is below the TNWR, flows at this site should be indicative of basin-wide precipitation, snowmelt, and streamflows. Flow in Toppenish Creek was low during the spring of 2001 due to drought conditions. The disparity between the two flow measures taken on Toppenish Creek was a result of stopping pumping from Toppenish Creek to wetland units. Flow in Snake Creek appeared to be less at the lower compared to the upper Snake Creek sites, although we took only one measurement at the lower site. The apparent reduction in flow between the upper and lower Snake Creek sites could reflect evaporation or groundwater flow. More detailed flow data is recommended in the future at TNWR. The low flows during spring 2000 prevented us from addressing the issue of steelhead stranding via overflooding of dikes at TNWR, one of the original concerns of the USFWS.

Conclusions and Recommendations

Juvenile steelhead studies at TNWR during 2001 provided answers to some questions, and raised some new issues. We demonstrated that a portion of the outmigrating steelhead are using Snake Creek and entering wetland units off of Snake Creek, though it is difficult to say what proportion of the total population enters Snake Creek. For fish that entered refuge Unit 3B through Snake Creek, about 75% were not detected at the lower trap -- the specific fate of the unaccounted for fish is not known. Because 2001 was a drought year we could not address questions related to dike overtopping.

Some useful follow-up work might be:

- **Fish sampling.** Continue sampling at the Snake Creek traps during other years to confirm the patterns observed in 2001. We found no steelhead at the Lateral Creek Units but sampling should be repeated there. Such sampling should start earlier to include the peak outmigration of juvenile steelhead in Toppenish Creek. Fyke-net sampling could be conducted on other units having culvert inlets and outlets. The drought of 2001 may have produced unusual patterns of fish abundance or movement on TNWR that would not be observed during normal hydrologic years. We would recommend that all juvenile steelhead captured be tagged with PIT tags, rather than dyes. PIT tagging would allow better monitoring of the movements and growth of individuals on the TNWR, and also would provide the opportunity to detect fish at downriver facilities such as Prosser juvenile bypass (Yakima River) and the mainstem Columbia River Dams. New techniques might be necessary to monitor fish movements during dike over-flooding events (radio telemetry, e.g.).
- **Water quality.** Our observations on water temperature with only three thermographs suggested that TNWR may not represent a thermal barrier to steelhead migration, and may provide some temperature benefits. A better understanding of temperature variation, and its potential effects, could be gained by deploying additional thermographs. We would recommend monitoring temperature in Snake Creek, several locations along Toppenish Creek, and in several of the refuge units. A thermograph further up the drainage where Snake and Toppenish Creek split would also be helpful to understand how water warms as it transits Snake Creek. More flow

data and possibly hydrologic modeling may help to give clues on water losses to evaporation or to groundwater that may provide cooling. Other water quality data on turbidity, in particular, would be helpful in understanding whether avian or fish predators might be more or less successful at certain times.

- **Sources of steelhead mortality on TNWR.** The results from 2001 suggested that a fairly large proportion of juvenile steelhead that entered unit 3B did not survive, or at least were not detected at the exit trap. The fates of fish on the refuge could be examined with specific studies. An observational or experimental study of feeding behavior and success by birds, particularly great blue herons, might be instructive. Such a study might, at first, involve observations of feeding behavior, sampling of the gut contents of some birds to determine diet proportions, observations of habitat use by birds (depth of water, vegetation, etc.), and perhaps some modeling of energetics. Caspian terns and gulls have been shown to consume large numbers of juvenile steelhead on islands in the lower Columbia River (Roby et al. 1998), and managers are undertaking measures to limit the mortality of the salmonids. Other sources of steelhead mortality (starvation, fish predation) appear less likely considering the 2001 data, but might be considered with additional data.
- **Water movement and habitat modeling.** Detailed models of water flow and water elevation might be useful tools. If bird predators are found to be a serious problem, for example, we could first develop habitat availability and use maps for the TNWR. Habitat data could be linked with a hydraulic model of water flow for the refuge (water depth based on inflow and elevation), making it possible to examine how changes in water management influenced total habitat and predation opportunities. A first step along these lines might be to develop detailed elevation data for the TNWR using aerial LIDAR surveys, upon which hydraulic models can be built.
- **Management options and tests.** Modifications of refuge structures or operations might be developed, tested, and evaluated. Restricting juvenile steelhead from entering Snake Creek, for example, might be explored. This would prevent steelhead from being entrained to unit 3B, but would not prevent steelhead from entering the refuge during flooding events. If wading birds such as great blue herons were determined to be a significant source of steelhead mortality, deepening of certain

