An Evaluation of Flow and Water Temperatures during the Spring for Protection of Salmon and Steelhead Smolts in the Trinity River, California

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by

Paul A. Zedonis
and
Tammy J. Newcomb

U.S. Fish and Wildlife Service
Coastal California Fish and Wildlife Office
Arcata, CA

TABLE OF CONTENTS

List of Figures

List of Tables

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Introduction

An important phase in the life history of Pacific salmonids (Oncorhynchus species) is the parr-smolt transition when juveniles undergo physiological changes and migrate to the ocean. Several factors influence the timing of this critical phase including water temperature, photoperiod, fish size and growth, and river flow (Folmar and Dickhoff 1980, Wedemeyer et al. 1980, Hoar 1988). In unregulated rivers, environmental influences determine river flow and water temperature; whereas in regulated rivers, flow and temperature regimes can be highly altered because of dam operations (Ward and Stanford 1979). In the Trinity River, a diversion project alters the temporal pattern of water flow as well as the total amount of water discharged to the river. In concert, these two conditions create a highly altered flow and thermal regime downstream of the dam which may negatively influence the migration of salmonid smolts. Because smolt migration is a sensitive and critical period in salmonid life history, high mortality rates can significantly influence an entire cohort as evidenced by a decline in adults returning to a river (Raymond 1979). Repeated years of significant mortality within cohorts can severely reduce a fish population and compromise their sustainment through time (Bond 1979). The objective of this document is to provide rationale for recommendations regarding water temperature and associated flows during spring smolt emigration from the Trinity River. We incorporate and apply information from scientific studies addressing: 1) physiological processes of smoltification in chinook salmon (0. *tshawytscha),* coho salmon (0. kisutch), and Steelhead (0. mykiss); 2) existing environmental conditions and fish migration patterns in the Trinity River watershed; and 3) management considerations for dam discharge and water temperature.

Study Approach

The following approach was used to make recommendations regarding temperature and flow in the Trinity River for the protection of emigrating salmon and Steelhead smolts:

1. We conducted a literature review on thermal tolerance ranges and the influence of flow on migration rates for chinook salmon, coho salmon, and Steelhead smolts;

2. We evaluated emigration timing data and corresponding water temperatures of the mainstem Trinity River and New River, an unregulated tributary to the Trinity River;

3. We used results of a water temperature model of the Trinity River to evaluate dam releases in the Trinity River that would result in suitable water temperatures for outmigrating salmon and Steelhead smolts;

4. We integrate the first three steps to provide guidance for water management decisions in the Trinity River Basin during the spring.

Description of the Trinity River Basin

The Trinity River, located in Northwestern California, is the largest tributary to the Klamath River (Figure 1). In the early 1960's, construction of Trinity and Lewiston Dams resulted in a regulated river system. Lewiston Dam, located at river kilometer (RKM) 180.2, serves as a re-regulating reservoir for releases from Trinity Dam to the Trinity River and a point of trans-basin diversion to the Sacramento basin. Lewiston Dam represents the furthest upstream point of anadromous fish migration.

Pre-dam flows in the Trinity River were much different than they are today, especially near Lewiston Dam (Figure 2A). At the time of closure of the dams (1963), the Trinity River received approximately 10% of the average annual runoff (120,000/1,250,000 acre-feet) above Lewiston. Today, and as a result of the Secretarial Decision in 1991, river flow has increased to approximately 28% of the average annual runoff (i.e., 340,000 acre-feet).

Dam closure also resulted in a loss of flow variability, especially immediately below Lewiston Dam (McBain and Trush 1997). The most notable hydrographic features that were lost included winter storm runoff and the spring/early summer snowmelt runoff, the latter of which provided a gradual reduction in flows during the spring and summer. (McBain and Trush 1997). Under present day flow conditions, hydrograph variability occurs only in downstream reaches as a result of flow accretion from tributaries below the dam.

Thermal regimes below Lewiston Dam correspondingly changed with construction and operation of the Trinity and Lewiston dams (Figure 2B). Whereas water temperatures were very warm during the summer months at Lewiston prior to dam construction, water drawn from the hypolimnion has resulted in cold water releases throughout the spring, summer, and fall under current dam operations. Today, water temperatures at Lewiston are less variable and generally range from 7 to 12 C throughout the year. Additionally, the water temperatures of the lower Trinity River have increased due to the lack of snowmelt runoff (large volumes of cold water) that typically occurred during the spring/summer period (USBR 1979) (Figure 3).

Smoltification Defined

The parr-smolt transformation, or smoltification process, involves changes in behavior and physiology of juvenile anadromous salmonids-that prepare them for survival in salt water (Folmar and Dickhoff 1980; and Wedemeyer et al. 1980). Summarized from Wedemeyer et al. (1980), some of the physiological and behavioral changes that occur during or at the onset of outmigration include: 1) body silvering and frn margin darkening; 2) reduced body condition (decreased weight per unit length), with a past trend of fast growth; 3) increased capacity to osmoregulate in saltwater; and 4) increased migratory behavior. Smoltifrcation can also be evaluated chemically by measuring levels of gill Na$^+$-K$^+$ ATPase (Zaugg and McClain 1970 and 1972, Zaugg and Wagner 1973,

