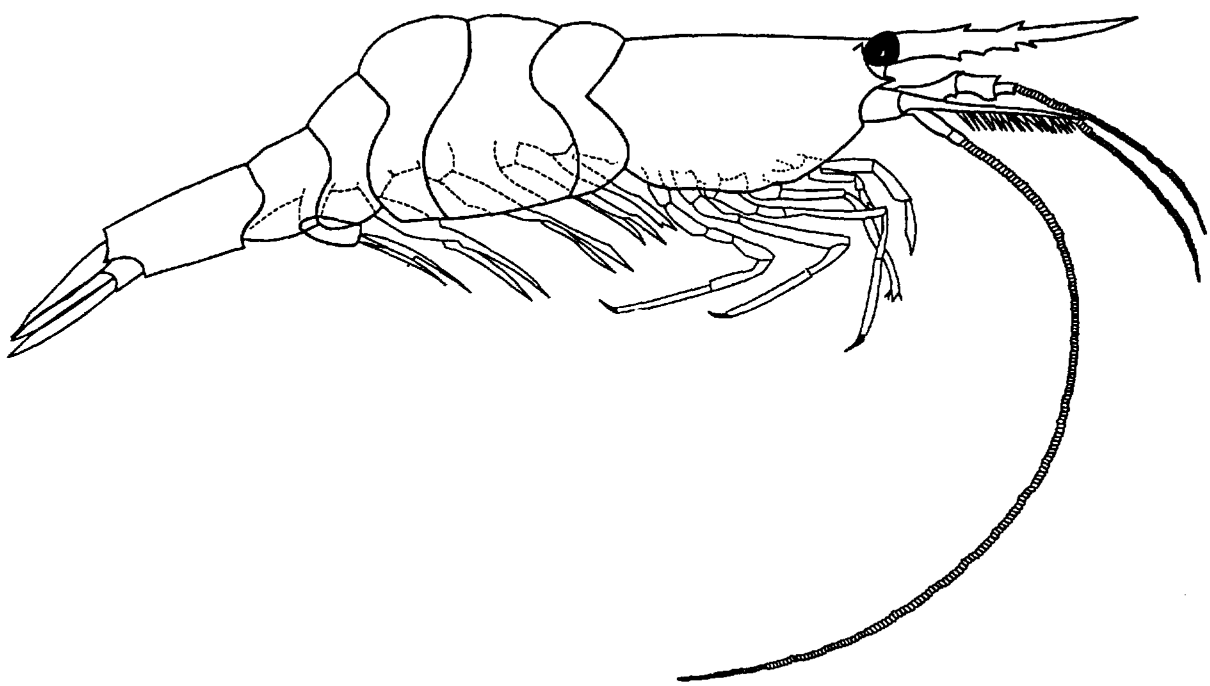
U.S. Fish & Wildlife Service

Recovery Plan for the California Freshwater Shrimp

(Syncaris pacifica Holmes 1895)



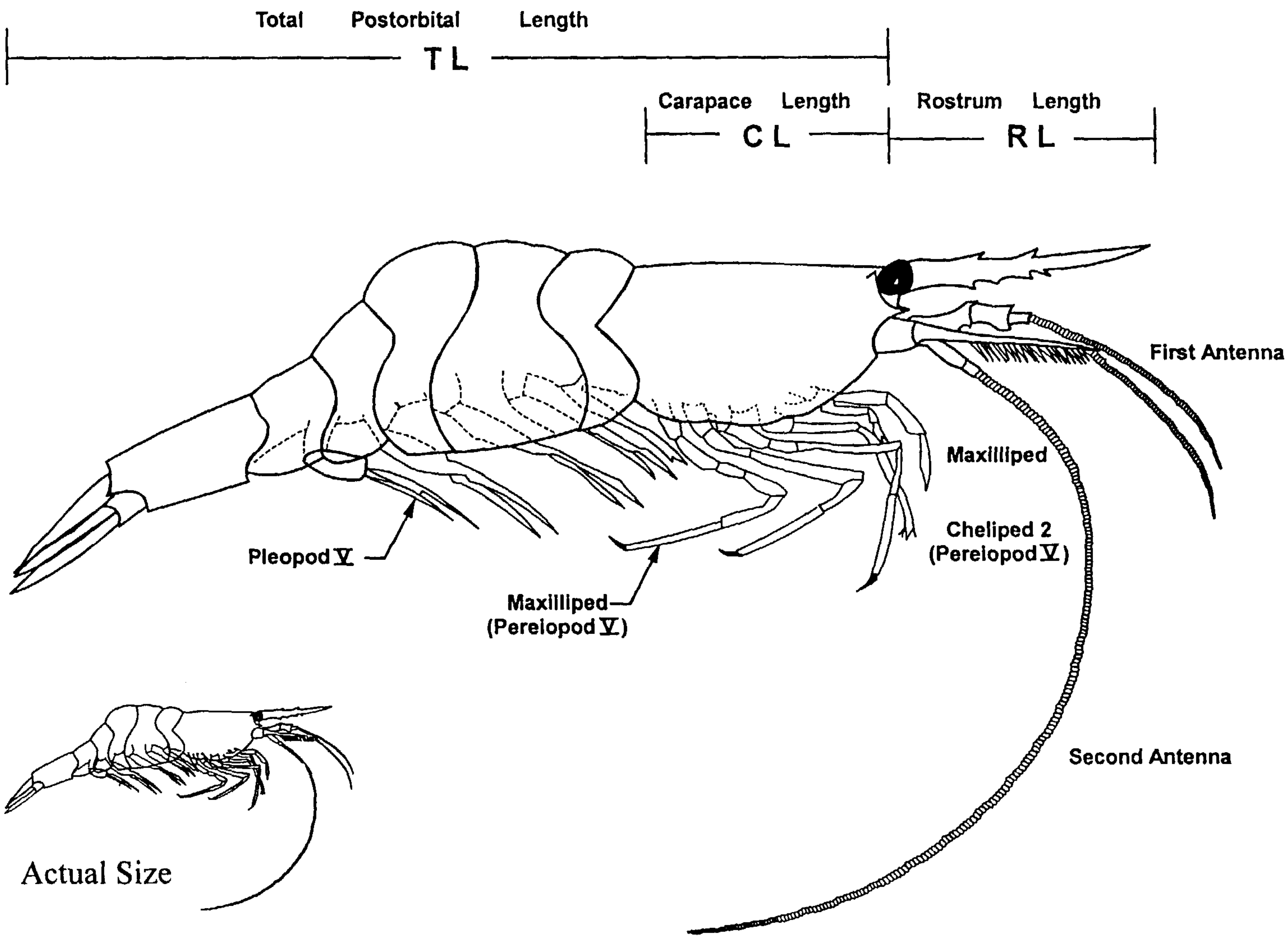


Figure 1. The California freshwater shrimp, *Syncaris pacifica*.

CALIFORNIA FRESHWATER SHRIMP

(*Syncaris pacifica* Holmes 1895)

RECOVERY PLAN

Region 1
U.S. Fish and Wildlife Service
Portland, Oregon

Approved: [signature]
Manager, California/Nevada Operations Office
Region 1, U.S. Fish and Wildlife Service

Date: 7/31/98

CALIFORNIA FRESHWATER SHRIMP

(*Syncaris pacifica* Holmes 1895)

RECOVERY PLAN

Region 1
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1998

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U.S. Fish and Wildlife Service. 1998. California Freshwater Shrimp *(Syncaris pacifica* Holmes) Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon. 94 pp.

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ACKNOWLEDGMENTS

This Recovery Plan was prepared by Darren Fong, National Park Service, and Matthew Vandenberg, U.S. Fish and Wildlife Service.

Special thanks to the California Department of Fish and Game's staff members Sharon Shiba, Associate Biologist, Inland Invertebrates Coordinator for the Department's Threatened and Endangered Species Project and William Cox, Associate Biologist, District Fishery Biologist for Sonoma and Marin Counties. The insight they had and the access they provided to their unpublished data helped in the preparation of this plan.

John Reynolds of the National Park Service, Pacific Great Basin Support Office; Elizabeth Caraker, Planner I, of Napa County Conservation, Development and Planning Department; Craig E. Anthony, Deputy Director for Resource Management and Bradley E. Valentine, Senior Wildlife Biologist for the California Department of Forestry and Fire Protection; and the Murray Dam Committee also provided helpful comments and suggestions that improved this plan.

EXECUTIVE SUMMARY

Current Species Status: The California Freshwater Shrimp (*Syncaris pacifica*) species is listed as endangered and is the only extant member of the genus *Syncaris*. The shrimp is endemic to Marin, Sonoma, and Napa Counties north of San Francisco Bay, California. Seventeen coastal streams currently support the shrimp. The historic distribution of the shrimp is unknown, but it probably inhabited most perennial lowland streams in the area.

Habitat Requirements and Limiting Factors: The shrimp is found in low elevation (less than 116 meters, 380 feet), low gradient (generally less than 1 percent) perennial freshwater streams or intermittent streams with perennial pools where banks are structurally diverse with undercut banks, exposed roots, overhanging woody debris, or overhanging vegetation. Most of the stream reaches flow through private lands. Existing populations are threatened by introduced fish, deterioration or loss of habitat resulting from water diversion, impoundments, livestock and dairy activities, agricultural activities and developments, flood control activities, gravel mining, timber harvesting, migration barriers, and water pollution.

Recovery Objective: The objectives of this recovery plan are two-fold: 1) to recover and delist the California freshwater shrimp when numbers increase sufficiently and suitable habitat is secured and managed within 17 watersheds harboring shrimp and 2) to enhance habitat conditions for native aquatic organisms that currently coexist or have occurred historically with the California freshwater shrimp.

Recovery Criteria: Four general drainage units support shrimp. The drainage units are 1) tributary streams in the lower Russian River drainage, 2) coastal streams flowing directly into the Pacific Ocean, 3) streams draining into Tomales Bay, and 4) streams flowing into San Pablo Bay. Problems within associated watersheds must be identified and watershed plans prepared for each of the 17 streams that now support shrimp.

Downlisting from endangered to threatened will be considered when:

1. a watershed plan has been prepared and implemented for Lagunitas Creek (including Olema Creek), Walker Creek (including Keys Creek), Stemple Creek, Salmon Creek, Austin Creek (including East Austin Creek), Green Valley Creek (including Atascadero, Jonive, and Redwood Creeks), Laguna de Santa Rosa (including Santa Rosa and Blucher Creeks), Sonoma Creek (including Yulupa Creek), Napa River (including Garnett Creek), and Huichica Creek;

2. long term protection is assured for at least one shrimp stream in each of the four drainage units; and

3. the abundance of California freshwater shrimp approaches carrying capacity in each of 17 streams.

Delisting of the California freshwater shrimp will be considered when:

1. a watershed plan has been prepared and implemented for Lagunitas Creek (including Olema Creek), Walker Creek (including Keys Creek), Stemple Creek, Salmon Creek, Austin Creek (including East Austin Creek), Green Valley Creek (including Atascadero, Jonive, and Redwood Creeks), Laguna de Santa Rosa (including Santa Rosa and Blucher Creeks), Sonoma Creek (including Yulupa Creek), Napa River (including Garnett Creek), and Huichica Creek;

2. long term protection in assured for at least eight shrimp streams, with at least one in each of the four drainage units;

3. shrimp-bearing streams having fewer than 8 kilometers (5 miles) of potential shrimp habitat have shrimp distributed in all potential habitat; those with more than 8 kilometers (5 miles) of potential shrimp habitat, have shrimp distributed over 8 kilometers (5 miles)

or more; and

4. populations of shrimp maintain stable populations approaching carrying capacity for at least 10 years in each of 17 streams.

Actions Needed:

1. Remove existing threats to known populations of shrimp.
2. Restore habitat conditions favorable to shrimp and other native aquatic species at extant localities.
3. Protect and manage shrimp populations and habitat once the threats have been removed and restoration has been completed.
4. Monitor and evaluate shrimp habitat conditions and populations.
5. Assess effectiveness of various conservation efforts on shrimp.
6. Conduct research on the biology of the species.
7. Restore and maintain viable shrimp populations at extirpated localities.
8. Increase public awareness and involvement in the protection of shrimp and native, cohabiting species through various outreach programs.
9. Assess effects of various conservation efforts on cohabiting, native species.
10. Assemble a California freshwater shrimp recovery team.

Total Estimated Cost of Recovery: $39,747,000

Anticipated Date of Recovery: **Year 2018**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

The California freshwater shrimp (*Syncaris pacifica* Holmes 1895) is endemic to perennial streams in Marin, Napa, and Sonoma Counties, California and is the only extant species in the genus *Syncaris* (Figure 1). Populations of the California freshwater shrimp (shrimp) now remain in reaches of 17 streams (Table 1) (Note: Due to the lack of information regarding interbreeding and for simplicity the term population, as used in this plan, refers to a local population unit that shares a common gene pool). The species is adapted to freshwater environments and has not been found in brackish or estuarine environments. The shrimp is found in low elevation (less than 116 meters, 380 feet) and low gradient (generally less than 1 percent) streams where banks are structurally diverse with under cut banks, exposed roots, overhanging woody debris, or overhanging vegetation (Eng 1981, Serpa 1986, Serpa 1991a). Excellent habitat conditions for the shrimp include streams 30 to 90 centimeters (12 to 36 inches) in depth with exposed live roots (e.g., alder and willow trees) along completely submerged undercut banks (horizontal depth greater than 15 centimeters, 6 inches) with overhanging stream vegetation and vines (e.g., blackberry) (Serpa 1991a).

Several factors led to the listing of the shrimp as endangered. These factors include the limited distribution of the shrimp, population declines associated with introduced fish, and the deterioration or loss of habitat resulting from water diversion, impoundments, livestock grazing, agricultural activities, urbanization, and water pollution. Many of the factors that led to the listing of the shrimp have intensified (D. Bowker pers. comm. 1989).

The shrimp was proposed as a threatened species on January 12, 1977, in the Federal Register (42 **FR** 2507). That proposal was withdrawn on December 10, 1979 (44 **FR** 70796) under a provision of the 1978 amendments to the Endangered Species Act of 1973, which required withdrawal of all pending proposals if they were not finalized within 2 years of the proposal. Significant new information (Eng 1981, Serpa 1986) on which to propose endangered status for the shrimp was incorporated in the April 22, 1987, proposed rule (52 **FR** 13254). On October 31, 1988 (53 **FR** 43884), the final rule listing the California freshwater shrimp as an endangered species was published, and became effective on November 30, 1988 (U.S. Fish and Wildlife Service 1988). Critical habitat was not designated. Under State law, the California Fish and Game Commission listed the shrimp as endangered on October 2, 1980. The U.S. Fish and Wildlife Service has assigned a Recovery Priority of 8C indicating that the species is under a moderate degree of threat and has a high potential for recovery. The "C" indicates a potential for conflicts with construction or other development projects.

A. SPECIES DESCRIPTION

Phylum Arthropoda
 Class Crustacea
  Subclass Malacostraca
   Division Eucarida
    Order Decapoda
     Family Atyidae (Four species in the United States, one of which is extinct)
      Genus *Syncaris* (Two species in the United States, one of which is extinct)
       Species *pacifica* Holmes 1895 (after Pennak 1989)

The California freshwater shrimp (Figure 1), *Syncaris pacifica* (Holmes), is a decapod crustacean of the family Atyidae. The members of the atyid family are considered an ancient, primarily tropical, freshwater group that were isolated from a marine environment sometime during the Jurassic Period (Born 1968), roughly 136 to 190 million years ago. Only four species are comprised by the atyid family in North America: *Palaemonias ganteri* (Hay), *Palaemonias alabamae* (Smalley), *Syncaris pacifica* (Holmes), and *Syncaris pasadenae* (Holmes) (Pennak 1989). Samual J. Holmes first described *S. pacifica* as *Miersia pacifica* in 1895. In 1900, Holmes erected a new genus, *Syncaris*. One other species, *S. pasadenae*, has been placed in this genus. However, *S. pasadenae*, which inhabited coastal streams in southern California, is now presumed extinct.

Other freshwater shrimp can be found in California. The grass shrimp, *Palaemonetes paludosus*, is found in California, as well as other locations in the United States (Amant and Day 1972, Pennak 1989). The opossum shrimp, *Mysis relicta*, was introduced into Lake Tahoe in the early 1960's as part of California Department of Fish and Game efforts to increase the food resources for juvenile lake trout (Linn and Frantz 1965).

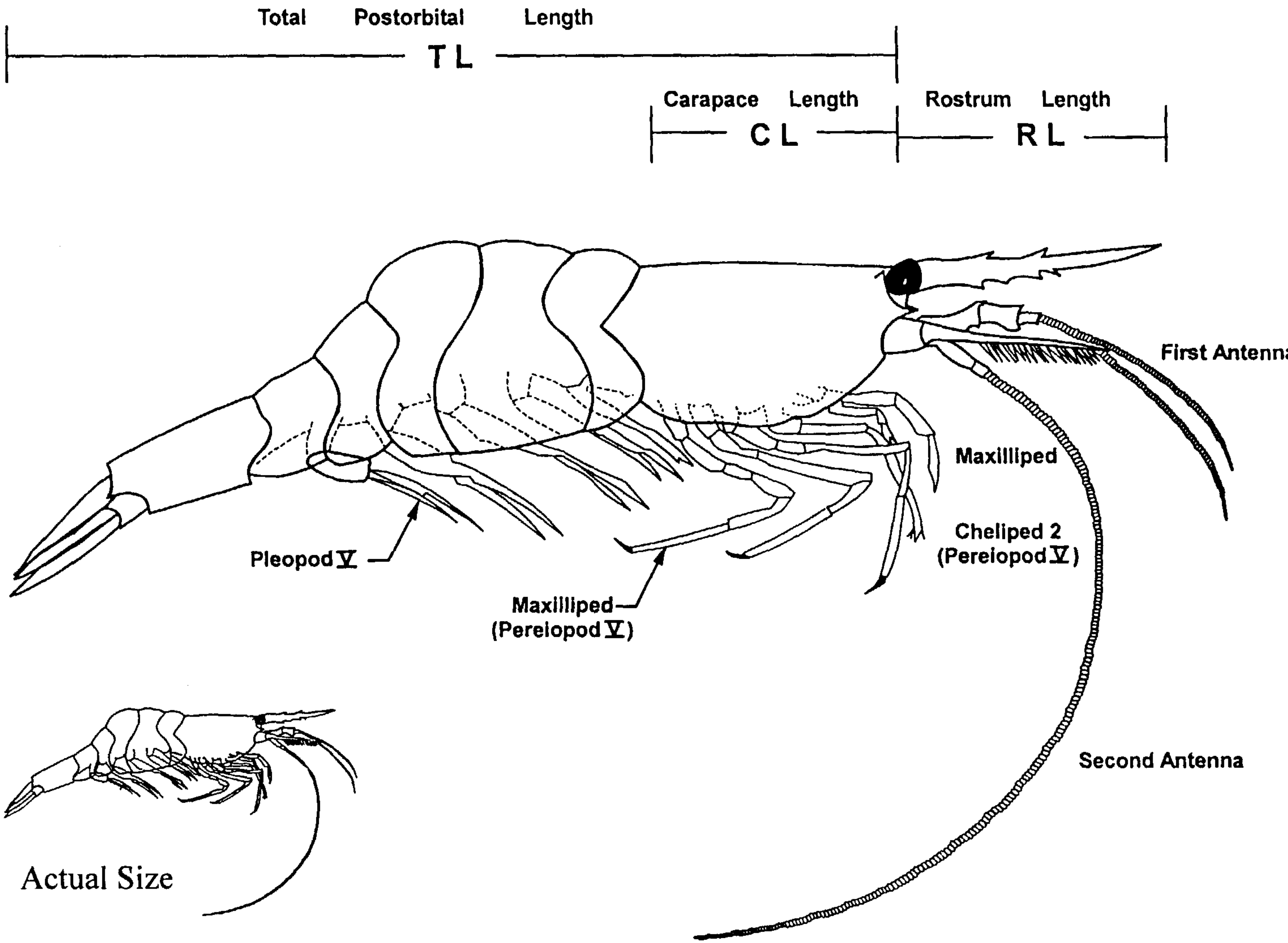

Figure 1. The California freshwater shrimp, *Syncaris pacifica*.

