2706

SUSITNA HYDROELECTRIC PROJECT

FEDERAL ENERGY REGULATORY COMMISSION
PROJECT No. 7114

ASSESSMENT OF THE EFFECTS OF THE PROPOSED SUSITNA HYDROELECTRIC PROJECT ON INSTREAM TEMPERATURE AND FISH RESOURCES IN THE WATANA TO TALKEETNA REACH

SUPPLEMENTAL REPORT: CASE E-VI AND ADDITIONAL CASE C OPERATING REGIMES

UNIVERSITY OF ALASKA
ARCTIC ENVIRONMENTAL INFORMATION AND DATA CENTER

UNDER CONTRACT TO

HARZA-EBASCO
SUSITNA JOINT VENTURE

FINAL REPORT

MAY 22, 1985
DOCUMENT No. 2706

ALASKA POWER AUTHORITY

Document No. 2706
Susitna File No. 4.3.1.2

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Report by

Arctic Environmental Information and Data Center

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Prepared for

Alaska Power Authority

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SUMMARY

This report presents the results of weekly instream temperature simulations for the Susitna River comparing Watana-only and Watana/Devil Canyon project configurations under a) Case E-VI and Case C "inflow matching", b) Case E-VI and Case C "warmest water", and c) Case C "inflow matching" and "warmest water" operating regimes. Results of Case C "inflow matching" simulations have been analyzed in a previous report (AEIDC 1984b) and a detailed explanation of methods employed in instream temperature modeling are presented there. Case E-VI simulations were obtained from the SNTEMP instream temperature model using historic hydrologic/meteorologic data covering two summers and one winter. The effect of these temperatures on anadromous and resident fish species is specific to temperature tolerance criteria established in AEIDC (1984b).

Simulated downriver temperatures under Case E-VI are quite similar to those under the Case C flow regime. Under a Watana-only configuration, summer temperatures from Case E-VI operations are virtually identical to those of Case C. Slight temperature differences appear under Case E-VI with the addition of the Devil Canyon dam, generally cooler overall, with warmer temperatures occurring later in the summer.

Winter simulations under Case E-VI show little variation from Case C simulations under a Watana-only configuration. Addition of the Devil Canyon dam results in consistently slightly cooler river temperatures under the Case E-VI operating regime.

Effects of attempts to pass warm water downriver during winter differ little from the inflow temperature matching model runs. Also, since Case E-VI differs only slightly from previously-analyzed Case C, the effects on fishery

resources from Case E-VI are essentially the same as presented in AEIDC (1984b).

INTRODUCTION

PURPOSE AND SCOPE

This report summarizes an assessment of the effects of changes in downstream thermal properties in the mainstem of the Susitna River resulting from various operational scenarios for the proposed Susitna hydroelectric project. Examined specifically are the effects of temperature changes on instream fishery resources due to the Case E-VI operating regime (Harza-Ebasco 1984). The approach to conducting an assessment of the effects of the proposed Susitna project on fishery resources of the Susitna basin has been described in AEIDC (1984b). This report is a supplement to that previous analysis.

An overview of the temperature assessment program for Susitna hydroelectric project environmental studies was provided in AEIDC (1984b). Reservoir operations and reservoir temperature simulation models, operated by Harza-Ebasco Susitna Joint Venture, are used to predict reservoir outflow discharge and temperature conditions associated with various power load demands in either the one- or two- dam configurations. These forecasts are then used by AEIDC as input data to an instream temperature simulation model, SNTEMP. The SNTEMP model predicts either natural or with-project instream temperature conditions. Currently, temperature simulations are run using average weekly time steps. Various combinations of meteorological and flow conditions are imposed on the reservoir operations, reservoir temperature, and instream temperature models in order to examine the effect of diverse climatic conditions on instream temperature.

This report describes the expected temperature changes and associated effects on fish resources in the Watana-to-Talkeetna mainstem reach of the Susitna River. Although temperature predictions for the Susitna River are provided downstream to the the Parks Highway bridge at Sunshine, fish assessments are only provided to RM 100 above the Chulitna confluence due to the lack of confidence in river temperature predictions in the extensively braided zone below Talkeetna.

For simulation purposes, the year has been divided into two segments, winter and summer. The winter period extends from September through April, while the summer period includes the months of May through September. Note that the month of September is included in both summer and winter simulations. Spawning occurs through September, yet the beginning of incubation also occurs in September; therefore, this month is included in both simulation periods to better assess temperature effects on both life phase activities.

Examined in this report are natural and with-project simulations for two summers and one winter. Two load demand years were examined for with-project simulations, that of Watana in the year 2001, and the Watana/Devil Canyon configuration of 2002. Two methods of operating the multi-level intake structures are examined for each of these cases: "inflow matching" where water is selected which most closely matches the natural influent temperature, and "warmest water" releases where the warmest obtainable water is released throughout the year. This latter option has been introduced as a means to limit ice formation downstream from the reservoirs, and thereby limit the slough overtopping associated with freezeup staging. All simulations consider the intake structures as described in the FERC license application (Acres American 1984). The 15 simulations covered in this report are summarized in table 1.

Table 1. Temperature Simulations for Case E-VI considered in this report

Season/ Year	Natural	Watana 2001 Demand		Watana/Devil Canyon 2002 Demand	
		Inflow Matching	Warmest Water	Inflow Matching	Warmest Water
Summer 1981	X	X	X	X	X
Summer 1982	X	X	X	X	X
Winter 1981-82	X	X	X	X	X

The temperature assessment criteria previously developed and presented in AEIDC (1984b) are updated and utilized in this report in order to directly compare the effects of the Case E-VI operating regime with other cases examined previously. These criteria were based on field investigations of fishery resources as well as literature assessment and a specific laboratory investigation conducted by the U.S. Fish and Wildlife Service (Wangaard and Burger 1983).

BACKGROUND

The Susitna River drains an area of 19,600 sq. mi. and flows 320 mi. from its origin to the Cook Inlet estuary in Southcentral Alaska. Major tributaries include the Talkeetna, Chulitna, and Yentna Rivers (figure 1).

The proposed Susitna hydroelectric project consists of two dams to be constructed over a period of about 15 years. The Watana dam would be completed in 1994 at a site three miles upstream from Tsusena Creek. This development would include an underground powerhouse and 885 ft high earthfill dam, impounding a reservoir 48 miles long with a surface area of 38,000 acres and a usable storage capacity of 3.7 million acre/ft (maf). Installed generating capacity would be 1020 megawatts (Mw) with an estimated average annual energy output of 3460 gigawatt hours (gwh).

The concrete arch Devil Canyon dam would be completed by 2002 at a site 33 miles downstream of the Watana dam site. This dam would be 645 ft high impounding a 26 mile-long reservoir with 7,800 surface acres and a usable storage capacity of 0.36 maf (Acres American 1983). Installed generating capacity would be 600 Mw, with an average annual energy output of 3450 gwh. Watana reservoir would be drawn down during high energy demand winter months

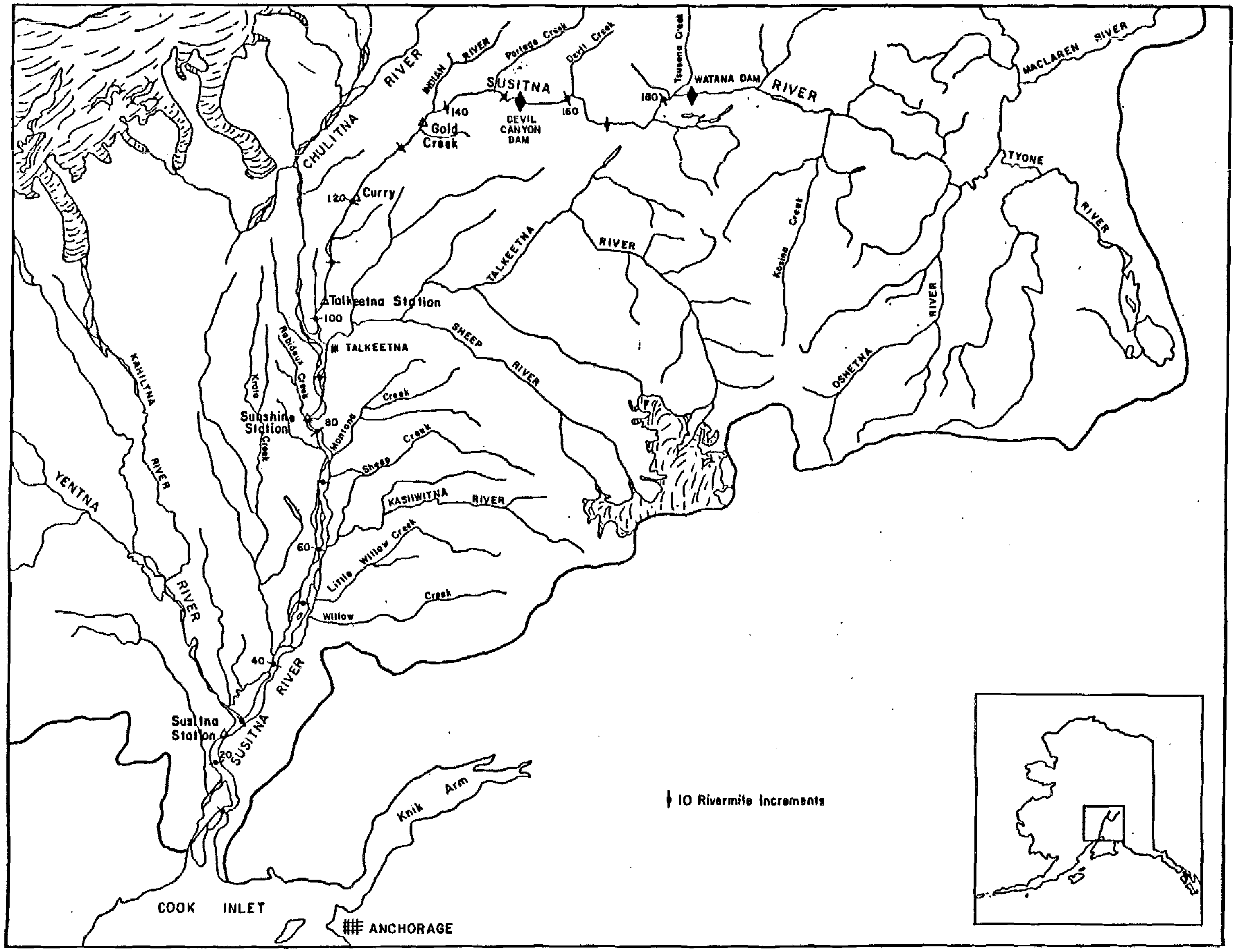


Figure 1. Map of the Susitna basin study region.

and filled during summer months when energy requirements in Southcentral Alaska are lowest. Devil Canyon reservoir would be operated with less fluctuation in water surface elevation.

Seven anadromous and 13 resident fish species are known to inhabitat the Susitna drainage, with 6 anadromous and 10 resident fish species found from the Watana dam site to the Parks Highway bridge (figure 2). Construction and operation of the Susitna hydroelectric project is expected to affect aquatic resources in the basin by altering the normal thermal regime of the river. Mainstem water temperatures downstream from the dams will be cooler in summer and warmer in winter than those currently found. A change in the ice regime downstream from the project is also expected due to altered temperatures and increased winter flows.

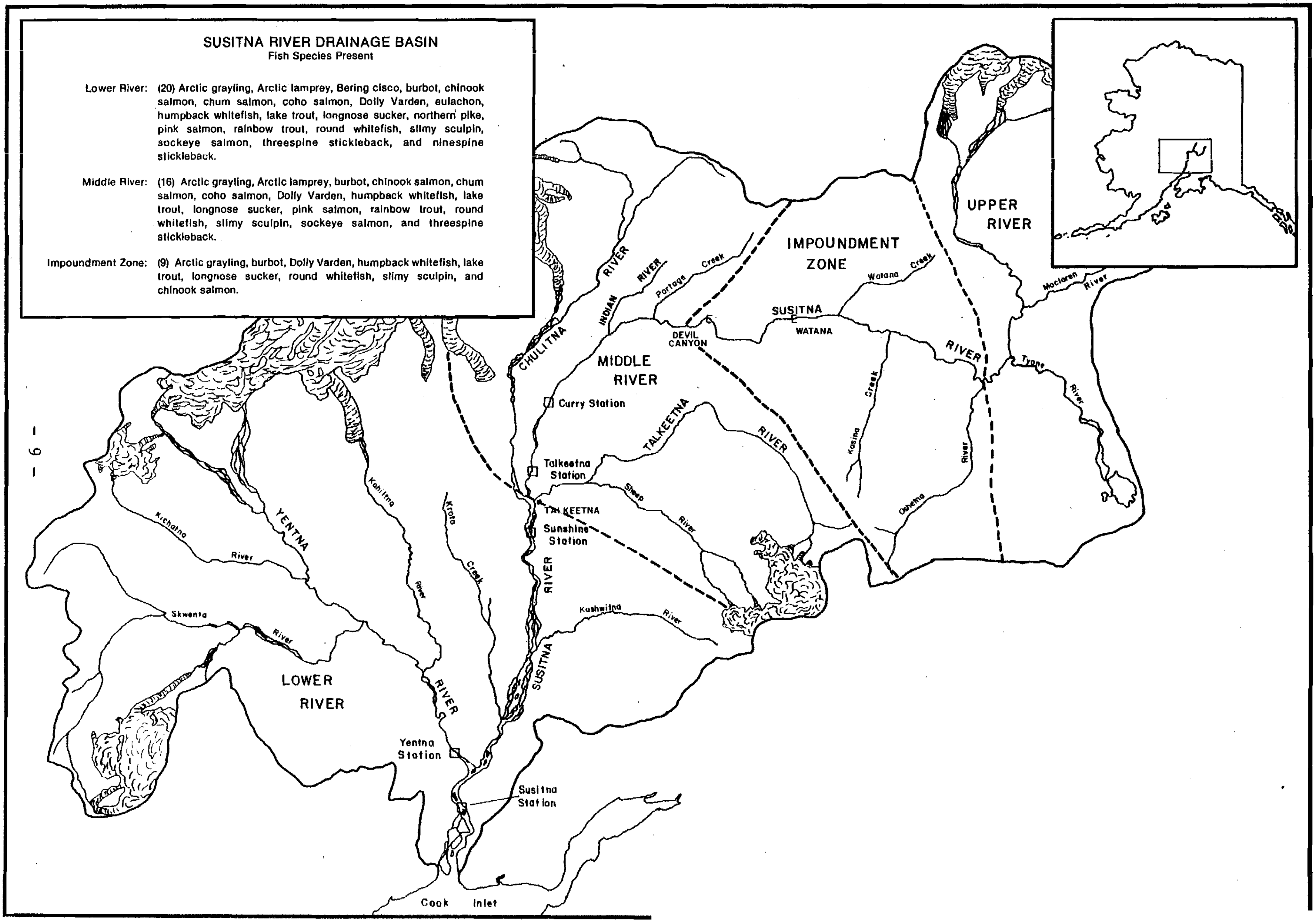
METHODS

INSTREAM TEMPERATURE MODELING

A computer version of an instream water temperature model (Theurer et al. 1983) has been used to analyze the downstream temperature changes associated with the Susitna hydroelectric project. The instream water temperature model (SNTEMP) predicts longitudinal, cross-sectioned averaged, mean weekly temperatures throughout a stream network. Application of this model to the Susitna basin has been previously discussed in (AEIDC 1983, 1984a, 1984b). For a complete description of the model, reference is made to Theurer et al. (1983) and AEIDC (1983).

Water weeks are used as the averaging time period. The first water week begins on October 1. All water weeks are seven days long except the fifty-second week which is eight days long; February 29 is not considered when

Figure 2. Susitna River drainage basin fish species by study zone.



it occurs. Table 2 is useful for converting between water weeks and calendar days. Stream temperatures have been simulated using average weekly hydrologic and meteorologic data. Temperature predictions, therefore, represent the 24-hour average stream temperature which would be expected to occur on the average day of the week. Winter simulations cover weeks 49 through 30 of the following water year; summer simulations cover weeks 31 through 52.

With-project stream temperature simulations require the flow and temperature of reservoir releases as input. Harza-Ebasco Susitna Joint Venture models the reservoir(s) operation to determine release flow and temperatures, and transmits the results to AEIDC. These results include daily flows and associated temperatures from powerhouse, cone valve and spillway releases. The daily results are processed to obtain single mean weekly flows and temperatures which incorporate releases from the three outflow structures. These results are then used as upstream boundary conditions for the SNTEMP model.

YEARS SELECTED FOR SIMULATION

Temperature simulations under the Case C flow regime were previously run for a number of meteorologic conditions in order to bracket the expected range of resultant river temperatures (AEIDC 1984b). Preliminary temperature simulations under Case E-VI flow requirements were run using summer 1981, summer 1982 and winter 1981-82 conditions. Differences in simulated temperatures between the Cases C and E-VI runs were considered slight enough not to warrant additional simulations (Harza-Ebasco 1985). It is assumed that these relative differences would apply regardless of climatic conditions.

Table 2. Water weeks for water year n.

WEEK NUMBER	FROM	TO	WEEK NUMBER	FROM	TO
	Day/Month/Year	Day/Month/Year		Day/Month/Year	Day/Month/Year
1	01 Oct n-1	07 Oct n-1	27	01 Apr n	07 Apr n
2	08 Oct n-1	14 Oct n-1	28	08 Apr n	14 Apr n
3	15 Oct n-1	21 Oct n-1	29	15 Apr n	21 Apr n
4	22 Oct n-1	28 Oct n-1	30	22 Apr n	28 Apr n
5	29 Oct n-1	04 Nov n-1	31	29 Apr n	05 May n
6	05 Nov n-1	11 Nov n-1	32	06 May n	12 May n
7	12 Nov n-1	18 Nov n-1	33	13 May n	19 May n
8	19 Nov n-1	25 Nov n-1	34	20 May n	26 May n
9	26 Nov n-1	02 Dec n-1	35	27 May n	02 Jun n
10	03 Dec n-1	09 Dec n-1	36	03 Jun n	09 Jun n
11	10 Dec n-1	16 Dec n-1	37	10 Jun n	16 Jun n
12	17 Dec n-1	23 Dec n-1	38	17 Jun n	23 Jun n
13	24 Dec n-1	30 Dec n-1	39	24 Jun n	30 Jun n
14	31 Dec n-1	06 Jan n	40	01 Jul n	07 Jul n
15	07 Jan n	13 Jan n	41	08 Jul n	14 Jul n
16	14 Jan n	20 Jan n	42	15 Jul n	21 Jul n
17	21 Jan n	27 Jan n	43	22 Jul n	28 Jul n
18	28 Jan n	03 Feb n	44	29 Jul n	04 Aug n
19	04 Feb n	10 Feb n	45	05 Aug n	11 Aug n
20	11 Feb n	17 Feb n	46	12 Aug n	18 Aug n
21	18 Feb n	24 Feb n	47	19 Aug n	25 Aug n
22	25 Feb n	03 Mar n	48	26 Aug n	01 Sep n
23	04 Mar n	10 Mar n	29	02 Sep n	08 Sep n
24	11 Mar n	17 Mar n	50	09 Sep n	15 Sep n
25	18 Mar n	24 Mar n	51	16 Sep n	22 Sep n
26	25 Mar n	31 Mar n	52	23 Sep n	30 Sep n

INSTREAM FISHERY RESOURCE ANALYSIS

The approach used in this study to determine the effects of altered water temperatures on instream fishery resources involved the development of temperature tolerance criteria for salmon. Criteria permit judgement of the nature of effects by examining the degree of departure from either preferred or tolerated environmental conditions. We prepared Susitna-specific thermal criteria through literature review as well as examination of Susitna field data and laboratory investigations conducted by the U.S. Fish and Wildlife Service (Wangaard and Burger 1983). These criteria included temperature ranges believed to be capable of supporting adult spawning migrations, spawning, incubation, rearing, and smolt migrations (table 3). A detailed description of thermal relations and terminology as well as the methods used to develop temperature criteria were presented in AEIDC (1984b).

At least 20 species of fish are known to inhabit the Susitna drainage, 16 of which have been captured in the Susitna River between Devil Canyon and Talkeetna (table 4). Six of these are anadromous and 10 are resident species. Since the major group of species inhabiting the Susitna basin are salmonids, the emphasis of field investigations as well as the focus of concern regarding the effects of the Susitna hydroelectric project have been on the salmonid resources. Detailed descriptions of the fish resources in the Susitna basin are available in Barrett, Thompson, and Wick (1984, 1985) and Schmidt et al. (1984a, 1984b) and were summarized in WCC and Entrix (1985) and AEIDC (1984b).

Temperature regimes in the Devil Canyon-to-Talkeetna reach are evaluated with respect to the tolerance ranges identified for the various fish life stages considered. In order to facilitate this evaluation, temperature tolerances are graphically presented over a 1-year time frame by fish life stage for the five species of Pacific salmon. The figures developed for the Pacific

Table 3. Salmon temperature tolerance criteria for Susitna River drainage.

SPECIES	LIFE PHASE	TEMPERATURE RANGE (C) TOLERANCE	PREFERRED
Chum	Adult Migration	1.5-18.0	6.0-13.0
	Spawning	1.0-14.0	6.0-13.0
	Incubation[1]	0-12.0	2.0- 8.0
	Rearing	1.5-16.0	5.0-15.0
	Smolt Migration	3.0-13.0	5.0-12.0
Sockeye	Adult Migration	2.5-16.0	6.0-12.0
	Spawning	4.0-14.0	6.0-12.0
	Incubation[1]	0-14.0	4.5- 8.0
	Rearing	2.0-16.0	7.0-14.0
	Smolt Migration	4.0-18.0	5.0-12.0
Pink	Adult Migration	5.0-18.0	7.0-13.0
	Spawning	7.0-18.0	8.0-13.0
	Incubation[1]	0-13.0	4.0-10.0
	Smolt Migration	4.0-13.0	5.0-12.0
Chinook	Adult Migration	2.0-16.0	7.0-13.0
	Spawning	5.0-14.0	7.0-12.0
	Incubation[1]	0-16.0	4.0-12.0
	Rearing	2.0-16.0	7.0-14.0
	Smolt Migration	4.0-16.0	7.0-14.0
Coho	Adult Migration	2.0-18.0	6.0-11.0
	Spawning	2.0-17.0	6.0-13.0
	Incubation[1]	0-14.0	4.0-10.0
	Rearing	2.0-18.0	7.0-15.0
	Smolt Migration	2.0-16.0	6.0-12.0

[1] Embryo incubation or development rate increases as temperature rises. Accumulated temperature units or days to emergence should be determined for each species for incubation.

Table 4. List of fish species found to date in the Susitna River between RM 100 and Devil Canyon.

Arctic lamprey	_Lampetra japonica_ (Martens)
Arctic grayling	_Thymallus arcticus_ (Pallas)
Bering cisco	_Coregonus laurettae_ Bean
Round whitefish	_Prosopium cylindraceum_ (Pallas)
Humpback whitefish	_Coregonus pidschian_ (Gmelin)
Rainbow trout	_Salmo gairdneri_ Richardson
Dolly Varden	_Salvelinus malma_ (Walbaum)
Pink (humpback) salmon	_Oncorhynchus gorbuscha_ (Walbaum)
Sockeye (red) salmon	_Oncorhynchus nerka_ (Walbaum)
Chinook (king) salmon	_Oncorhynchus tshawytscha_ (Walbaum)
Coho (silver) salmon	_Oncorhynchus kisutch_ (Walbaum)
Chum (dog) salmon	_Oncorhynchus keta_ (Walbaum)
Longnose sucker	_Catostomus catostomus_ (Forster)
Threespine stickleback	_Gasterosteus aculeatus_ Linnaeus
Burbot	_Lota lota_ (Linnaeus)
Slimy sculpin	_Cottus cognatus_ Richardson

salmon are then overlayed with the temperature profiles from RM 100, 130, and 150 for the period May 1981 through April 1982 (See Appendices A-D). In cases where the tolerance range was not fully determined (resident species) existing life history knowledge was compared to predicted with-project temperatures. Because information on resident fish is incomplete, assessment of with-project effects on them is less rigorous.

Only in cases where the simulated temperature regimes fall outside the life phase temperature tolerances is an obvious adverse impact expected. In cases where project conditions do not exceed tolerances but are substantially different from natural, a discussion of the likely effects of this situation is presented.

RESULTS AND DISCUSSION

PROJECT EFFECTS ON INSTREAM TEMPERATURE

Results from temperature simulations under Case C flow requirements and an "inflow matching" operating rule have been previously discussed in AEIDC 1984b). Simulations made since that report include Case C "warmest water" releases, Case E-VI "inflow matching" and Case E-VI "warmest water" scenarios. Results from these simulations are discussed here through three sets of comparisons:

1. Case C "inflow matching" compared to Case C "warmest water";
2. Case C "inflow matching" compared to Case E-VI "inflow matching";
3. Case C "warmest water" compared to Case E-VI "warmest water".

Temperature chronology graphs for summers 1981 and 1982 for both the Watana 2001 and the Watana/Devil Canyon 2002 configurations at three river locations (RM 150, 130, and 100) are provided in Appendix A. Tabular results for RM 130 are provided for all scenarios in table 5. Mean summer temperatures (water weeks 31 through 52) are provided for all these cases as well as for natural simulations in table 6. Mean simulated winter temperatures (water weeks 5 through 30) are given in table 7. A discussion of the results at RM 130 follows.

Table 5. Comparison of Water Temperatures (C) at RM 130 (LRX 33) for Case C and Case E-VI.

	Water Week 1981																					
Case	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Watana 2001 E-VI IF Match	3.3	4.1	4.7	6.0	7.4	7.6	9.2	10.9	9.1	8.6	8.3	9.6	10.6	10.2	9.5	7.9	7.8	9.0	9.0	7.9	8.3	6.1
Watana 2001 C IF Match	3.9	4.4	4.8	6.0	7.3	7.1	9.0	10.7	8.6	8.5	8.2	9.8	10.7	10.3	9.1	8.0	7.8	9.0	9.0	7.9	8.1	6.0
Watana 2001 E-VI Warmest W	3.0	4.0	4.6	5.9	7.3	7.6	9.3	10.8	10.0	9.8	9.0	9.8	10.6	10.4	10.5	8.8	8.3	8.9	9.5	8.9	8.5	6.7
Watana 2001 C Warmest W	3.1	4.1	4.6	5.7	7.1	6.9	8.8	10.6	9.3	9.6	8.8	9.8	10.8	10.4	9.0	8.5	8.5	8.9	9.7	9.0	8.6	6.8
D.C. 2002 E-VI IF Match	2.8	3.8	4.7	5.2	5.9	5.9	6.8	7.5	7.4	7.3	5.8	4.9	6.7	7.7	8.0	7.7	7.5	8.0	8.5	8.4	8.5	7.5
D.C. 2002 C IF Match	3.0	4.0	4.7	5.4	6.0	6.5	8.0	8.7	7.8	7.6	6.7	5.1	6.0	7.6	7.8	7.6	7.5	7.9	8.2	8.2	8.2	7.6
D.C. 2002 E-VI Warmest W	3.3	4.1	4.8	5.3	5.8	5.7	6.7	7.4	7.8	7.9	5.8	4.9	6.7	7.6	7.9	7.9	8.0	8.2	8.7	8.6	8.6	7.5
D.C. 2002 C Warmest W	2.7	3.7	4.5	5.1	5.8	5.8	7.0	8.1	8.8	9.8	7.9	5.3	6.1	7.8	8.0	7.8	7.9	8.1	8.2	8.3	8.4	7.7
Natural	5.1	7.5	8.2	8.1	9.4	8.8	11.5	12.3	9.1	9.0	9.4	9.9	10.3	10.0	10.0	7.6	8.1	10.1	7.9	7.3	6.5	2.2

Table 5 (cont'd). Comparison of Water Temperatures (C) at RM 130 (LRX 33) for Case C and Case E-VI.

	Water Week 1981-1982																					
Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Watana 2001 E-VI IF Match	5.2	4.6	3.9	3.3	1.9	1.7	.9	.3	1.6	1.1	1.5	2.0	.7	.2	.2	0.0	0.0	1.1	2.2	.3	0.0	.8
Watana 2001 C IF Match	5.1	4.7	4.0	3.4	2.0	1.6	1.3	1.4	2.0	1.1	1.4	1.9	.3	0.0	.1	0.0	0.0	1.3	2.1	0.0	0.0	.4
Watana 2001 E-VI Warmest W	5.3	4.5	3.9	3.3	1.9	2.0	1.5	1.6	2.7	1.9	2.3	2.7	1.5	1.2	1.2	1.1	.7	2.3	2.9	1.0	.6	1.5
Watana 2001 C Warmest W	5.4	4.7	4.0	3.5	2.1	1.8	1.1	1.1	1.7	.8	1.1	1.6	.4	0.0	0.0	0.0	0.0	1.0	1.7	0.0	0.0	.2
D.C. 2002 E-VI IF Match	6.6	6.4	5.9	5.5	4.2	3.7	2.6	1.0	1.5	1.1	1.4	1.7	.8	.5	.7	.6	.4	1.7	2.0	.8	.6	1.3
D.C. 2002 C IF Match	6.8	6.5	6.1	5.4	4.4	3.8	2.6	.6	1.2	1.2	1.5	1.8	1.2	.9	1.1	.9	.7	2.0	2.2	1.1	1.0	1.5
D.C. 2002 E-VI Warmest W	6.6	6.4	6.0	5.6	4.3	3.8	2.8	1.5	2.1	1.5	1.8	2.1	1.2	.9	1.1	.9	.7	1.9	2.2	1.0	.8	1.5
D.C. 2002 C Warmest W	7.1	6.9	6.4	5.8	4.6	4.1	3.0	1.7	2.1	1.6	1.8	2.1	1.4	1.0	1.2	1.0	.8	1.9	2.2	1.1	1.0	1.6
Natural	1.0	0.9	1.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5 (cont'd). Comparison of Water Temperatures (C) at RM 130 (LRX 33) for Case C and Case E-VI.

	Water Week 1981-1982							
Case	23	24	25	26	27	28	29	30
Watana 2001 E-VI IF Match	1.7	1.4	2.5	1.4	1.9	2.7	3.9	4.3
Watana 2001 C IF Match	.7	.2	3.0	1.9	2.2	2.8	4.1	4.6
Watana 2001 E-VI Warmest W	2.4	2.1	3.0	1.8	1.9	2.6	3.8	4.2
Watana 2001 C Warmest W	1.4	1.1	2.5	1.4	1.7	2.3	3.7	4.2
D.C. 2002 E-VI IF Match	2.0	1.9	2.7	2.1	2.4	3.0	3.8	4.2
D.C. 2002 C IF Match	2.1	1.9	2.5	1.9	2.3	3.0	3.8	4.2
D.C. 2002 E-VI Warmest W	2.1	2.0	2.8	2.2	2.5	3.1	4.0	4.3
D.C. 2002 C Warmest W	2.1	2.1	2.8	2.3	2.5	3.1	3.9	4.2
Natural	0.0	0.0	0.5	0.0	0.0	0.5	4.6	5.8

Table 5 (cont'd). Comparison of Water Temperatures (C) at RM 130 (LRX 33) for Case C and Case E-VI.

Case	Water Week 1982																					
	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Watana 2002 E-VI IF Match	4.2	3.7	4.1	4.2	5.0	5.9	6.6	7.3	8.6	8.8	9.7	10.5	9.4	10.0	10.3	10.2	10.6	9.3	8.7	8.2	6.9	6.1
Watana 2001 C IF Match	4.3	3.6	4.0	4.0	5.0	5.8	6.3	7.3	8.5	10.3	10.2	10.1	9.2	9.7	10.0	9.9	10.5	9.0	8.9	8.5	7.6	7.2
Watana 2001 E-VI Warmest W	3.9	3.4	3.9	4.2	5.4	6.2	7.1	7.7	9.2	9.7	10.4	11.0	10.1	11.0	11.8	11.4	11.7	11.2	9.5	8.7	7.4	6.7
Watana 2001 C Warmest W	4.0	3.4	3.9	4.0	5.0	5.7	6.3	7.3	9.5	10.5	10.4	10.4	9.7	10.5	11.7	12.0	12.4	11.5	10.1	9.0	7.9	7.5
D.C. 2002 E-VI IF Match	4.2	4.1	4.6	4.7	5.2	5.2	5.6	6.8	7.6	7.8	6.2	5.9	6.0	6.9	8.2	8.2	8.5	8.2	8.0	7.9	7.7	7.9
D.C. 2002 C IF Match	4.2	4.2	4.6	4.8	5.2	5.3	5.7	6.8	7.8	8.5	10.2	6.9	5.6	6.2	7.4	8.3	9.0	8.7	8.6	8.5	8.3	8.0
D.C. 2002 E-VI Warmest W	4.3	4.1	4.6	4.8	5.2	5.3	5.6	6.7	7.6	7.7	6.2	5.9	6.0	6.9	8.1	8.1	8.4	8.4	8.7	8.2	7.7	7.8
D.C. 2002 C Warmest W	4.2	4.0	4.5	4.7	5.2	5.2	5.5	6.5	7.4	8.3	9.3	7.0	5.5	6.1	7.7	8.4	8.8	8.8	9.0	8.8	8.5	8.4
Natural	5.5	4.7	6.7	6.6	8.4	8.9	8.0	9.6	11.8	10.6	11.1	11.2	10.0	11.0	11.2	11.0	11.0	9.5	8.0	6.7	6.6	4.4

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Table 6. Mean summer water temperatures (C) for water weeks 31-52 at RM 130 for 1981 and 1982.

	NATURAL	Watana 2001				Devil Canyon 2002			
		Inflow Match		Warmest Water		Inflow Match		Warmest Water	
		C	E-VI	C	E-VI	C	E-VI	C	E-VI
Summer '81	8.6	7.9	8.0	8.1	8.3	6.8	6.7	7.0	6.8
Summer '82	8.8	7.7	7.7	8.3	8.3	7.0	6.6	6.9	6.7

Table 7. Mean winter water temperatures (C) for water weeks 5-30 at RM 130 for 1981-82.

Natural	Watana 2001				Devil Canyon 2002			
	Inflow Match		Warmest Water		Inflow Match		Warmest Water	
	C	E-VI	C	E-VI	C	E-VI	C	E-VI
0.5[1]	1.5	1.5	1.3	2.1	2.1	2.0	2.3	2.2

[1]Simulations assume no ice cover. Thus, warming that occurs in late winter (weeks 25-30) may not be realistic. In this case, simulated water temperatures would be unnaturally high.

SUMMER

Case C warmest water compared to Case C inflow matching

Operating the reservoir under the "warmest water" release operating rule results in warmer downriver temperatures in the summer as well as during the winter for either dam configuration. Mean summer temperatures at RM 130 were 0.2 and 0.6 C warmer (1981 and 1982 respectively) under warmest water operation for the Watana 2001 scenario. Mean summer river temperatures were less different (0.2 and 0.1 C warmer, 1981 and 1982 respectively) under the Devil Canyon 2002 scheme. Most often, the warmest water rule resulted in slightly cooler temperatures early in the summer (May-June) and slightly warmer temperatures later in the season (July-September).

Case E-VI inflow matching compared to Case C inflow matching

Under the Watana 2001 scenario, river temperatures at RM 130 are virtually identical for both the Case C and Case E-VI flow requirements. With the addition of the Devil Canyon reservoir, E-VI operating temperatures are slightly cooler (0.1 and 0.4 C for 1981 and 1982). Most notable is the lower peak temperatures early in the summer.

Case E-VI warmest water compared to Case C warmest water

Once again, under the Watana 2001 scheme, water temperatures at RM 130 are virtually identical for both Cases C and E-VI flow requirements. The addition of the Devil Canyon reservoir results in slightly cooler mean summer temperatures under E-VI than under Case C (0.2 C cooler for both 1981 and 1982). There is a notable difference, however, in the timing of these temperatures. E-VI temperatures are cooler than Case C temperatures early in the summer (May-June), but warmer during the latter part of the season.

WINTER

Case C warmest water compared to Case C inflow matching

There is no clear pattern here. Under the Watana configuration, overall winter temperatures are slightly cooler (1.3 versus 1.5 C) with "warmest water" than with "inflow matching". There is no consistency, however, from week-to-week, as the "inflow matching" case is sometimes warmer, sometimes cooler. Addition of the Devil Canyon reservoir results in slightly warmer river temperatures under "warmest water" than under "inflow matching", both on a seasonal basis (2.3 versus 2.1 C) and consistently week-to-week.

Case E-VI inflow matching compared to Case C inflow matching

Under the Watana 2001 load, mean winter temperatures are the same (1.5 C) for both flow requirements. The differences between individual weeks, however, are as high as 1.2 C. Under the Devil Canyon 2002 load, Case E-VI operations result in slightly cooler winter temperatures throughout the winter, with seasonal means of 2.0 and 2.1 C.

Case E-VI warmest water compared to Case C warmest water

Under the Watana configuration, E-VI river temperatures are consistently warmer than Case C, with winter means of 2.1 and 1.3 C respectively. Under the two dam configuration, the reverse occurs with E-VI temperatures consistently a bit cooler (winter mean of 2.2 versus 2.3 C).

EFFECTS OF PROJECT-RELATED TEMPERATURES ON FISH RESOURCES

INTRODUCTION

In this section, natural and with-project temperature regimes in the Devil Canyon-to-Talkeetna reach are evaluated with respect to the salmon life stage temperature tolerances previously established (see AEIDC 1984b). In order to evaluate project effects, the established temperature tolerance criteria have been graphically illustrated covering a one-year time frame (1981-82) for each of the five species. In cases where life phases overlap, that life phase most sensitive to temperature was chosen when preparing the tolerance criteria. The criteria, then, establish the narrowest temperature tolerance window for evaluation.

These figures (Appendices B-D) are then compared, using graphic overlays, with the weekly natural and with-project temperature profiles at river miles 100, 130, and 150. Three cases are examined: 1) natural versus Case C "inflow matching" and "warmest water" for both one and two dams (Appendix B); 2) natural versus Case C "inflow matching" and Case E-VI "inflow matching" (Appendix C); and 3) natural versus Case C "warmest water" and Case E-VI "warmest water" (Appendix D). For each of the three groups, Watana-only and the two-dam scenarios are presented.

Only in cases where the simulated temperature regimes fall outside the life phase temperature tolerances is an adverse impact established. It should be noted that this occasionally happens for natural scenarios. For example, temperatures from late September through the winter fall below the tolerance level established for chinook, sockeye, and coho salmon (Appendix B). Outmigration for these species continues into October and is the life phase activity most sensitive to temperature at this time of year. The lower temperature tolerances for outmigrating chinook juveniles is therefore set at 4 C for this period even though it is past their peak outmigration and very few fish would still be migrating. The winter lower tolerance level is set at 2 C for chinook, coho, and sockeye. This represents the more sensitive rearing life phase activity. Natural temperatures are below this in winter; however, it should be noted that juvenile salmon have been found rearing in warmer upwelling-influenced areas and not in the 0 C mainstem waters.

CASE C WARMEST WATER COMPARED TO CASE C INFLOW MATCHING

Watana Only

Case C "warmest water" versus "inflow matching" scenarios are included to show the effects of 1) attempts to pass as warm a volume of water as possible to keep the ice front farthest downriver, and 2) attempts to match the natural reservoir inflow temperature regime, respectively. Case C "warmest water" is only slightly warmer in the summer and slightly cooler in the winter than Case C "inflow matching."

For Watana only, both Case C "inflow matching" and "warmest water" temperatures are slightly cooler early in the summer and warmer in the fall and winter than under natural conditions. The similarities between the two Case C temperature scenarios are so close as to render delineation of their temperature effects on fish impractical. From these temperature simulations, there is no evidence of with-project temperatures falling outside the tolerance zones (Appendix B).

Devil Canyon

With both dams operating, Case C "warmest water" is slightly warmer than "inflow matching" year-round. Both cases are considerably cooler than natural over the summer and are warmer than natural in the fall and winter. As with Watana alone, similarities in these two cases make delineation between them of temperature effects on fish impractical.

In both Case C scenarios, there is a potential for pink and chinook salmon inmigration problems upstream of RM 130 in late June to mid-July as temperatures fall below the tolerance level for this life phase (Appendix B). This is, however, mainly a concern for pink salmon because the potential block could preclude access to more habitat, would occur nearer the peak of inmigration, and the period of exposure to temperatures below tolerance levels would be of longer duration. Inmigration, we believe, would be delayed but would ultimately occur 5 to 15 days later. This may result in a shorter period between the time pink salmon occupy spawning grounds and the occurrence of actual spawning. Taken by itself, a delay in spawning of this duration might be sufficient to noticeably depress reproductive success by ultimately delaying fry emergence. It is important to note that under the worst case scenarios, model results indicate that the temperature block would disappear slightly before peak inmigration occurred. Thus, the majority of fish would continue to reach their natal areas in synchrony with endogenous biological clocks. Temperatures upstream of RM 130 in July also fall outside pink and chinook salmon spawning tolerance zones (Appendix B). This only occurs for about a week and should pose no long-term problems to spawning. It also should be noted that neither pink nor chinook salmon presently use this habitat for spawning, and that this could be more of a future mitigation constraint rather than a present impact concern.

As described in AEIDC (1984b), some reduction of juvenile growth would occur due to cooler summer temperatures, even though the Case C "warmest water" and "inflow matching" temperature scenarios are within the established range of salmon tolerance. Although unquantifiable, effects on rearing chinook salmon should be the most severe as they are the most numerous in habitats directly under mainstem temperature influence. Growth modeling indicates that, depending on climate and the temperature of reservoir-released waters, growth rates of juveniles rearing in affected mainstem areas (above RM 130) could be reduced by 8 to 29% (AEIDC 1984). These growth-reduction rate estimates include the increased growth from the warmer fall temperatures. They are also based in part on the assumption that affected juvenile fish would feed to satiation. Since this probably does not happen in the wild, these estimates could be viewed as worst case scenarios. Also, a better mainstem incubating and rearing habitat could exist in the open water zone above the ice front under the two-dam scenarios due to the warmer-than-natural mainstem water temperatures provided that other suitable habitat parameters existed. In both of these life phases, due to the similarities between Case C "inflow matching" and "warmest water", the same impacts and concerns described for Case C inflow matching in AEIDC (1984b) apply directly to the Case C "warmest water".

CASE E-VI INFLOW MATCHING COMPARED TO CASE C INFLOW MATCHING

Watana Only

Predicted weekly water temperatures for Case C and E-VI for Watana only are almost identical (Appendix C). We believe, therefore, that the same impacts described in the previous section and in AEIDC (1984b) for Case C "inflow matching" would apply to Case E-VI.

Devil Canyon

Again, the weekly water temperatures for Case E-VI are nearly the same as for Case C (Appendix C). The impacts of Case E-VI would be essentially the same as previously described (AEIDC 1984b).

CASE E-VI WARMEST WATER COMPARED TO CASE C WARMEST WATER

Watana Only

Predicted river temperatures for the open water season for these two cases are almost identical (Appendix D). Impact statements presented for Case C during the summer period in AEIDC (1984b) would also apply to Case E-VI. During winter, however, water temperatures are warmer for Case E-VI than Case C. Because of these warmer temperatures, an improved rearing and incubating habitat would exist above RM 130 during the Case E-VI "warmest water" operation.

Devil Canyon

Predicted summer river temperatures for the two cases are almost identical, although an increase in water temperature occurs in early July for Case C (Appendix D). The effects described in AEIDC (1984b) for Case C during summer would also apply to E-VI. In converse to that described above for the Watana-only scenario, during winter both cases are almost identical with Case C being slightly warmer. We believe no notable effects can be attributed to Case E-VI other than previously defined for Case C in AEIDC (1984b).

CONCLUSIONS

Because of the similarity between the Case E-VI and Case C temperature simulations for 1981-82, it is very difficult to attribute the very slight temperature differences between the E-VI and C scenarios to a definitive effect on fish. The expected temperature effects of the Case C scenario have been previously described in AEIDC (1984b). The same concerns expressed there are held for Case E-VI. Based on existing data, model runs, thermal tolerance criteria, life history information, and professional judgement, no direct mortality on fish is anticipated to occur from with-project temperatures. Based on the temperature tolerance criteria for salmon, the cooler summer temperatures for the two-dam scenarios could cause some delay in pink and chinook salmon inmigration and spawning above RM 130. Some reduction of juvenile growth may occur due to cooler summer temperatures, even though the simulated temperatures are within the established range for tolerance. Outmigrants from tributaries and sloughs upstream of RM 130 in late May and early June would encounter considerably colder-than-natural mainstem waters during Devil Canyon operation. During cold years, outmigrating salmon could avoid the mainstem and delay outmigration until temperatures warm in late June. Mainstem winter water temperatures, which under natural conditions may be limiting to salmon overwintering and incubation, could be improved from the warmer project operation waters. This is especially true of the two-dam scenarios.

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APPENDICES

A. Temperature chronologies at three middle river locations comparing natural and with-project conditions.

Part 1. Natural, Case C "warmest water," and Case C "inflow matching"

Part 2. Natural, Case C "inflow matching," and Case E-VI "inflow matching"

Part 3. Natural, Case C "warmest water," and Case E-VI "warmest water"

B. Temperature chronologies at three middle river locations in relation to five Pacific salmon life stage temperature tolerance criteria for natural, Case C "warmest water," and Case C "inflow matching"

C. Temperature chronologies at three middle river locations in relation to five Pacific salmon life stage temperature tolerance criteria for natural, Case C "inflow matching," and Case E-VI "inflow matching"

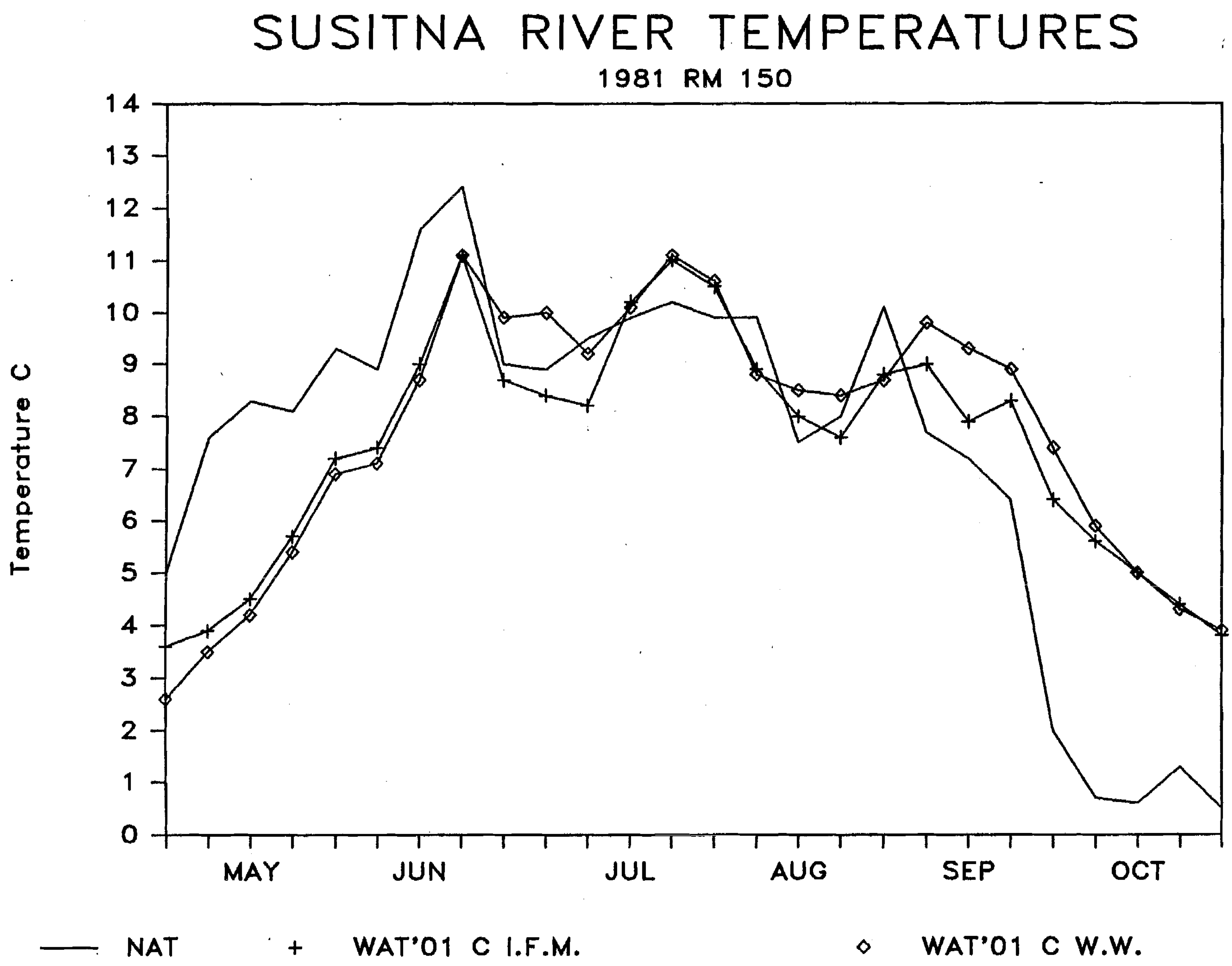
D. Temperature chronologies at three middle river locations in relation to five Pacific salmon life stage temperature tolerance criteria for natural, Case C "warmest water," and Case E-VI "warmest water"

APPENDIX A

Temperature chronologies at three middle river locations comparing natural and with-project conditions

APPENDIX A. PART 1

Natural, Case C "Warmest water," and Case C "inflow matching"



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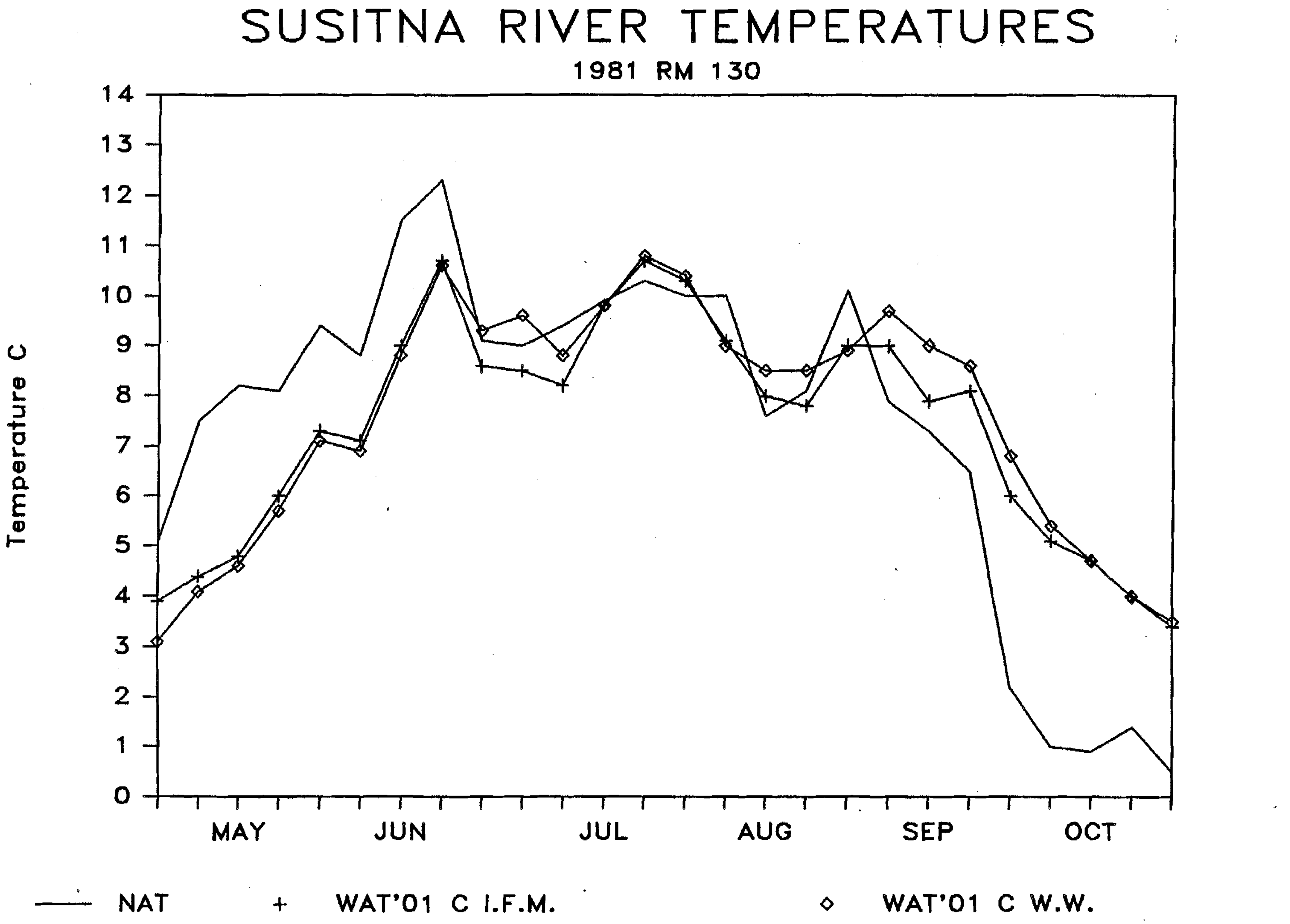
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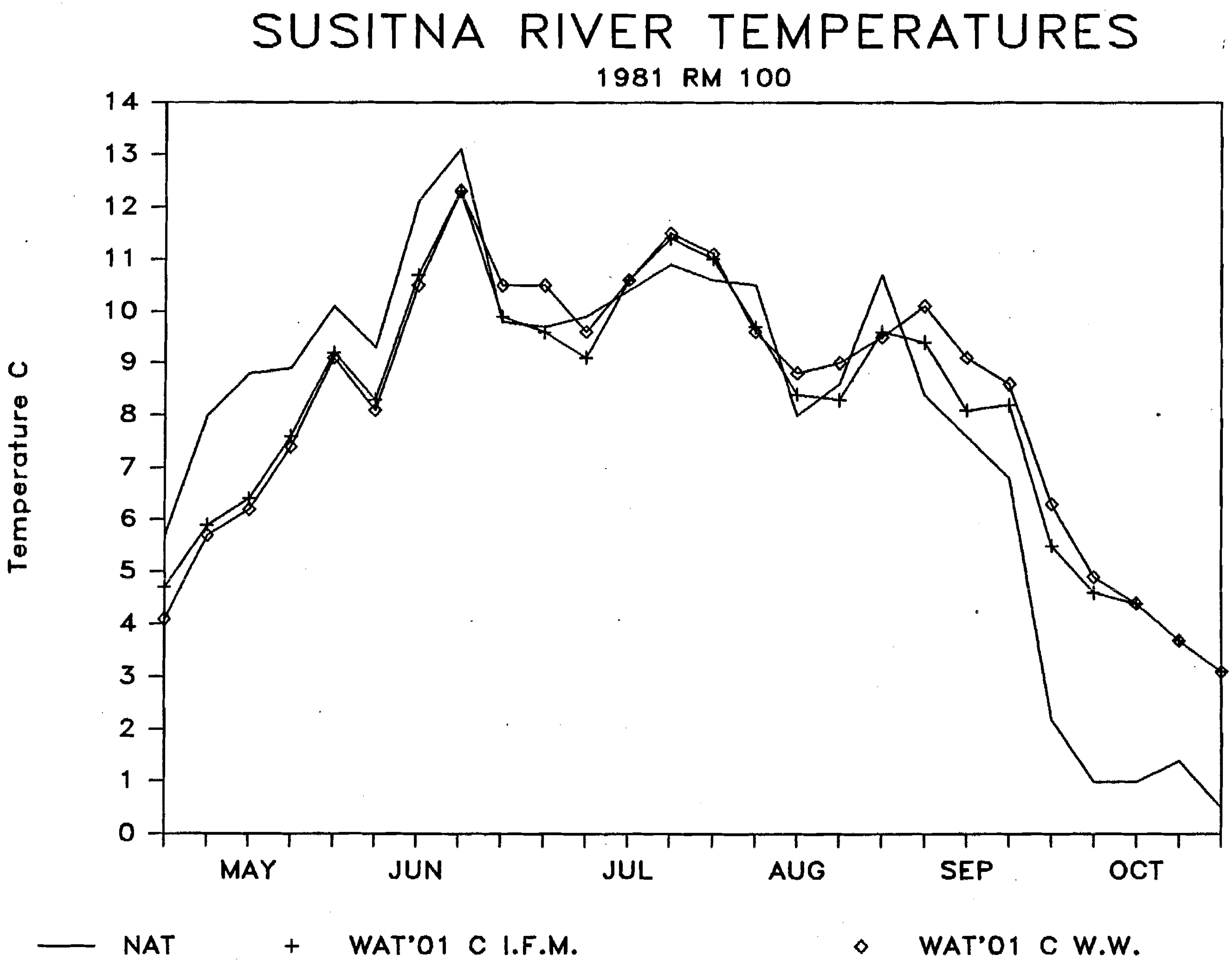
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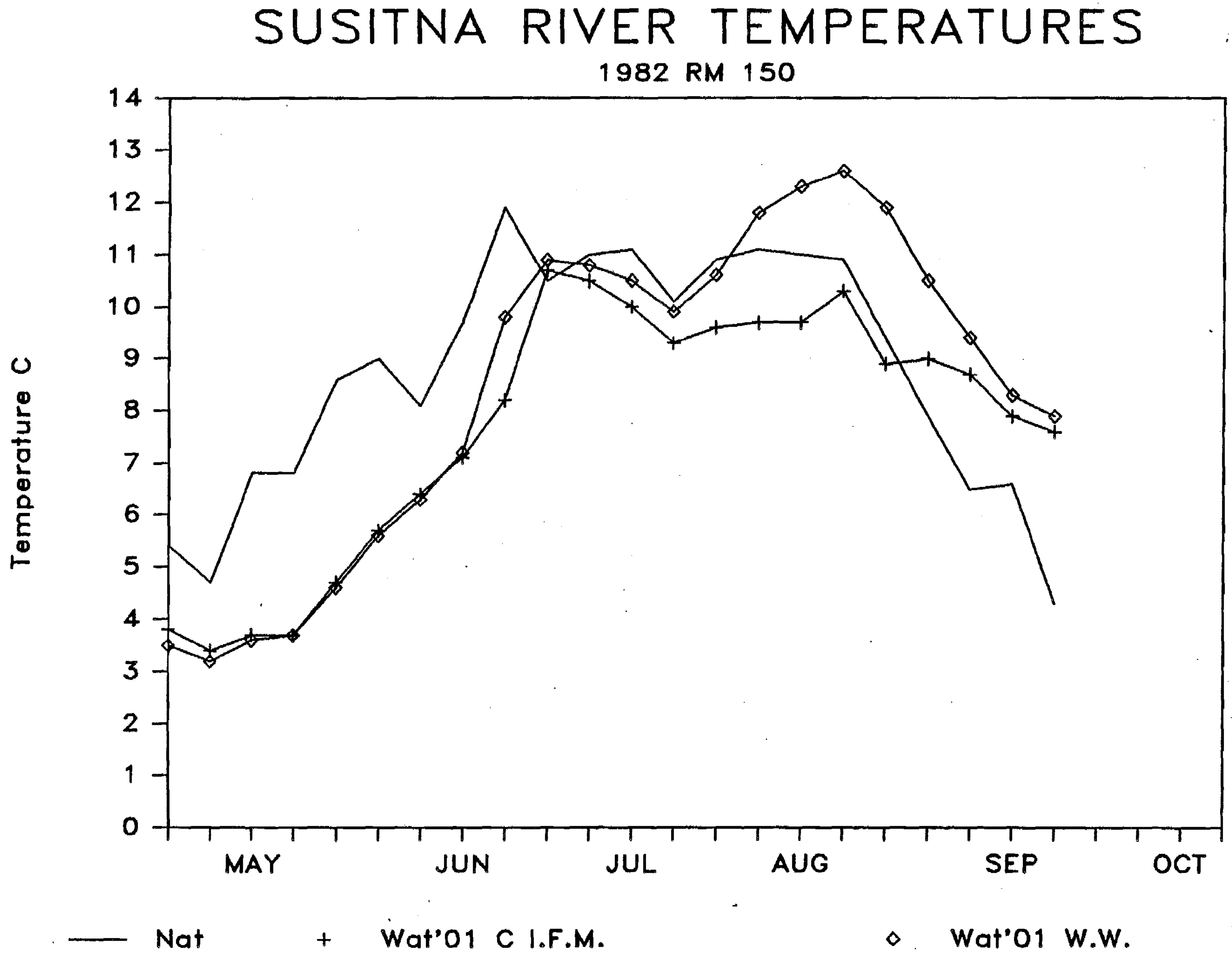
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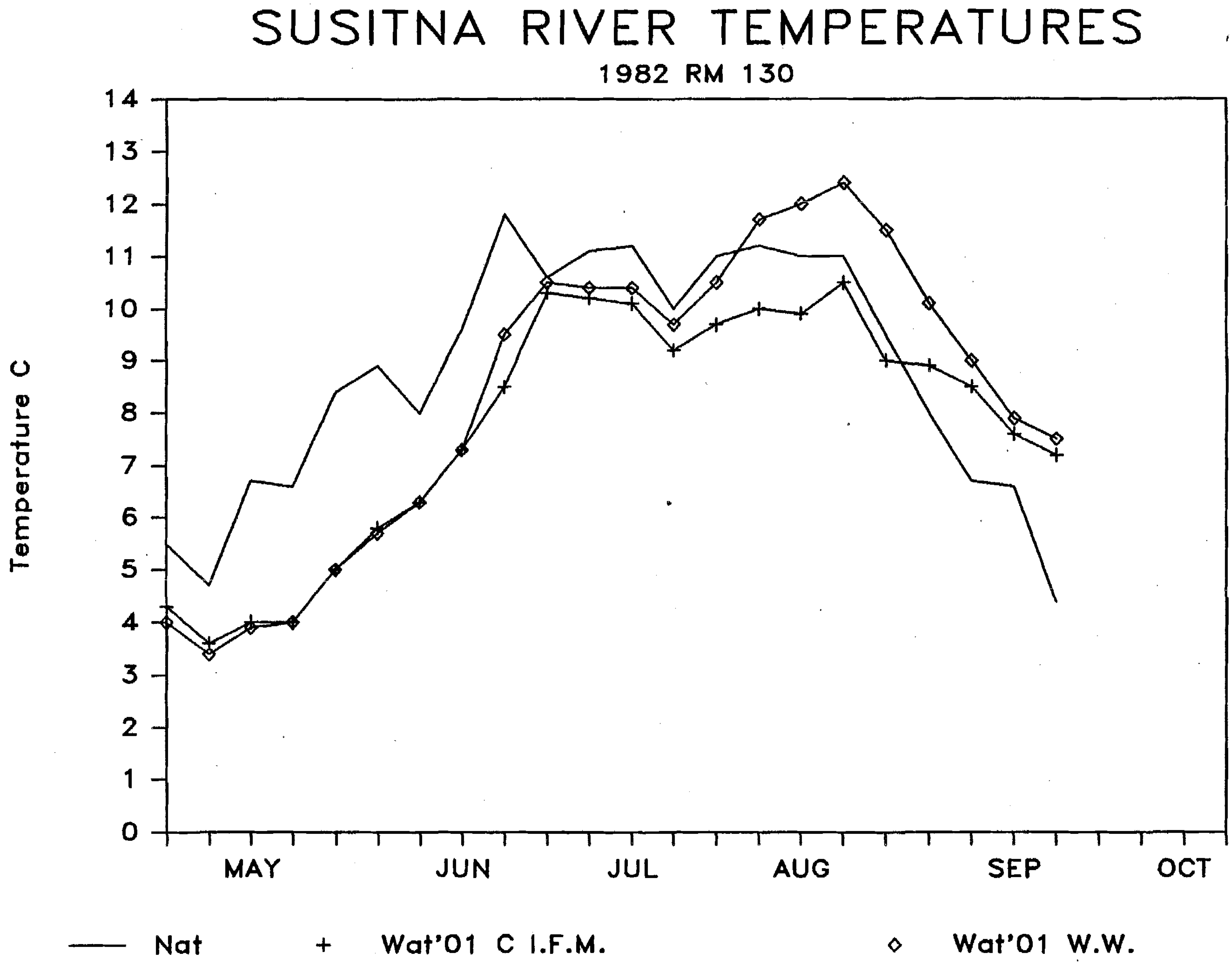
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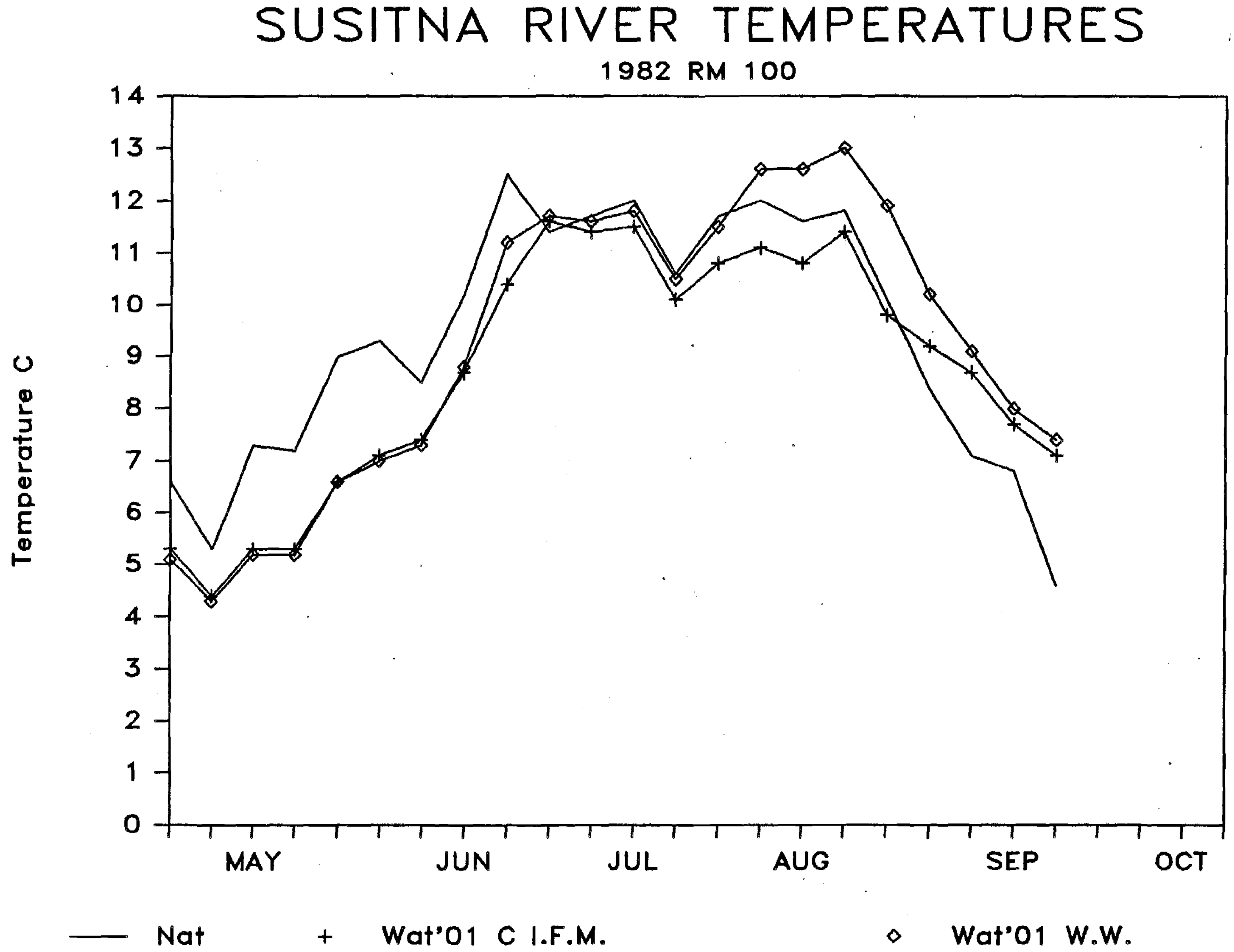
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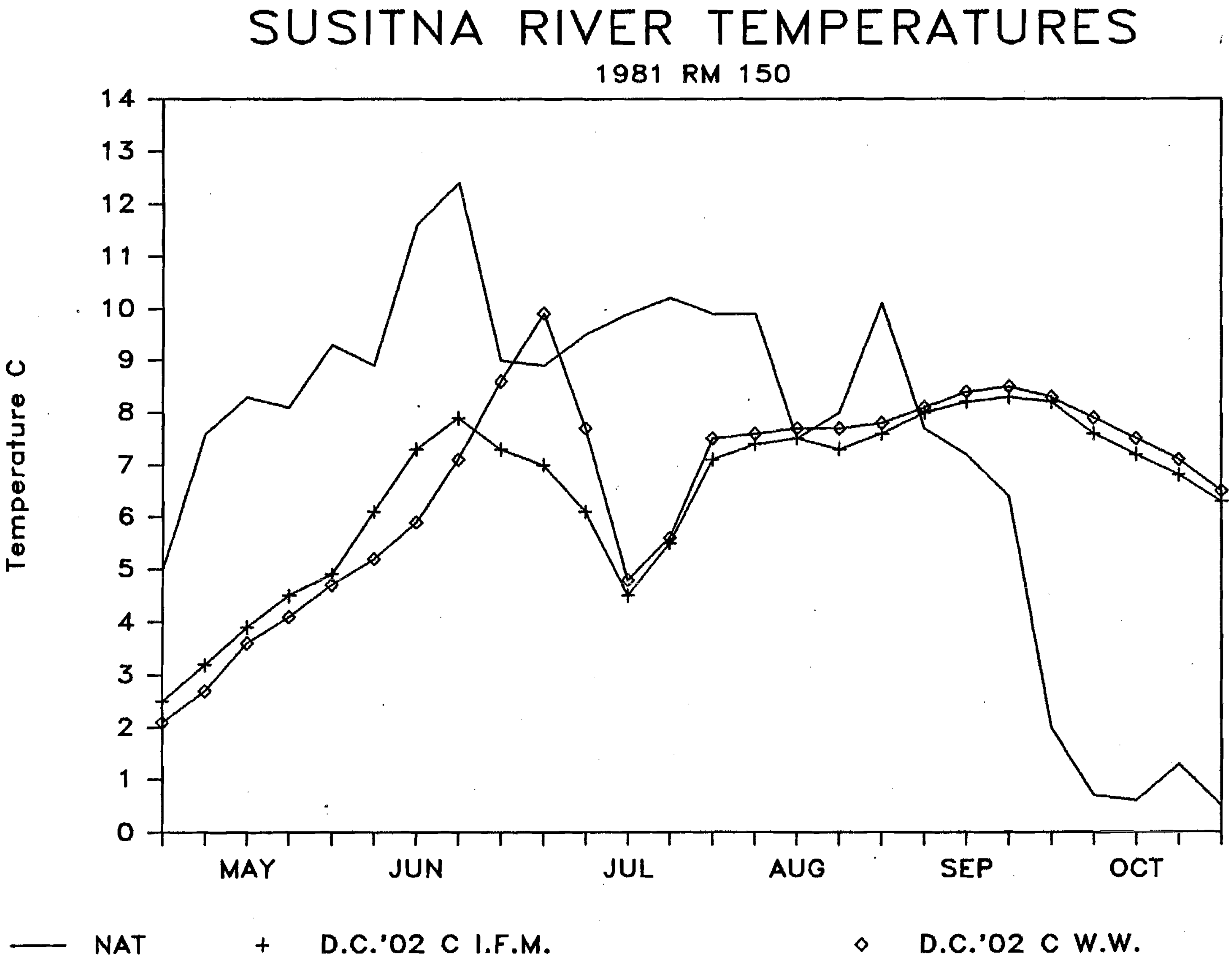

