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Geographic and seasonal distribution of the infective stage of *Ceratomyxa shasta* (Myxozoa) in Northern California

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ABSTRACT: The geographic distribution of the infective stage of *Ceratomyxa shasta* (in California, USA) is limited to the San Joaquin, Sacramento, Pit, and Klamath river systems. In the San Joaquin system, the infective stage occurs in the Mokelumne River. In the Sacramento system, the infective stage occurs in the mainstem of the Sacramento River as well as in some major tributaries (Feather River, Butte Creek). In the Klamath system, only the mainstem of the Klamath River is infective. The occurrence of infective *C. shasta* in the Klamath River is seasonal. During 1986–1987, the river was infective until December 5 to 15 (water temperature 7 °C). The river was non-infective until spring of 1987. Infectivity reoccurred on April 9 to 20 (water temperature 15 °C).

INTRODUCTION

Ceratomyxosis is a disease of trout and salmon in the Pacific northwest caused by the myxozoan *Ceratomyxa shasta* Noble, 1950. Ceratomyxosis has caused disease and deaths in hatchery and wild salmonids, both juvenile and adult (Rucker et al. 1954, Wales & Wolf 1955, Conrad & DeCew 1966, Schafer 1968, Sanders et al. 1970, Sanders et al. 1972, Ratliff 1981, Buchanan et al. 1983). Salmonid species and strains vary widely in susceptibility to ceratomyxosis (Schafer 1968, Johnson 1975, Zinn et al. 1977, Ratliff 1981, Buchanan et al. 1983, Ching 1984, Ching & Munday 1984b). Within a species or strain susceptibility may vary from highly susceptible to resistant.

The life cycle of *Ceratomyxa shasta* is not completely known. In particular, the stage infective to fish is unknown even though its ecology and infection process have been studied. The geographic distribution of *C. shasta* is limited to northern California, Oregon, Washington, Idaho, and British Columbia (Johnson et al. 1979, Ching & Munday 1984a). Within its geographic range, only certain waters contain the stage infective to fish (infective stage). Other waters may contain infected salmonids but lack the infective stage (Sanders et al. 1970, Johnson 1975, Johnson et al. 1979). Little work has been done on the geographic distribution of the infective stage of *C. shasta* in California (Table 1). Nothing has been reported concerning rivers tested but negative for the infective stage.

The infection process is seasonal and is generally limited to about May to November (Schafer 1968, Johnson 1975, Udey et al. 1975, Johnson et al. 1979, Ratliff 1983, Ching & Munday 1984a). However, seasonal occurrence in California has been examined only at the Crystal Lake Hatchery in the Pit River drainage (Schafer 1968). At Crystal Lake, infection did not occur at temperatures less than 10 °C. January, February, and March were non-infective depending on water temperature. California rivers and streams with anadromous fish runs have not been studied in this regard. At warmer temperatures, the course of the disease is faster (Udey et al. 1975).

There is no known treatment for ceratomyxosis hence prevention and management are paramount. Management involves stocking resistant species or strains wherever waters are known to harbor the infective stage, and releasing hatchery fish during periods of low or no infectivity. The objectives of this study were to determine the geographic and seasonal occurrence of the infective stage of *Ceratomyxa shasta* in California. Such information is essential to management of resident and anadromous salmonids.

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Table 1 *Cerato myxa shasta*. Geographic distribution of the infective stage in California

Location and watershed	Comments	Source
Sacramento River, Shasta Lake	Upstream from mouth to and including Shasta Lake	Wolf & Manzer unpubl. (cited in Johnson et al. 1979)
Feather River	Downstream from Oroville to confluence with Sacramento River	Wolf & Manzer unpubl. (cited in Johnson et al. 1979)
Pit River	Between Sucker Springs and confluence with Fall River	Schafer (1968)
Crystal, Baum, Rising River and Britton Lakes	Probably throughout each	Schafer (1968)
Rising River	Throughout river	Shafer (1968)
Hat Creek	Below Baum Lake	Shafer (1968)
Fall River	Probably entire river	Schafer (1968)
Klamath River	Upstream from mouth to and including Klamath Lake in Oregon	Johnson et al. (1979)

MATERIAL AND METHODS

Shasta rainbow trout used as sentinels (and highly susceptible to *Ceratomyxa shasta*) were obtained from California Department of Fish and Game's (CDFG) Mount Shasta Hatchery or American River Hatchery, USA. Fish were held at the Humboldt State University (HSU) Hatchery or CDFG Fish Disease Laboratory until needed for field exposures.

Geographic distribution of the infective stage of *Ceratomyxa shasta* was determined by placing caged sentinels in test streams and rivers. When a river system was first tested, cages were placed near the mouth of the system but above tidal influence. Further exposures in the same system were performed only if the infective stage was present and were always performed further up river. Plastic minnow traps (43.5 long × 23 cm wide) with entrance holes plugged or collapsible wood and plastic mesh cages (1.0 × 1.0 × 1.0 m) were used for field exposures. Up to 25 fish (depending on size) were placed in minnow trap-type cages. Up to 100 fish were placed in larger cages. Caged sentinels were left in test streams for 10 to 14 d to allow for infection to take place. Sentinels were not fed during exposure. Sentinels were then returned to the HSU Telonicher Marine Laboratory or CDFG Fish Disease Laboratory for rearing.