portions of units might provide a deep-water refuge for fish. Habitat use studies on juvenile steelhead might also be conducted to see if shoreline vegetation or more permanent structures could be used to provide cover and thus an escape from predators.

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Appendices

Appendix 1. Average daily temperatures at three locations on the Toppenish National Wildlife Refuge, 2001.
Data begins on April 24 (Day of year 114) and ends on May 31 (Day of year 151). *N* =24 for each day and location.

Obs	doy	ltop	utop	snake
1	113	16.6	16.8	17.5
2	114	16.3	14.2	14.3
3	115	16.0	16.6	18.3
4	116	17.4	17.9	20.2
5	117	16.8	16.8	18.1
6	118	15.4	15.4	15.5
7	119	13.5	13.2	12.9
8	120	12.6	12.4	12.1
9	121	11.4	11.6	10.8
10	122	12.2	12.5	12.1
11	123	13.8	14.1	14.9
12	124	15.0	15.0	16.7
13	125	14.0	14.0	14.5
14	126	14.1	14.2	14.6
15	127	15.1	15.3	16.7
16	128	16.4	16.6	18.9
17	129	16.8	17.2	19.3
18	130	17.1	16.9	18.7
19	131	17.4	17.5	19.4
20	132	18.3	18.6	20.6
21	133	17.9	18.2	19.3
22	134	15.9	15.5	15.8
23	135	14.2	14.2	14.2
24	136	14.2	14.4	14.6
25	137	14.2	14.0	15.0
26	138	14.4	14.8	16.1
27	139	16.2	16.1	18.6
28	140	16.5	16.8	18.5
29	141	17.7	17.8	19.3
30	142	19.0	19.5	21.9
31	143	20.8	21.5	23.6
32	144	22.3	23.0	24.0
33	145	22.6	23.1	22.8
34	146	22.0	23.3	21.9
35	147	21.2	22.0	18.4
36	148	18.2	17.8	17.2
37	149	16.4	16.9	16.4
38	150	17.3	18.6	17.5
39	151	19.4	20.8	19.6

Appendix 2. Size and condition data of juvenile steelhead at TNWR.
Loc is fish collected at the upper Snake Creek trap (usnake) or the lower Snake Creek trap (lsnake). Doy is julian day of the year.