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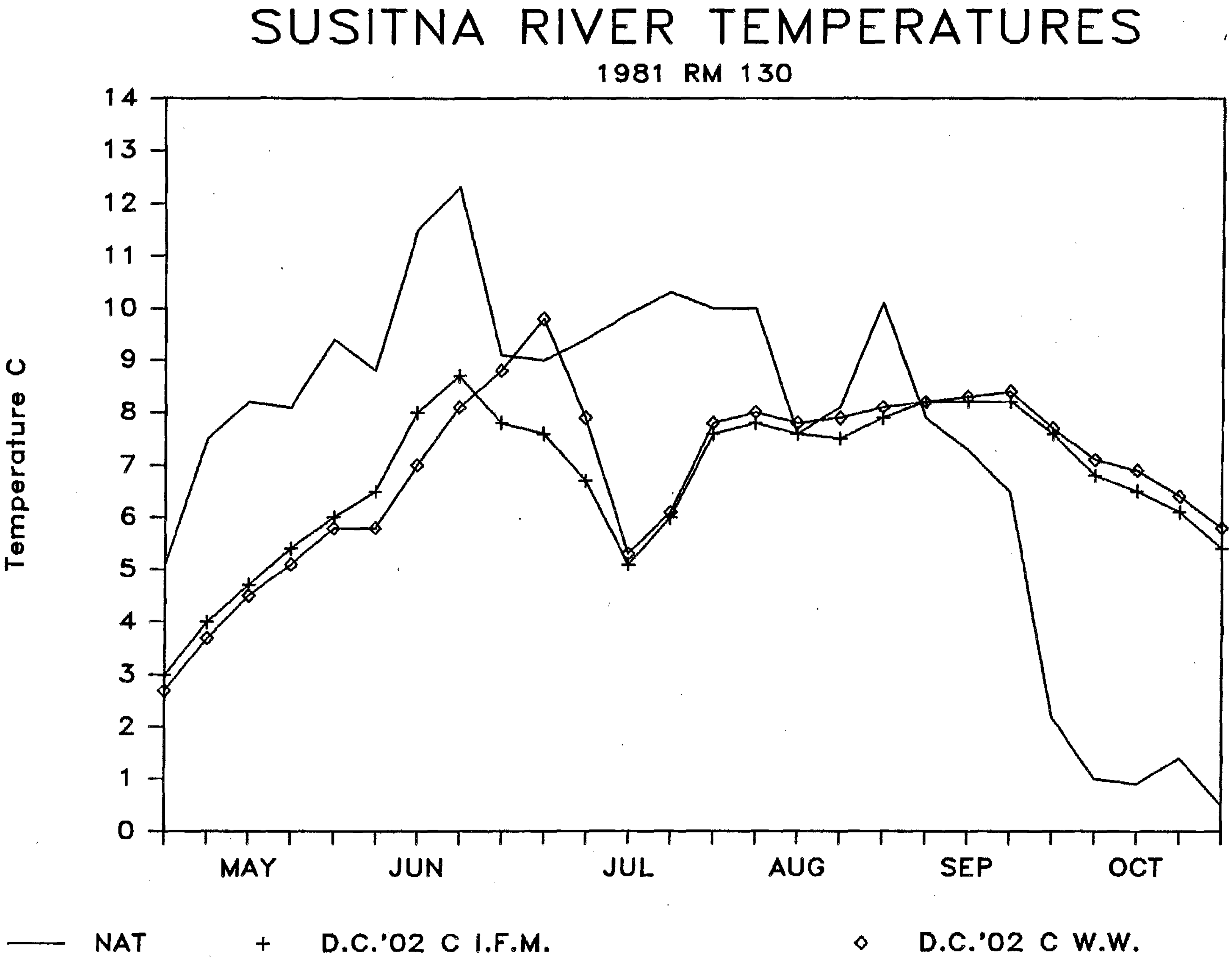
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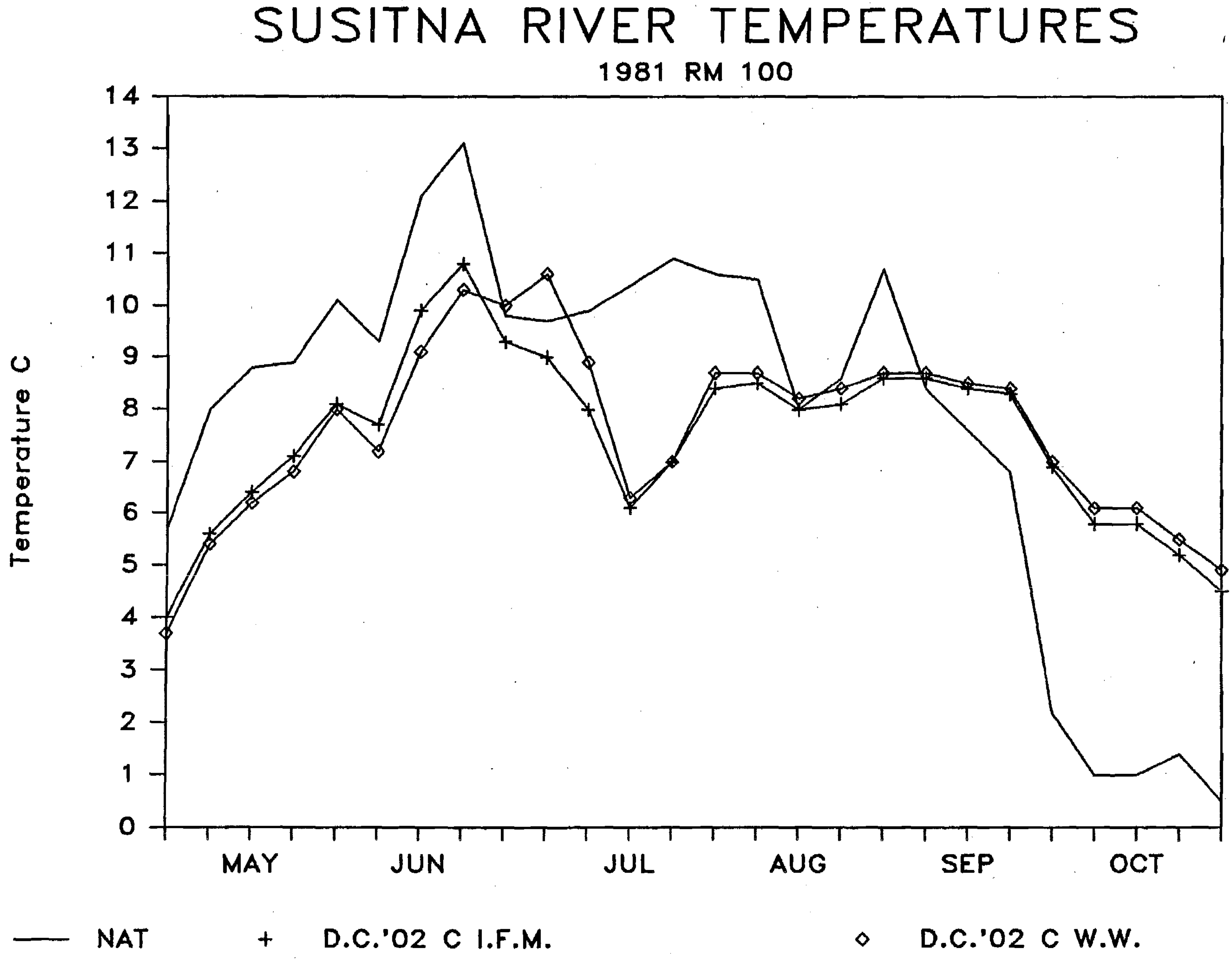

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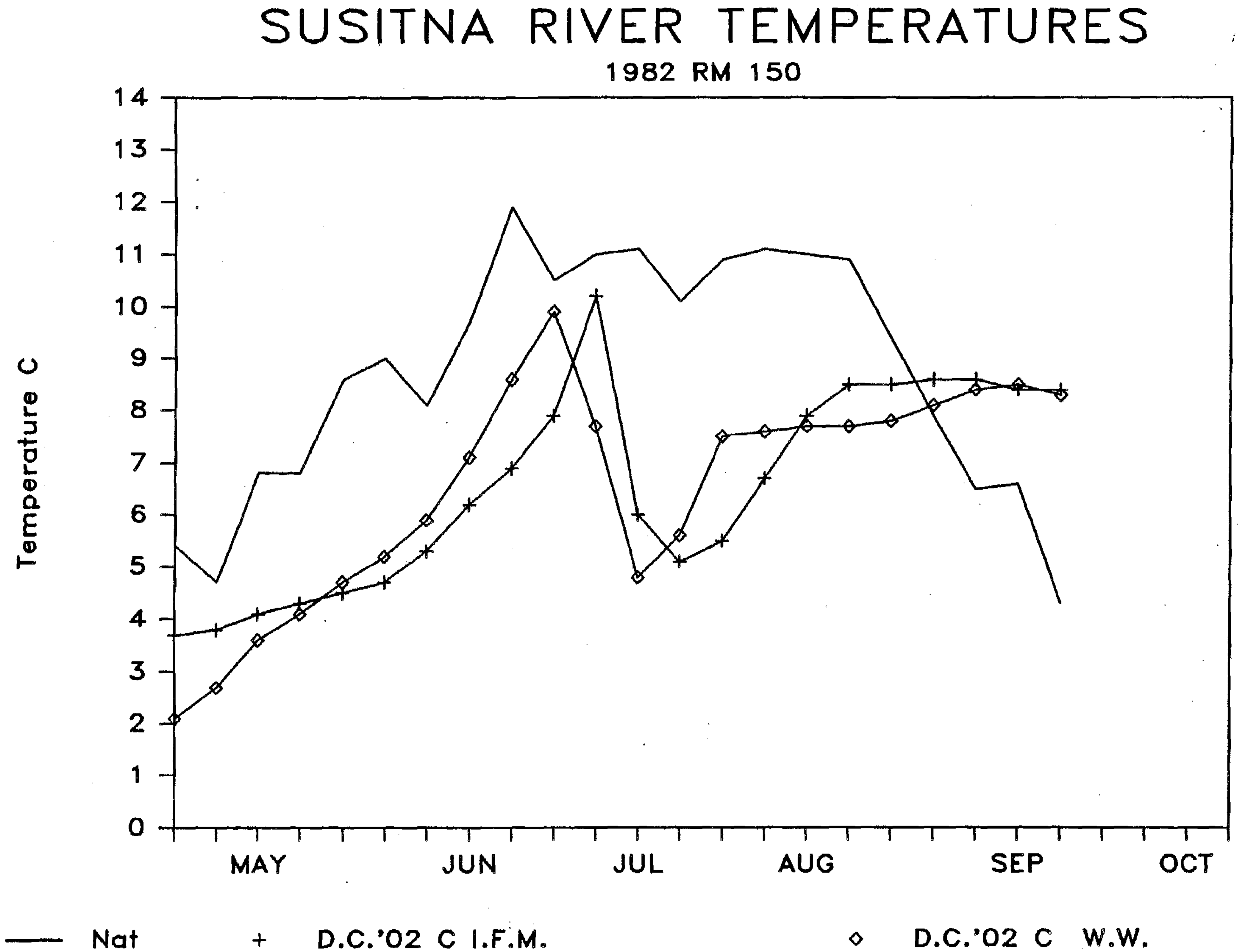
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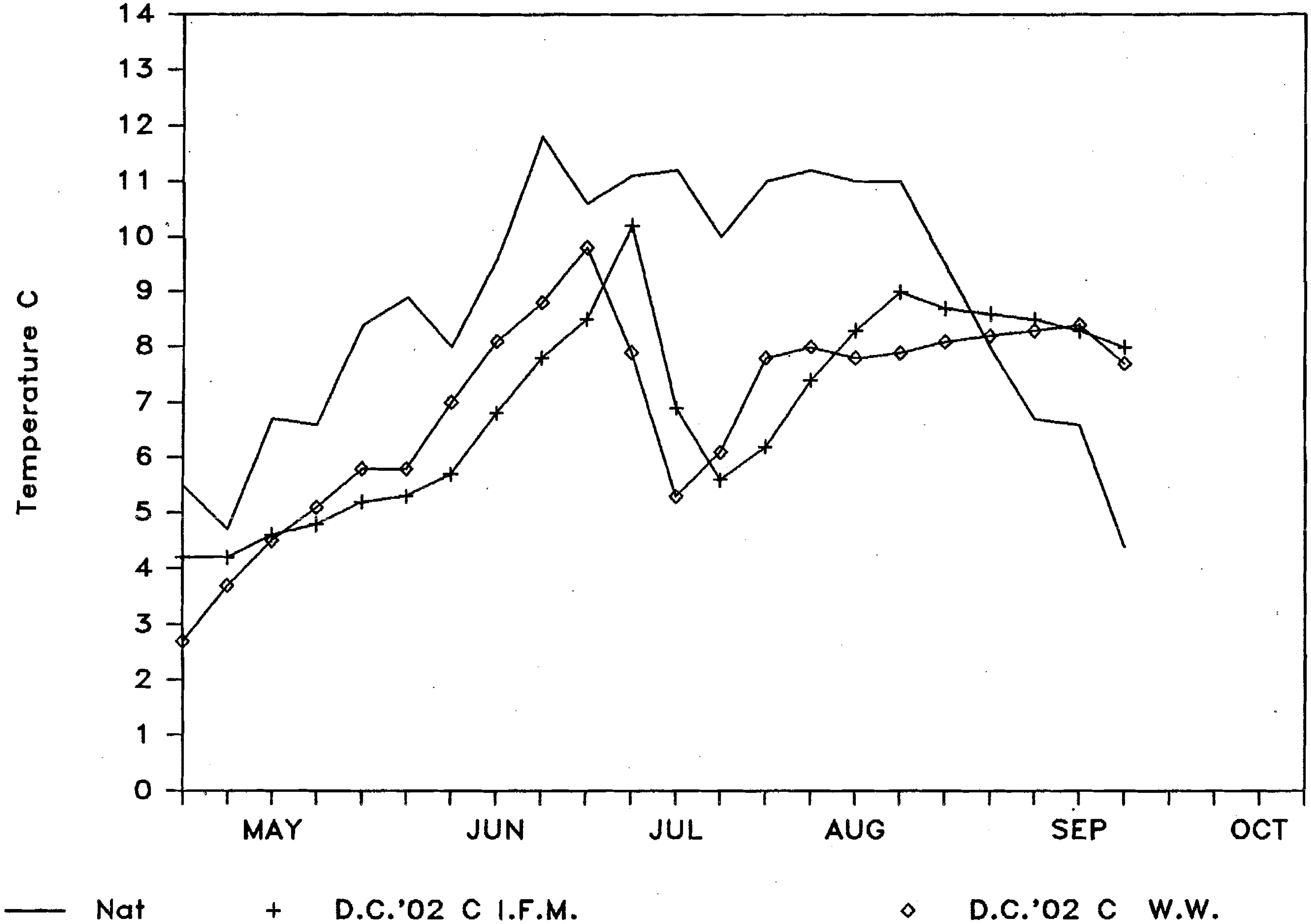

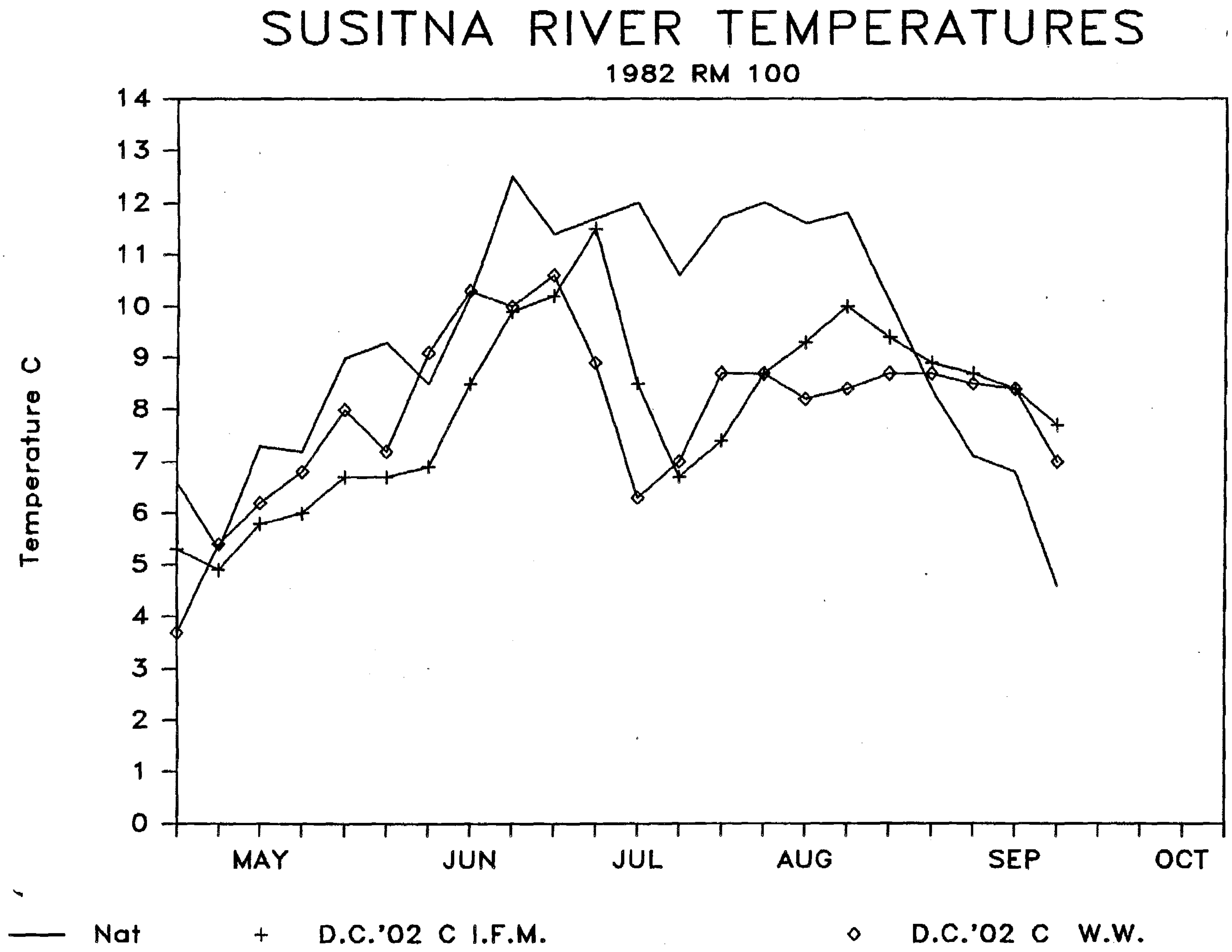

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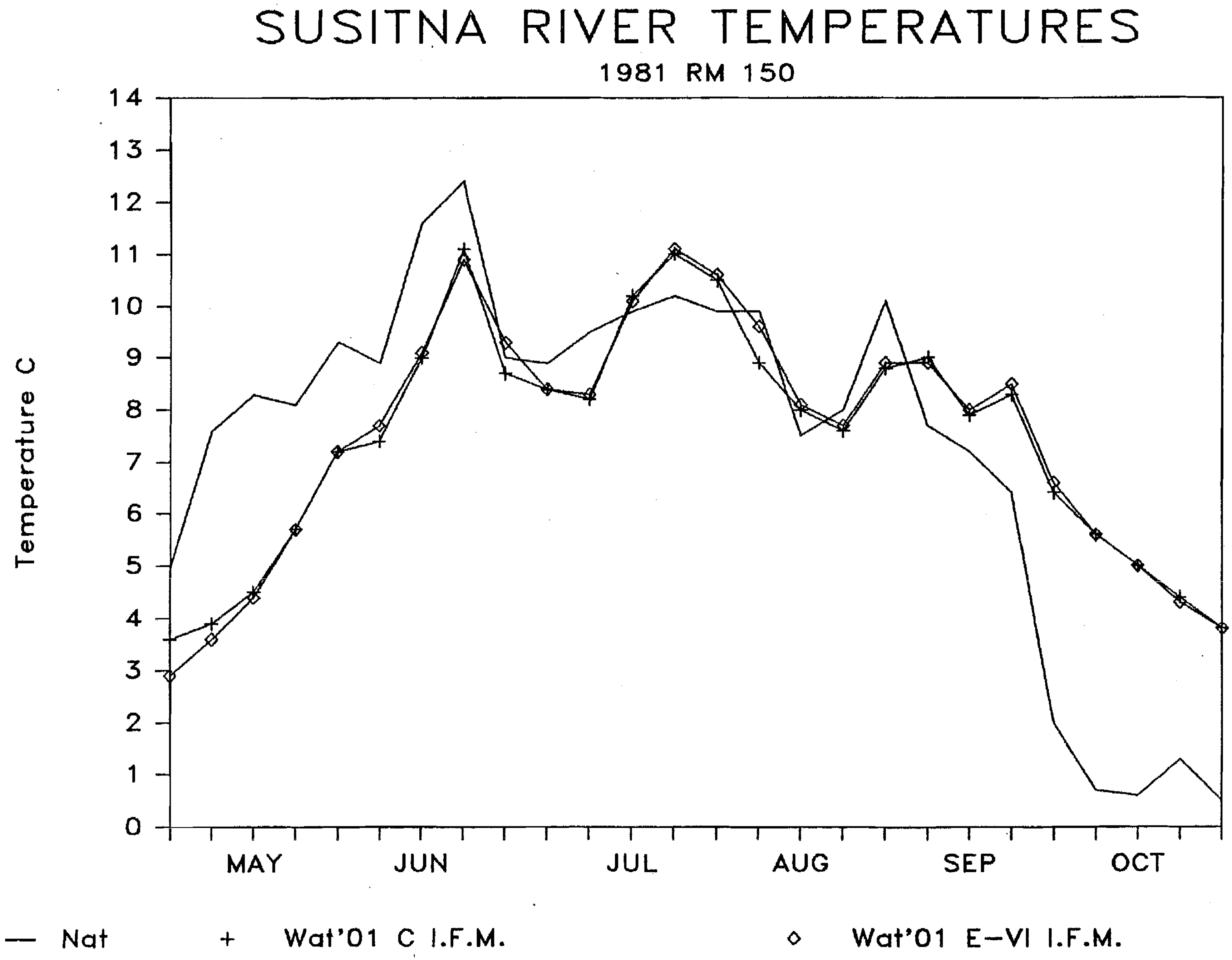
APPENDIX A. PART 2

Natural, Case C "inflow matching," and Case E-VI "inflow matching"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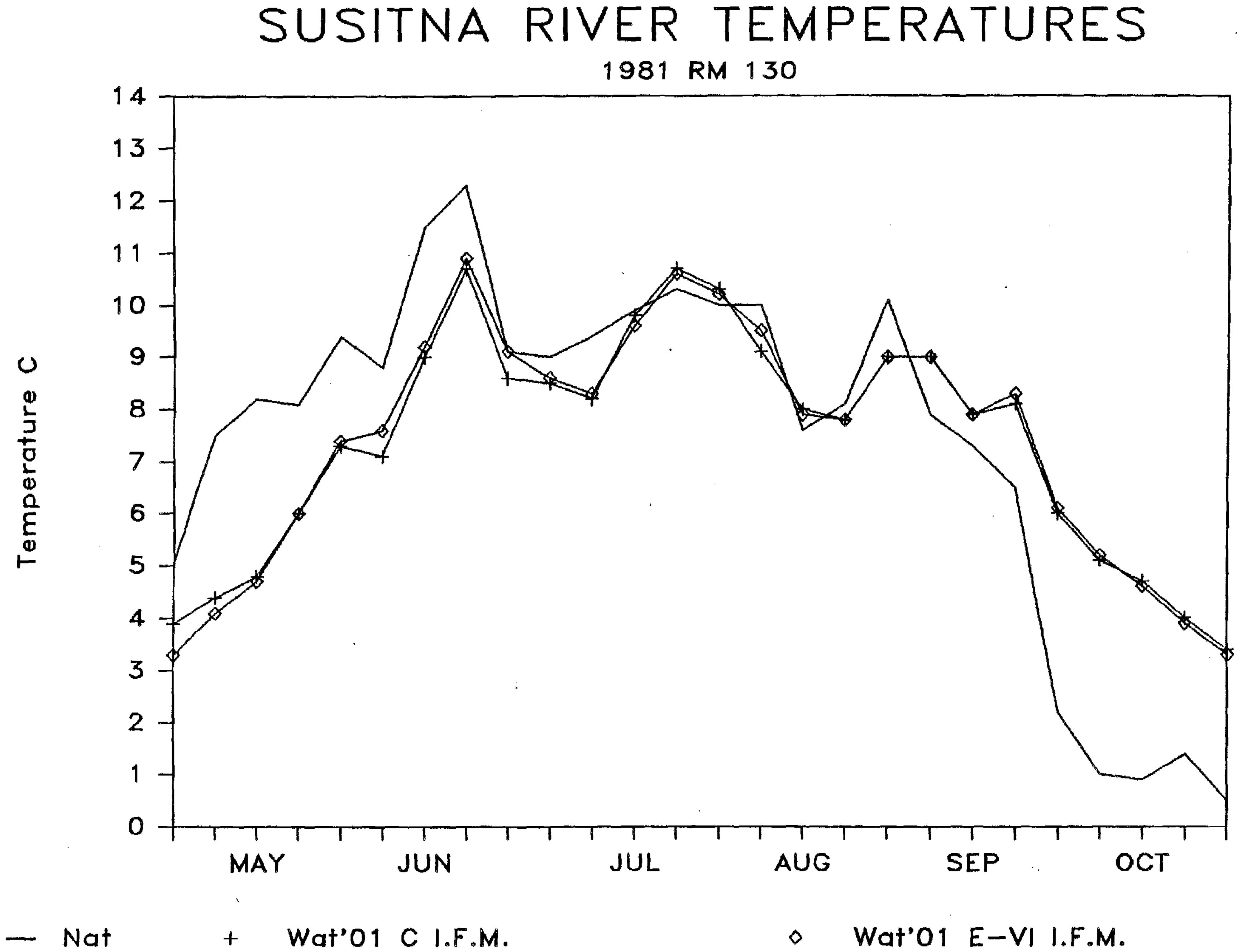
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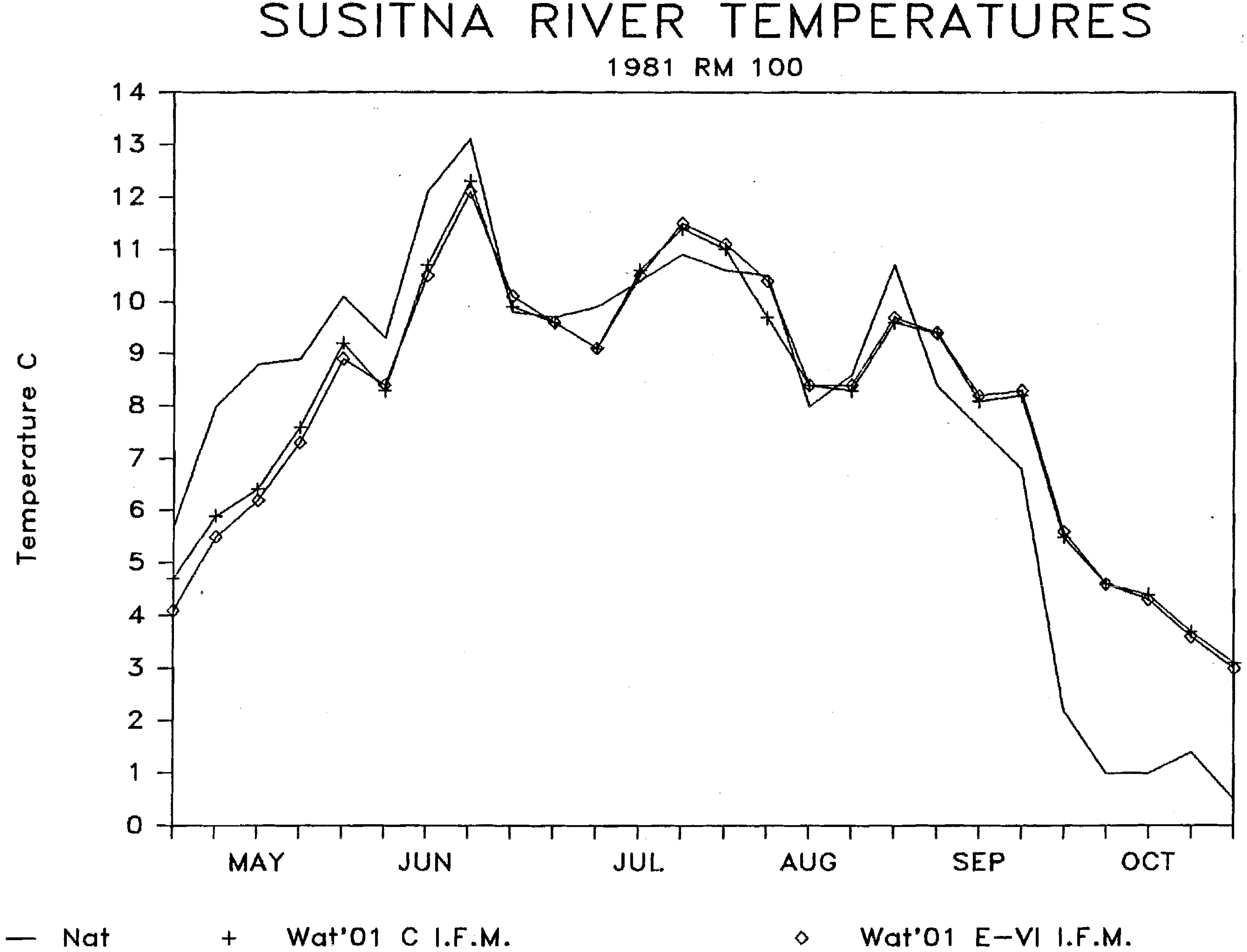

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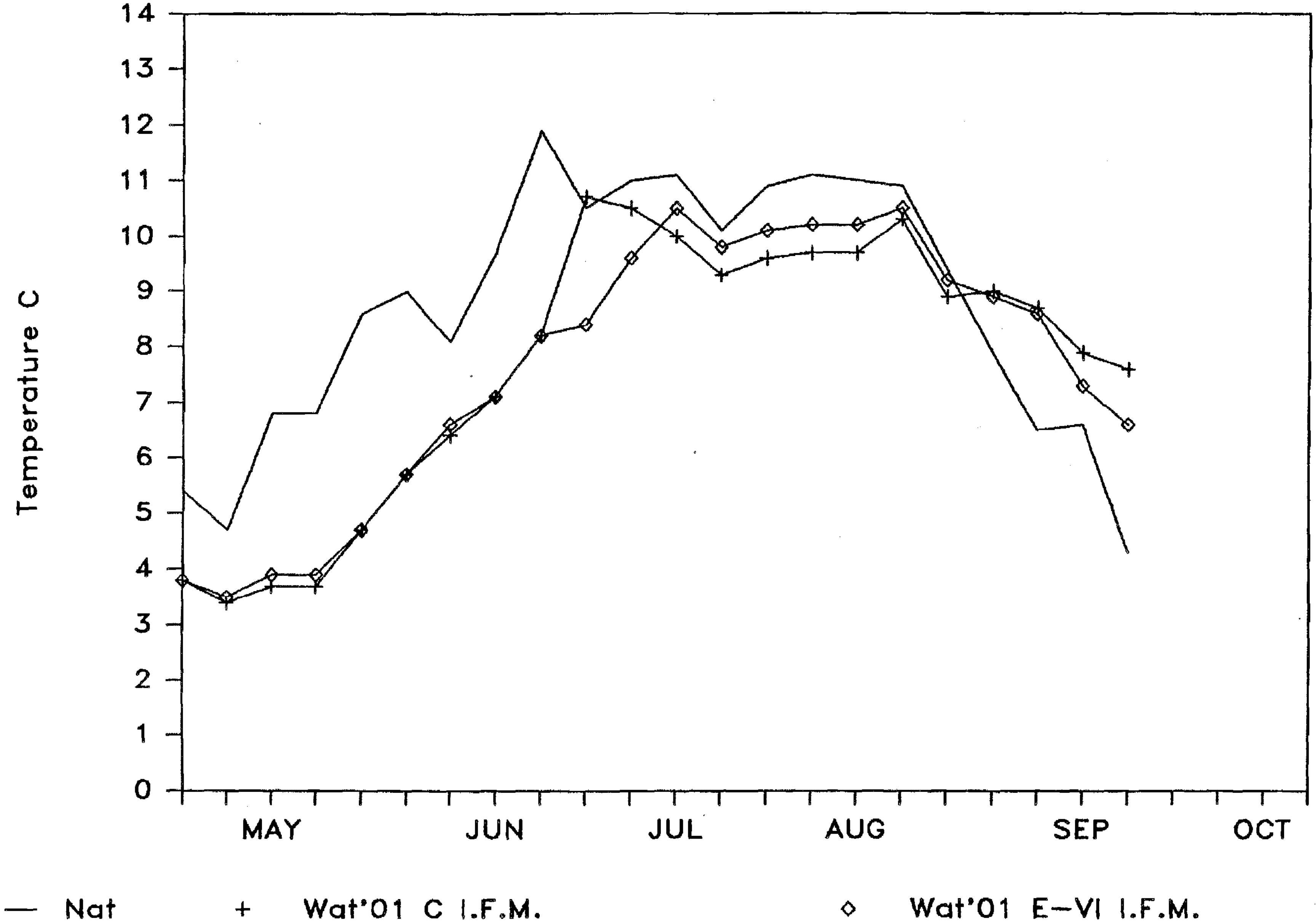
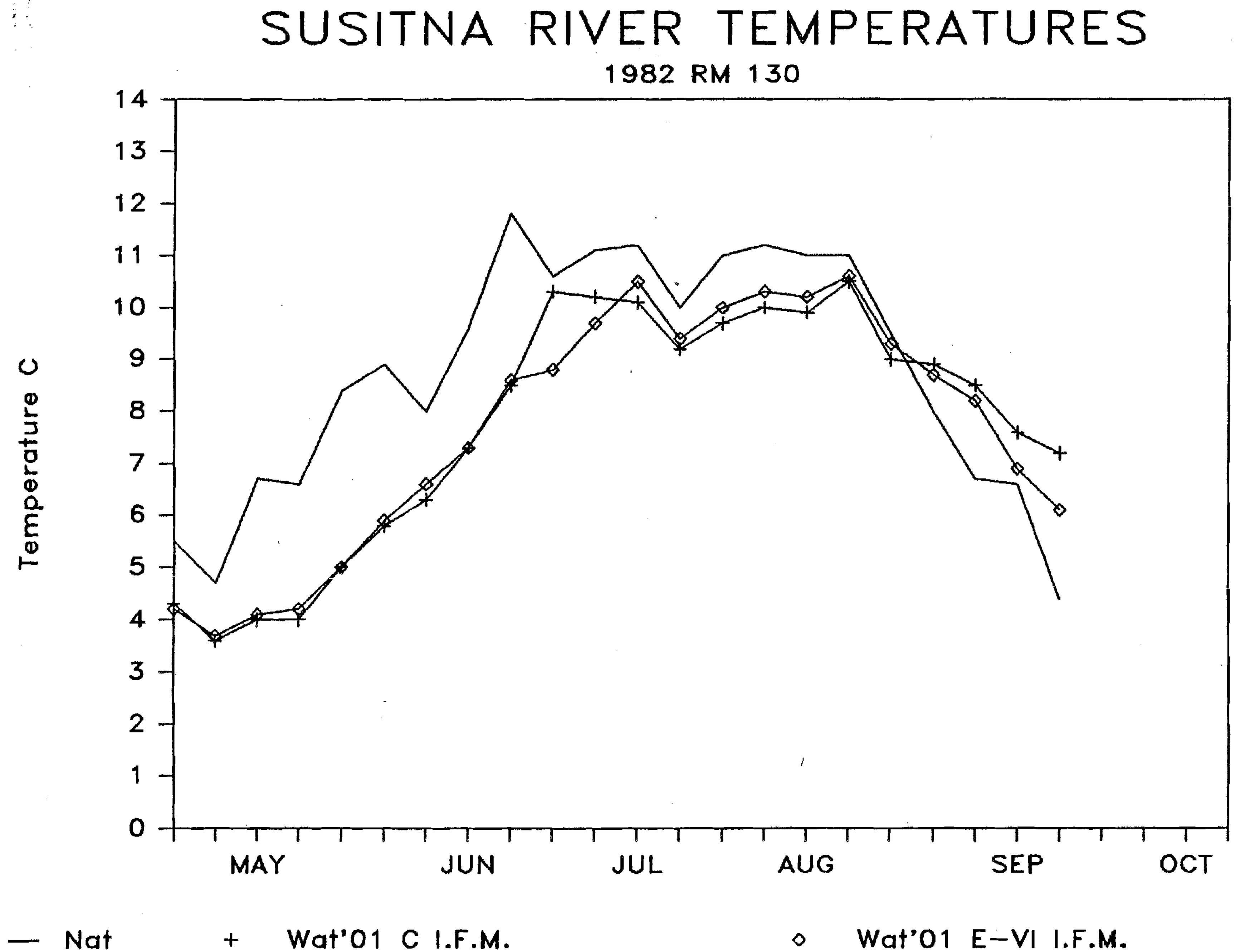
SUSITNA RIVER TEMPERATURES

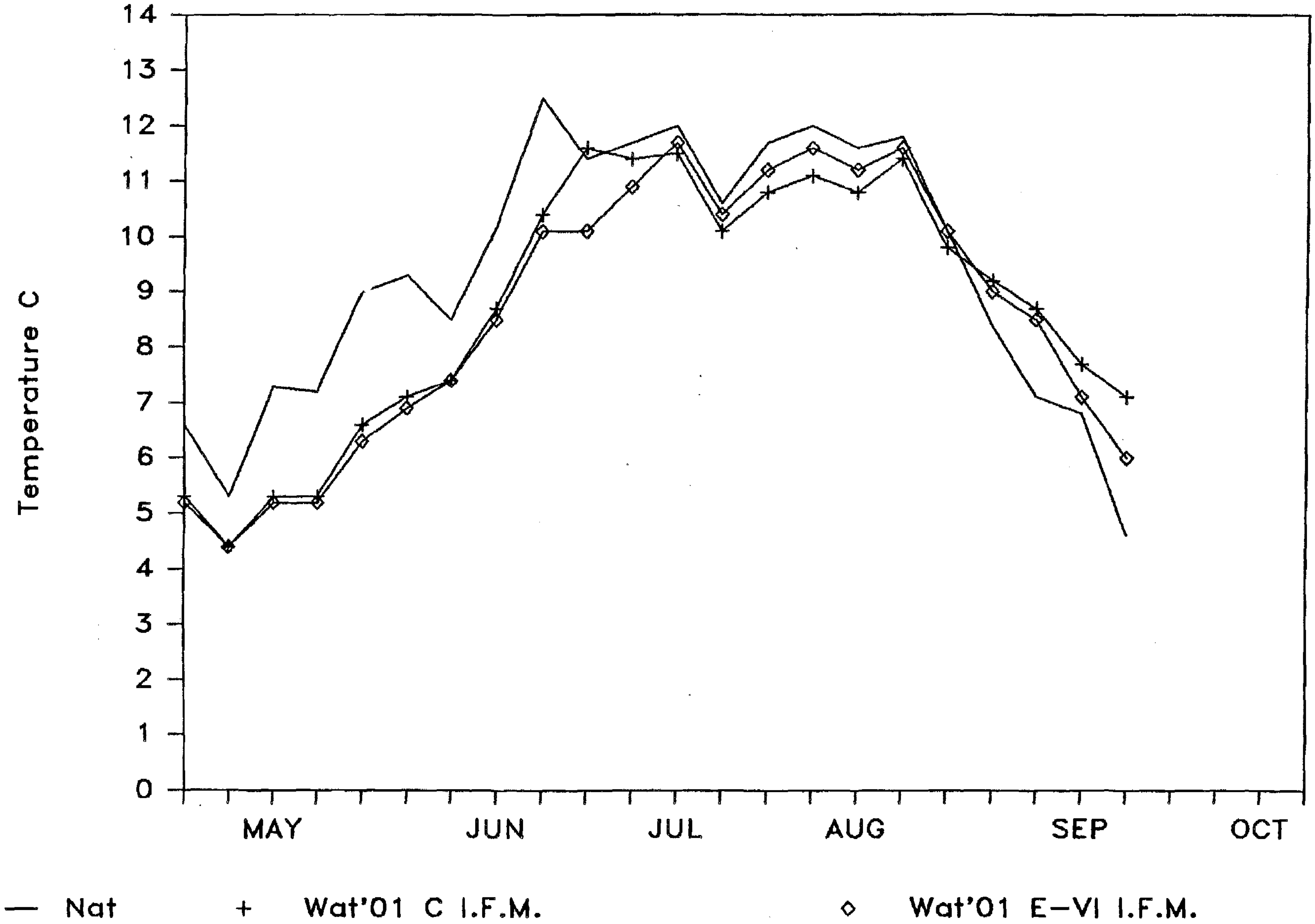
1982 RM 150

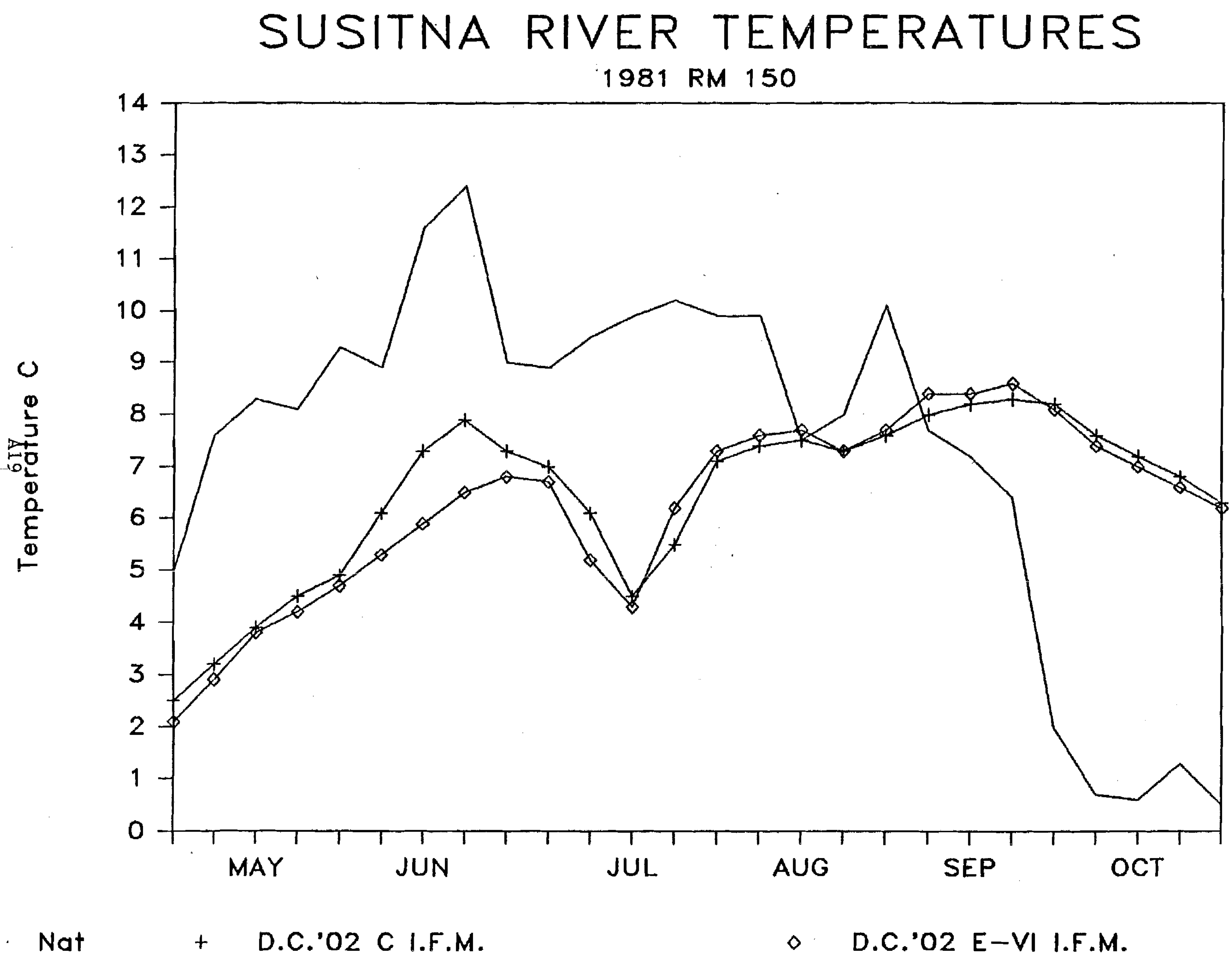



SUSITNA RIVER TEMPERATURES
1982 RM 130
Temperature C
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
MAY
JUN
JUL
AUG
SEP
OCT
— Nat
+ Wat'01 C I.F.M.
◇ Wat'01 E-VI I.F.M.

SUSITNA RIVER TEMPERATURES

1982 RM 100





SUSITNA RIVER TEMPERATURES
1981 RM 150
Temperature C
0
1
2
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4
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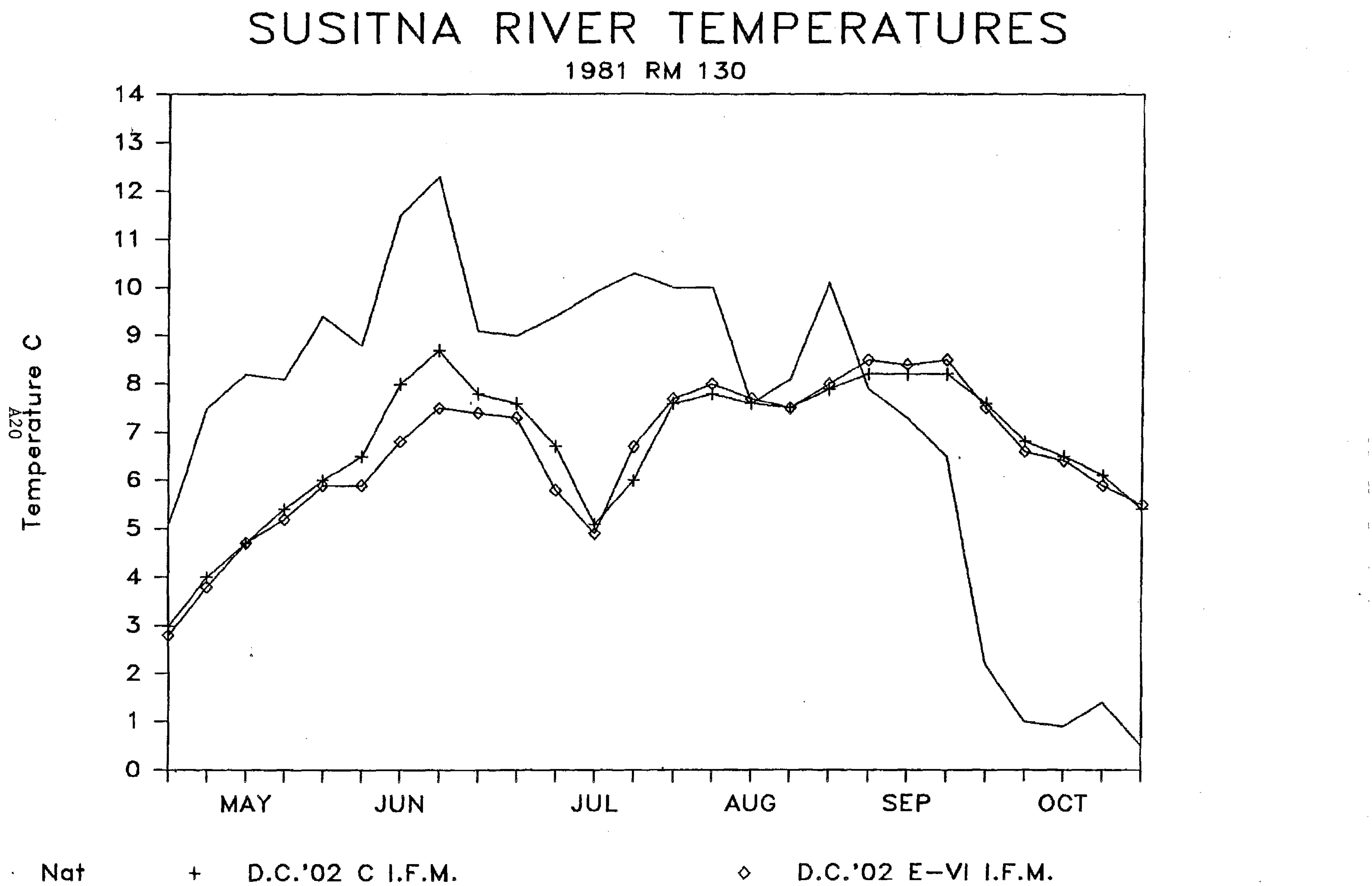
13
14
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ D.C.'02 C I.F.M.
◇ D.C.'02 E-VI I.F.M.

A19


SUSITNA RIVER TEMPERATURES
1981 RM 130
Temperature C
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MAY
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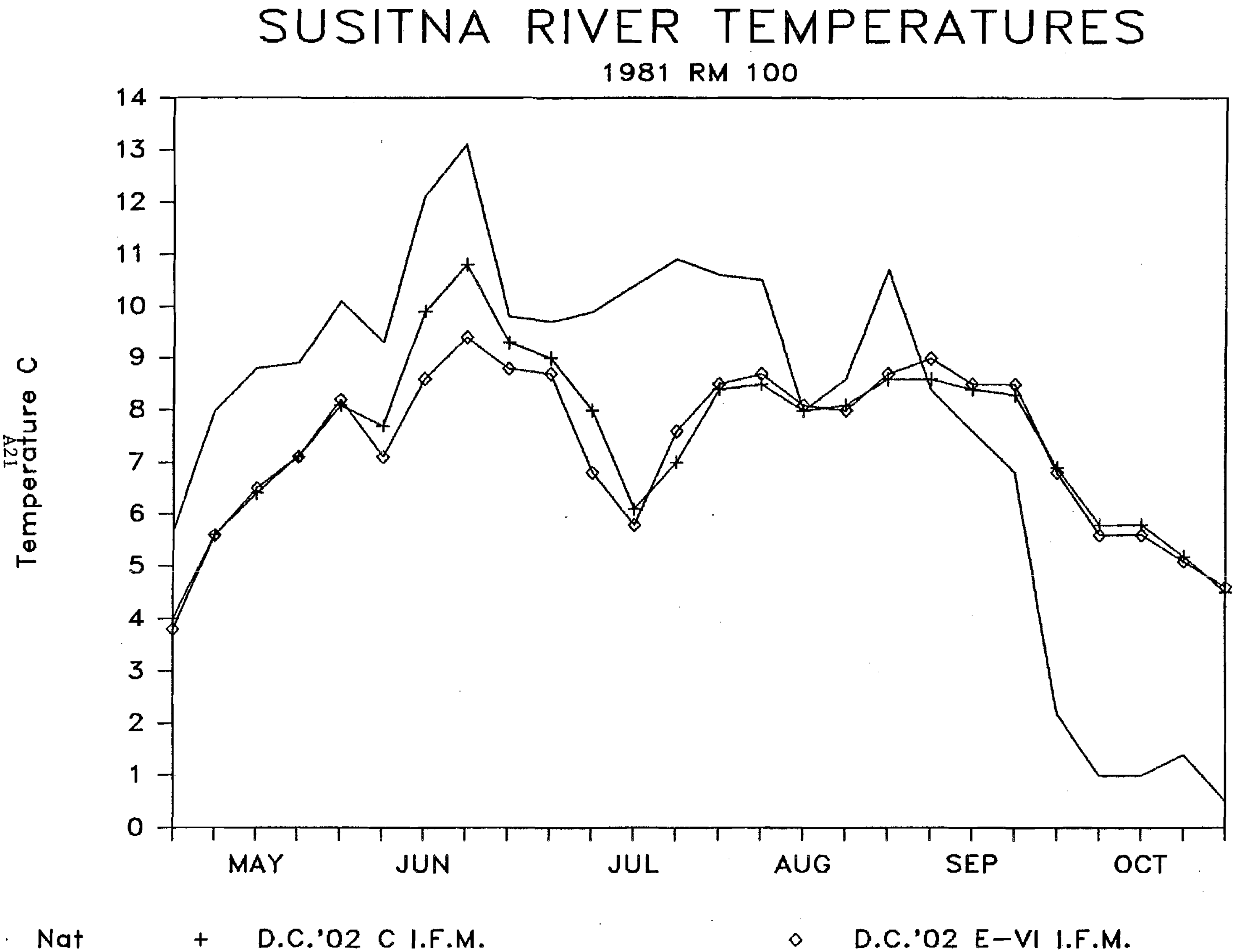
AUG
SEP
OCT
Nat
+ D.C.'02 C I.F.M.
◇ D.C.'02 E-VI I.F.M.



SUSITNA RIVER TEMPERATURES
1981 RM 100
Temperature C
0
1
2
3
4
5
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7
8
9
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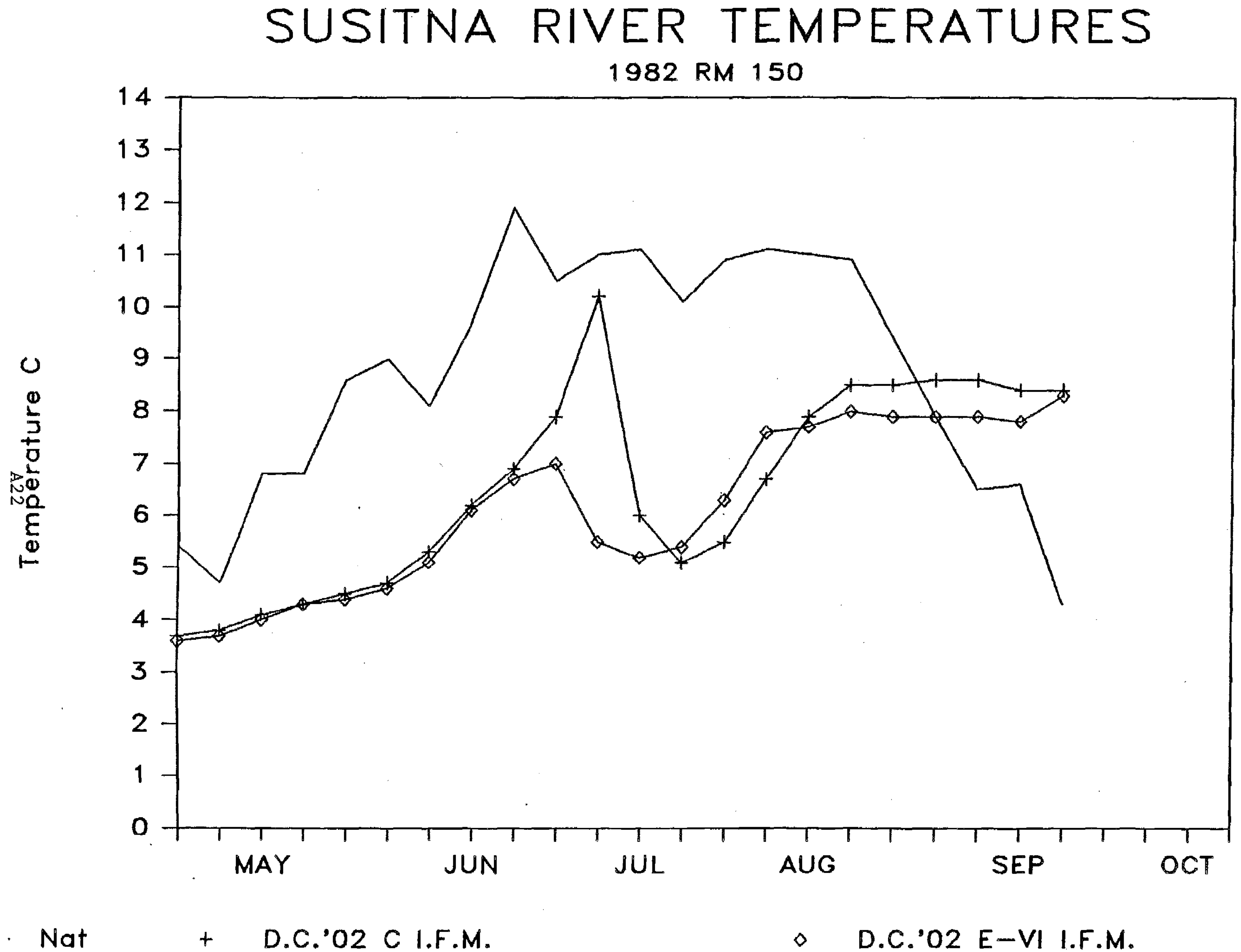
11
12
13
14
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ D.C.'02 C I.F.M.
◇ D.C.'02 E-VI I.F.M.