The shrimp is similar overall in appearance to other North American freshwater shrimps. Atyid shrimps can be separated from others based on the lengths of chelae (pincer-like claws) and presence of terminal setae (bristles) at the tips of the first and second chelae (Eng 1981, Pennak 1989). The presence of a short supraorbital spine (above the eye) on the carapace (body) and the angled articulation of the second chelae with the carpus (wrist) separate the California freshwater shrimp from other shrimps found in California.

According to Eng (1981), adults are generally less than 50 millimeters (2.17 inches) in postorbital length (from eye orbit to tip of tail). Females are generally larger than males. Based on shrimp collected in October, Eng (1981) described females ranging between 32 to 45 millimeters (1.3 to 1.8 inches) in length whereas males ranged from 29 to 39 millimeters (1.2 to 1.5 inches) in length. Messer and Brumbaugh (1989) note that females are typically deeper bodied than males.

Shrimp coloration is quite variable. Male shrimp are translucent to nearly transparent, with small surface and internal chromatophores (color-producing cells) clustered in a pattern to help disrupt their body outline and to maximize the illusion that they are submerged, decaying vegetation. Undisturbed shrimp move slowly and are virtually invisible on submerged leaf and twig substrates, and among the fine, exposed, live roots of trees along undercut stream banks. Both sexes may darken their bodies uniformly or gradually from top to bottom, but females have the striking ability to darken much more than males. Eng (1981) observed that the coloration of females ranges from a dark brown to a purple color. Two observed individuals in Lagunitas Creek were red (L. Serpa pers. comm. 1994). In some females, a broad tan dorsal band may also be present. Females may change rapidly from this very dark cryptic color to transparent with diffuse chromatophores, a distinctly different coloration. Eng (1981) never observed juveniles or males with the same ability to change color to this degree. Further morphological details can be found in Holmes (1895, 1900). Preserved specimens are available for viewing at the California Academy of Sciences, San Francisco, California.

B. HISTORIC AND CURRENT DISTRIBUTION

Prior to human disturbances, the shrimp is assumed to have been common in low elevation, perennial freshwater streams within Marin, Sonoma, and Napa Counties. Today, the shrimp is found in 17 stream segments within these counties (Figure 2). With the exception of Lagunitas Creek, stream reaches containing populations of shrimp flow through private lands. A substantial portion of Lagunitas Creek flows through the Samuel P. Taylor State Park, managed by the California Department of Parks and Recreation, and the Golden Gate National Recreation Area, managed by the National Park Service. A small segment of Salmon Creek flows through the Watson School historic site, managed by the Sonoma County Department of Parks and Recreation. On East Austin Creek, the Austin Creek State Recreation Area lies immediately upstream of shrimp populations.

The presence of shrimp in these stream segments is based on studies conducted by Hedgpeth (1968, 1975), Gidley *et al.* (1980), Eng (1981), Li (1981), Serpa (1986, 1991a), Messer and Brumbaugh (1989), California Department of Fish and Game (*in litt.* 1989), K. Taniguchi (U.S. Fish and Wildlife Service *in litt.* 1990a), WESCO (*in litt.* 1990), G. Falxa (U.S. Fish and Wildlife Service *in litt.* 1993), G. Fleisher (*in litt.* 1993), and W. Cox (pers. comm. 1994). The most extensive surveys to date for the shrimp have been conducted by Mr. Larry Serpa, with The Nature Conservancy. Serpa (1986) surveyed 146 locations in 53 streams for shrimp between 1982 and 1985.

The distribution of the shrimp can be separated into four general drainage units: 1) tributary streams in the lower Russian River drainage, which flow westward into the Pacific Ocean, 2) coastal streams flowing westward directly into the Pacific Ocean, 3) streams draining into a small coastal embayment (Tomales Bay), and 4) streams flowing southward into northern San Pablo Bay (Table 1). Many of these streams contain shrimp populations that are now isolated from each other (Fig. 2).

Even streams that appear isolated from other freshwater streams probably had shrimp because of past linkages to other shrimp-bearing waters. Geologic and climatic changes may have isolated populations by severing freshwater connections between streams.

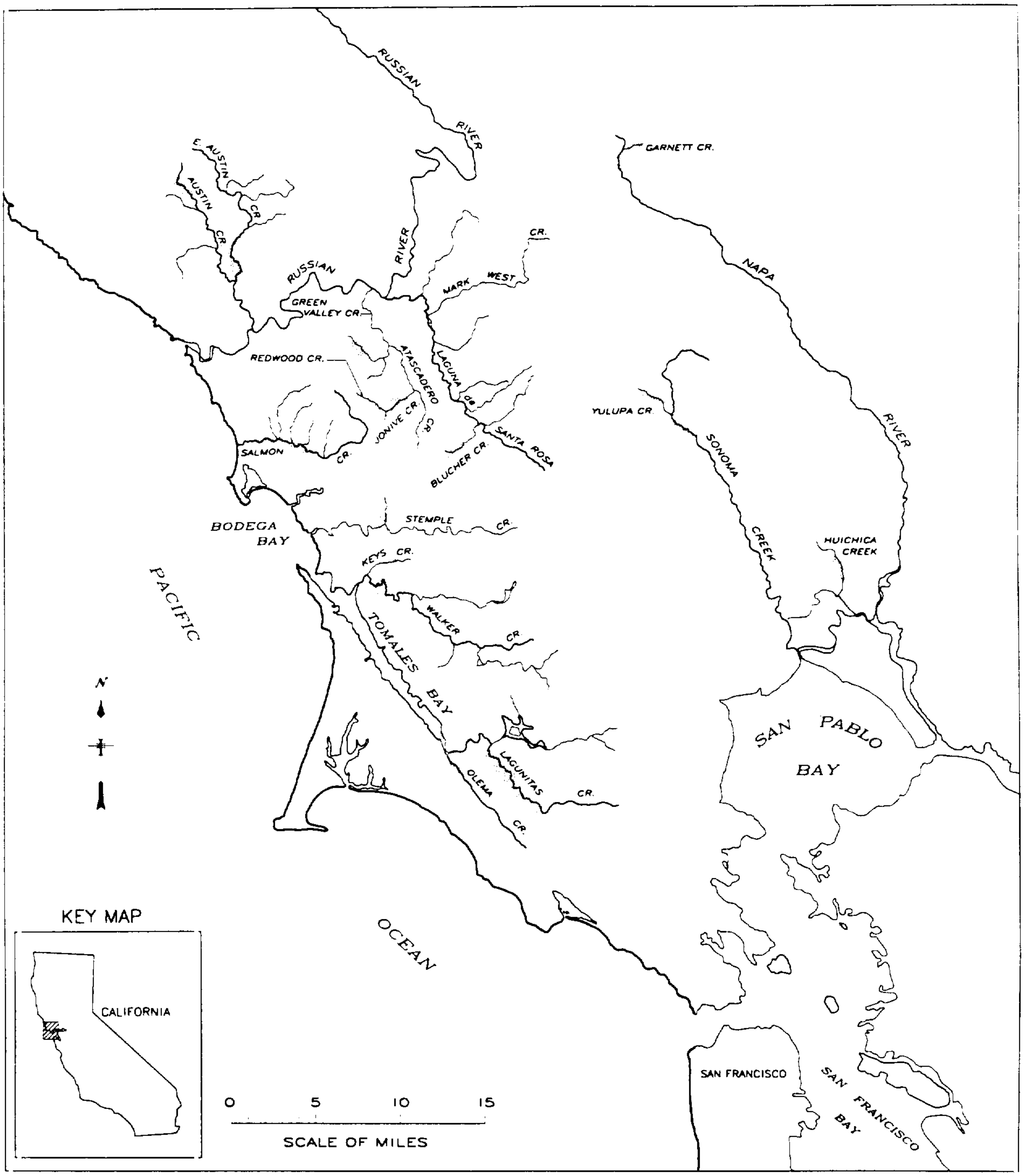

Figure 2. Distribution of the California Freshwater Shrimp

Table 1. Past and current distribution, habitat characteristics, and nature of threats to shrimp populations.

County	Stream (Drainage Unit)*	Shrimp Occurrence/ Existing Habitat Value**	Length (kilometers)	Nature of Threats	Citations
Marin	Lagunitas (3)	Extant/ Poor to excellent	13.4	a, d, f, l,	1, 1a, 2, 3, 4, 5, 6, 7, 8
	Olema (3)	Extant/ Not rated	Unknown	a,l	20
	Walker (3)	Extant/ Not rated	4.8	a, f, l	4, 4a, 6, 8
	Keys (3)	Extant/ Not rated	0.3	a, b	4a
	Stemple (2)	Extant/ Not rated	1.6	a, b, l	2, 4, 4a, 9, 10, 11
Sonoma	Blucher (1)	Extant/ Excellent	3.2	a, p	2, 4, 4a, 6, 7, 12
	Santa Rosa (1)	Extinct/ Not rated	NA	b, j, m, p, q	1, 1a, 2, 4, 4a, 12
	Jonive (1)	Extant/ Excellent	3.2	e, i, k, p	4, 6, 7, 12
	Redwood (1)	Extant/Not rated	Unknown	e, p	12
	Atascadero (1)	Unknown/ Not rated	Unknown	a, b, h, j, p	1, 2, 4, 12, 13, 14
	Green Valley (1)	Extant/ Fair	6.0	b, d, e, h, i, j, k, l, m, o, p	4, 6, 12, 13, 14
	Salmon (2)	Extant/ Excellent	19.1	a, b, c, e, k, p	1, 1a, 2, 4, 6, 7, 12
	East Austin (1)	Extant/ Excellent	4.8	e, g, h, i, o, p	1, 1a, 2, 4, 6, 7, 12, 15, 16
	Big Austin (1)	Extant/ Poor	5.9	e, g, l, n, o, p	1, 1a, 4, 6, 7, 12, 15, 16
	Sonoma (4)	Extant/ Fair	5.6	c, d, k, l, n, p	1a, 2, 4, 6, 7, 12, 17

County	Stream (Drainage Unit)*	Shrimp Occurrence/ Existing Habitat Value**	Length (kilometers)	Nature of Threats	Citations
	Yulupa (4)	Extant/ Good	1.5	d, i, k, l, p	4, 6, 7, 12
	Garnett (4)	Extant/ Not rated	1.7	c, d, k, l, m, p	4a, 7, 9
	Huichica (4)	Extant/ Excellent	2.5	c, d, h, k, l, m, q	1, 1a, 2, 4, 4a, 6, 7, 9, 18
	Napa (4)	Extant/ Not rated	2.5	c, d, h, k, l, m, q	1, 1a, 2, 4, 4a, 6, 7, 9, 19

Key to Codes:

* Drainage Unit: (1) - tributary streams in the lower Russian River, (2) - coastal streams flowing directly into the Pacific Ocean, (3) - streams draining into Tomales Bay, and (4) - streams flowing into north San Pablo Bay

** Existing Habitat Value rating determined by Serpa (1986). The rating is qualitative and applies only for reaches where shrimp have been found. Habitat conditions may have changed since rating period.

(a) Grazing
(b) Dairy Operations
(c) Viticulture operations
(d) Irrigation diversions
(e) Water withdrawal
(f) Water storage facilities
(g) Summer dams and crossings
(h) Sewerage (point discharge and/or septic)
(i) Roads (maintenance, location of fill slopes, and runoff)
(j) Flood control practices (vegetation removal and channelization)
(k) Bank protection
(l) Introduced predators
(m) Migration barriers (culverts, bridge footings/sills, and grade control structures)
(n) Aggregate extraction/processing
(o) Timber harvest
(p) Rural residential
(q) Urban residential/commercial

Citations

(1) Hedgpeth (1968)
(1a) Hedgpeth (1975)
(2) Eng (1981)
(3) Li (1981)
(4) Serpa (1986)
(4a) Serpa (1991a)
(5) Smith (1986)
(6) California Department of Fish and Game *in litt.* (1987)
(7) Messer and Brumbaugh (1989)
(8) Josselyn *et al.* (1993)
(9) Leidy (1984)
(10) Commins *et al.* (1990)
(11) Soil Conservation Service (1992)
(12) Sonoma County Planning Department (1989)
(13) CH2MHill and Merritt Smith Consulting (1994)
(14) ESA (1993)
(15) U.S. Fish and Wildlife Service *in litt.* (1990b)
(16) Fleisher *in litt.* (1993)
(17) EIP Associates (1990)
(18) Napa County Resource Conservation District (1993)
(19) Whyte *et al.* (1992)
(20) W. Cox pers. comm. (1998)

Many drainage areas have been separated by geologic uplift. Weaver (1949a) notes that Walker Creek, which now drains westward to Tomales Bay, and San Antonio Creek, which now flows in the opposite direction to San Pablo Bay, were once part of the same stream in the early Quaternary Period. Geologic uplift occurred in the middle of the stream and resulted in separate and opposite draining streams.

Geologic activity has also deflected the course of the Russian River. Weaver (1949b) surmises that the Russian River may have flowed south through the Cotati and Petaluma valleys to join the drainage from the Great Valley of California. Later geologic events during the Quaternary Period elevated the old valley floor of the lower Russian River between Santa Rosa and Petaluma, causing the river to veer west and empty directly into the Pacific Ocean (Weaver 1949a). Moyle (1976) notes that this historic connection may be one explanation for both the Russian and Sacramento Rivers having the same freshwater fish assemblage (e.g., Sacramento sucker, California roach, Sacramento squawfish, hardhead, hitch, and tule perch) despite their current isolation.

During the last Pleistocene glacial advances, from 10,000 to 70,000 years ago, sea levels were as much as 90 to 120 meters (295 to 394 feet) below present elevations (Helley *et al.* 1979). Streams draining into the San Francisco Bay region were tributaries of a river that flowed out past the Farallon Islands, 48 kilometers (30 miles) west of the existing coast. Around 15,000 years ago, melting glaciers in the northern latitudes initiated a rise in sea levels (Helley *et al.* 1979). This sea level rise appears to have also coincided with the subsidence of an area near the Golden Gate, the current entrance to San Francisco Bay (Weaver 1949a). Presumably, formerly connected creeks such as the Napa River, Huichica Creek, and Sonoma Creek are now isolated because of rising sea levels and subsidence of old river channels.

Rising sea levels may also explain the presence of isolated populations in streams draining into Tomales Bay and the Pacific Ocean. Before the last sea level rise, the California coastline was 24 to 32 kilometers (15 to 20 miles) westward from where it is situated today. During this period, Stemple, Walker and Lagunitas Creeks were probably connected tributaries. The presence of shrimp in Walker

Creek could have resulted in their movement to other streams draining into Tomales Bay during this period.

New information regarding the distribution of the shrimp has been collected since its listing. The shrimp has been rediscovered in Stemple Creek and new populations found in Keys, Redwood, and Garnett Creeks (Serpa 1991a, W. Cox pers. comm. 1994). In addition, U.S. Fish and Wildlife Service biologists and Larry Serpa found a shrimp population in a new location on Austin Creek, upstream of its confluence with East Austin Creek (U.S. Fish and Wildlife Service *in litt.* 1990a). With the exception of Stemple Creek, shrimp at these locales are adjacent to previously known populations. As evidenced by the recent discovery of shrimp within Keys, Garnett, and Redwood Creeks, unsampled and inadequately sampled streams within Marin, Sonoma, and Napa Counties could contain additional shrimp populations.

Since the final rule, there have been no new extirpations of known populations. Surveys by Serpa (1986, 1991a) have failed to rediscover shrimp in Santa Rosa Creek. It is unknown if shrimp populations still persist in Laguna de Santa Rosa or Atascadero Creeks. The Yulupa Creek shrimp population is probably under the greatest threat of extirpation.

No shrimp have been reported from streams flowing westward into San Pablo Bay from East Bay counties (Hedgpeth 1975, P. Alexander pers. comm. 1994, California Academy of Sciences *in litt.* 1994). Also, no shrimp populations have been documented in coastal drainages north of the Russian River (Serpa 1986, California Academy of Sciences *in litt.* 1994, R. Macedo pers. comm. 1994). Past surveys by Hedgpeth (1975) also failed to reveal the presence of shrimp north of the Russian River to the Oregon border. However, J. Hedgpeth (pers. comm. 1994) indicated that road access dictated which streams were sampled.