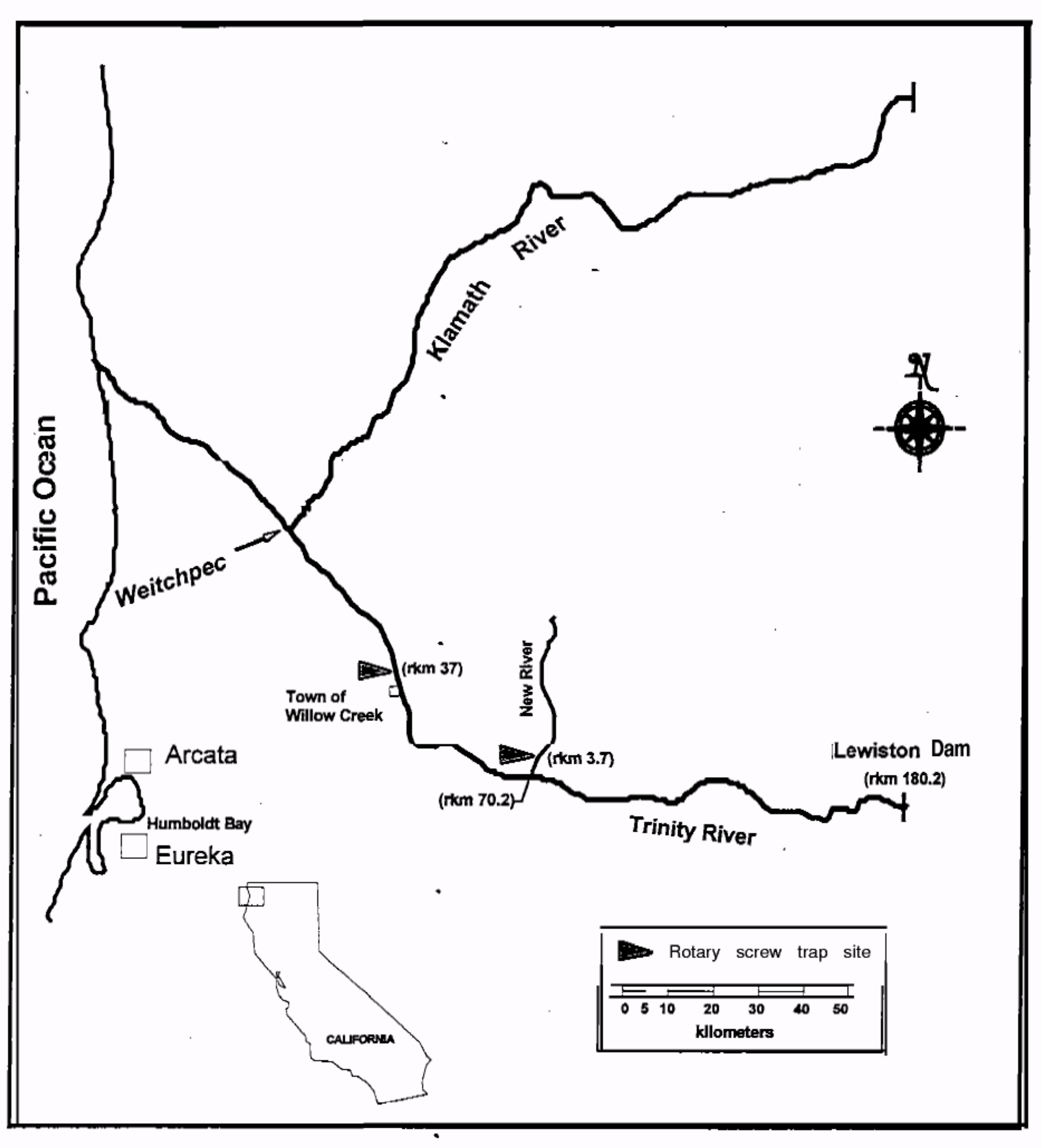


Figure 1. Trinity River Basin, Northwestern California

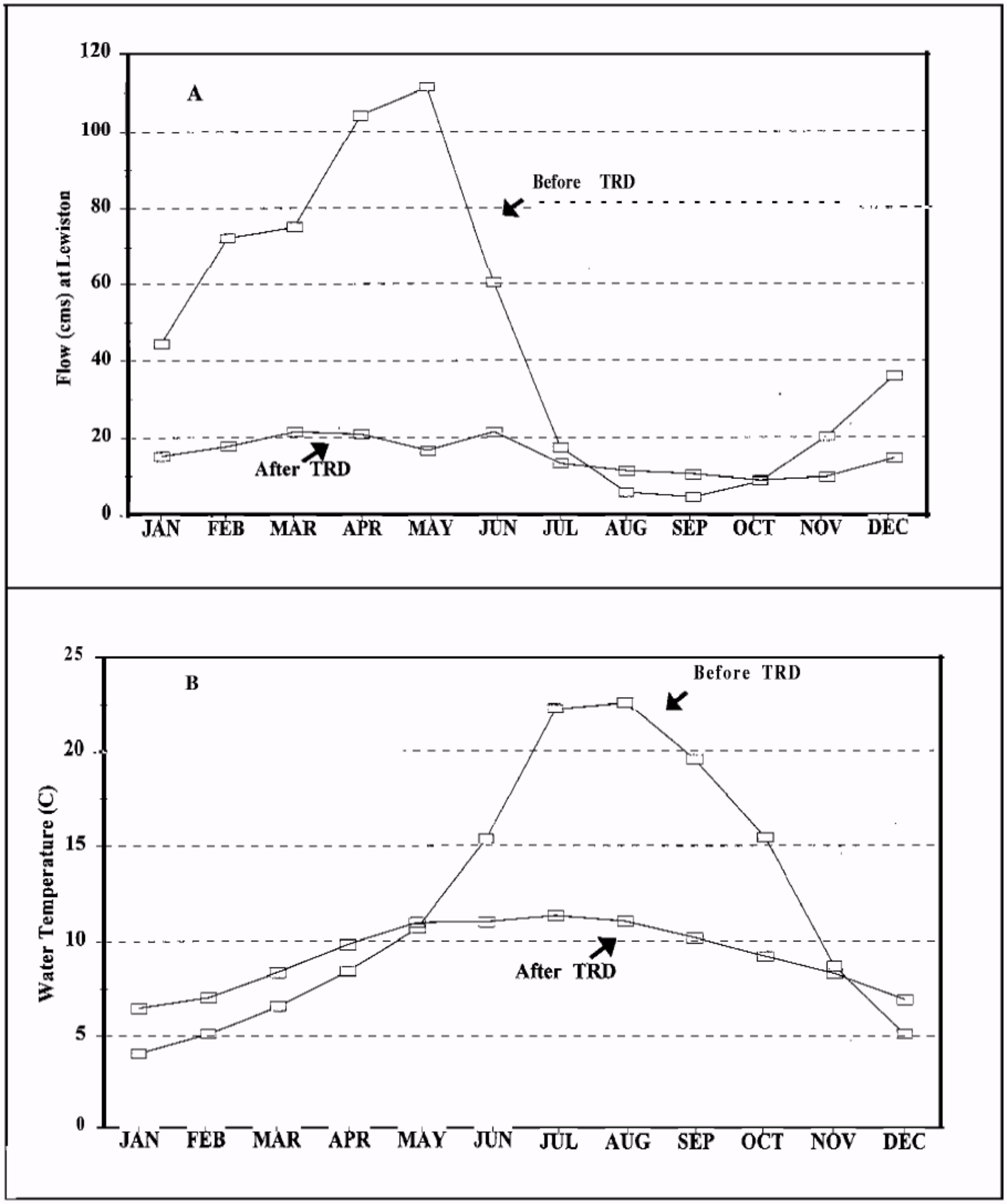
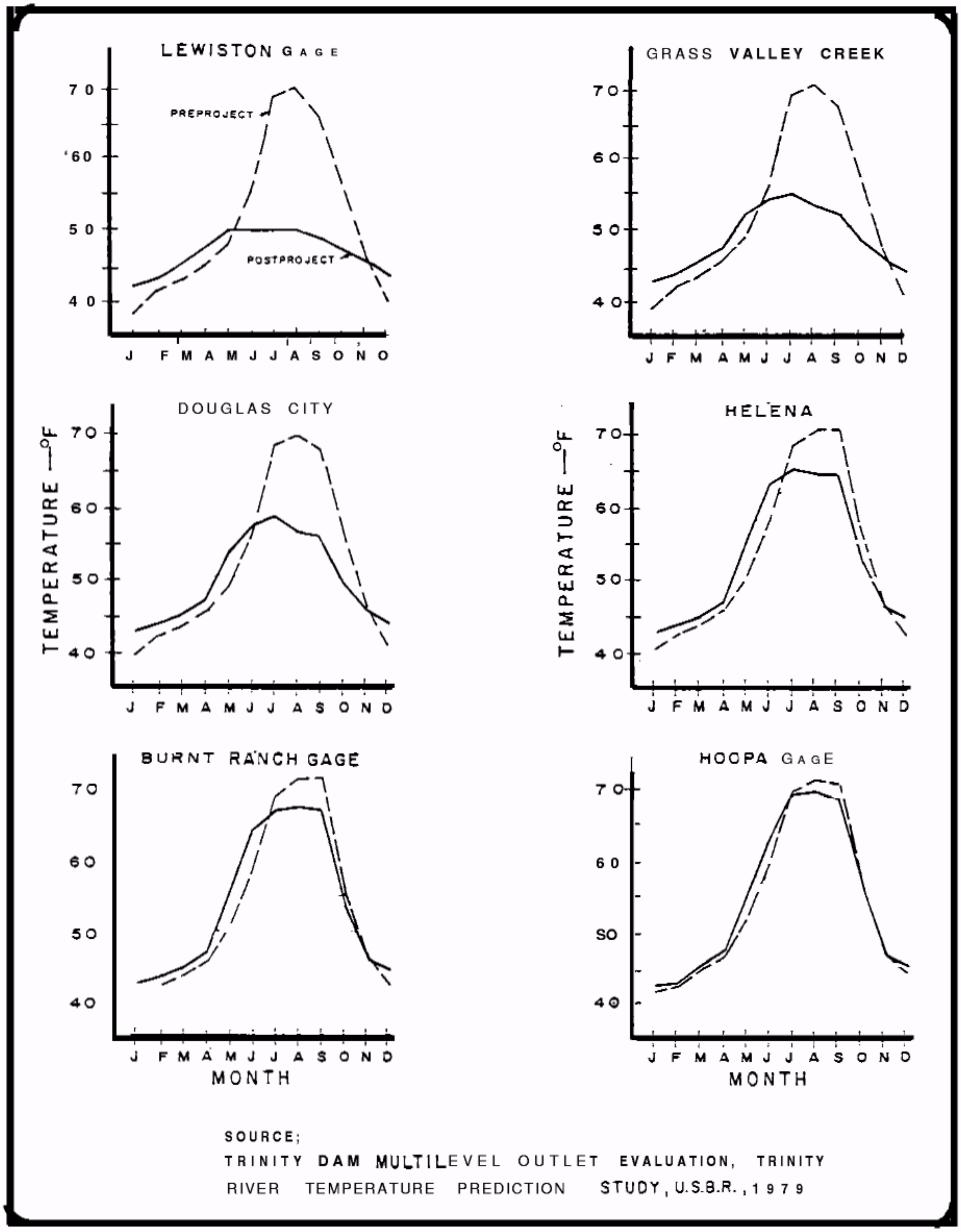


Figure 2. Average monthly river flow (A) and water temperatures (B) at Lewiston before and after construction the Trinity River Division in 1963. Flow data are from 1912 to 1959 (before) and 1978 to 1994 (after), and water temperature data are horn 1942 to 1946 and 1959 to 1960 (before), and 1964 to 1983 and 1987 to 1992 (after).



SOURCE;
TRINITY DAM MULTILEVEL OUTLET EVALUATION, TRINITY
RIVER TEMPERATURE PREDICTION STUDY, U.S.B.R., 1979

Figure 3. Average monthly water temperatures at several locations of the Trinity River before and after construction of the Trinity River Division of the Central Valley Project (Figure reproduced from Frederiksen, Kamine and Associates 1980).

Boeuf 1982). Increased levels of Na^+-K^+ ATPase indicate greater ability to hypoosmoregulate and increases in Na^+-K^+ ATPase begin in advance of smolting and peak during the migratory phase and entry to seawater (Hoar 1988). In the absence of appropriate environmental cues, smoltification may not occur; resulting in smolts reverting back to parr (desmoltification) and remaining in freshwater for another year (Hoar 1988).

Environmental cues such as increasing photoperiod (daylength) and water temperature (warming trend) elevate levels of Na^+-K^+ ATPase (Zaugg and Wagner 1973, Zaugg and McLain 1976, Ewing et al. 1979, Zaugg 1981, Muir et al. 1994). While photoperiod and water temperature are primarily responsible for initiating smoltification of juvenile coho salmon and Steelhead, water temperature alone appears to be the most important migration and smoltification cue for chinook salmon (Folmar and Dickhoff 1980; Wedemeyer et al. 1980; Hoar 1988). Water temperature has also been implicated as a modifier to photoperiod responses during the smoltification process; when water temperature is slow to warm in the spring, the Na^+-K^+ ATPase activity is extended and smolts migrate over a longer time period. Conversely, if water temperatures warm quickly in the spring, Na^+-K^+ ATPase activity is shortened and the time frame for emigration is shortened (Wagner 1974, Hoar 1988,). Additionally, when smolts emigrate in high temperatures, the ability to hypoosmoregulate and grow in sea water can be compromised, resulting in decreased survival of smolts (Adams et al. 1975, Wedemeyer. et al. 1980, Hoar 1988).