A21


SUSITNA RIVER TEMPERATURES
1982 RM 150
Temperature C
14
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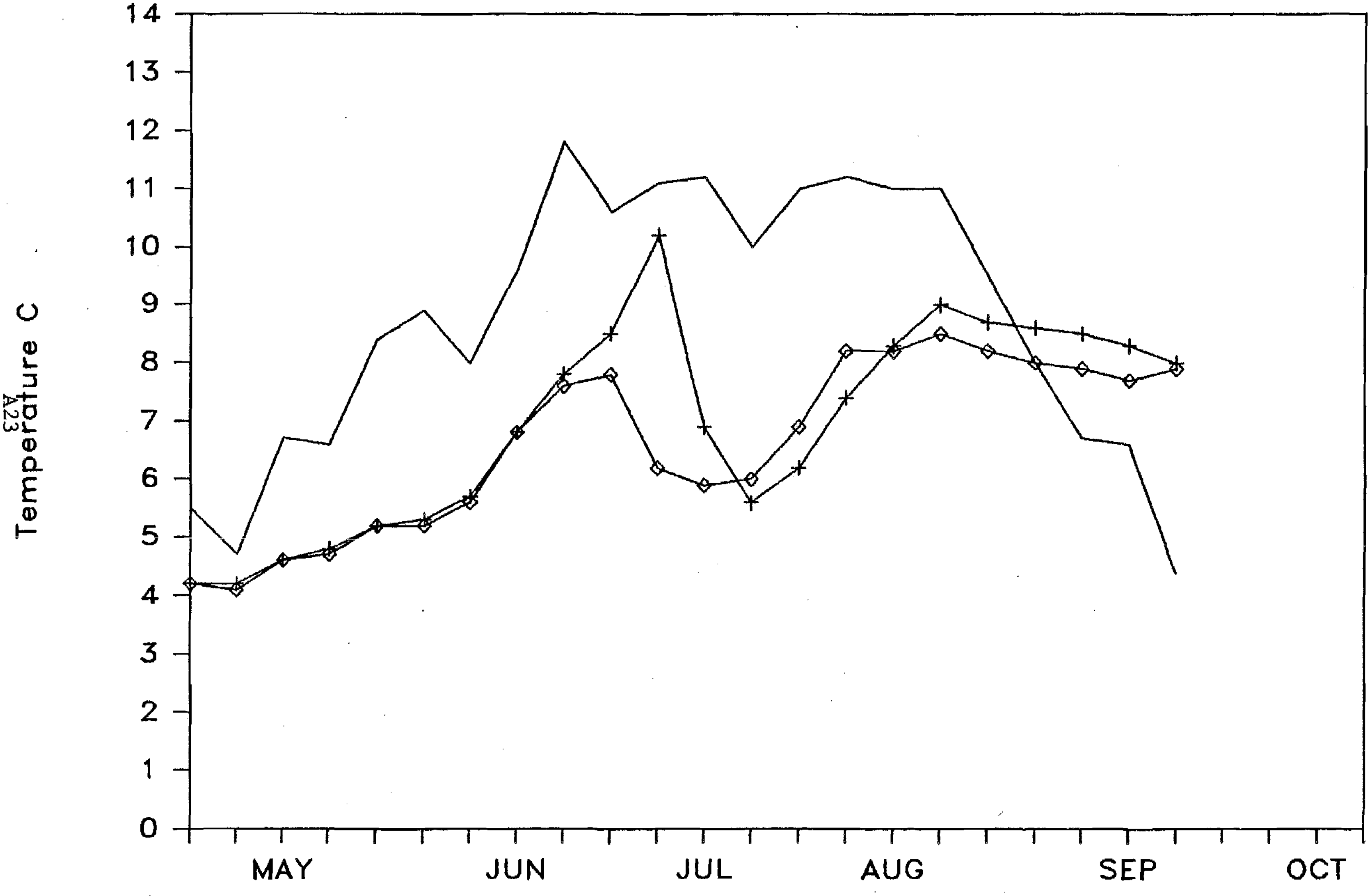
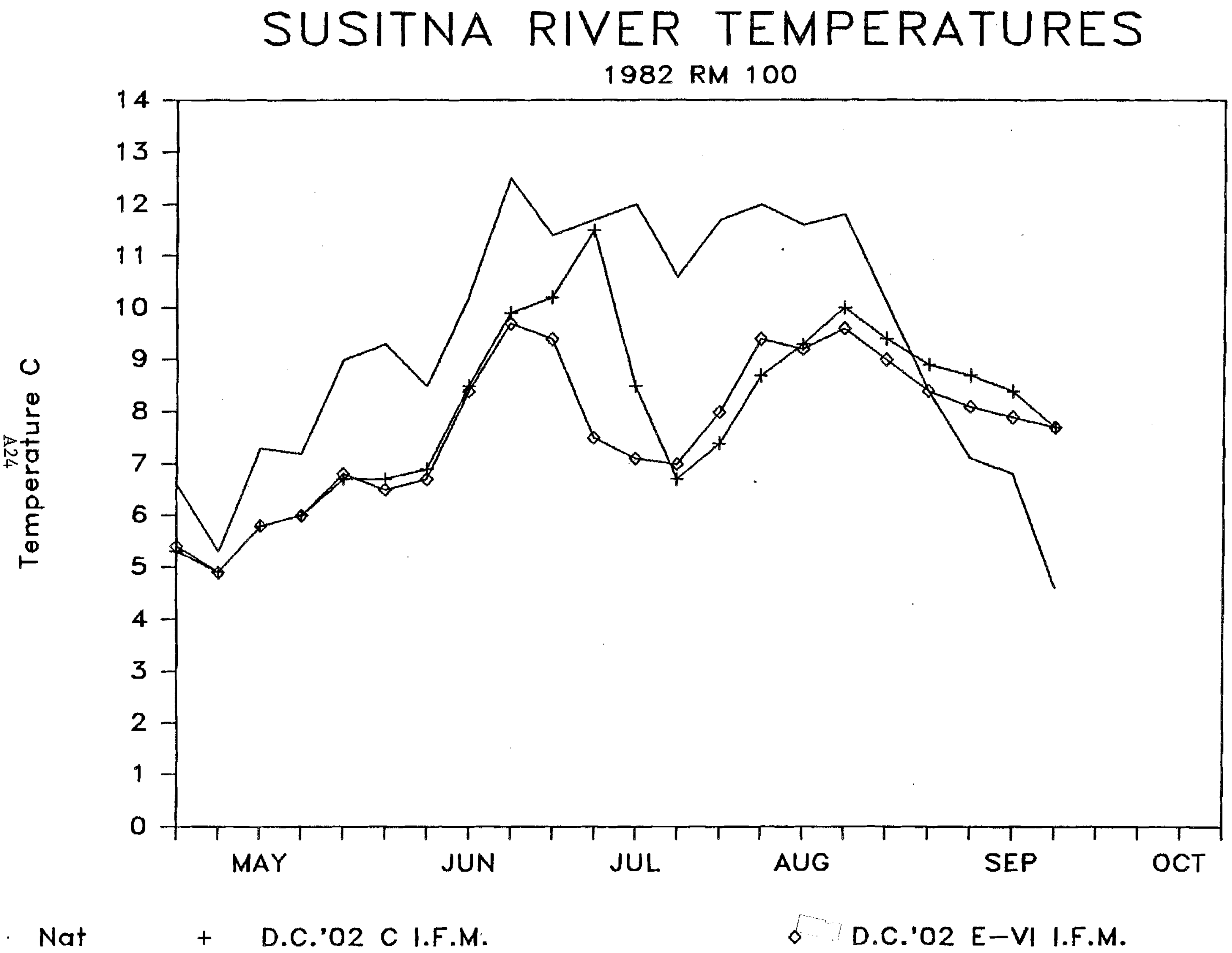
0
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ D.C.'02 C I.F.M.
◇ D.C.'02 E–VI I.F.M.

SUSITNA RIVER TEMPERATURES

1982 RM 130



Nat + D.C.'02 C I.F.M. ◇ D.C.'02 E-VI I.F.M.


SUSITNA RIVER TEMPERATURES
1982 RM 100
Temperature C
14
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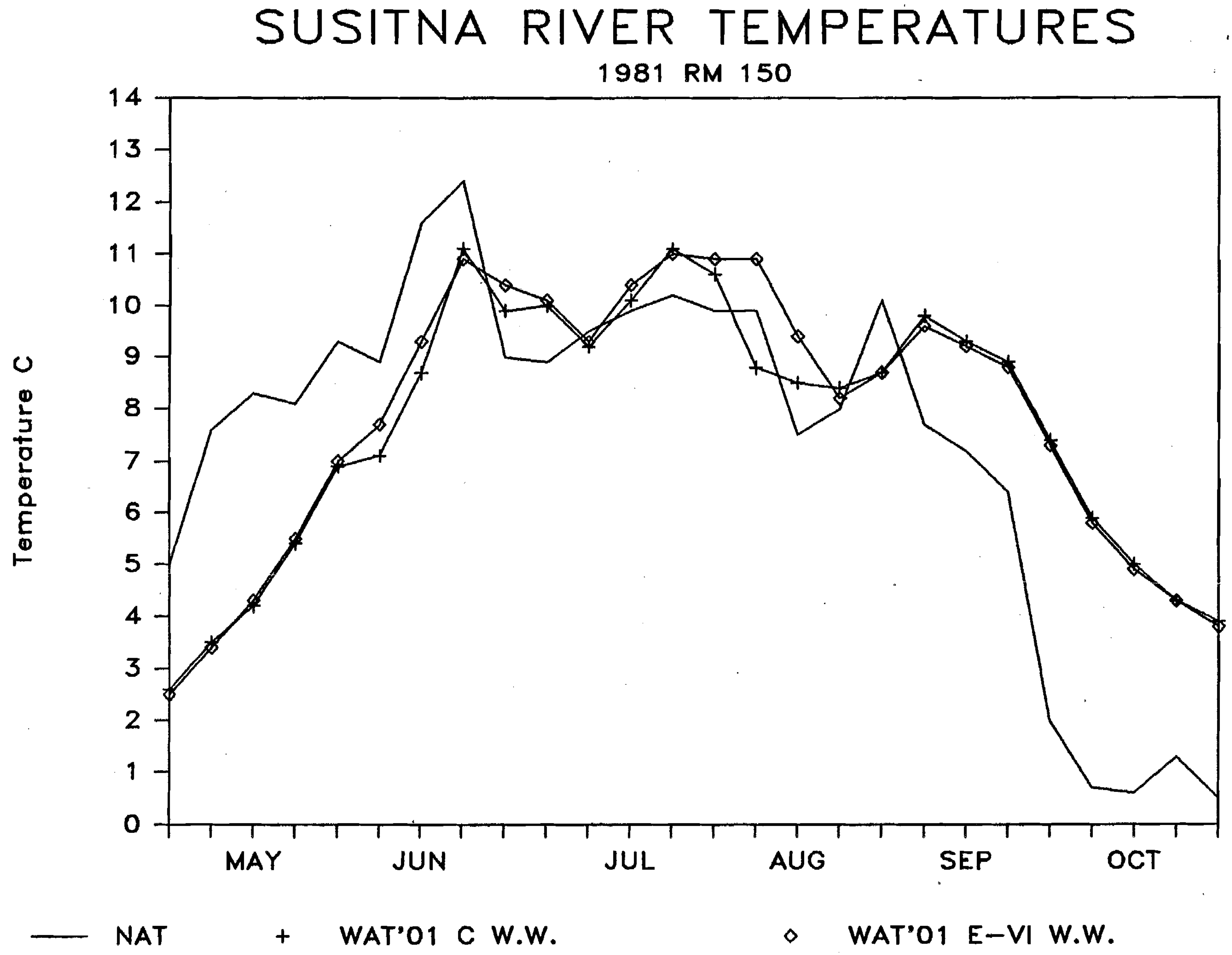
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ D.C.'02 C I.F.M.
◇ D.C.'02 E-VI I.F.M.

APPENDIX A. PART 3

Natural, Case C "warmest Water," and Case E-VI "warmest water"


SUSITNA RIVER TEMPERATURES
1981 RM 150
Temperature C
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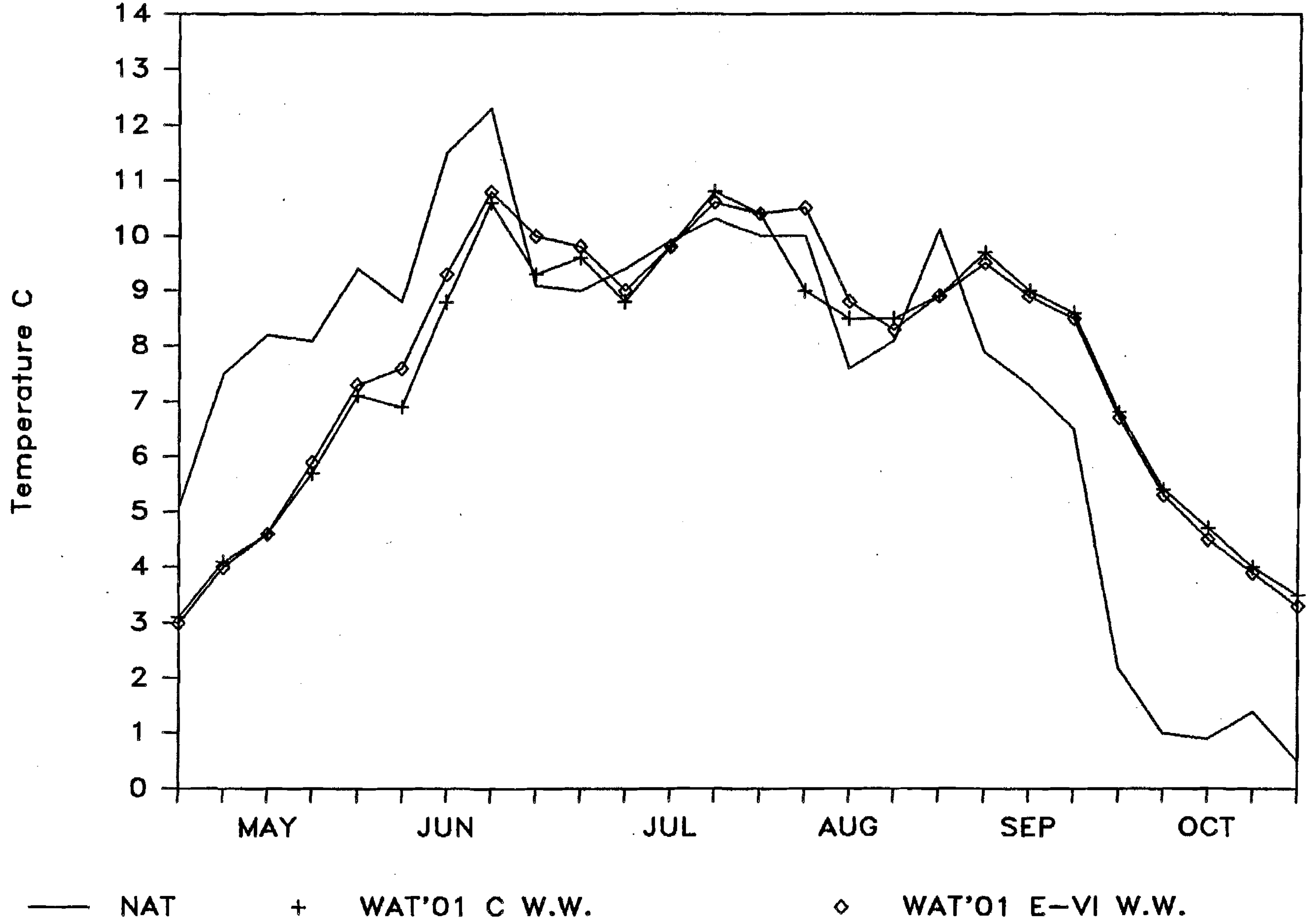
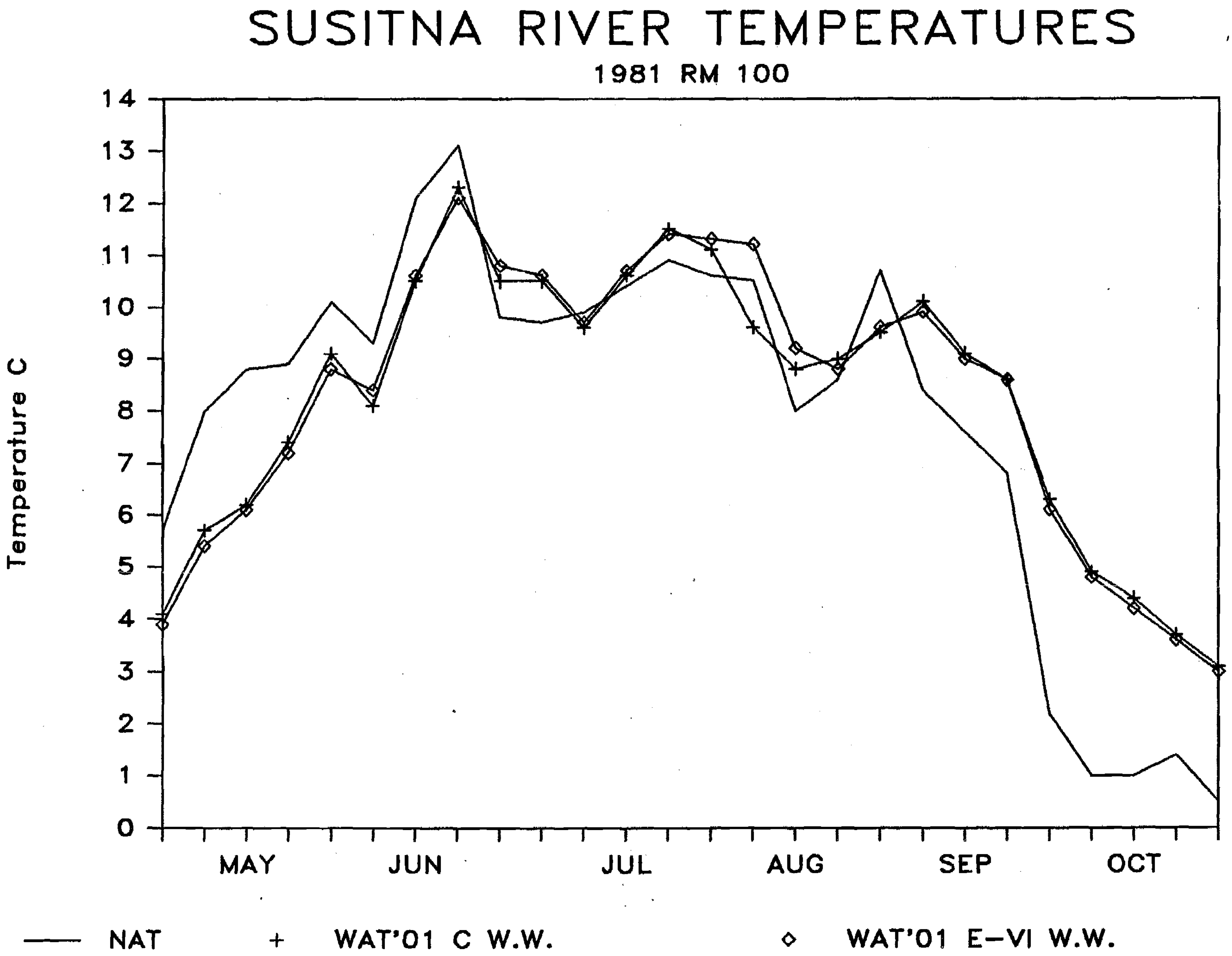
14
MAY
JUN
JUL
AUG
SEP
OCT
NAT
+ WAT'01 C W.W.
◇ WAT'01 E-VI W.W.

SUSITNA RIVER TEMPERATURES

1981 RM 130




SUSITNA RIVER TEMPERATURES
1981 RM 100
Temperature C
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4
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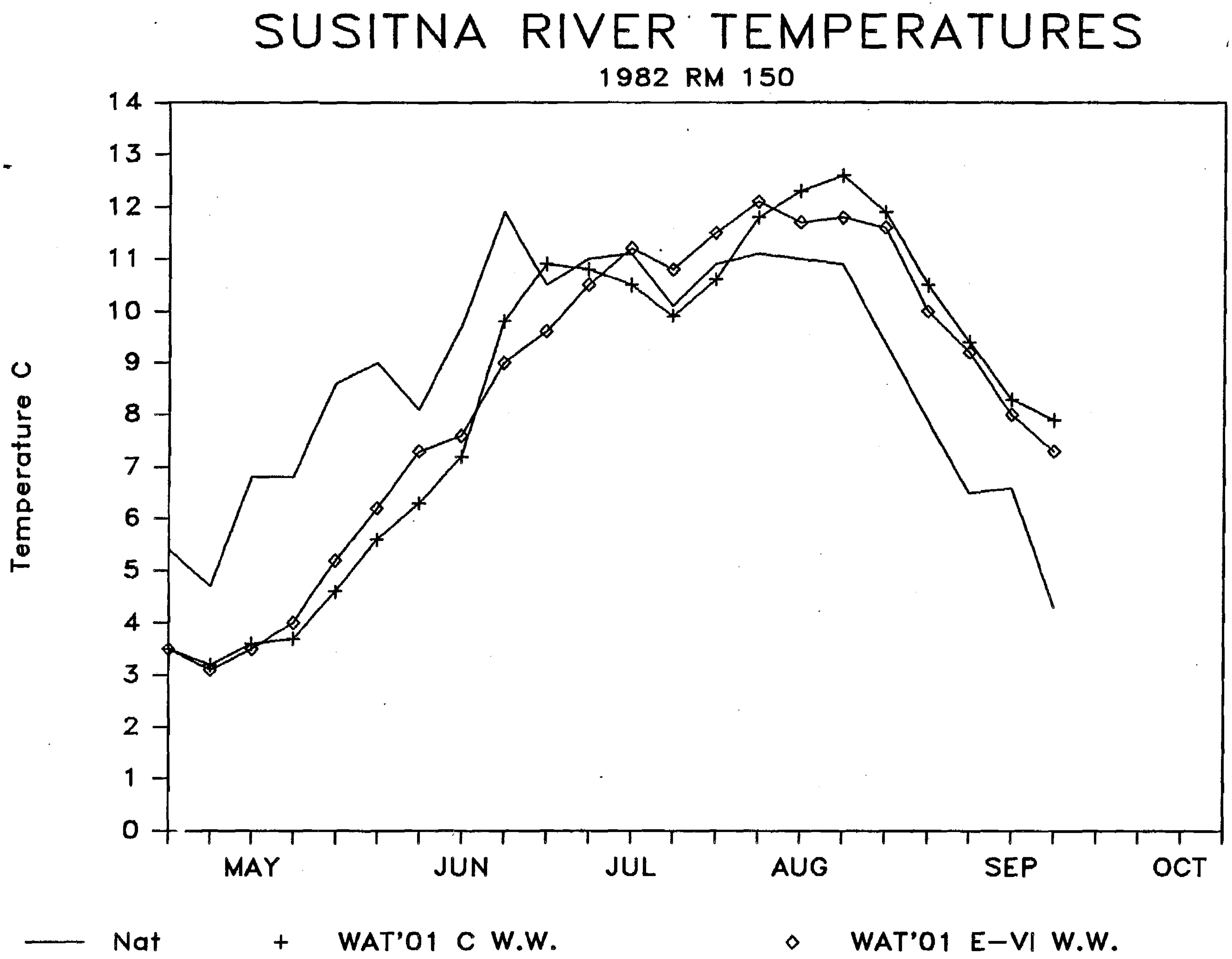
MAY
JUN
JUL
AUG
SEP
OCT
NAT
WAT'01 C W.W.
WAT'01 E-VI W.W.



SUSITNA RIVER TEMPERATURES
1982 RM 150
Temperature C
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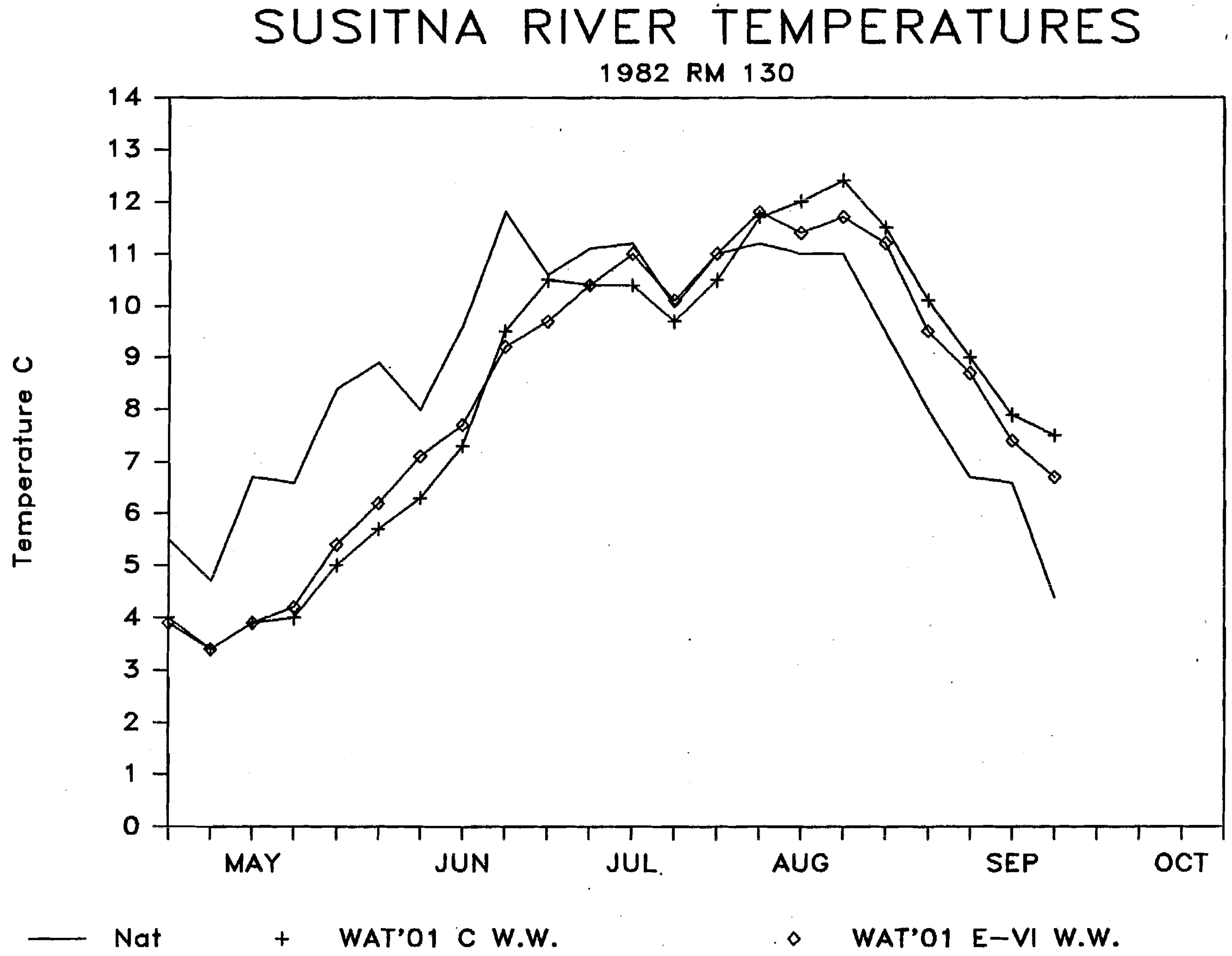
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ WAT'01 C W.W.
◇ WAT'01 E–VI W.W.



SUSITNA RIVER TEMPERATURES
1982 RM 130
Temperature C
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11
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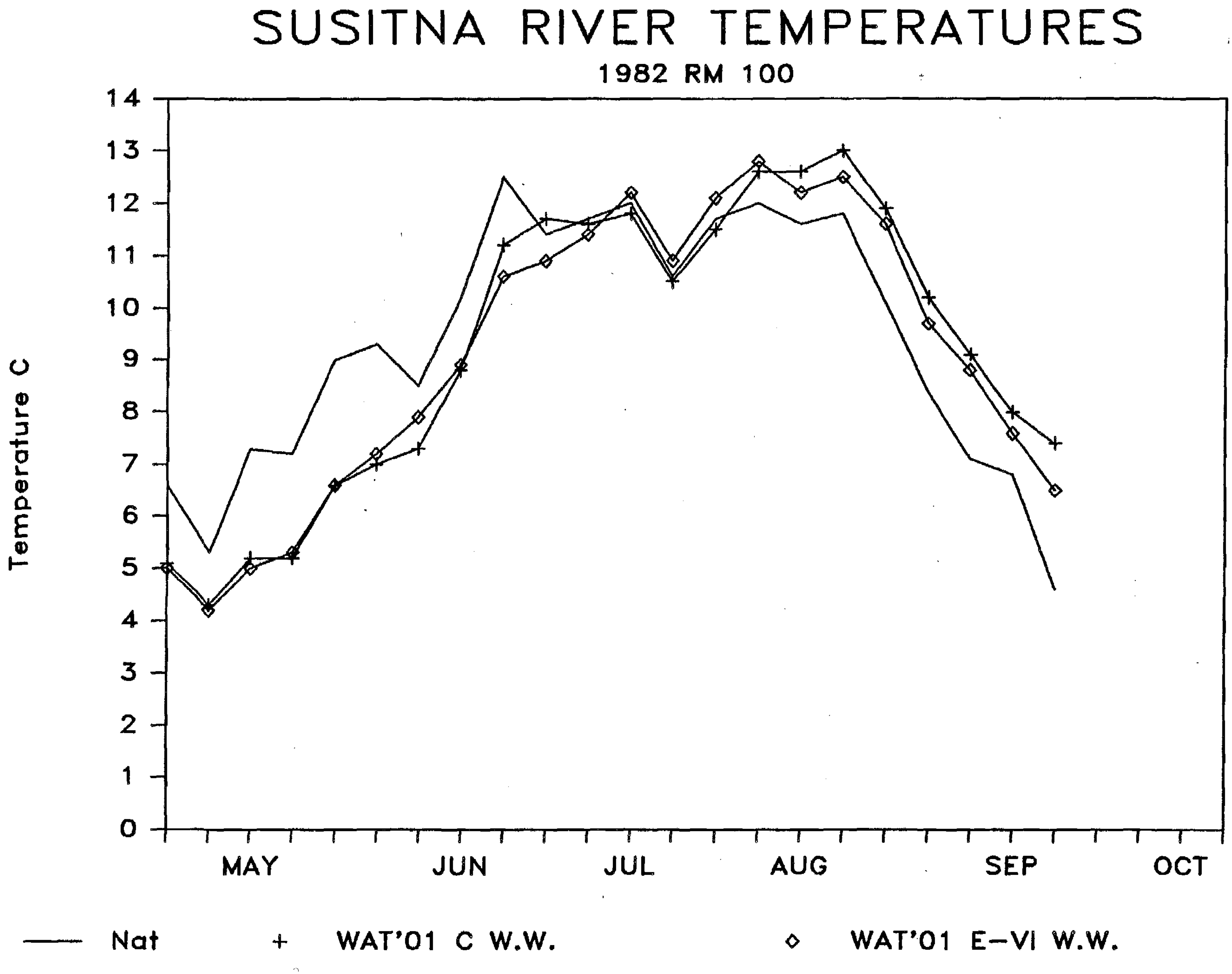
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ WAT'01 C W.W.
◇ WAT'01 E–VI W.W.


SUSITNA RIVER TEMPERATURES
1982 RM 100
Temperature C
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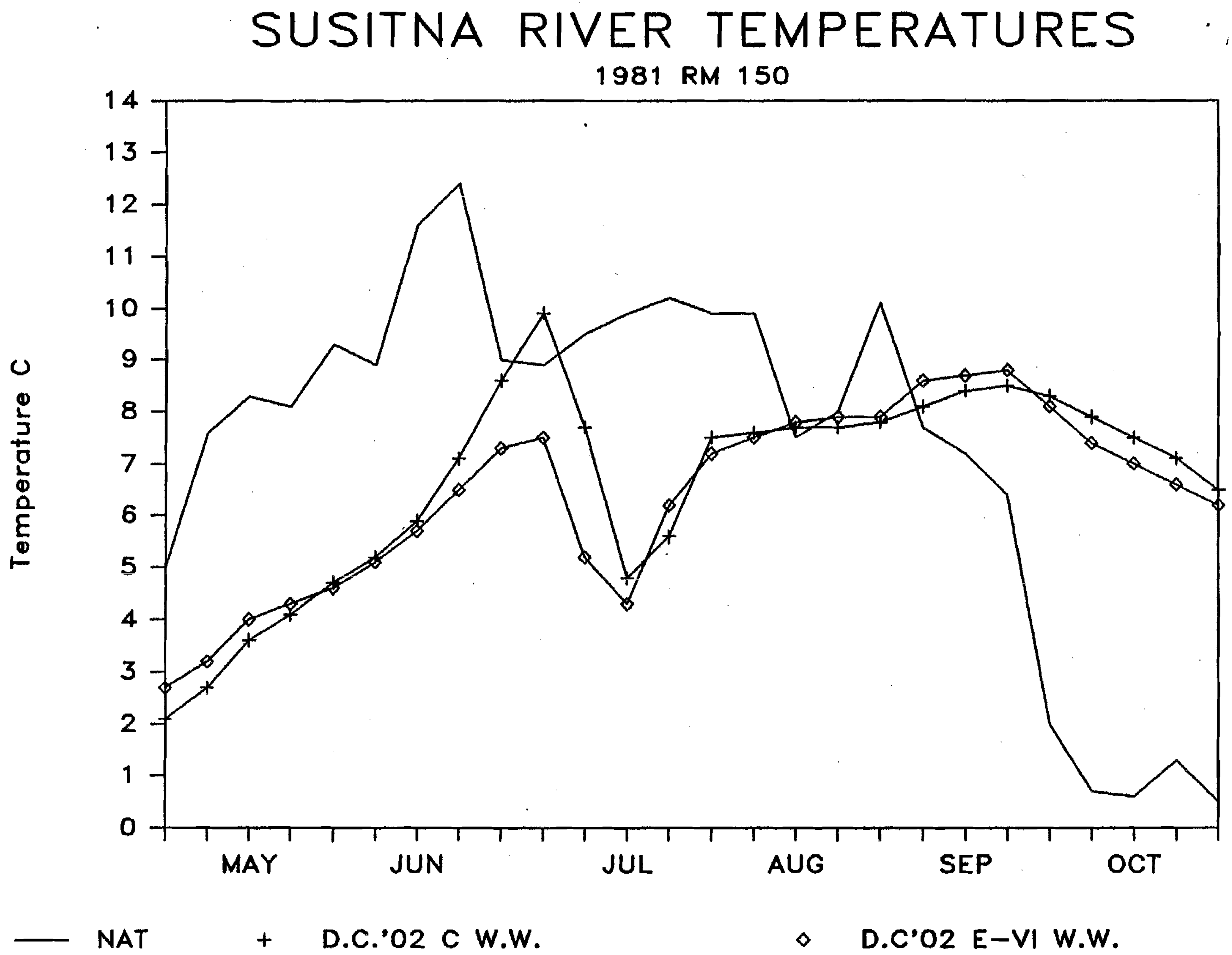
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ WAT'01 C W.W.
◇ WAT'01 E-VI W.W.

A30


SUSITNA RIVER TEMPERATURES
1981 RM 150
Temperature C
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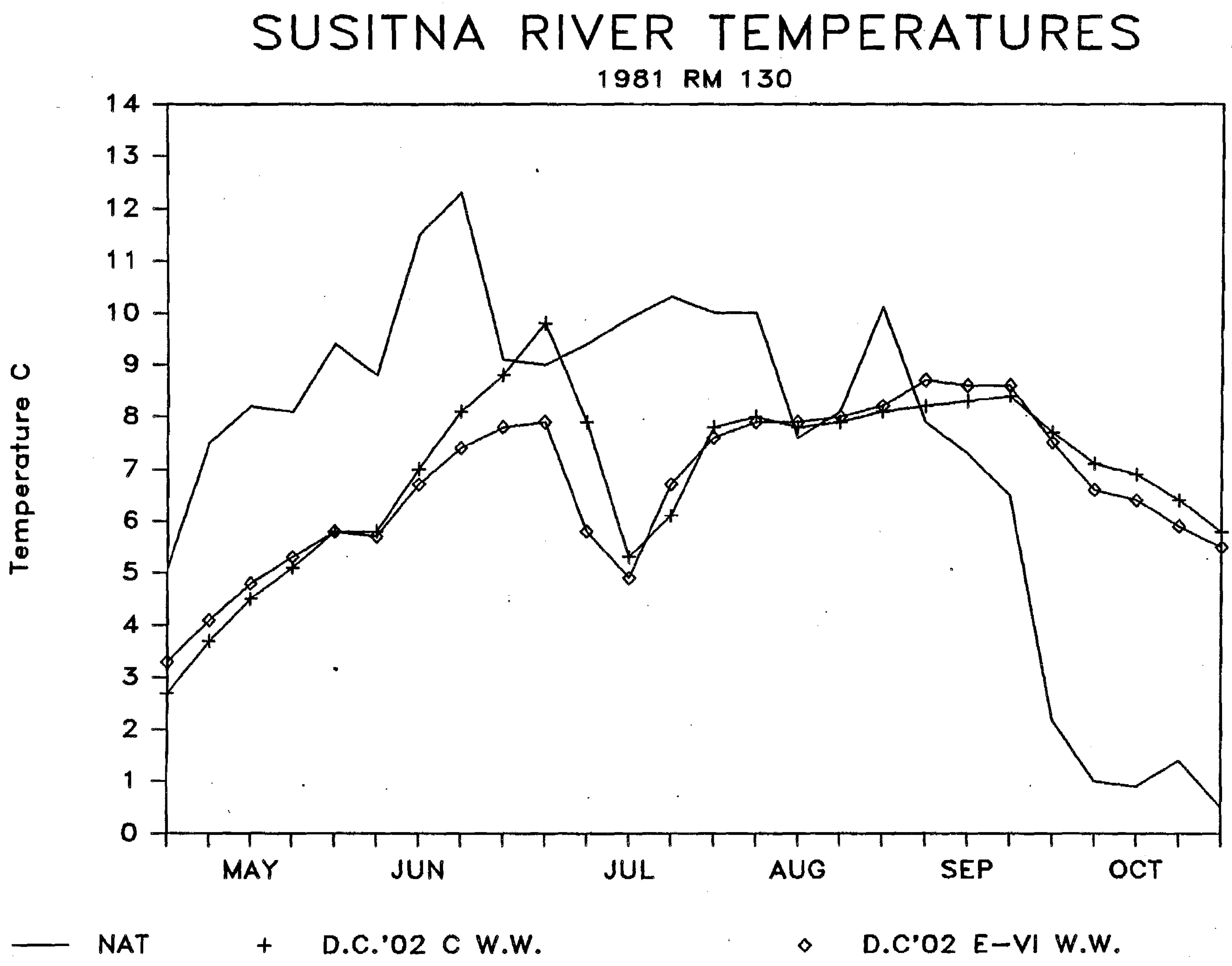
MAY
JUN
JUL
AUG
SEP
OCT
NAT
+ D.C.'02 C W.W.
◇ D.C'02 E-VI W.W.


SUSITNA RIVER TEMPERATURES
1981 RM 130
Temperature C
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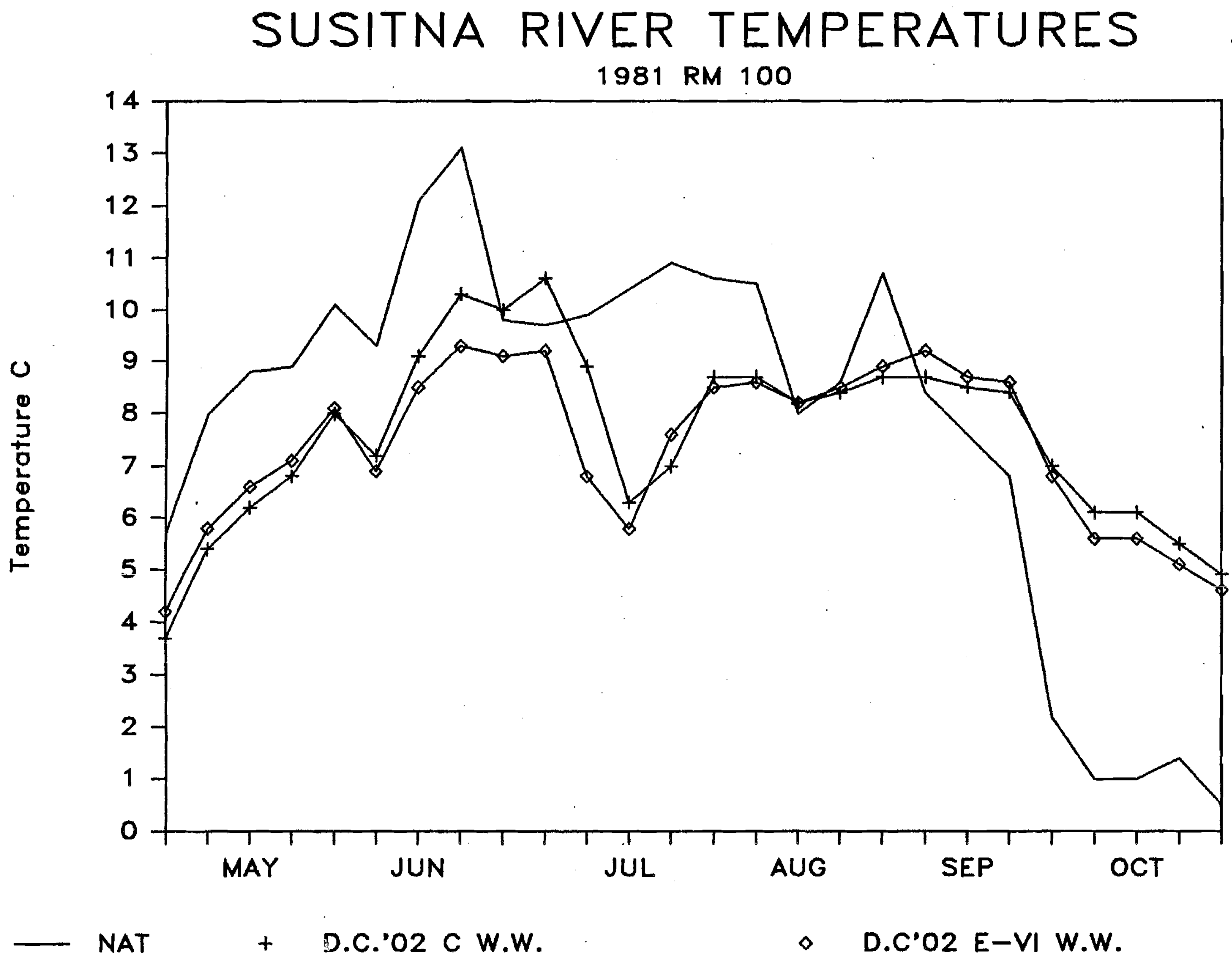
MAY
JUN
JUL
AUG
SEP
OCT
NAT
+ D.C.'02 C W.W.
◇ D.C'02 E-VI W.W.


SUSITNA RIVER TEMPERATURES
1981 RM 100
Temperature C
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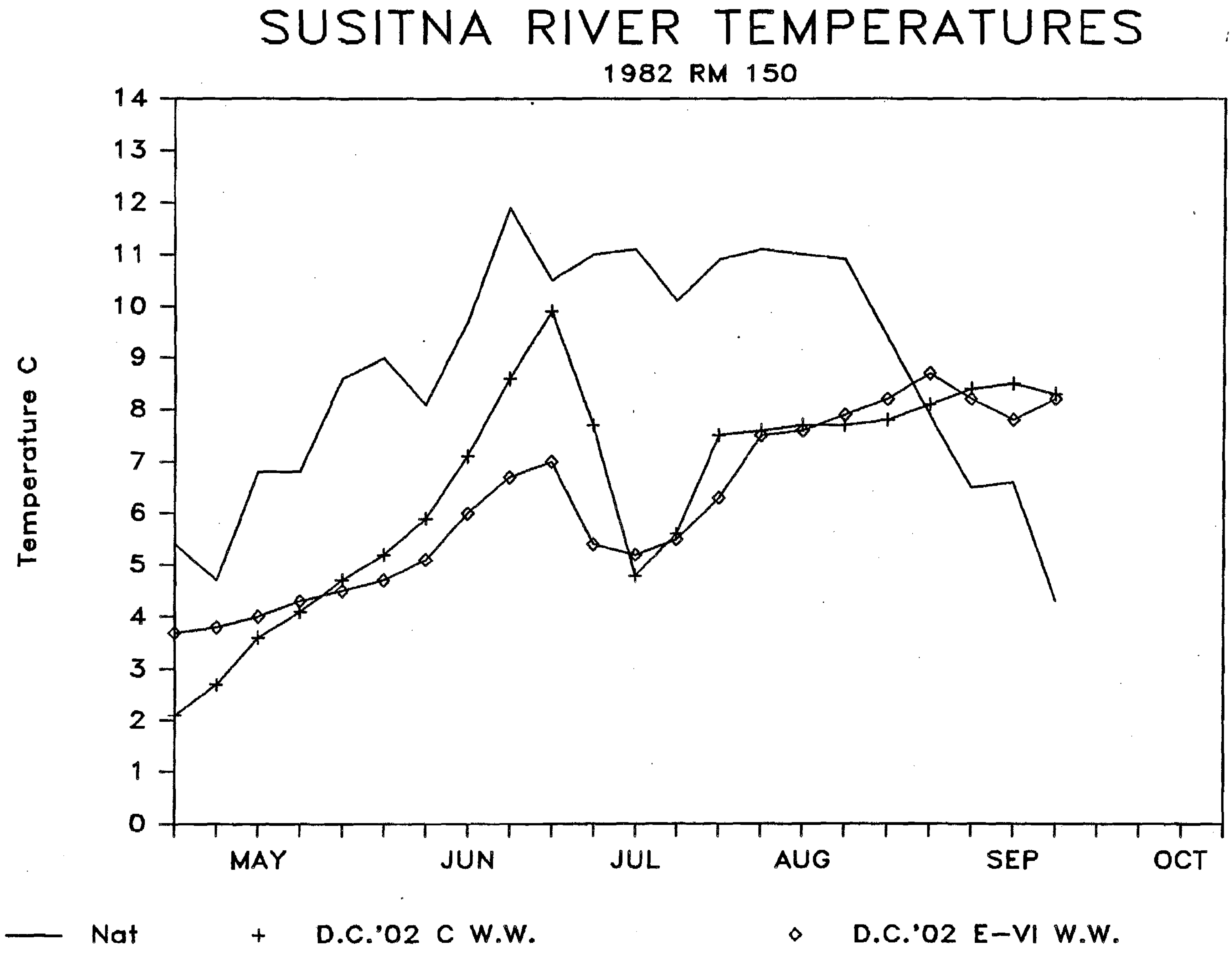
MAY
JUN
JUL
AUG
SEP
OCT
NAT
D.C.'02 C W.W.
D.C'02 E-VI W.W.


SUSITNA RIVER TEMPERATURES
1982 RM 150
Temperature C
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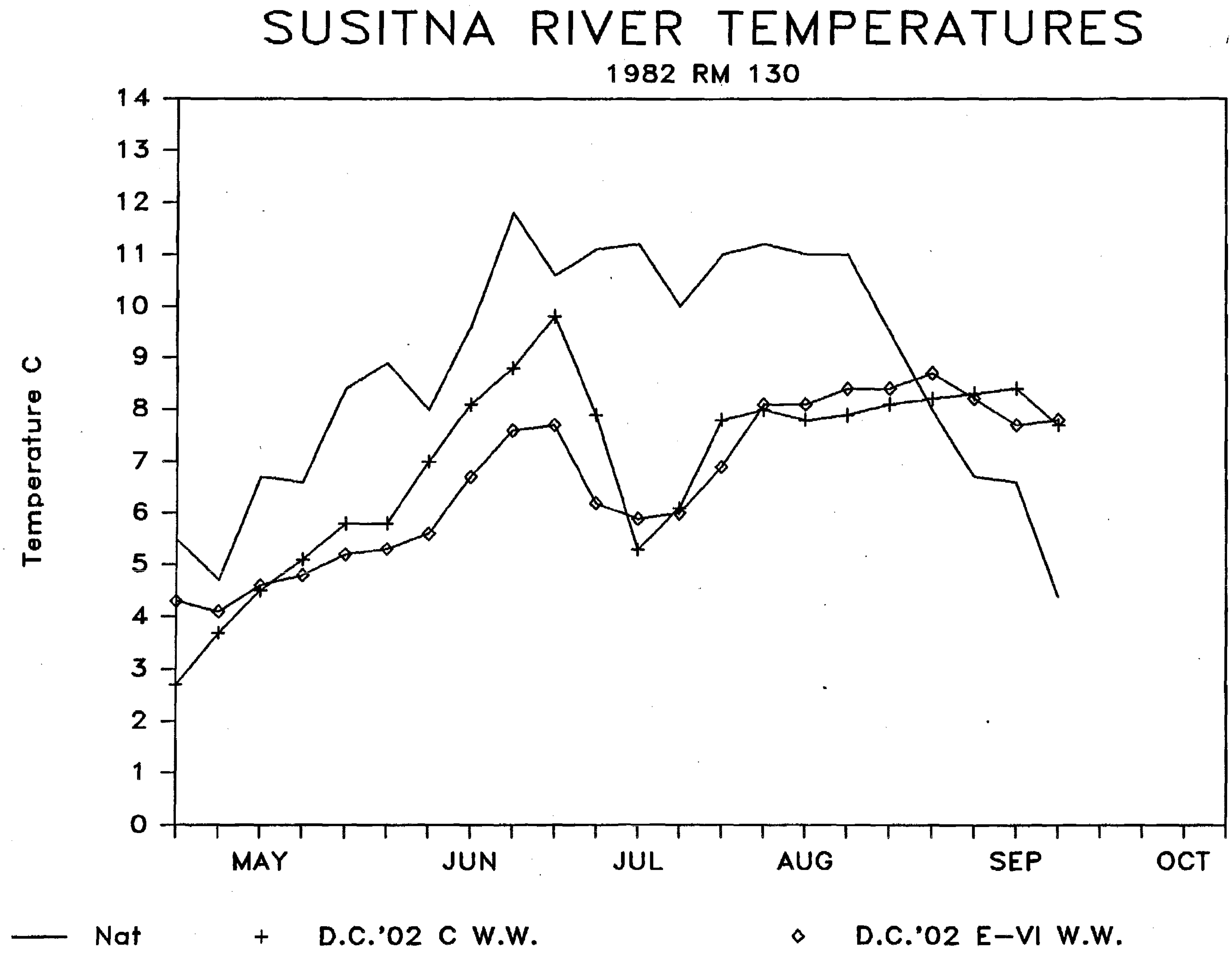
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ D.C.'02 C W.W.
◇ D.C.'02 E–VI W.W.


SUSITNA RIVER TEMPERATURES
1982 RM 130
Temperature C
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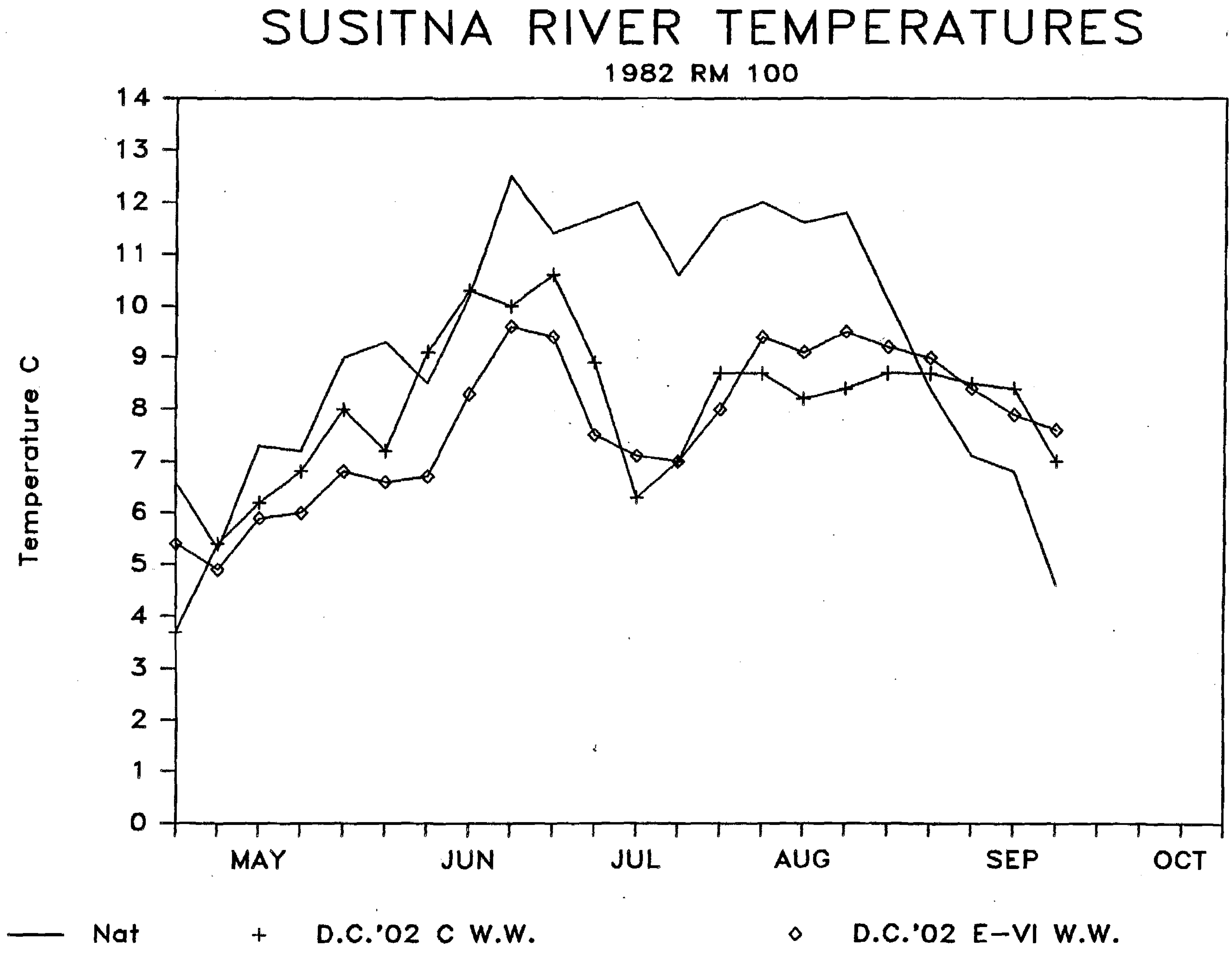
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ D.C.'02 C W.W.
◇ D.C.'02 E-VI W.W.


SUSITNA RIVER TEMPERATURES
1982 RM 100
Temperature C
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12
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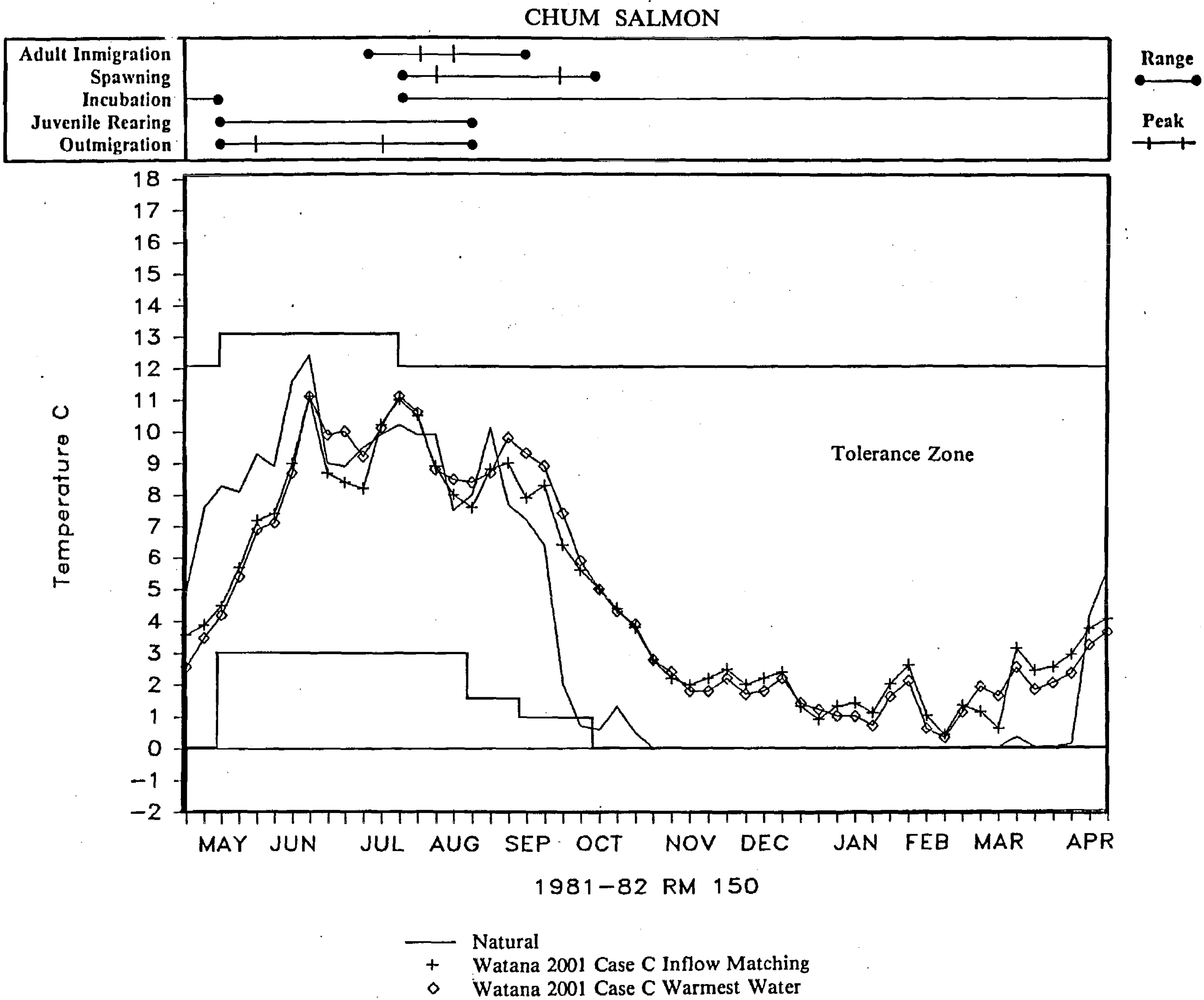
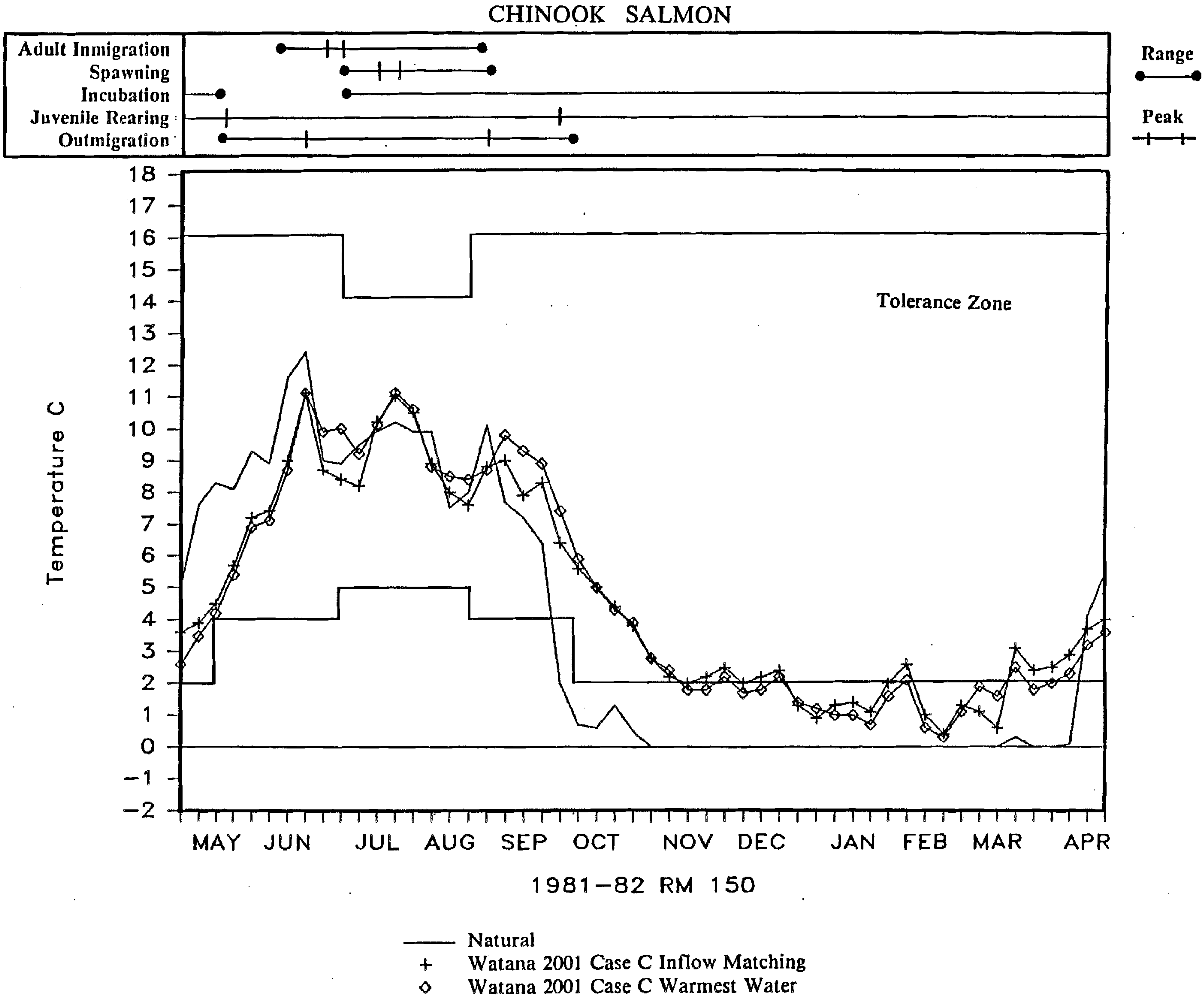
14
MAY
JUN
JUL
AUG
SEP
OCT
Nat
+ D.C.'02 C W.W.
◇ D.C.'02 E-VI W.W.

APPENDIX B.