Field exposures, to determine seasonal occurrence of the infective stage of *Ceratomyxa shasta*, were carried out in the Klamath River at Klamath Glen, California, during the winter of 1986–1987. This portion of the river is highly infective. Twenty caged sentinels were placed in the river for 10 d at 10-d intervals. Only minnow trap-type cages were used for seasonal studies. Sentinels were not fed during exposure. River water temperature was monitored throughout the study. Sentinels were brought to the HSU Telonicher Marine Laboratory for rearing.

Sentinels from geographic and seasonal studies were reared for at least 70 d or until ceratomyxosis was diagnosed. This rearing period allowed for development of the characteristic spores of *Ceratomyxa shasta*. Rearing was performed at the HSU Telonicher Marine Laboratory or at CDFG Fish Disease Laboratory. Individual lots of fish were kept separate at all times. Each lot was maintained in a self-contained rearing unit (tank and filter) or on a separate water supply to prevent cross contamination. Sentinel fish were fed a maintenance ration throughout rearing.

Sentinel fish were examined for ceratomyxosis either when they died or after 70 or more d rearing. A small piece of lower intestine was removed from each fish and 2 wet mounts prepared from the fluid contents. Each wet mount was examined at 400× or 1000× for 10 min or until spores were observed. Diagnosis of ceratomyxosis was based on recovery of the characteristic kidney bean-shaped spores of *Ceratomyxa shasta*.

RESULTS

We found the infective stage of *Ceratomyxa shasta* in the San Joaquin, Sacramento, and Klamath River systems (Table 2). In the San Joaquin system, the infective stage occurs in the Mokelumne River. In the Sacramento system, the infective stage occurs in the mainstem of the Sacramento River as well as some of the major tributaries (Feather River, Butte Creek). In the Klamath system, only the mainstem of the Klamath

Table 2. *Ceratomyxa shasta*. Sites tested for presence of infective stage; map locations; and results. Map locations refer to range (R), township (T), and section (S) on U. S. Geological Survey topographic maps. Pos: infective stage detected by sentinel fish; Neg: negative

Test site	Map location	Result
Coastal rivers		
Smith River	R1E, T17N, S32	Neg
Praire Creek	R1E, T11N, S22	Neg
Redwood Creek	R1E, T10N, S11	Neg
Mad River	R2E, T6N, S31	Neg
Eel River	R1W, T3N, S29	Neg
Mattole River	R2W, T2S, S9	Neg
Ten-Mile River	R17W, T20N, S34	Neg
Noyo River	R17W, T18N, S1	Neg
Big River	R17W, T17N, S24	Neg
Navarro	R16W, T15N, S7	Neg
Gualala River	R15W, T11N, S26	Neg
Russian River	R11W, T7N, NE ¼ sec (at Duncans Mills)	Neg
Klamath-Trinity system		
Klamath River at Klamath Glen	R2E, T13N, S 19 (river mile 7)	Pos
at Weitchpec	R4E, T9N, S10 (river mile 43.5)	Pos
above Salmon River	R6E, T12N (river mile 71)	Pos
at Beaver Creek	R8W, T46N, S6 (river mile 161)	Pos
above Scott River	R10W, T46N, S32 (river mile 144)	Pos
at Iron Gate Hatchery	R5W, T47N, S17 (river mile 189.5)	Pos
at Copco Lake	R4W, T48N, S35 (river mile 202)	Pos
Trinity River at Weitchpec	R4E, T9N, S10 (river mile 0)	Neg
at Willow Creek	R5E, T7N, S28 (river mile 25.5)	Neg
at Big Bar	R12W, T33N, S6 (river mile 63.5)	Neg
Salmon River	R6E, T11N, S2	Neg
Scott River	R10W, T45N, S21	Neg
Shasta River	R6W, T45N, S29	Neg
Bogus Creek	R5W, T47N, S13	Neg
Humbug Creek	R7W, T46N, S16	Neg
Sacramento river system		
Sacramento River at Los Molinos	R2W, T25N (river mile 229)	Pos
Sacramento River just above Keswick Dam	R5W, T32N, S21 (river mile 302.5)	Pos
Sacramento River above Shasta Lake	R5W, T36N, S15	Neg
Feather River (between Yuba City/Marysville)	R3E, T15N (river mile 29)	Pos
Lake Almanor	R7E, T27–28N; R8E, T27–28N	Neg
Butt Valley Reservoir	R7E, T26–27N	Neg
Antelope Reservoir	R12E, T27N, S15, 22–26	Neg
Spanish Creek (tributary to East Branch NF)	R9E, T25N, S22	Neg
East Branch North Fork Feather River	R7E, T25N, S21	Neg
North Fork Feather River at Belden Reservoir	R7E, T26N, S25	Pos
North Fork Feather River at Rock Creek Reservoir	R6E, T25N, S26	Pos
Milk Ranch Creek (½ mile above confluence with NF Feather River)	R6E, T24N, S2	Neg
Bear River	R5E, T13N, S2	Neg
Butte Creek	R1W, T16N, S35	Pos
San Joaquin river system		
North Mokelumne River	R4E, T4N (river mile 9)	Pos

River is infective. Coastal rivers lack the infective stage.