Many studies document that parr must obtain a minimum length before smoltification can occur. Increased body size is also shown to increase gill Na^+-K^+ ATPase levels which, in turn, results in a stronger migratory stimulus (Zaugg 198 1) and increased survival in seawater (Johnsson and Clarke 1988, Wagner 1974). Steelhead parr spend 1-3 years in freshwater and are the largest smolts ranging from 160 to 200 mm in length (Zaugg 1981). Coho and chinook salmon smolts have hypoosmoregulatory abilities at smaller sizes of 90 mm or larger (Conte et al. 1966, Ewing and Birks 1982).

Although fish size has been correlated with the smoltification process, some studies indicate that rate of growth is also an important factor influencing survival of smolts in seawater (Hoar 1988). Wagner et al. (1969) noted that fall chinook salmon exhibiting high growth rates showed better seawater tolerance than larger, slower-growing fish. In a review by Wedemeyer et al. (1980), coho and Steelhead were also found to have increased hypoosmotic regulatory ability with increased growth until smolting occurs. However, if they are not allowed to enter sea water during smoltification, their ability to hypoosmoregulate decreases. In a study conducted by Varnavsky et al. (1992), coho salmon smolts that exhibited fast growth migrated through the estuary more quickly than slower-growing fish.

Migration to the ocean by juvenile salmon and Steelhead is generally preceded by substantial increases in river flow along with rising water temperatures (Bell 199 1). Migration rates can vary between species and occur more quickly later in the smolt run with increases in photoperiod and temperature (Fangstam 1993, Muir et al. 1994). Flow rates can also influence the rate of smolt movement. Several studies show that smolts migrate more quickly with increases in discharge, particularly chinook salmon (Raymond 1979, Cada et al. 1994, Achord et al. 1996, Giorgi et al. 1997).

Species Specific Temperature Requirements for Smelting and Migration

Chinook salmon, coho salmon and Steelhead emigrate from rivers under slightly different timing patterns and temperature regimes. Each species has an upper thermal limit beyond which migration ceases and desmoltification can occur. However, smolts exposed to cooler water after experiencing warm water temperatures typical of reversion to parr may continue to exhibit elevated levels of gill Na^+-K^+ ATPase and may subsequently smolt (Zaugg and McLain 1976). While several laboratory studies examine lethal water temperatures on salmonids, this paper focuses on studies that documented declines in physiological tendencies for the process of smoltification.

Chinook Salmon

Chinook salmon smolts encounter and smolt in the highest temperatures observed for the three salmonid species of interest. While the Trinity River supports fall-run chinook salmon, there may be some applicability from the information on spring chinook salmon. Zaugg and McLain (1972) observed that spring chinook salmon raised in freshwater as cool as 6-7°C experienced increases in Na^+ -K^+ ATPase and in hatchery experiments, warming trends to water temperatures of 1 1-12°C have been shown to support smoltification (Muir et al. 1994). For fall-run chinook salmon, studies conducted by Clarke et al. (198 1), indicated that the best hypoosmoregulatory performance was observed and maintained in chinook salmon reared in temperatures of 10°C versus 15°C and a dramatic decline in hypoosmoregulatory performance was observed in underyearling chinook salmon held at 15°C for 6 weeks. Similarly, Clarke and Shelbourn (1985) also found that chinook salmon reared in freshwater between 10°C and 17.5°C experienced the best ability to hypoosmogregulate. More recently, Clarke (1992) recommended temperatures from 10 to 16°C for best survival in seawater less than 15°C.

Baker et al. (1995) used extensive information (7-years- 15 releases of hatchery fall-run chinook salmon smolt data) to model smolt mortality under natural conditions as they migrated from the Sacramento-San Joaquin Delta. The results of this analysis corresponded well with laboratory studies used to determine the upper incipient lethal level for chinook salmon. Approximately 50% mortality was observed for smolts emigrating in water temperatures of 23.01 ± 1.08°C, whereas smolts migrating in water less than 20°C, experienced survival rates of 90%.

Conclusions

Based on the evidence obtained from hatchery, laboratory, and natural experimental settings, water temperatures that support smoltification for fall-run chinook salmon ranges from 10 to 20°C. Within this range, the colder water temperatures represent more optimal conditions (10 to 17°C) whereas the warmer conditions (17 to 20°C) represent marginal conditions. While successful migration may occur at temperatures as high as 20°C (Baker et al. 1995), laboratory evidence suggests that survival and smoltification become compromised at water temperatures above 17°C.

Coho Salmon

Coho salmon smolts also exhibit a greater ability to hypoosmogregulate when reared in colder water temperatures. One study suggests that coho salmon smolts may be the least dependent of the three species on spring water temperatures for timing of emigration (Holtby et al. 1989); however, upper temperature limits have been observed with desmoltification in coho salmon smolts and decreases in hypoosmoregulatory ability (Donaldson and Brannon 1976, Clark and Shelbourn 1977).

In early laboratory studies on coho smolts, Zaugg and McLain (1972) found that smolts reared in 6°C freshwater and transferred to 10°C freshwater, experienced a subsequent increase in Na^+ K^+ ATPase, In further experimental studies, Zaugg and McLain (1976) found: 1) elevated freshwater temperatures (15 and 20°C) resulted in a shortened period of elevated Na^+ K^+-ATPase activity when compared to fish reared in 6 and 10°C freshwater; 2) coho salmon reared in a constant 6°C environment experienced increases in Na+ K^+-ATPase levels which remained elevated through July; and 3) coho salmon reared at 6°C and exposed to water temperatures of 10°C, 15°C and 20°C experienced an initial increase in ATPase levels which then declined gradually at 10°C, more quickly at 15" , and rapidly in 20°C water. Conversely, fish reared in 15°C water and then exposed to lower water temperatures experienced extended periods of elevated Na^+ K^+-ATPase. Clarke et al. (198 1) found that the ability to hypoosmoregulate was greatest for coho salmon reared in freshwater at 10°C versus 15°C and more recently, Clarke (1992) recommended rearing coho salmon at temperatures between 10 and 15°C and that water temperatures below ~ 17°C are required for survival in seawater. In a study using snorkeling observations of migrating smolts, McMahon and Holtby (1992) recorded coho smolts in a British Columbia creek emigrating in May and June in water temperatures ranging from 6.5 to 8.5°C.

Conclusions

Based on the varied responses and temperature ranges used in the experiments with coho salmon and direct observation, evidence suggests that water temperatures that range from 6 to 10°C would provide optimal smelting conditions and temperatures approaching 15°C can be tolerated for a short period of time before the smolts revert to parr. Smoltification at temperatures greater than 15-1 7°C would likely be brief with unknown hypoosmoregulatory success, and water temperatures greater than about 17°C would probably result in complete reversion to parr.

Steelhead

Steelhead smolts are the most sensitive of the three species to elevated water temperatures (Wedemeyer et al. 1980). Under constant rearing conditions, Adams et al. (1973) observed that water temperatures greater than 15°C did not stimulate Na^+-K^+ ATPase activity or reduce body condition normally associated with smoltification and inhibition of smoltification occurred between 10 and 15°C. Furthermore, Adams et al.

(1975) found a water temperature of 11.3°C to be the upper temperature for extended high Na^+-K^+ ATPase activity. Similarly, Zaugg and Wagner (1973) concluded that water temperatures greater than 13°C may interfere with Steelhead parr-smolt transformation and in further studies, Zaugg (198 1) also observed a reduction in migratory tendencies after Steelhead were exposed to water temperatures of 13°C for 20 days versus those exposed to 6°C under natural photoperiod condition. In a laboratory study that examined the effects of water temperature and hypoosmoregulatory function, salinity tolerance was found to be the highest at 11°C, lowest at 17°C, and intermediate at 5°C (Johnson and Clarke 1988). In a study conducted by Kerstetter and Keeler (1976), they speculated that water temperatures near 17°C were responsible for the sharp decline in the number of wild migrating Steelhead smolts captured during the spring in the lower Trinity River at Weitchpec. However, they also speculated that water temperatures greater than 15°C were responsible for the low ATPase values in yearling hatchery Steelhead reared in Trinity River Hatchery.

Conclusions

Based on the literature information, Steelhead smolts exhibited the most limited tolerance for temperature during smoltification. Water temperatures less than 13°C represent optimal conditions, whereas water temperatures to 15°C are marginal. Water temperatures greater than 15°C, for any period of time during migration, would result in decreased smolting tendencies for Steelhead smolts.

Migration Timing of Naturally Produced Mainstem Trinity River Smolts

Local studies conducted in recent years have provided insight to migration timing and trends in the Trinity River Basin. Rotary screw traps operated in the Trinity River near Willow Creek from 1989 to 1995 during the spring, summer and fall have provided valuable information on timing, peak migration, and duration of the salmonid parr/smolt migration (Lang et al. 1997). Using expansion for the volume of water not sampled, Lang et al. (1997) developed abundance indices that standardized the screw trap data for between year comparisons. In addition, water temperature data was collected near the trapping locations. The screw trap data presented below pertains to naturally produced steelhead and chinook salmon smolts and both hatchery and naturally produced coho salmon smolts.