Obs	length	mass	condition	loc	doy	mark
1	167	43.8	0.94043	usnake	114	LV
2	154	34.9	0.95557	usnake	114	LV
3	.	.	.	usnake	114	
4	165	43.1	0.95946	usnake	114	LV
5	192	64.4	0.90988	usnake	115	A
6	155	36.7	0.98553	usnake	115	A
7	185	58.2	0.91920	usnake	116	BC
8	163	49.0	1.13144	usnake	116	BC
9	190	64.4	0.93891	usnake	117	D
10	210	74.1	0.80013	usnake	117	D
11	172	46.5	0.91383	usnake	117	D
12	241	162.3	1.15949	usnake	117	D
13	182	55.4	0.91896	usnake	117	D
14	180	53.3	0.91392	usnake	117	D
15	172	52.1	1.02389	usnake	117	D
16	166	42.3	0.92473	usnake	117	D
17	179	51.3	0.89445	usnake	117	D
18	160	41.0	1.00098	usnake	117	D
19	169	49.4	1.02345	usnake	117	D
20	166	48.0	1.04934	usnake	117	D
21	174	58.2	1.10478	usnake	118	LP
22	172	42.7	0.83916	usnake	118	LP
23	171	53.4	1.06795	usnake	118	LP
24	182	67.4	1.11801	usnake	118	LP
25	156	35.1	0.92456	usnake	118	LP
26	207	83.1	0.93689	usnake	118	LP
27	183	57.8	0.94314	usnake	118	LP
28	157	36.6	0.94576	usnake	118	LP
29	198	67.2	0.86571	usnake	118	LP
30	147	27.6	0.86887	usnake	118	LP
31	197	76.6	1.00191	usnake	118	LP
32	165	41.0	0.91271	usnake	118	LP
33	167	45.2	0.97049	usnake	118	LP
34	166	47.8	1.04497	usnake	118	LP
35	176	55.4	1.01618	usnake	118	LP
36	168	47.7	1.00598	usnake	118	LP
37	182	58.5	0.97038	usnake	118	LP
38	190	69.0	1.00598	usnake	118	LP
39	188	59.8	0.89997	usnake	118	LP
40	194	68.7	0.94092	usnake	118	LP
41	195	71.2	0.96023	usnake	118	LP
42	153	37.3	1.04144	usnake	118	LP
43	144	28.6	0.95781	usnake	118	LP
44	127	18.6	0.90803	usnake	118	LP
45	207	86.2	0.97184	usnake	118	LP
46	161	45.5	1.09027	usnake	118	LP
47	144	30.2	1.01139	usnake	118	LP
48	188	63.4	0.95415	usnake	118	LP
49	182	56.3	0.93389	usnake	118	LP

Obs	length	mass	condition	loc	doy	mark
50	203	75.2	0.89894	usnake	118	LP
51	217	99.4	0.97276	usnake	118	LP
52	184	61.8	0.99205	usnake	118	LP
53	145	28.1	0.92173	usnake	118	LP
54	170	54.6	1.11134	usnake	118	
55	159	41.9	1.04237	usnake	119	RV
56	159	41.3	1.02745	usnake	119	RV
57	179	67.3	1.17343	usnake	119	RV
58	152	33.4	0.95108	usnake	119	RV
59	145	26.8	0.87908	usnake	120	DA
60	173	51.2	0.98885	usnake	120	DA
61	153	28.9	0.80691	usnake	120	DA
62	196	75.2	0.99873	usnake	120	DA
63	172	49.9	0.98065	usnake	120	DA
64	169	47.2	0.97787	usnake	120	DA
65	170	47.2	0.96072	usnake	120	DA
66	159	39.8	0.99013	usnake	120	DA
67	171	47.0	0.93996	usnake	120	DA
68	162	42.1	0.99023	usnake	120	DA
69	159	37.2	0.92545	usnake	121	UC
70	173	52.3	1.01010	usnake	121	UC
71	121	19.1	1.07815	usnake	121	UC
72	143	30.2	1.03276	usnake	121	UC
73	173	56.3	1.08735	usnake	121	UC
74	179	55.4	0.96594	usnake	121	UC
75	208	92.5	1.02790	usnake	121	UC
76	169	50.0	1.03588	usnake	121	UC
77	214	86.9	0.88670	usnake	121	UC
78	158	35.4	0.89749	usnake	121	UC
79	169	45.3	0.93851	usnake	121	UC
80	151	35.4	1.02819	usnake	121	UC
81	175	51.4	0.95907	usnake	121	UC
82	121	15.2	0.85800	usnake	121	UC
83	148	37.2	1.14751	usnake	121	UC
84	164	45.8	1.03833	usnake	121	UC
85	176	49.5	0.90796	usnake	121	UC
86	153	36.1	1.00794	usnake	121	UC
87	182	57.1	0.94716	usnake	122	RPRV
88	172	48.4	0.95117	usnake	122	RPRV
89	156	38.4	1.01148	usnake	122	RPRV
90	162	40.0	0.94084	usnake	122	RPRV
91	179	57.1	0.99558	usnake	123	ABC
92	166	48.4	1.05809	usnake	123	ABC
93	.	.	.	usnake	123	
94	163	42.3	0.97674	usnake	124	LPLV
95	162	41.9	0.98553	usnake	124	LPLV
96	144	27.1	0.90757	usnake	124	LPLV
97	154	35.4	0.96926	usnake	125	DUC
98	159	36.5	0.90803	usnake	126	RPA