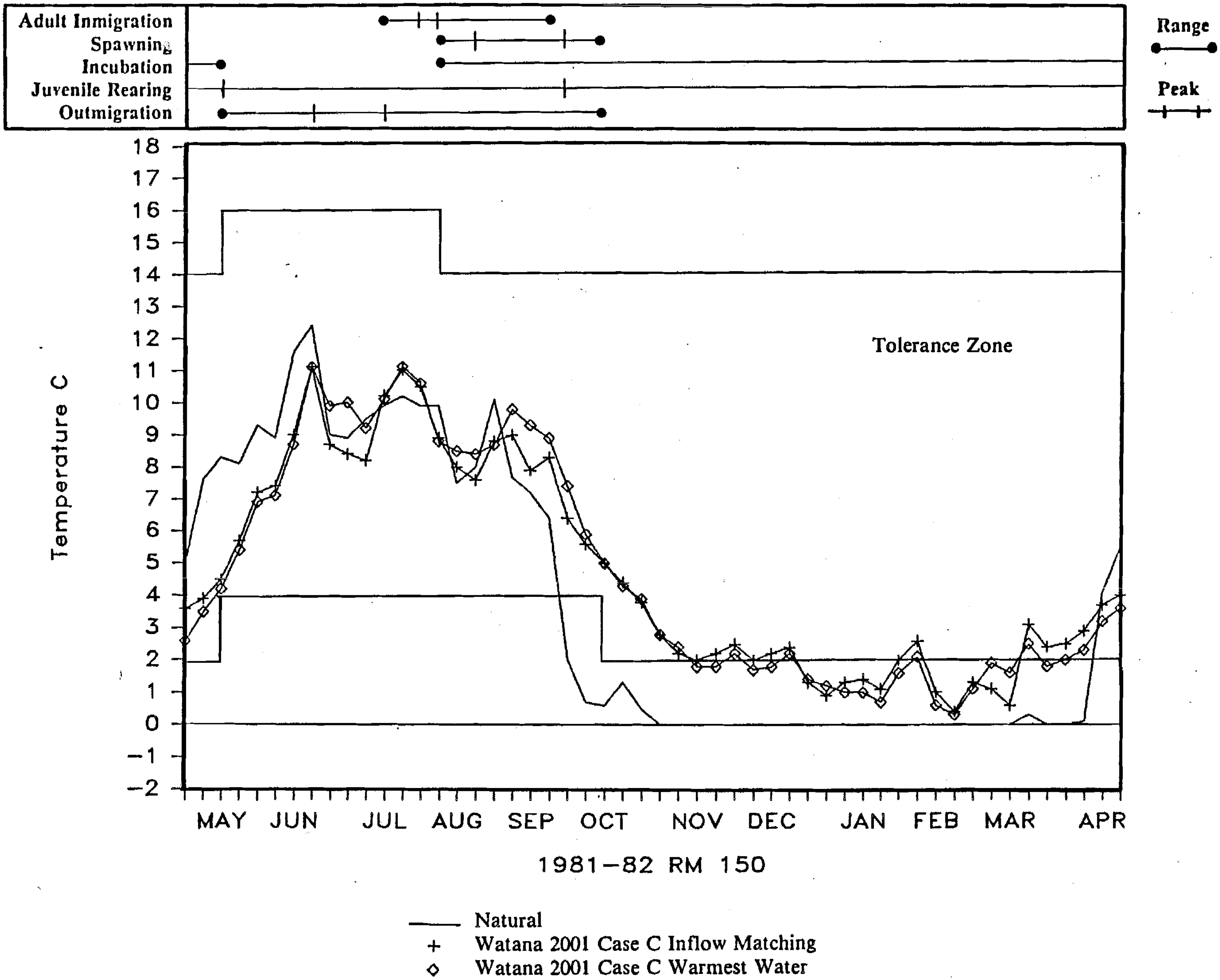
Temperature chronologies at three middle river locations in relation to five Pacific salmon life state temperature tolerance criteria for natural, Case C "warmest water," and Case C "inflow matching"


CHUM SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981-82 RM 150
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water



CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1981−82 RM 150
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water

SOCKEYE SALMON



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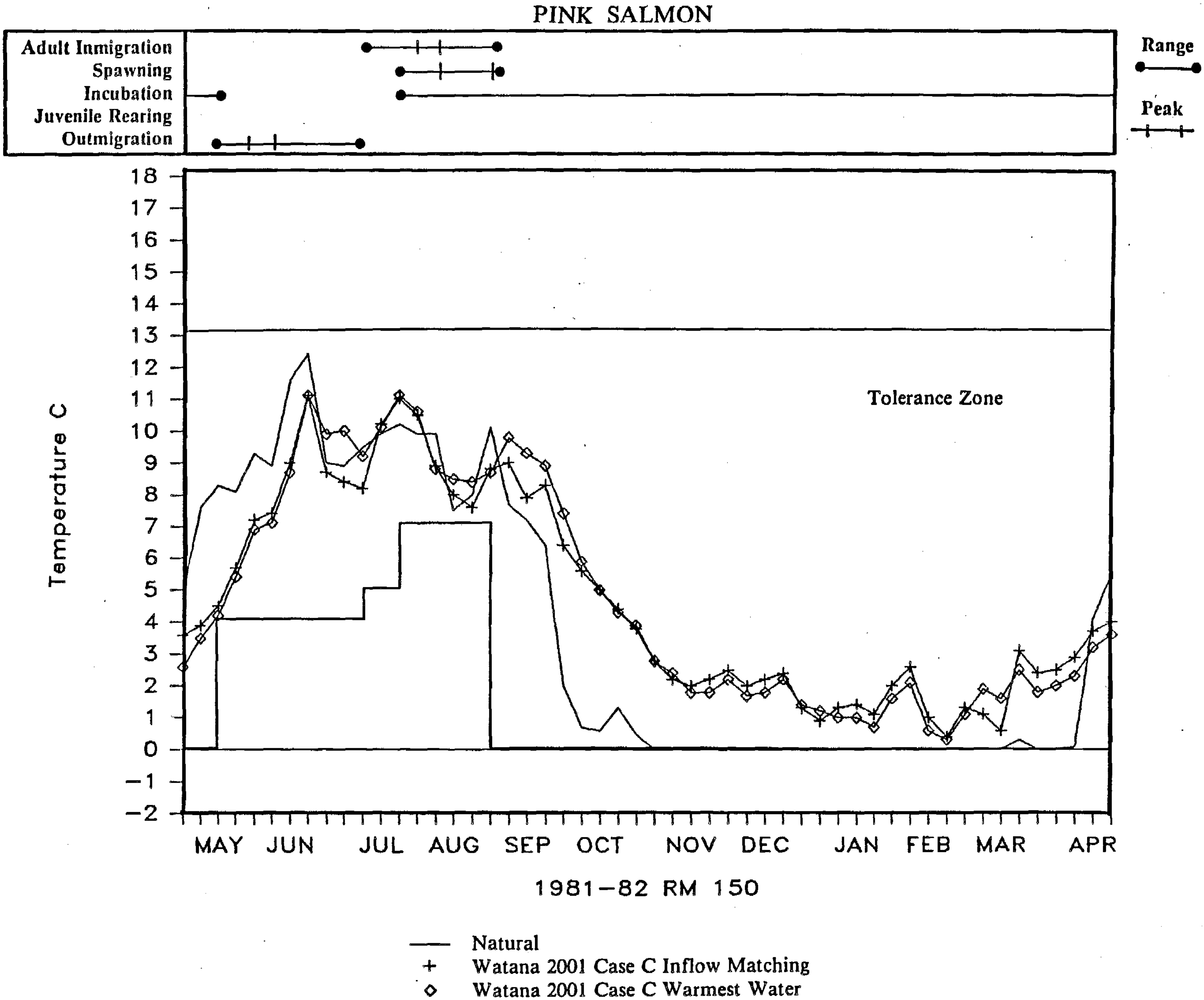
PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
18
17
16
15
14
13
12
11
10
9
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7
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5
4
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2
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−1
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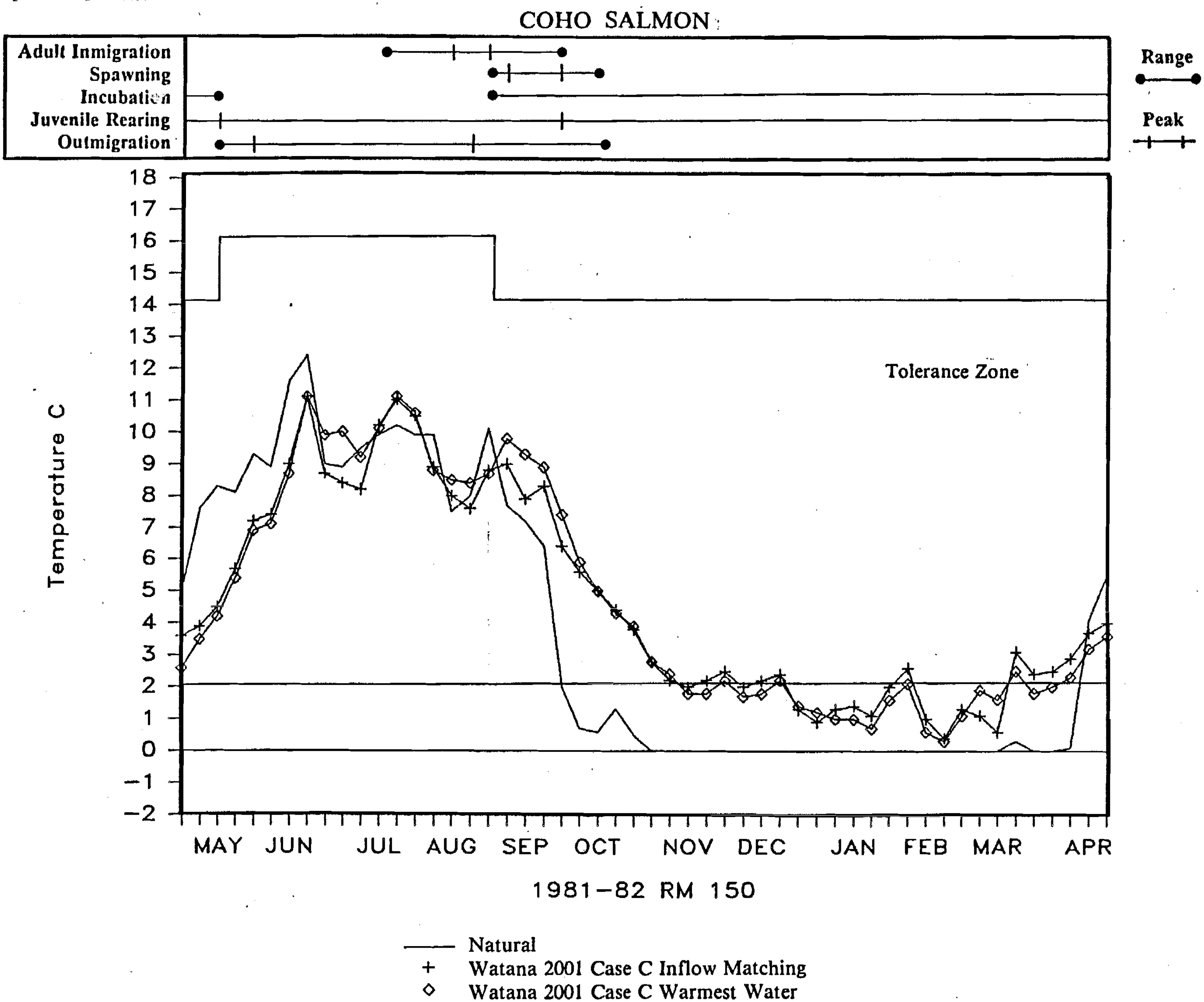
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water


COHO SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
18
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13
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11
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9
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6
5
4
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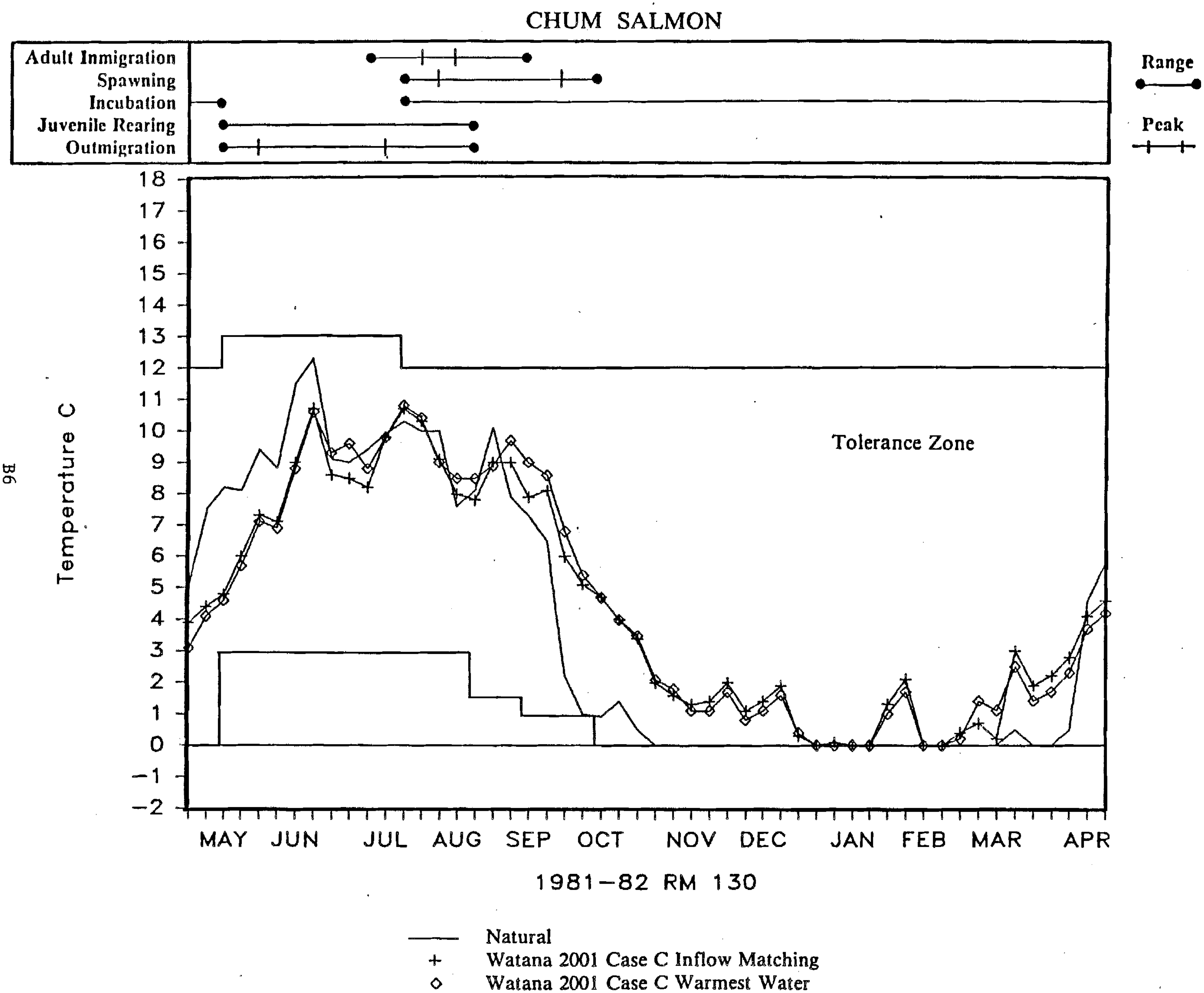
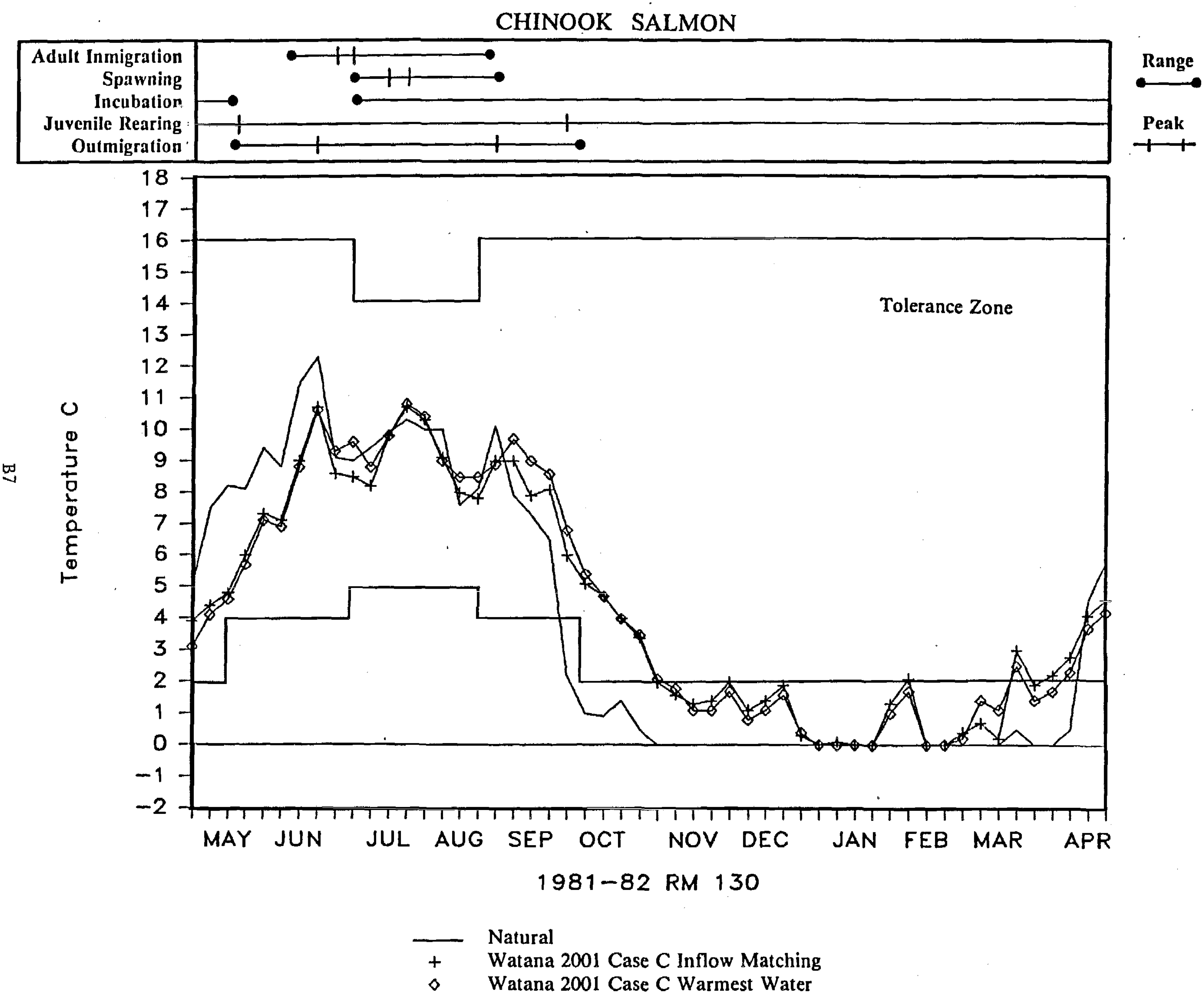
2
1
0
−1
−2
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1981−82 RM 150
Natural
+ Watana 2001 Case C Inflow Matching
◇ Watana 2001 Case C Warmest Water



CHUM SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981–82 RM 130
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water


CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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1
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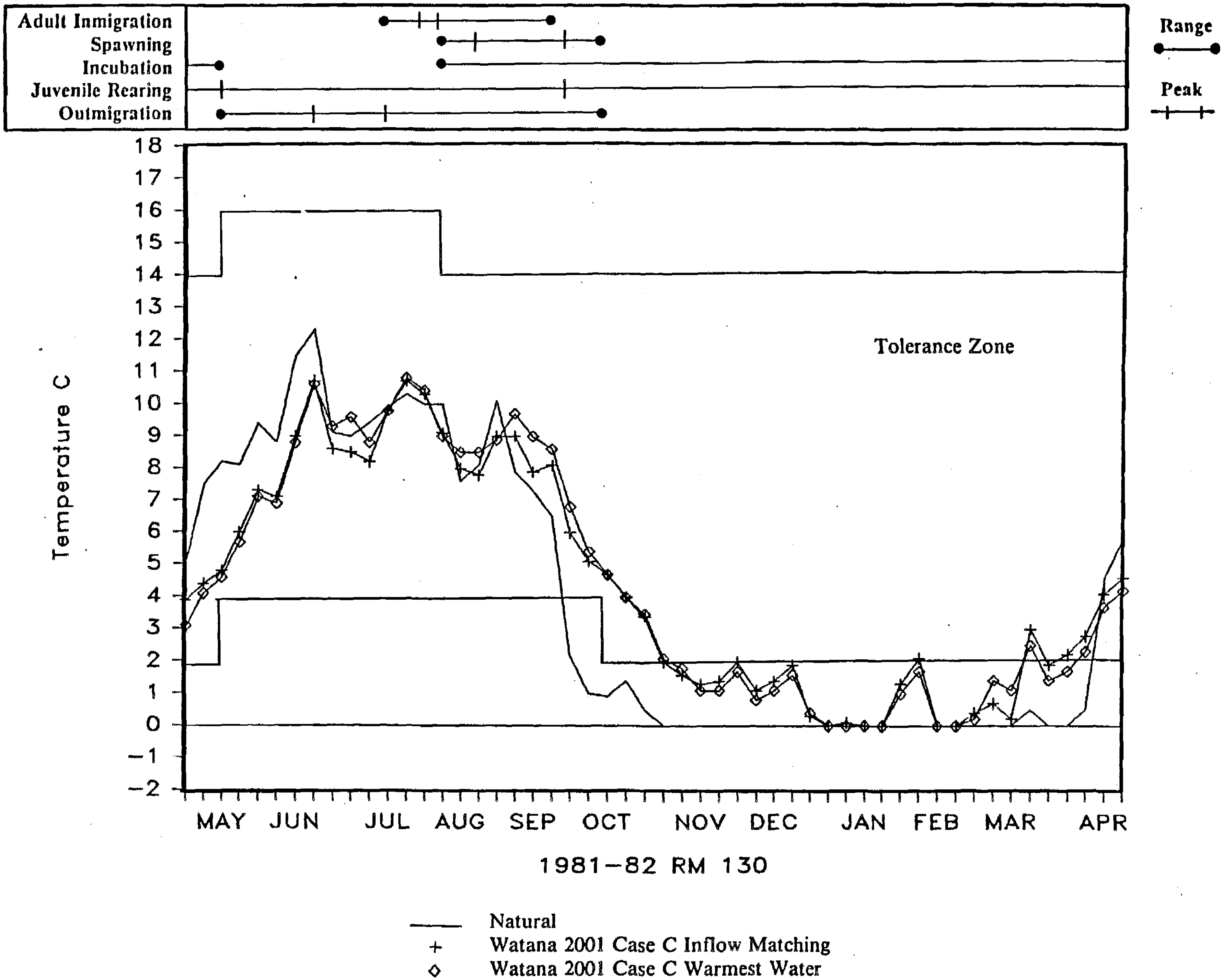
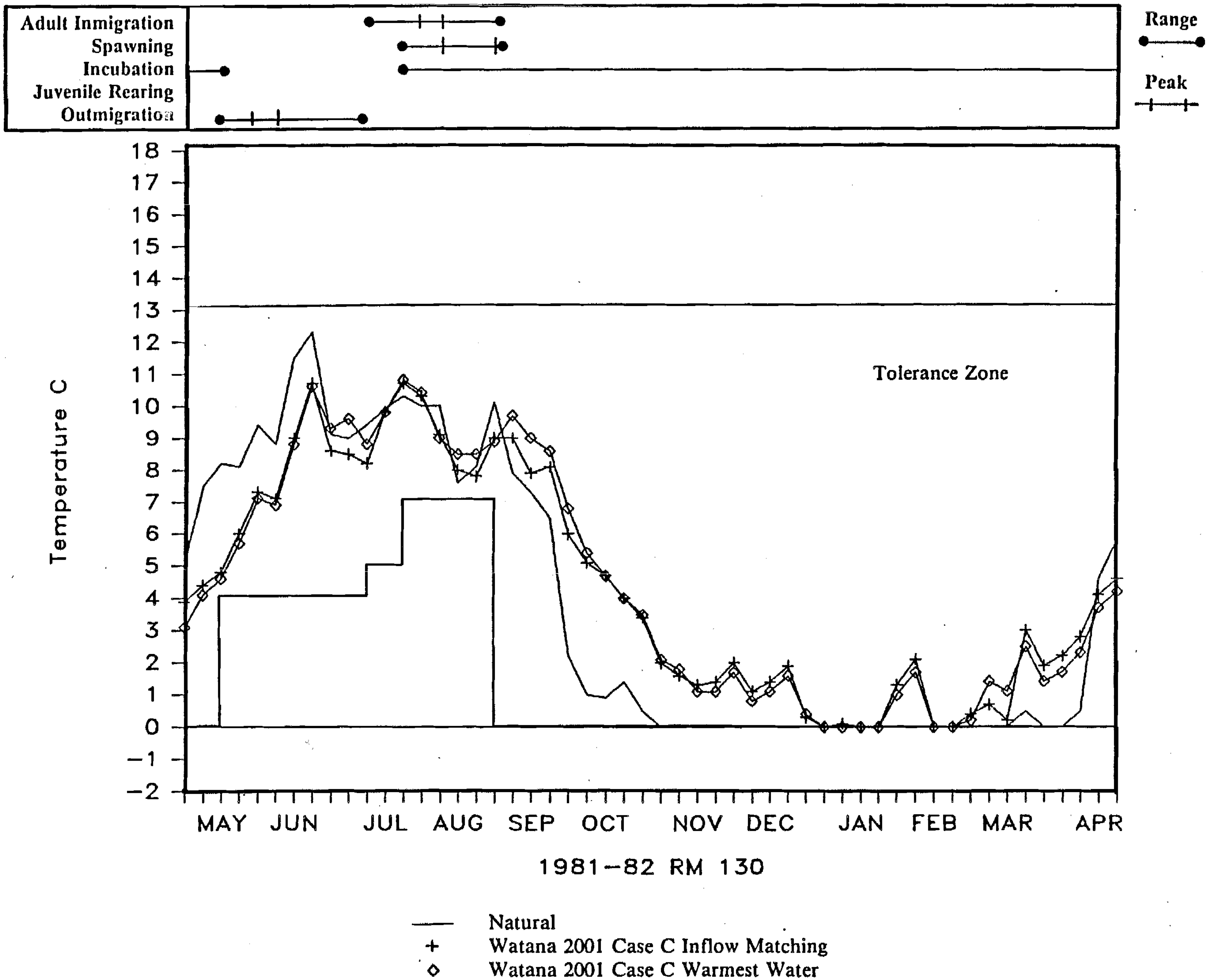
−1
−2
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 130
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water

SOCKEYE SALMON



PINK SALMON



Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
18
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1
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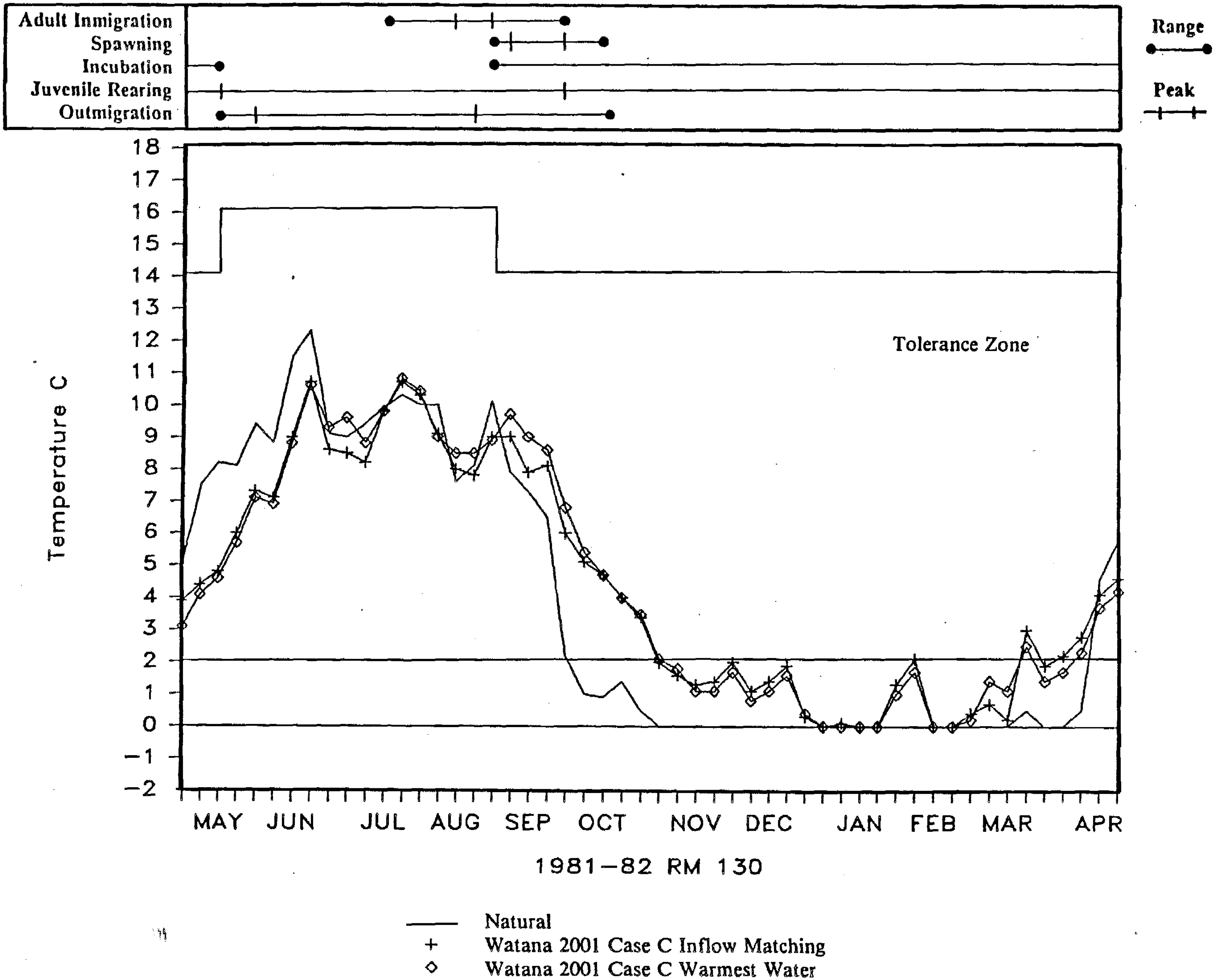
−1
−2
Tolerance Zone
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1981−82 RM 130
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water

COHO SALMON


Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
18
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−1
−2
Temperature C
Tolerance Zone
MAY
JUN
JUL
AUG
SEP
OCT
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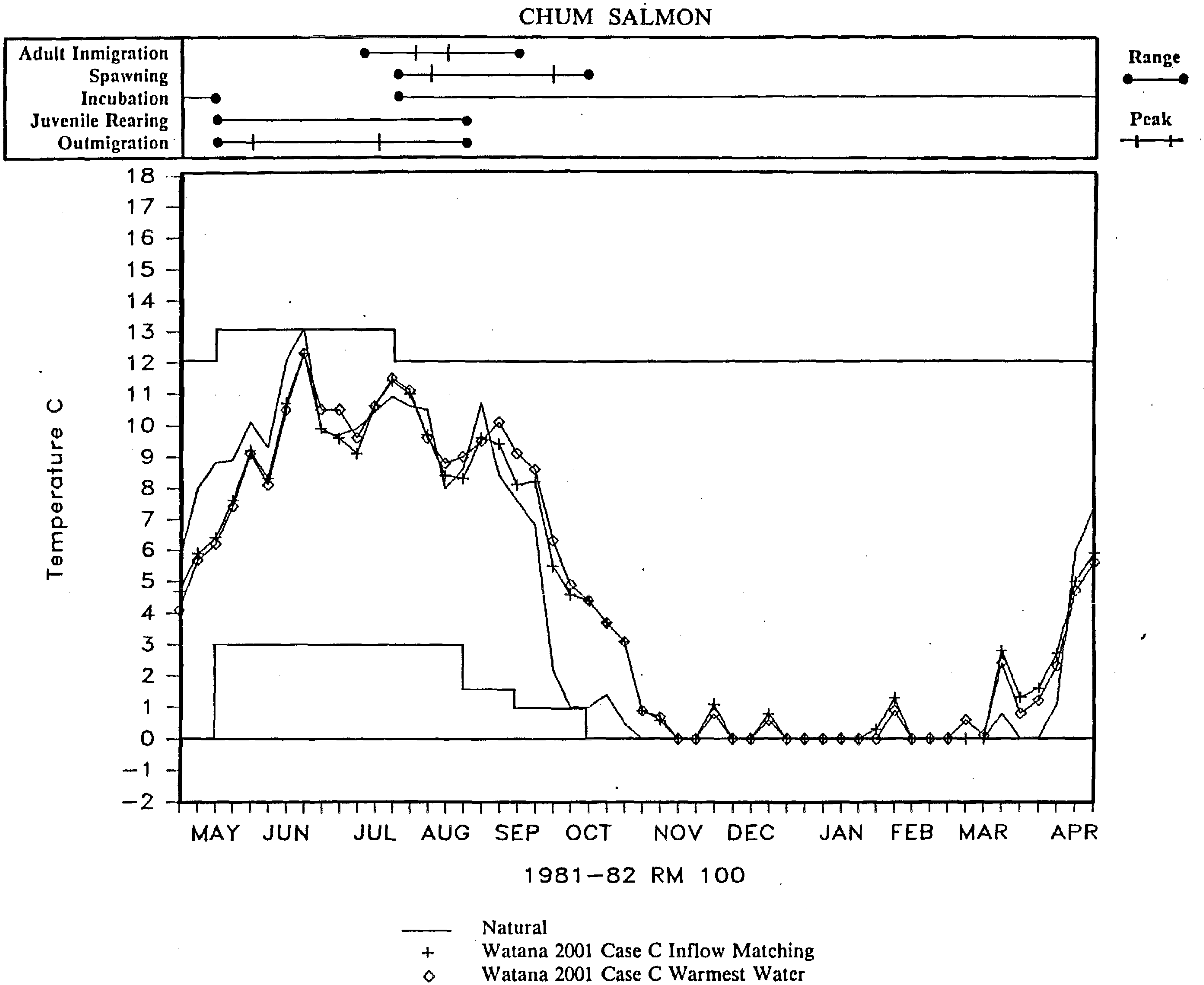
DEC
JAN
FEB
MAR
APR
1981−82 RM 130
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water


CHUM SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
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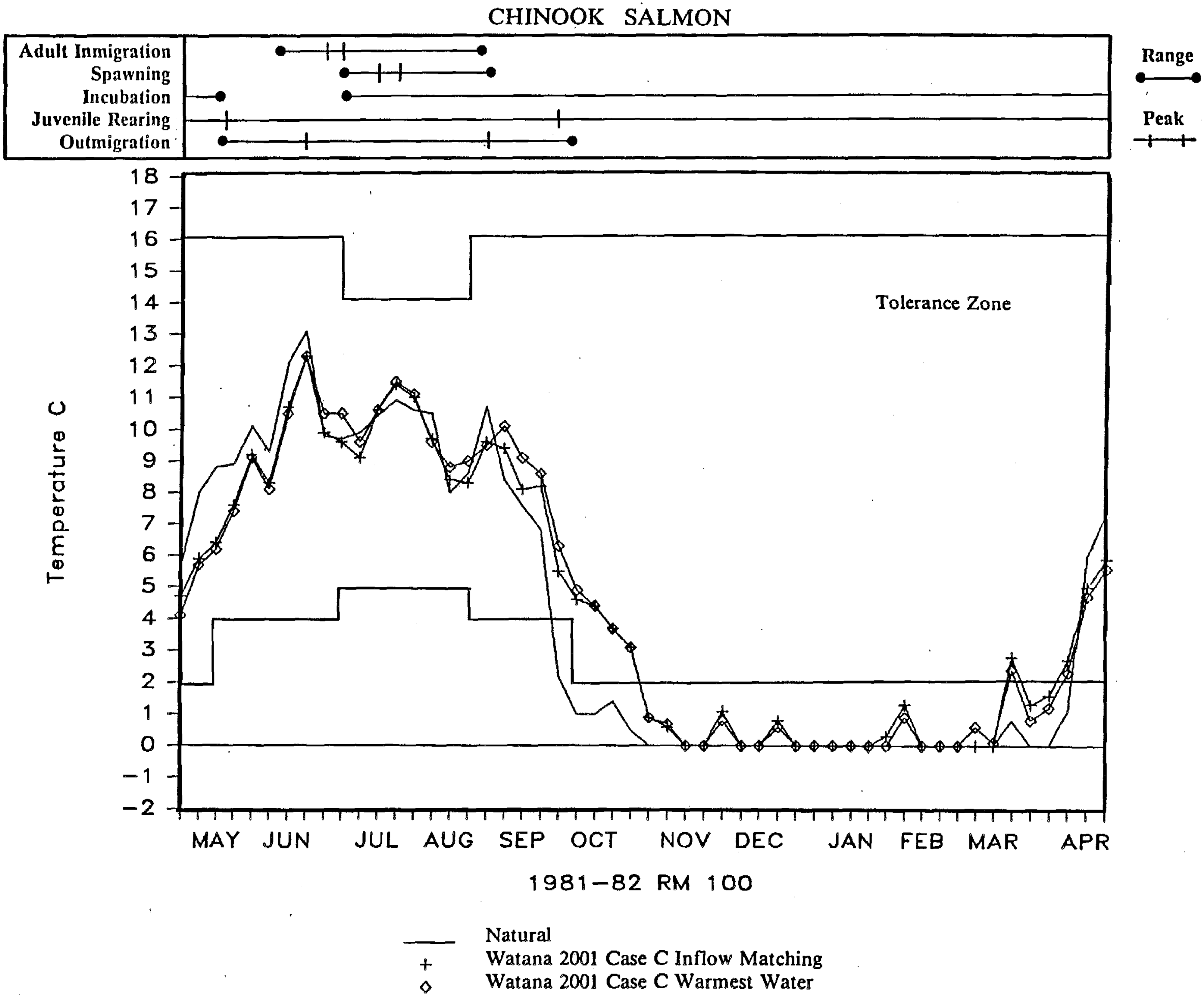
Temperature C
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 100
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water


CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
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−1
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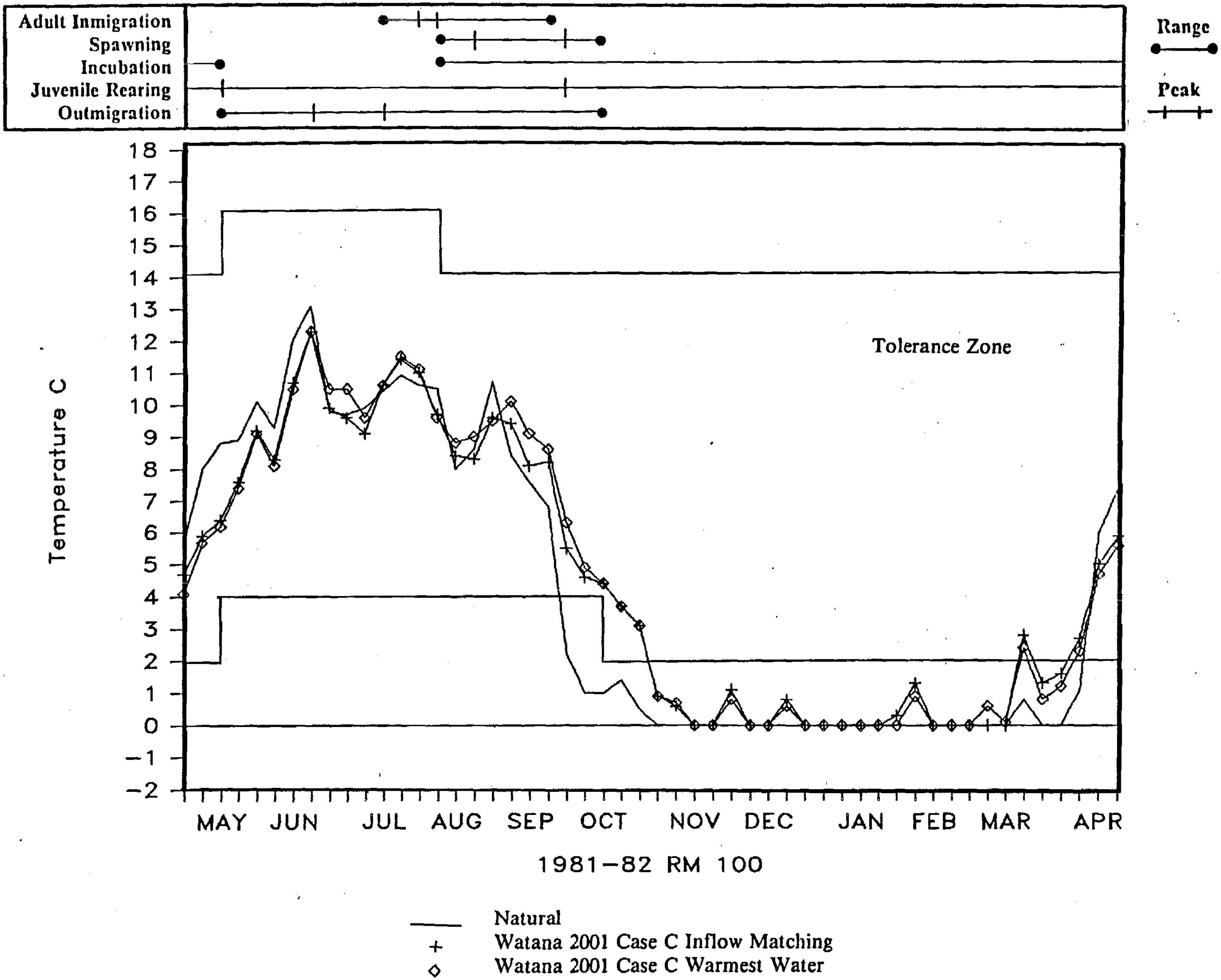
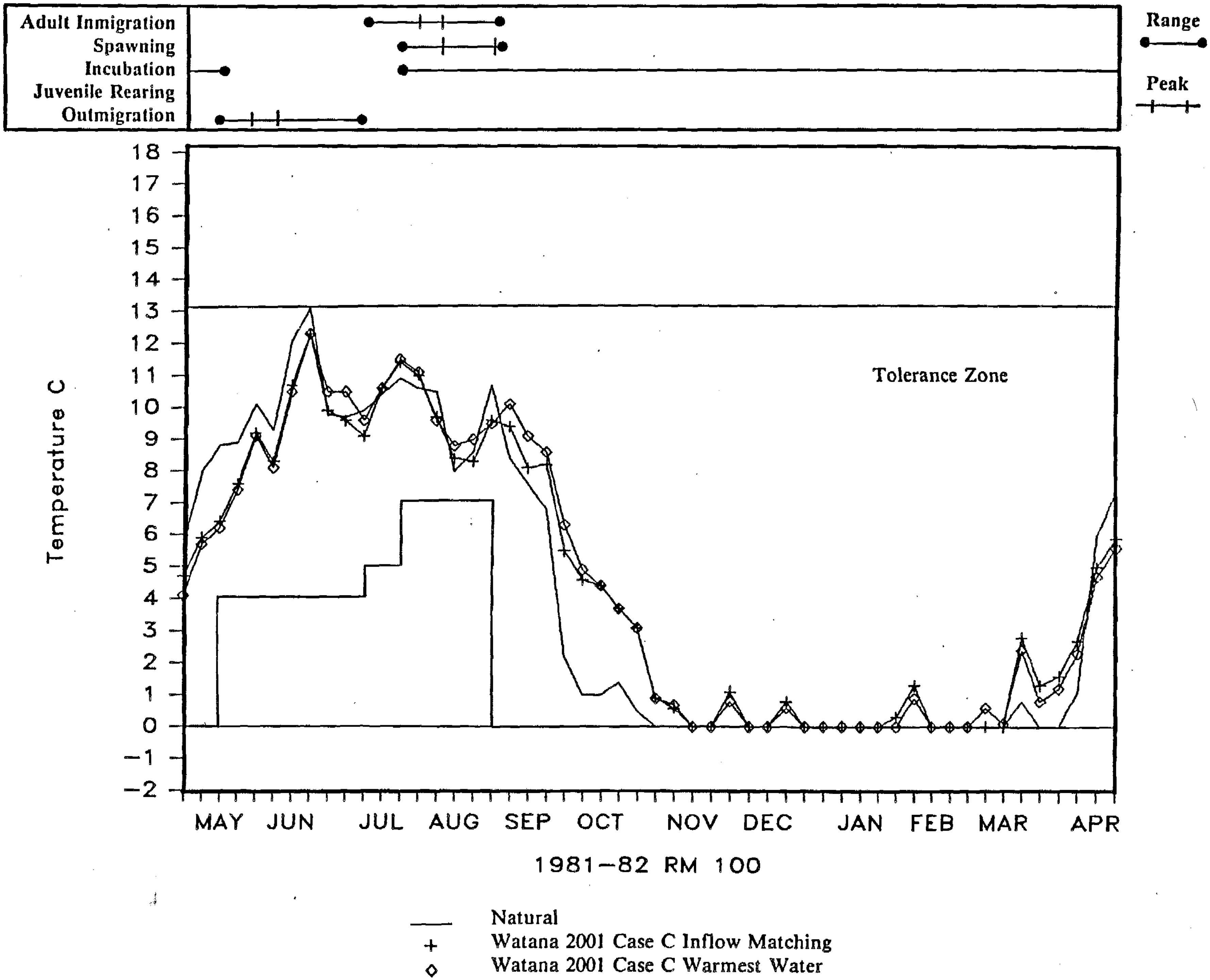
Tolerance Zone
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1981−82 RM 100
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water

SOCKEYE SALMON



PINK SALMON



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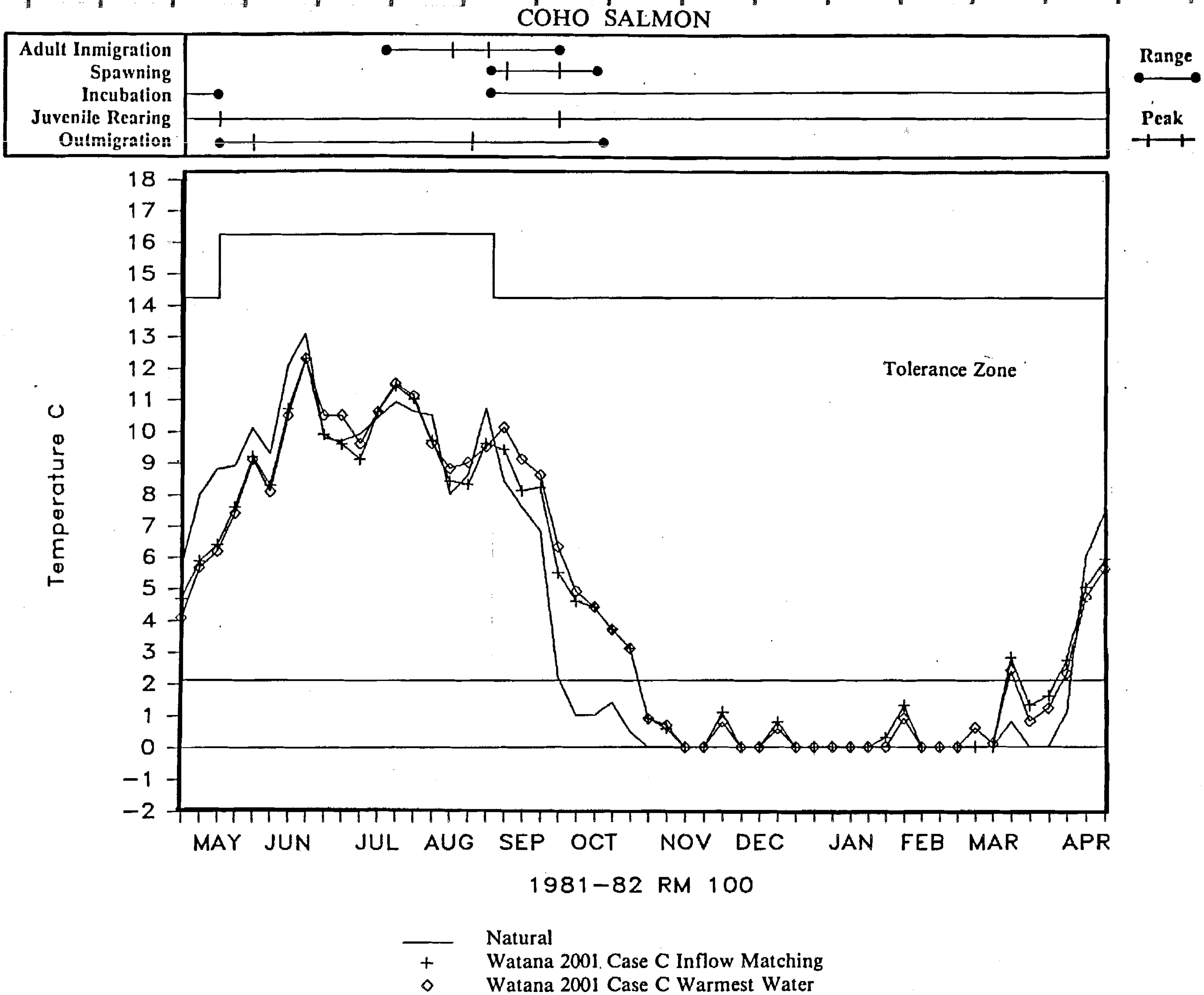
COHO SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
Tolerance Zone
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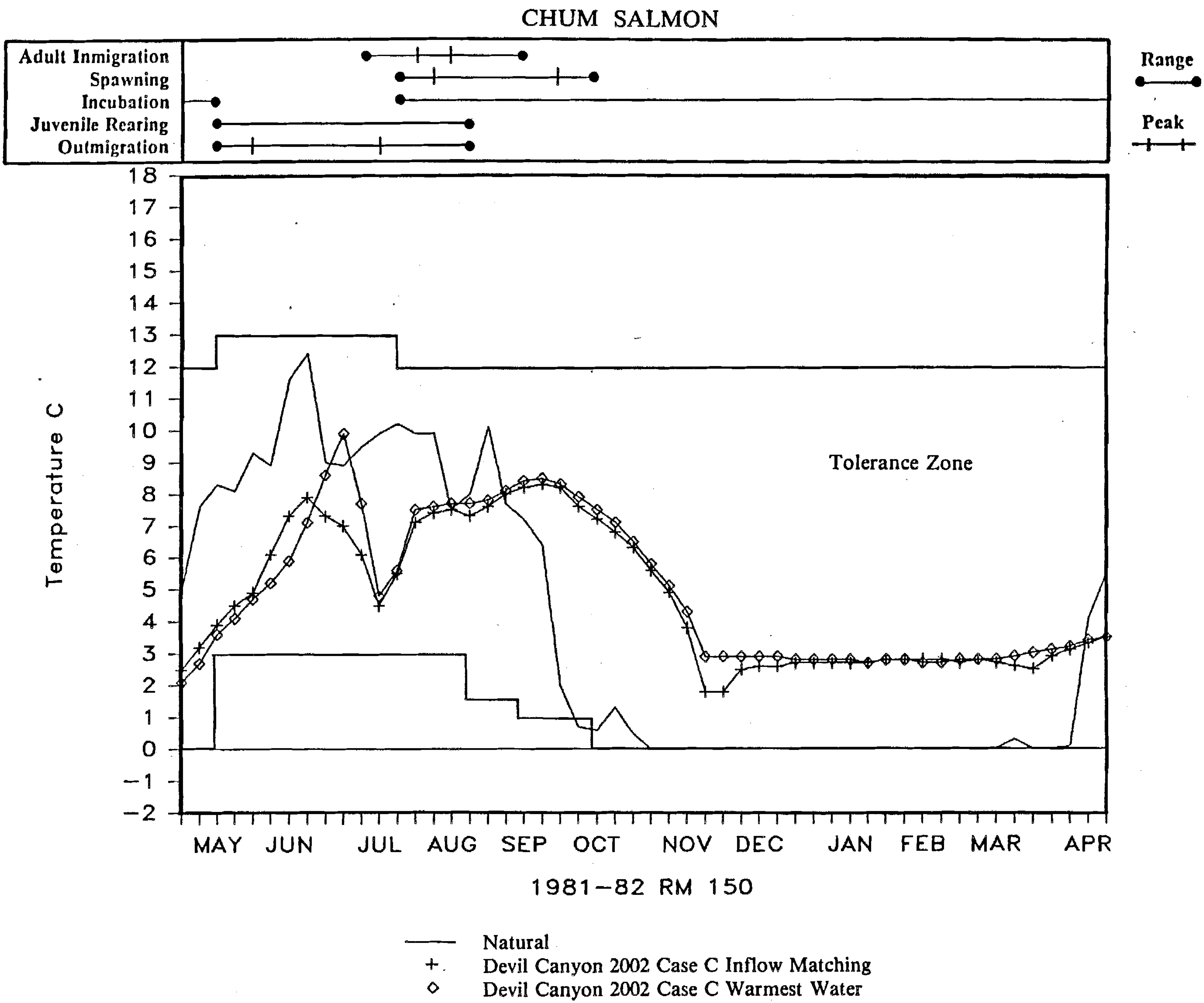
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 100
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case C Warmest Water


CHUM SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
Tolerance Zone
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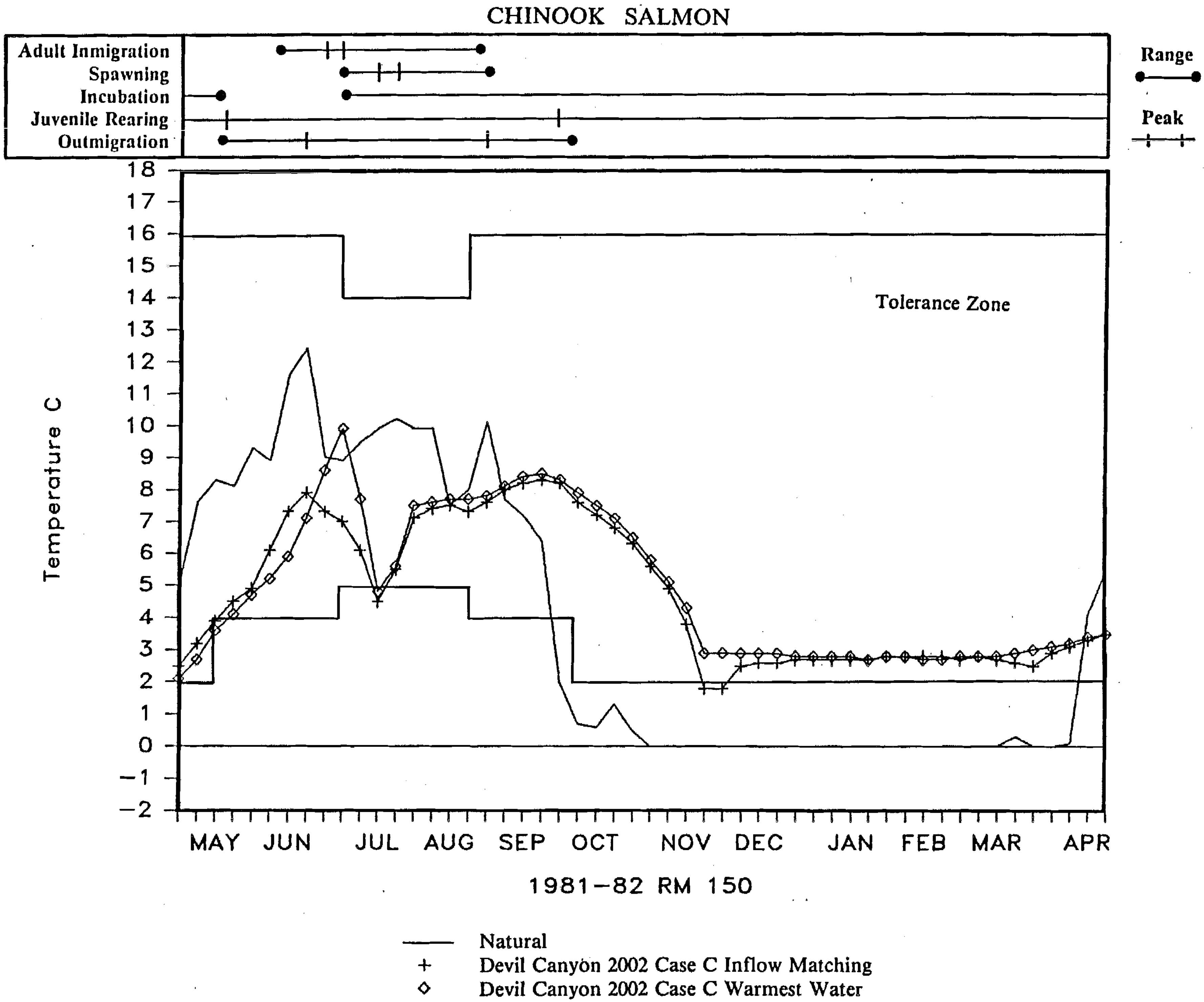
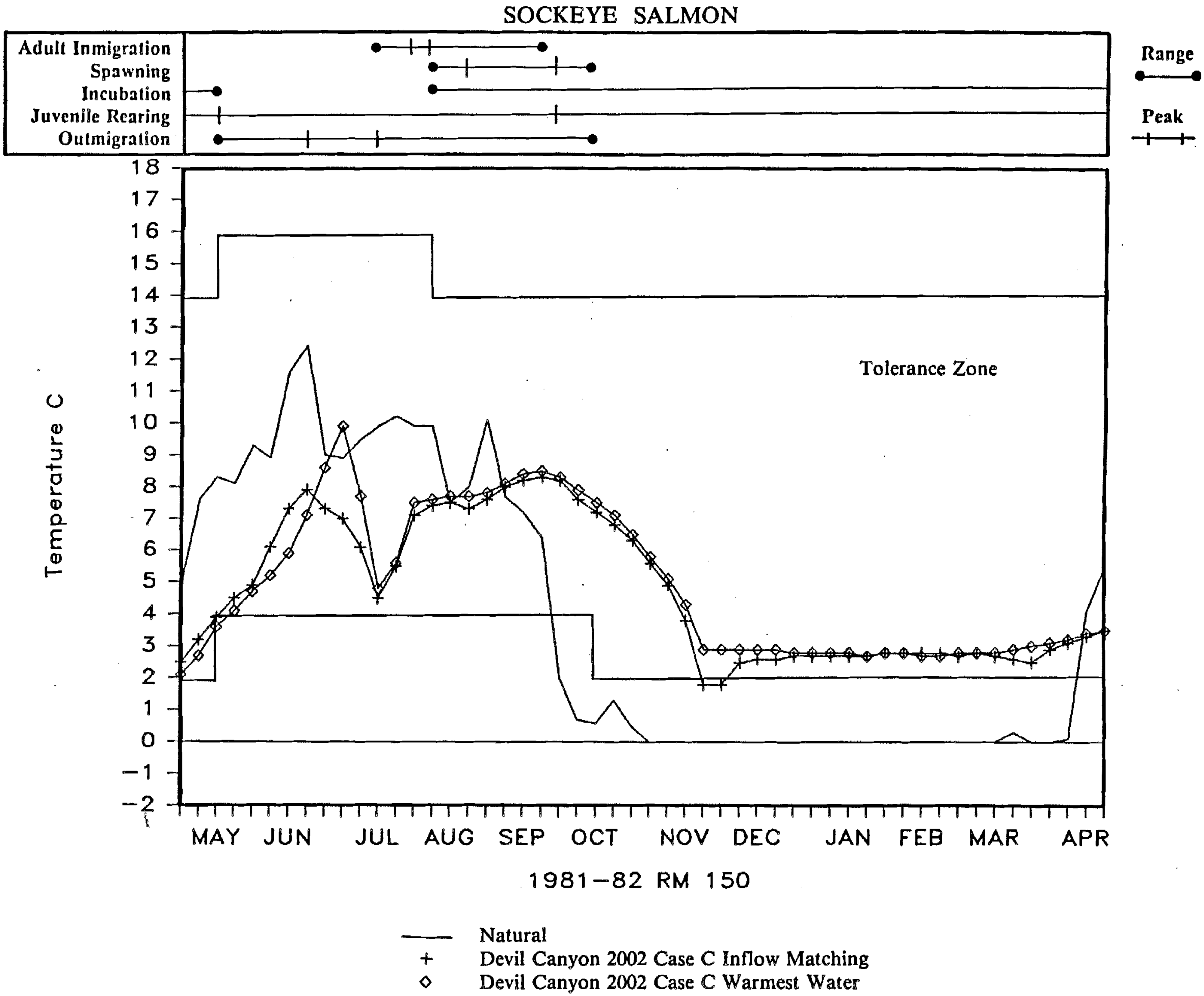
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case C Warmest Water


CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 −1 −2
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case C Warmest Water


SOCKEYE SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
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Tolerance Zone
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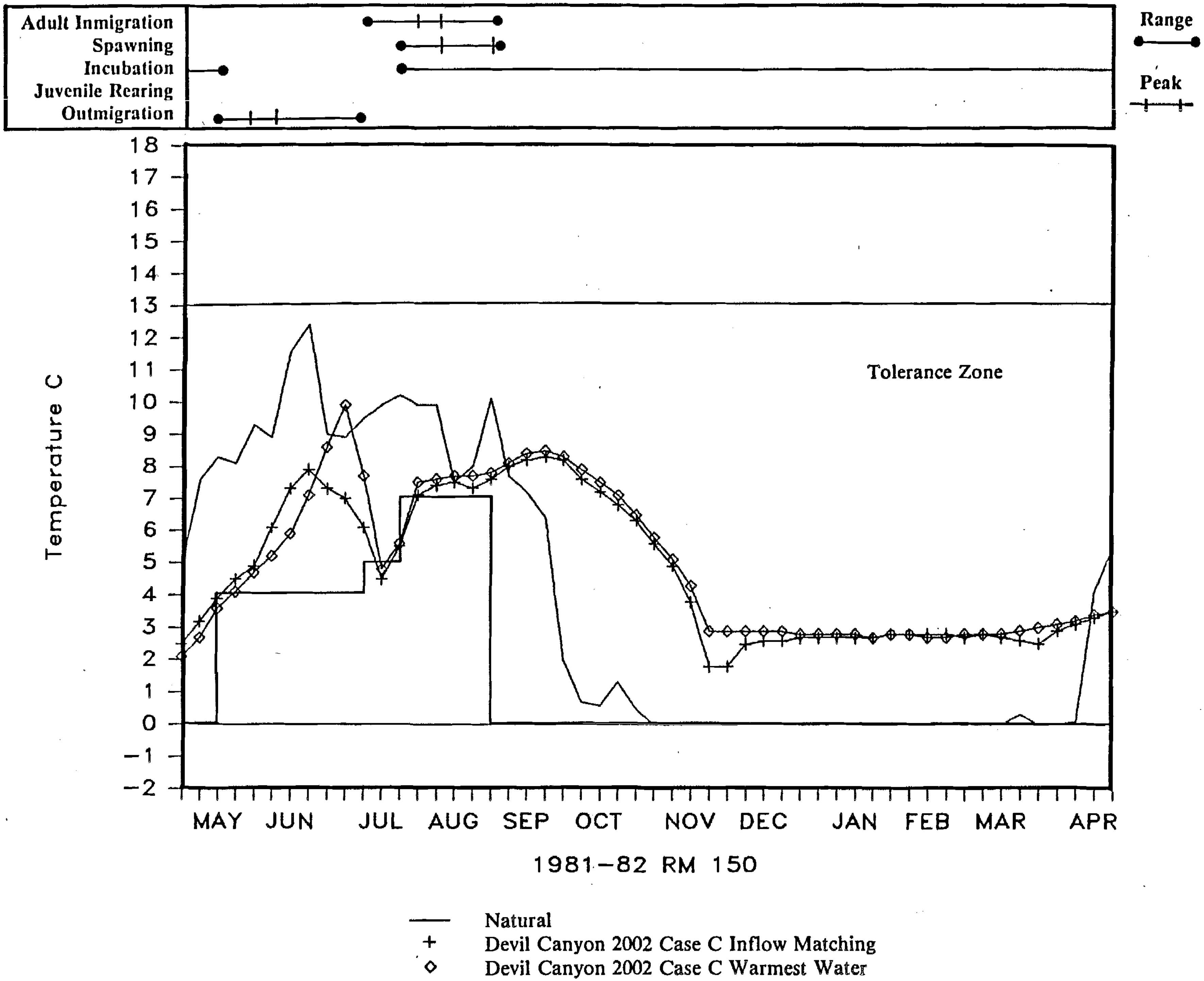
APR
1981−82 RM 150
Natural
+ Devil Canyon 2002 Case C Inflow Matching
◇ Devil Canyon 2002 Case C Warmest Water

PINK SALMON



Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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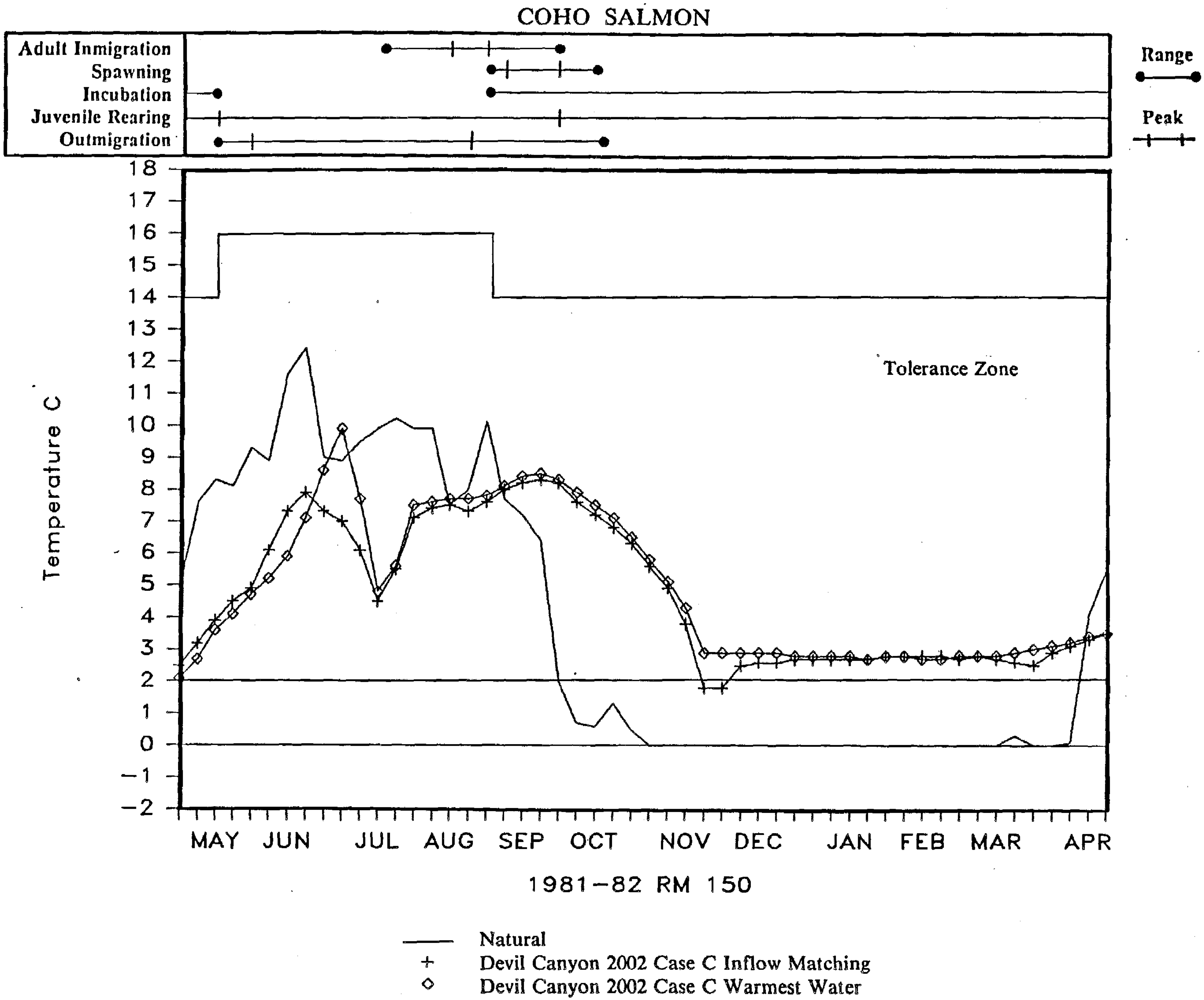
1981−82 RM 150
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case C Warmest Water


COHO SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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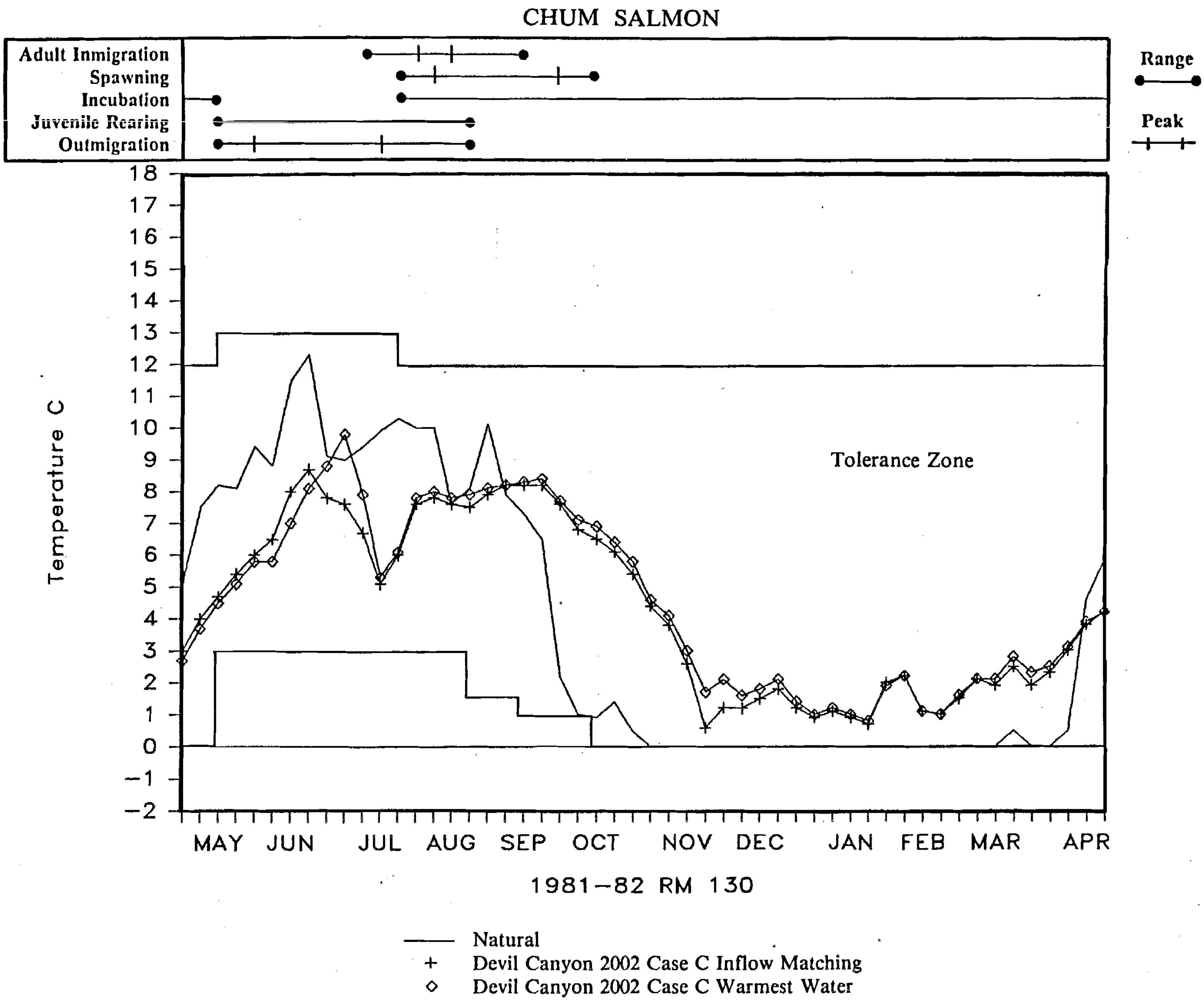
1981−82 RM 150
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case C Warmest Water