Chinook Salmon

Rotary screw trap data, from 1989 to 1995 near Willow Creek on the Trinity River (RKM 34), revealed that chinook salmon parr/smolt migration occurred between early March, peaked during June, and continued into or through the summer (Figure 4). Trapping data for 1992 indicated that an experimental high flow release of 170 cubic meters/sec (cms) (6,000 cfs) in mid-June, resulted in few captured fish. After the high flow, however, migration rates increased. Although speculative, the reason for the decline may have been related to the cold water associated with the high release. During this event, average

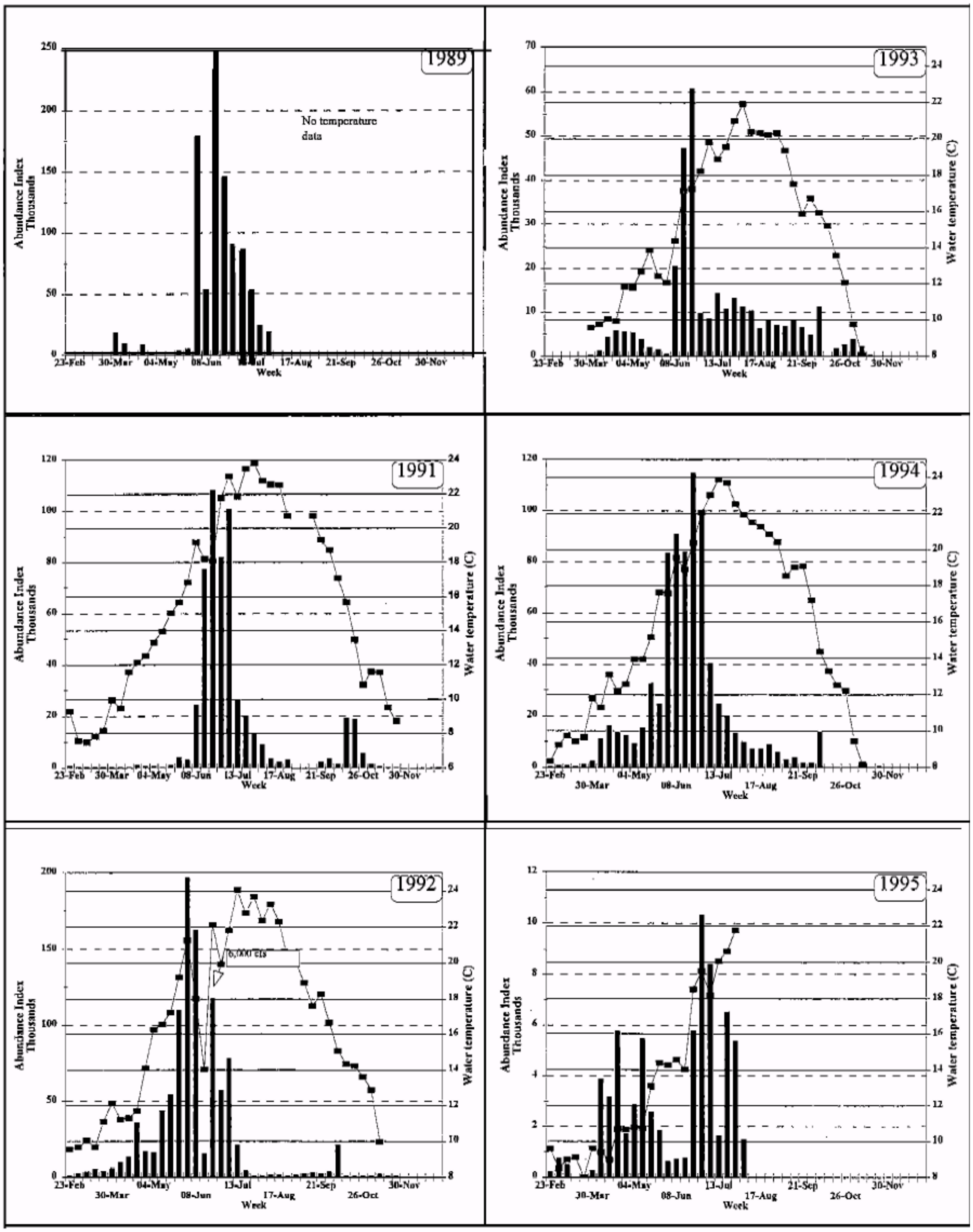


Figure 4. Weekly abundance indices (bars) of emigrating natural juvenile chinook salmon at Willow Creek of the Trinity River, 1989, and 1991 to 1995, and average weekly water temperatures (line). Data collected by the U.S. Fish and Wildlife Service, Arcata, CA.

weekly water temperatures decreased from approximately 21°C to 14°C (See Figure 4). From 1991 to 1995, decreased capture rates often coincided with water temperatures of 18 - 22°C.

Trinity River water temperature appeared to influence the timing of outmigration of chinook salmon smolts. Cumulative indices for the Willow Creek trap indicate that the onset of migration occurred earlier in 1992 and 1994 (Figure 5, both of which would be classified as dry and critically dry years, respectively), when water temperatures were warmer than 1993 and 1995 (Figures 5 or 6, both of which would be classified as wet and extremely wet years). In late April, May and early June of 1992, approximately 50% of fish trapped for the season occurred before June 1. In the years that had cooler temperature regimes, indices indicate that nearly 50% of season totals were trapped 2 to 3 weeks later and migration at least in 1993, migration occurred throughout the summer months. Before construction of the Trinity and Lewiston Dams, Moffett and Smith (1950) reported that peak migration of Trinity River chinook salmon occurred during May and June at Lewiston, decreased in July, and nearly ceased in August. They speculated that migration stopped because average daily water temperatures increased to over 21°C. In the Klamath River estuary, recent studies conducted by Wallace (1994) found Trinity chinook salmon smolt abundance to peak in mid-June and continue through September in the estuary. In this same study, he assumed that peak estuary abundance indicated peak emigration from the basin. Wallace (1994) also 'calculated travel rates from coded wire tag smolts stocked in the Trinity and found that fish captured in the estuary during the peak abundance period started emigrating from the Trinity River from late March to late May. This time-frame is earlier than the peak recorded in the screw traps and may indicate that there is better survival for smolts migrating in cooler water temperatures earlier in the spring.

Coho Salmon

Trapping data at Willow Creek on the Trinity River indicated that the time of emigration of coho salmon smolts begins by late March or early April, peaks in May, and subsides by mid-June (Figure 7). Unlike the chinook salmon smolts, which appear to respond to differing temperature regimes, cumulative indices for coho (Figure 5) did not show a consistent relation of warmer water and onset of migration. For example, in 1994 (a critically dry year) the time of 90% capture occurred by mid-May, but in 1992, which was a dry year , the time of 90% capture did not occur until June 15. Trapping data for 1992 through 1995 indicated that nearly 50% of captured fish occurred in early May, when water temperatures were less than 17°C. Further downstream, studies conducted by Wallace (1994) indicate that peak abundance of coho smolts occurs in April and May in the Klamath River estuary.

Steelhead

Data from rotary screw traps in the mainstem Trinity River at Willow Creek (1989, 199 1- 1995) show that steelhead smolt migration begins by at least late February, increases during March and April, peaks in May, and decreases sharply in early June (Figure 8).