Based on existing information, the distribution of shrimp within streams is quite restricted. Using data from Serpa (1986, 1991a), the median distance of occurrence was 3.2 kilometers (2 miles) for 15 streams (Table 1, Figure 3). A high number of streams (six) had shrimp within distances of 2 kilometers (1.2 miles) or less. It should be noted that distribution within all these streams was not

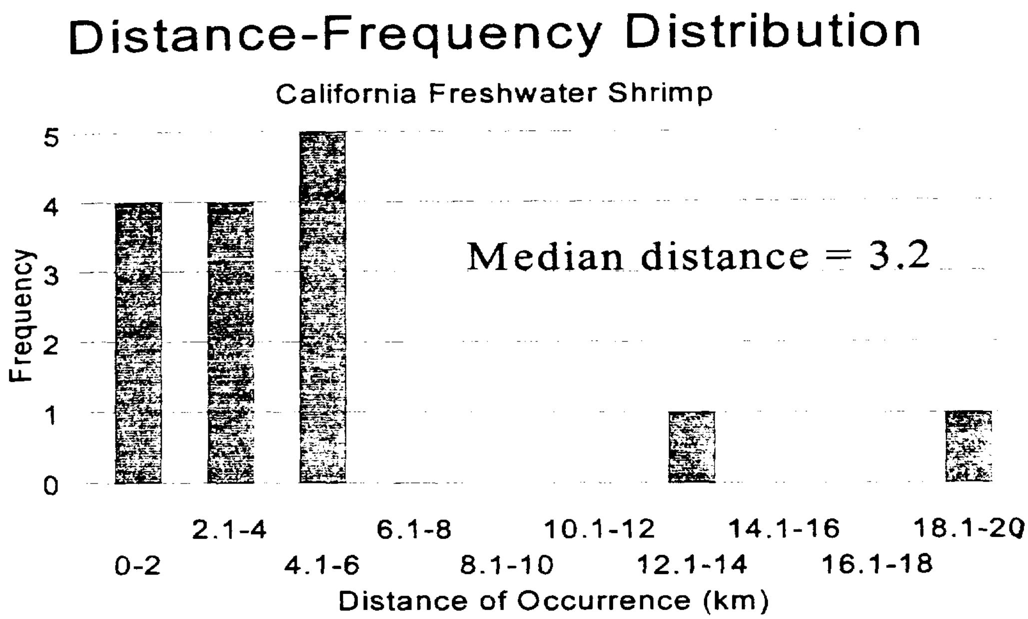

Figure 3. Distance-frequency distribution of the California freshwater shrimp (Syncaris pacific) in 15 streams in Marin, Sonoma, and Napa Counties, California. Data from Serpa (1986, 1991a).

continuous, primarily because unsuitable habitat was often interspersed between suitable habitat containing shrimp. Finally, the actual extent of distribution may extend beyond the reported values (Table 1). In certain streams (e.g., Salmon and Keys), permission to survey areas of potential habitat was not always granted or in the case of Austin and East Austin Creeks, the presence of marijuana growers posed safety risks to biologists (Messer and Brumbaugh 1989, Serpa 1991a).

Distribution of shrimp populations within streams is not expected to be static because of habitat changes by natural or man made forces. Distribution within streams may expand or contract depending upon existing conditions. For example, recent long-term drought conditions in California may have resulted in more discontinuous shrimp populations in Huichica Creek (Serpa 1991a). Gradual removal of unnatural barriers to shrimp dispersal and restoration of natural habitat conditions in Austin Creek are expected to expand the distribution of shrimp beyond its existing occurrence.

In instances where shrimp are present (historically or currently) in two connecting watercourses, the smaller tributaries generally support more abundant numbers of shrimp than the larger, receiving streams. Examples include Garnett Creek (tributary to the Napa River), Keys Creek (tributary to Walker Creek), East Austin Creek (tributary to Austin Creek), Jonive Creek (tributary to Green Valley), and Blucher Creek (tributary to Laguna de Santa Rosa). An exception to this pattern, Yulupa Creek (tributary to Sonoma Creek) contained fewer shrimp than Sonoma Creek (Messer and Brumbaugh 1989). However, Yulupa Creek has less suitable habitat than Sonoma Creek due to relatively high channel gradient and the absence of overhanging vegetation and undercut banks.

C. HABITAT AND ECOSYSTEM

General. Streams inhabited by California freshwater shrimp are part of the coast range, a geomorphic province that lies between the Pacific Ocean on the west and the Central Valley of California on the east. The coast ranges are composed of marine sedimentary rocks interspersed with metamorphic and igneous materials (Rantz 1972). Geologically recent erosion of surrounding mountains has resulted in the deposition of variable depths of alluvial materials along the flood plains and valleys of most of the shrimp-bearing streams. Shrimp have been found only in low elevation (less than 116 meters, 380 feet) and low gradient (generally less than 1 percent) streams. With the exception of Yulupa Creek, shrimp have not been found in stream reaches with boulder and bedrock bottoms. In fact, high velocities and turbulent flows in these streams may hinder upstream movement of shrimp.

The streams occur in counties with a Mediterranean climate. Shrimp-bearing streams near the town of Sonoma experience average air temperatures of approximately 8 degrees Celsius [46 degrees Fahrenheit] in the winter to 21 degrees Celsius (70 degrees Fahrenheit) in the summer. However, peak air temperatures during summer days can exceed 38 degrees Celsius (100 degrees Fahrenheit) and minimum temperatures during winter months can extend below freezing (National Oceanic and Atmospheric Administration 1992). Consequently, water temperatures in low gradient streams, such as Stemple Creek with minimal base flow and cover, can reach 31 degrees Celsius (88 degrees Fahrenheit) during summer months and 6 degrees Celsius (43 degrees Fahrenheit) in winter months (M. Rugg, California Department of Fish and Game, unpubl. data 1994).

Precipitation falls mainly between the months of October and March with annual precipitation ranging from 71 centimeters (28 inches) in the town of Sonoma, Sonoma County, to 104 centimeters (41 inches) in the town of Graton, Sonoma County. Little, if any, precipitation falls as snow. For the Napa River, which drains to northern San Pablo Bay, roughly 85 percent of the annual runoff to the river occurs between October and March (Rantz 1972). Consequently, stream flows are markedly different throughout the year with flash flood flows in the winter to minimal or zero flows in the summer and fall months (Figure 4). Coastal streams such as Walker Creek exhibit the same runoff pattern (Figure 4).

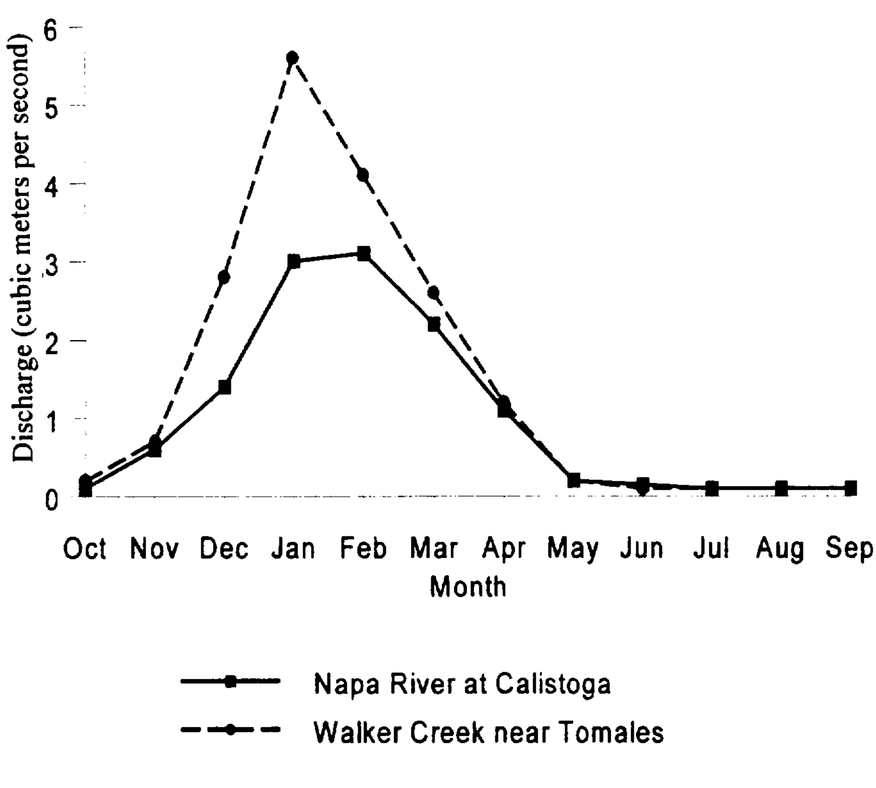

Figure 4. Mean monthly discharge for Walker Creek in Marin County and Napa River in Napa County, California.

Water Quality. The California freshwater shrimp has evolved to survive a broad range of stream and water temperature conditions characteristic of small, perennial coastal streams. However, no data are available for defining the optimum temperature and stream flow regime for the shrimp or the minimum and maximum limits it can tolerate. The shrimp appears to be able to tolerate warm water temperatures (greater than 23 degrees Celsius, 73 degrees Fahrenheit) and no-flow conditions that are detrimental or fatal to native salmonids. Under controlled conditions, juvenile and mature shrimp in an aquarium can tolerate standing water and 27 degrees Celsius (80 degrees Fahrenheit) water temperatures for extended periods (L. Week pers. comm. 1989).

In the only study that collected both shrimp and water quality information, Messer and Brumbaugh (1989) found shrimp in Salmon, Jonive, Blucher, Lagunitas, and Yulupa Creeks between temperatures of 7 and 16 degrees Celsius (45 to 61 degrees Fahrenheit), dissolved oxygen levels of 3.3 to 12.3 parts per million, and pH ranges from 5.85 to 9.1. However, the study period did not sample during the summer months when water quality conditions for aquatic organisms are generally the most stressful, nor did it report water quality information for locations lacking shrimp.

Information regarding the tolerance of other freshwater shrimps and prawns to various water quality parameters is available from aquaculture literature. Optimum pH levels for the tropical, freshwater prawn larvae (*Macrobrachium rosenbergii*) range from 7.0 to 8.5 (New 1990). Mass mortalities of prawn larvae occurred at pH levels over 9.5 (New 1990). These pH levels occur in eutrophic systems and the resulting mortality may be the result of oxygen depletion after algal blooms or increased availability of un-ionized ammonia. Also, high pH and alkalinity can cause mortality of freshwater prawns through the precipitation of calcium carbonate and resulting gill occlusion (Sandifer *et al.* 1983).

The toxicity of ammonia is of particular concern for the shrimp, because many streams drain land uses such as grazing and dairy operations, which are sources of nitrogenous wastes. Ammonia is present in an un-ionized form (NH_3) and an ionized form (NH_4+); the un-ionized form predominates at high pH because fewer H+ (hydrogen) ions are available to protonate NH_3 to NH_4+. Both forms cause mortality. High concentrations of un-ionized ammonia in stream water prevents excretion by reducing the rate of diffusion outward from the body (Armstrong *et al.* 1978). High concentrations of ionized ammonia interfere with sodium transport within the organism (Armstrong *et al.* 1978). Freshwater prawn larvae experienced 50 percent mortality at pH of 6.8, 0.27 milligrams-NH_3 per liter and 79.74 milligrams-NH_4+ per liter, and at pH of 8.34, 1.35 milligrams-NH_3 per liter, and 12.65 milligrams-NH_4+ per liter over a 6-day period (Armstrong *et al.* 1978).

Salinity Tolerance. Two studies have investigated the tolerance of the shrimp to varying salinities. As with most freshwater organisms, the shrimp is hypertonic with respect to its freshwater environment. Born (1968) found that shrimp were somewhat able to osmoregulate (balance internal fluids) at salinities less than 16 to 17 parts per thousand (50 percent of the concentration of sea water) by increased urine concentrations, whereas test shrimp in higher salinities were practically isotonic to the environment. Similarly, in a 13-day study, Hedgpeth (1968) found that shrimp were able to persist in salinities up to 16 to 17 parts per thousand and feeding and molting activities occurred without any apparent ill effects. Test organisms at higher salinities experienced mortality or showed signs of chronic effects (Hedgpeth 1968).

Although the laboratory studies indicate that the shrimp can tolerate brackish water conditions, at least for short periods of time, all records of the shrimp are from freshwater reaches in streams. Similarly, other atyid shrimps in the genus *Paratya* have demonstrated laboratory tolerance to brackish water, but have not been found in similar salinities in nature (Williams 1977). Although speculative, long-term exposure of adults to brackish waters or sea waters may have adverse effects on the population through impaired reproductive success, increased vulnerability to predation, and increased competition from more salinity tolerant shrimps (e.g., *Palaemon macrodactylus*, *Neomysis* spp.). The current disjunct distribution of the shrimp and its suspected intolerance to ocean salinities make movement of adults among coastal streams and streams flowing into Tomales and San Pablo Bays highly unlikely.

Microhabitat Conditions. The shrimp are generally found in stream reaches where banks are structurally diverse with undercut banks, exposed roots, overhanging woody debris, or overhanging vegetation (Eng 1981, Serpa 1986, 1991a). Excellent habitat conditions for the shrimp involve streams 30 to 90 centimeters (12-35 inches) in depth with exposed live roots (e.g., alder and willow trees) along undercut banks (greater than 15 centimeters, 6 inches) with overhanging stream vegetation and vines (Serpa 1991a).

During the winter, the shrimp is found beneath undercut banks with exposed fine root systems or dense, overhanging vegetation. These microhabitats may provide shelter from high water velocity as well as some protection from high suspended sediment concentrations typically associated with high stream flows (Eng 1981).

Habitat preferences apparently change during late-spring and summer months. Eng (1981) rarely found shrimp beneath undercut banks in the summer; submerged leafy branches were the preferred summer habitat. In Lagunitas Creek, Marin County, the shrimp was found in a wide variety of trailing, submerged vegetation (Li 1981). Highest concentrations of shrimp were in reaches with adjacent vegetation consisting of stinging nettles (*Urtica* sp.), grasses, vine maple (L. Serpa [pers. comm. 1994] suspects periwinkle was misidentified as vine maple), and mint (*Mentha* sp.). None were caught from cattails (*Typha* sp.), cottonwood (*Populus fremontii*), or California laurel (*Umbellularia californica*). He also noted that populations of shrimp were proportionately correlated with the quality of summer habitat provided by trailing terrestrial vegetation. However, during summer low flows, shrimp have been found in apparently poor habitat such [illegible] isolated pools with minimal cover. In such streams, opaque waters may allow [illegible] to escape predation and persist in open pools despite the lack of cover [illegible]pa 1991a). Further research is needed to determine if both winter and summer habitat needs to be provided within the same location or if shrimp can move [illegible] ontaining either winter or summer habitat.

[illegible]rgely absent from existing streams, large, complex organic debris [illegible] may have been prevalent in streams supporting shrimp populations. These [illegible] have been important feeding and refugial (resting) sites for the [illegible] structures collect detrital material (shrimp food) as well as leaf [illegible] can be later broken down by microbial activity and invertebrates to [illegible] detrital material (Triska *et al.* 1982). In addition, debris dams may offer shelter during high flow events and reduce displacement of invertebrates (Covich *et al.* 1991).

Interestingly, atyid shrimps from other parts of the world, display similar habitat preferences. Highest densities of *Caridina fernandoi* were found in areas underneath branched hairy roots of trees and only very low numbers were found on decaying leaves (De Silva and De Silva 1989). They speculate that tree roots afford protection from fish predation.

Serpa (1986) developed a rating system for qualitatively assessing habitat value for the shrimp-bearing streams. He classified habitat into four categories based on features known to be important to the shrimp, including water quality, water depth and flow, presence or absence of undercut banks, and the quality and quantity of tree roots and vegetation hanging into the water. His habitat ratings are included in Table 1.

D. LIFE HISTORY AND ECOLOGY

Reproductive Ecology. The reproductive ecology of the California freshwater shrimp has not been formally described. Reproduction seems to occur once a year. Based upon the reproductive physiology and behavior of other marine and freshwater shrimps, the male probably transfers and fixes the sperm sac to the female shrimp immediately after her last molt, before autumn. It is typical for aquatic crustaceans to copulate during the female's molt just prior to the time of year she becomes egg bearing. The timing of mating was deduced from the presence of ovigerous (egg bearing) females starting in September (Born 1968, Eng 1981). By November, Serpa (1991a) noticed that most adult females in Huichica Creek are bearing eggs. Adult females produce relatively few eggs, generally, 50 to 120 (Hedgpeth 1968, Eng 1981). The eggs adhere to the pleopods (swimming legs on the abdomen) where they are protected and cared for during the winter incubation. Average egg dimensions for shrimp from Salmon Creek are 1.3 by 0.9 millimeter (0.05 by 0.04 inch) (Born 1968). Although not documented, fecundity and egg size may vary based on the size of the female. In studies of other freshwater atyid shrimps, fecundity and egg size increased as the size of the female increased (Williams 1977, De Silva 1988a, De Silva and De

Silva 1989). Young are released in May or early June and are approximately 6 millimeters (0.24 inch) in length (Eng 1981).

Atyid shrimp (*Caridina* spp.) in tropical climates tend to breed throughout the year while atyid shrimps in more temperate areas breed primarily in the summer (De Silva 1988b). Apparently, the California freshwater shrimp is one of the few atyid species that breeds during the winter period. Hedgpeth (1975) viewed the winter (December - March) incubation period as advantageous because the larvae are released during the favorable part of the hydrologic cycle in California, following winter and spring high flows.

Several aspects of the reproductive ecology of the shrimp are unknown. Courtship and mating behavior have not been described. No information is available on the percentage of larvae that reach reproductive maturity. In addition, there is no information as to whether aspects of reproduction are density dependent. The proportion of egg bearing females of a tropical atyid shrimp has been shown to decline with increased population density (De Silva 1988b).

Growth and Development. Newly hatched young (postlarvae) grow rapidly and reach 19 millimeters (0.75 inch) in length by early autumn (Eng 1981). Growth slows through the fall, winter, and early spring, and then increases through the second summer (Messer and Brumbaugh 1989). A size difference between males and females is apparent at the end of the second summer (Messer and Brumbaugh 1989). Larger female size is consistent with characteristics of other freshwater shrimp (Neilsen and Reynolds 1977). Shrimp reach sexual maturity by the end of their second summer of growth (Eng 1981). The California freshwater shrimp may live longer than 3 years (Eng 1981). Some tropical atyid shrimp live only 1 year (De Silva 1988a, De Silva and De Silva 1989).

No data are available on how often the shrimp molt or the conditions that may initiate it. It is probable that molting ceases under stressful environmental conditions (e.g., lack of food availability).

High densities of shrimp may result in reduced individual growth. Serpa (1991a) describes juveniles and adult shrimp from Blucher Creek as being much smaller than those found in other locations. He attributed this discrepancy to intraspecific competition for limited resources.

Distribution and Abundance. Shrimp were last reported in Stemple Creek in 1955-1956 by Hedgpeth (1975). Subsequent surveys by Hedgpeth (1975) and Serpa (1986) found no shrimp. However, a later study found the shrimp to be present not only in the same general locations as previous reports, but also at upstream locations (Serpa 1991a). Shrimp are not uniformly distributed within creeks. On Garnett Creek, shrimp were found in 34 to 52 pools that were sampled in a 1.7 kilometer (approximately 1 mile) reach. Densities of shrimp in sampled Garnett Creek pools ranged from 0.0 to 11.8 shrimp per meter with a mean value of 1.2 shrimp per meter. The majority of the shrimp (81 percent) were found in just 10 pools (Serpa 1991a). Other streams had similar distribution of shrimp.

Distribution of age classes varies within streams. In Blucher Creek, the abundance of juveniles per sample site ranged from 14 to 61 percent (Serpa 1991a). Also, streams sampled in the fall contained proportionally higher numbers of juveniles than adults. Juveniles in Blucher, Keys, and Garnett Creeks and Napa River constituted 51 to 71 percent of the sampled populations (Serpa 1991a).

Information is not currently available to determine the susceptibility of various populations to extinction. Research is needed to determine the amount of interbreeding, carrying capacity, rates of population growth, effective population size, annual and seasonal population fluctuations, recruitment, and survivorship.