CHUM SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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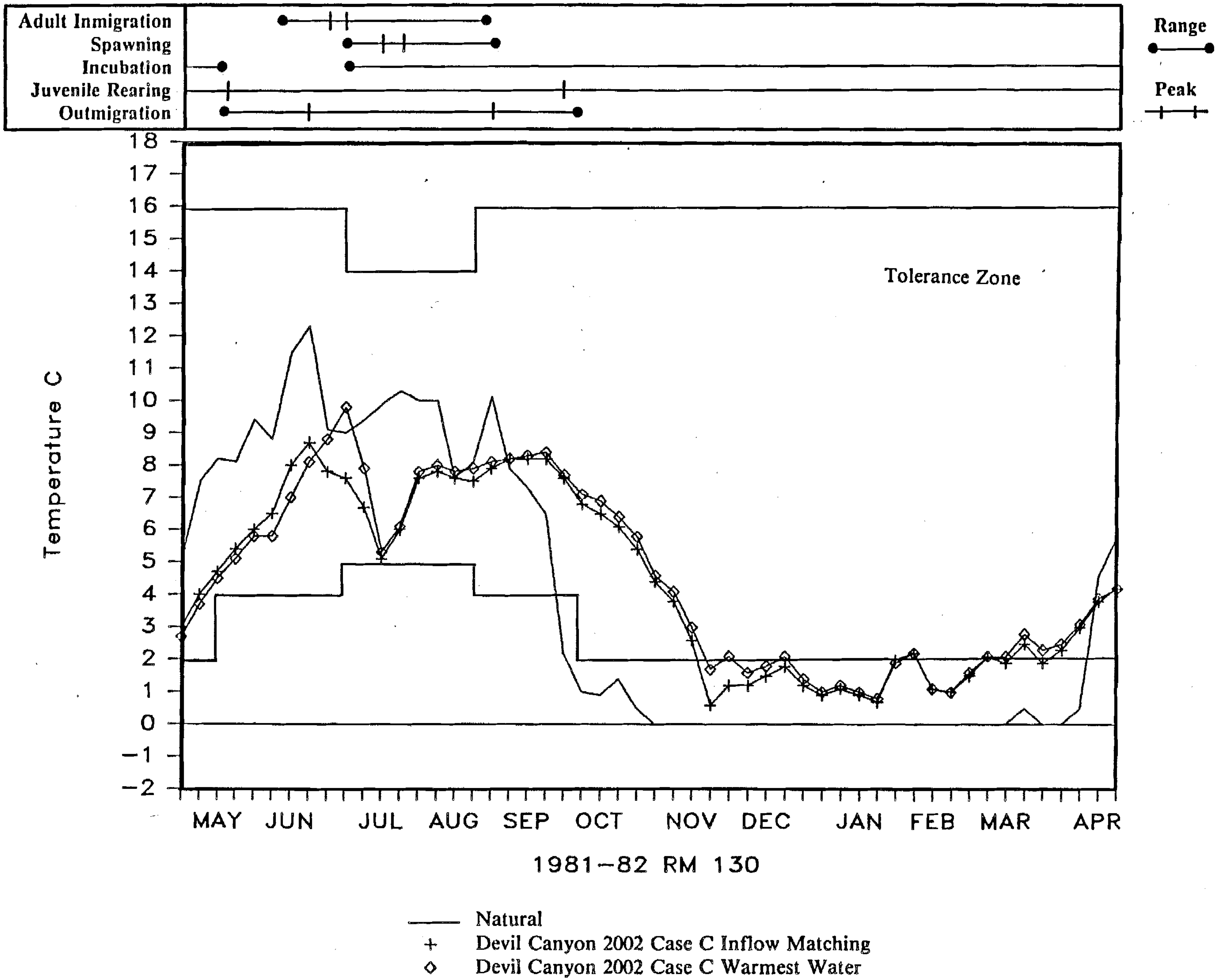
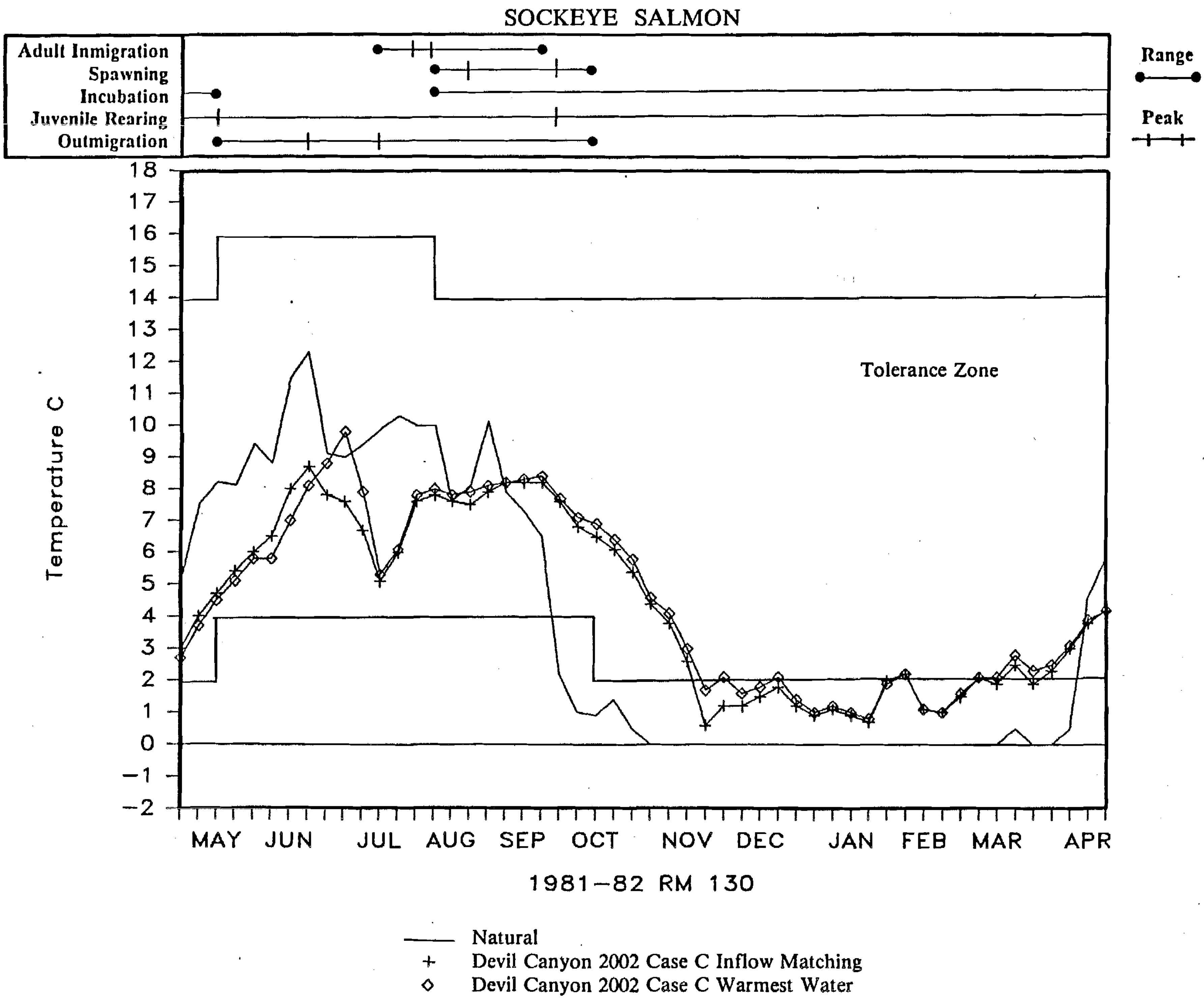
JAN
FEB
MAR
APR
1981−82 RM 130
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case C Warmest Water

CHINOOK SALMON




SOCKEYE SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 130
Natural
+ Devil Canyon 2002 Case C Inflow Matching
◇ Devil Canyon 2002 Case C Warmest Water

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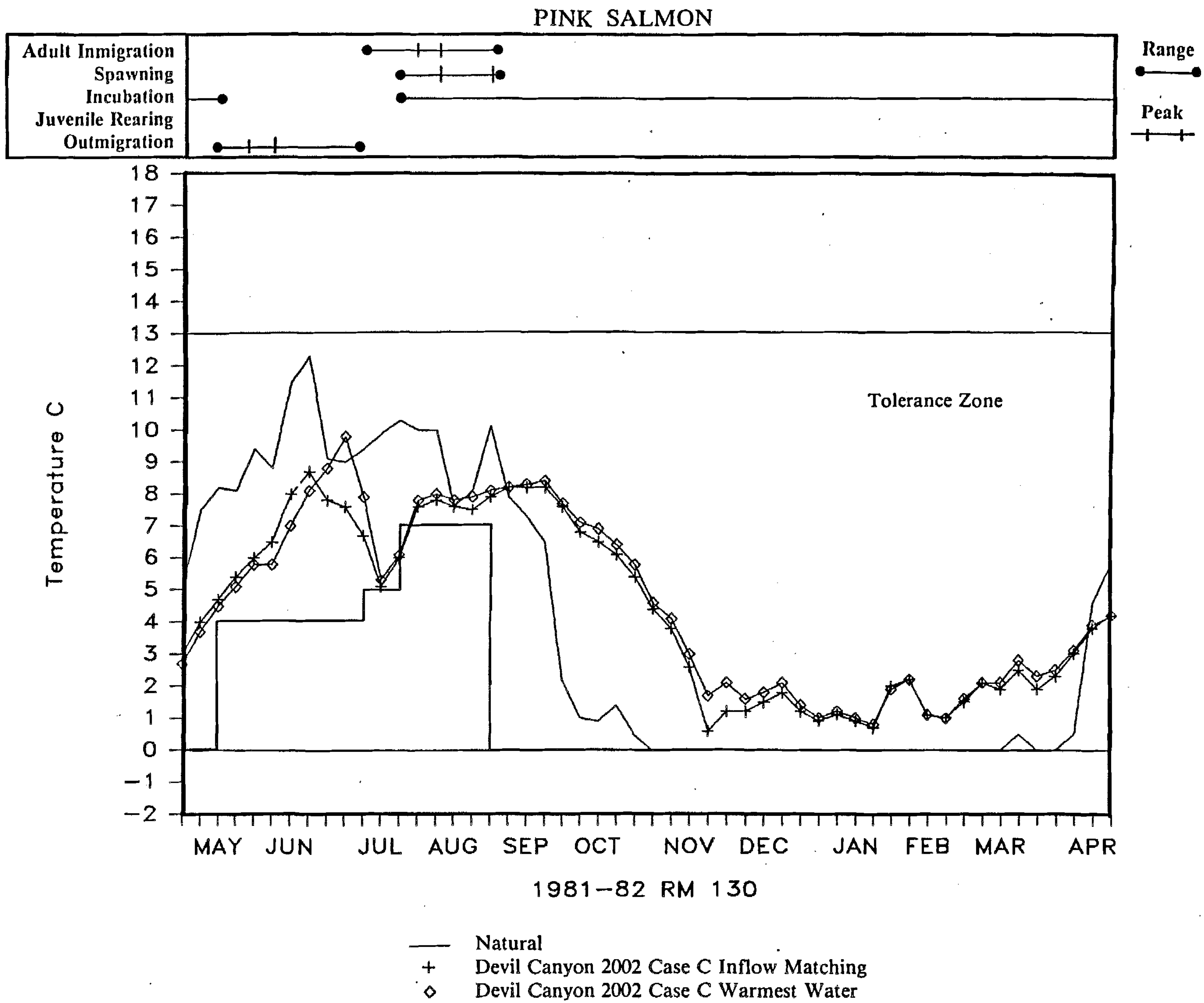
PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
Tolerance Zone
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SEP
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DEC
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FEB
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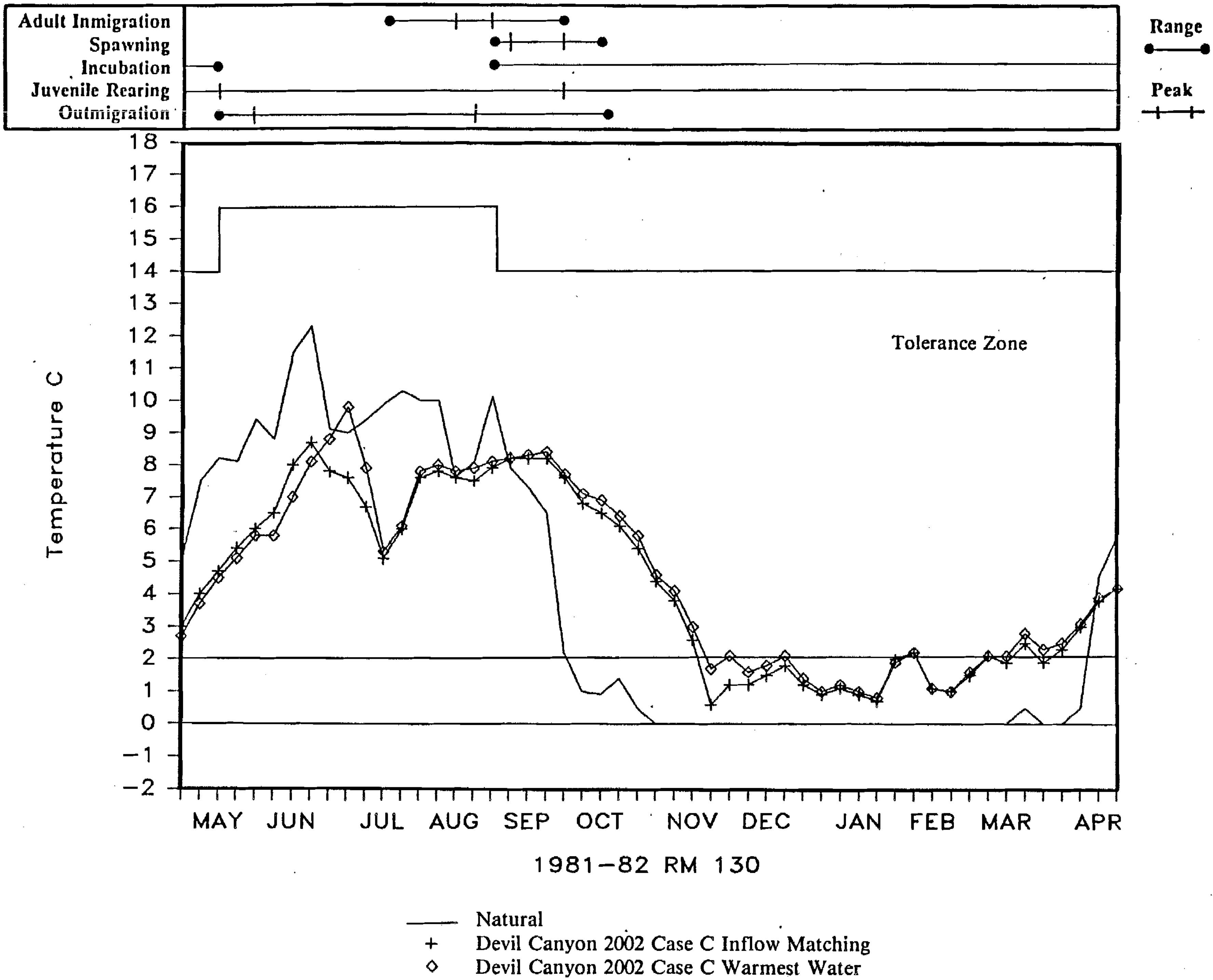
APR
1981−82 RM 130
Natural
+ Devil Canyon 2002 Case C Inflow Matching
◇ Devil Canyon 2002 Case C Warmest Water

COHO SALMON



Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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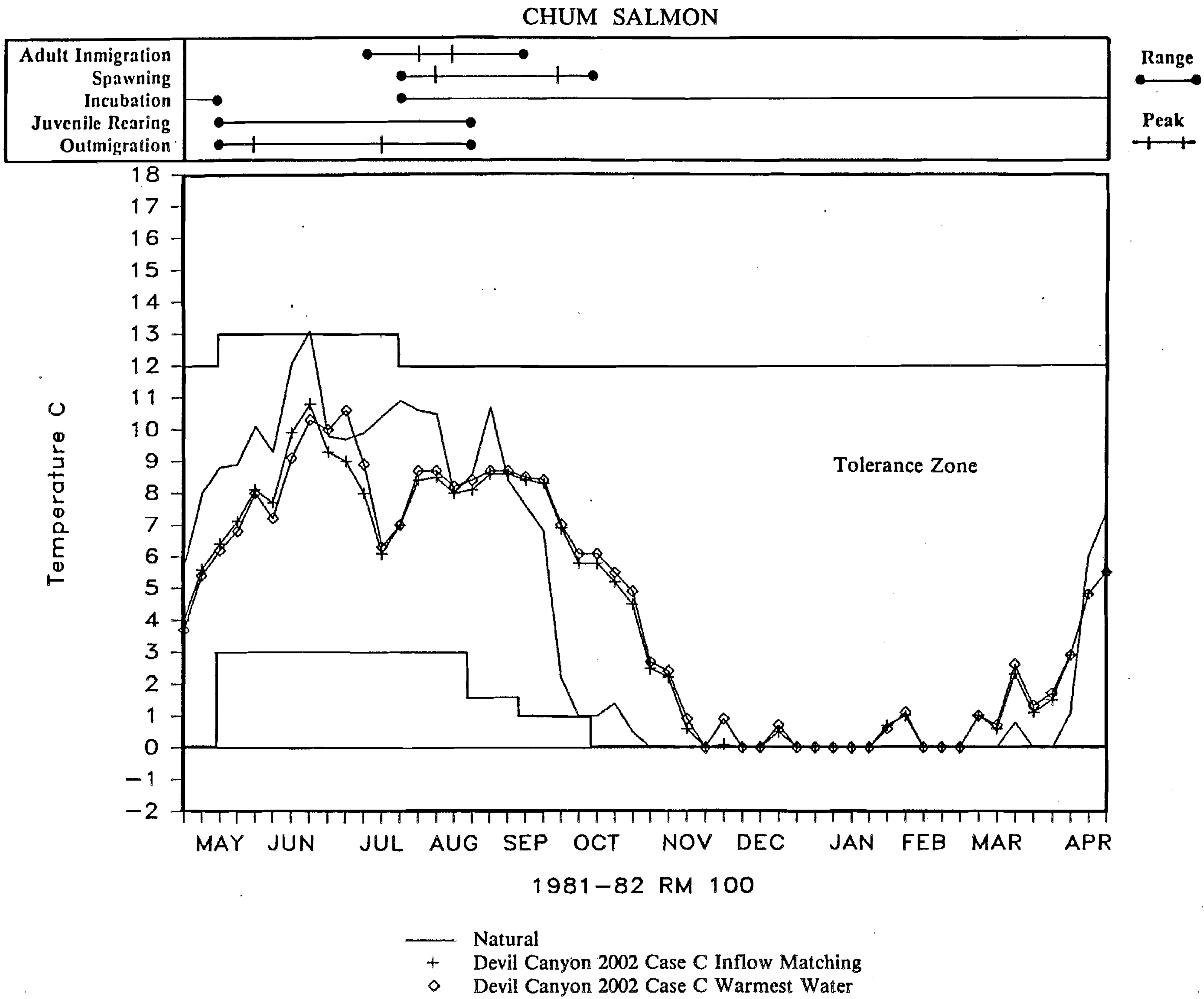
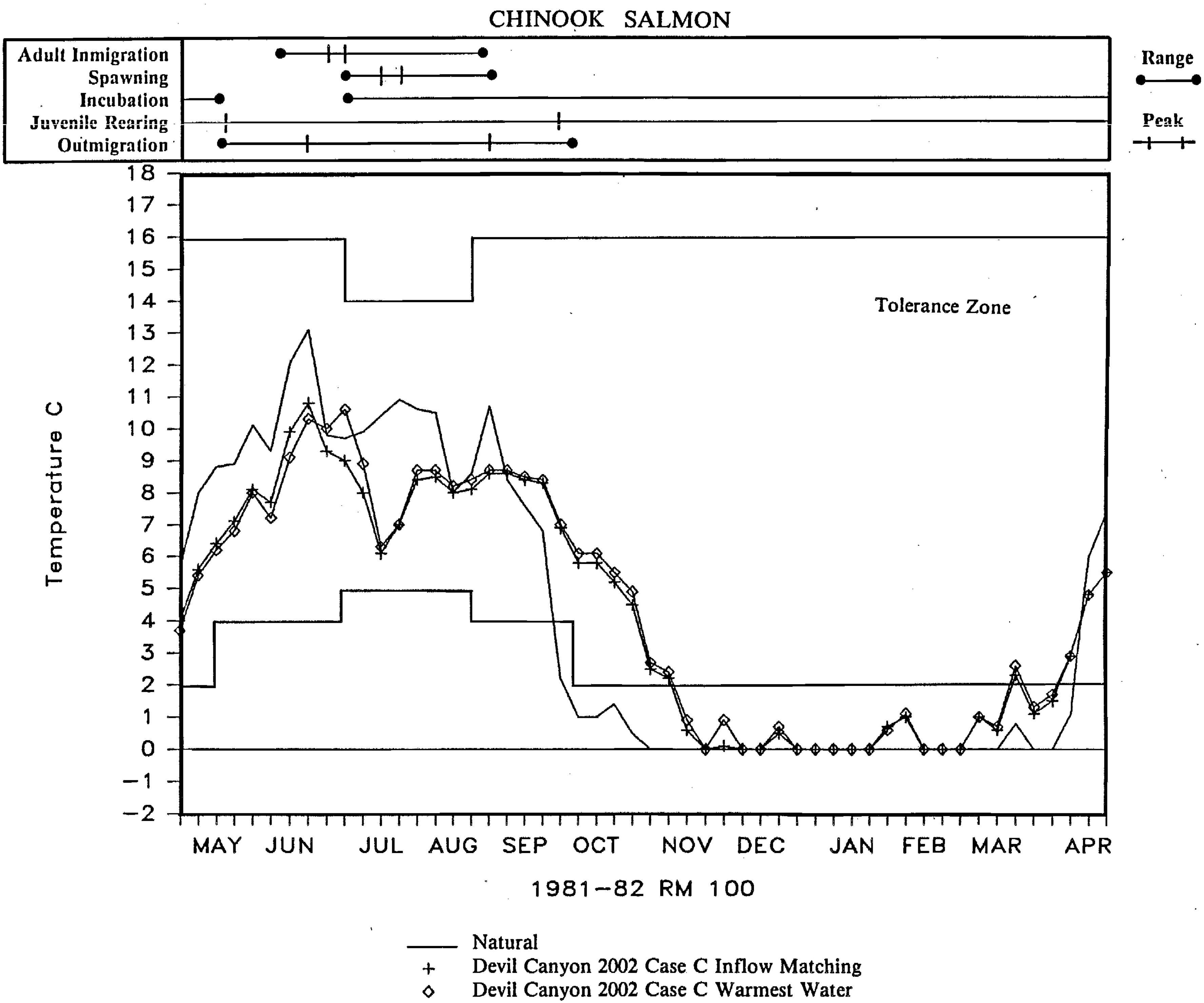
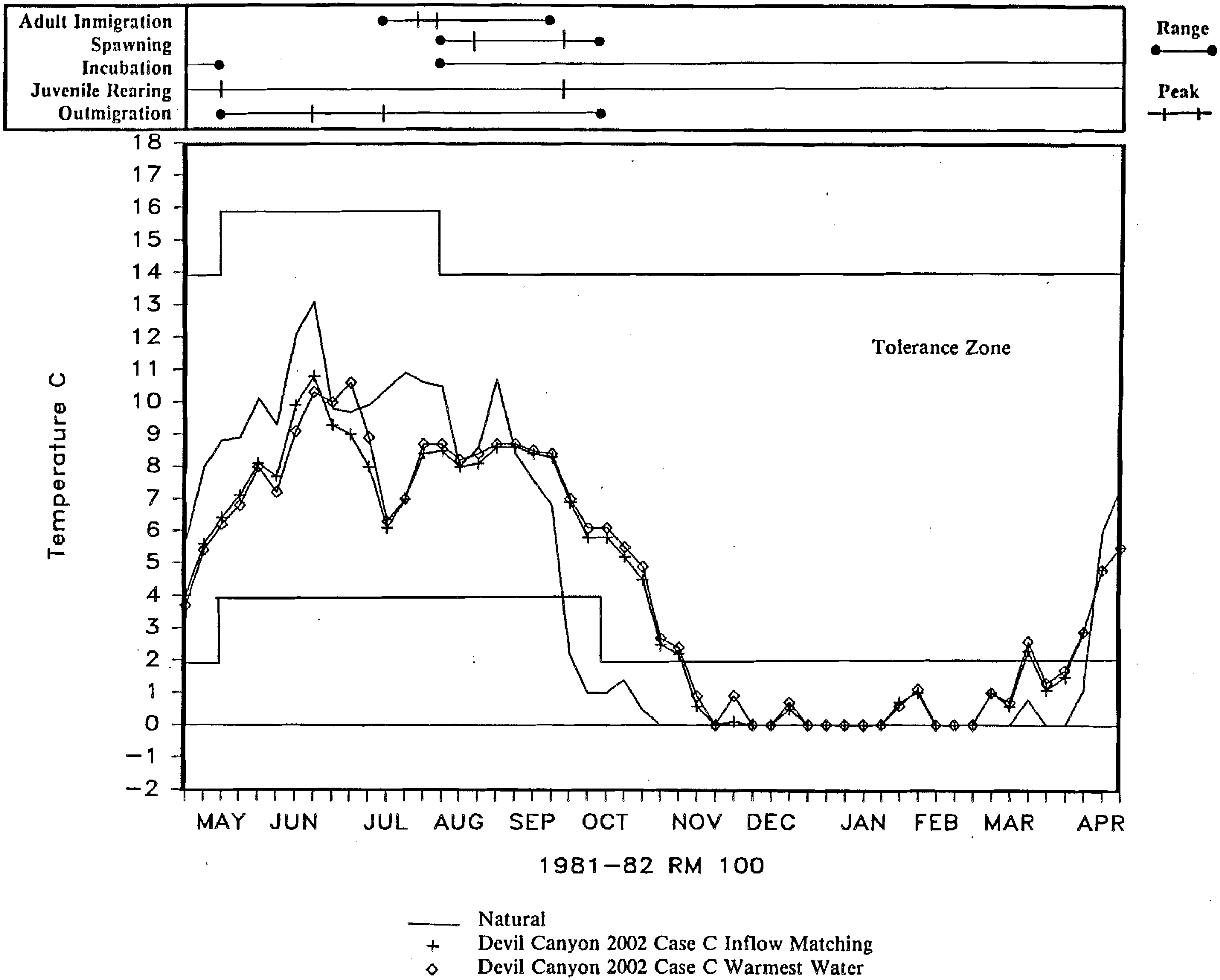
1981−82 RM 130
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case C Warmest Water

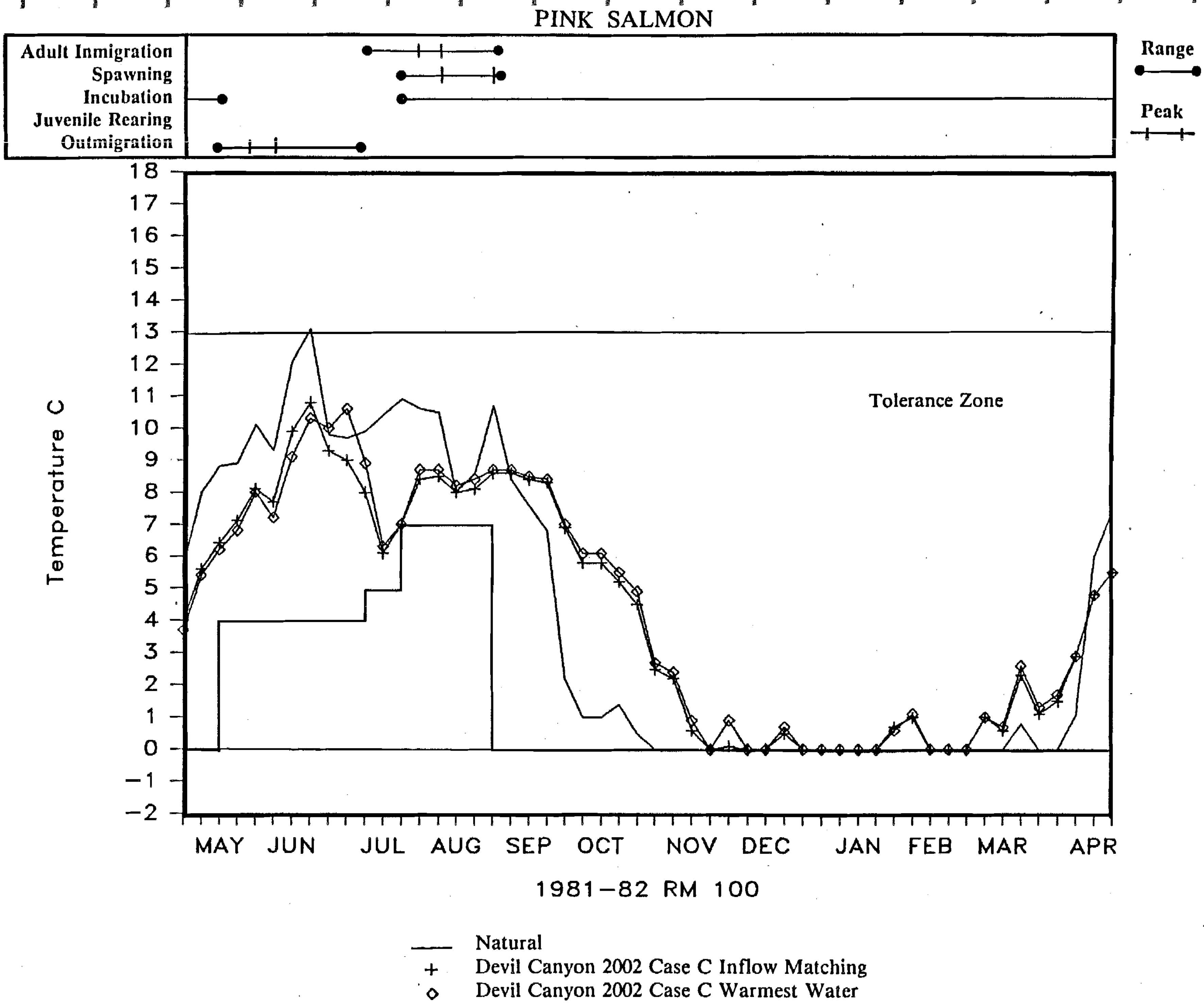

CHUM SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981–82 RM 100
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case C Warmest Water

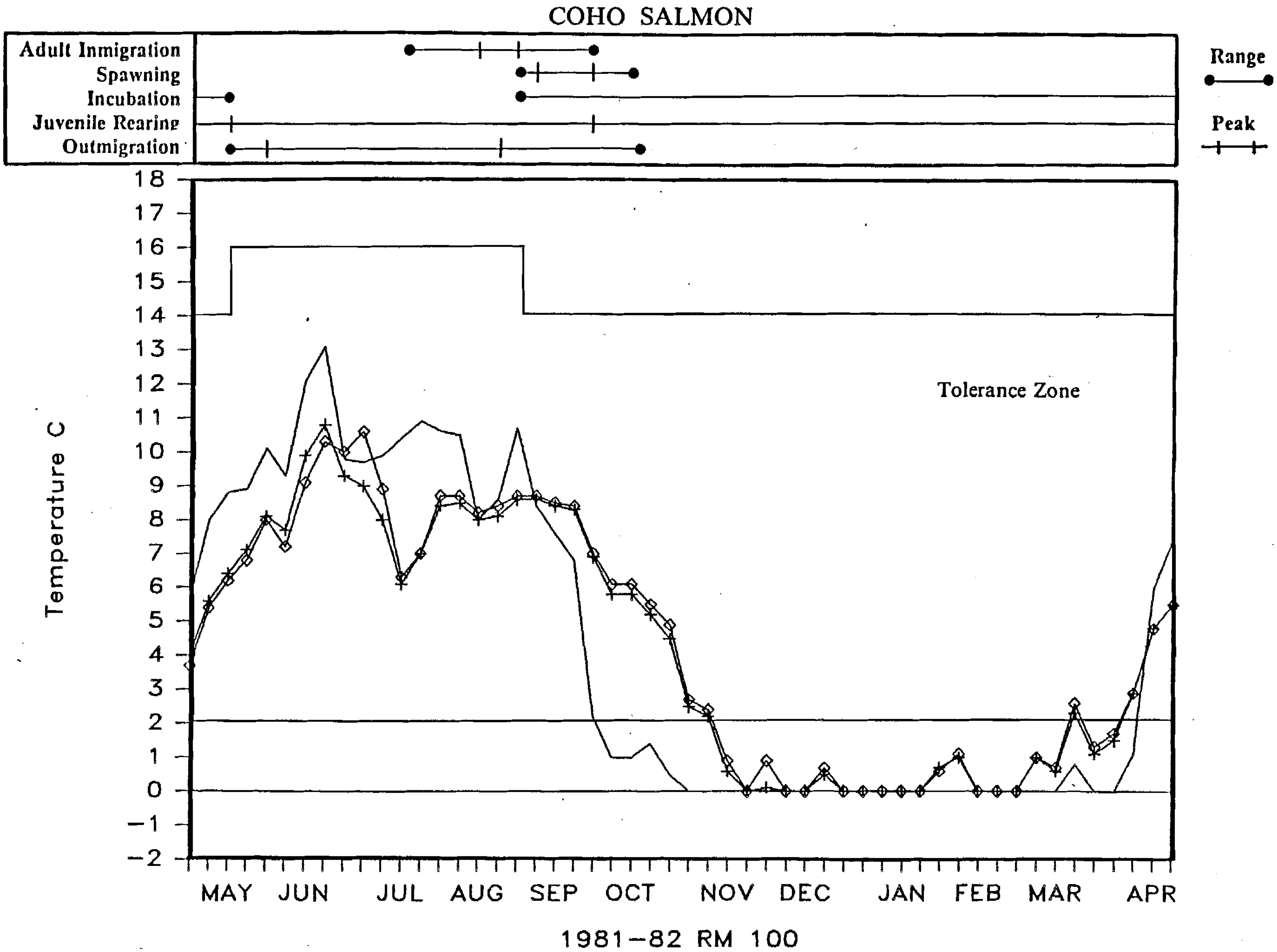


CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981-82 RM 100
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case C Warmest Water

SOCKEYE SALMON




PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981-82 RM 100
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case C Warmest Water

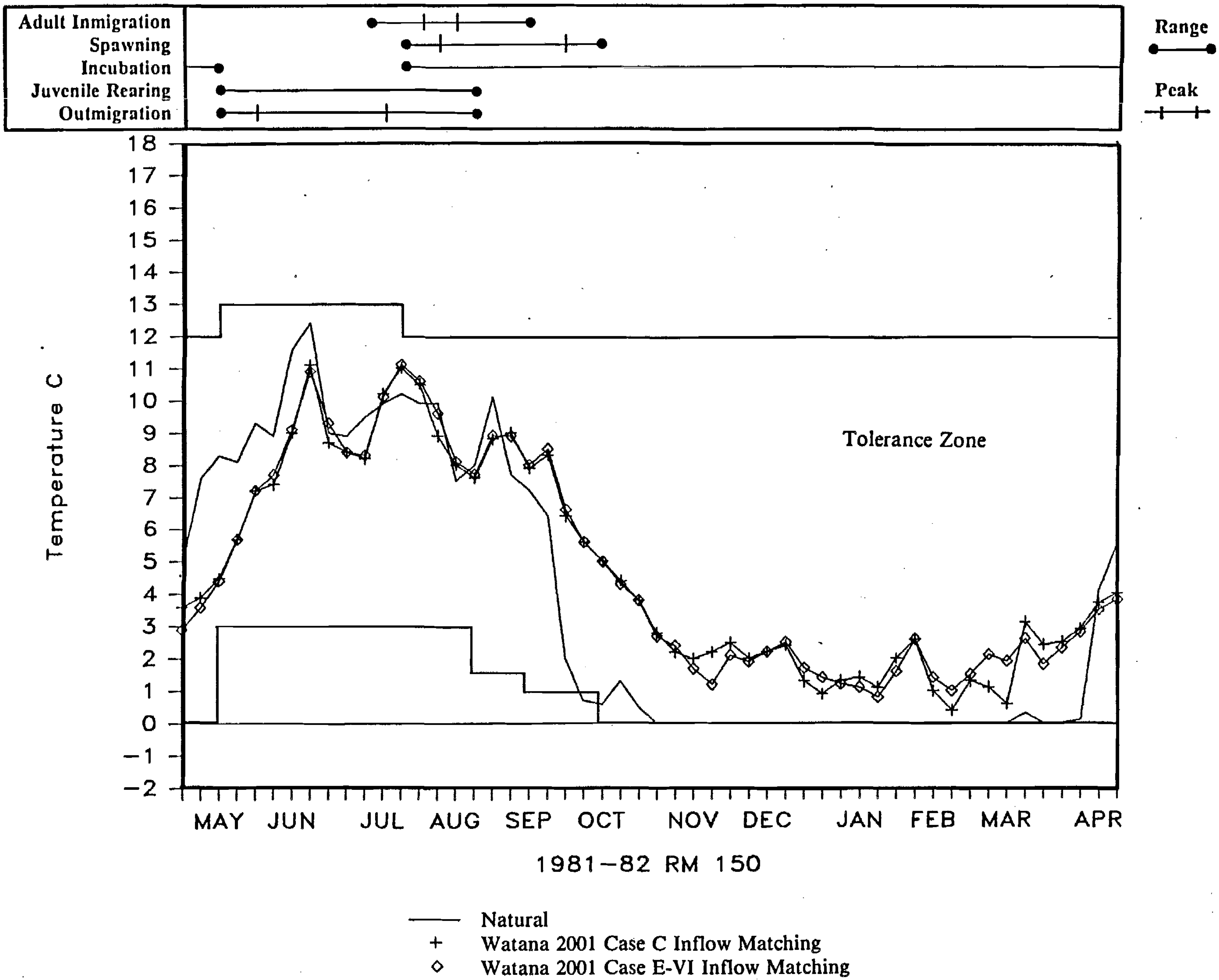


— Natural
\+ Devil Canyon 2002 Case C Inflow Matching
◇ Devil Canyon 2002 Case C Warmest Water

APPENDIX C

Temperature chronologies at three middle river locations in relation to five Pacific salmon life stage temperature tolerance criteria for natural, Case C "inflow matching," and Case E-VI "inflow matching"

CHUM SALMON


Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
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Tolerance Zone
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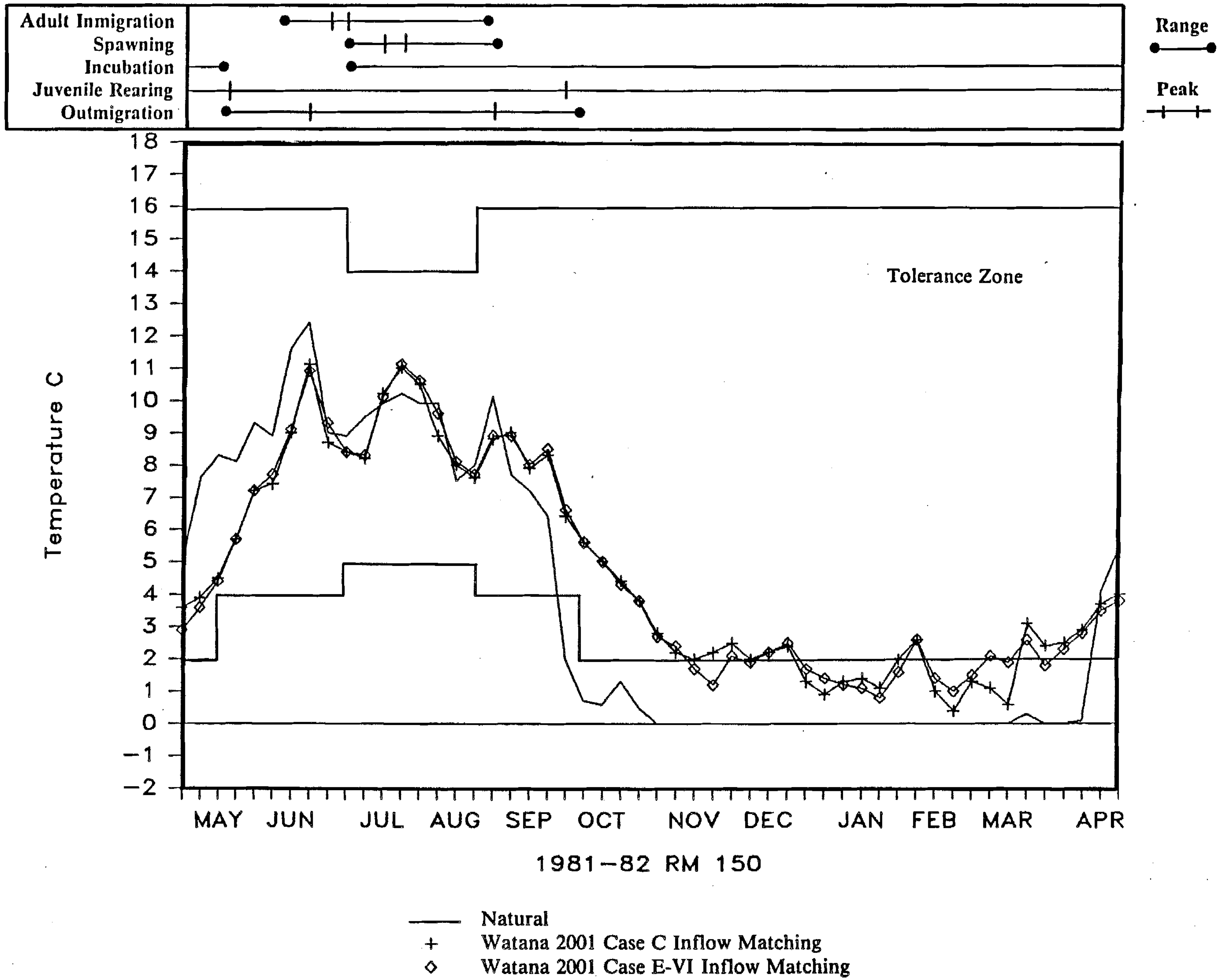
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
+ Watana 2001 Case C Inflow Matching
◇ Watana 2001 Case E-VI Inflow Matching

CHINOOK SALMON



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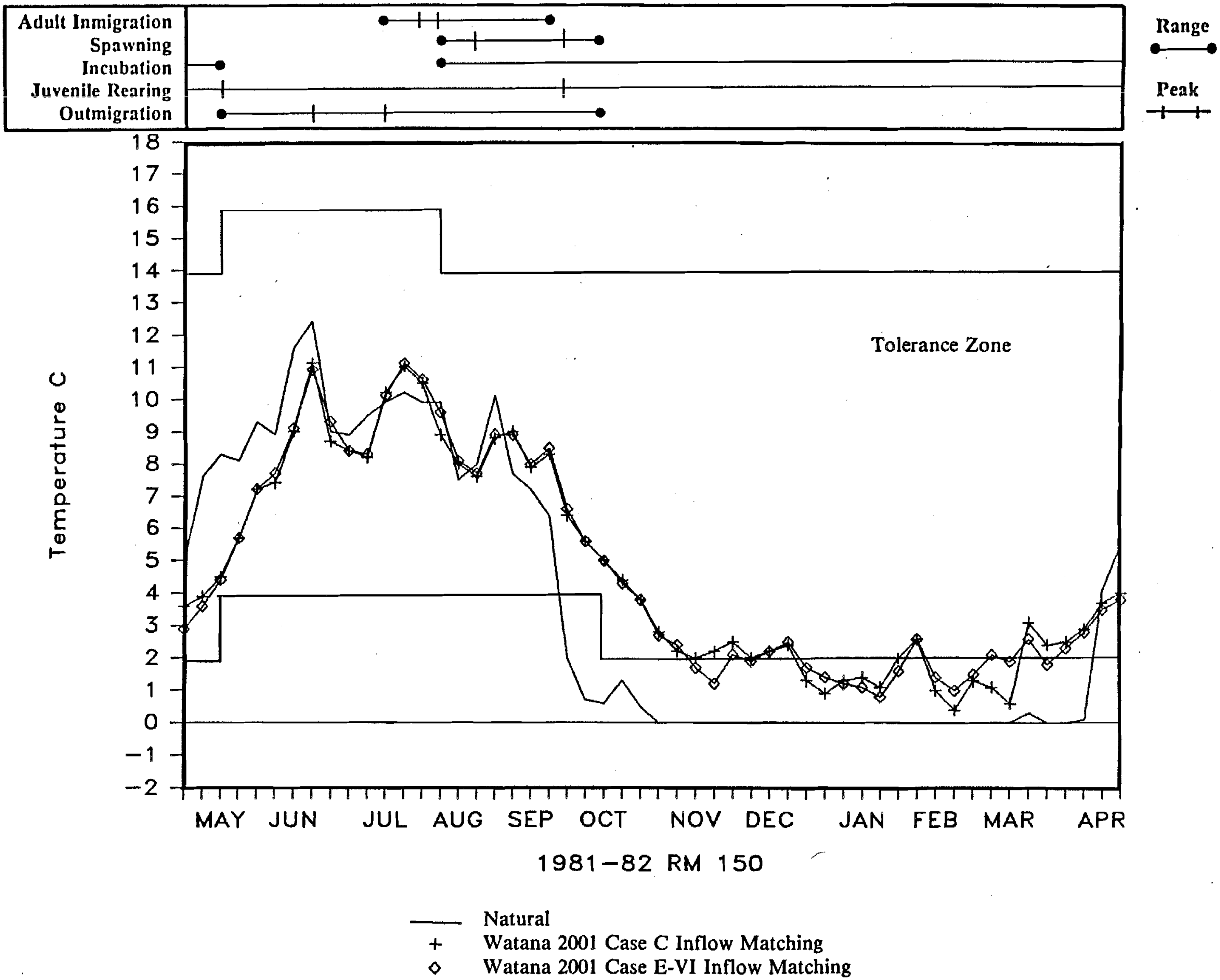
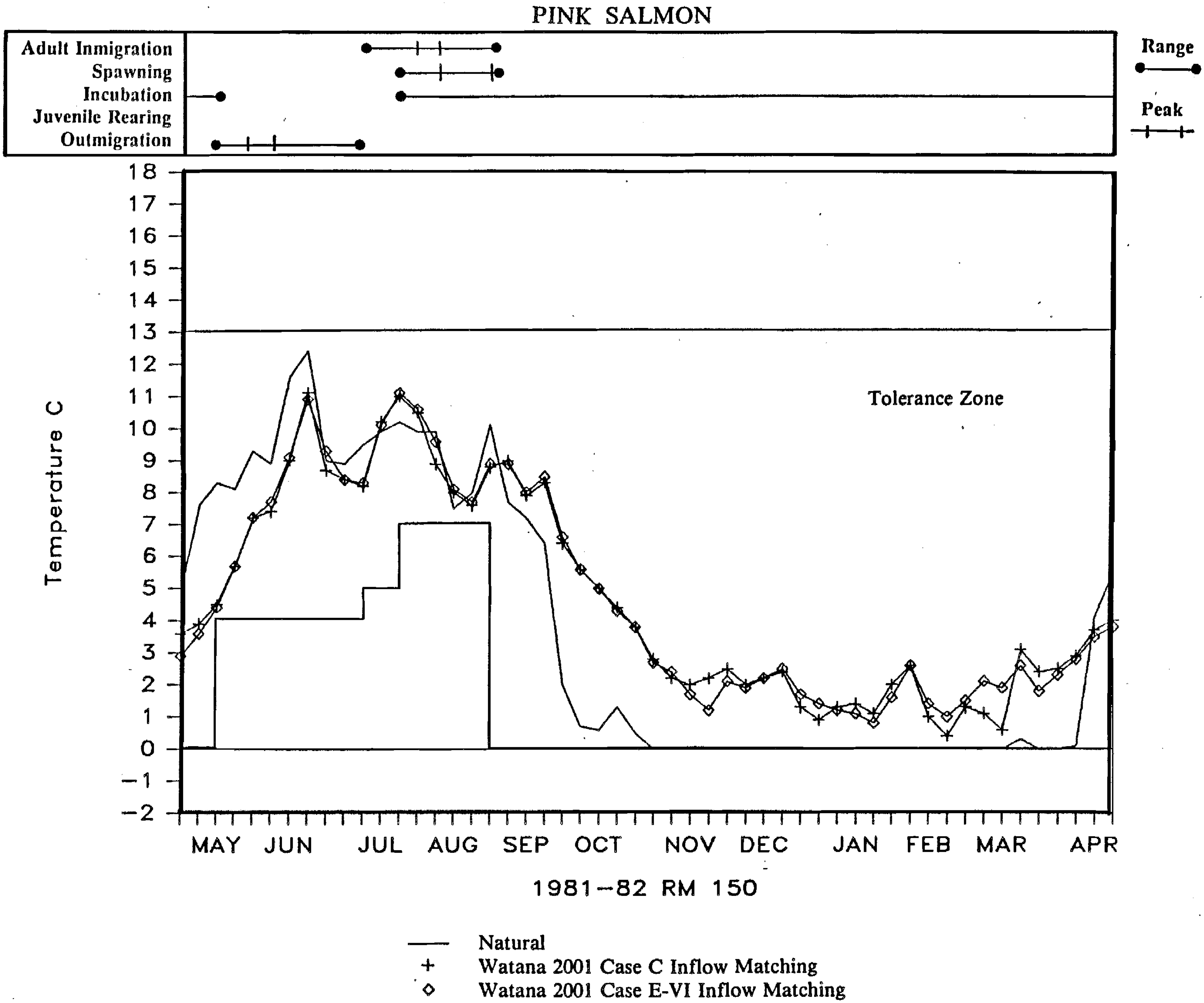
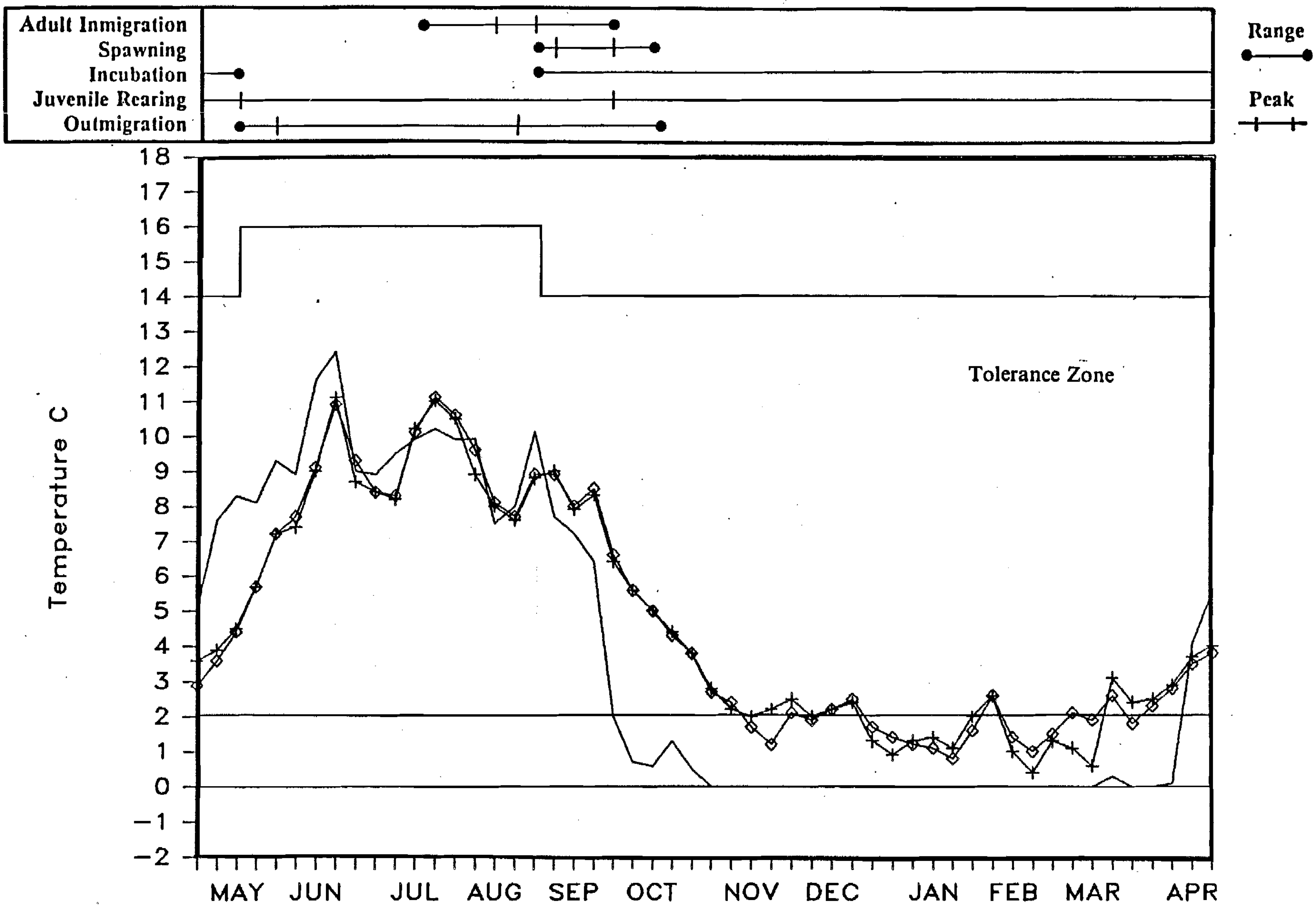



PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981–82 RM 150
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case E-VI Inflow Matching

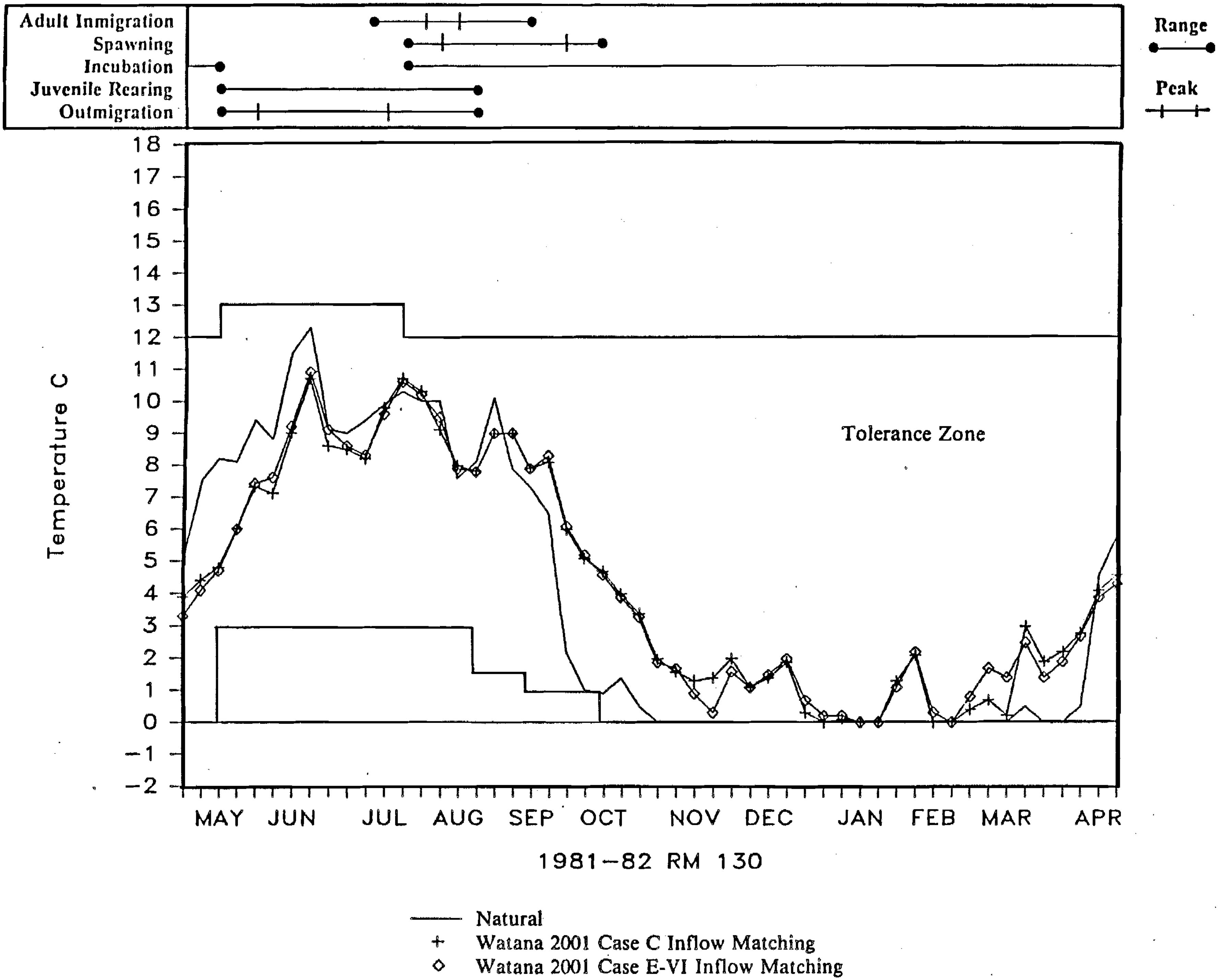
COHO SALMON



1981−82 RM 150

—— Natural
\+ Watana 2001 Case C Inflow Matching
◇ Watana 2001 Case E-VI Inflow Matching

CHUM SALMON



Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
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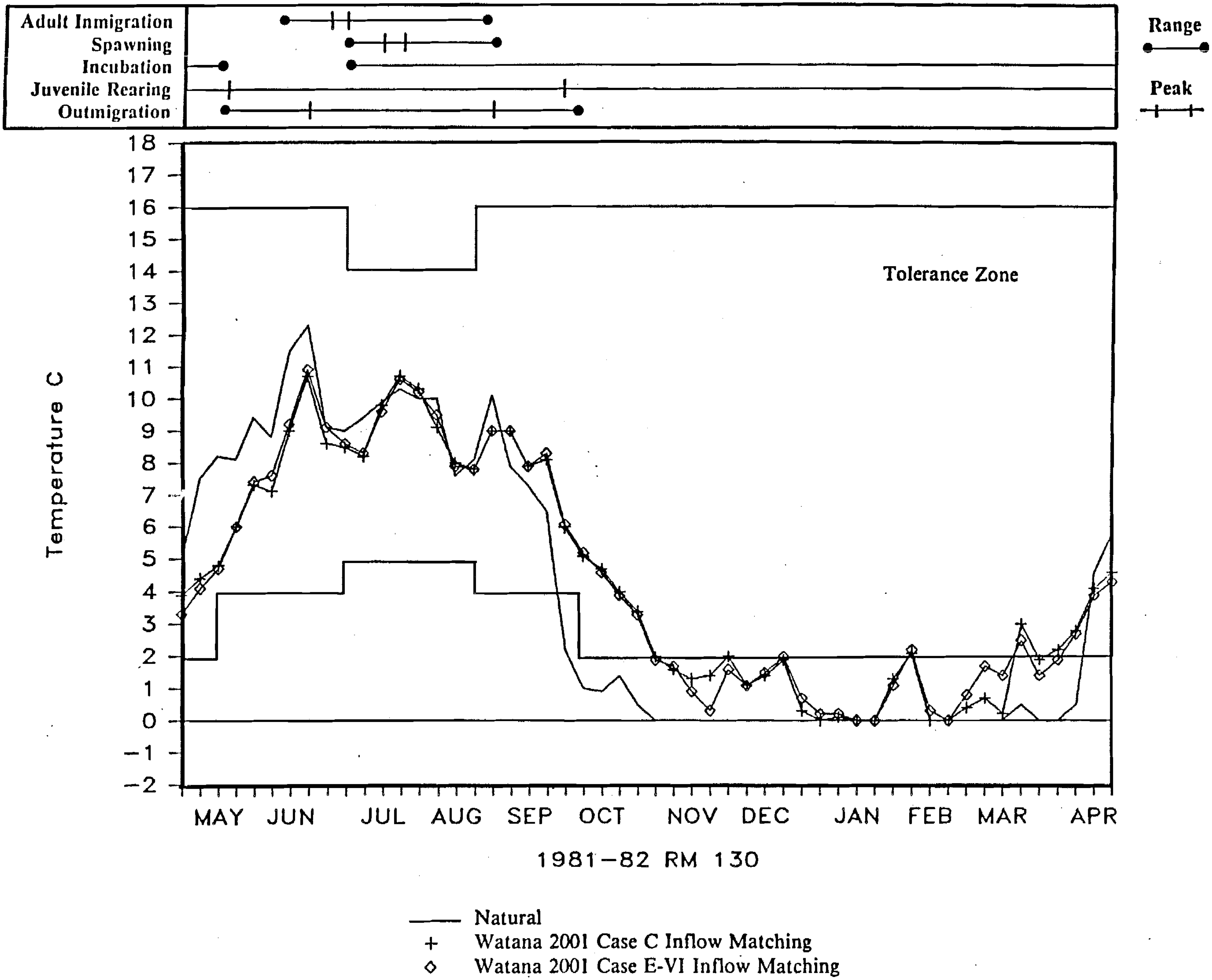
1981−82 RM 130
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case E-VI Inflow Matching

CHINOOK SALMON



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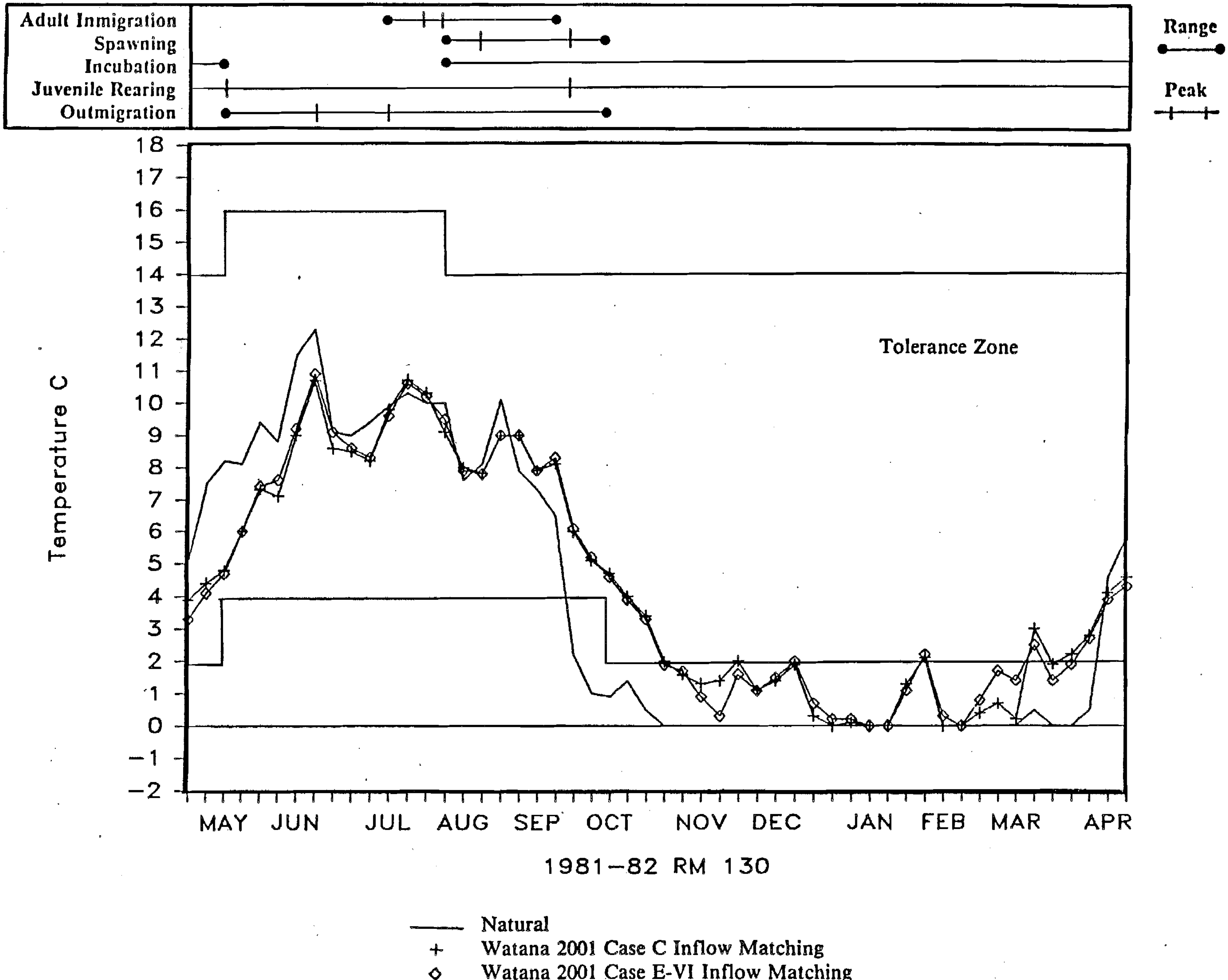
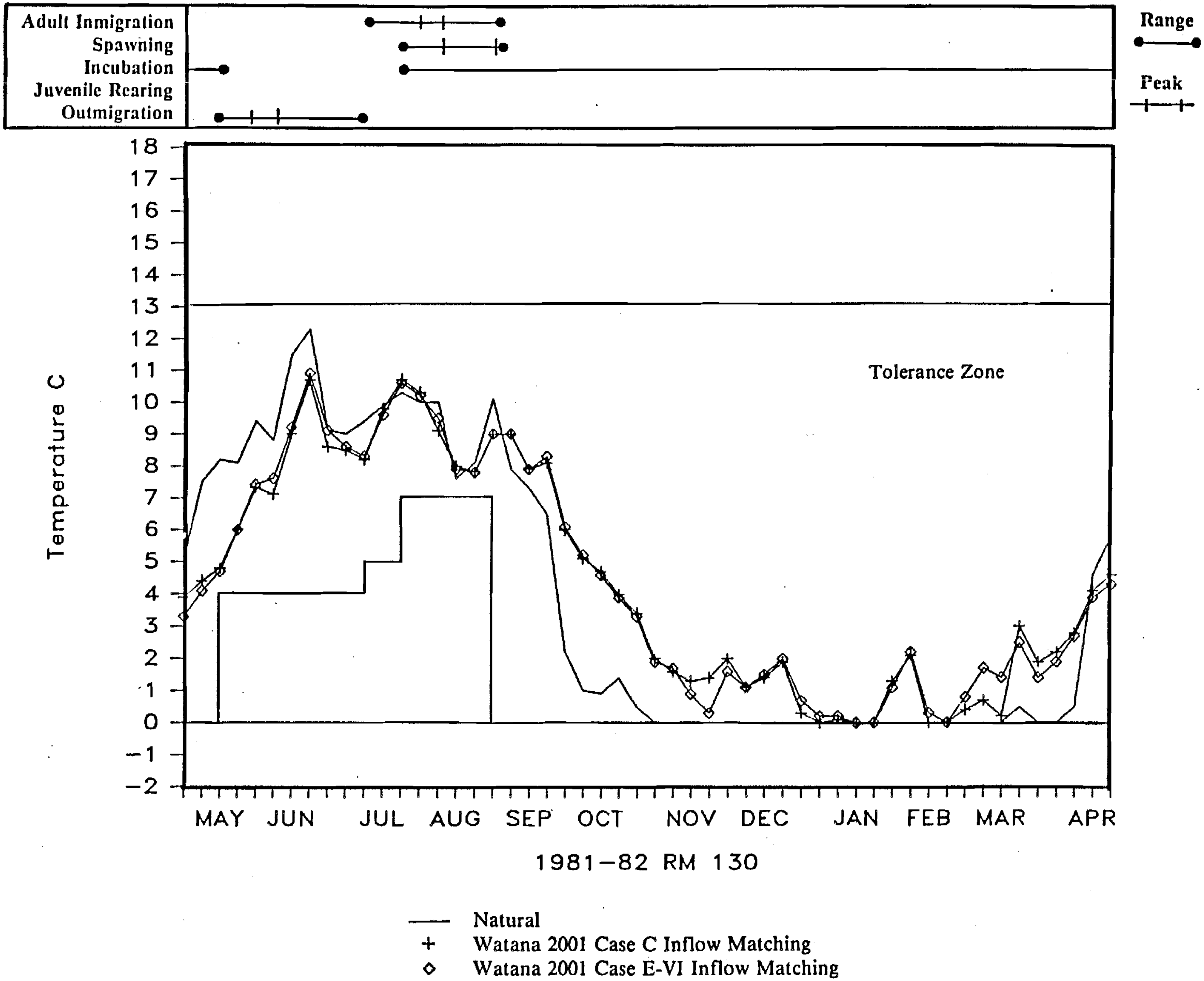