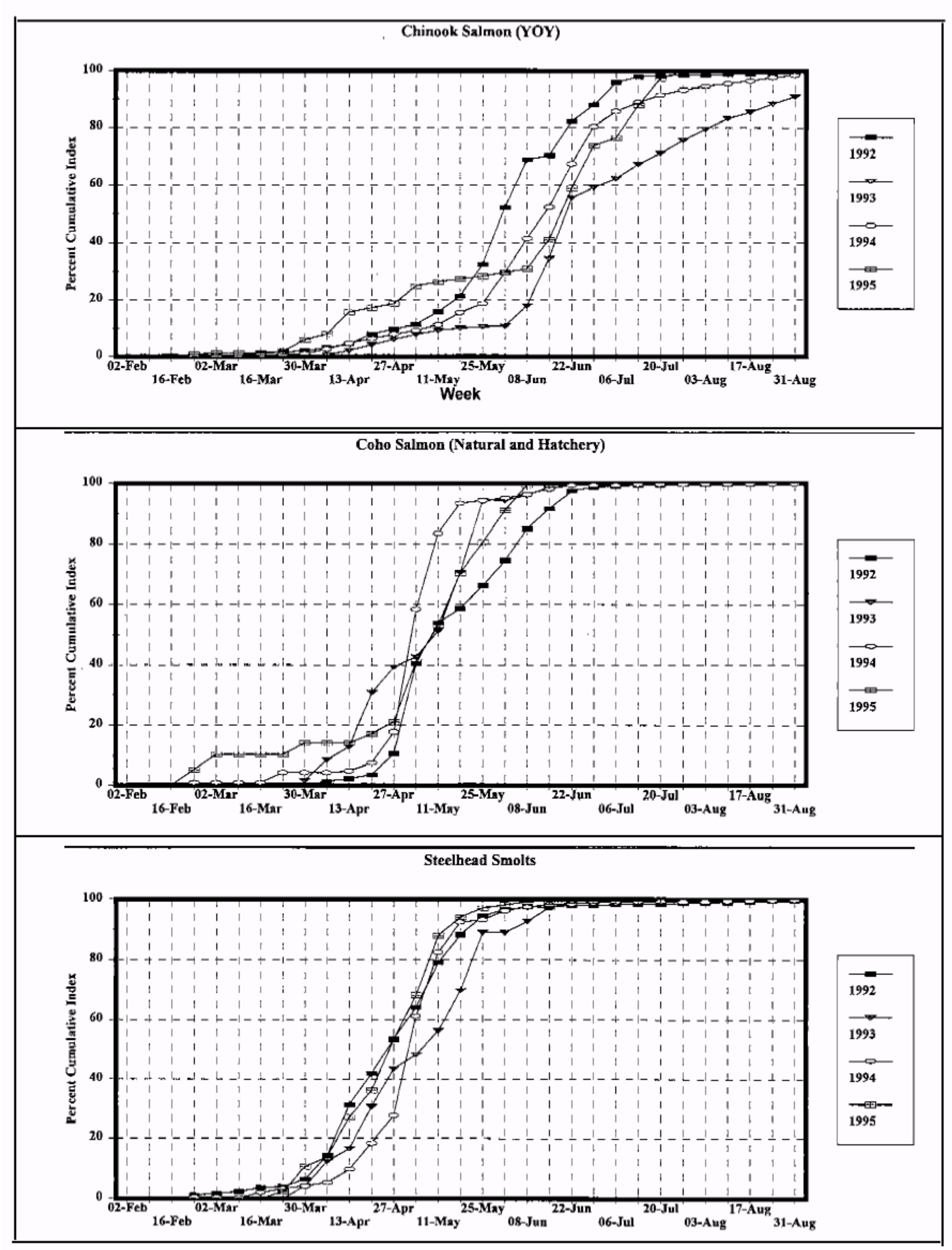


Figure 5. Cumulative abundance indices for outmigrating chinook and coho salmon and Steelhead. Data collected at the Willow Creek Trap (RM 21.1) on the Trinity River, 1992 to 1995. Data collected by the USFWS, Arcata, CA.

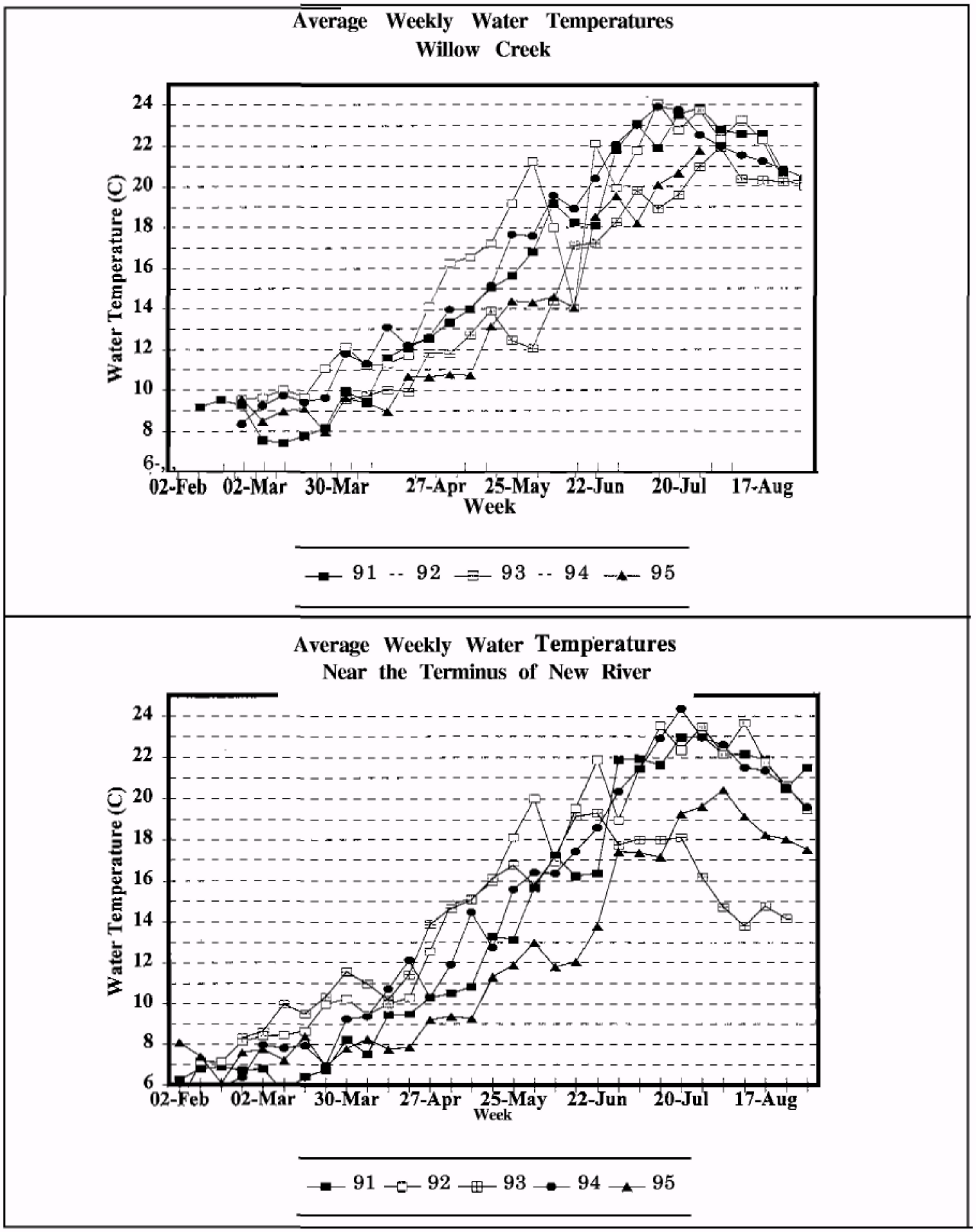


Figure 6. Average weekly water temperatures of the Trinity River at Willow Creek and New River, a tributary of the Trinity River, 1991 through 1995.

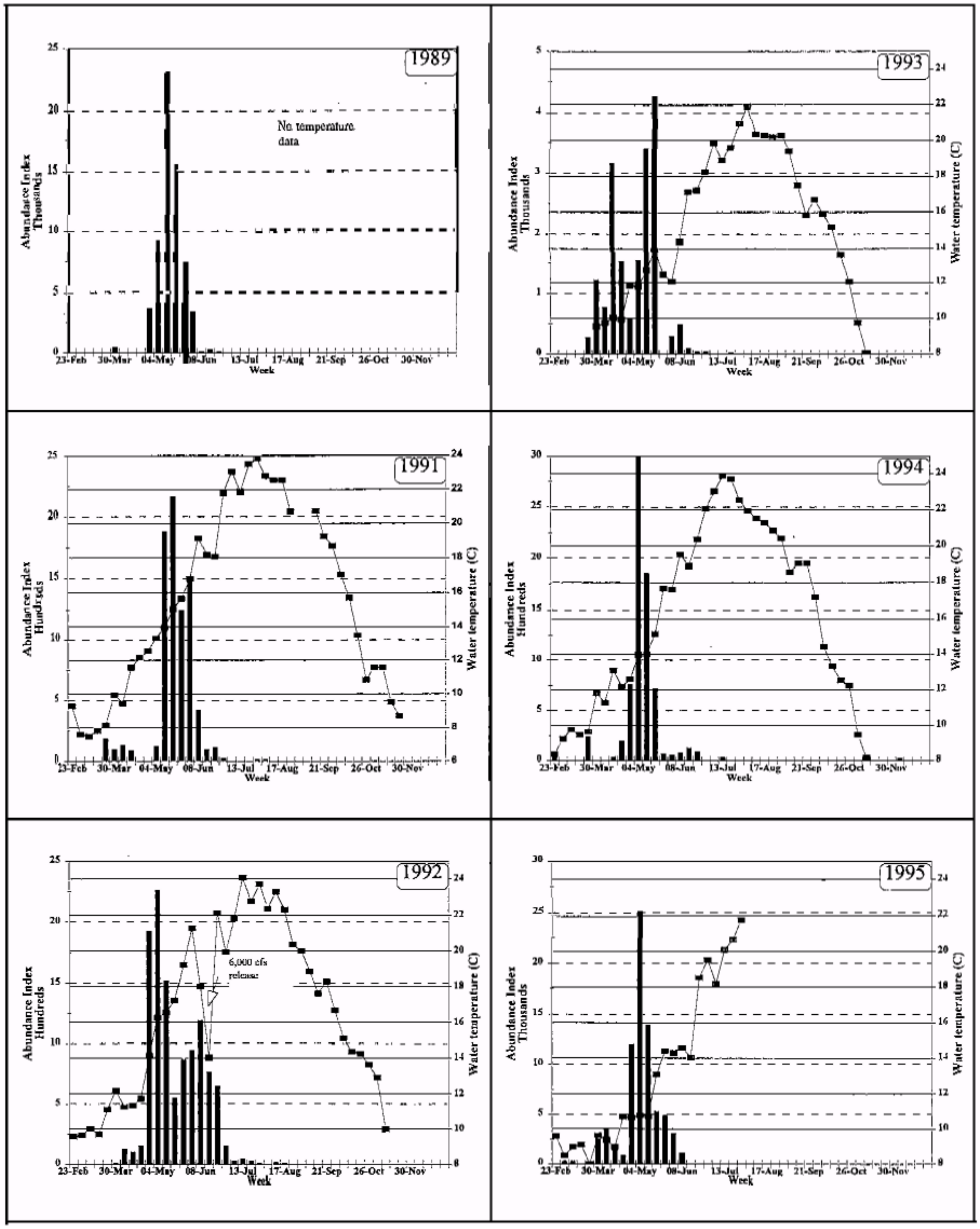


Figure 7. Weekly abundance indices (bars) of emigrating natural and hatchery smolt coho salmon at Willow Creek of the Trinity River, 1989, and 1991 to 1995, and average weekly water temperatures (line). Data collected by the U.S. Fish and Wildlife Service, Arcata, CA.