An interim measure is needed to assess the health of existing shrimp populations in sampled streams. Populations with the poorest relative health should receive immediate protection. Therefore, a qualitative and relative index of health was computed based upon the length of distribution and total numbers of collected shrimp from Li (1981), Serpa (1986, 1991a), and Messer and Brumbaugh (1989) (Table 2). The index assumes equivalent abundance estimates and lengths of distribution on separate streams afforded somewhat similar levels of protection from disturbance. This index is an interim measure to assess the relative health of populations and does not preclude future recovery criteria models that will determine the effective population sizes needed to prevent extinction.

Although the data are complicated by differences in sampling dates and slight differences in sampling techniques, populations on Salmon and Lagunitas Creeks were rated good to excellent due to the relatively high numbers of sampled shrimp over a relatively long distance. Populations on Stemple, Green Valley, Austin, Walker, and Yulupa Creeks and Napa River were rated extremely poor to fair poor due to limited distribution and low numbers of sampled shrimp. No ratings are available for Atascadero Creek, Redwood Creek, Olema Creek, and Laguna de Santa Rosa due to insufficient information.

Table 2. Shrimp abundance and distribution index.

Stream	Abundance	Distance (km)	Rating
Lagunitas Creek	1947	15.1	10

(Data from Li 1981)

Stream	Abundance	Distance (km)	Rating
Walker Creek	1	0	1
Yulupa Creek	30	1.37	2
Jonive Creek	74	3.22	4
Sonoma Creek	28	5.63	4
Big Austin Creek	6	5.95	4
Green Valley	8	6.03	4
Blucher Creek	157	3.22	4
Huichica Creek	244	4.02	5
Lagunitas Creek	234	13.4	7
Salmon Creek	182	19.1	7
East Austin Creek	more than 101	3.12	No Rating

(Data from Serpa 1986)

Stream	Abundance	Distance (km)	Rating
Big Austin Creek	0	0	0
Walker Creek	0	0	0
Green Valley	28	0.401	2
East Austin Creek	33	1.76	2
Yulupa Creek	8	1.12	2
Napa River	12	1.6	2
Huichica Creek	87	2.06	2
Sonoma Creek	19	4.01	3
Jonive Creek	227	1.2	4
Blucher Creek	127	3.21	4
Salmon Creek	574	14.04	8

(Data from Messer and Brumbaugh 1989)

Stream	Abundance	Distance (km)	Rating
Napa River	35	1.6	2
Stemple Creek	20	1.6	2
Keys Creek	79	0.3	2
Garnett Creek	994	1.7	5
Blucher Creek	231	3	5
Huichica Creek	512	2.7	6

(Data from Serpa 1991a)

Key to Composite Rating System

Distance (km)	Rating	Density (n/km)	Rating	Rating System	Description
15 or greater	5	1000 or greater	5	9 to 10	Excellent
10 to 15	4	501 to 1000	4	7 to 8	Good

Distance (km)	Rating	Density (n/km)	Rating	Rating System	Description
5 to 10	3	201 to 500	3	5 to 6	Moderately Good
2.5 to 5	2	101 to 200	2	3 to 4	Fair
0 to 2.5	1	1 to 100	1	1 to 2	Poor
0	0	0	0	0	Extremely Poor

Sex Ratios. Eng (1981) and Serpa (1991a) provide the only information regarding the ratio of male to female shrimp. A male:female ratio of 1.11:1 was computed for adults from seven streams (Serpa 1991a). A male:female ratio of 1.39:1 was computed for adults sampled from Lagunitas and Huichica Creeks by Eng (1981). However, there was a wide variation in the proportion of males to females among the streams sampled by Serpa (1991a). Therefore, these ratios should be interpreted with caution. Also, no attempt has been made to describe and correct potential biases associated with sex determinations. Continued evaluation of sex ratios using standard sampling techniques may permit the use of change-in-ratio estimators to determine differential mortality between males and females (Downing 1980).

Activity Patterns. Information regarding daily and seasonal activity patterns is not available for the shrimp. Because rates of growth slow between fall and spring, it is presumed that foraging activities are reduced during this period as well.

Movements. Basic information regarding the mobility of the species (e.g., dispersal conditions, age and sex composition of drift, passive vs. active dispersal) is not known. In aquaria, observed shrimp have remained motionless for long periods, clinging to plants and other objects (Hedgpeth 1968). Cryptic coloration and limited movements probably reduce its risk of predation. Field observations by Li (1981) found adults and young maintaining their positions in midwater through movements of their pleopods (swimming legs on the abdomen) and telson (tail). In addition to being able to swim forwards and backwards, shrimp can "skip" over the water surface when disturbed (Hedgpeth 1968).

Field surveys conducted by Serpa (1986, 1991a) have found shrimp at various upstream locations, within a given stream, and no shrimp at other downstream locations. In subsequent field surveys, this trend reversed with shrimp found at downstream sites and not at upstream sites. This trend may suggest a downstream migration of the species, however, this movement may merely be the result of high stream flows. Although many experts in the field of shrimp biology would agree that upstream migration of shrimp occurs, no data to date have been collected to show how this is done.

Feeding. Following a functional feeding group classification system by Merritt and Cummins (1978), atyid shrimps can be described as collectors feeding upon fine particulate organic matter. The food sources may range from fecal material produced by shredders (a functional group that feeds on coarse particulate organic matter), organic fines produced by physical abrasion and microbial maceration, senescent periphytic (organisms attached to underwater surfaces) algae, planktonic (free-floating) algae, aquatic macrophyte (large plants) fragments, zooplankton (microscopic animals), particles formed by the flocculation (small loose clusters) of dissolved organic matter, and aufwuchs (a matrix of bacteria, extracellular materials, fungi, algae, and protozoa) (Anderson and Cummins 1979, Goldman and Horne 1983). Shrimp observed on pool bottoms, submerged twigs and vegetation seemed to feed on fine particulate matter (Eng 1981). Atyid shrimp use their chelae (pincer-like claws) to scrape and sweep detritus and small organisms from substrates. Captive shrimp have been observed frequently moving their maxillipeds (front legs) from substrate to mouth (Serpa 1986). Much of the material ingested is probably indigestible cellulose.

Shrimp may use visual, tactile, or chemical cues in foraging activities. Shrimp maintained in aquaria scavenge dead fish and shrimp (Eng 1981). Observations by Serpa (1986) indicate that captive shrimp have been able to detect and selectively consume commercial fish feeds. Commercially formulated feeds for prawns often incorporate chemoattractants such as glycine, proline, taurine, and trimethylammonium hydrochloride (imparts a fecal odor) (New 1990).

Presumably, shrimp diets change with food availability and age. Algae and plant matter increase in the stomachs of grass shrimp by the summer months (Beck and Cowell 1976). However, detritus and insects become more important in the winter (Beck and Cowell 1976). Younger grass shrimp typically had a higher percentage of detrital material in their stomachs than older, larger grass shrimp (Beck and Cowell 1976). With this example, it should be noted that the diets of the grass shrimp and the California freshwater shrimp may not necessarily be similar.

Predation and Competition. The shrimp's cryptic coloration and behavioral characteristics imply that predation played an important role in the evolution of the species. All life stages of the shrimp may be prey items for native fish. According to Eng (1981), native fish such as California roach (*Hesperoleucus symmetricus*), threespine stickleback (*Gasterosteus aculeatus*), and riffle sculpin (*Cottus gulosus*) are small opportunistic feeders that probably only rarely feed on recently hatched shrimp. Young coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*) presumably prey on shrimp; however, the shrimps cryptic coloration affords them some protection from predation. Where present, Sacramento squawfish (*Ptychocheilus grandis*) also may prey upon the shrimp (Eng 1981). In the Columbia River, Washington, northern squawfish (*Ptychocheilus oregonensis*) of less than 225 millimeters (9 inches) in fork length (from the tip of the mouth to the "fork" in the tail) subsist entirely on invertebrates and only switch to eating fish at larger sizes (Poe *et al.* 1991).

Other aquatic vertebrate predators may include western pond turtles, salamanders and newts, which are probably present throughout many of the streams. The diet of western pond turtles, although opportunistic generalists, usually consists of small to moderate-sized invertebrates (Holland 1991). They are able to consume water column invertebrates such as *Daphnia* spp. through a form of gape-and-suck feeding (Holland 1991) and may presumably use this technique to consume shrimp as well. The Pacific giant salamander (*Dicamptodon ensatus*) has been captured along with shrimp in Huichica Creek (Serpa 1991a). Invertebrate predators may include water scorpions, predaceous diving beetles, and dragonfly and damselfly nymphs.

Human alteration of native habitat along with the introduction of nonnative fish species, primarily from eastern United States, have led to the decline of native fish assemblages. Leidy and Fiedler (1985) note the increased presence of introduced species with increased levels of human disturbance in streams draining into San Francisco Bay. Introduced fish species commonly found in the Russian River drainage and streams draining into San Francisco Bay include mosquito fish (*Gambusia affinis*), green sunfish (*Lepomis cyanellus*), smallmouth bass (*Micropterus dolomieui*), largemouth bass (*Micropterus salmoides*), and several introduced minnows (Leidy and Fiedler 1985, EIP Associates 1990).

Introduced fish may also significantly affect the distribution of shrimp through predation. Carp (*Cyprinus carpio*) occur in Stemple Creek (Serpa 1986), a stream severely disturbed by grazing activities. Carp dislodge and consume invertebrates from plants and silty bottoms through their rooting activities (Moyle 1976). Mosquitofish may also prey on shrimp. Williams (1977) summarized research, which found no coexistence between mosquitofish and atyids in Hawaiian streams presumably due to predation on newly hatched atyid larvae. Introduced sunfish are likely predators on shrimp. For example, a freshwater shrimp, *Palaemonetes kadiakensis*, represented 64 percent of the stomach contents of bluegill in a Missouri pond with a greater occurrence in stomachs of small bluegills rather than large ones (Nielsen and Reynolds 1977). Predation caused seasonal declines in the freshwater shrimp populations. The behavior, habitat, and food preferences also make the green sunfish a likely predator on the California freshwater shrimp. Because of the relatively recent introduction of exotic fish such as mosquitofish, the shrimp probably has not developed defense mechanisms that would reduce its risk of predation. Like the shrimp, many of the introduced fish, such as the mosquitofish and green sunfish, are able to persist under relatively poor water quality conditions that may have allowed the shrimp to persist in isolated pools during the summer in the absence of natural predators such as juvenile steelhead trout. Green sunfish are capable of surviving high water temperatures (36 degrees Celsius, 97 degrees Fahrenheit), low oxygen levels (less than 3 parts per million), and high alkalinities (Moyle 1976).

Disease, Parasites, and Commensals. No information is available concerning the types of pathogens, parasites or types of coexisting species that may be associated with the shrimp. Between molts, external surfaces of the crayfish often become covered with algae and attached protozoans (Pennak 1989). A parasitic isopod (*Probopyrus* sp.) is often found in the gill chambers of palaemonid shrimp (Pennak 1989). It is possible that similar associations may be found with the shrimp. Specific information regarding the role of disease and parasitism in controlling individual and population fitness is needed.

E. REASONS FOR LISTING

Several features of the shrimp's distribution and life history make it vulnerable to extinction. Existing shrimp distribution within streams is not continuous and is often along short distances (Figure 3, median distance = 3.2 kilometers; approximately 2 miles). The number of streams that historically supported the shrimp was limited to permanent, low gradient streams in three counties. Through geologic and climatic changes, shrimp populations in coastal streams, such as Salmon Creek that may have been formerly connected, are now isolated by inhospitable reaches of sea water. As previously noted, adult shrimp are unable to effectively adjust internal body fluids at high salinities and presumably have lost ability to persist in sea water. Therefore, when local extinctions occur in streams draining to saline waters recolonization by natural means may not be possible.

Furthermore, the shrimp does not have life history characteristics that favor quick recovery following disturbances. The shrimp has relatively low fecundity, is believed to reproduce only once a year, and maturation requires over 1 year of growth. Wallace (1990) summarized studies that have shown mollusks are among the last taxa to recolonize disturbed reaches of streams, whereas insect recolonization occurs faster. However, shrimp may be even less adapted to disturbances than mollusks. Some aquatic snails are able to persist following chemical spills by closing their operculums and in the absence of water through laying of dormant eggs. The shrimp has no known resistant or dormant stage.

The shrimp is threatened by several types of human activities, many of which operate synergistically and cumulatively with each other and with natural disturbances (e.g., floods and droughts). Factors associated with declining populations of shrimp include degradation and loss of its habitat through increased urbanization, instream gravel mining, overgrazing, agricultural development and activities, impoundments, water diversion, water pollution, and introduced predators. Shrimp populations in most streams are threatened by more than one factor (Table 1). Although there have been no new threats to the shrimp since its listing, some of the factors that have led to its listing have intensified.

Urbanization: Population growth in the San Francisco Bay region has shifted away from traditional urban centers and has moved into formerly rural areas (San Francisco Estuary Project 1992). If growth proceeds in accordance with county and local general plans, the San Francisco Estuary Project (1992) estimates that 870 additional hectares (2,150 acres) of watershed draining the Napa and Petaluma Rivers would be impacted by development.

Steps should be taken to regulate development within floodplains of rivers harboring shrimp as well as those containing features of shrimp habitat by implementing stream setbacks. Individuals seeking erosion control methods along current or proposed urbanized areas should avoid hard fixes, such as rock gabions and riprap and implement biotechnical engineering to provide or maintain habitat areas. Riparian vegetation should be protected to maintain and increase shrimp populations.

Agriculture: Land and surface water resources in Napa and Sonoma Counties are being intensively developed for vineyards (D. Bowker pers. comm. 1989). Streams in these counties drain much of the prime vineyard land. In Huichica Creek, 40 percent of the watershed area is planted in grapes (Napa County Resource Conservation District 1993). Vineyards are often placed in close proximity to creeks due to water availability and terrain. Threats to shrimp populations and habitat from agricultural activities include 1) loss of riparian vegetation, 2) inadvertent introduction of herbicides and pesticides into creek water through aerial drift, spills, and runoff, 3) diversion of water, and 4) increased soil erosion. Irrigation diversions from streams reduce available habitat and also have the potential for taking shrimp if diversions are positioned such that they interfere with the natural behavior of the shrimp. To reduce this impact, diversion structures should be in the form of offset wells or other types of subsurface collectors. Problems associated with vineyards are expected to increase in the future as development of vineyards continues. Vineyard acreage in Napa County alone is expected to increase from 81,296 hectares (32,900 acres) (1989) to 128,492 hectares (52,000 acres) by 2010 (Whyte *et al.* 1992).

Livestock Grazing and Dairy Farming: Livestock grazing (predominantly cattle and sheep) and dairy farming are major land uses in many watersheds containing streams with shrimp (Table 1). For example, the Stemple Creek watershed contains roughly 30 dairy operations and grazing occurs in 50 percent of the watershed (Soil Conservation Service 1992, R. Rivera pers. comm. 1994). As a consequence, these activities exert a strong influence on habitat quality for the shrimp. Incompatible grazing and dairy operations destroy suitable habitat through the removal of riparian vegetation, adverse bank and channel changes, decreased water quality, increased sediment loads, change in runoff characteristics, and increased water temperature fluctuations.

Grazing activities typically concentrate along watercourses, particularly during the summer when the creek and adjacent riparian areas offer the livestock water and palatable forage. Extended foraging along the creek results in the loss of vegetation, trampled stream banks, and increased stream bank erosion (Figure 5). As an example, Stemple Creek has lost much of its riparian vegetation. Current riparian habitat along Stemple Creek and its tributaries extends only along 20 percent of its length (Southern Sonoma and Marin County Resource Conservation Districts 1994). Excessive grazing activities remove the shrimp's preferred microhabitats--undercut banks with trailing overhanging vegetation and pools with emergent or aquatic vegetation.

Heavy grazing reduces the structurally complex habitat preferred by shrimp. Americano and Stemple Creeks were dominated by large, isolated pools and bottom substrates of silt and mud, whereas sections of Salmon Creek were structurally diverse with pools and riffles, instream woody debris, larger sized substrates, and a healthy riparian corridor (EIP Associates 1990). Surveys by Serpa (1986, 1991a) found greater numbers of shrimp over greater distances on Salmon Creek than Stemple Creek.

Figure 5: Bank and channel conditions in Stemple Creek, Marin County, California.

Loss of riparian vegetation alters the temperature regime and dissolved oxygen levels in streams. Streams lacking riparian cover exhibit greater daily and annual temperature ranges, higher daily and seasonal maxima, and lower temperature minima (Ward 1984). In addition, streams with riparian cover warm more slowly in the spring and cool less rapidly in autumn than do open streams (Ward 1984).

Dissolved oxygen levels and water temperatures are intimately related; increased water temperatures result in decreased amounts of dissolved oxygen in the water (Goldman and Horne 1983). While the shrimp has demonstrated a wide tolerance to temperature extremes, stream temperatures in grazed areas may not reflect optimal temperatures for growth and reproduction.

Heavy grazing in riparian areas also results in progressive and unfavorable channel changes that may extend considerable distances upstream and downstream from grazed locations. In alluvial streams, the removal of riparian vegetation increases bank erosion and runoff and results in channel undercutting and loss of flood plains and lowered water tables. Channel undercutting can extend upstream through headward erosion. The result is sheer, steep channel banks that offer little habitat for the shrimp. These physical changes can be observed in several streams including Huichica Creek. Sediments eroded from degraded reaches are transported downstream and result in a modification of the stream bottom through deposition (EIP Associates 1990).

Loss of riparian vegetation changes availability of aquatic food sources and alters invertebrate species composition and production in streams (Haefner and Wallace 1981, Hawkins *et al.* 1982, Ward 1984). Streams with dense riparian cover typically have limited instream primary production, and organic matter inputs rely heavily on leaf litter, fallen terrestrial insects, etc. from the riparian zone. Grazed streams typically have high production of algae due to high insolation and increased nutrient input. Mild increases in algal productivity may favor certain functional feeding groups such as grazing invertebrates on attached algae (e.g., certain mayflies), filter-feeding invertebrates (e.g., blackflies) and collectors (e.g., certain mayflies) (Wiederholm 1984). Although shrimp are gathering collectors, they may not benefit from the seasonal pulse of algae in open streams. In grazed streams, loss of refugial habitat (e.g., undercut banks) may override any benefits in increased summer food production. Furthermore, insect species benefitting from increased attached algae production are often benthic (bottom dwelling) species, whereas the shrimp are more associated with stream edges.

Grazing impacts on shrimp habitat are not restricted to riparian areas. Reduced forage cover and increased soil compaction by trampling within the watershed decreases groundwater recharge and results in higher peak flows following winter storms and lower base flows during summer and fall. In the Stemple Creek watershed, 70 percent of the sediment yield is due to human activity, with erosion identified as the major source of sediments to the creek (Soil Conservation Service 1992). High sediment-laden flood flows may increase the susceptibility of shrimp to downstream displacement and low base flows can reduce the number of permanent pools needed by shrimp during summer months. In addition, heavy metals, agricultural chemicals, and nutrients adhere to fine sediments and may be ingested by shrimp.