PINK SALMON



Adult Inmigration
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Incubation
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Outmigration
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1981−82 RM 130
Natural
+ Watana 2001 Case C Inflow Matching
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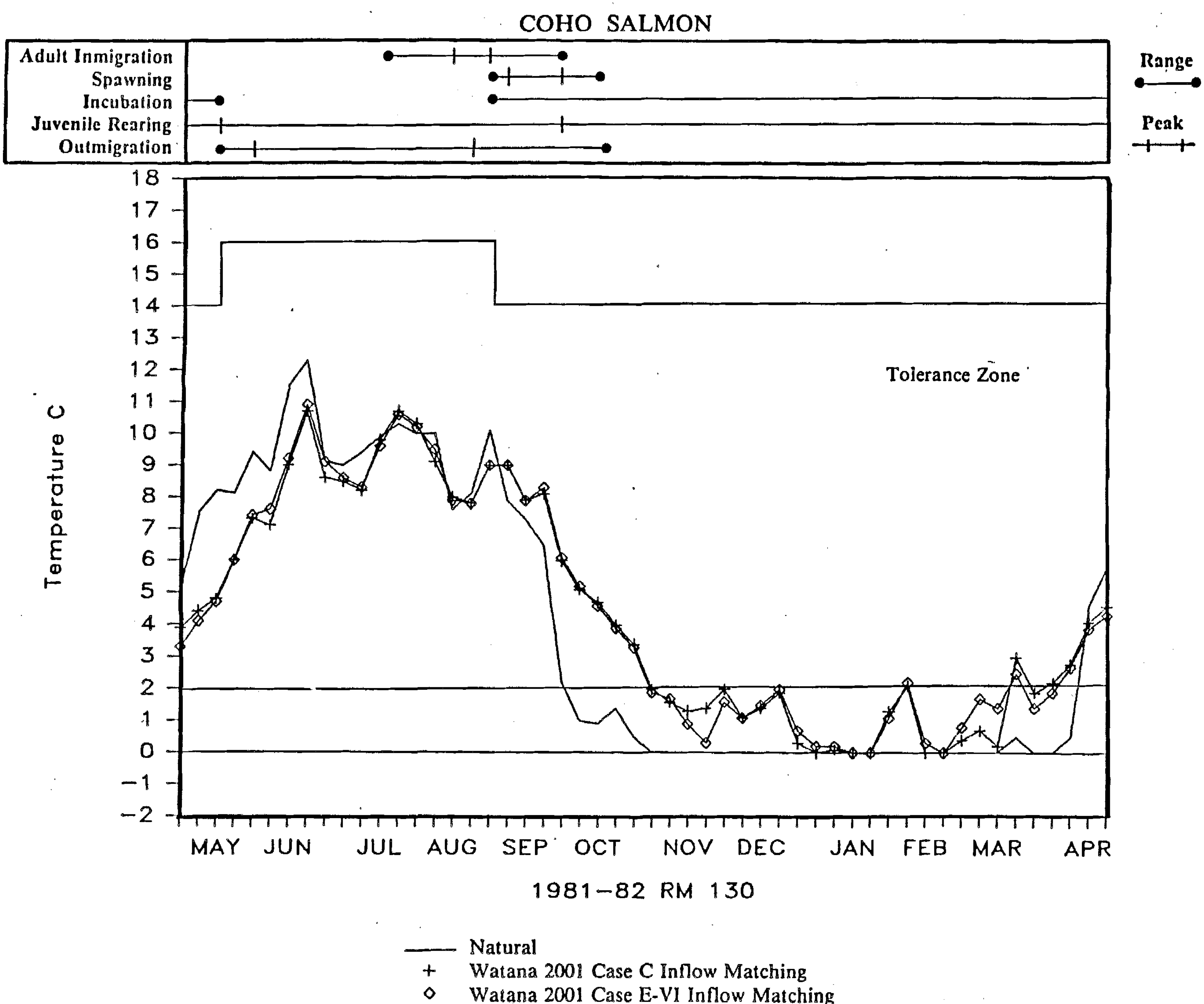

COHO SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
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Tolerance Zone
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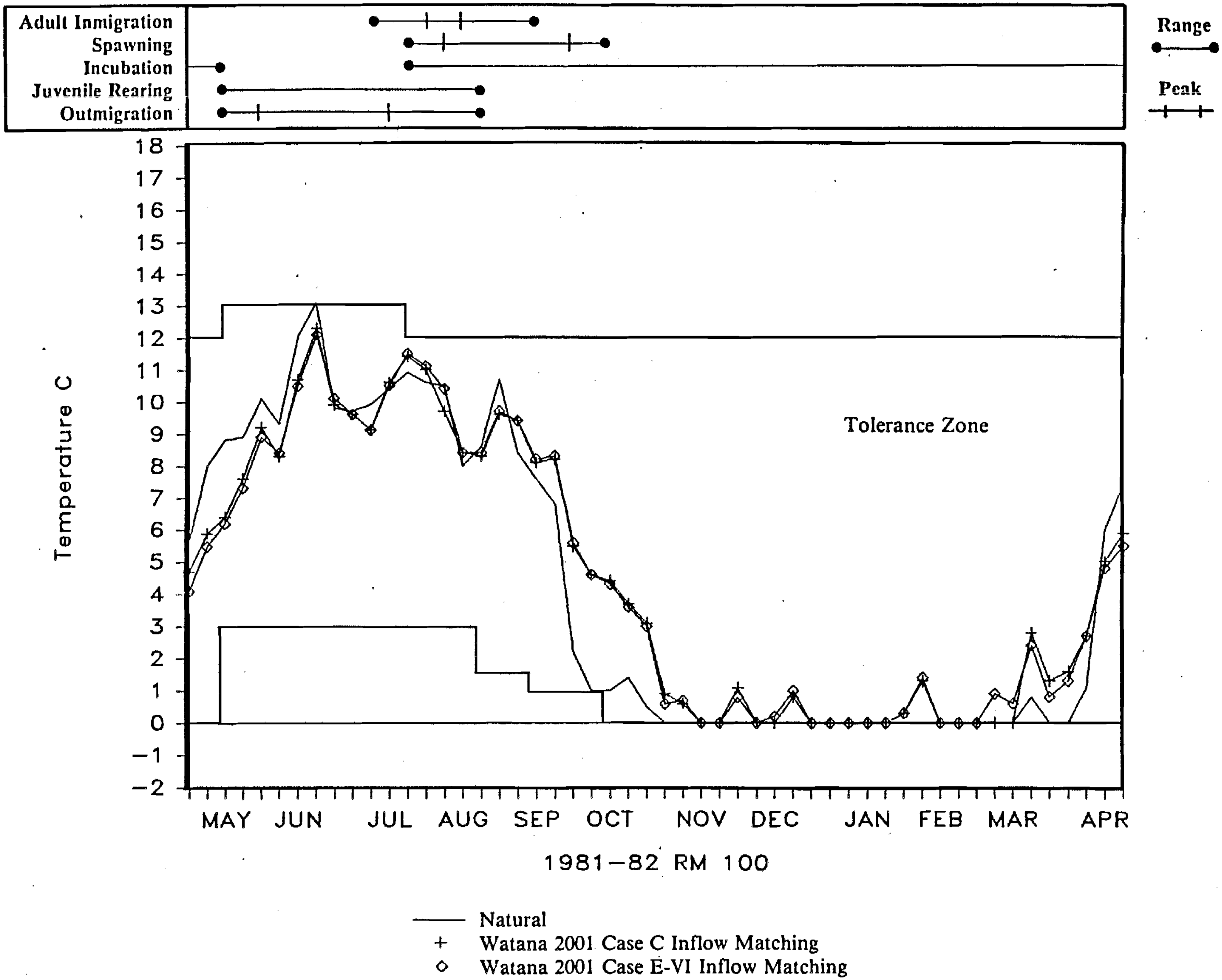
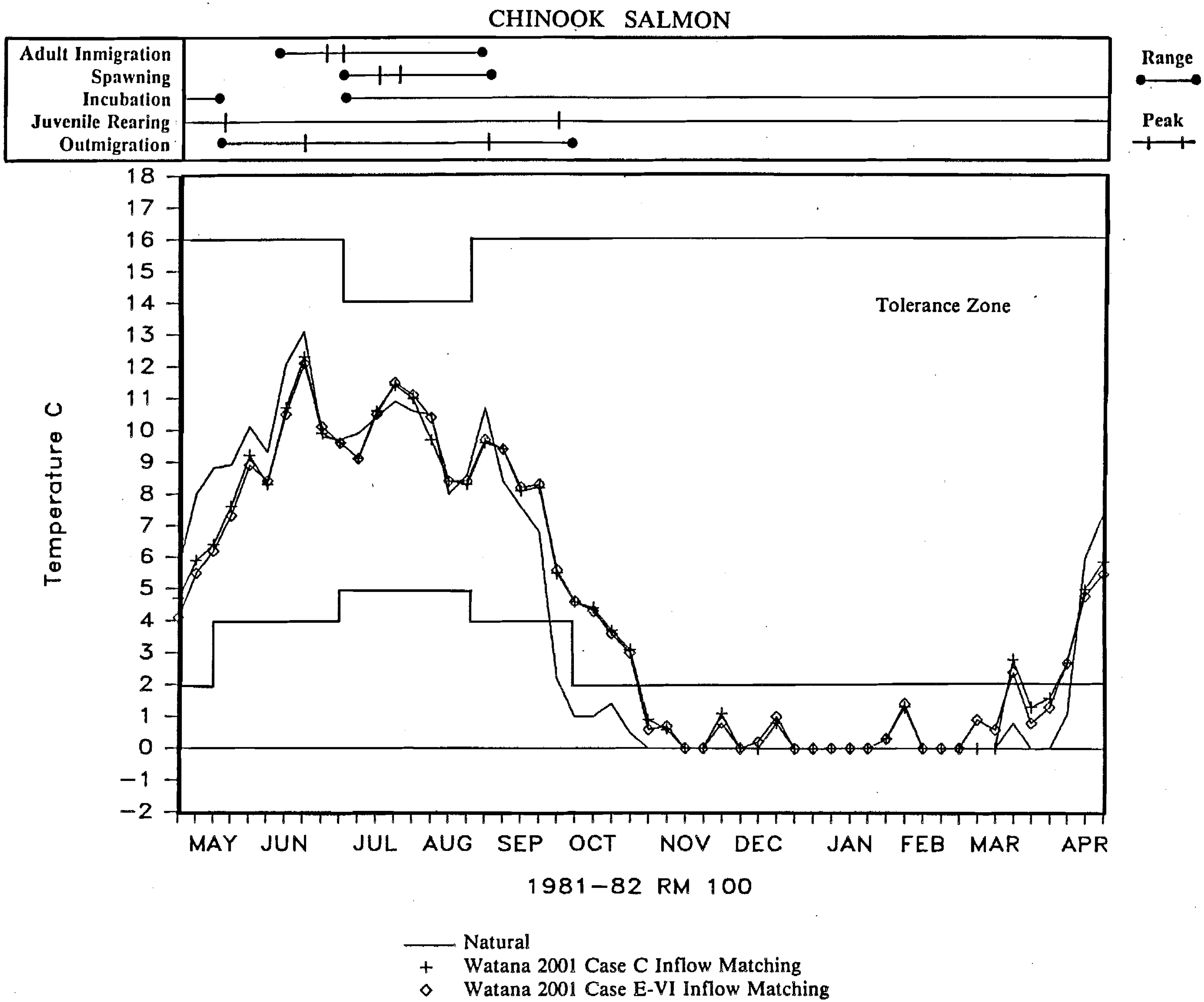
1981−82 RM 130
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case E-VI Inflow Matching

C10

CHUM SALMON



Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981–82 RM 100
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case E-VI Inflow Matching


CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
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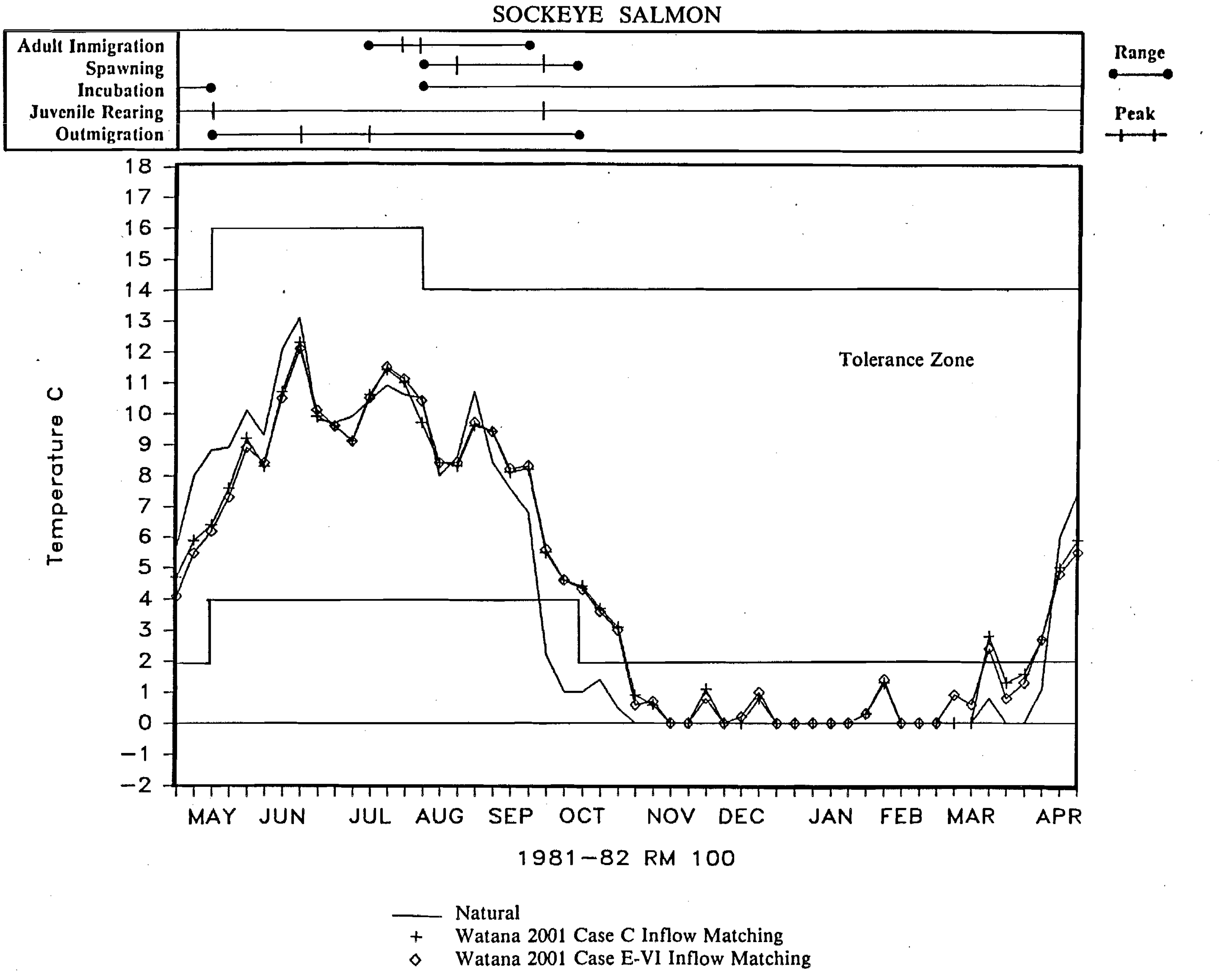
1981−82 RM 100
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case E-VI Inflow Matching


SOCKEYE SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
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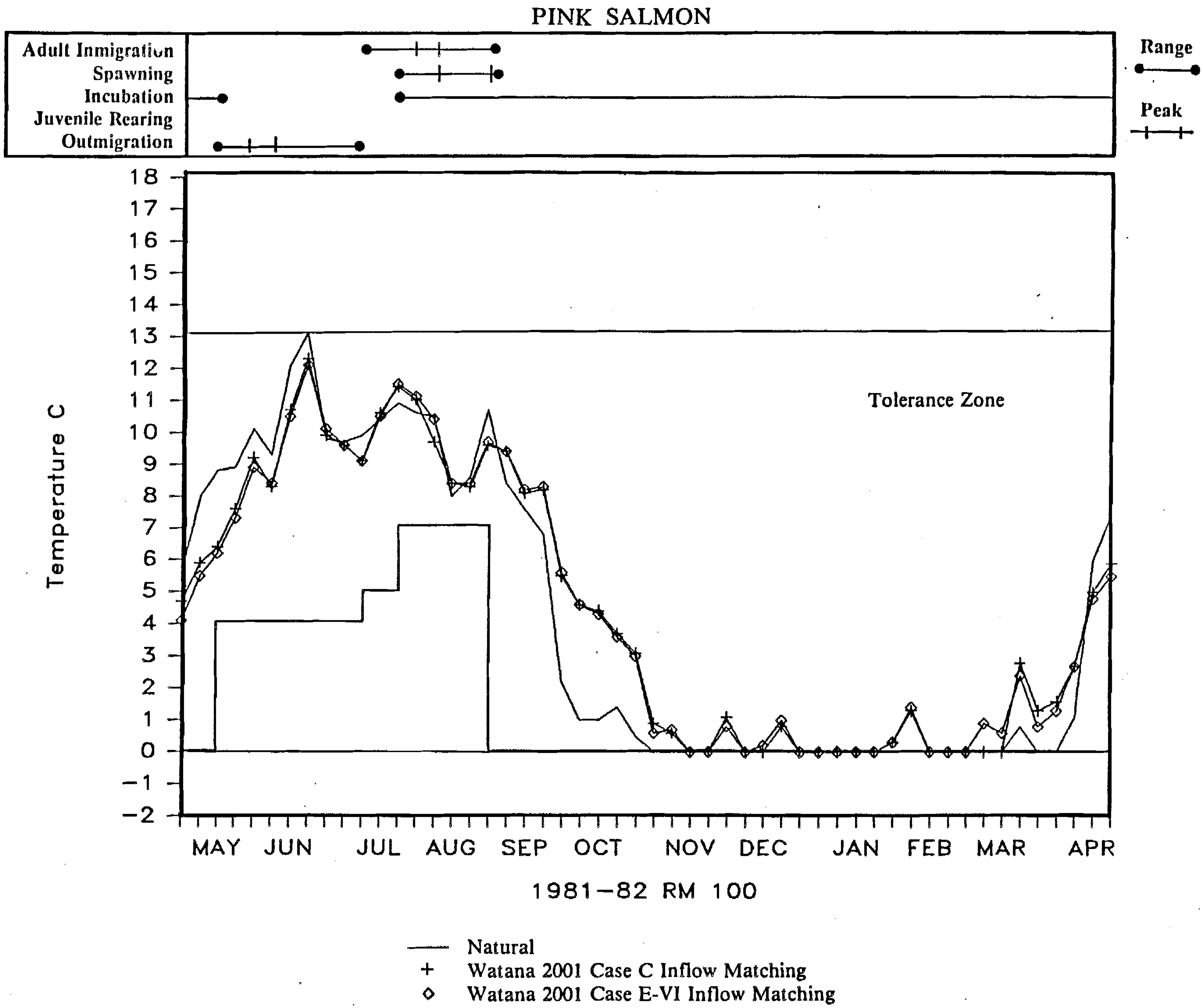
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 100
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case E-VI Inflow Matching


PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
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Tolerance Zone
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1981−82 RM 100
Natural
+ Watana 2001 Case C Inflow Matching
◇ Watana 2001 Case E-VI Inflow Matching

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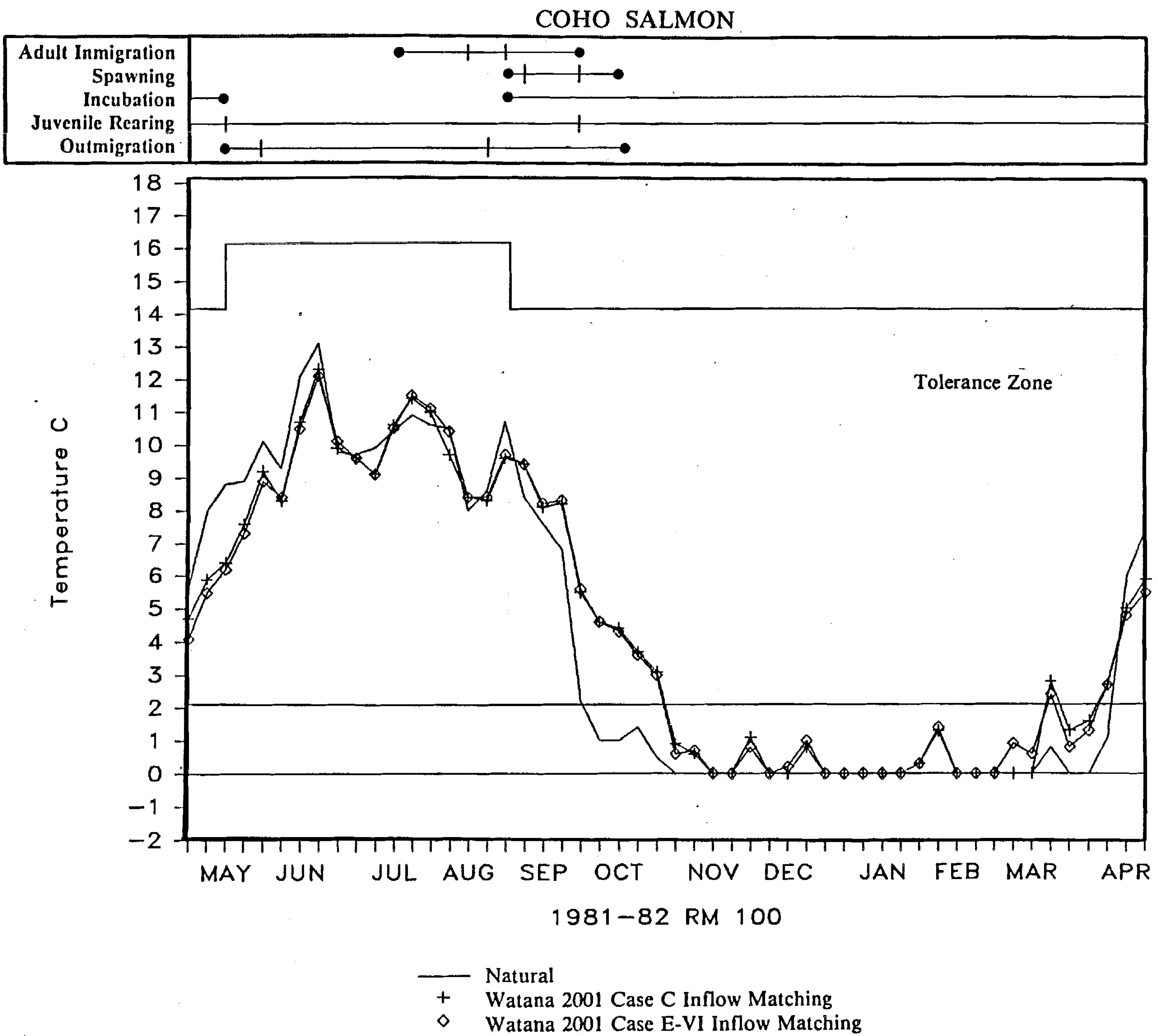
COHO SALMON
Adult Inmigration
Spawning
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Juvenile Rearing
Outmigration
Range
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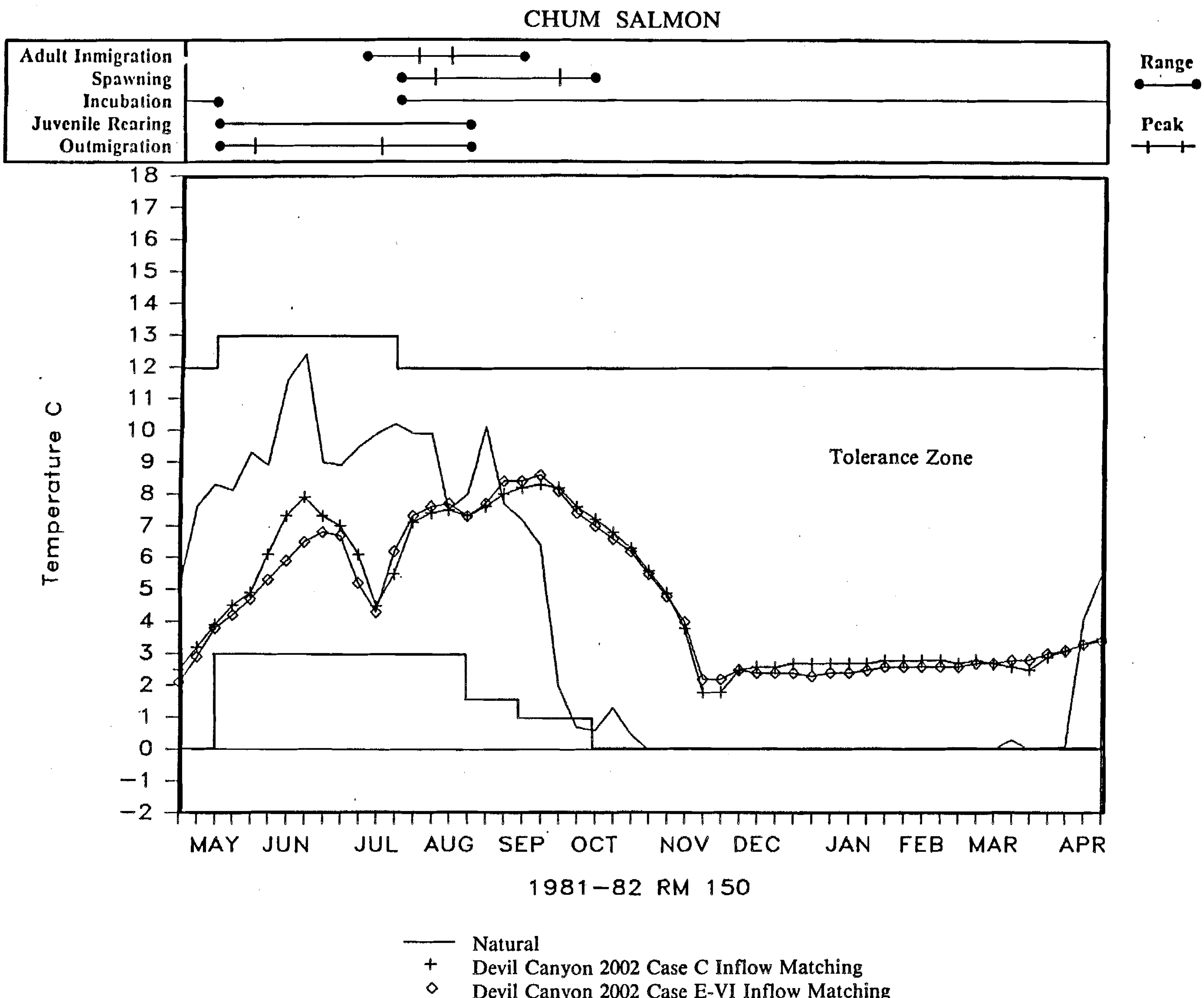
1981−82 RM 100
Natural
Watana 2001 Case C Inflow Matching
Watana 2001 Case E-VI Inflow Matching



CHUM SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
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Tolerance Zone
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1981−82 RM 150
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching

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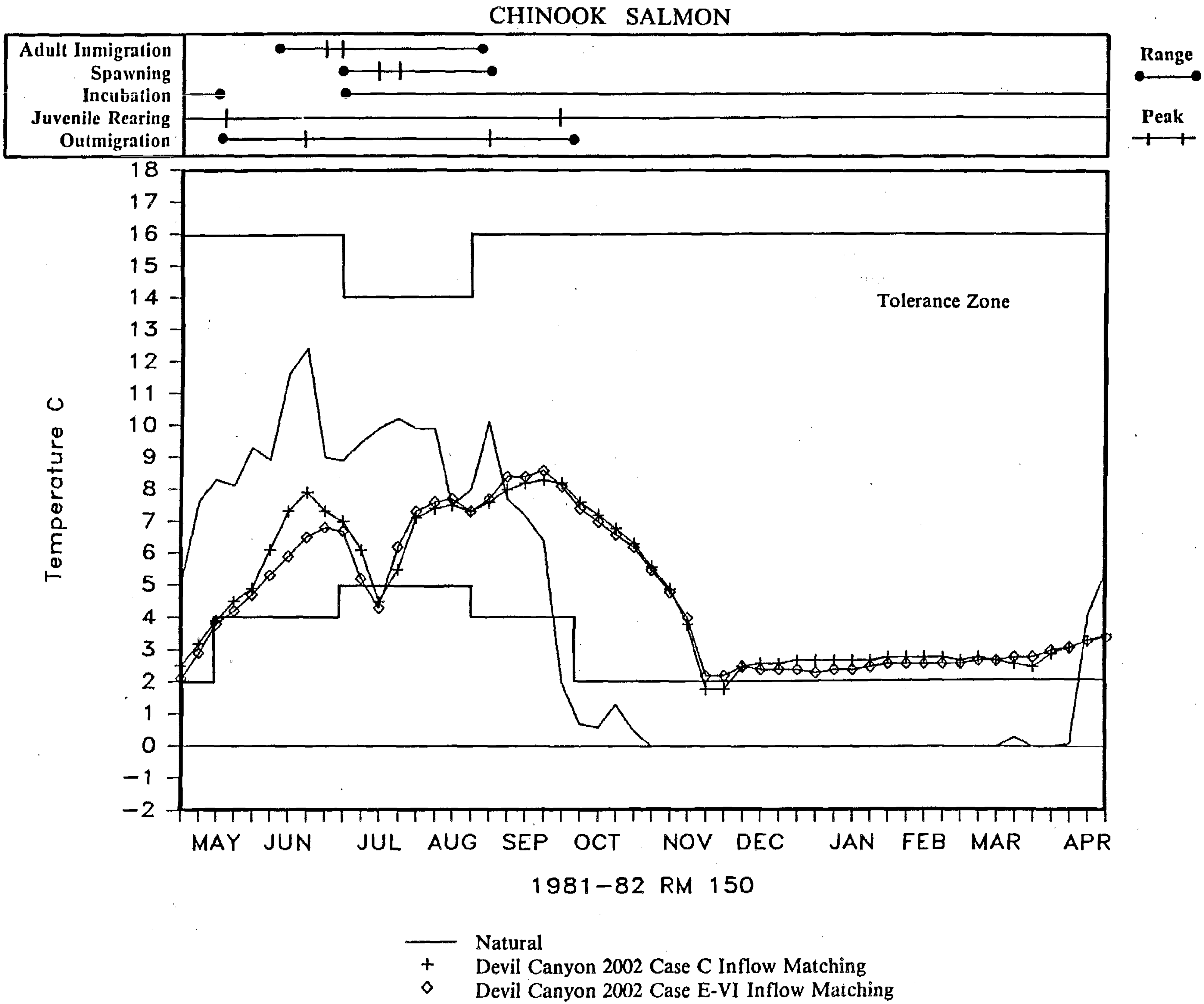
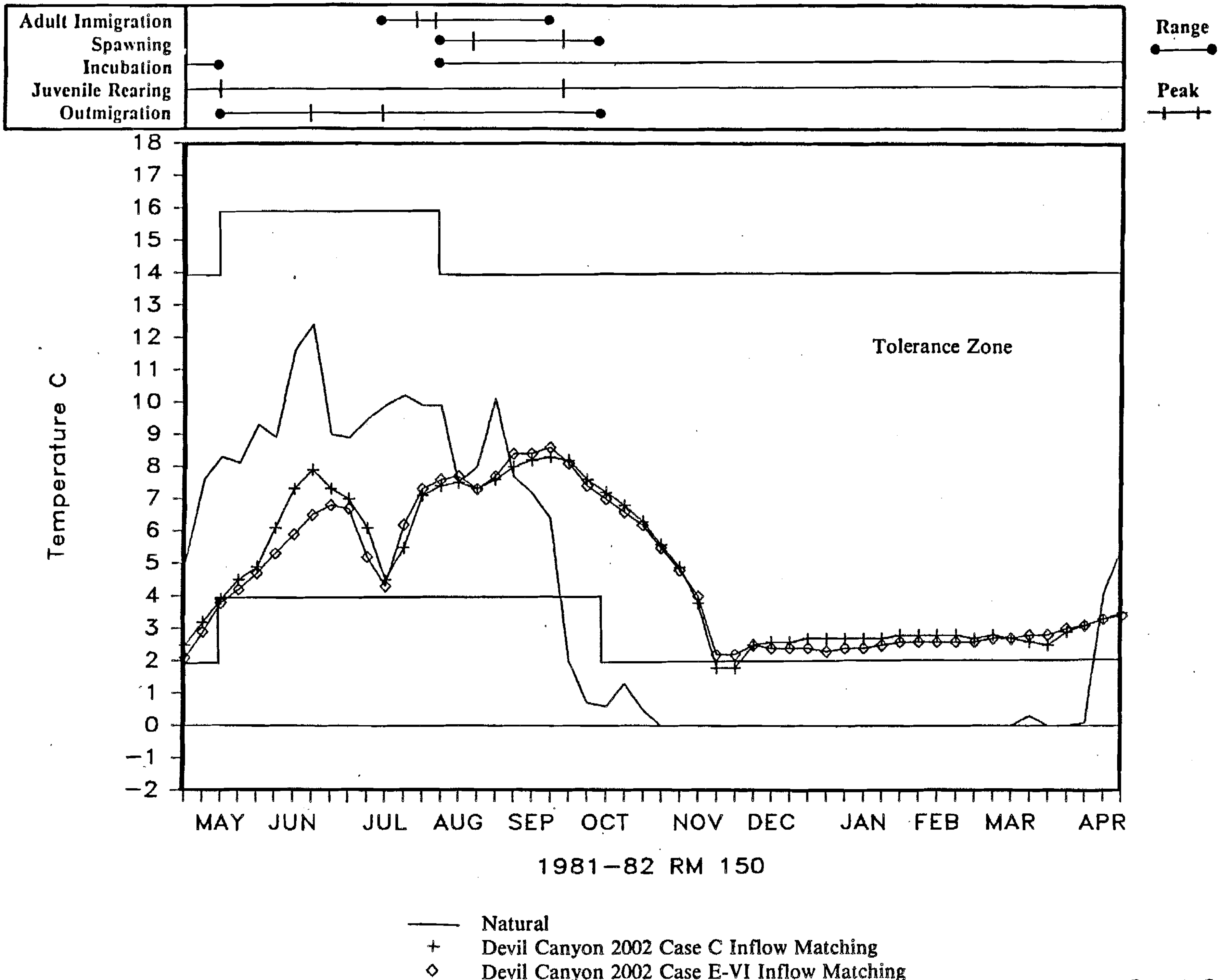
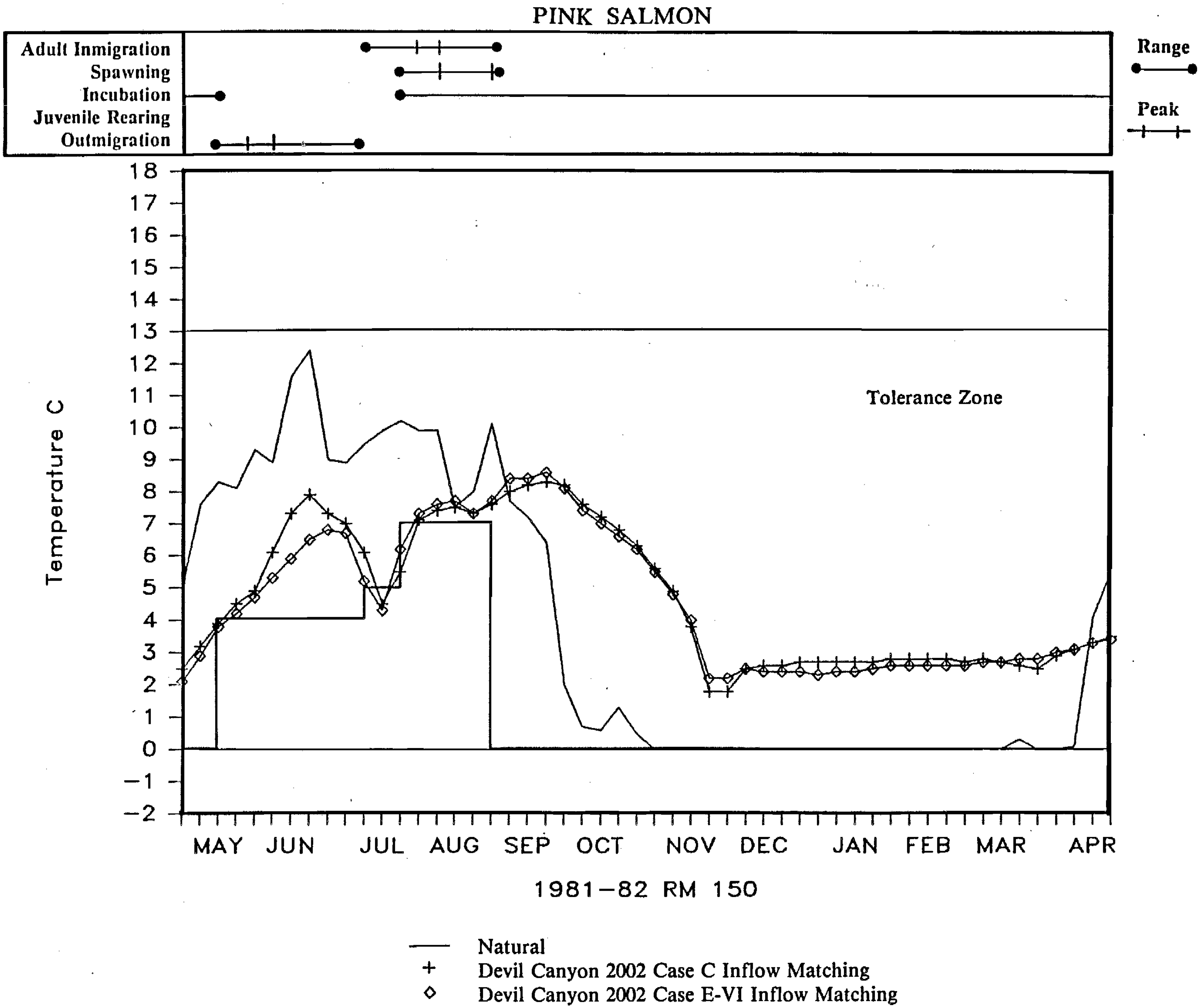

CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 −1 −2
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching

SOCKEYE SALMON




PINK SALMON
Adult Inmigration
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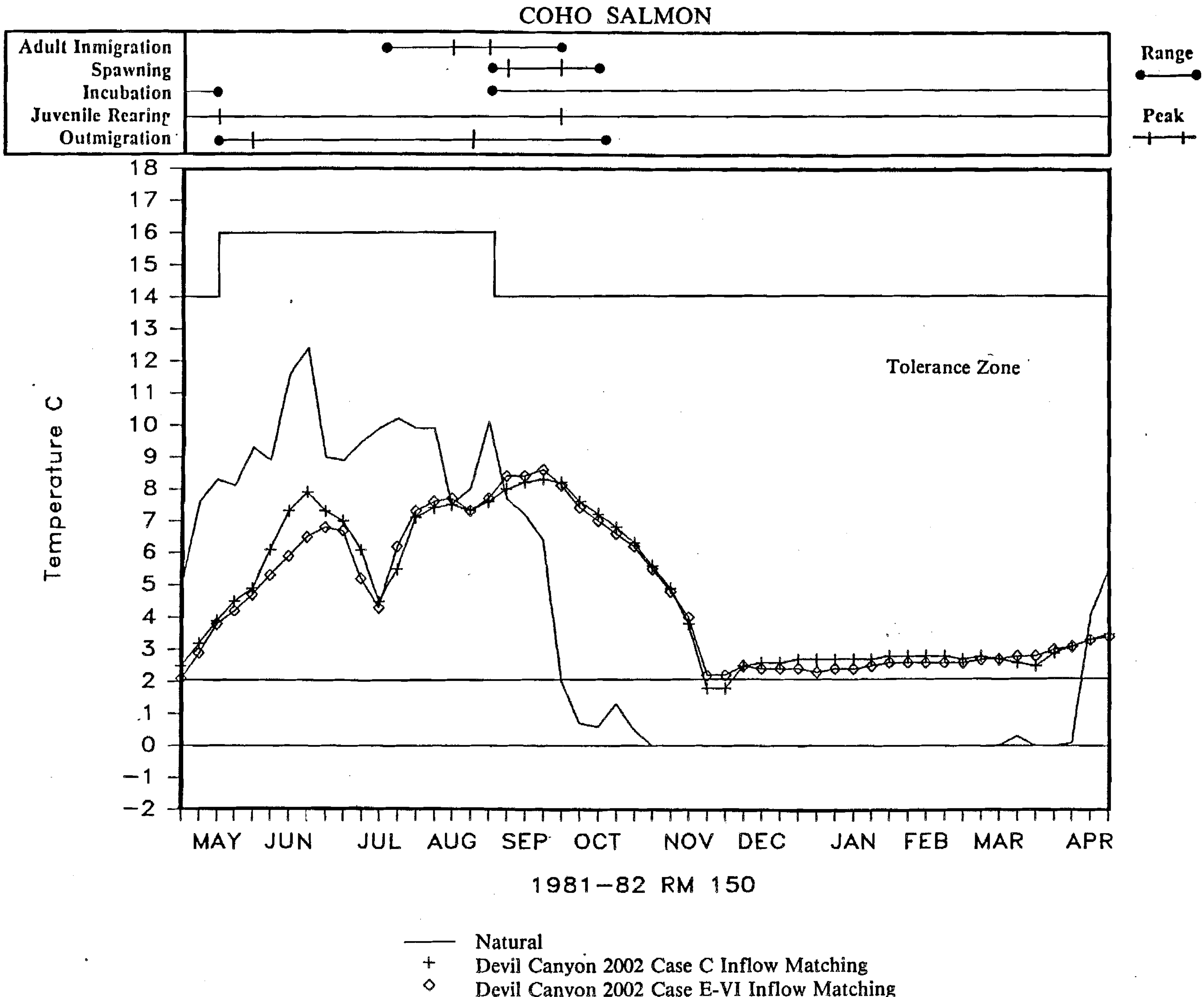
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching



COHO SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
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Tolerance Zone
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Devil Canyon 2002 Case C Inflow Matching
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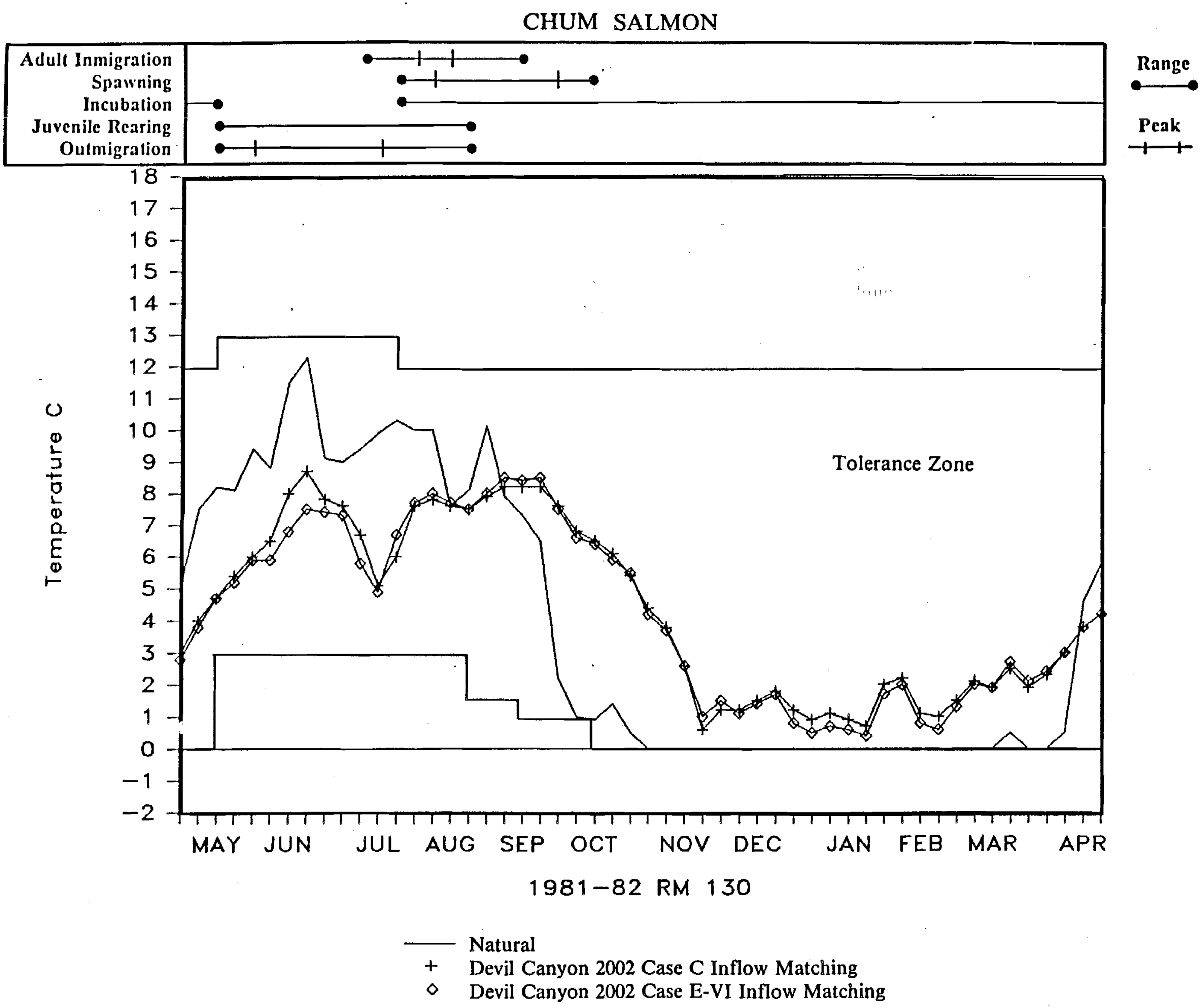
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Tolerance Zone
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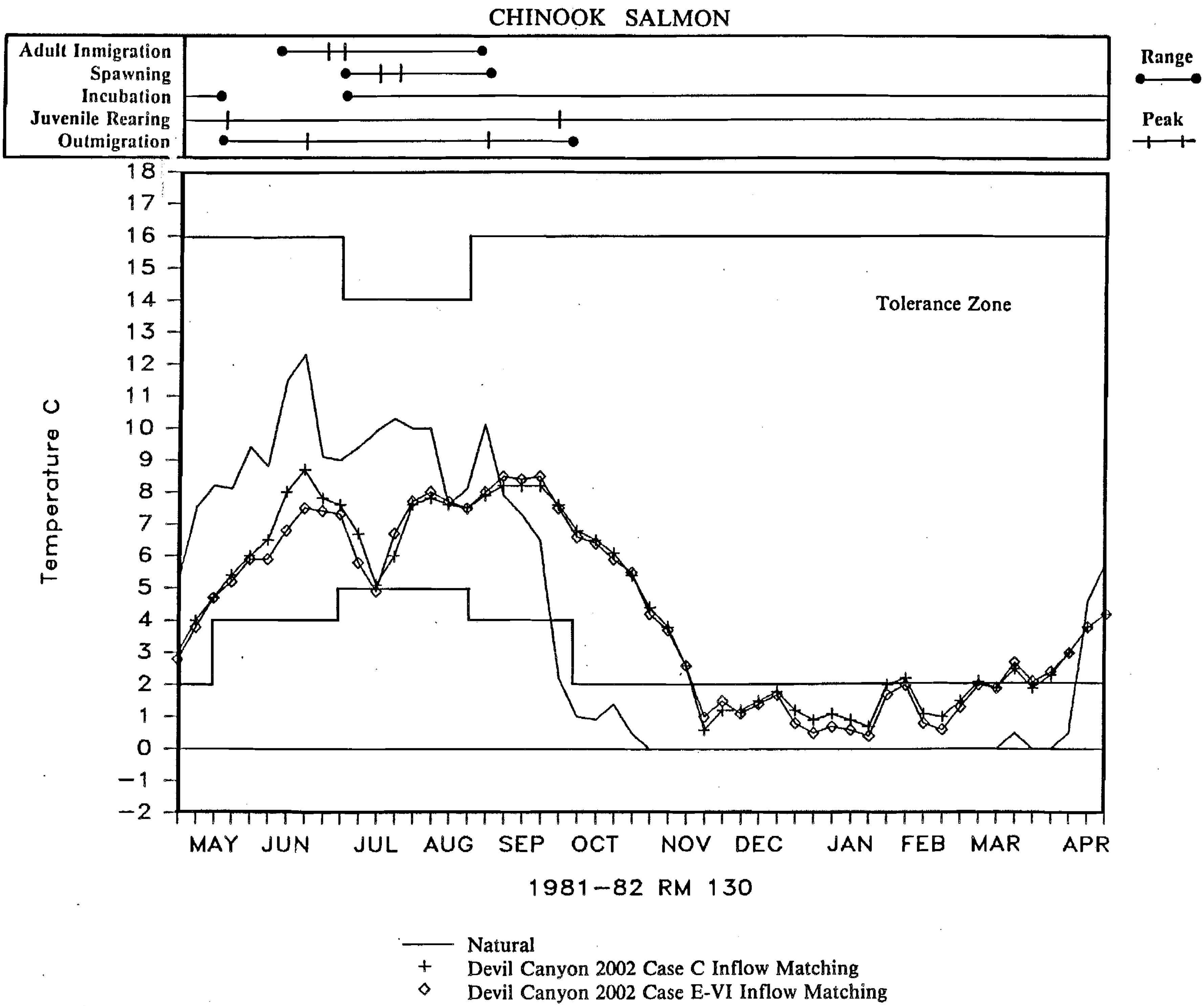
1981−82 RM 130
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching



CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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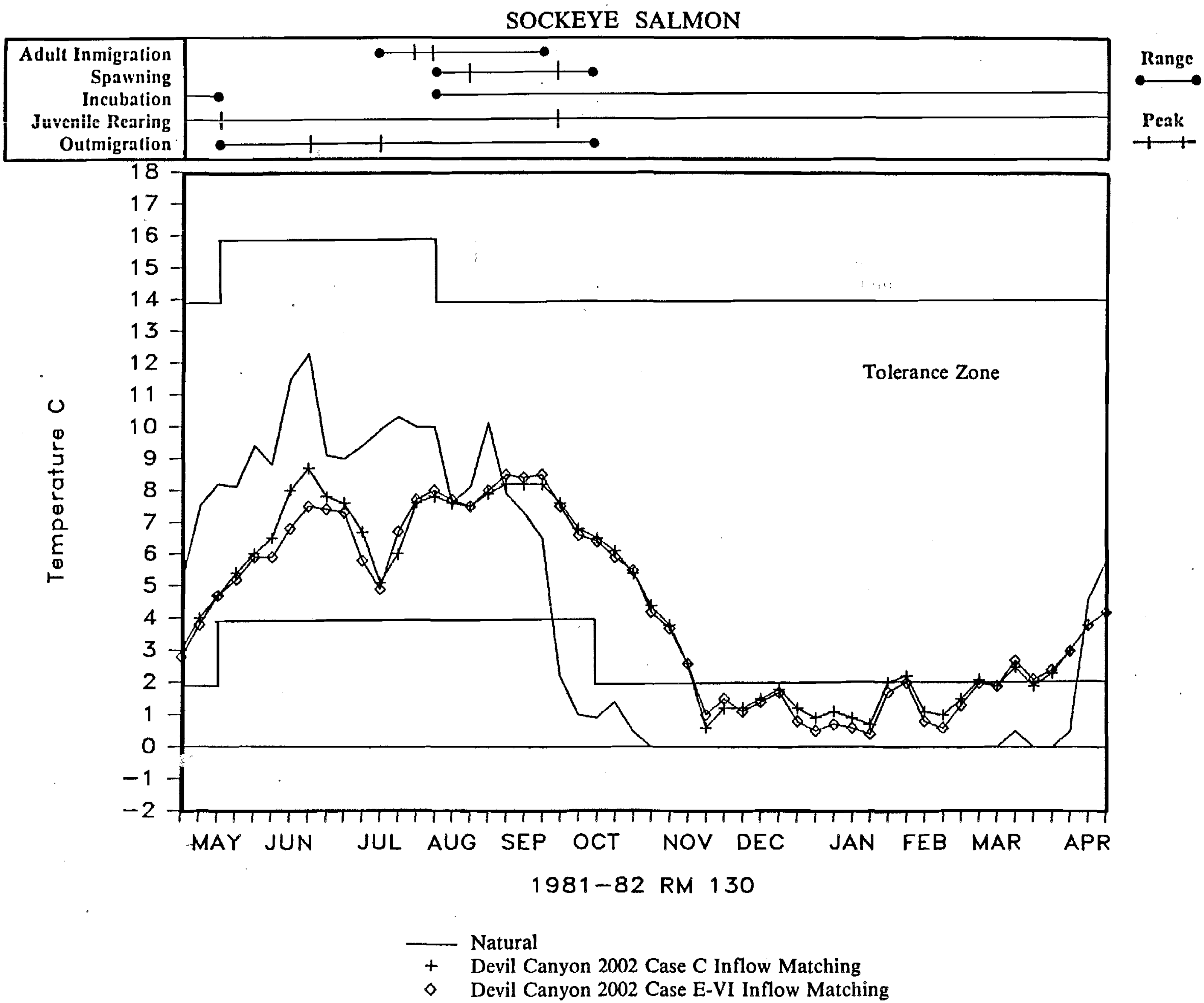
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 130
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching


SOCKEYE SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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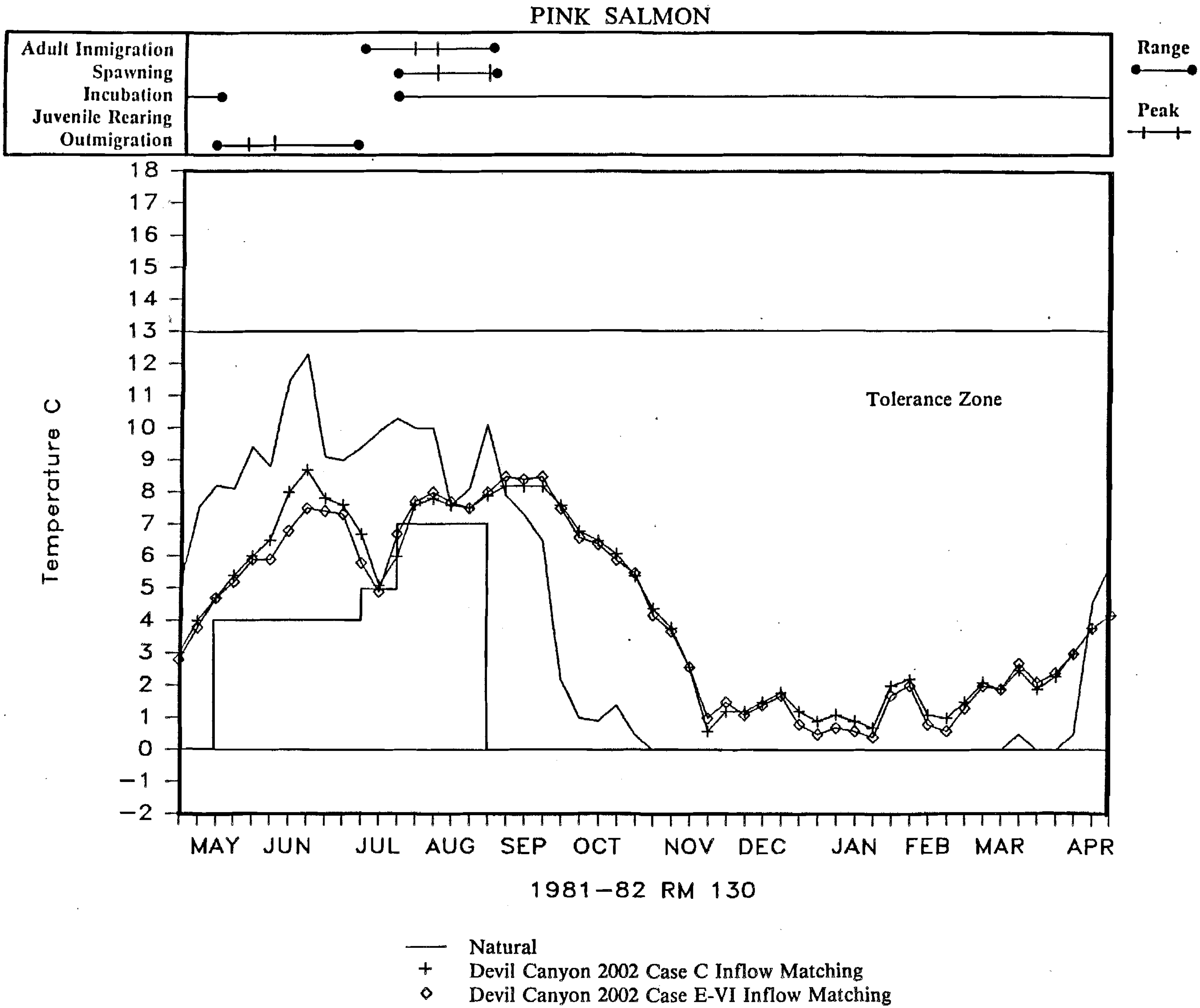
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 130
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching

C23


PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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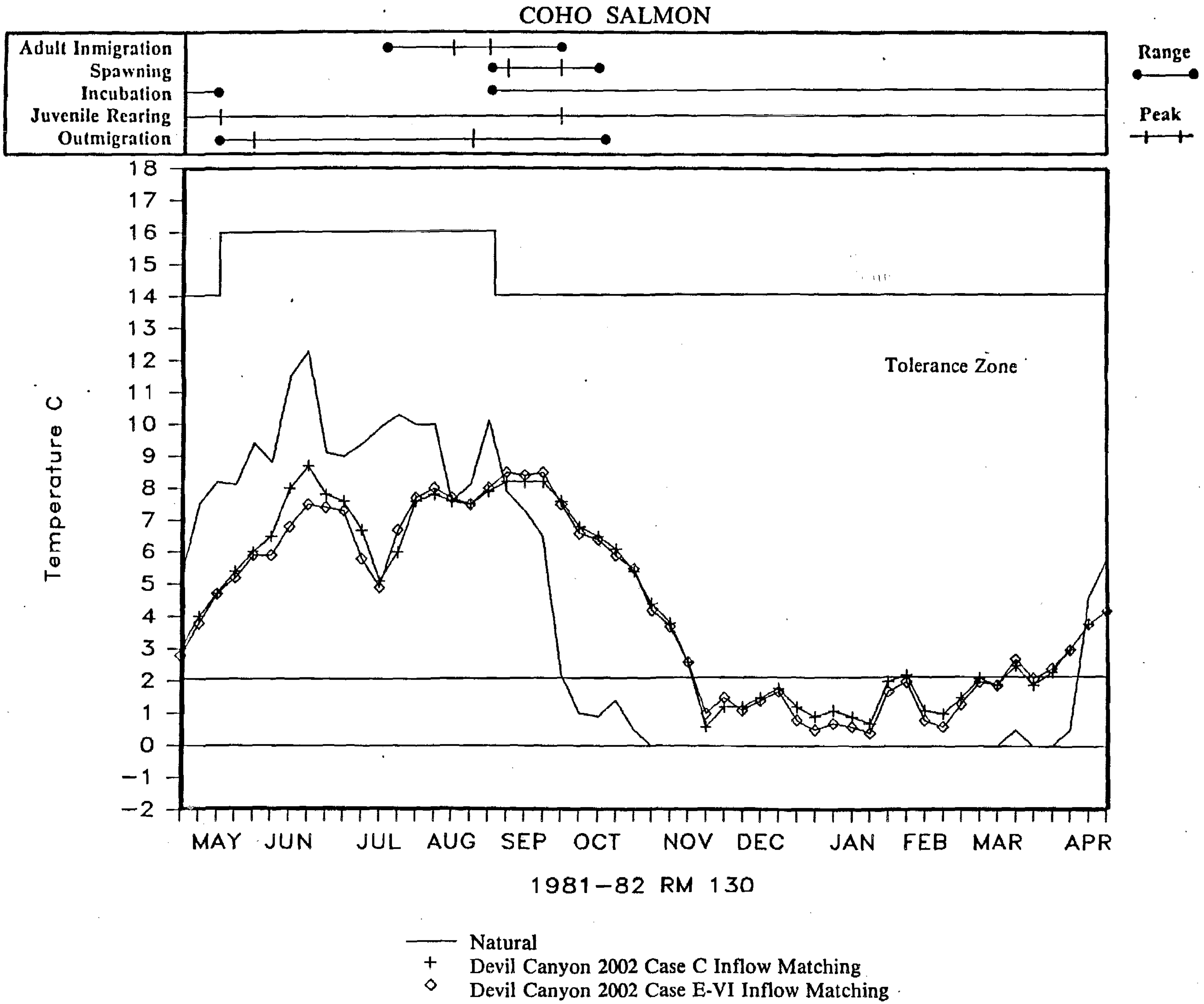
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 130
Natural
+ Devil Canyon 2002 Case C Inflow Matching
◇ Devil Canyon 2002 Case E-VI Inflow Matching

C25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Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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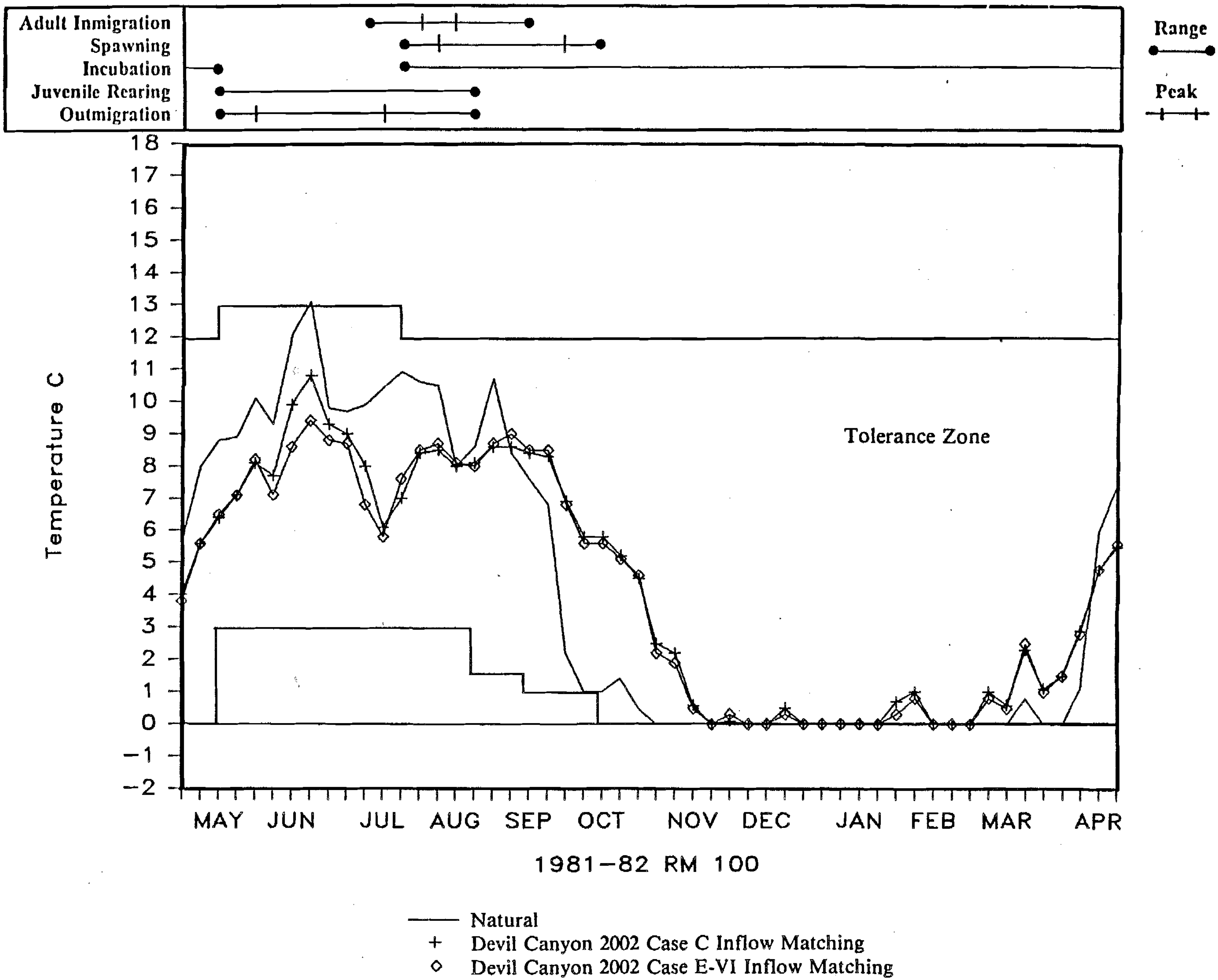
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 130
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching