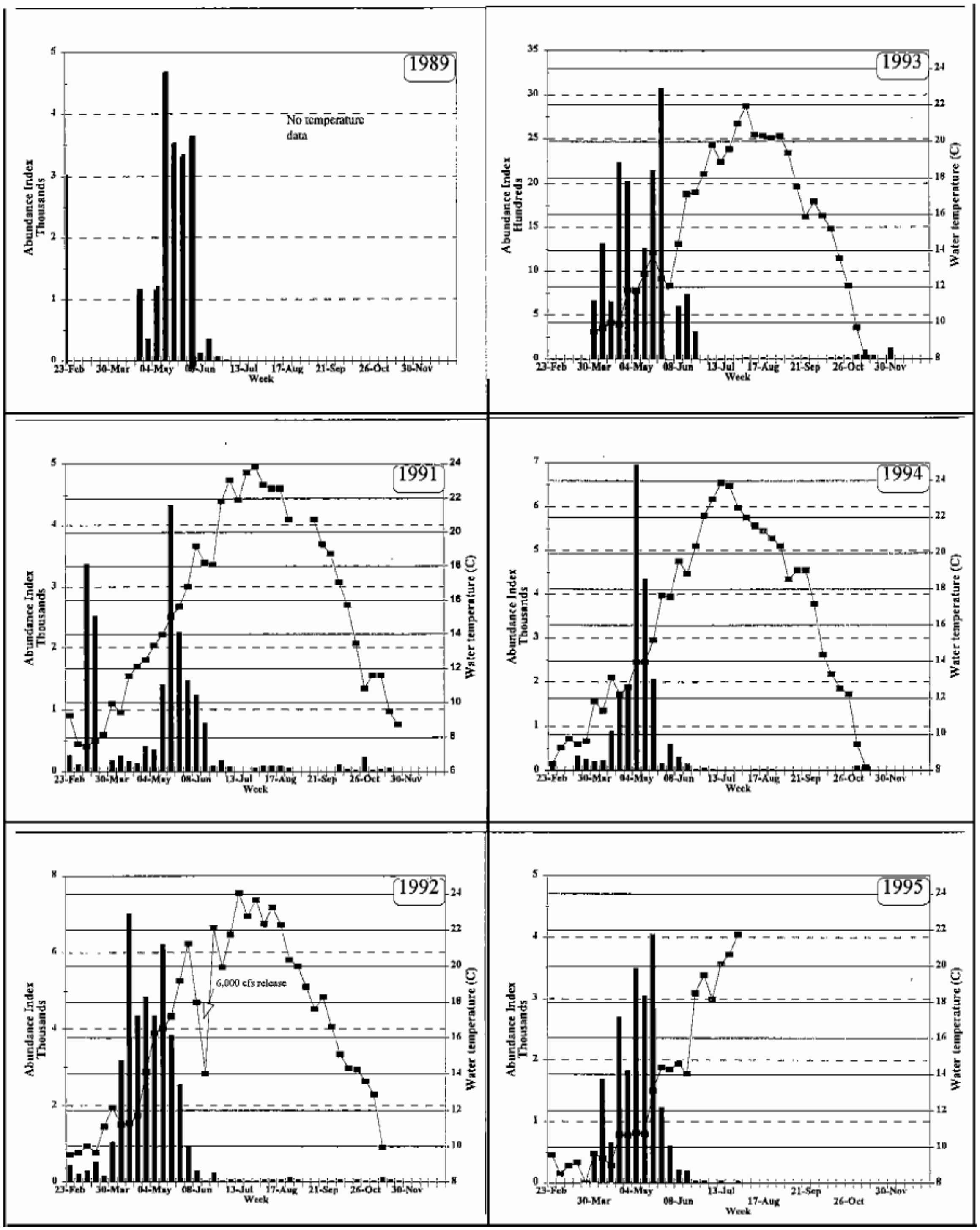


Figure 8. Weekly abundance indices (bars) of emigrating natural smolt Steelhead at Willow Creek of the Trinity River, 1989, and 1991 to 1995, and average weekly water temperatures (line). Data collected by the U.S. Fish and Wildlife Service, Arcata, CA.

Cumulative abundance indices indicated that proportions of catches were relatively constant between years for respective time periods. Nearly 80 to 90 % of Steelhead smolts were captured within a two-week period before May 25 in all years (Figure 5), when average weekly water temperatures were always below 18°C (Figure S). Similar to what is reported in the literature (Folmar and Dickhoff 1980; Wedemeyer et al. 1980; Hoar 1988), these consistent timing trends through varied water temperature regimes indicate that photoperiod is probably the dominant variable affecting the timing of emigrating of natural Steelhead smolts in the Trinity River. Average weekly water temperatures at the time of increased abundance generally ranged from 14-16°C. Similar to the coho salmon, Steelhead smolts were most abundant in the Klamath River estuary in April or May (Wallace 1994).

Migration Timing of Naturally Produced Smolts from New River, a Major Tributary of the Trinity River

Out-migrant trapping in New River, which enters the Trinity River at RKM 70.2, has shown migration trends of an unregulated stream within the Trinity River Basin. Trapping results reveal that migration patterns are similar in timing to that of the mainstem with a more abrupt cessation to emigration. The Willow Creek trap also captures smolts emigrating from upstream tributaries and so this correlation in patterns is not unexpected. Migration of juvenile chinook salmon generally begins in early April, steadily increasing until June when it peaks, and decreases sharply in early to mid July at which time the average weekly water temperature is approximately 18 - 19°C (Figure 9). Trapping data for Steelhead smolts in the same years indicated that migration began in February to March, peaked in late April and May, and sharply declined in early June (Figure 10). Too few coho salmon were captured in this tributary to make meaningful comparison.

In New River, water temperatures experienced by chinook salmon and Steelhead smolts were relatively consistent between years. During 1989 and 1991 through 1994, 90% of chinook salmon were captured when average weekly water temperatures were below 17°C with one exception; during 1992, water temperature reached 20°C during the peak of the smolt run which then ended within the week In all years, Steelhead smolts generally migrated earlier than chinook salmon and when water temperatures were between 10 and 15°C.

Flow and Transport

An obvious effect of increased dam releases is reduced time-of-travel of water particles. In a study conducted by Limerinos (1967), dye concentrations were used to assess water travel time in the Trinity River at flows of 5.7 cms (200 cfs) to 8.5 cms (300 cfs). Results of this study indicated that approximately 8 days were required for peak dye concentrations to travel from Lewiston to Weitchpec. While evaluations of higher releases have not been completed using this methodology, pulse flows from Lewiston dam have provided insight into this relationship. In odd numbered years, a pulse flow of 34 cms (1,200 cfs) are released from Lewiston Dam on the third week of August