Dairy and grazing operations can also cause poor water quality in streams. Runoff from manure lots following storms and direct inputs increase nutrient levels and result in high production of algae. Algal blooms cause oxygen supersaturation during the day and result in oxygen depletion at night because of respiration and decomposition (Goldman and Horne 1983). Also, decomposition of fecal material can deplete oxygen concentrations to levels injurious to aquatic life. In Stemple Creek, above existing shrimp populations, dissolved oxygen levels dropped as low as 0.8 milligrams per liter (M. Rugg unpubl. data 1994). In Americano Creek, a creek that historically may have had shrimp, dissolved oxygen levels fell as low as 0.0 milligrams per liter because the biological oxygen demand (BOD) value reached a staggering high rate of 40,800 (BOD).

Of equal concern are the seasonally high levels of ammonia in streams adjacent to dairy operations. Ammonia, a waste product associated with fecal material, apparently enters the creeks during rainfall runoff in the winter and spring (Commins *et al.* 1990). In Americano Creek, un-ionized ammonia levels reached 650 milligrams NH_3 per liter (M. Rugg unpubl. data 1994). Water samples collected between 1991 and 1994 from both Americano and Stemple Creeks routinely exceeded the Environmental Protection Agency's ammonia criteria for the protection of aquatic life.

In addition, copper concentrations in both Americano and Stemple Creeks have exceeded the Environmental Protection Agency's criterion (Commin *et al.* 1990). The source of the high copper concentrations has been linked to dairy practices. Copper sulfate foot baths are used to control foot rot. Smith *in litt.* (1990) speculates that rainfall and surface runoff transports copper from spread manure into the creeks.

Timber Harvesting: Silvicultural practices, particularly those that remove stream side vegetation, have and may continue to impact shrimp populations and habitat. Stream side timber harvests in sampled northern California streams reduced channel stability, decreased canopy cover, and increased instream debris, resulting in changes in benthic macroinvertebrate populations (e.g., diversity and taxa shifts) (Roby *et al.* 1977, Hawkins *et al.* 1982). Timber harvests within the watershed increase peak flows, decrease base flows, and increase sediment transport and deposition in streams (Brown and Krygier 1971, Karr and Schlosser 1978, Harr 1982), resulting in destabilizing changes in channel structure. Timber harvests in the Austin Creek drainage may have added to the channel degradation near the confluence with the Russian River. Possible water quality changes include increased water temperatures and elevated nutrient loads.

Gravel Mining: A single freshwater shrimp was collected by U.S. Fish and Wildlife Service biologists and Larry Serpa in 1990 in Austin Creek about 0.5 kilometer (0.3 mile) above Highway 116 (U.S. Fish and Wildlife Service *in litt.* 1990a). This observation is within a reach designated by Sonoma County's Aggregate Resources Management Plan for instream aggregate extraction (EIP Associates and Sonoma County Planning Commission 1994). Gravel mining practices can alter natural channel geomorphology in downstream reaches by interrupting the supply of gravel (Collins and Dunne 1990) and result in localized shallow, braided channels. Under natural conditions, point bars on inside bends are covered with fine sediments and organic materials from overbank flooding, eventually making the area suitable for vegetation (Collins and Dunne 1990). Long-term gravel mining on point bars retards the development of appropriate soil conditions for riparian vegetation. Continued instream gravel mining activities (e.g., bar skimming) along historic shrimp habitat in Austin and Sonoma Creeks without adequate safeguards and mitigation measures will preclude the reestablishment of favorable habitat conditions for the shrimp. In the Lagunitas Creek watershed, a cement plant is located near the confluence of Nicasio and Lagunitas Creeks. Impacts on shrimp populations from this operation, particularly from the disposal of processing waters, are not known.

Terrestrial mining activities may also have resulted in the transport of sediment and contaminants into shrimp streams. Erosion of sediments from open pits mined during World War II in the Big Austin Creek drainage may have resulted in channel alteration and loss of surface water flow in the summer in areas just above shrimp localities.

Water Development Activities: Most streams that harbor shrimp contain impoundments within their drainage area. The impoundments are intended to reduce flood hazards, provide recreational benefits, and provide a water supply. Direct and indirect impacts of water impoundments and diversions to shrimp populations include migration barriers, loss of upstream habitat, introduced predators, altered hydrology and sediment transport, reduced downstream flows, and shrimp bring swept away in diverted waters.

For example, the Marin Municipal Water District has developed several water storage and diversion facilities on Lagunitas Creek and Nicasio Creek, a major tributary (Smith 1986). The presence of two reservoirs (Kent Lake and Nicasio Reservoir) effectively precludes the use of former stream habitat upstream of the dams. Water storage facilities serve as continual sources of introduced fishes, and operations of storage facilities tend to eliminate normal high discharges that can flush introduced sunfish from the system. Operation of these facilities change natural hydrology and sediment transport within Lagunitas Creek. Alteration of natural winter flood events may reduce the amount of adventitious roots associated with riparian trees. Young red alder form these fine roots when flooded (Harrington *et al.* 1994). Smith (1986) notes that occasional high winter flows are also needed to maintain undercut banks and pools for the shrimp and that fluctuating summer flows would be detrimental to shrimp populations. During drought years, natural reductions in flow combined with water exports could result in losses to shrimp populations, therefore, scheduled water releases from reservoirs and minimum flows must be maintained.

As human population increases in the Bay Area, demand for local water sources will increase as well. On the Napa River, the Napa County Flood Control and Water Conservation District is exploring increased water diversions during winter periods and storage facilities to meet anticipated demands (Kennedy/Jenks Consultants 1992). There are already substantial demands to appropriate water from many streams containing shrimp. Estimates of total water yield in the Huichica Creek watershed range from 1,759 acre-feet in dry years to 3,097 acre-feet in wet years (Napa County Resource Conservation District 1993). Landowners are permitted or have requested permission to appropriate 2,019 acre-feet of water (Napa County Resource Conservation District 1993). Even under favorable hydrologic conditions, full appropriation of requested water could reduce the yearly volume of water in the creek by two-thirds. Without instream flow requirements, particularly during stressful summer low flow periods, existing pools could become dry. In addition, reduction in natural flows can intensify impacts from pollutants.

Appropriation of groundwater is also of concern. On Salmon Creek, Eng (1981) and Hedgpeth (1975) speculated that freshwater pumping for municipal uses may increase the likelihood of saltwater intrusion. Although brackish water may not result in direct mortality, stress in combination with competition from shrimps normally found in brackish water (*Neomysis* spp.) may result in their eventual displacement. In addition, groundwater pumping may reduce summer base flows and reduce normal riparian habitats.

Summer Impoundments: Seasonal construction of beaches and summer dams within the Austin Creek drainage adversely impacted shrimp populations. Construction activities occurred annually over several decades and resulted in the loss of dense overhanging stream-bank vegetation. The annual construction of summer dams has prevented the reestablishment of riparian vegetation. Increased predation on shrimp likely resulted from the higher numbers of large predators introduced within the impoundments. These summer impoundments likely obstructed the movements of shrimp. In the absence of summer dams on East

Austin Creek in 1990, U.S. Fish and Wildlife Service biologists captured shrimp in Austin Creek below its confluence with East Austin Creek (U.S. Fish and Wildlife Service *in litt.* 1990a). A survey conducted in the same area when the summer dams were in place failed to collect a single shrimp (Messer and Brumbaugh 1989). Impounded waters also create habitat favorable for predatory fish (U.S. Fish and Wildlife Service *in litt.* 1990b). Summer impoundments have also resulted in adverse water quality conditions. Chlorine was applied to a seasonal impoundment on East Austin Creek in 1987. This action resulted in the loss of aquatic invertebrates downstream from the seasonal impoundment to the confluence with East Austin Creek (U.S. Fish and Wildlife Service *in litt.* 1990b).

In addition to the adverse impacts to shrimp, steelhead and coho salmon populations likely diminished over time as a result of the placement of summer dams. As a result of fishery concerns expressed by resource agencies, the Army Corps of Engineers issued a permit in 1991 (Permit number 12828-96) that phased out summer dams in the Austin Creek drainage, with no dams authorized after 1996. Summer impoundments prove to be problematic not only to shrimp but to other associated species. Thus, summer impoundments on any shrimp bearing stream should be discouraged.

Urban Runoff: Urban runoff consists of both runoff that occurs from precipitation and dry weather flows such as irrigation (Whyte *et al.* 1992). Urban development increases the area of pavement and other impervious surfaces and results in higher peak flows in streams. In addition, urban development increases the amount of nonpoint source pollutants that enter streams and has the potential to result in more point discharges of greater volume. The sources of pollutants vary, however, ranging from runoff from golf courses to illegal disposal of paints and automotive fluids into storm drains. Hedgpeth (1975) cited spillage of chlorinated swimming pool waters as a major problem in shrimp streams. In Santa Clara County, urban runoff is the primary contributor to many trace elements, biochemical oxygen demand, and total suspended solids in South Bay streams (San Francisco Estuary Project 1992). The acute and sublethal effect of these pollutants on shrimp populations is not known. Continued urban development is expected to result in decreased stream water quality.

Wastewater Discharge: Several streams that contain existing populations of shrimp or perhaps had historic populations receive wastewater effluent and leachate from septic systems. Eutrophic conditions often result from excess nutrient inputs from septic systems near streams and from wastewater discharges into streams. Wastewater discharges and septic systems were identified as important contributors to excessive summer algal growth in Laguna de Santa Rosa, which frequently resulted in dissolved oxygen levels lower than Environmental Protection Agency criteria for coldwater and warmwater fish (CH2MHill and Merritt Smith Consulting 1994). Continued urban development will increase nutrient loading to streams.

Several streams such as Green Valley, Atascadero, and Santa Rosa Creeks receive treated sewage and untreated stormwater runoff. Failures in wastewater treatment facilities may result in discharges of partially treated effluent or chlorinated effluent that could adversely affect shrimp. In 1993, discharge of 80,000 to 91,000 gallons of wastewater to Santa Rosa Creek killed several hundred small fish (R. Maddox *in litt.* 1993). Water quality data indicated that the discharge area was affected by ammonia and chlorine.

Flood Control: Development along stream courses, particularly within the floodplain of a river or stream, has resulted in the need to protect these properties from flood damages. Hedgpeth (1968, 1975) notes that Santa Rosa Creek supported shrimp populations prior to a flood control project that resulted in the natural channel being straightened, channelized, and lined with concrete. In a recent survey, Serpa (1991a) noted that the effected area did not have any remaining riparian vegetation and also no shrimp. Structural flood control practices eliminate habitat for shrimp by removing undercut banks and riparian vegetation, increase water velocities during storm events, and increase temperature fluctuations. The degraded and simplified systems also favor establishment of introduced fish species that can prey on shrimp.

Standard flood control practices also degrade or eliminate habitat for the shrimp. Routine flood control practices include applying herbicide, dredging, altering channel and bank configuration, removing instream and riparian woody debris, and removing other vegetation. All these actions reduce natural habitat complexity.

Bank Protection: Alluvial streams are rarely static, as channels adjust laterally through the development of point bars and erosion of outside bends, and vertically through channel alteration processes. However, natural readjustments pose hazards for developments adjacent to streams.

On Garnett Creek, a subdivision placed rock gabion bank protection in an area that has shrimp populations. Rock bank protection will effectively preclude the development of undercut banks and retards the development of natural riparian vegetation and woody debris. Herbaceous vegetation such as sedges known to provide summer habitat for shrimp are best established on alluvial banks. In addition, rock bank protection typically creates scour holes and bank failures upstream and downstream of the bank protection. Loss of natural banks can be expected to increase as greater numbers of developments are built along stream corridors.

Installation of bank protection generally requires an Army Corps of Engineers section 404 permit. Review of bank protection projects in areas containing shrimp and suitable habitat allows the U.S. Fish and Wildlife Service to recommend measures that can protect shrimp and their habitat. However, as with the Garnett Creek example, many bank protection efforts are being constructed without Army Corps of Engineers authorization.

Culverts and Grade Control Structures: Several creeks contain unnatural impediments to upstream movements of shrimp. Sills designed to protect bridge footings from being exposed have scoured downstream areas and formed ledges, effectively impeding upstream movement of shrimp. On Huichica Creek, downcutting below the Highway 12 road crossing has resulted in the culvert being 1 to 1.2 meters (3 to 4 feet) higher than the area immediately downstream. Barriers to shrimp movement may result in the future extirpation of shrimp in streams and also may preclude expansion of shrimp into areas with suitable habitat. Expanding human populations in the three counties will undoubtedly increase the need for more and wider roads and road crossings will, of course, become more prevalent. The increase in barriers may result in fragmented shrimp populations, possibly restricting gene flow and increasing the likelihood of extirpation. However, removal of existing migration barriers may result in channel readjustments and cause erosion upstream. Existing migration barriers may limit upstream dispersal and establishment of introduced fish species. Existing barriers should not be removed until all possible effects have been thoroughly considered. Creation of new barriers should be avoided.

Introduced Predators: Introduced predators are widely distributed in many streams containing shrimp. According to a distributional study by Leidy (1984), introduced species in Bay Area streams were most common in large, highly disturbed pools at low and intermediate elevations. These areas may have been suitable habitat for shrimp prior to alterations favoring the establishment of introduced fishes. For example, summer impoundments and vegetation removal by flood control activities result in increased water temperatures that favor introduced predators such as sunfish. Removal of riparian cover also results in the loss of shelter from predators and high flows. Low numbers of shrimp are present in the upper Napa River despite the abundance of good habitat. Serpa (1991a) and Eng (1981) suspect that the presence of green sunfish in the drainage may contribute to the shrimp's current, limited distribution in the upper Napa River. Off-channel impoundments adjacent to streams also pose a problem. L. Serpa (pers. comm. 1994) noted that overflows during storm events from a pond adjacent to the headwaters of Huichica Creek is a probable source of bluegills into the system. Personal observations by Darren Fong found numerous mosquitofish in an ornamental pond directly adjacent to shrimp populations in Redwood Creek.

F. CONSERVATION MEASURES

Since the shrimp's listing in 1988, there have been several conservation measures undertaken to 1) determine the population status of the shrimp, 2) increase awareness of local residents regarding their stream resources including the shrimp, 3) restore habitat, and 4) enact sound land management practices. Most conservation efforts were undertaken by other Federal, State, and local agencies with strong support from local environmental groups. Many actions were aimed at providing several benefits; restoring habitat conditions for shrimp was just one of them. Because of the shrimp's relatively recent listing, most conservation efforts are still in their planning stages with only a few efforts by the National Park Service, Circuit Riders Production, Natural Resources Conservation Service, Napa County Resource Conservation District, and Brookside Elementary School actually resulting in habitat restoration. In addition, activities are limited by the number of grants available. The U.S. Fish and Wildlife Service has been in the past, and continues to be, a technical resource for recommending mitigation measures for specific projects through the section 7 process under the Endangered Species Act. The following briefly describes conservation measures accomplished to date.

The U.S. Fish and Wildlife Service funded Larry Serpa, with The Nature Conservancy, to study existing populations of freshwater shrimp in an effort to determine their current status. His work identified a new locale for shrimp as well as documented the absence of shrimp in Santa Rosa Creek reported by Hedgpeth (1968, 1975). Various agencies, including the Regional Water Quality Control Board, Natural Resources Conservation Service, local Resource Conservation Districts, and California Department of Fish and Game, are encouraging local ranchers to reduce grazing impacts on streams.

Lagunitas Creek: The California State Coastal Conservancy funded improvement activities to reduce soil erosion caused by grazing, logging, and development activities (Josselyn *et al.* 1993). Restoration actions included instream erosion control (e.g., check dams, plantings, and exclusionary fencing), watershed soil stabilization, and repair of roads and under-sized culverts. These actions have been deemed successful in controlling stream-bank erosion and sedimentation within the watershed (Josselyn *et al.* 1993) although supportive, quantitative evidence is apparently not available.

The Point Reyes National Seashore (National Park Service) has implemented measures to improve habitat conditions for the reach of Lagunitas Creek that flows through their management area. Specifically, installation of fencing and exclusion of grazing within the riparian area, when combined with the fortuitous lack of scouring flood flows, have allowed for significant recovery of riparian vegetation since 1990 (National Park Service *in litt.* 1991). Such areas revegetated naturally without any grading of banks or planting. Unfortunately, no effort has been made to document how changing riparian and channel conditions have influenced shrimp populations.

Walker Creek: The California State Coastal Conservancy funded improvements to reduce unnatural levels of soil erosion caused by grazing and logging activities (Josselyn *et al.* 1993). Restoration actions included gully and instream remediation (e.g., check dams, seedings, plantings, and exclusionary fencing), slide stabilization, and repair of unpaved roads. Restoration actions have been deemed successful in controlling stream-bank erosion and sedimentation within the watershed (Josselyn *et al.* 1993) although supportive, quantitative evidence is apparently not available.

Salmon Creek: The California State Coastal Conservancy provided $1.2 million to a nonprofit organization, Circuit Rider Production, to develop and implement a project to reduce sediment loading in four streams, including Salmon Creek (R. Thompson pers. comm. 1994). Although the project was not intended to benefit the shrimp, project actions such as revegetation will, in the long-term, enhance habitat conditions for the shrimp. As with Lagunitas Creek, no monitoring efforts are proposed to assess the influence of changing riparian and channel conditions on shrimp populations.

Stemple Creek: Students from the Brookside Elementary School in San Anselmo, Marin County, adopted the shrimp and formed a "Shrimp Club" to help recover the shrimp. Members of the Shrimp Club, with the cooperation of a local dairy farmer, revegetated a portion of Stemple Creek that was impacted by cattle. Blackberries, willows, and native grasses were planted in an effort to restore the stream and improve habitat conditions for the shrimp. The students' efforts won them national awards, grants, and prizes. Follow-up efforts to monitor habitat conditions and shrimp populations are needed.

The Natural Resources Conservation Service has provided technical expertise and funds to rehabilitate some of the more grievous erosion problems in the Stemple Creek watershed (R. Rivera pers. comm. 1994). Grade control structures have been placed in gullies to prevent further erosion.

Blucher Creek: Along shrimp-bearing stretches of Blucher Creek, The Nature Conservancy has gained voluntary cooperation to protect the shrimp with various landowners through their Land Owner Contact Program (Serpa 1991a). Landowners allow access to their property for monitoring of shrimp populations. In addition, The Nature Conservancy provides informal advice on management practices that would benefit the shrimp. As a result, some owners have excluded grazing from sections of their stream. The landowners also promise to inform The Nature Conservancy upon sale of their properties so that cooperation of new owners in protecting shrimp habitat can be obtained.

Laguna de Santa Rosa: A coordinated resources management and planning process is being developed to determine management goals and implementation strategies with cooperation of public agencies, private groups, and individual landowners. This creek historically supported California freshwater shrimp, however, the shrimp is now considered extirpated.