In winter 1986, the Klamath River was infective up to and including the exposure interval from December 5 to 15. At this time the water temperature was 7 °C. The river was not infective until the spring of 1987. Sentinels were first infected during the exposure interval from April 9 to 20, 1987 at a water temperature of 15 °C.

DISCUSSION

The known distribution of the infective stage of *Ceratomyxa shasta* in California is shown in Fig. 1 Rivers or streams which tested negative via sentinels for the presence of the infective stage are also included. The figure is based on Schafer (1968), Wolf & Manzer as reported by Johnson et al. (1979), and on this study.

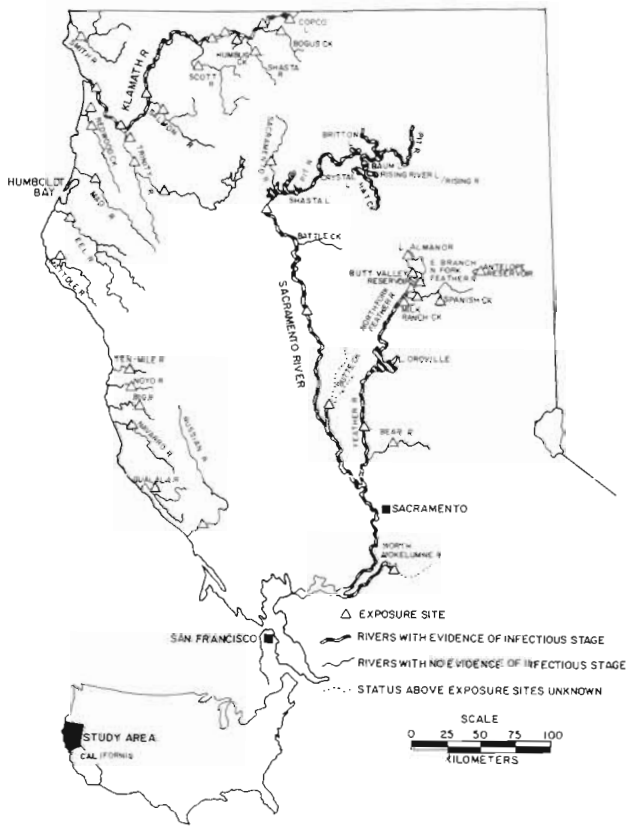

Fig. 1. *Ceratomyxa shasta*. Known geographic distribution of the infective stage in California. Includes all known sources

In 1 instance another source was used. Horsch (1986, U.S. Fish and Wildlife Service, Coleman National Fish Hatchery, Anderson, California, pers. comm.) planted caged sentinels in Battle Creek (Sacramento Drainage) to demonstrate non-infectivity in these waters.

The distribution of the infective stage of *Ceratomyxa shasta* in California is limited to the San Joaquin, Sacramento, Klamath, and Pit River system. The Sacramento and Klamath are two of the most important salmon and steelhead production areas in California. The Pit River system includes many of California's blue ribbon trout streams (e.g. Hat Creek, Fall River, Rising River).

Susceptible salmonids may be subjected to high mortalities during outmigration through infective waters or following stocking into infective waters. Therefore, no fish should be released into infective waters until their susceptibility to ceratomyxosis has been assessed. The California Department of Fish and Game's current policy is to release infected anadromous stocks only to those infective waters where the parent stock originated. Resident trout production is restricted to non-infective waters since current policy would generally not permit release of infected stocks even into infective waters.

The reason(s) for the limited distribution of the infective stage of *Ceratomyxa shasta* is unknown. However, the patchiness of the distribution might reflect distribution of an intermediate host. This patchiness of distribution suggests fairly specific ecological requirements for the infective stage. Thus, accidental introductions of this pathogen would seem unlikely Nevertheless transfer of fish from infective to non-infective waters is, at best, unwise.

The seasonal distribution of the infective stage of *Ceratomyxa shasta* in the Klamath River appears similar to that reported by Schafer (1968) at Crystal Lake Hatchery. However, it seems likely that given the appropriate temperatures and water flow regimes, the Klamath could be infective at any time of year. The Fraser River, British Columbia, Canada, can be infective at temperatures as low as 4 to 6 °C (Ching & Munday 1984a). Hatchery releases should, however, be timed so as to minimize contact between fish and infective waters. This means outmigrants should contact infective waters as early in the spring or as late in the fall as possible. In particular late spring releases of age-0 chinook that must contact infective waters should be avoided. In response to ceratomyxosis in Lake Simtustus and the Deschutes River, Oregon Department of Fish and Wildlife releases into these waters only age-1 spring chinook smolts that outmigrate before *C. shasta* infectivity begins in late spring (Ratliff 1981). Such a program should prove useful in California also.

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