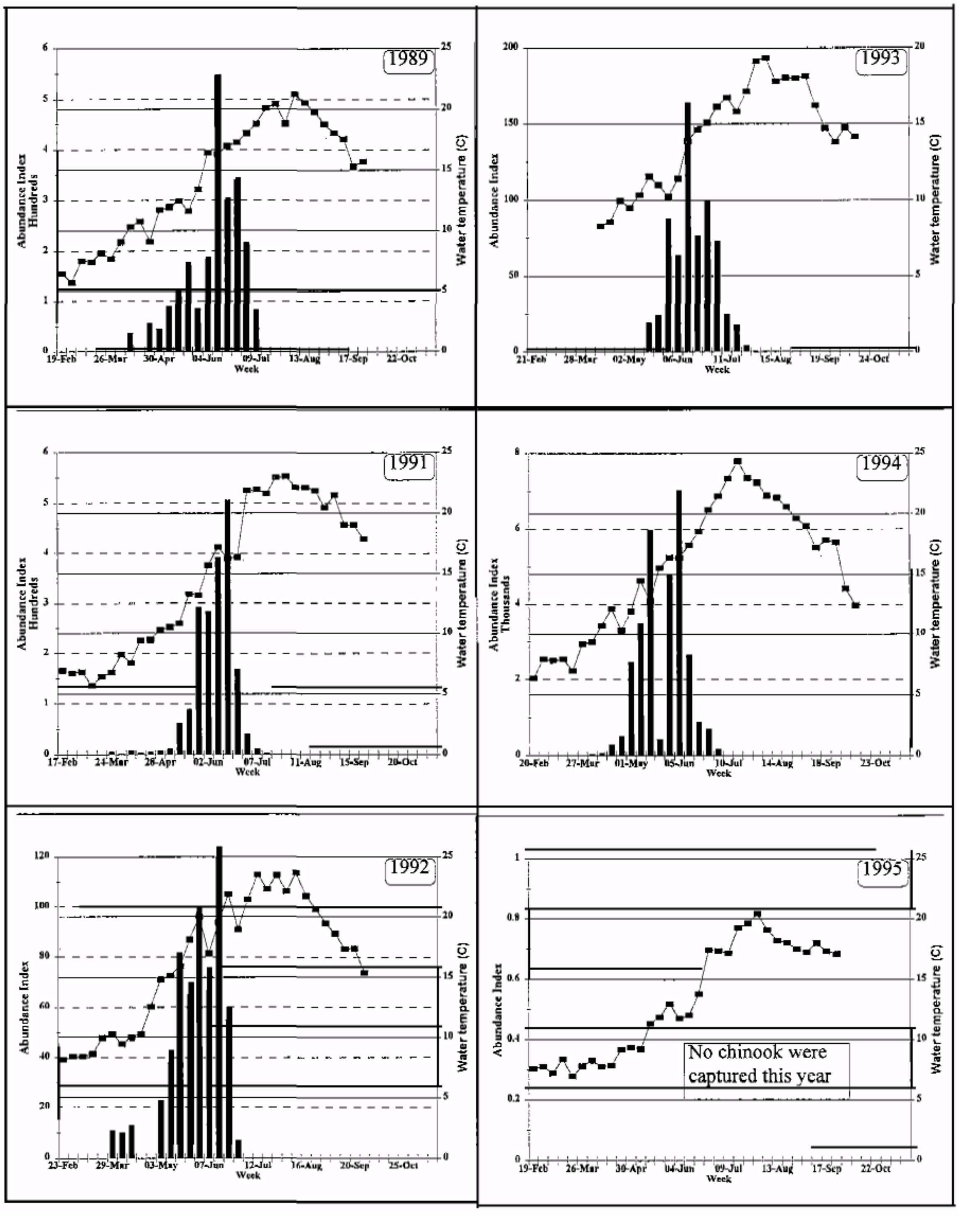


Figure 9. Weekly abundance indices (bars) of emigrating juvenile chinook salmon in New River, Tributary to the Trinity River, 1989, 1990 - 1995, and average weekly water temperatures (line). Data collected by the U.S. Fish and Wildlife Service, Arcata, CA.

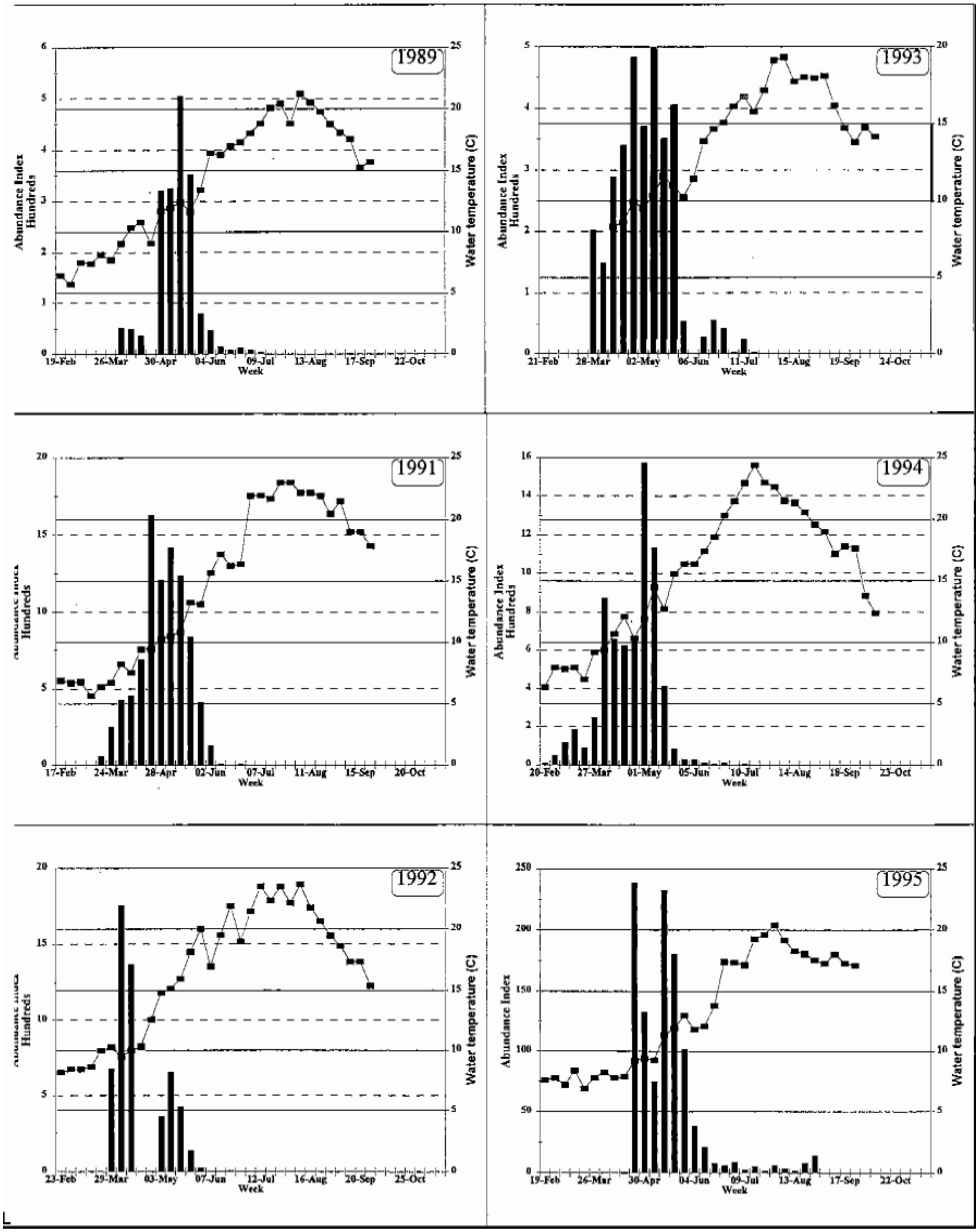


Figure 10. Weekly abundance indices (bars) of emigrating Steelhead smolts in New River, Tributary to the Trinity River, 1989, 1990 - 1995, and average weekly water temperatures (line). Data collected by the U.S. Fish and Wildlife Service, Arcata, CA.

to provide water for ceremonial purposes of the Hoopa Valley Reservation near the confluence of the Klamath River (approx. 180 km). Pulse flows are released approximately 1.5 days prior to the time at which the higher flows are needed.

Several researchers have found evidence that increased flows result in reduced travel time of smolts. For example, in the Snake River, peak migrations of wild spring chinook salmon coincided with periods of peak river flow (Achord et al. 1996) and in the Columbia River, flow was found to be significantly correlated in determining the rate of chinook salmon smolt outmigration (Raymond 1979, Brege et al. 1996, Giorgi et al. 1997). Achord et al. (1996) also suggested that based on their studies, it may be beneficial to outmigrating chinook smolts to release more water after mid-May to increase the migration rates of smolts in the Snake River. Bell (1991) also reports that migration rates are positively correlated with river flow. Cada et al. (1994) in a fairly extensive review of the literature concluded that in the Columbia basin, a positive relationship between increased flows and smolt survival was a reasonable conclusion based on the scientific evidence and furthermore, studies outside of the basin also supported this relationship. While there are no known studies investigating the effect of flows levels on the travel rates of natural outmigrating smolts in the Trinity River, it is likely that smolts in the Trinity River would respond similarly to increased flows.

Water Temperature Control

In addition to faster water velocities, large volume releases from Lewiston Dam also result in decreased water temperatures down the entire length of the Trinity River. Empirical evidence from an experimental 170 cms (6,000 cfs) release in June of 1992 (Figures 4, 7, and 8) indicated that the average weekly water temperatures decreased from -21 to 14°C at Weitchpec. Water temperature modeling of the Trinity River has provided insight into flow and temperature relations (Zedonis 1997). Using hypothetical years represented by hot-dry (approx. 90% probability of flow exceedence), median (50%), and cold-wet (10%) environmental conditions, Zedonis (1997) demonstrated that dam releases influence spring and summer water temperatures in the lower Trinity River near Weitchpec (Figure 11).

Temperature modeling indicated that the larger the water release, the greater the cooling effect of flow on water temperatures near Weitchpec. For example, as compared to a 8.5 cms (300 cfs) release, a 57 cms (2,000 cfs) release may result in water temperatures that are nearly 5°C colder (17.5°C) on a hot-dry July 1, 4°C colder (17°C for a median July 1, and 2°C colder (16°C) for a cold-wet July 1. Regardless of meteorological conditions, dam releases (170 cms or 6,000 cfs) on July 1 results in water temperatures that approach 14°C.