CHUM SALMON


Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
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Temperature C
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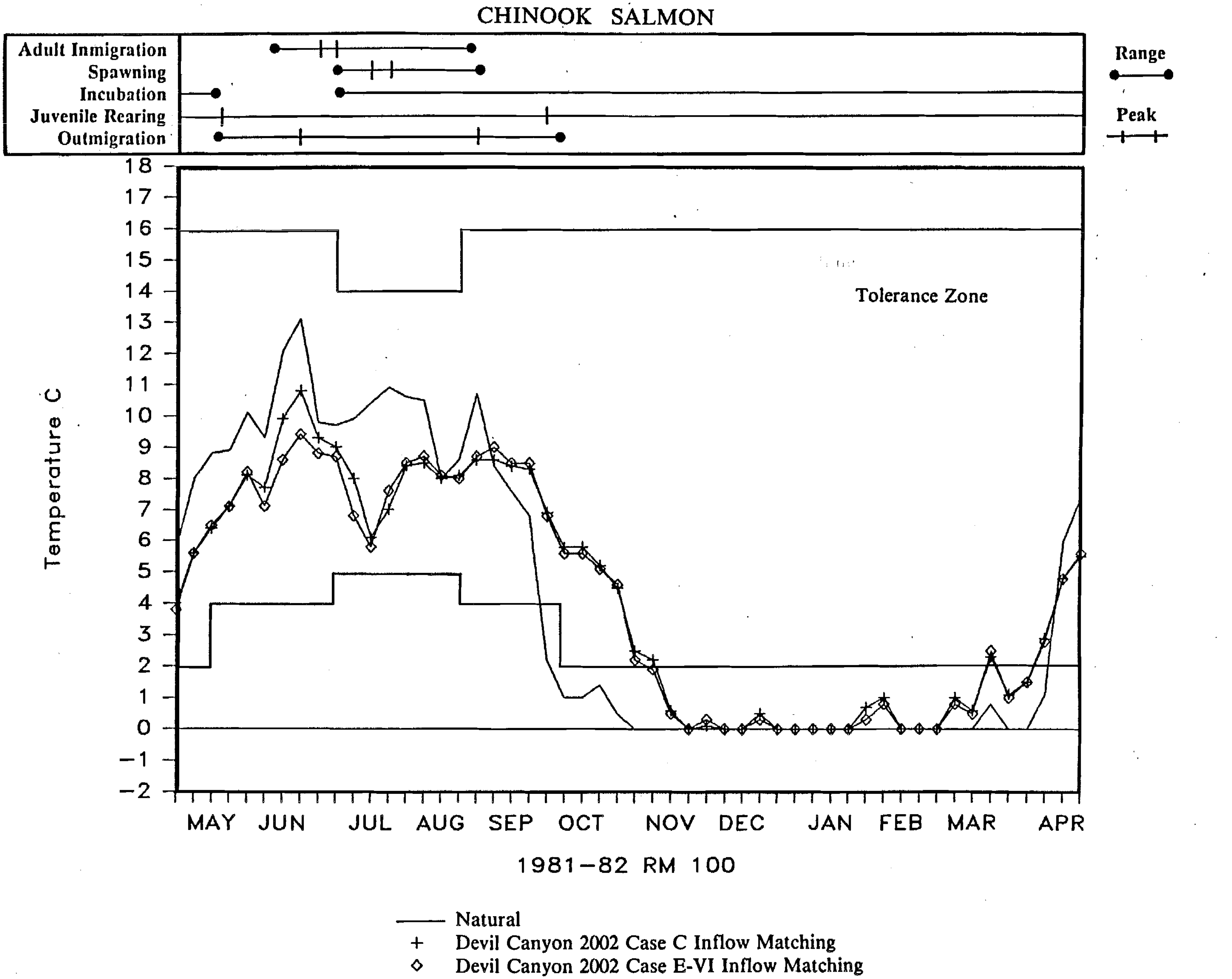
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 100
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching


CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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FEB
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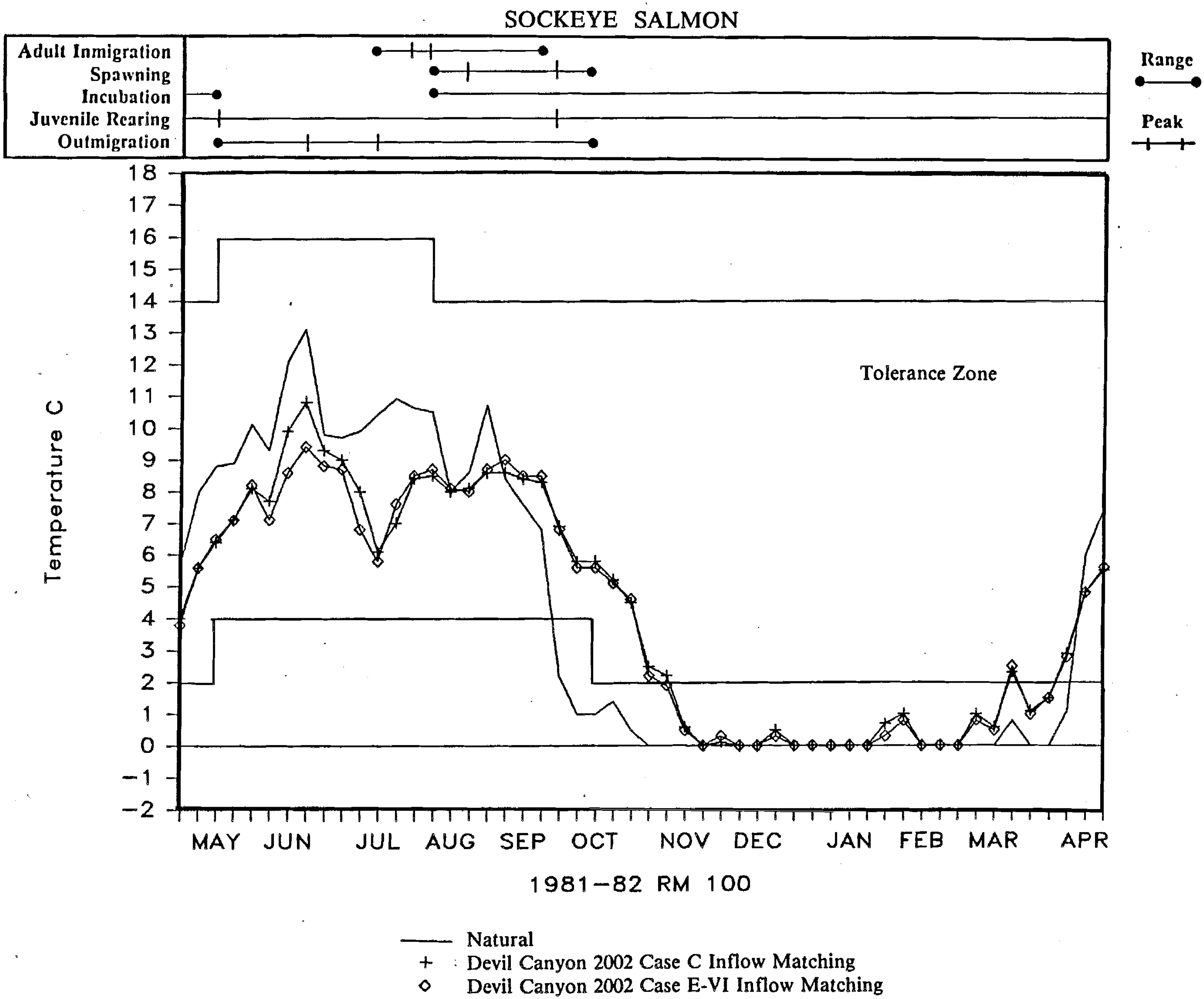
1981−82 RM 100
Natural
+ Devil Canyon 2002 Case C Inflow Matching
◇ Devil Canyon 2002 Case E-VI Inflow Matching


SOCKEYE SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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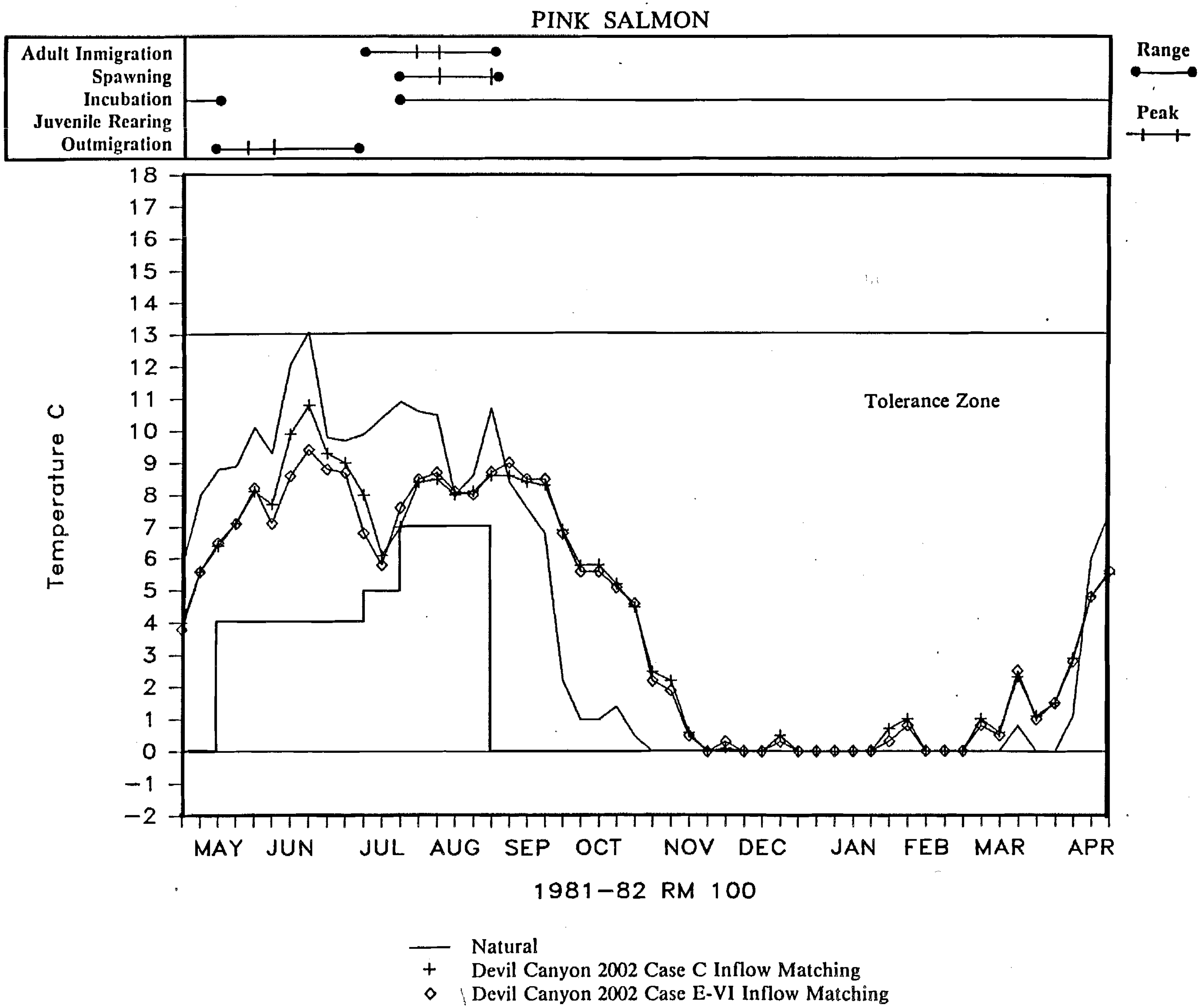
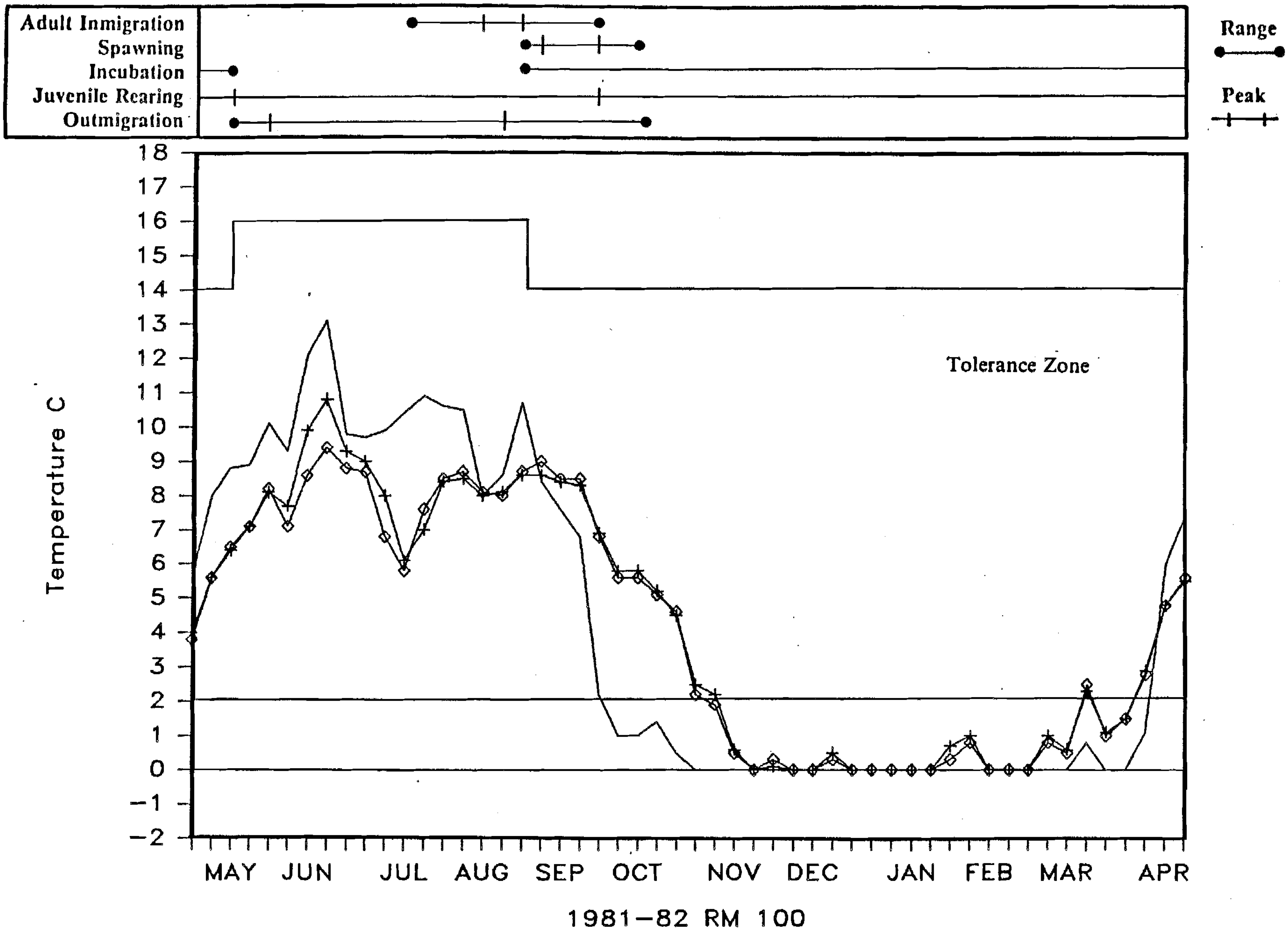
1981−82 RM 100
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching


PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981-82 RM 100
Natural
Devil Canyon 2002 Case C Inflow Matching
Devil Canyon 2002 Case E-VI Inflow Matching

COHO SALMON

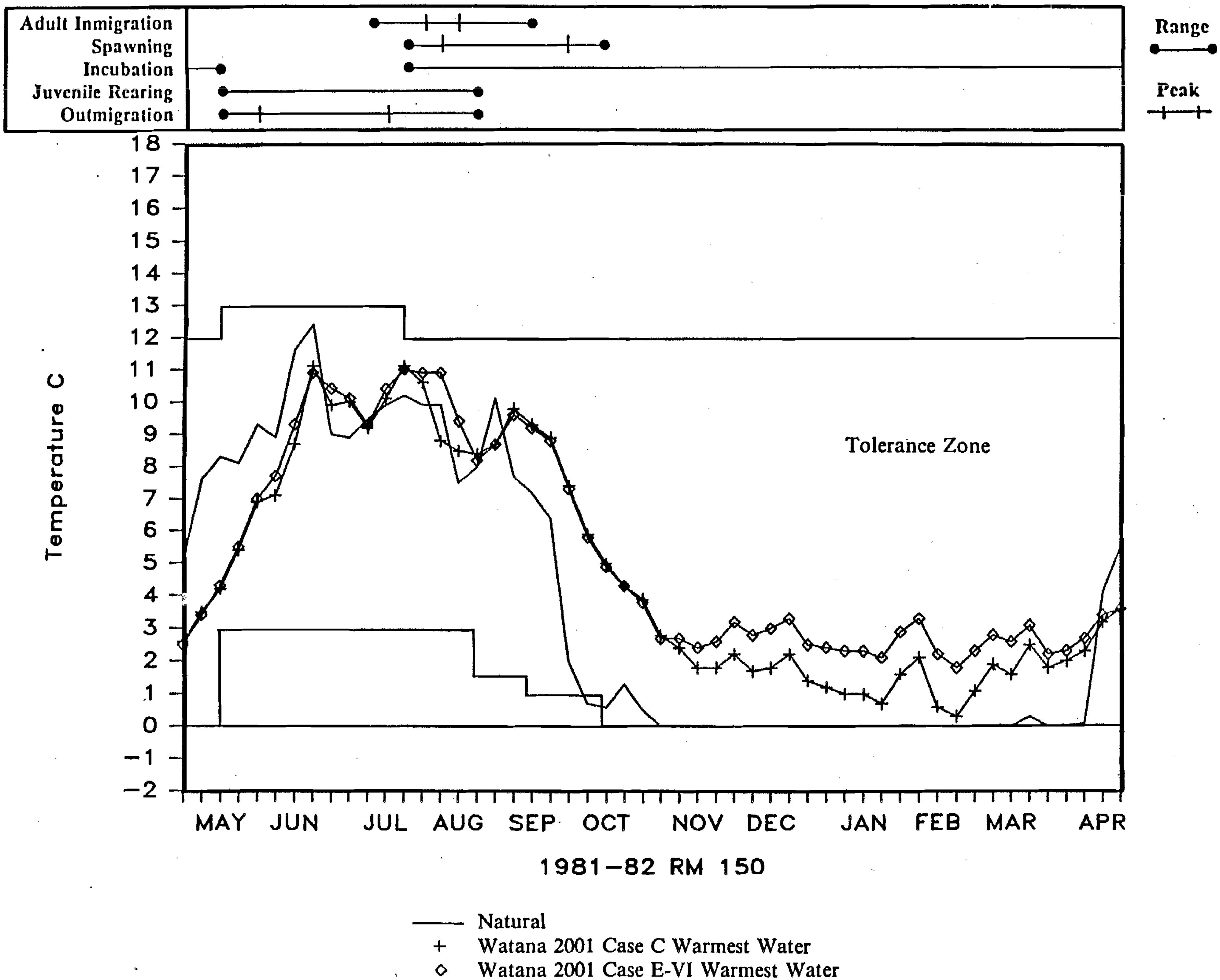


— Natural
+ Devil Canyon 2002 Case C Inflow Matching
◇ Devil Canyon 2002 Case E-VI Inflow Matching

APPENDIX D

Temperature chronologies at three middle river locations in relation to five Pacific salmon life stage temperature tolerance criteria for natural, Case C 'warmest water," and Case E-VI "warmest water"

CHUM SALMON



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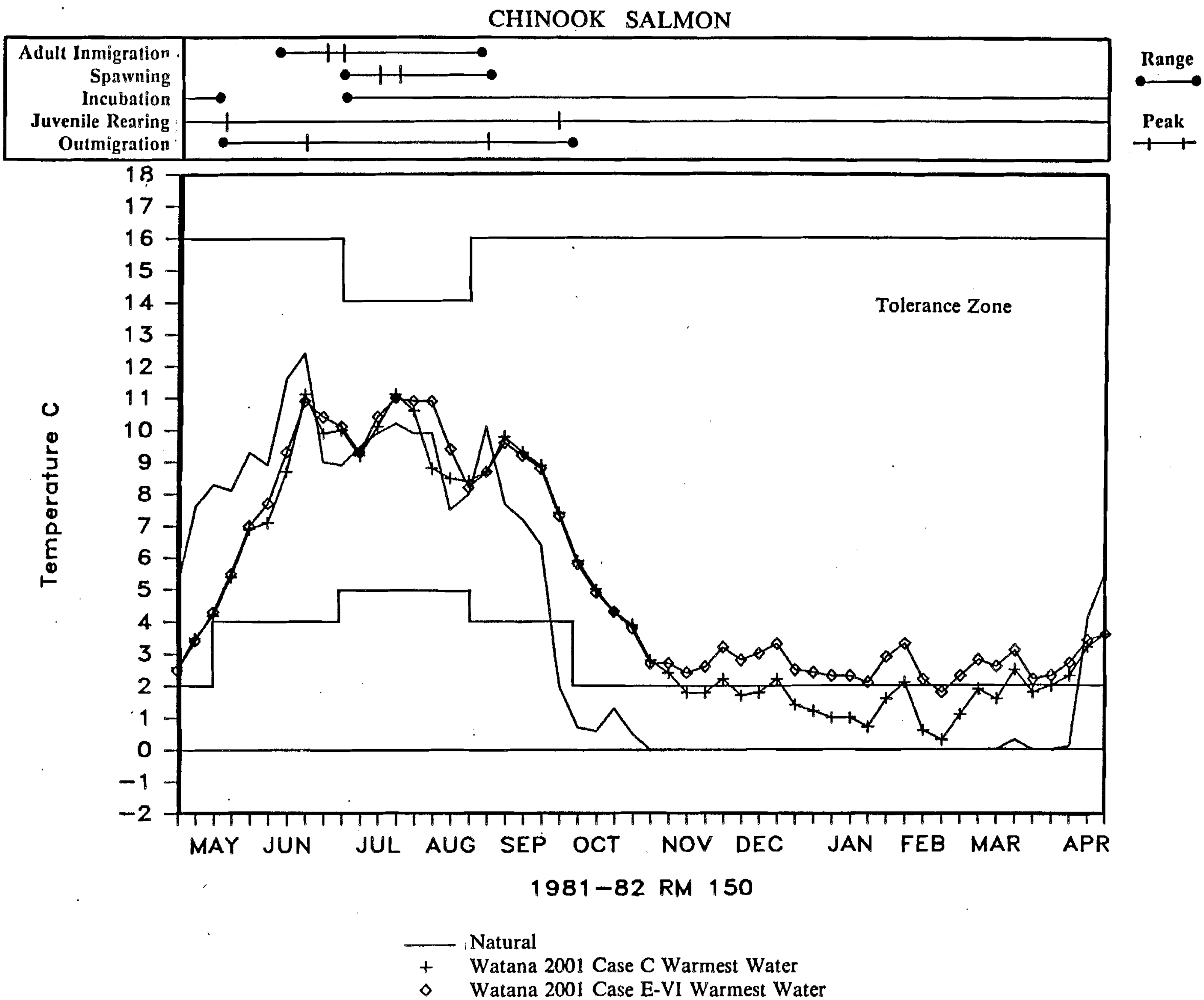

CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
Watana 2001 Case C Warmest Water
Watana 2001 Case E-VI Warmest Water

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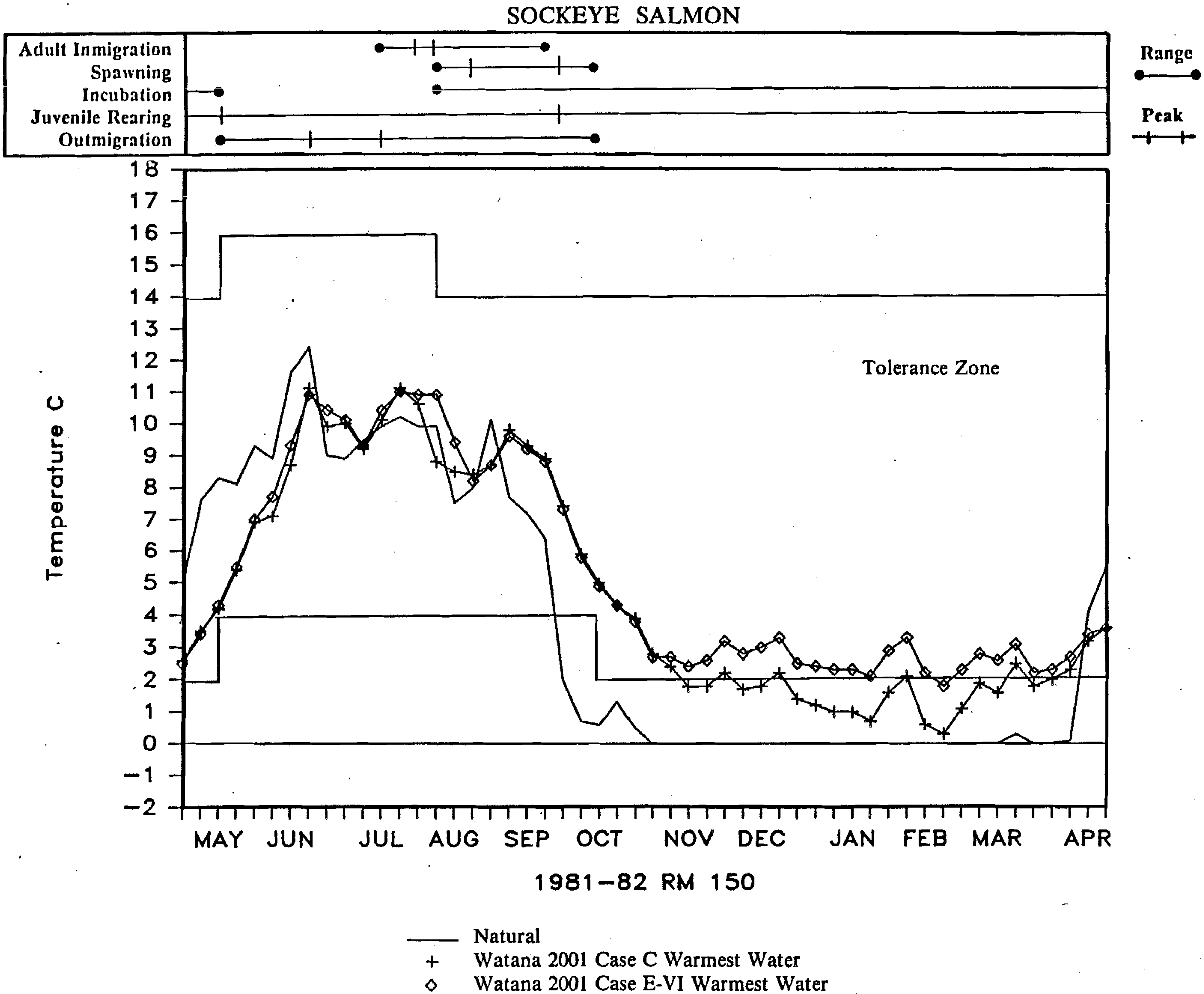
SOCKEYE SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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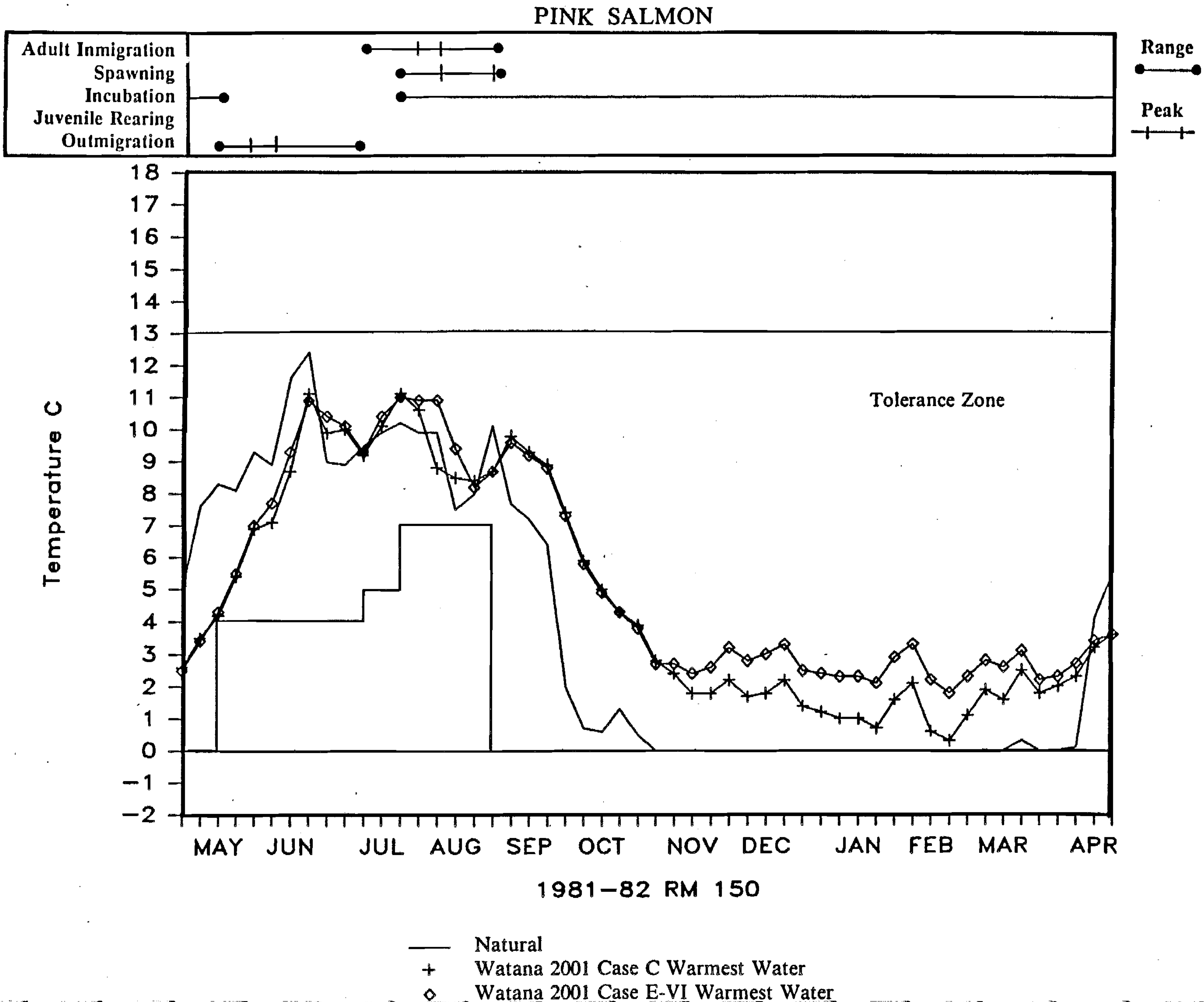
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
+ Watana 2001 Case C Warmest Water
◇ Watana 2001 Case E-VI Warmest Water


PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
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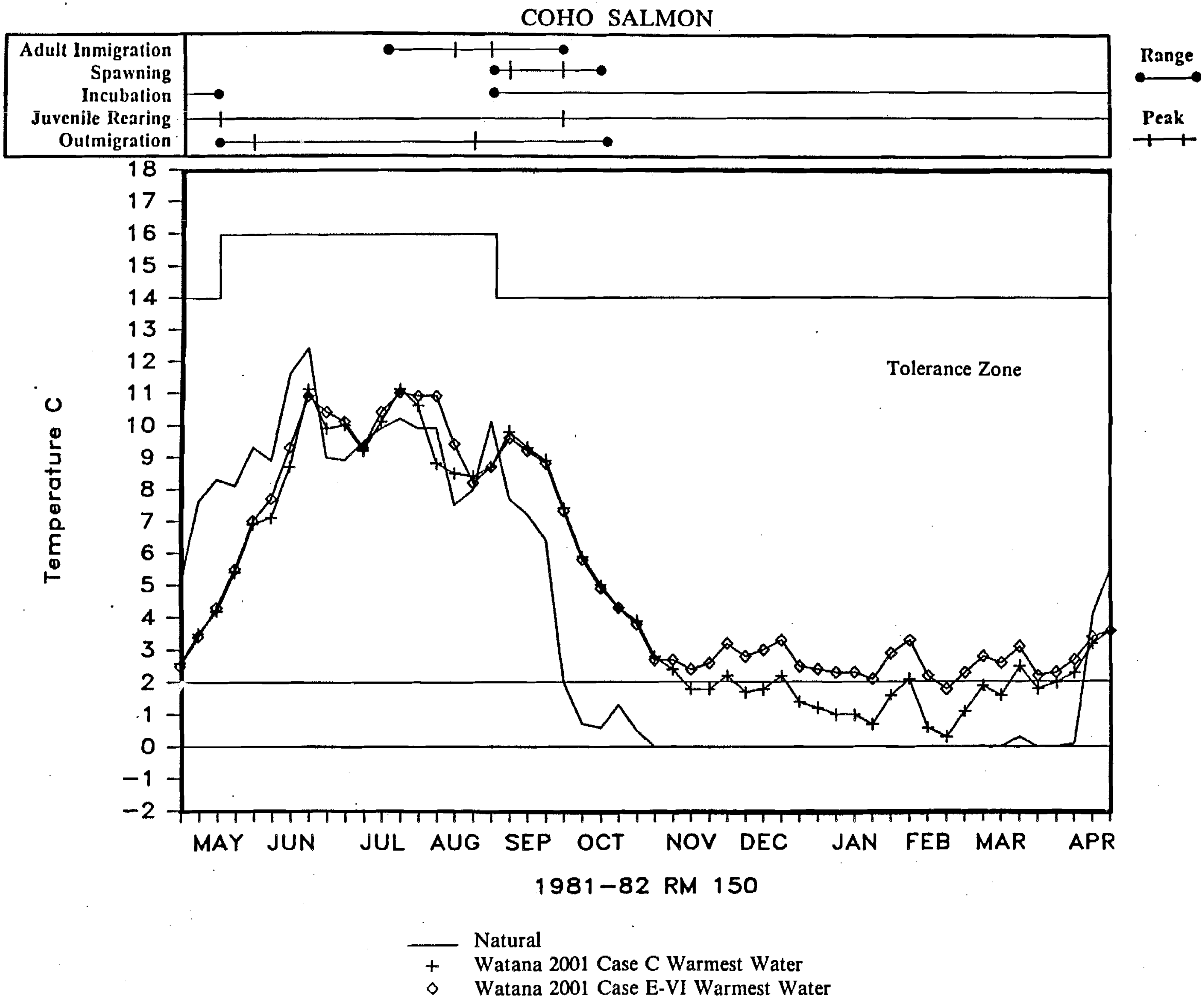
Temperature C
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
Watana 2001 Case C Warmest Water
Watana 2001 Case E-VI Warmest Water


COHO SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
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Tolerance Zone
Temperature C
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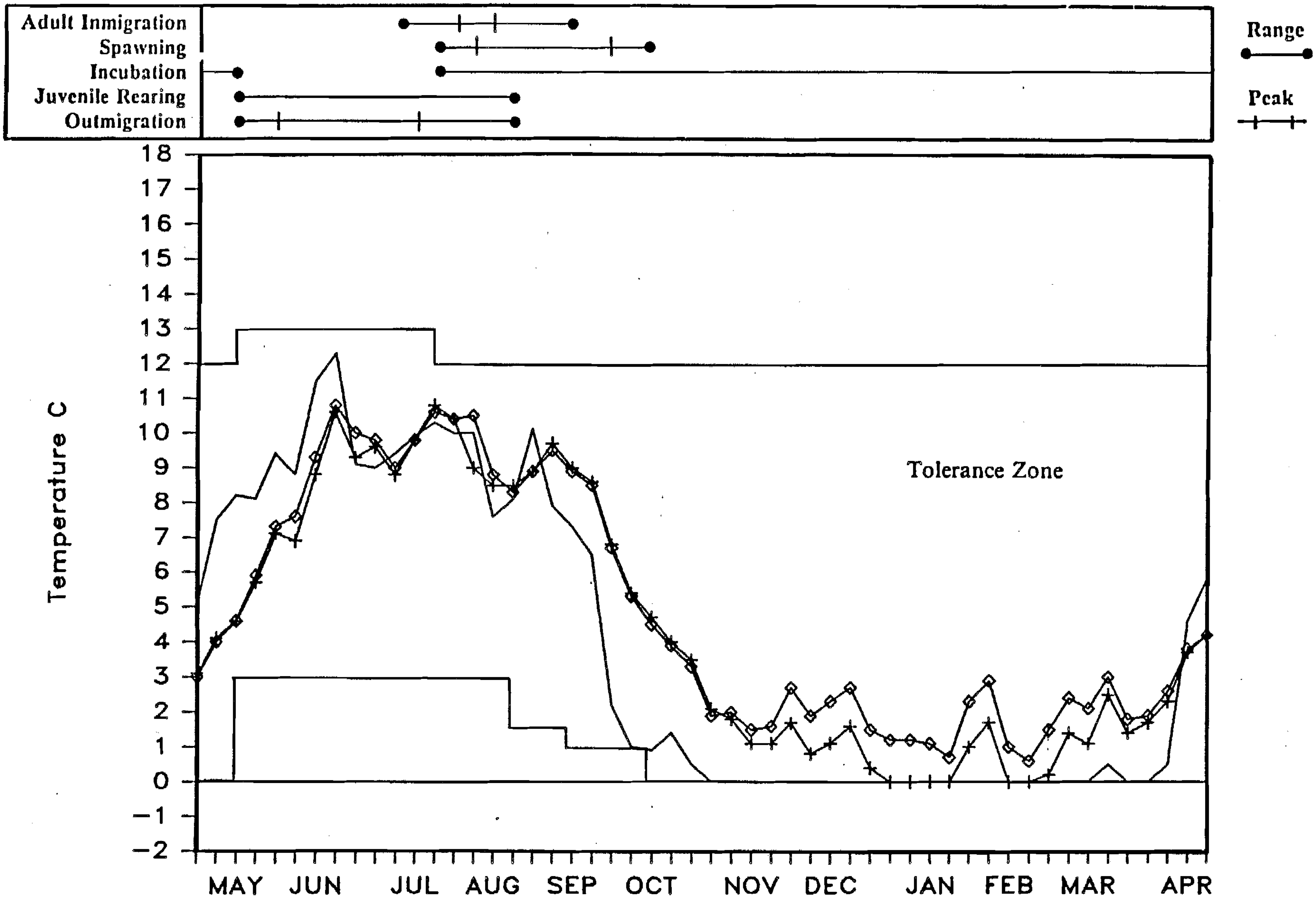
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
Watana 2001 Case C Warmest Water
Watana 2001 Case E-VI Warmest Water

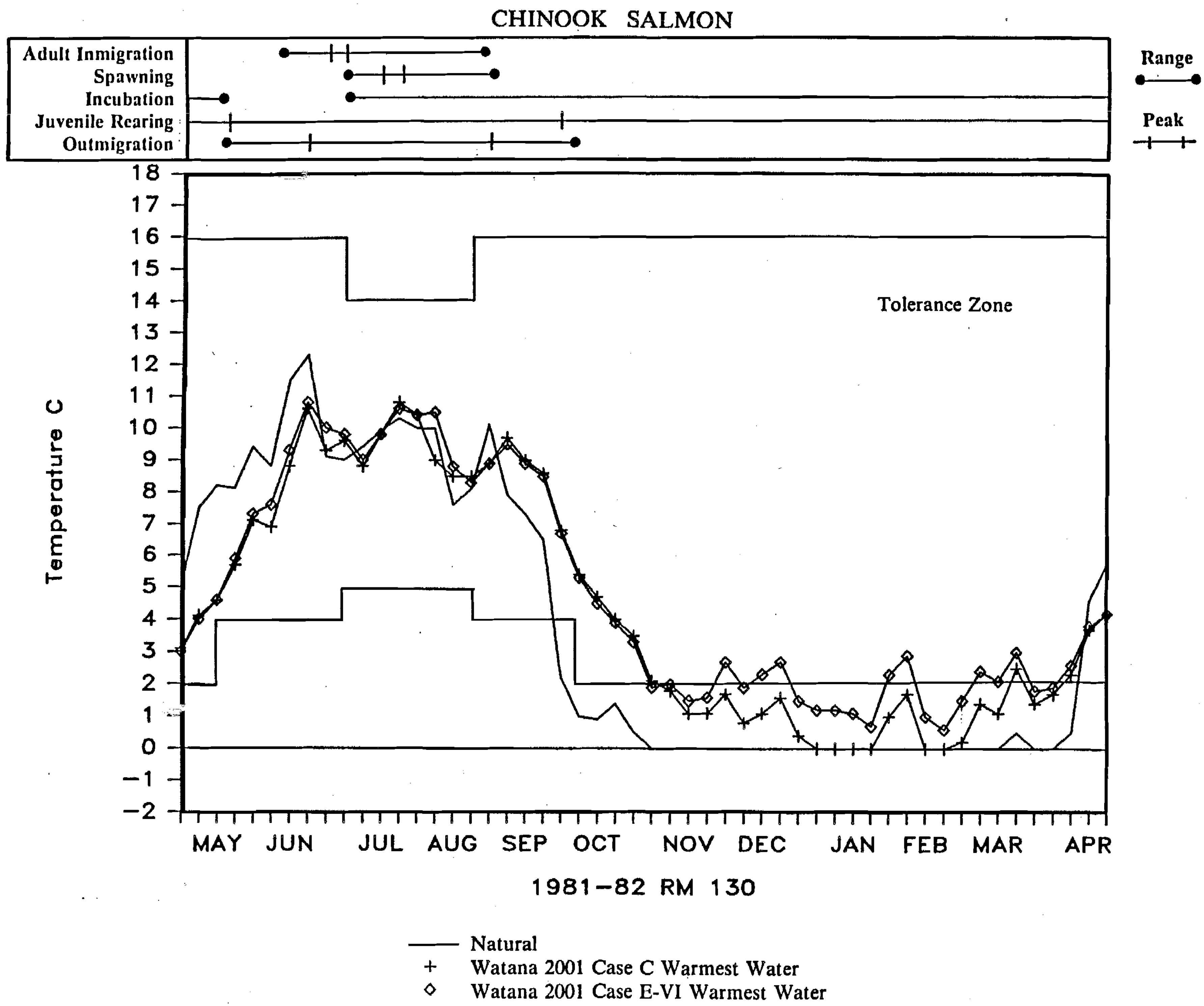
D5

CHUM SALMON



1981−82 RM 130

— Natural
+ Watana 2001 Case C Warmest Water
◇ Watana 2001 Case E-VI Warmest Water


CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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MAY
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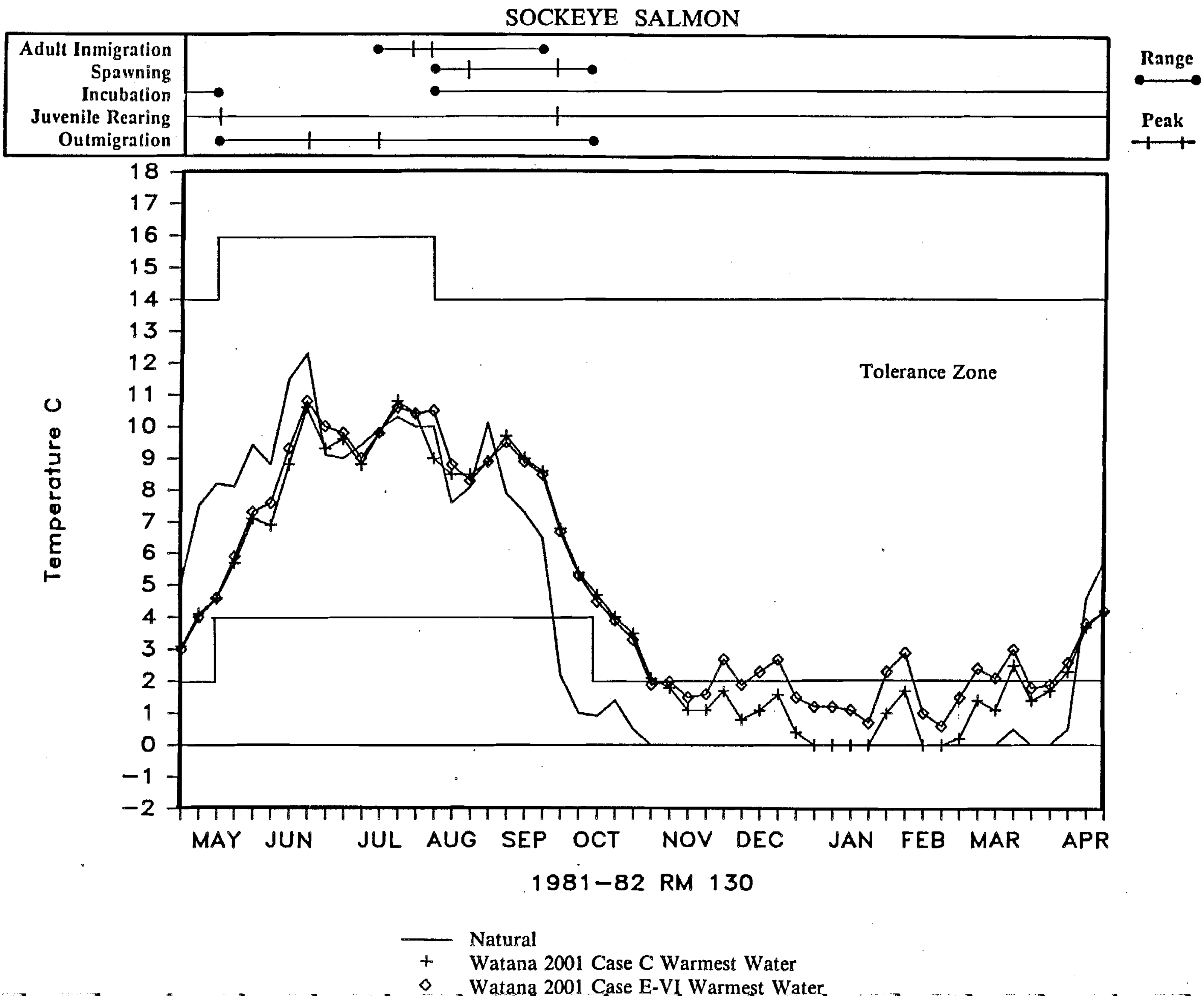
1981−82 RM 130
Natural
Watana 2001 Case C Warmest Water
Watana 2001 Case E-VI Warmest Water


SOCKEYE SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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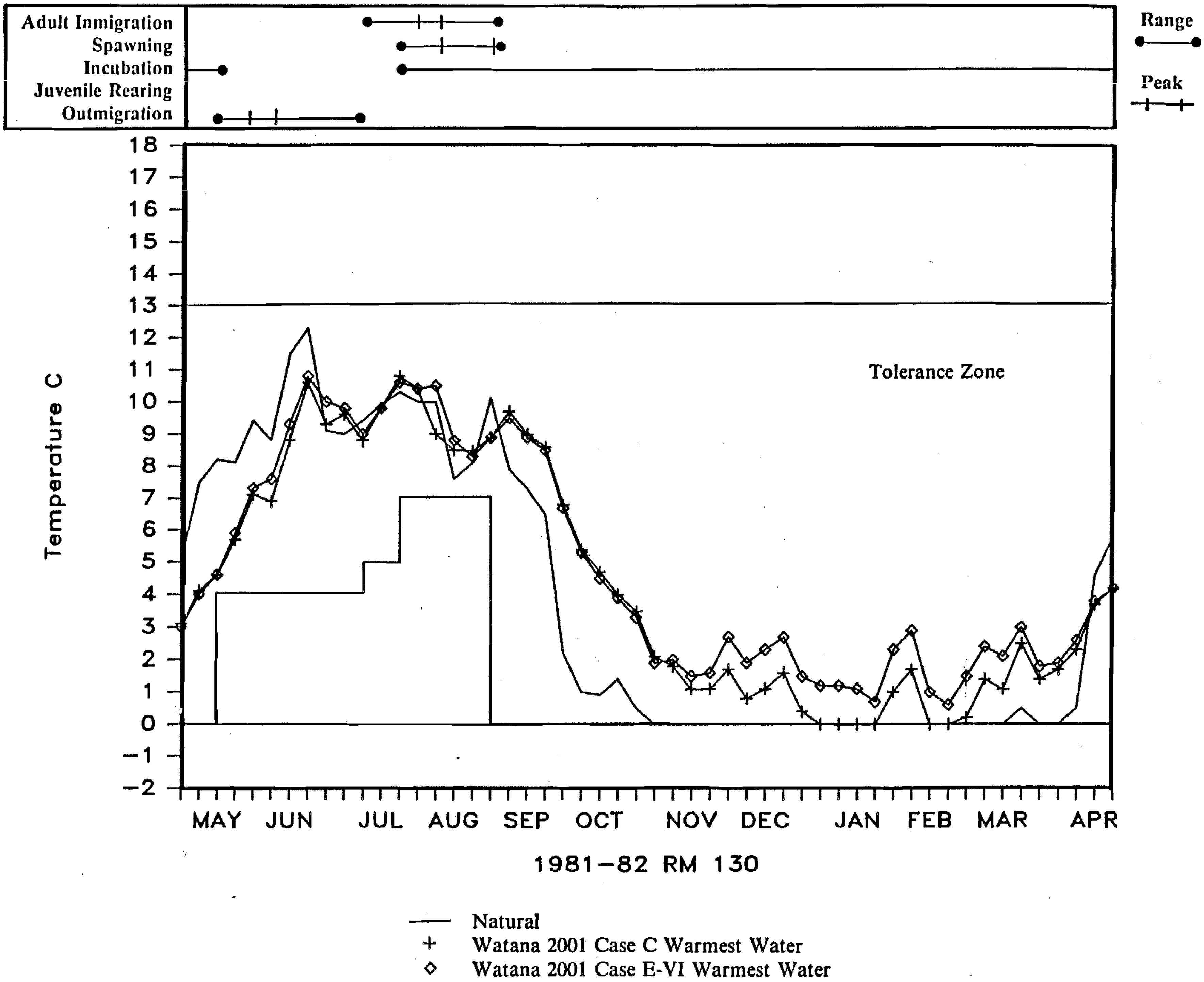
1981−82 RM 130
Natural
+ Watana 2001 Case C Warmest Water
◇ Watana 2001 Case E-VI Warmest Water

PINK SALMON



Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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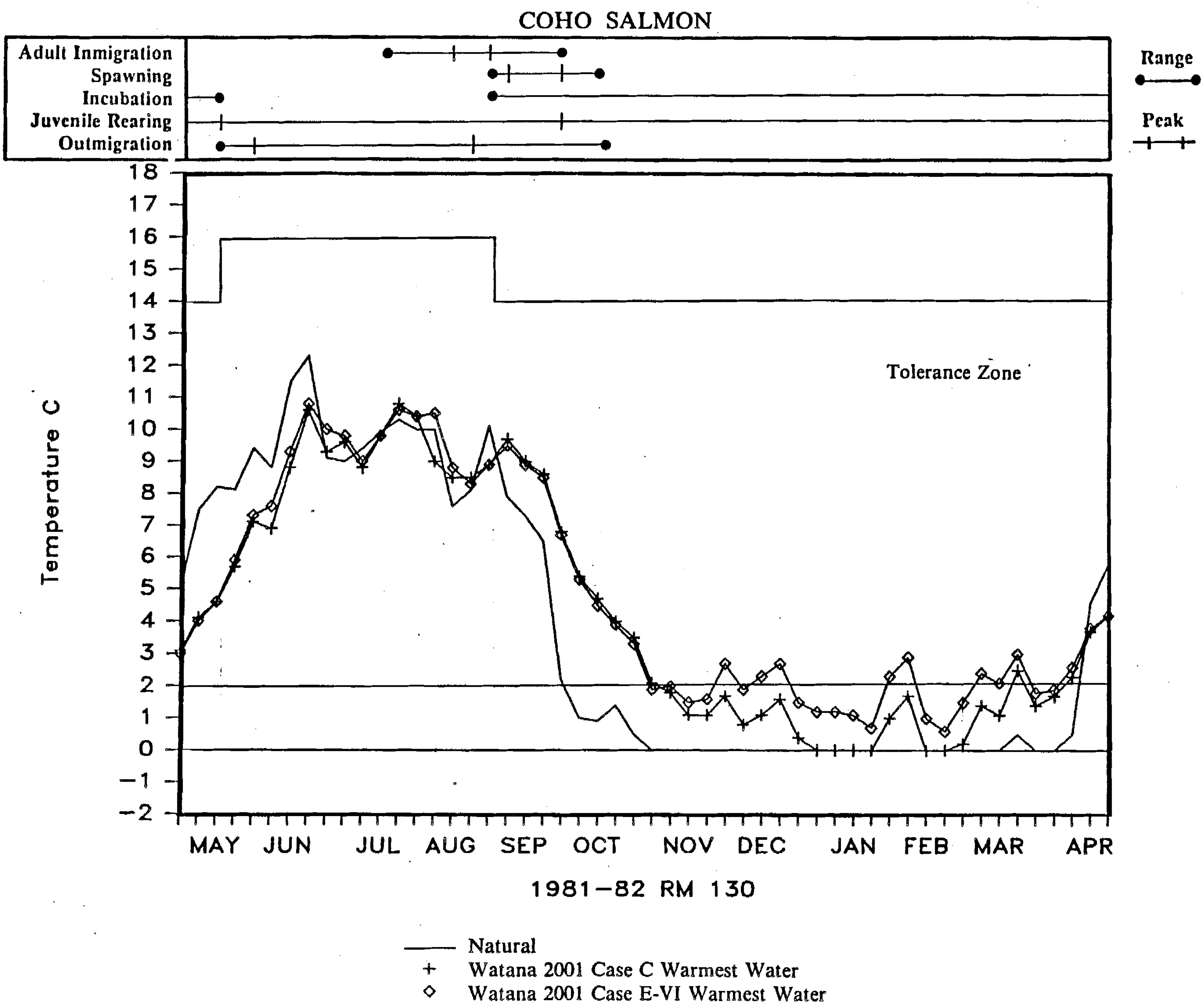
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 130
Natural
Watana 2001 Case C Warmest Water
Watana 2001 Case E-VI Warmest Water



COHO SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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Natural
Watana 2001 Case C Warmest Water
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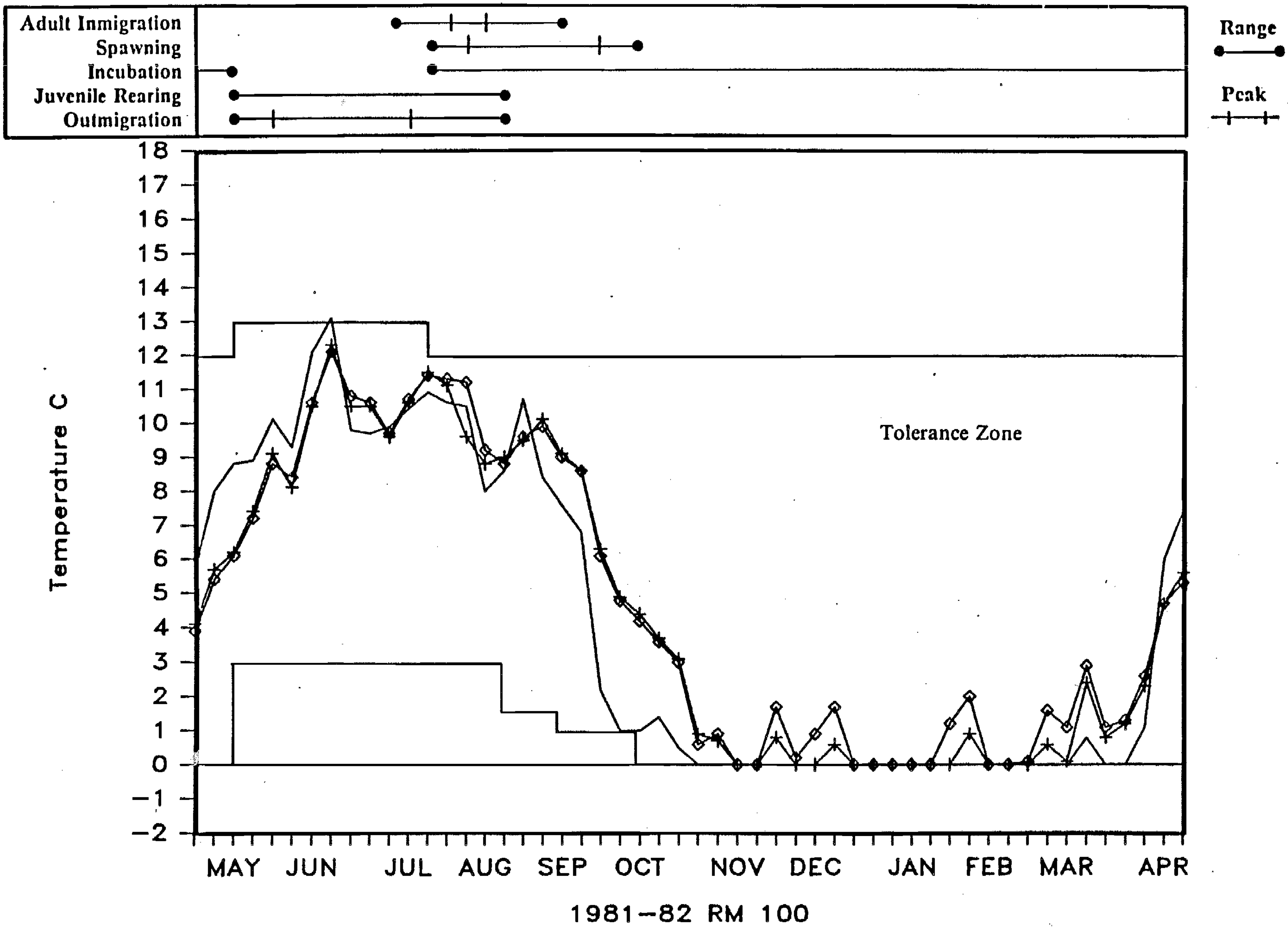
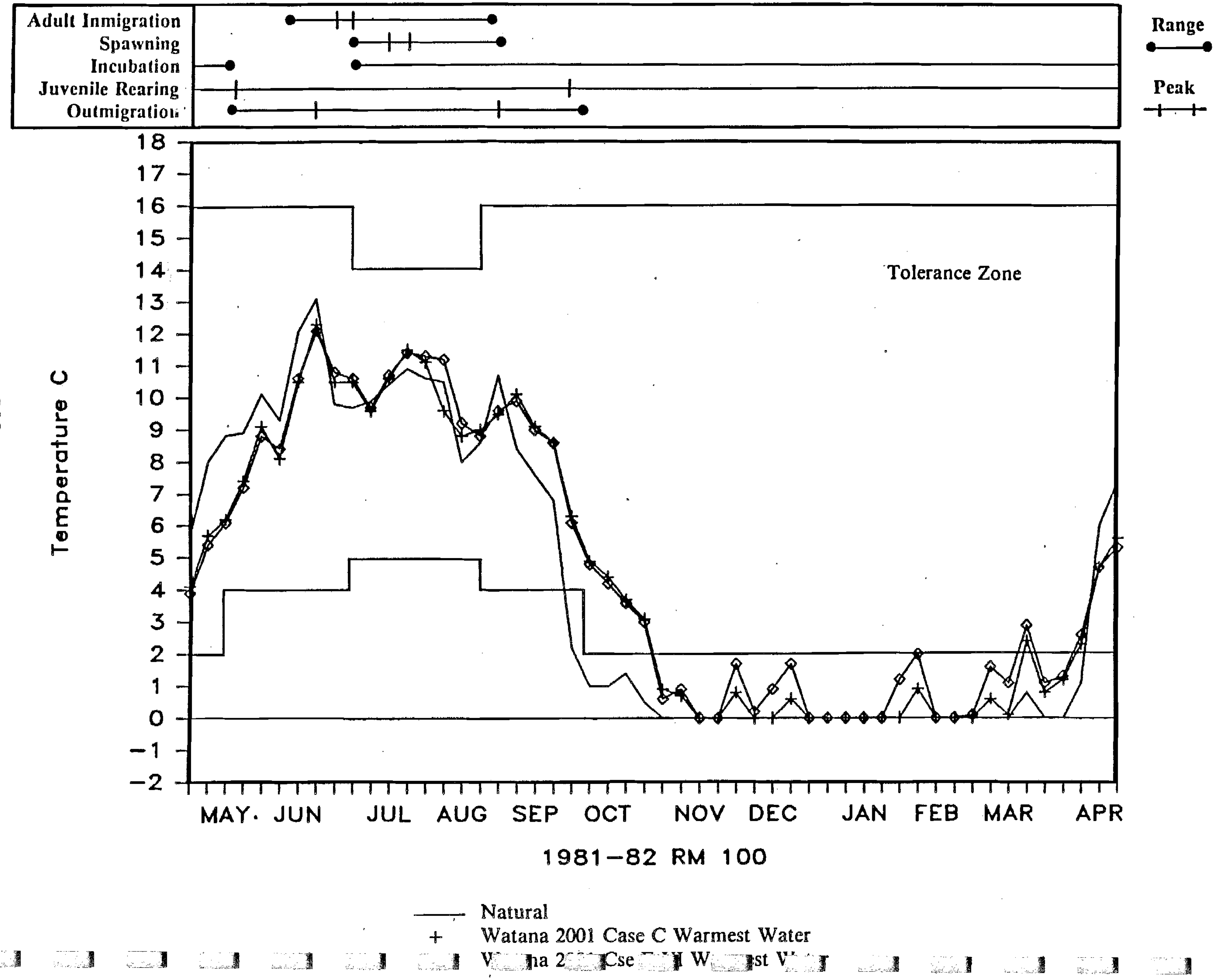
CHUM SALMON