Obs	length	mass	condition	loc	doy	mark
99	164	41.2	0.93404	usnake	126	RPA
100	159	41.1	1.02247	usnake	126	RPA
101	163	39.1	0.90285	usnake	126	RPA
102	161	41.2	0.98723	usnake	126	RPA
103	.	.	.	usnake	126	
104	175	48.7	0.90869	usnake	126	RPA
105	176	51.6	0.94648	usnake	131	UCBC
106	156	33.6	0.88505	usnake	131	UCBC
107	248	151.3	0.99194	usnake	132	RVD
108	140	25.2	0.91837	usnake	133	LPA
109	144	29.6	0.99130	usnake	134	RP
110	160	35.4	0.86426	usnake	134	RP
111	230	129.8	1.06682	usnake	134	RP
112	142	27.3	0.95345	usnake	134	RP
113	173	45.8	0.88456	usnake	134	RP
114	169	39.9	0.82663	usnake	134	RP
115	173	47.5	0.91739	usnake	134	RP
116	140	23.7	0.86370	usnake	134	RP
117	159	38.5	0.95779	usnake	134	RP
118	142	31.3	1.09315	usnake	134	RP
119	153	37.5	1.04702	usnake	134	RP
120	181	53.1	0.89549	usnake	134	RP
121	171	44.4	0.88796	usnake	134	RP
122	170	44.7	0.90983	usnake	134	RP
123	173	46.9	0.90580	usnake	134	RP
124	151	30.0	0.87135	usnake	134	RP
125	170	39.6	0.80602	usnake	134	RP
126	167	39.4	0.84595	usnake	135	LV
127	172	49.2	0.96690	usnake	136	A
128	169	49.3	1.02138	usnake	136	A
129	145	32.7	1.07261	usnake	136	A
130	159	59.8	1.48768	usnake	136	A
131	155	36.8	0.98822	usnake	136	A
132	148	34.3	1.05806	usnake	136	A
133	150	39.3	1.16444	usnake	136	A
134	159	40.2	1.00008	usnake	136	A
135	168	.	.	usnake	136	
136	154	.	.	usnake	136	A
137	162	33.5	0.78795	usnake	136	A
138	154	36.8	1.00759	usnake	136	A
139	148	32.3	0.99636	usnake	136	A
140	154	39.4	1.07878	usnake	136	A
141	162	43.2	1.01611	usnake	136	A
142	159	45.1	1.12198	usnake	136	A
143	165	46.7	1.03960	usnake	136	A
144	171	48.5	0.96996	usnake	136	A
145	159	51.3	1.27622	usnake	136	A
146	156	41.4	1.09050	usnake	136	A
147	150	38.2	1.13185	usnake	136	A