Relation of Flow and Species Specific Water Temperature Targets

Utilizing the information presented in the previous sections of this paper, guidelines were formulated that could be used for future flow recommendations (Table 1). Guidelines

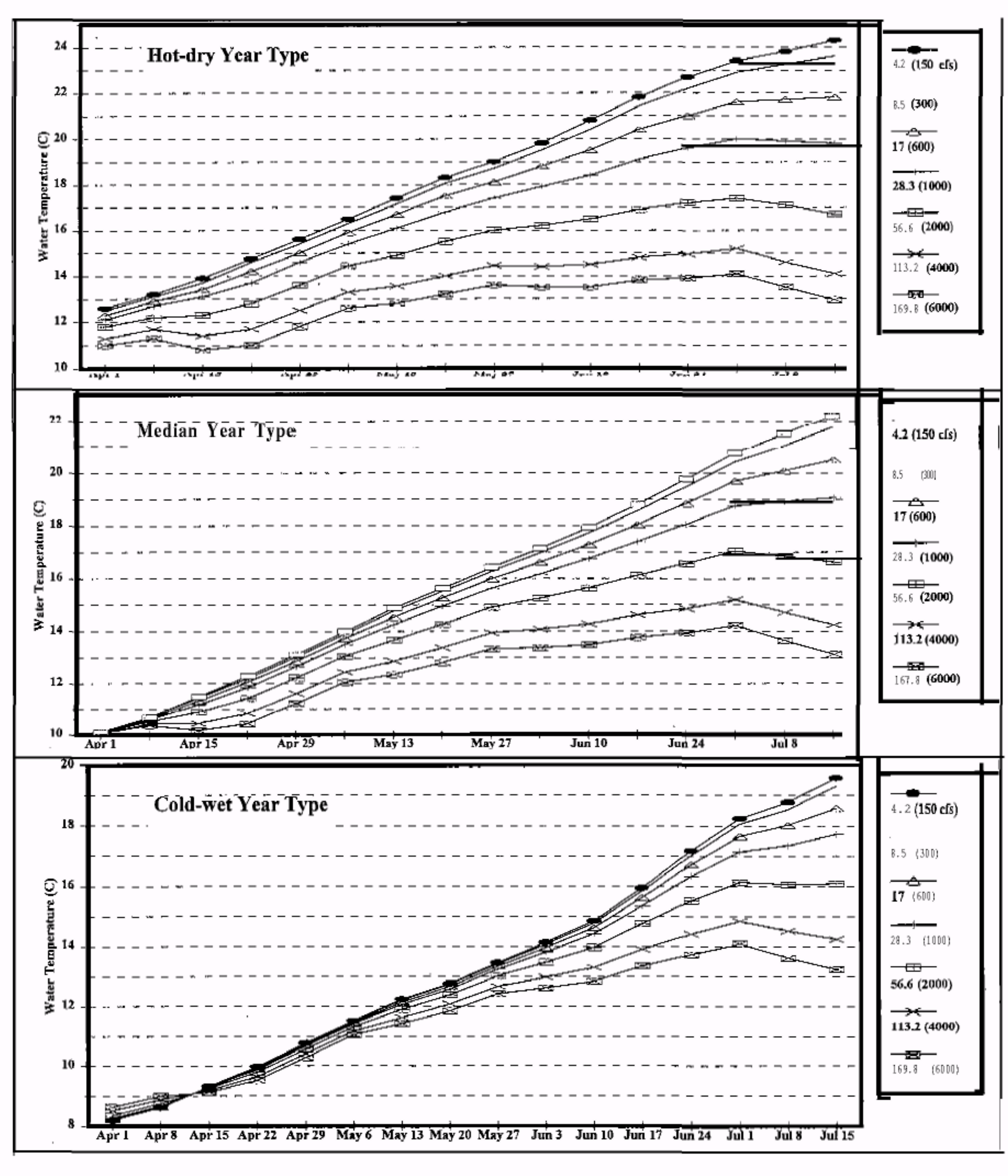


Figure 11 Stream Network Water Temperature Model (SNTEMP) temperature predictions (7-day average) for the Trinity River (Rkm 1.1) with Lewiston Dam releases between 4.2 cms (150 cfs) and 170 cms (6,000 cfs) and cold-wet (CW), median (Med), and hot-dry (HD) year type conditions. Release water temperatures used were minimum daily averages of the 'I-day average daily water temperatures observed below Lewiston Dam from 1987 to 1994. Lines drawn between markers for visual reference.

were developed in the context of meeting target temperatures (both optimal and marginal) for median year conditions for the time in which 80 to 96% of naturally produced smolts have passed the Willow Creek trap site. Use of the median year modeling conditions were chosen to represent reasonable conditions to base recommendations, because median conditions, both hydrologic and meteorologic, are most likely to occur over a wider range of hydrologic years than the other two year types (i.e., hot-dry and cold-wet). Steelhead, which leave the lower Trinity River the earliest of the three species (May 22), would require a flow near 170 cms (6,000 cfs) or 34 cms (1,200 cfs) to meet the targets of 13°C for optimal conditions or 15°C for marginal conditions, respectively. In the case of the coho salmon, which have a more protracted migration period than Steelhead (80 to 90% depart by June 4), flows of 74 cms (2,600 cfs) and 8.5 cms (300 cfs) would maintain near optimal (<15°C) or marginal (<17°C) temperature conditions, respectively. For Chinook smolts, which have the most variable of migration patterns among the species examined and leave the lower Trinity River the latest, it would require dam releases near 54 cms (1,900 cfs) until July 9 to maintain near optimal water temperature conditions (< 17°C) or a flow of 20 cms (700 cfs) to maintain marginal temperature conditions (< 20°C).

Table 1. Approximate Dam releases at Lewiston required to meet potential temperature targets for smolt emigration in the Trinity River.

		Optimal Temperature Conditions		**Marginal Temperature Conditions**	
Species	Approximate Date of 80 to 90 % Emigration	Water Temp. Targets (°C)	Approximate Dam release magnitude (cms (cfs)) to meet the target under Median Year conditions	Water Temp. Targets (°C)	Approximate Dam release magnitude (cms (cfs)) to meet the target under Median Year conditions
Steelhead	May 22	< 13	170 (6,000 cfs)	< 15	34 (1,200 cfs)
Coho Salmon	June 4	< 15	74 (2,600 cfs)	< 17	8.5 (300 cfs)
Chinook Salmon	July 9	< 17	54 (1,900 cfs)	<20	20 (700 cfs)

Conclusions

Higher flows during the spring outmigration would result in more suitable water temperature and flow conditions throughout the Trinity River for naturally produced salmon and Steelhead smolts. Information used to draw this conclusion are: 1) the current state of knowledge of factors (e.g., water temperature, flow, photoperiod, etc.) that influence the process of smoltification suggest that water temperature and flow, are certainly influential, if not critical, and 2) water temperatures in the lower Trinity River can be controlled by operations of the Trinity River Division during the time of spring smolt outmigration.

Through the elimination of the high-volume snowmelt runoff that consistently occurred during the spring, water temperatures can be inferred, through the SNTEMP model results, to have been colder during the spring in the lower Trinity River prior to construction of the dams. This is especially true for the months of April and May, which, on average, were colder or similar to contemporary thermal regimes at Lewiston, yet had much larger magnitudes of flow (average ~ 108 cms (3,800 cfs))(refer back to Figure 2A and 2B). These larger flows would have resulted in a thermal regimen in the lower Trinity River that was as much as a 2.1°C colder (e.g. for the week of May 27 under median conditions) than contemporary flow conditions (8.5 cms (300 cfs)). These results are consistent with a study conducted by the U.S. Bureau of Reclamation (USBR 1979), and are illustrated in Figure 3. Therefore, higher flows during the spring/early summer snowmelt period would not only restore an important feature of the hydrograph, but it would also help restore the water temperature regimen that is critical to smolt survival. Of course, snowmelt runoff also varied between years and thus so did thermal regimes.

The initiation and timing of spring high flows should also be considered by those who make decisions on flow management in the Trinity River. Because the spring smolt emigration is usually preceded by high spring flows and warming water temperatures (Bell 1991, Lang et al. 1997), flows should peak before water temperatures begin to warm significantly in the lower river (early May, but this may vary with year type). After the peak flow, flows should be maintained or slowly decreased to provide for suitable temperature regimes for outmigrating Steelhead, coho and chinook salmon smolts throughout the length of the Trinity River (such as those provided in Table 1). Maintaining a high flow (e.g., 56.6 cms (2,000 cfs)) or slow reduction in discharge from a higher flow (e.g. 170 cms (6,000 cfs) would provide for a meteorological warming trend (a cue to leave), while maintaining cooler water temperatures and moderating the extremes that accompany low flows.

Consideration should also be given to allowing for variable flow patterns with year types, since the literature and migration studies on the Trinity River indicate that water temperature is a dominant variable influencing the migration timing of chinook salmon smolts and thermal regimes vary depending on snowpack (i.e., year type). Because of this association, flow patterns that follow the peak should slowly decrease in a fashion which allows for temperature benefits (such as a natural rescinding limb of the snow-melt hydrograph) while maintaining variability that is associated with hydrologic year type.

The guidelines presented in Table 1 should be considered as a starting point to obtain idealized water temperature conditions for smolts. While these are not to be regarded as the panacea for the Trinity River, they do represent a culmination of the best available scientific information for protection of smolts in the Trinity River. If management actions are taken to improve the smolting conditions for Steelhead, coho salmon and chinook salmon, monitoring programs should be instituted to evaluate the influence of flow and-water temperature on survival of smolts. Although smolt monitoring programs may provide insight to the success or failure of maintaining cooler water temperatures, final judgment of success or failure of flow manipulations may be the numbers of returning naturally produced adults salmonids to the Trinity River, and perhaps the Klamath River, systems.

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