Napa River: The Regional Water Quality Control Board has developed a Comprehensive Napa River Watershed Management and Protection Plan (September 17, 1992). Subsequently, the Napa County Resource Conservation District received funds from the Regional Water Quality Control Board to develop an integrated resource management plan for the Napa River watershed. The Napa County Resource Conservation District has initiated a program called "Adopt-A-Watershed", which provides elementary schools and high schools with classroom curricula on various components of the watershed. It also tries to involve classes in long-term field studies, and restoration and enhancement projects. Three schools in Napa have signed up, although no projects are underway yet (S. Adams pers. comm. 1994). The Napa County Resource Conservation District is currently surveying channel conditions and fish populations.

The Napa County Conservation, Development, and Planning Department established conservation measures under the Napa County Conservation Regulations, the Napa County Flood Plain Management Plan, and the California Department of Forestry Timber Harvest Plan requirements. The Flood Plain Management Plan regulates development within the Napa River flood plain. Both the Napa County Conservation Regulations and the California Department of

Forestry Timber Harvest Plan regulations address erosion control and riparian protection. Napa County regulations restrict development within established stream setbacks from blue line streams. Stream setbacks range from a minimum of 10.67 meters (35 feet), increasing with the slope average from the top of bank to the edge of the proposed development area.

Huichica Creek: In the Huichica Creek watershed, the Napa County Resource Conservation District created the Huichica Creek Land Stewardship group consisting of watershed landowners, local, State, and Federal agencies (including the U.S. Fish and Wildlife Service), to develop and implement a long-term conservation plan for the watershed. A major benefit of this effort has been the willingness of many winery operations to participate in this program and their increased awareness of the need to protect aquatic resources, including the shrimp. The plan includes measures recommended by the U.S. Fish and Wildlife Service to reduce the risk of pesticides entering streams and a standard screen design for water intake structures to prevent take of shrimp. In addition, the Natural Resource Protection and Enhancement Plan (Napa County Resource Conservation District 1993) developed for the watershed recommends use of cover crops to minimize soil erosion and water conservation measures. D. Bowker (pers. comm. 1994) has observed a reduction in unnatural amounts of fine sediments in Huichica Creek after implementation of the plan's recommendations by landowners.

G. CO-OCCURRING SENSITIVE SPECIES

The U.S. Fish and Wildlife Service's mission is to conserve, protect, and enhance the Nation's fish and wildlife and their habitats for the continuing benefit of the American people. Fulfilling this mission requires the long-term maintenance of healthy ecosystems and the U.S. Fish and Wildlife Service is committed to applying an ecosystem approach to conservation to allow for efficient and effective conservation of our Nation's biological diversity (U.S. Fish and Wildlife Service *in litt.* 1994). In terms of recovery plans, it is the policy of the U.S. Fish and Wildlife Service to incorporate ecosystem considerations in the following manner:

1) Develop and implement recovery plans for communities or ecosystems where multiple listed species and species of concern occur;

2) Develop and implement recovery plans for threatened and endangered species in a manner that restores, reconstructs, or rehabilitates the structure, distribution, connectivity, and function upon which those listed species depend. In particular, these recovery plans shall be developed and implemented in a manner that conserves the biotic diversity of the ecosystems upon which the listed species depend;

3) Expand the scope of recovery plans to address ecosystem conservation by enlisting local jurisdictions, private organizations, and affected individuals in recovery plan development and implementation (U.S. Fish and Wildlife Service/National Marine Fisheries Service 1994a); and

4) Develop and implement agreements among multiple agencies that allow for sharing of resources and decision making on recovery actions for wide-ranging species (U.S. Fish and Wildlife Service/National Marine Fisheries Service 1994b).

One of the objectives of this plan is to enhance habitat conditions for native, aquatic species within the historic range of the shrimp. There are several species of concern, proposed, and listed fish and wildlife species that occur or historically have occurred in or adjacent to the streams supporting existing or historic shrimp populations (Table 3). In addition, several candidate, proposed, and listed plant species may be adjacent to existing or historic shrimp streams (Table 4).

Table 3. Co-occurring sensitive fish and wildlife.

Common Name	Scientific Name	Federal Status
northern spotted owl	*Strix occidentalis caurina*	Threatened
tidewater goby	*Eucyclogobius newberri*	Endangered
Russian River tule perch	*Hysterocarpus traskii pomo*	species of concern
coho salmon	*Oncorhynchus kisutch*	Threatened
steelhead trout	*Oncorhynchus mykiss*	Threatened
California red-legged frog	*Rana aurora draytonii*	Threatened
western pond turtle	*Clemmys marmorata*	species of concern
Tomales asellid	*Caecidotea tomalensis*	species of concern

Table 4. Co-occurring sensitive plants.

Common Name	Scientific Name	Federal Status
Sonoma alopecurus	*Alopecurus aequalis* var. *sonomensis*	Endangered
Suisun Marsh aster	*Aster chilensis* var. *lentus*	species of concern
Clara Hunt's milk-vetch	*Astragalus clarianus*	Endangered
Thurber's reedgrass	*Calamagrostis crassiglumis*	species of concern
swamp harebell	*Campanula californica*	species of concern
white sedge	*Carex albida*	Endangered
Pitkin Marsh paintbrush	*Castilleja uliginosa*	species of concern
Vine Hill clarkia	*Clarkia imbricata*	Endangered
Burke's goldfields	*Lasthenia burkei*	Endangered
delta tule pea	*Lathyrus jepsonii* var. *jepsonii*	species of concern
legenere	*Legenere limosa*	species of concern
Mason's lilaeopsis	*Lilaeopsis masonii*	species of concern
Pitkin Marsh lily	*Lilium paradalinum* spp. *pitkinense*	Endangered

Common Name	Scientific Name	Federal Status
Sebastopol meadowfoam	*Limnanthes vinculans*	Endangered
Calistoga allocarya	*Plagiobothrys strictus*	Endangered
northcoast semaphore grass	*Pleuropogon hooverianus*	species of concern
Napa bluegrass	*Poa napensis*	Endangered
California beaked-rush	*Rhynchospora californica*	species of concern
Kenwood Marsh checkermallow	*Sidalcea oregana* spp. *valida*	Endangered
showy Indian clover	*Trifolium amoenum*	Endangered
Baker's blennosperma	*Blennosperma bakeri*	Endangered

Northern spotted owl (*Strix occidentalis caurina*). Northern spotted owls typically live in mature, undisturbed Douglas fir and mixed conifer forests. The southern end of their historic range extended to coastal areas of the San Francisco Bay. Activities such as logging and land clearing for agriculture that have impacted shrimp populations have also impacted owl populations (U.S. Fish and Wildlife Service 1990).

Tidewater goby (*Eucyclogobius newberri*). The tidewater goby occurs in the upper end of coastal lagoons in salinities less than 10 parts per thousand (U.S. Fish and Wildlife Service 1994a). Lagoons that contain goby populations and shrimp populations upstream include Salmon Creek, Estero de San Antonio (Stemple Creek), and Lagunitas Creek (Swift *et al.* 1989). Tidewater gobies were collected in 1897 in Walker Creek, although there are no recent records of this species (Swift *et al.* 1989). Although the goby resides in coastal streams and lagoons typically farther downstream than shrimp, activities within the contributing watershed can also result in adverse impacts to the goby. Alterations in natural hydrology and impaired water quality resulting from upstream activities have been cited as potential causes for the decline of this species (U.S. Fish and Wildlife Service 1994a). Nutrient enrichment from agricultural and sewage effluent can result in algal blooms and deoxygenation. Excessive cattle grazing in watersheds causes increased sedimentation of coastal lagoons. As an example, about 70 percent of the erosion in the Stemple Creek watershed results from manmade causes (Soil Conservation Service 1992) resulting in the deposition of 6,000 tons per year within Estero de San Antonio, potentially shortening its life span as an estuary. Because the goby breeds in sand or mud substrates, excessive sedimentation from erosion may interfere with successful reproduction by covering and suffocating eggs or larvae. A combination of these factors may explain the relatively low number of tidewater gobies in Estero de San Antonio. Because Stemple Creek drains pastures and dairy operations, water quality samples during spring and summer months contained either 1) high biochemical-oxygen-demand elevated levels of un-ionized ammonia or 2) low dissolved oxygen (M. Rugg unpubl. data 1994). Trawl samples in Estero de San Antonio had manure-like odor and contained recently killed mysid shrimps, dungeness crabs, and shore crabs (Smith *in litt.* 1990).

Russian River tule perch (*Hysterocarpus traskii pomo*). The Russian River tule perch is the only freshwater representative of a live-bearing family of fish, the family Embiotocidae. Restricted to the Russian River drainage, this species is typically found in flowing water in pools more than 1 meter (0.3 foot) deep with abundant cover such as dense submersed vegetation, instream woody debris, and overhanging plants (Moyle 1976). The perch feeds on benthic (bottom) as well as plant-dwelling invertebrates. Threats to this fish include poor water quality and introduced predatory fish. The perch may co-occur with the shrimp in the Austin Creek drainage.

Coho salmon (*Oncorhynchus kisutch*). The coho salmon is an anadromous species. In small, coastal streams, most coho return to freshwater systems to spawn in fall and winter months (Moyle 1976). Spawning occurs in small to medium-sized gravel at well-aerated sites, typically near the head of a riffle (Moyle 1976). These streams have summer temperatures seldom exceeding 21 degrees Celsius (70 degrees Fahrenheit). The first year is spent in freshwater. Emergent fry utilize shallow nearshore areas, whereas optimal habitat conditions for juveniles and subadults seems to be deep pools created by rootwads and boulders in heavily shaded stream sections (Moyle *et al.* 1993). Many of the streams supporting shrimp populations may also support coho runs. One example, Lagunitas Creek, has been identified by Moyle (Moyle *et al.* 1993) as having one of the better, small-stream coho runs in California with historic run sizes ranging between 500 and 2,000 spawners yearly.

Because of dramatic declines in population numbers, the National Marine Fisheries Service has listed a number of Evolutionarily Significant Units of coho salmon on the west coast. The Central California Coast Evolutionarily Significant Unit, which includes coastal drainages within the range of the California freshwater shrimp, was listed as threatened in 1996 (National Marine Fisheries Service 1996). In Sonoma County alone, it is estimated that 86 percent of the coastal streams historically supporting coho salmon have lost their coho runs. Causes of coho salmon declines in California include incompatible land-use practices such as logging and urbanization, loss of wild stocks, introduced diseases, over harvesting, and climatic changes (Moyle *et al.* 1993).

Additional losses of coho salmon occur offshore in the form of overharvest by recreational fisheries, predation by pinnipeds (seals, etc.) and piscivorous fish species, and loss of marine habitats (National Marine Fisheries Service 1996).

Steelhead (*Oncorhynchus mykiss*). Steelhead trout are anadromous fish found in many of the streams containing shrimp, including Sonoma Creek, Yulupa Creek, Stemple Creek, Huichica Creek, Napa River, and Garnett Creek (Leidy 1984). The National Marine Fisheries Service has listed a number of Evolutionarily Significant Units of steelhead on the west coast. The Central California Coast and Central Valley Evolutionarily Significant Units, which include the range of the California freshwater shrimp, were listed as threatened in 1997 and 1998 (National Marine Fisheries Service 1997, 1998). Adult steelhead typically spawn in the spring, from February to June (Moyle 1976) in gravel riffles. Optimum temperatures for growth ranges from 13 to 21 degrees Celsius (55 to 70 degrees Fahrenheit) (Moyle 1976). Steelhead typically spend 2 to 3 years in freshwater (Moyle 1976). Like coho fry, steelhead fry reside in nearshore areas. In the presence of coho juveniles, steelhead juveniles tend to utilize riffles. Threats to steelhead populations are similar to those facing other native aquatic species including the shrimp.

Western pond turtles (*Clemmys marmorata*). These turtles have been classified as habitat generalists and historically occurred in a wide variety of permanent and intermittent aquatic habitats (Holland 1991). The turtle has been found co-occurring with shrimp in Huichica Creek and it undoubtedly can be found in other streams containing shrimp populations. In streams and rivers, turtles generally avoid fast-moving and shallow waters and are concentrated in pools and backwater areas (Holland 1991). In streams, turtles are uncommon in heavily shaded areas, being concentrated where openings in the streamside canopy allow sufficient sunlight to facilitate basking (Holland 1991). Threats to the turtles include introduced predators, including bullfrogs; habitat alteration; poaching; historic commercial exploitation; water pollution; and disease (Holland 1991). Excessive grazing activities in riparian areas adversely impacts turtle populations by collapsing undercut banks used as shelter and by consuming emergent vegetation used as habitat by hatchling and first-year turtles (Holland 1991).

California red-legged frog (*Rana aurora draytonii*). The California red-legged frog is found primarily in wetlands and streams in coastal drainages of central California (U.S. Fish and Wildlife Service 1994b). The frog may be found in suitable habitat in existing shrimp-bearing streams draining into San Pablo Bay and coastal streams from Marin County south. Red-legged frogs found to the north exhibit intergrade characteristics of the California red-legged frog and the northern red-legged frog. Both the California red-legged frog and the intergrade type occur within the historic range of the shrimp.

The frog favors specific aquatic and riparian features. Adults prefer dense, emergent or shrubby vegetation closely associated with deep (greater than 0.7 meter, 2.3 feet), still or slow-moving water (U.S. Fish and Wildlife Service 1994b). The highest densities of California red-legged frogs have been associated with deep-water pools with dense stands of overhanging willows and an intermixed fringe of cattails (U.S. Fish and Wildlife Service 1994b). Aestivation (summer hibernation) sites are located up to 26 meters (85 feet) from water in dense riparian vegetation (U.S. Fish and Wildlife Service 1994b).

Many of the threats to the shrimp have also been identified as reasons for the decline of California red-legged frog populations. Threats to red-legged frogs include predation by introduced fishes and bullfrogs, and loss of habitat from agriculture, urbanization, water projects, flood control activities, livestock grazing, and timber harvesting (U.S. Fish and Wildlife Service 1994b).

Tomales asellid (*Caecidotea tomalensis*). The asellid, an aquatic sowbug, inhabits moist soils or water bodies with perennial flows. The absence of fish and winter scouring flows appears to encourage establishment of the asellid. In addition, the asellid has been found in areas with submerged decaying leaves. They are found in greatest abundance in areas with dense mats of marsh pennywort (*Hydrocotyle* sp.) (Serpa 1991b). There are 11 known locations of the asellid. The asellid has been found in a northern tributary of Stemple Creek, above areas that harbor the shrimp. Threats to this species are unknown. However, adverse water quality, flood control activities that remove aquatic vegetation or activities that remove riparian shrubs and trees may be expected to result in habitat loss and degradation.

Associated sensitive plants. The associated sensitive plant species listed in Table 4 are found throughout the shrimp's range. These plant species are located adjacent to existing or historic shrimp streams. The Sonoma alopecurus, a perennial herb belonging to the grass family, is found in seasonally wet areas. The Suisun Marsh aster, a perennial herb belonging to the sunflower family, is found in freshwater marsh habitat. The Clara Hunt's milk-vetch, an annual herb belonging to the pea family, is found in grasslands or openings of blue oak woodland. The Thurber's reedgrass, a perennial herb belonging to the grass family, is found in freshwater marsh habitat. The swamp harebell, a perennial herb of the bellflower family, is found in freshwater marshes and meadows.

The white sedge, once thought to be extinct, was discovered in a sphagnum bog in 1987. Pitkin Marsh paintbrush, a perennial herb of the figwort family, is found in upper montane coniferous forest. The Vine Hill clarkia, an annual herb in the evening primrose family, grows in open grasslands. Burke's goldfields, an annual herb in the aster or sunflower family, associates with vernal pools. The delta tule pea, a perennial herb of the pea family, is found in freshwater marsh areas. The legenere, an annual herb belonging to the bellflower family, is found in and amongst vernal pools. Mason's lilaeopsis, perennial herb belonging to the carrot family, is found in freshwater marsh habitat. The Pitkin Marsh lily is found in freshwater marsh or wet meadow habitat. Sebastopol meadowfoam, a multistemmed herb of the false mermaid family, is found in seasonally wet meadows and vernal pools. The Calistoga allocarya, an annual herb in the borage family, is located near small thermal hot springs. The northcoast semaphore grass, a perennial herb belonging to the grass family, is found in meadows, vernal pools, and north coast coniferous forests. Napa bluegrass, a perennial member of the grass family, is found near small thermal hot springs. The California beaked-rush, a perennial herb of the rush family, is found in meadows and freshwater marshes. The Kenwood Marsh checkermallow, a perennial in the mallow family, is found in freshwater marsh habitat. The showy Indian clover, an annual in the pea family, is found in grassland habitat.

Threats to the sensitive plants associated with the shrimp include, but are not limited to, urban development, competition with nonnative plant species, recreation, trampling of plant species, and grazing.

H. RECOVERY STRATEGY

The following activities will promote recovery of the California freshwater shrimp:

1. Remove existing threats to known populations of shrimp.
2. Restore habitat conditions favorable to shrimp and other native aquatic species at extant localities.
3. Protect and manage shrimp populations and habitat once the threats have been removed and restoration has been completed.
4. Monitor and evaluate shrimp habitat conditions and populations.
5. Assess effectiveness of various conservation efforts on shrimp.
6. Conduct research on the biology of the species.

7. Restore and maintain viable shrimp populations at extirpated localities.

8. Increase public awareness and involvement in the protection of shrimp and native, cohabiting species through various outreach programs.

9. Assess effects of various conservation efforts on cohabiting, native species.

10. Assemble a California freshwater shrimp recovery team.

Improved habitat conditions for cohabiting species will undoubtedly occur through attainment of shrimp recovery objectives. As noted previously, many of the threats facing native, coexisting organisms have also resulted in the decline of the shrimp. Monitoring of cohabiting organisms is recommended as a task of this plan, and shrimp recovery actions that result in adverse impacts to associated sensitive species will be adjusted to reduce the impacts. However, the net effect on native species of implementing this plan will be overwhelmingly positive. The following describes potential effects of recovery tasks on specific taxa.

Northern spotted owl. On some streams, activities that restore riparian habitat for shrimp may also provide secondary benefits for terrestrial species such as the spotted owl. Restored riparian habitat could increase foraging opportunities for the owl. Major prey items for the owl include rodents such as woodrats and squirrels, which would be expected to increase in numbers with the restoration of riparian vegetation (U.S. Fish and Wildlife Service 1990).

Tidewater goby. Implementation of tasks to recover shrimp populations should also improve habitat conditions for gobies. Improvement of riparian areas along the main creek channels will reduce sediments from bank erosion. Improvements in grazing and dairy practices will improve water quality in lagoons by reducing nutrient inputs and resulting eutrophic conditions.

Russian River tule perch. Removal of threats to shrimp habitat and implementation of habitat restoration activities will also improve conditions for the tule perch. In particular, increased amounts of submerged woody materials, submersed plants and overhanging vegetation will increase available habitat for the tule perch.