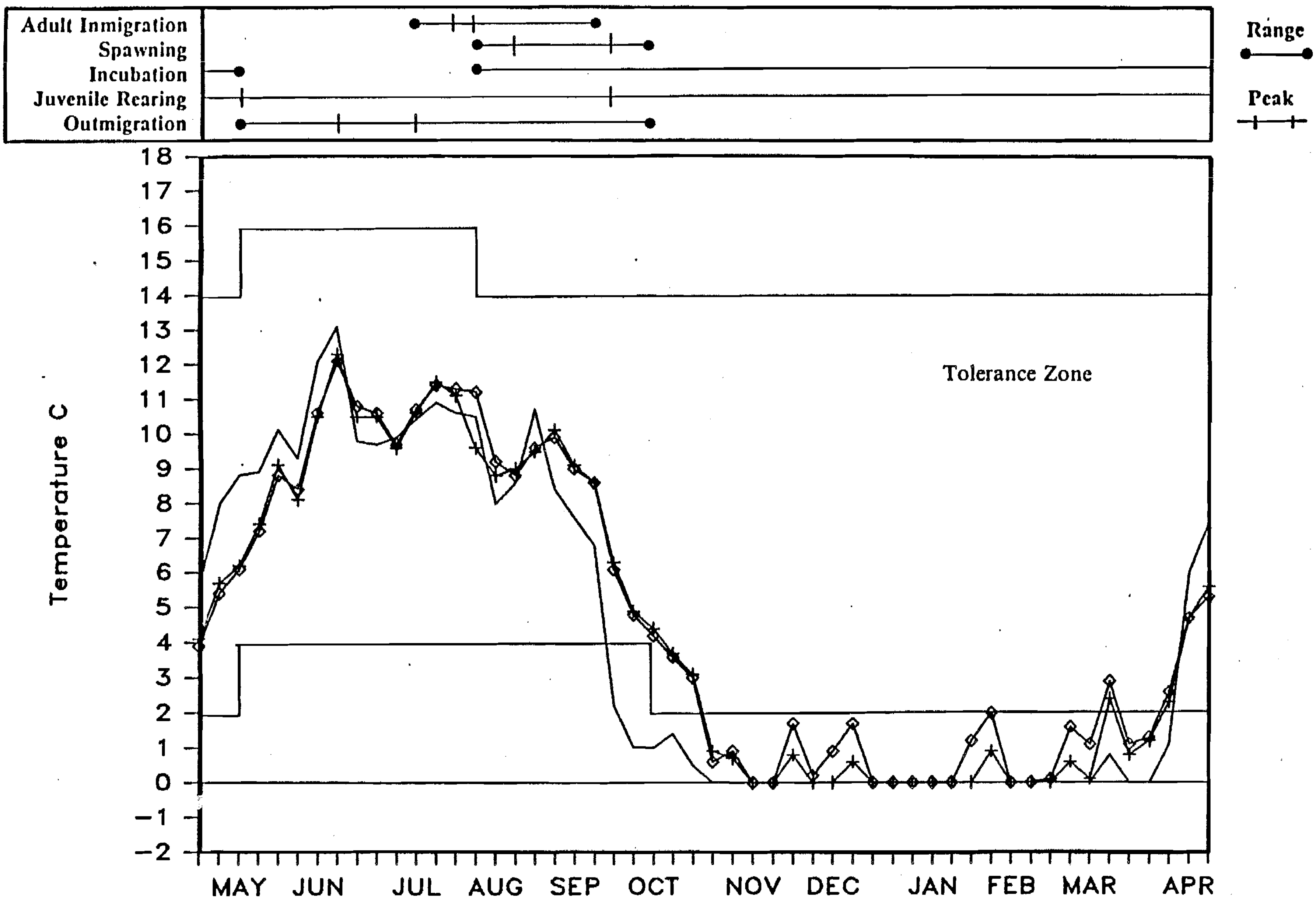


Natural
\+ Watana 2001 Case C Warmest Water
◇ Watana 2001 Cse E-VI Warmest Water

CHINOOK SALMON

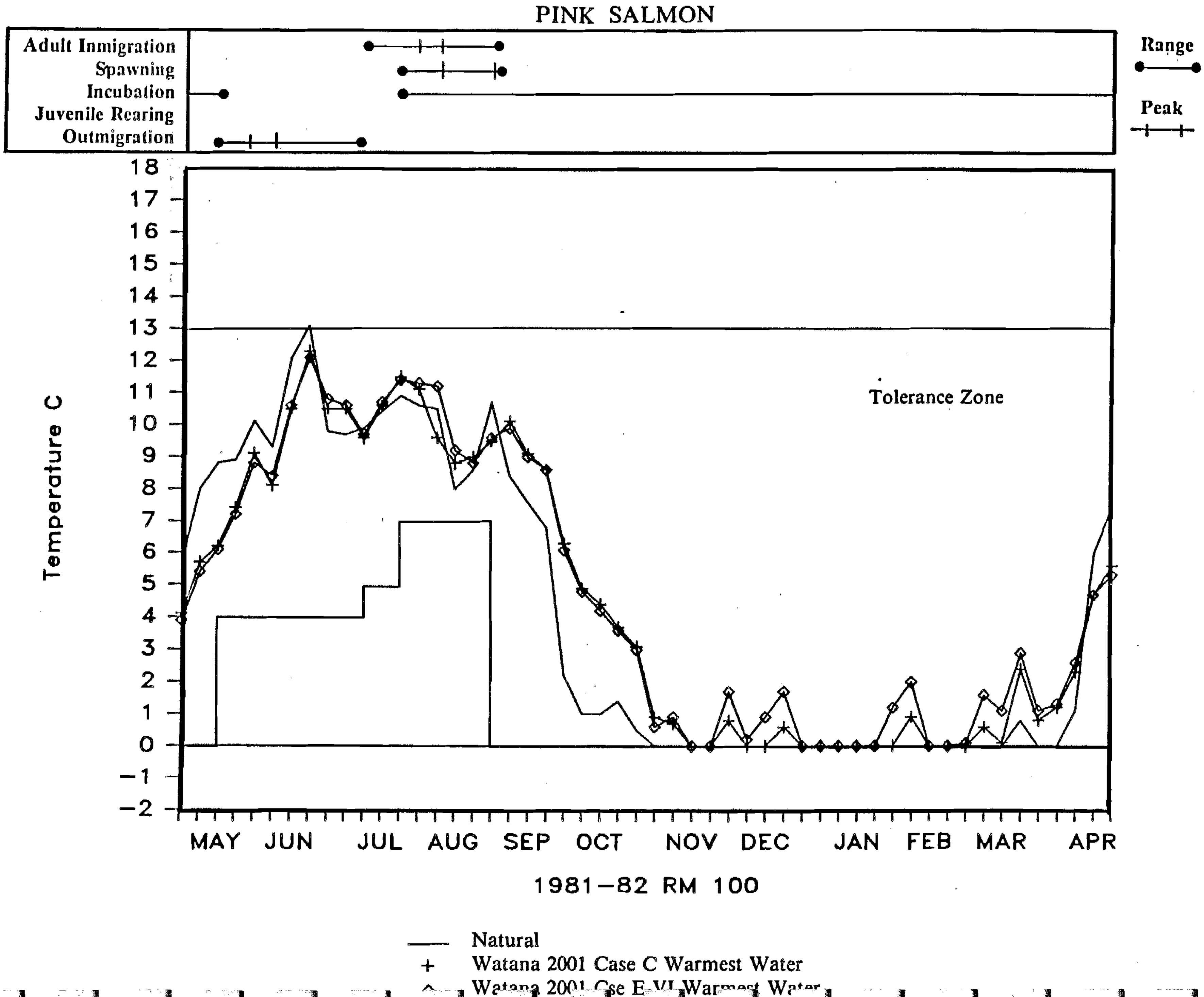


SOCKEYE SALMON



1981–82 RM 100

Natural
+ Watana 2001 Case C Warmest Water
◇ Watana 2001 Cse E-VI Warmest Water



PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
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Temperature C
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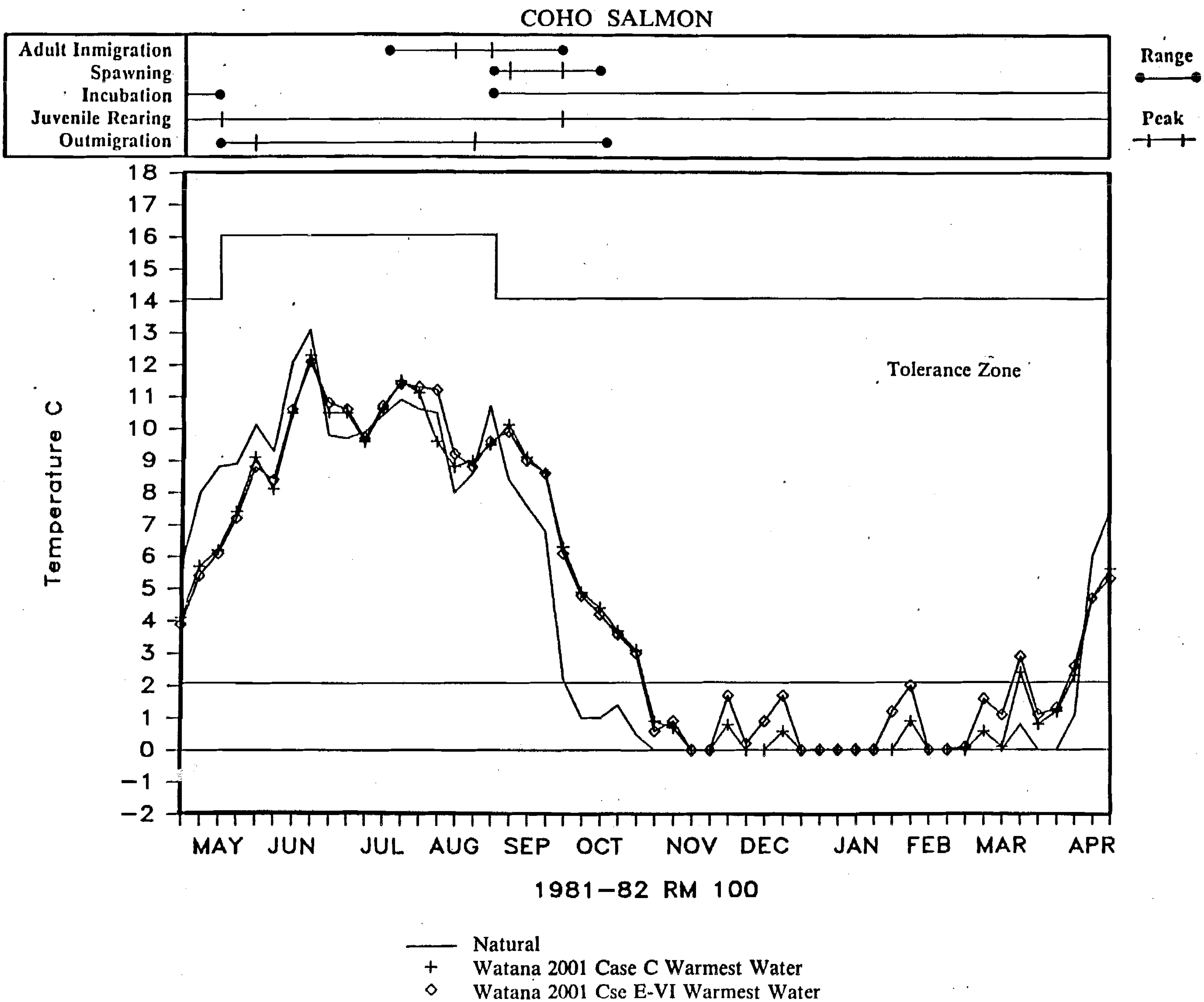
1981−82 RM 100
Natural
Watana 2001 Case C Warmest Water



COHO SALMON
Adult Inmigration
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Outmigration
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1981−82 RM 100
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+ Watana 2001 Case C Warmest Water
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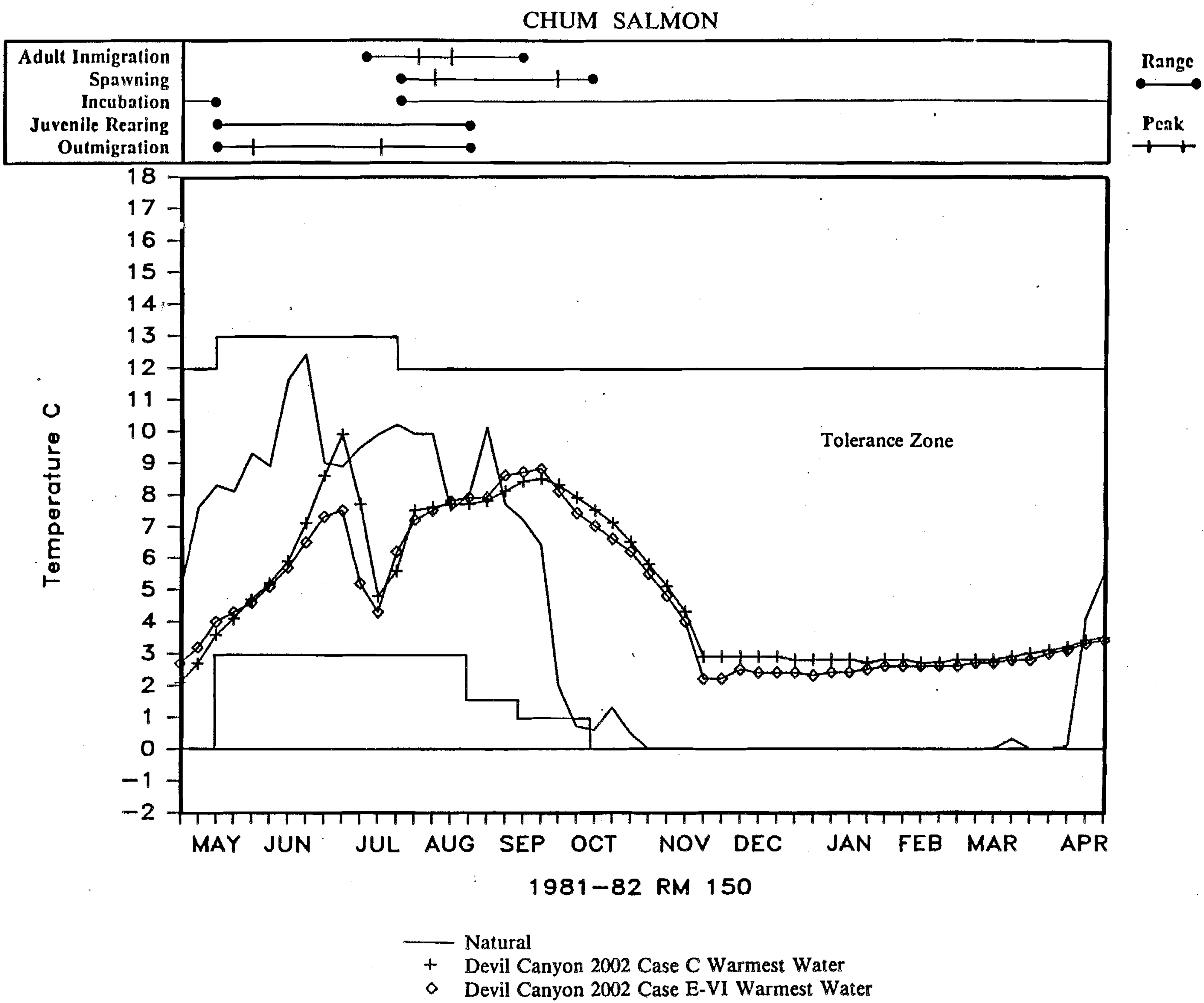
CHUM SALMON
Adult Immigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
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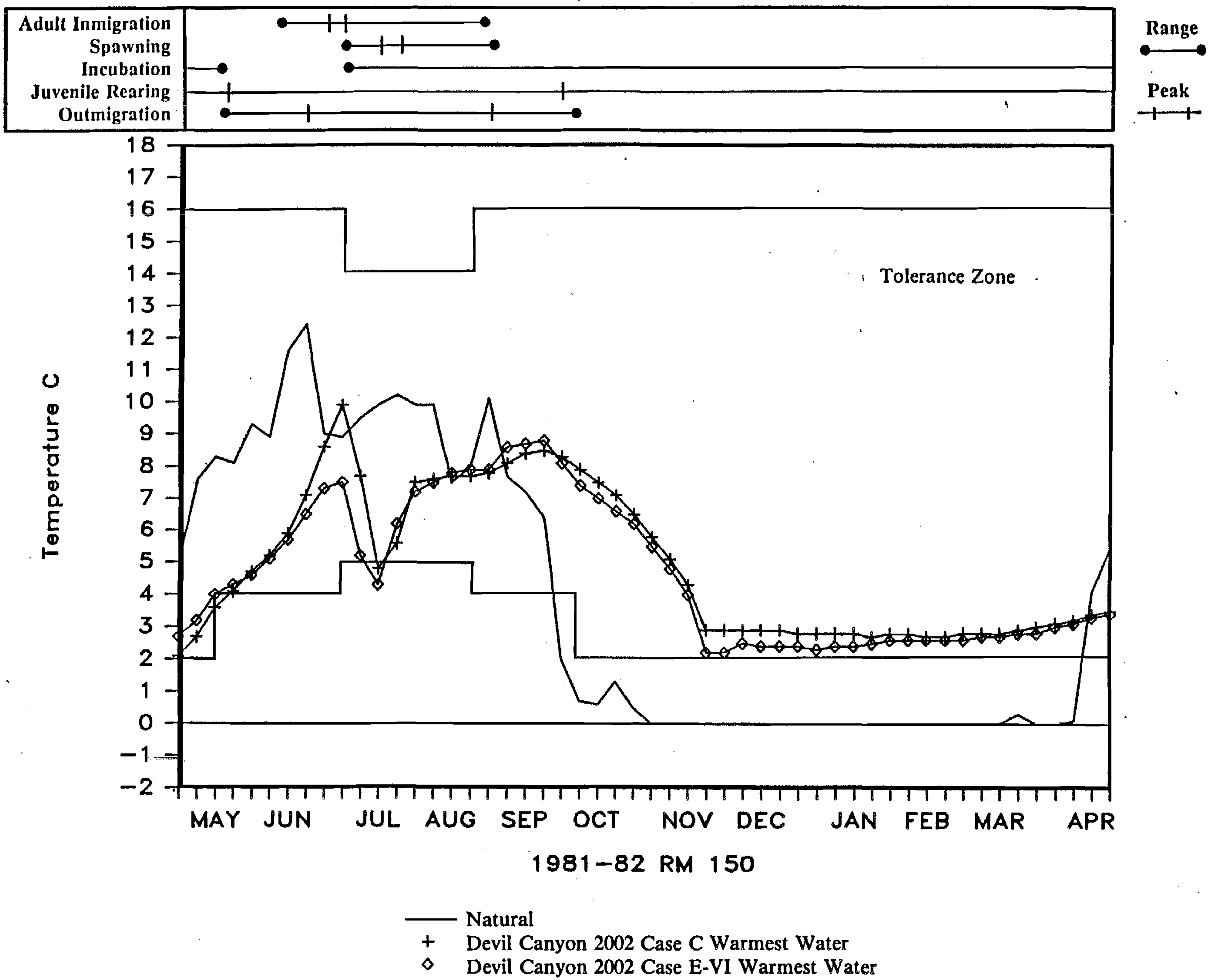
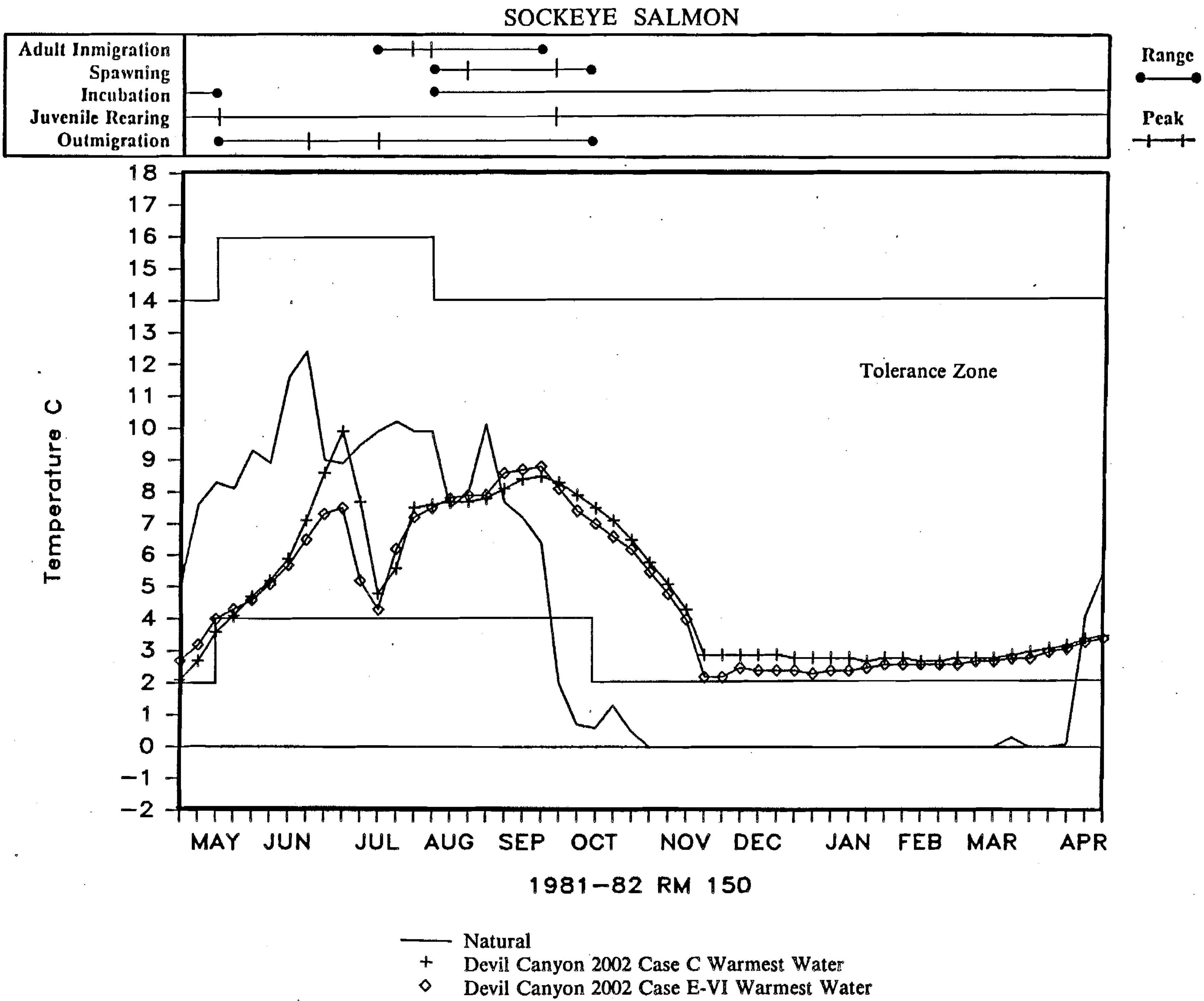
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981-82 RM 150
Natural
Devil Canyon 2002 Case C Warmest Water
Devil Canyon 2002 Case E-VI Warmest Water

CHINOOK SALMON




SOCKEYE SALMON
Adult Inmigration
Spawning
Incubation
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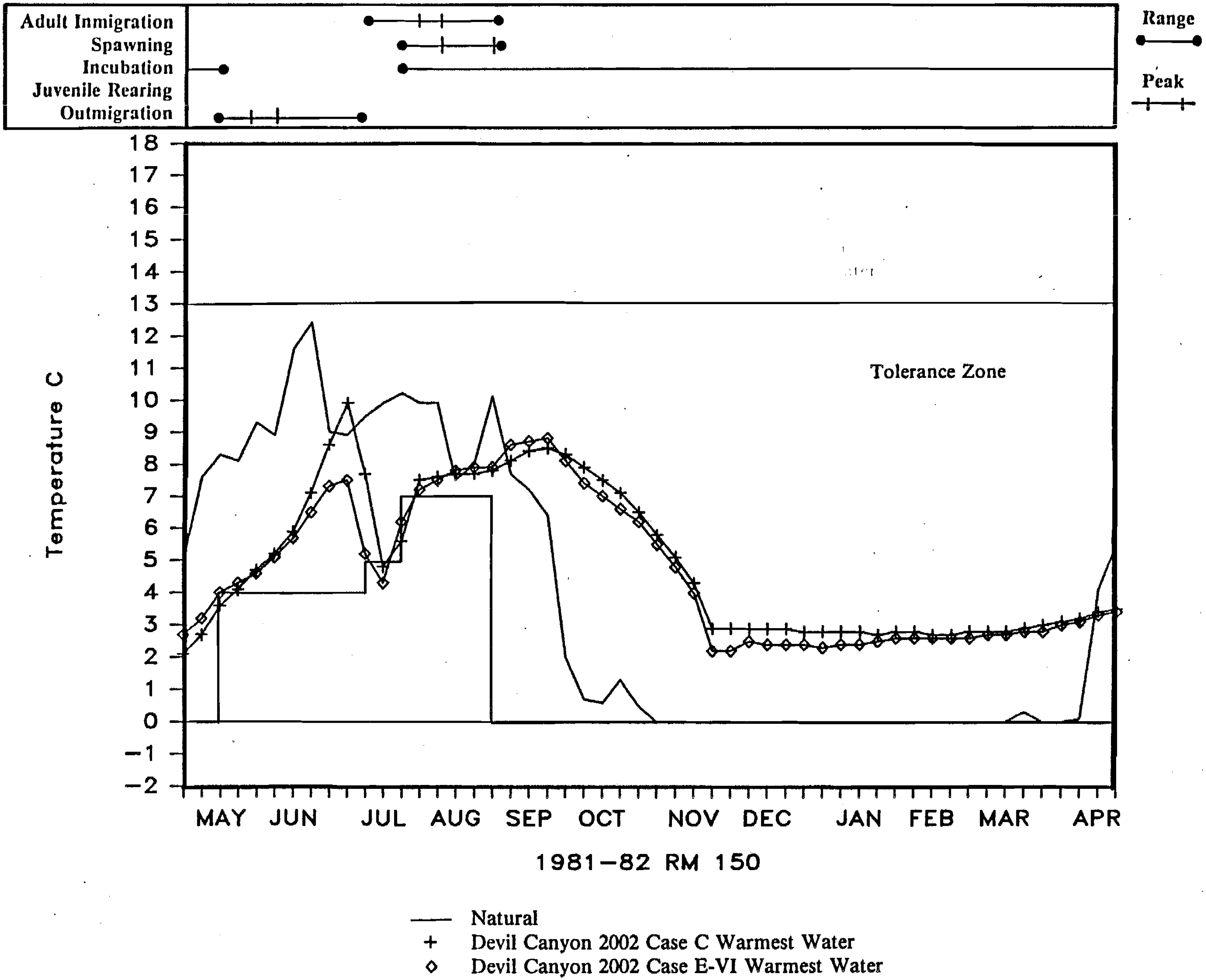
Temperature C
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 150
Natural
Devil Canyon 2002 Case C Warmest Water
Devil Canyon 2002 Case E-VI Warmest Water

PINK SALMON



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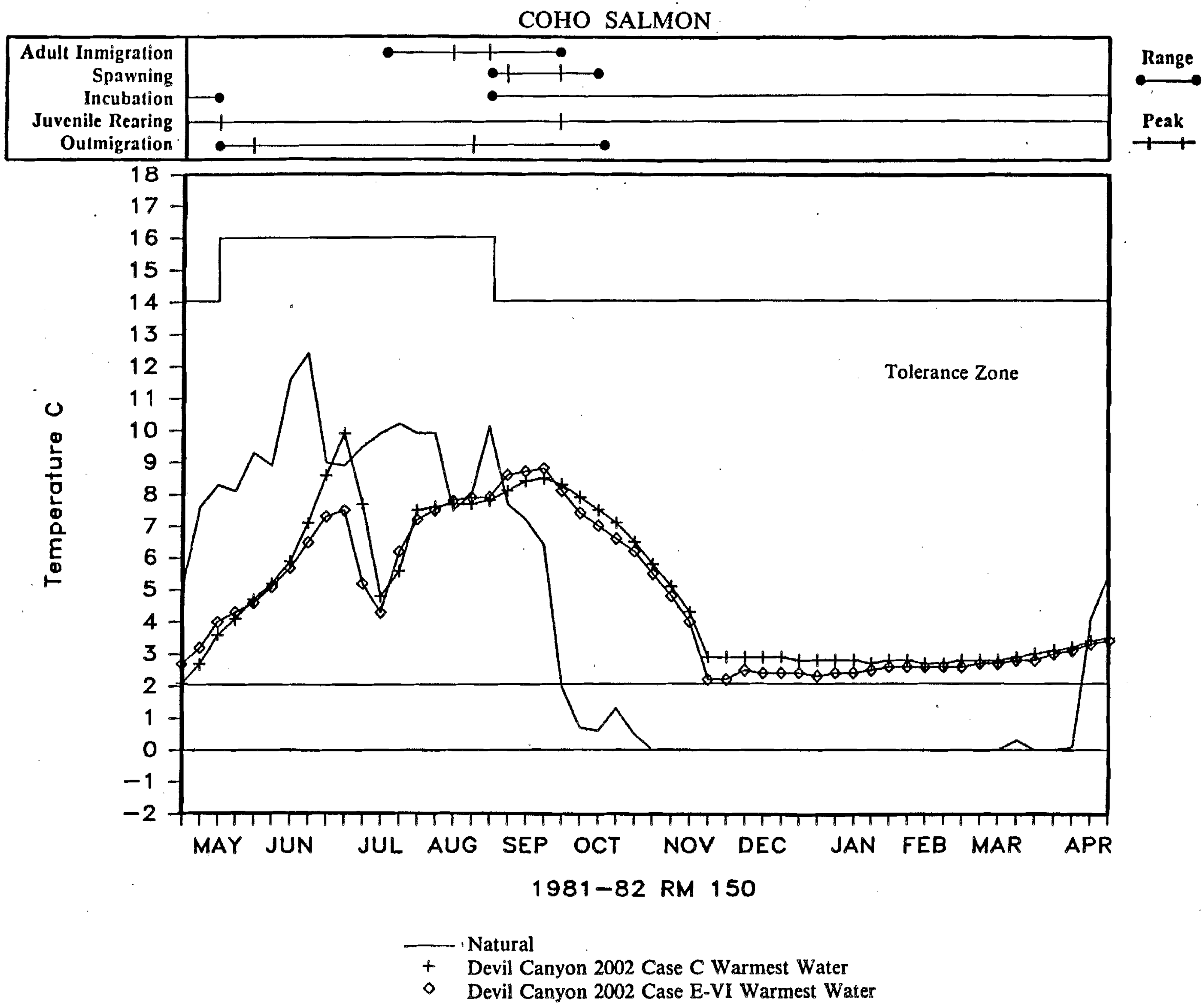

COHO SALMON
Adult Inmigration
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Juvenile Rearing
Outmigration
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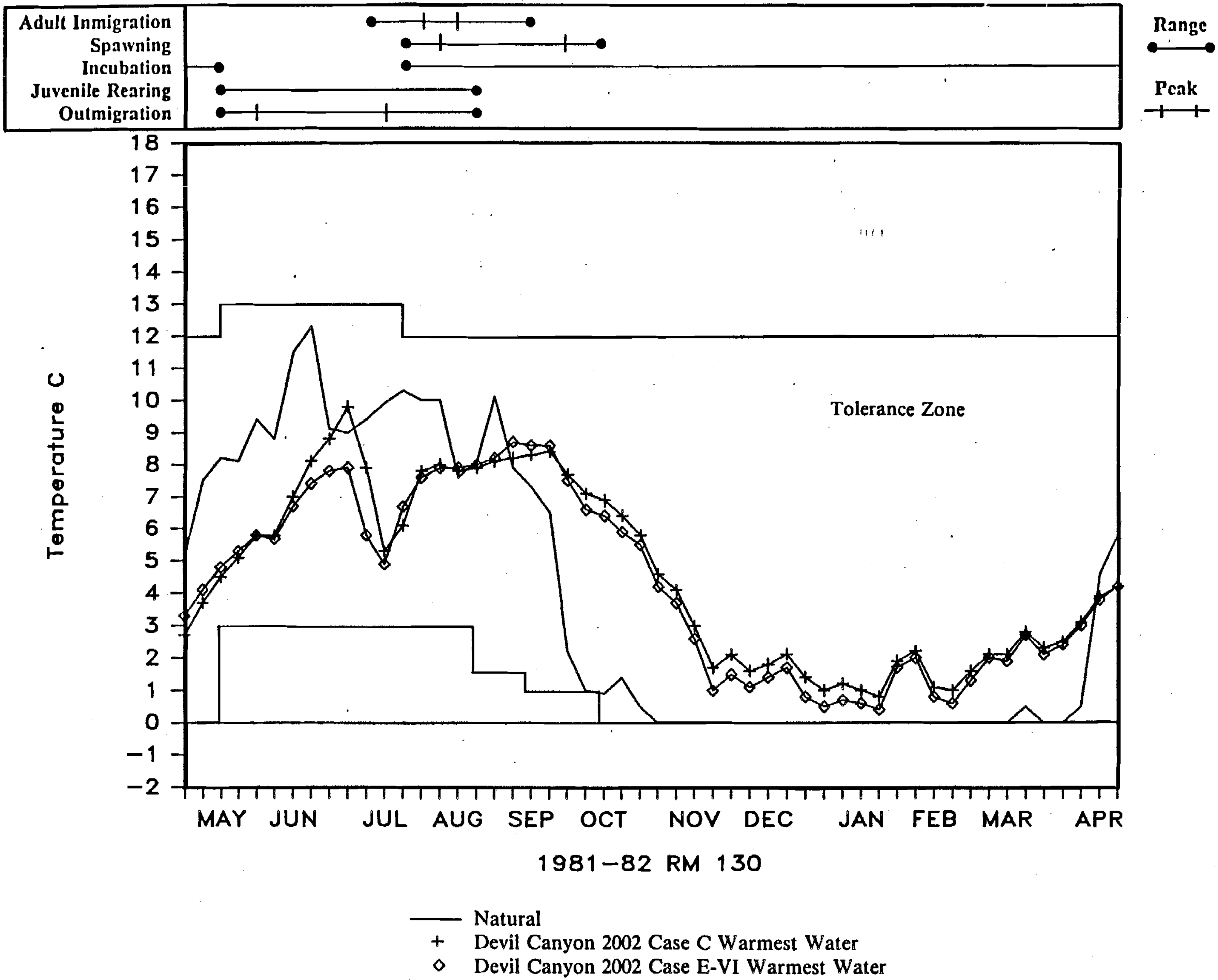
1981−82 RM 150
Natural
Devil Canyon 2002 Case C Warmest Water
Devil Canyon 2002 Case E-VI Warmest Water

D20

CHUM SALMON



Adult Inmigration
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Outmigration
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1981−82 RM 130
Natural
Devil Canyon 2002 Case C Warmest Water
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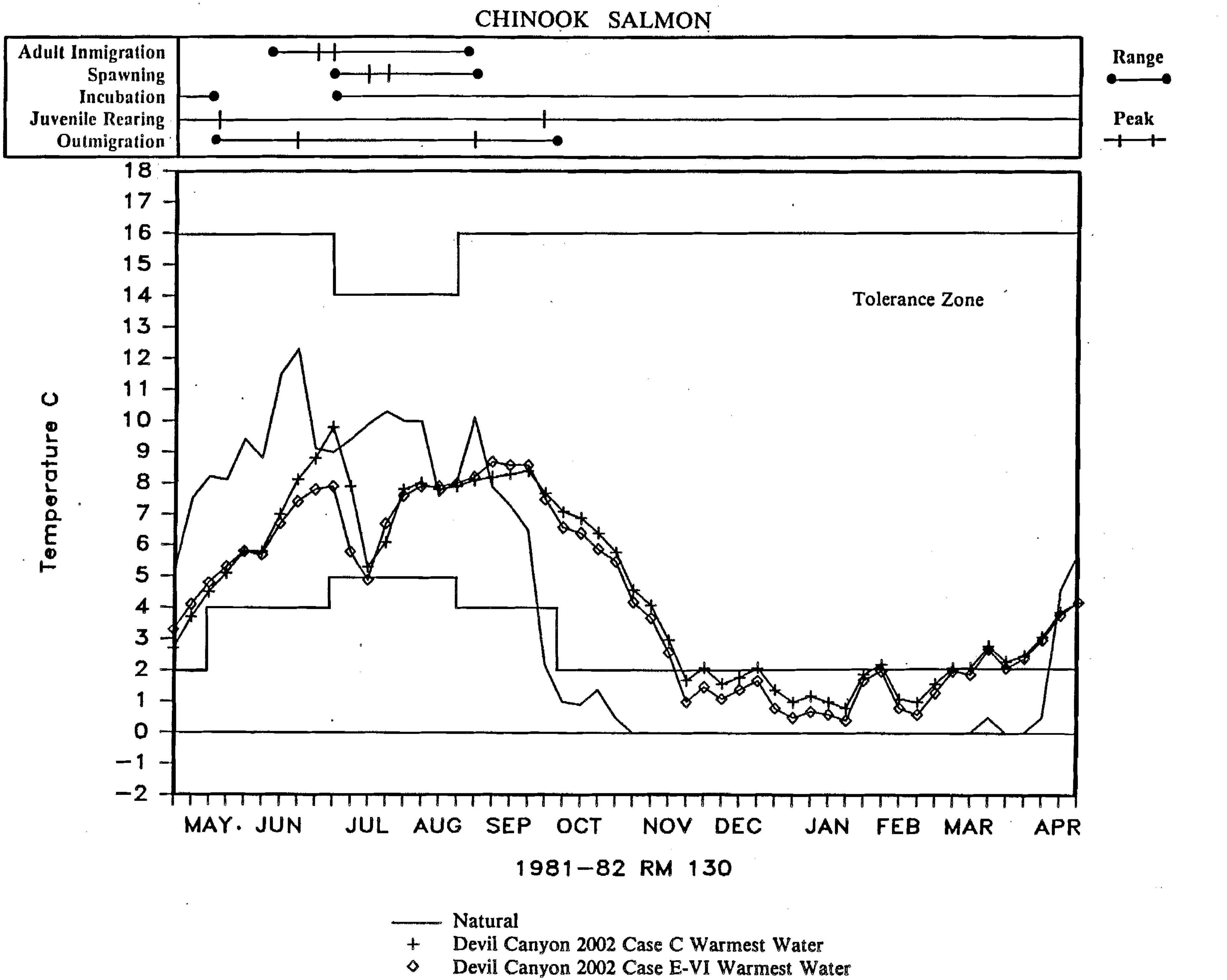

CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
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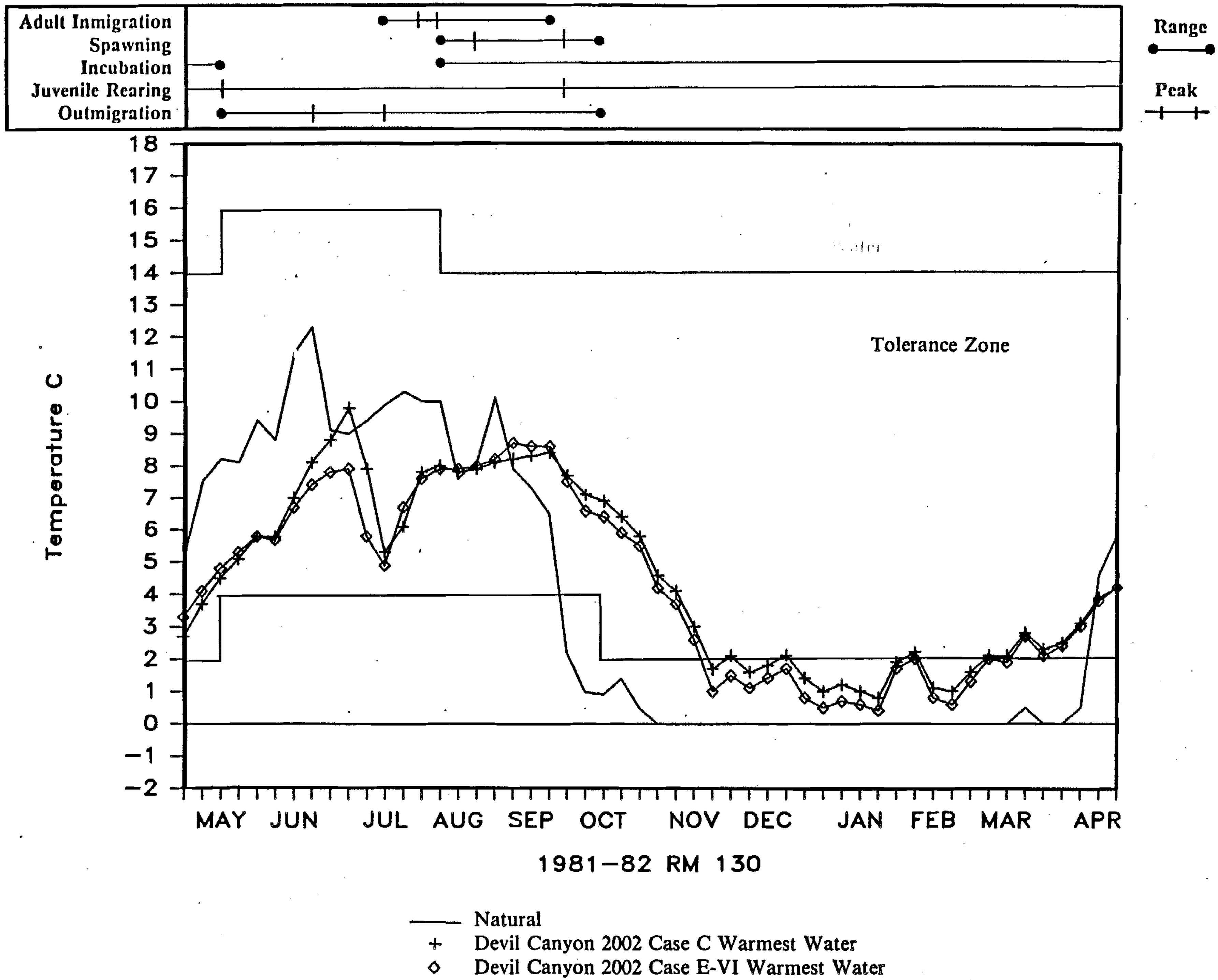
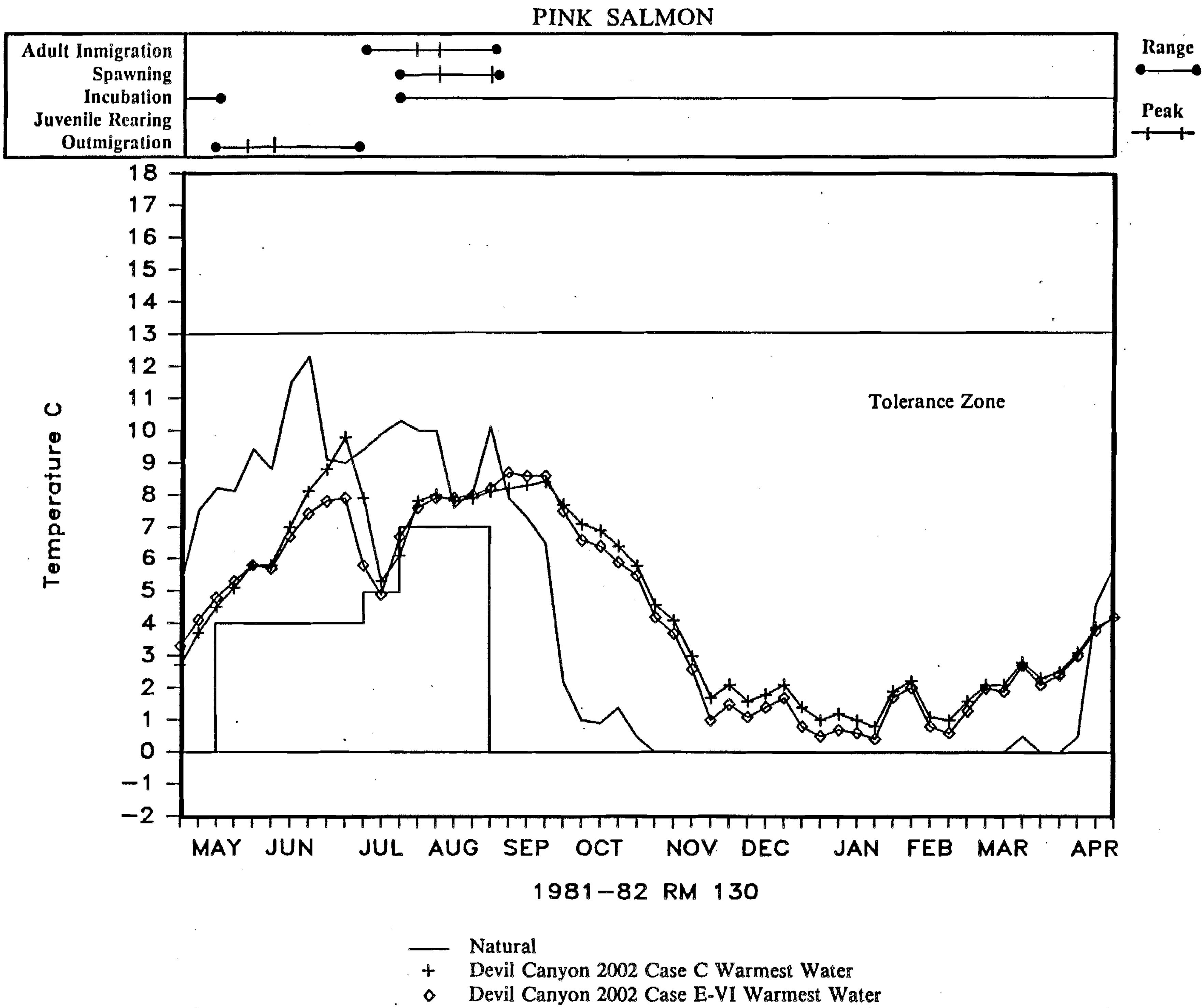
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 130
Natural
Devil Canyon 2002 Case C Warmest Water
Devil Canyon 2002 Case E-VI Warmest Water

SOCKEYE SALMON




PINK SALMON
Adult Inmigration
Spawning
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Outmigration
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MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
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Devil Canyon 2002 Case C Warmest Water
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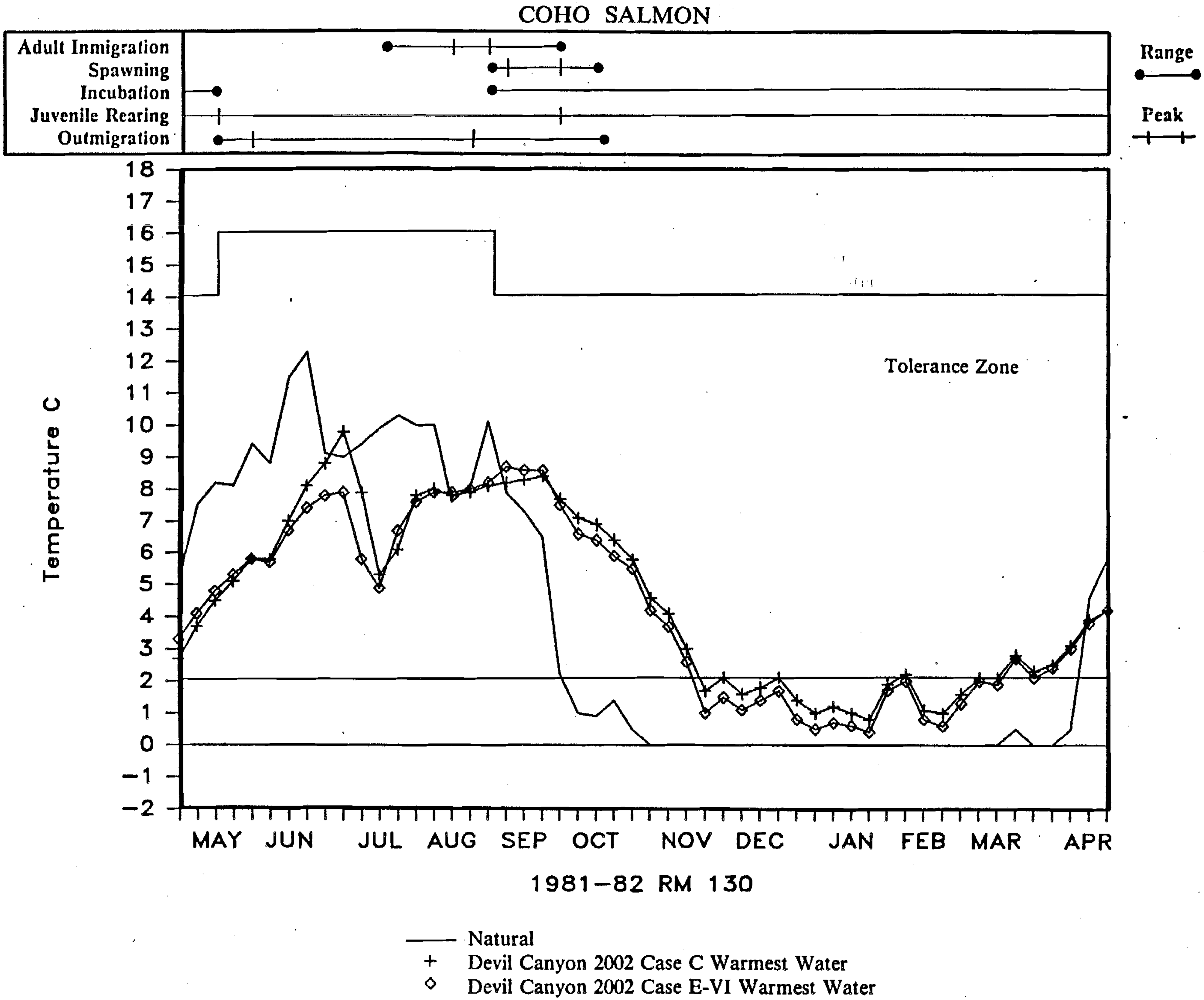

COHO SALMON
Adult Immigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
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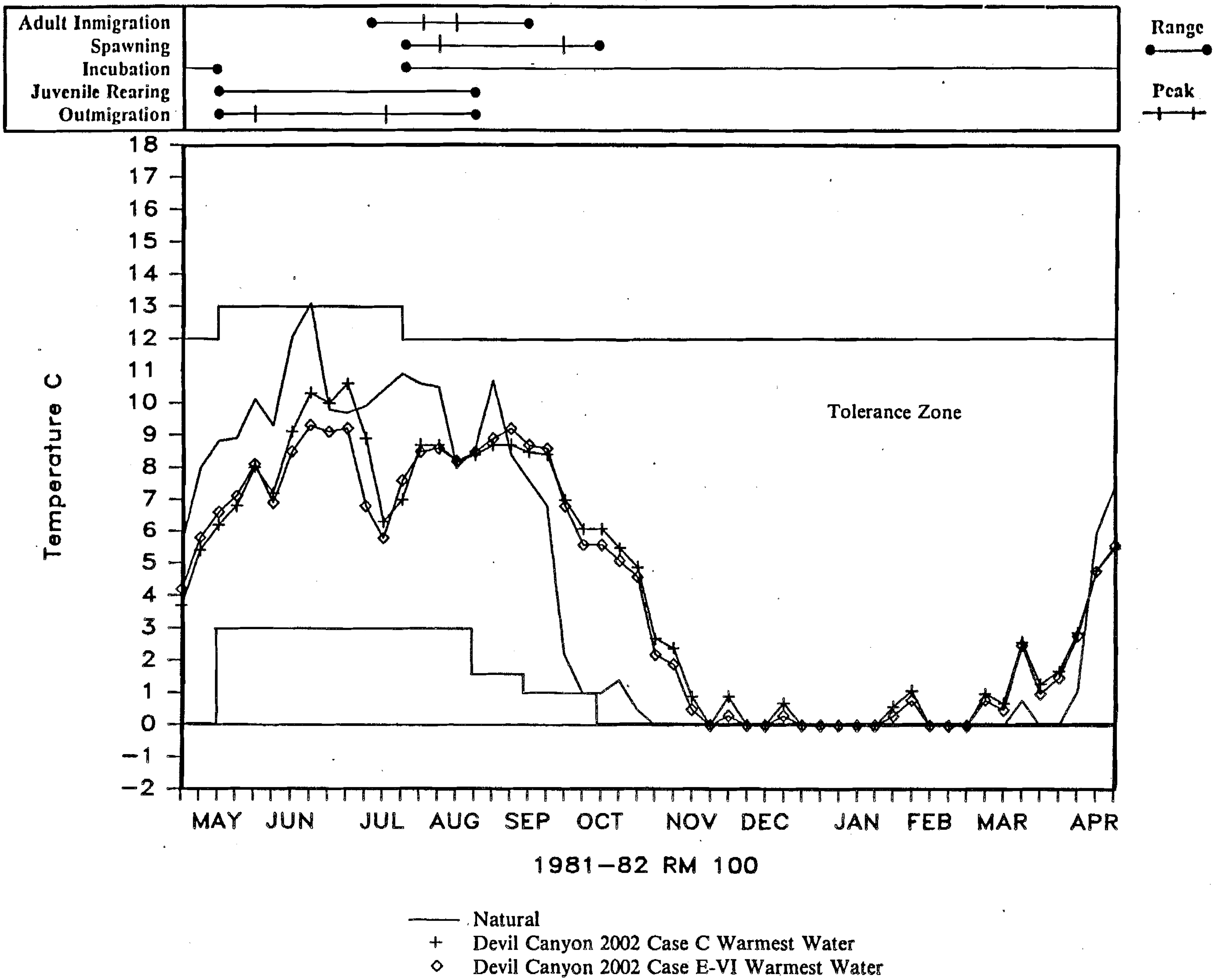
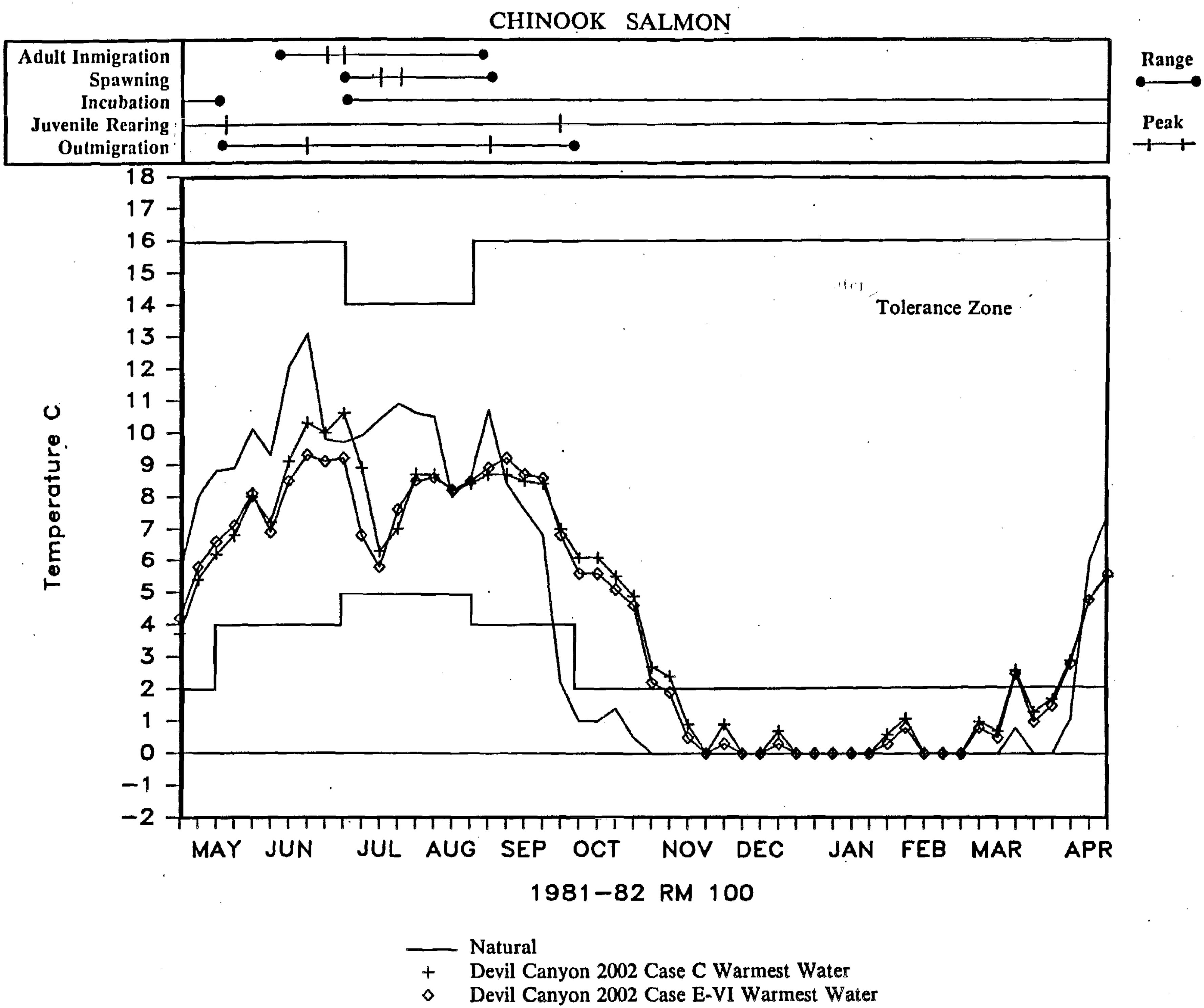
1981−82 RM 130
Natural
Devil Canyon 2002 Case C Warmest Water
Devil Canyon 2002 Case E-VI Warmest Water

D25

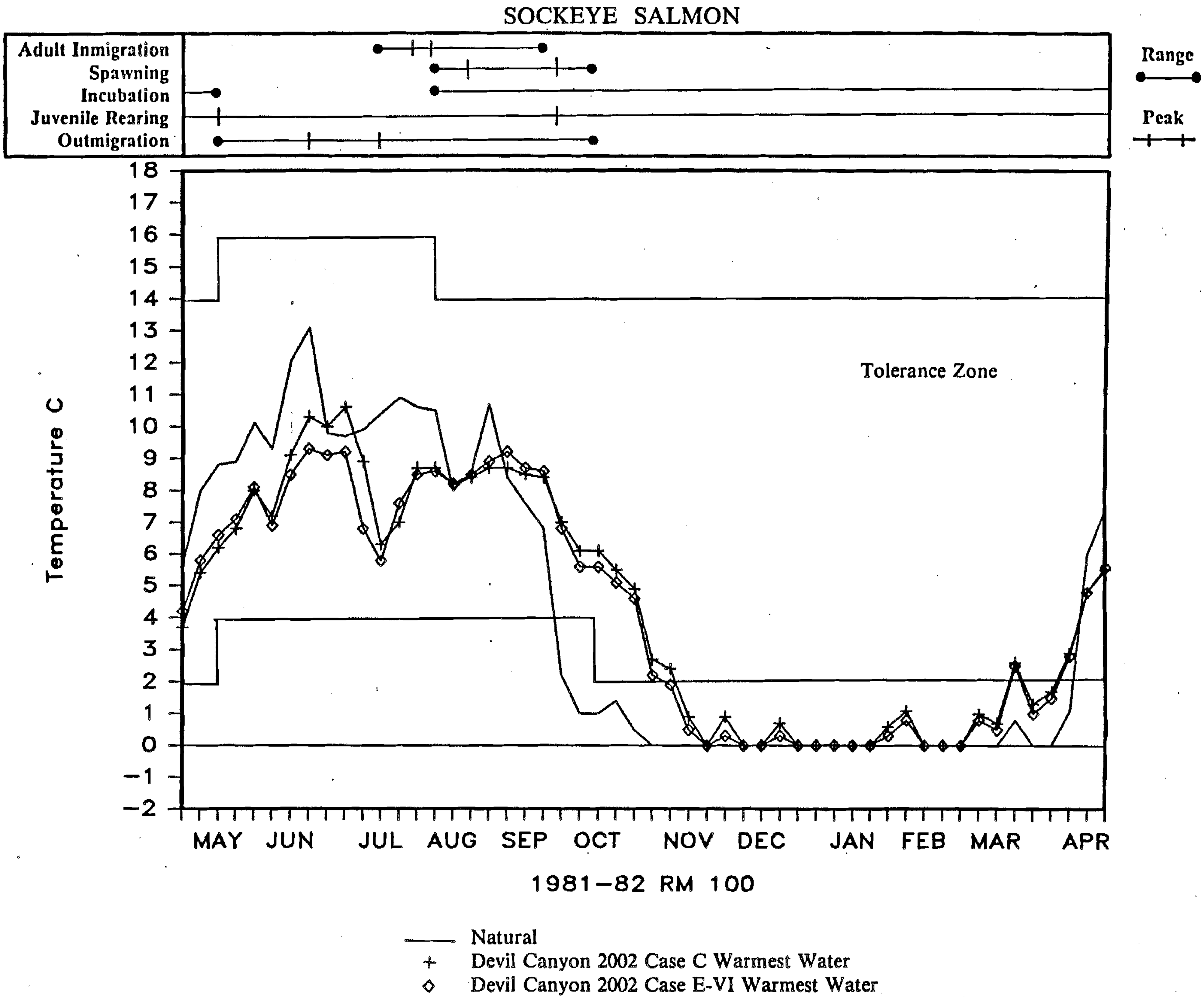
CHUM SALMON


Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981–82 RM 100
Natural
Devil Canyon 2002 Case C Warmest Water
Devil Canyon 2002 Case E-VI Warmest Water

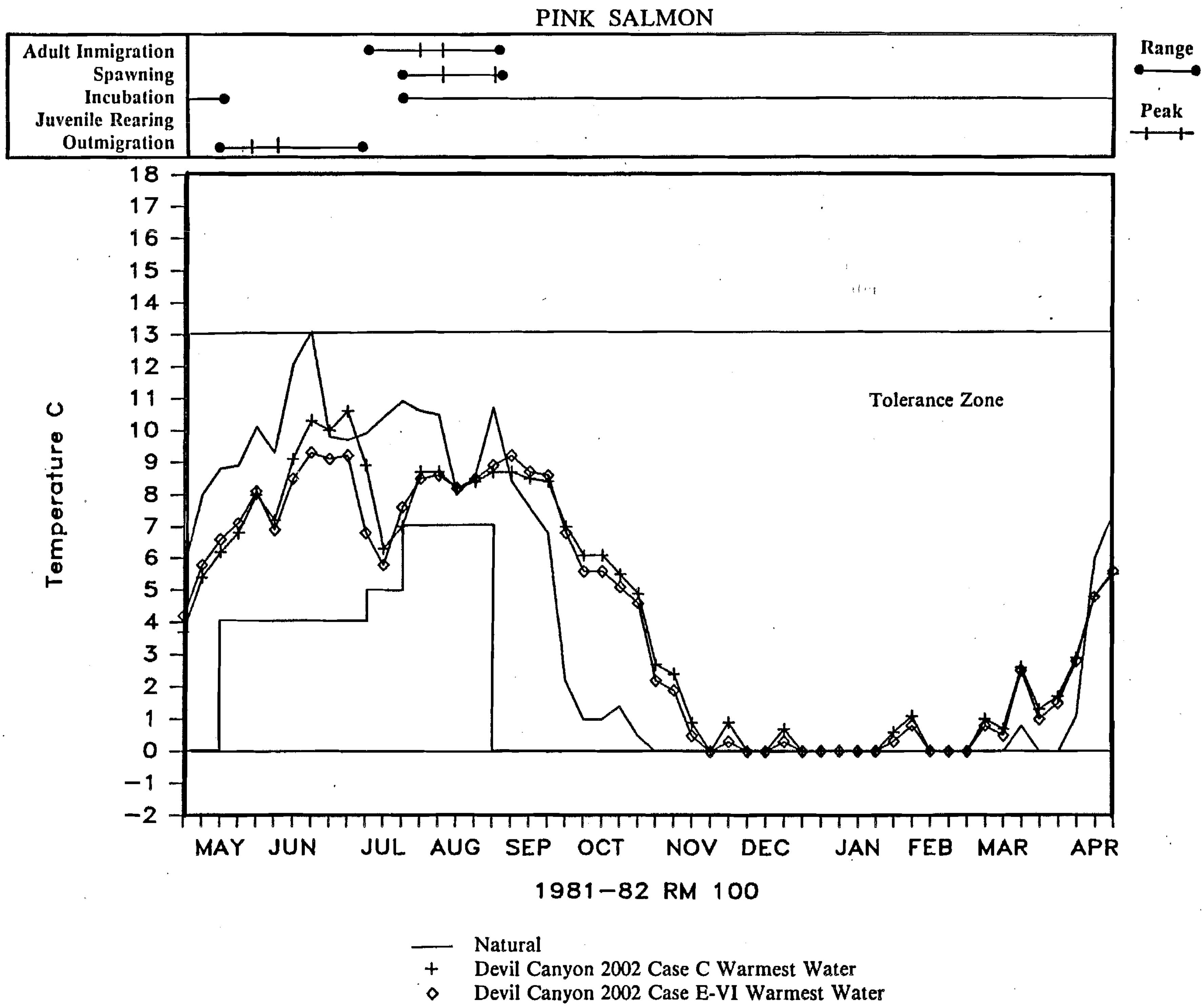


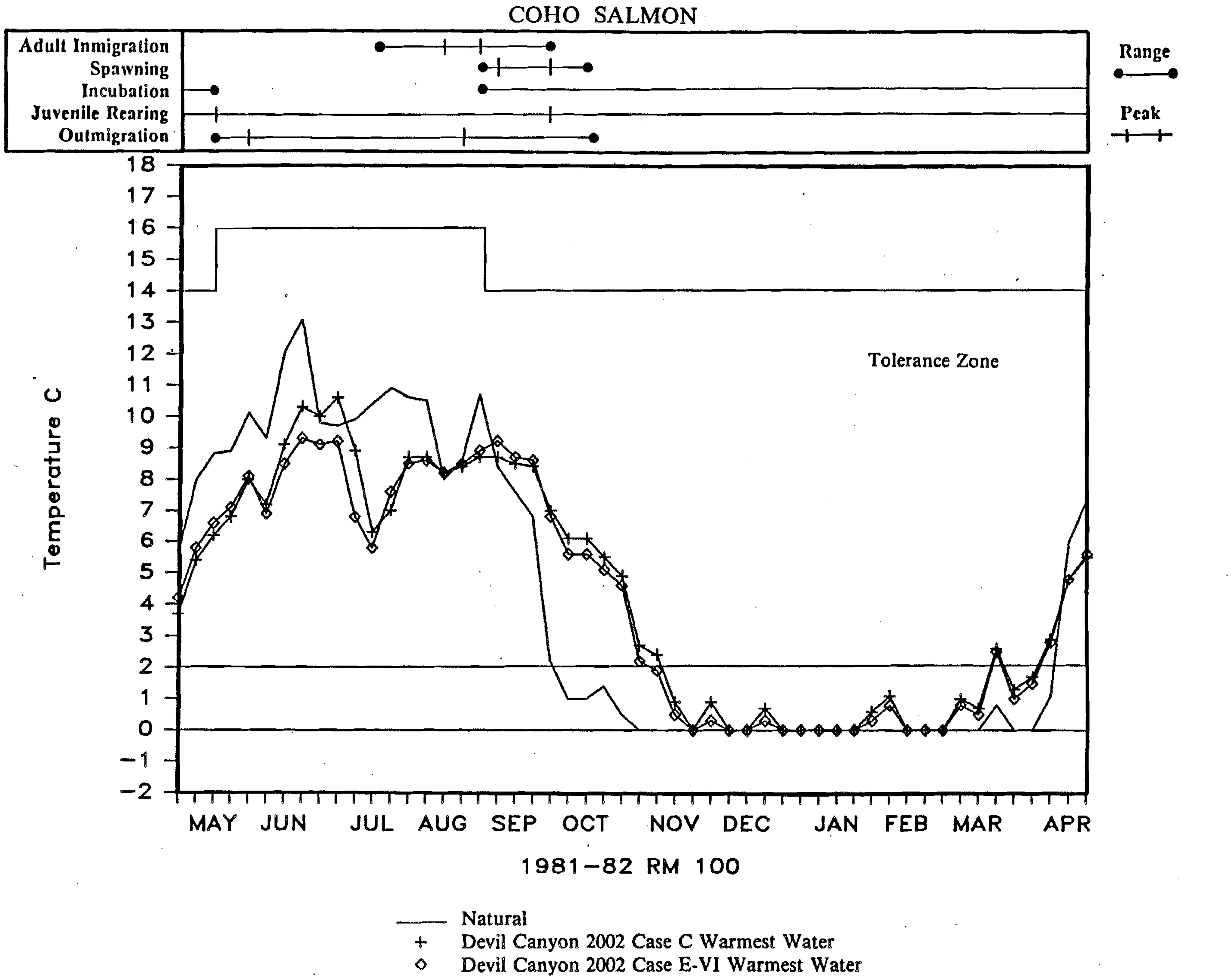
CHINOOK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1981−82 RM 100
Natural
Devil Canyon 2002 Case C Warmest Water
Devil Canyon 2002 Case E-VI Warmest Water

D27


SOCKEYE SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
Tolerance Zone
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
1981−82 RM 100
Natural
Devil Canyon 2002 Case C Warmest Water
Devil Canyon 2002 Case E-VI Warmest Water

D28


PINK SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Temperature C
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
Tolerance Zone
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1981−82 RM 100
Natural
Devil Canyon 2002 Case C Warmest Water
Devil Canyon 2002 Case E-VI Warmest Water


COHO SALMON
Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
Range
Peak
Tolerance Zone
Temperature C
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1981−82 RM 100
Natural
+ Devil Canyon 2002 Case C Warmest Water
◇ Devil Canyon 2002 Case E-VI Warmest Water