Obs	length	mass	condition	loc	doy	mark
148	191	62.9	0.90271	usnake	137	BC
149	175	50.3	0.93854	usnake	137	BC
150	130	22.8	1.03778	usnake	137	BC
151	175	53.1	0.99079	usnake	138	D
152	155	39.2	1.05267	usnake	138	
153	150	33.4	0.98963	usnake	138	D
154	159	38.4	0.95530	usnake	139	LP
155	184	60.5	0.97118	usnake	139	LP
156	166	49.0	1.07120	usnake	139	LP
157	146	31.5	1.01217	usnake	139	LP
158	161	36.7	0.87940	usnake	140	RV
159	149	31.6	0.95527	usnake	140	RV
160	175	50.8	0.94787	lsnake	115	
161	242	135.8	0.95819	lsnake	115	
162	235	138.4	1.06643	lsnake	115	
163	175	52.8	0.98519	lsnake	115	
164	171	43.2	0.86396	lsnake	116	
165	224	112.6	1.00183	lsnake	117	
166	174	52.2	0.99088	lsnake	117	
167	165	45.4	1.01066	lsnake	118	D
168	185	63.4	1.00132	lsnake	118	D
169	178	.	.	lsnake	118	
170	192	66.4	0.93813	lsnake	118	
171	174	53.4	1.01366	lsnake	118	D
172	170	.	.	lsnake	119	D
173	197	.	.	lsnake	119	D
174	167	41.2	0.88460	lsnake	119	LP
175	172	49.6	0.97476	lsnake	119	LP
176	189	69.6	1.03092	lsnake	119	
177	181	55.6	0.93765	lsnake	120	D
178	149	30.8	0.93109	lsnake	120	
179	205	.	.	lsnake	120	LP
180	198	71.5	0.92111	lsnake	120	A
181	169	53.4	1.10632	lsnake	120	LP
182	169	47.0	0.97373	lsnake	120	LP
183	205	79.0	0.91699	lsnake	120	LP
184	166	41.9	0.91599	lsnake	120	LP
185	153	.	.	lsnake	121	RV
186	158	.	.	lsnake	121	
187	243	.	.	lsnake	121	
188	147	.	.	lsnake	121	LP
189	126	.	.	lsnake	121	
190	174	.	.	lsnake	121	D
191	168	.	.	lsnake	121	D
192	144	28.9	0.96786	lsnake	122	UC
193	175	54.5	1.01691	lsnake	122	UC
194	152	35.5	1.01088	lsnake	122	UC
195	170	46.2	0.94036	lsnake	122	DA
196	176	48.2	0.88412	lsnake	123	UC

Obs	length	mass	condition	loc	doy	mark
197	154	34.8	0.95283	lsnake	124	UC
198	144	29.8	0.99800	lsnake	124	
199	171	54.8	1.09595	lsnake	125	LP
200	225	121.1	1.06316	lsnake	125	
201	252	171.4	1.07105	lsnake	125	
202	194	78.5	1.07514	lsnake	125	
203	159	39.5	0.98267	lsnake	125	RURP
204	169	43.7	0.90536	lsnake	126	
205	147	32.9	1.03572	lsnake	128	
206	171	47.2	0.94396	lsnake	135	RP
207	174	46.5	0.88268	lsnake	135	RP
208	198	69.2	0.89148	lsnake	136	
209	194	.	.	lsnake	136	A?
210	.	.	.	lsnake	136	
211	.	.	.	lsnake	136	
212	160	.	.	lsnake	136	
213	155	.	.	lsnake	136	A
214	147	.	.	lsnake	136	
215	270	.	.	lsnake	136	
216	172	41.2	0.80968	lsnake	136	RP
217	160	43.7	1.06689	lsnake	136	
218	157	.	.	lsnake	136	
219	143	.	.	lsnake	136	RP
220	166	.	.	lsnake	136	LC
221	164	.	.	lsnake	136	
222	144	.	.	lsnake	136	RP
223	161	36.3	0.86982	lsnake	136	
224	155	39.2	1.05267	lsnake	137	
225	159	35.7	0.88813	lsnake	137	
226	155	39.2	1.05267	lsnake	138	
227	155	35.2	0.94525	lsnake	138	
228	163	42.3	0.97674	lsnake	138	
229	157	39.8	1.02845	lsnake	138	A
230	157	37.7	0.97419	lsnake	139	A
231	162	39.4	0.92673	lsnake	139	RP
232	138	26.1	0.99312	lsnake	139	
233	150	40.1	1.18815	lsnake	139	
234	154	36.4	0.99664	lsnake	140	
235	147	30.6	0.96332	lsnake	140	
236	188	63.6	0.95716	lsnake	142	
237	240	.	.	lsnake	144	
238	150	.	.	lsnake	144	
239	232	.	.	lsnake	144	RP
240	275	.	.	lsnake	144	