Salmonids. Removal of threats to shrimp habitat and implementation of habitat restoration activities for the shrimp should also enhance overall conditions for coho and other salmonids. Reduced fine sediment loading to streams should allow for successful egg incubation and better rearing and holding pool habitat. Improved water quality will benefit salmonids, particularly egg, fry, and juvenile life stages. Protection and restoration of natural riparian conditions will moderate extreme temperature fluctuations, reduce sediment transport to streams, provide terrestrial insects for food, eventually provide instream woody debris and undercut banks for cover, and create habitat conditions less favorable to introduced predators and competitors. Removal of migration barriers for adults will facilitate upstream passage.

Western pond turtle. Holland (1991) notes that downed logs and undercut banks are important cover for the turtle and undercut banks may be a critical factor maintaining populations in small streams. Therefore, activities that would increase the frequency and extent of undercut banks will benefit turtle populations, as well as shrimp populations.

Many sections of existing shrimp bearing streams contain open canopy areas as a result of land-use activities. There is concern that protection and establishment of a dense riparian corridor may result in the reduction of existing open canopy areas, potentially reducing the availability of basking sites. However, the low numbers of turtles despite the abundance of basking sites indicate that other factors are limiting turtle populations. Recovery actions are expected to result in a net increase in turtles due to improvements in water quality and increases in cover.

Furthermore, natural disturbance regimes such as floods are expected to contribute to an ecologically diverse system (Naiman *et al.* 1993). Therefore, in unregulated streams, removal of human disturbance from riparian areas should eventually lead to the development of riparian corridor successional stages, including open canopy stream segments with basking sites for turtles. In regulated streams, restoration of more natural flow regimes would be necessary to maintain optimum turtle populations.

California red-legged frog. Preservation and improvement of riparian habitat will provide necessary summer sheltering habitat, movement corridors, and feeding sites for adult frogs. Improved water quality and instream cover from overhanging and emergent aquatic vegetation will be beneficial for egg and larval stages.

Tomales asellid. Actions to improve habitat conditions for the shrimp will not adversely affect habitat or populations of the asellid. No asellids have been found directly in sites containing shrimp. However, actions in Stemple Creek that encourage the development of dense beds of aquatic vegetation will provide potential habitat for the asellid.

Associated sensitive plants.

Implementation of tasks that restore habitat and lead to the recovery of shrimp populations may also improve habitat for the associated sensitive plants. Improvements in grazing and dairy practices will improve habitat conditions for these species by reducing associated trampling in the riparian zones. The removal of human disturbance from riparian areas will eventually lead to the development of riparian corridor succession, which in turn could lead to the establishment of associated sensitive species. The minimized use or avoidance of traditional flood control and bank protection practices will maintain existing open space and allow for the establishment of sensitive plants species. Implementation of a routine and comprehensive habitat monitoring plan will aid in the establishment of sensitive species and provide additional in-sight on the requirements needed to keep these species flourishing. Increased public awareness of shrimp and native, cohabiting species may lead to faster development and implementation of watershed management plans, which in turn will lead better establishment of cohabiting species.

II. RECOVERY

A. RECOVERY OBJECTIVES

The objectives of this recovery plan are two-fold: 1) to recover and delist the California freshwater shrimp when numbers increase sufficiently and suitable habitat is secured and managed within 17 watersheds harboring shrimp and 2) to enhance habitat conditions for native aquatic organisms that currently coexist or have occurred historically with the California freshwater shrimp.

B. RECOVERY CRITERIA

Downlisting from endangered to threatened will be considered when:

1. a watershed plan has been prepared and implemented for Lagunitas Creek (including Olema Creek), Walker Creek (including Keys Creek), Stemple Creek, Salmon Creek, Austin Creek (including East Austin Creek), Green Valley Creek (including Atascadero, Jonive, and Redwood Creeks), Laguna de Santa Rosa (including Santa Rosa and Blucher Creeks), Sonoma Creek (including Yulupa Creek), Napa River (including Garnett Creek), and Huichica Creek;

2. long term protection is assured for at least one shrimp stream in each of the four drainage units; and

3. the abundance of California freshwater shrimp approaches carrying capacity in 17 streams.

Four general drainage units support shrimp. The drainage units are 1) tributary streams in the lower Russian River drainage, 2) coastal streams flowing directly into the Pacific Ocean, 3) streams draining into Tomales Bay, and 4) streams flowing into San Pablo Bay. Problems associated with these different watersheds must be identified and a watershed plan prepared for each stream that now supports shrimp. The task list presented later in this document could serve as an outline for watershed studies. Once these watershed plans are implemented, the abundance and distribution criteria found in Table 2 could be utilized to determine an increase in the relative health of the populations.

Delisting of the California freshwater shrimp will be considered when:

1. a watershed plan has been prepared and implemented for Lagunitas Creek (including Olema Creek), Walker Creek (including Keys Creek), Stemple Creek, Salmon Creek, Austin Creek (including East Austin Creek), Green Valley Creek (including Atascadero, Jonive, and Redwood Creeks), Laguna de Santa Rosa (including Santa Rosa and Blucher Creeks), Sonoma Creek (including Yulupa Creek), Napa River (including Garnett Creek), and Huichica Creek;

2. long term protection in assured for at least eight shrimp streams, with at least one in each of the four drainage units;

3. shrimp-bearing streams having fewer than 8 kilometers (5 miles) of potential shrimp habitat have shrimp distributed in all potential habitat; those with more than 8 kilometers (5 miles) of potential shrimp habitat, have shrimp distributed over 8 kilometers (5 miles) or more; and

4. populations of shrimp maintain stable numbers approaching carrying capacity for at least 10 years in each of 17 streams; and

Recovery of the shrimp, and subsequent delisting, depends primarily upon removal of existing threats, greater knowledge of the species biology, and restoration of optimum habitat conditions. Long-term monitoring of habitat and shrimp populations is needed to establish baseline conditions and to evaluate changes resulting from implementation of recovery tasks. Further research will allow the initial recovery criteria to be verified or refined. In addition, research on the species biology and optimal habitat conditions for the shrimp will assist in the development of proper habitat restoration goals and techniques. Restored habitat and populations require long-term protection from threats. Involvement of the public in recovery efforts, increased public awareness of the shrimp and its habitat, participation by the U.S. Fish and Wildlife Service in watershed and county planning and conservation programs, and enforcement of applicable laws and regulations should assist in the long-term protection of populations and habitats from threats. Periodic review and reevaluation of the recovery plan are needed to ensure that the recovery objectives are being met.

C. NARRATIVE OUTLINE OF RECOVERY ACTIONS

1. Remove existing threats to known populations of shrimp.

Because most shrimp streams flow through private lands, cooperative efforts are required to remove threats to shrimp habitat and cohabiting, native species. Currently, coordinated resource management programs are being developed for several watersheds containing shrimp populations. Resolution of the varied and pervasive threats requires continuation of these cooperative efforts.

1.1. Mitigate adverse agricultural impacts on stream and riparian habitats within watersheds harboring shrimp.

As noted previously, agricultural practices adversely affect shrimp populations through removal of riparian habitat, reduced water quality and quantity, by individuals carried off through diversions, and alterations in channel conditions through excessive sedimentation. However, healthy riparian and stream habitats can coexist with agriculture activities provided that best management practices (least damaging) are implemented to minimize impacts. In most instances, best management practices not only protect riparian and stream habitats but provide economic benefits to the landowners. In cooperation with local resource conservation districts and the University of California Cooperative Extension Service, existing information on best management practices to reduce agricultural impacts on streams should be disseminated to local growers.

The purposes of this task are to 1) gather baseline information on existing agricultural practices in watersheds harboring shrimp, 2) assess the magnitude of impacts associated with agricultural activities, 3) develop best management practices or mitigation measures to avoid, minimize, rectify, reduce, or compensate for impacts, and 4) implement best management practices or mitigation measures. Implementation of other tasks are needed to monitor habitat and population changes (Task 4), evaluate effectiveness of efforts (Task 5), and protect habitat and populations from future agricultural threats (Task 3).

1.1.1. Continue to determine the extent, nature, and trend of agricultural threats.

This process involves identification of the agricultural activities adjacent to streams in watersheds harboring shrimp. Existing county general plans can provide general information regarding the general intensity of agricultural activities; however, specific agricultural practices are not detailed. Existing practices (e.g., management activities and riparian buffer characteristics) need to be documented through remote sensing information (e.g., aerial photography), field inspections, and data from county agricultural commissioners and landowners. To facilitate analysis of long-term changes in agricultural activities, the information should be part of a database, preferably a geographic information system (See Task 4.5).

1.1.2. Develop and implement best management practices to maintain riparian communities.

Measures are needed that would maintain a natural riparian community in area, length, and species composition. Riparian vegetation, particularly shrubs and trees, should be protected to allow development of undercut banks with exposed, fine roots as winter habitat for the shrimp. Trailing vines and overhanging woody vegetation are extremely important components of summer habitat for the shrimp and can also be best maintained through preservation of a healthy riparian corridor. Setbacks from riparian areas can be achieved through voluntary efforts by landowners, county planning ordinances, and conservation easements.

1.1.3. Develop and implement best management practices to prevent impacts to shrimp from agricultural chemicals.

Measures are needed that would prevent adverse impacts to shrimp populations from use of pesticides and other agricultural chemicals. Currently, the shrimp has an unknown sensitivity to pesticides routinely used in vineyards or other agricultural practices. Therefore, water quality standards should be developed based on preexisting data from related species or from standard toxicity tests. The standards can then be used to develop and implement appropriate guidelines for the use of pesticides. This part of the task may be omitted if it can be satisfactorily demonstrated that standard best management practices do not result in measurable degradation of habitat.

In the absence of water quality standards, existing best management practices should be used to prevent the movement of pesticides into the aquatic environment. Well-vegetated riparian areas intercept aerial drift and overland flow of chemicals and should be preserved to reduce the input of agricultural chemicals into streams. The U.S. Fish and Wildlife Service participated with various agencies and landowners to develop pesticide use guidelines for agricultural activities within the Huichica Creek watershed (Napa County Resource Conservation District 1993). Application of these guidelines along all streams containing shrimp populations would minimize the risk of take.

1.1.4. Develop and implement measures to ensure that agricultural diversions do not take shrimp or result in loss of habitat.

Information is needed to determine the level of summer and winter flows necessary to maintain habitat conditions for viable shrimp populations and other native species (See Task 1.5.2). Measures must be developed to ensure that agricultural diversions do not take shrimp or result in loss of habitat during the dry season. Additionally, bypass flows of at least 2 cubic feet per second must be maintained to ensure that creeks do not run dry. The recommended mode of water appropriation may depend upon the amount and timing of appropriation, as well as the distribution and abundance of shrimp within the stream. For degraded streams with low numbers and limited distribution of shrimp (e.g., Walker, Keys, Stemple, Yulupa, East Austin, Austin, and Green Valley Creeks and Napa River), recommended measures may include prohibition on diversions directly from the stream within and above shrimp populations. Offset wells or some other type of subsurface collectors should be explored. Water from outside sources also should be investigated. For example, irrigation with tertiary treated wastewater may reduce the need for instream appropriations.

In other streams, water intake designs should be developed and implemented to prevent the loss of shrimp at agricultural diversions. Subsurface water collection systems would be preferable to instream diversions particularly because intake velocities and screen mesh sizes needed to prevent the loss of juvenile shrimp are unknown. Information and recommendations produced in Task 1.5 will apply here.

1.1.5. Develop and implement measures to reduce unnatural rates of sediment deposition in streams.

Measures should be developed and implemented to reduce erosion and deposition of sediments in stream environments. Reduction in sedimentation will benefit local landowners by reducing the risk of channel changes that may adversely affect adjacent agricultural lands (e.g., increased flood elevations and lateral channel migration). Prevention of soil loss will also maintain the long-term productivity of the site for crops.

Several standard management practices are available from the University of California Cooperative Extension Service, the Natural Resources Conservation Service, and local resource conservation districts that, if implemented, will reduce the risk of soil loss. In the Huichica Creek watershed, the use of grass cover between vines has been recommended to reduce soil loss and sediment transport (D. Bowker pers. comm. 1994). Well-vegetated riparian corridors also reduce sedimentation by acting as a filter, trapping and reducing the amounts of suspended sediments carried in overland flow from reaching the aquatic environment (Karr and Schlosser 1978).

Reduction of sediment deposition should benefit the aquatic environment by maintaining pool depth, reducing the risk of unnatural morphological channel changes, maintaining appropriate substrate quality for spawning anadromous fish, and reducing unnatural inputs of nutrients.

1.2. Mitigate adverse livestock grazing and dairy farming impacts on stream and riparian habitats within watersheds bearing shrimp.

Grazing and dairy farming activities can destroy suitable habitat for the shrimp through removal of riparian vegetation, adverse bank and channel changes, decreased water quality, increased sediment loads, altered runoff characteristics, and increased water temperature and dissolved oxygen fluctuations.

The purposes of this task are to 1) gather baseline information on existing livestock management practices in watersheds harboring shrimp, 2) assess the magnitude of impacts associated with livestock management activities,

3) develop best management practices or mitigation measures to avoid, minimize, rectify, reduce, or compensate for impacts, and 4) implement best management practices or mitigation measures. Implementation of other tasks are needed to monitor habitat and population changes (Task 4), evaluate effectiveness of efforts (Task 5), and protect habitat and populations from future agricultural threats (Task 3).

1.2.1. Continue to determine the extent and nature of threats to shrimp from livestock grazing and dairy operations. The extent of livestock grazing and dairy operations should be determined for all watersheds harboring shrimp. To facilitate analysis of long-term changes in agriculture activities, the information should be part of a database, preferably a geographic information system (Task 4.5). Because many of the streams failed to meet existing water quality standards, efforts are already underway to identify and quantify problems in the Stemple Creek and Laguna de Santa Rosa watersheds (Soil Conservation Service 1992, M. Rugg unpubl. data 1994, CH2MHill and Merritt Smith Consulting 1994).

1.2.2. Develop and implement best management practices for livestock operations.

Expertise from local livestock interests and agencies (e.g., University of California Cooperative Extension Program, Natural Resources Conservation Service, and resource conservation districts) should be used to develop best management practices to prevent take of shrimp and/or loss of habitat. Existing water quality attainment plans (e.g., Laguna de Santa Rosa) and watershed natural resource protection and enhancement plans (e.g., Huichica Creek) provide good recommendations for minimizing dairy operation impacts on streams (Napa Resource Conservation District 1993, CH2MHill and Merritt Smith Consulting 1994).

A variety of management options to minimize grazing impacts on stream environments should be investigated. Selected options will depend upon the severity of habitat degradation and upon the local biological, geographical, and climatic conditions governing rates of habitat recovery. For stream reaches severely degraded by cattle and containing relatively low numbers of shrimp (e.g., Keys, Stemple, and Walker Creeks), expeditious construction of exclusionary fencing along the stream corridor is needed to prevent local extinction. Exclusionary fencing of the riparian zone provides optimum protection in the shortest amount of time. For less severely altered areas, other management techniques may be explored including a) grazing systems that control season, duration, and intensity of livestock use in riparian areas; b) provision of alternate sources of shade, water, and foraging habitat (e.g., irrigated pastures); and c) changes to less damaging livestock (e.g, sheep and horses) (Platts and Raleigh 1984, Clary and Webster 1989, Chaney *et al.* 1993).

1.3. Mitigate adverse impacts to shrimp and habitat from timber harvests.

Timber harvesting has occurred on private lands in the Austin Creek watershed and has likely resulted in increased sediment loads to this creek. The California Department of Forestry requires preparation of timber harvest plans for private timber harvests. Logging and related activities such as road construction and culvert installation can be regulated to protect aquatic life, including the shrimp.

The purposes of this task are to 1) gather baseline information on existing timber harvest practices in watersheds harboring shrimp, 2) assess the magnitude of impacts associated with timber harvest activities, and 3) develop and implement best management practices or mitigation measures to avoid, minimize, rectify, reduce, or compensate for impacts. Implementation of other tasks is needed to monitor habitat and population changes (Task 4), evaluate effectiveness of efforts (Task 5), and protect habitat and populations from future timber harvesting threats (Task 3).

1.3.1. Continue to determine the extent and nature of timber harvest threats to shrimp.

The extent of timber harvesting operations should be determined for all shrimp watersheds. To facilitate analysis of long-term changes in timber harvesting activities, the information should be part of a database, preferably a geographic information system (See Task 4.5). Because adverse impacts associated with timber harvesting are often long-term, watersheds with historic timber harvesting activities such as Austin Creek should be assessed. This information should be used to evaluate the need to rehabilitate watersheds and streams impacted from historic logging activities (See Task 2).

1.3.2. Develop and implement best management practices for timber harvest.

Research is needed to determine the types of logging activities that prevent habitat degradation and loss of shrimp. Interim best management practices should be further developed and required by the California Department of Forestry to avoid, minimize, rectify, reduce, or compensate for impacts. Additionally, participation with, or results from, activities already under way by the California Department of Forestry's is needed to further evaluate the impacts of timber harvests on shrimp and its habitat.

1.4. Prevent adverse impacts to shrimp from gravel mining operations.

Gravel mining activities can adversely impact shrimp populations through the removal of riparian habitat and changes to natural channel morphology. Currently, instream gravel mining operations are regulated by the Army Corps of Engineers through section 404 of the Clean Water Act and by local county and State regulations. To prevent adverse impacts on existing shrimp habitat, Marin, Sonoma, and Napa County planning departments and the Army Corps of Engineers should prohibit gravel mining and related activities that would alter natural channel morphology and riparian habitats. Gravel mining should only be permitted if benefits to shrimp and other native aquatic fauna can be demonstrated. Best management practices such as adequately sized and maintained detention ponds should be required for upland mining operations.

If instream gravel mining (including floodplain pit and skimming operations) continue to be permitted, measures should be developed to 1) gather baseline information on existing gravel mining activities in watersheds harboring shrimp, 2) assess the magnitude of impacts associated with these activities, 3) develop best management practices or mitigation measures to avoid, minimize, rectify, reduce, or compensate for impacts, and 4) implement best management practices or mitigation measures. Implementation of other tasks are needed to monitor habitat and population changes (Task 4), evaluate effectiveness of efforts (Task 5), and protect habitat and populations from future gravel mining threats (Task 3). To facilitate analysis of long-term changes in gravel mining activities, the information should be part of a database, preferably a geographic information system (Task 4.5).

1.5. Remove adverse impacts of water development activities on shrimp habitat and populations.

Water development activities can result in a multitude of direct and indirect impacts to shrimp and its habitat ranging from losses of shrimp from unscreened diversions to loss of riparian habitat by excessive groundwater withdrawals.

1.5.1. Continue to determine the extent and nature of water development threats.

To implement this subtask, baseline information must be gathered on existing and proposed water development activities in watersheds harboring shrimp. Necessary information includes the development of a water budget for each watershed harboring shrimp. Impacts associated with these activities should be determined.

1.5.2. Mitigate adverse impacts of water development activities on shrimp habitat and populations.

To mitigate for water development impacts, information should be developed to identify the instream flow needs necessary to maintain optimal habitat for protection and recovery of the shrimp. Measures should be proposed to secure needed flows and avoid losses at diversions.

Recommendations should be used by appropriate agencies (e.g., the State Water Resources Control Board) to review existing water rights so that they are consistent with protection of the shrimp. During the interim period, all unauthorized diversions within all existing shrimp populations should be removed.

Implementation of other tasks are needed to monitor habitat and population changes (Task 4), evaluate effectiveness of efforts (Task 5), and protect habitat and populations from existing and future water development threats (Task 3).

1.6. Remove existing summer impoundments in streams with shrimp and prevent future instream impoundments.

Summer impoundments adversely impact shrimp by increasing predation risk, precluding establishment of riparian vegetation, and blocking natural movements. Within the Austin Creek drainage, no summer dams are authorized by the Army Corps of Engineers after 1996. Continued vigilance is needed to prevent the installation of future instream impoundments in shrimp habitat.

1.7. Mitigate adverse impacts of urban runoff and wastewater discharges on shrimp populations and habitat.

Urban runoff and wastewater discharges adversely impact water quality and the shrimp. The purposes of this task are to 1) gather baseline information on urban runoff and wastewater discharges in watersheds harboring shrimp, 2) assess the magnitude of impacts associated with these activities, 3) develop and implement best management practices or mitigation measures to avoid, minimize, rectify, reduce, or compensate for impacts. Implementation of other tasks are needed to monitor habitat and population changes (Task 4), evaluate effectiveness of efforts (Task 5), and protect habitat and populations from existing and future threats (Task 3).

1.7.1. Continue to determine the extent and nature of urban runoff and wastewater threats to shrimp.

For each watershed harboring shrimp, the extent and nature of urban runoff, wastewater discharges, and septic systems should be described. To facilitate analysis of long-term changes in water quality, the information should be part of a database, preferably a geographic information system (See Task 4.5). Collection of baseline water quality data and characterization of urban runoff and wastewater discharges have been initiated for the Laguna de Santa Rosa, Atascadero and Green Valley Creeks (Forestville-Graton Wastewater Plan), and waterways associated with the City of Santa Rosa's Subregional Long-Term Wastewater Project (EIP Associates 1990, ESA 1993, and CH2MHill and Merritt Smith Consulting 1994).

1.7.2. Develop and implement best management practices for wastewater discharge.

Specific water quality standards for shrimp should be developed that include, but are not limited to, temperature, ammonia, pH, dissolved oxygen, nutrients, and pesticides. Water quality standards should focus on the most sensitive life stage of the shrimp. Ammonia bioassay tests with the freshwater prawn (*Macrobrachium rosenbergii*) indicate differential sensitivity among different prawn life stages (Robinette *et al.* 1988). Baseline should be developed to mitigate impacts to shrimp habitat. A multiagency memorandum of understanding could be used to establish appropriate flood control practices.

1.9. Develop and implement measures to remove unnatural barriers, where feasible, to facilitate upstream and downstream passage of shrimp.

Streams containing shrimp should be surveyed to identify the location and types of man-made barriers to movement of shrimp. Research information gathered in Task 6.3 should be used to identify features that function as barriers to shrimp. Barriers may include adverse environmental conditions (e.g., water quality) that restrict movement. The impacts of removing barriers should be evaluated and should consider post-removal changes in stream morphology and introduced species. Measures should be recommended to prevent the development of future barriers from proposed development projects. For example, road crossings with natural bottoms may be required for any new streams crossings in shrimp habitat. This task will likely require additional research in the area of shrimp movements to better determine various types of barriers.

1.10. Reduce predation on shrimp by introduced species.

The purposes of this task are to 1) gather baseline information on the extent, abundance, and types of introduced predators in streams containing shrimp, and 2) develop and implement measures to reduce introduced predators and their impacts. Implementation of other tasks are needed to monitor habitat and population changes (Task 4), evaluate effectiveness of efforts (Task 5), and protect habitat and populations from existing and future threats (Task 3).

1.10.1. Identify locations with high concentrations of introduced predators.

Although introduced predators can be considered ubiquitous within watersheds harboring shrimp, areas of high concentrations should be identified.

1.10.2. Develop and implement measures to reduce predation on shrimp.

The extent and numbers of introduced predators in watersheds containing shrimp should be reduced. Furthermore, future introductions of predators in streams and adjacent water bodies in these watersheds should be prevented.

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1.10.2. Develop and implement measures to reduce predation on shrimp.

The extent and numbers of introduced predators in watersheds containing shrimp should be reduced. Furthermore, future introductions of predators in streams and adjacent water bodies in these watersheds should be prevented.

Recommended actions, such as removal of habitat threats and restoration of natural stream conditions, particularly riparian canopy, should create conditions favorable to native rather than introduced species. Introduced fishes such as mosquitofish, bluegill, and green sunfish are abundant in disturbed locations, typically containing pools with little shading of the water surface by terrestrial vegetation (Leidy 1984). Also, Leidy (1984) found with mosquito abatement programs, habitat modification remains the most effective means, in terms of cost and sustainability, of controlling nuisance species.

Active predator removal may be required on streams until recovery of natural habitat conditions are able to influence populations of introduced species. Shrimp populations upstream of barriers to introduced fish may benefit the most from active predator removal efforts (e.g., Huichica Creek above Highway 12) (Serpa 1991a).

2. Restore habitat conditions favorable to shrimp and other native aquatic species at extant localities.

Implementation of tasks to remove existing threats to shrimp and their habitat should result in improvements to shrimp populations. However, cessation of harmful activities does not always result in immediate habitat improvements. For example, McCashion and Rice (1983) found that the maximum volume of erosion occurred 11 to 15 years after construction of logging roads and coincided with road failures and an extreme flood event. Therefore, active restoration efforts may be needed in streams and watersheds where long periods of time are required for natural recovery processes to significantly improve habitat conditions. Active restoration is particularly applicable to land-use activities such as grazing and logging that have resulted in large-scale alterations within the watershed.

2.1. Identify locations for habitat restoration.

Locations suitable for habitat restoration should be developed in conjunction with development of best management practices under Task 1.

2.2. Develop and implement habitat restoration plans.

Because the various shrimp-bearing watersheds face a different array of problems, restoration plans are needed for each watershed. All restoration plans should be designed to ensure that adequate habitat for the shrimp (e.g., food sources and shelter) are created and/or maintained throughout the length of the creek. In addition, habitat restoration actions should maintain and enhance exchange of genetic material among population segments through provision of corridors and removal of barriers. Streams affected minimally by human disturbance, such as Lagunitas Creek with relatively abundant numbers of shrimp, may be used as templates in the development of habitat restoration plans.

Because funds for restoration work may be limited, restoration efforts should be initiated first on sites identified as having the least resilience to disturbance (e.g., Keys, Walker, and Stemple Creeks).

3. Protect and manage shrimp populations and habitat.

3.1 Obtain long-term habitat protection.

Long-term habitat protection remains the best way to maintain shrimp habitat in the long-run. One of the highest rated (Table 2) shrimp-bearing streams, Lagunitas Creek, flows through lands that are partly in public ownership (National Park Service and California Department of Parks and Recreation) and is afforded long-term protection from adverse land-use activities. Traditional fee title acquisition by government or private resource interests is an effective, but expensive, way of protecting resources. Other mechanisms to protect habitat on private lands include 1) local zoning restrictions that prevent incompatible uses, 2) transfer of development rights, 3) fee title donations, 4) sale or donation of conservation easements, 5) sale and backlease or resale programs with restrictive covenants, and 6) tax incentives and disincentives (Norcross and Calvo 1993).

Shrimp streams are separated into four different drainage units. Because of ecological isolation and possible genetic differences among shrimp populations in different drainages, it is important to ensure long-term protection of all necessary lands associated with at least one shrimp stream from each of the four general drainage units: 1) tributary streams in the lower Russian River drainage, 2) coastal streams flowing directly into the Pacific Ocean, 3) streams draining into Tomales Bay, and 4) streams flowing into San Pablo Bay. Long-term protection of more than four locations may be required if tasks to remove threats and restore habitat do not result in timely improvements in habitat and shrimp populations. Preservation of adequate instream flows is also a necessity. Development and implementation of such a plan is addressed in Task 1.5.

For each stream identified for long-term protection, a plan should be developed to identify 1) landowners, 2) funding sources, 3) the amount and extent of necessary lands and water, 4) the long-term management entity, and 5) management goals and strategies necessary for long-term protection of the shrimp and its habitat. Funds should be secured for protection efforts as well as long-term management. Expansion of stream segments already in public ownership (East Austin Creek and Lagunitas Creek) should be given strong consideration.

3.2. Enforce applicable local, State, and Federal laws, regulations and policies to protect the shrimp and its habitat.

Federal, State and local laws, regulations and policies exist to protect the shrimp and its habitat. The Endangered Species Act of 1973, the Coastal Zone Management Act of 1972, the Clean Water Act, the Food Security Act of 1985, the California Endangered Species Act of 1984, and other applicable laws need full compliance and enforcement to protect the shrimp and its habitat.

Under the public trust doctrine, the State of California received title of tidal and submerged lands and the beds of navigable waterways (sovereign lands) after its admission to the United States on September 9, 1850. The State Lands Commission has been designated as the agency having jurisdiction over these sovereign lands. On inland rivers and lakes not subject to tides, the State claims fee ownership to the ordinary low water mark (Jacobs 1993). A public trust easement extends between the ordinary low and high water marks (Jacobs 1993). All such areas, whether owned in fee or easement, are subject to the public trust doctrine, which protects traditional rights to use waterways for navigation, commerce, and fisheries (Jacobs 1993). Preservation of the natural values of waterways also has been recognized as an aspect of the public trust doctrine. The extent of State fee title ownership or easements within watersheds and waterways harboring shrimp is unclear. Therefore, it is important to determine the extent of sovereign lands in watersheds harboring the shrimp and to use the public trust doctrine to protect habitat in these locations.

There have not always been sufficient staff resources available to ensure the effective enforcement of applicable laws, regulations, and policies. It is important that sufficient resources be committed to enforcement efforts directed at preservation of the shrimp.

4. Monitor and evaluate shrimp habitat conditions and populations.

Adequate monitoring information regarding shrimp populations and habitat quality and quantity needs to be collected from all shrimp-bearing streams. As evidenced by recent discoveries of shrimp populations in Keys, Redwood, and Garnett Creeks, small perennial tributaries within shrimp-bearing watersheds also need to be identified and surveyed so that unknown populations can be protected before they become extirpated. Routinely collected monitoring information is needed to assess the effectiveness of recovery efforts and to determine trends in population and habitat conditions among shrimp streams. A comprehensive monitoring program may also help determine the habitat features most responsible for controlling shrimp populations. In addition, monitoring efforts should document presence of new threats to the shrimp.

Development and use of a database accessible to the public and agencies is recommended. The most suitable format for monitoring long-term habitat changes at various scales is a geographic information system.

4.1. Develop a routine and comprehensive habitat monitoring plan.

Inventory and monitoring of wildlife habitat assumes that measurements of a set of habitat attributes can be used to predict presence or abundances of wildlife species (Cooperrider 1986). The strength of habitat relationships depends largely on a good grasp of the species' biology. Because understanding of the shrimp's biology is still in its infancy, initial monitoring efforts will likely be extensive and exhaustive. Therefore, a monitoring plan should be developed to collect habitat data over time at various spatial scales ranging from watershed to microhabitat information from individual stream reaches. For example, a sequence of aerial photos or other remote sensing data and a geographic information system could be used to determine changes over time in the continuity, composition and length of the riparian corridor within the watershed. Water quality data such as temperature, ammonia, pH, dissolved oxygen, nutrients, etc. should also be gathered. Products of the monitoring plan should permit the assessment of recovery efforts in increasing habitat for the shrimp.

4.2. Implement a habitat monitoring plan.

Habitat monitoring efforts should be coordinated with landowners, various agencies, schools, conservation organizations, and academic institutions.

4.3. Develop a routine and comprehensive population monitoring plan for shrimp.

The purposes of the population monitoring plan should be three-fold: 1) to investigate previously unsampled or inadequately sampled sites within the historic range to determine exact distribution of the shrimp, 2) to provide status information to assess impacts of recovery actions, and 3) to provide basic information necessary for the refinement of quantitative recovery criteria.

Distributional information will also help determine the relative resilience of populations within drainage basins to disturbances. This information would be useful in prioritizing the expenditure of limited recovery funds.

4.4. Implement a population monitoring plan.

A population monitoring plan should be coordinated with landowners, various agencies, conservation organizations, and academic institutions. The plan should assess trends in the abundance and distribution of California freshwater shrimp within all shrimp-bearing creeks. The monitoring program should reasonably define the range of the species and assess population trends, while causing the least amount of impact to the shrimp. To accomplish this, representative sampling should be done in areas where shrimp are likely to exist.

4.5. Develop a database to collect, store, analyze and exchange monitoring information.

Monitoring information from Task 4.4 should be placed in a database accessible to all interested parties. Shrimp population information should be sent to the California Department of Fish and Game (Natural Heritage Division) for input into their natural diversity database system. Stream and watershed habitat information should also be placed in a database accessible to resource agencies and the general public. The California Resources Agency and the National Park Service, in a cooperative effort, are developing a California Rivers Assessment Program for the state's river resources. A primary goal of this program is to provide a computerized forum for collecting, storing, analyzing, exchanging and retrieving river-related resource data. The program intends to organize data into a geographic information system accessible in various computer formats. Several of the streams and rivers proposed for this database contain existing shrimp habitat and populations including Stemple Creek, Lagunitas Creek, and the Napa River.

However, several shrimp-bearing watersheds are not proposed for inclusion in this California Rivers Assessment Program. Therefore, a database system that is compatible with other programs should be developed to collect, store, analyze, exchange, and retrieve information from all watersheds containing shrimp.

4.6. Develop and implement survey training programs for biologists.

A training program on the proper use of aquatic dip nets, aerial insect nets, capture techniques (working the roots and vegetation along the sides of streams), and handling should be conducted to provide surveyors with knowledge on how to avoid accidental injury or mortality to shrimp. This knowledge could then be used to help expedite the issuance of U.S. Fish and Wildlife Service scientific collecting permits.

5. Assess effectiveness of various conservation efforts for shrimp.

Monitoring should be used to assess the effectiveness of various conservation efforts in improving habitat conditions and shrimp populations. Baseline conditions and post-project monitoring of physical habitat conditions, water quality, and aquatic biota are necessities. Remediation measures should be enacted for conservation efforts that have not improved conditions for shrimp.

6. Conduct research on the biology of the species.

Further ecological information regarding characteristics of suitable shrimp habitat and information about population characteristics are needed to determine what constitutes a viable population. Implementation of this task should provide sufficient information to refine quantitative recovery criteria.

6.1. Determine preferred habitat conditions for shrimp.

Additional research is needed to fully determine optimal habitat conditions including life stage requirements, interspersion of winter and summer habitats, water quality conditions, and microhabitat conditions under different flow regimes. The information will assist in the development of appropriate habitat restoration goals and techniques.

6.1.1. Determine characteristics of refugia for shrimp.

Refugia can be characterized by habitats or environmental factors that convey spatial and temporal resistance or resilience to biotic communities disturbed by biophysical processes (Sedell *et al.* 1990). The ability of a population to persist in spite of environmental disturbances depends, in large extent, on the number, location, and quality of refugia. The ability to persist is especially important for lotic (flowing or moving waters) systems in California that experience environmental fluctuations ranging from droughts to flood events. Tributary streams play an important role in providing resilience to populations within the drainage basin of a larger stream. Some shrimp populations may depend on dispersal from upstream tributaries.

Determining the optimal refugial characteristics necessary to maintain a viable population is extremely important for the shrimp due to their limited swimming abilities and susceptibility to predation. Identification of refugial characteristics at various spatial (e.g., reach and drainage basin) and temporal (e.g., seasonal and yearly) scales is needed. For example, observations indicate that undercut banks convey protection from high flows; however, further investigation is needed to determine the role of woody debris, flood plains, and side channels as winter habitat and refugia.

6.1.2. Obtain further information regarding feeding ecology.

Limited information is available concerning the types of food required for optimal growth and reproduction of shrimp. Riparian conditions (e.g., open vs. closed canopy and plant species composition) will influence the types of food items available for consumption. Knowledge of types and quantity of food items necessary for optimal growth and reproduction should help guide the development of habitat restoration efforts.

6.2. Identify population characteristics and reproductive ecology.

Research is needed to determine if shrimp within and among streams represent isolated breeding populations with genetic, morphological, and behavioral differences. Existing populations should be evaluated as to their susceptibility to extinction. Research is needed to determine carrying capacity, rates of population growth, effective population size, annual and seasonal population fluctuations, recruitment, generation length, and survivorship.

6.3. Characterize shrimp dispersal capabilities and the environmental and habitat characteristics necessary for movement.

The environmental factors and habitat characteristics that hinder or facilitate movement of various life stages should be determined. This information would be used to determine whether active reintroduction efforts are necessary following habitat restoration. The information, in conjunction with shrimp monitoring data, will also help define isolated shrimp populations. Remediation measures can be identified for isolated shrimp populations at risk of local extinction.

6.4. Develop protocol for a captive propagation program.

Shrimp from captive propagation efforts may be required for reintroduction efforts or as an insurance measure to forestall extinction of wild populations in the event of catastrophic population declines. Although a large-scale captive propagation program is not recommended at this time for the shrimp, protocol for captive breeding should be established based on a small-scale program. The need for extensive research is not expected because of existing information and experience on commercial shrimp and prawn propagation. Collected information would be ready to initiate a large-scale effort if the need arose. Criteria should be developed to determine when large-scale captive propagation should be initiated.

Propagation techniques should be designed to minimize loss of genetic diversity and the introduction and spread of exotic diseases. Laboratory experiments (e.g., toxicity and feeding studies) should only use shrimp from captive propagation efforts. Captive propagation efforts should be combined with educational displays at frequently visited aquaria to increase public awareness as well as gather scientific data (See Task 8).

7. Restore and maintain viable shrimp populations at extirpated localities.

Extirpated sites include Santa Rosa Creek and stream reaches where habitat conditions have been severely degraded and repeated survey efforts have failed to detect the presence of shrimp where they were found previously. In addition, extirpated locations contain impediments to natural recolonization. Habitat restoration would be the first priority followed by an intensive inventory to confirm absence of shrimp to not overwhelm the genetic integrity of local populations; then reintroduction could be initiated to test the success of methods. Santa Rosa Creek would be an ideal area to obtain valuable information about restoration and reintroduction techniques. Developing reliable restoration techniques provides an extra margin of safety in the event that recovered populations become threatened by unforseen events.

8. Increase public awareness and involvement in the protection of shrimp and native, cohabiting species.

8.1. Develop and implement participation plans to protect, enhance, and restore stream and riparian habitats.

Implementation of recovery tasks requires cooperative efforts on the part of resource and regulatory agencies, local landowners, conservation groups, and planning interests. The U.S. Fish and Wildlife Service anticipates the development and implementation of separate participation plans for each watershed harboring shrimp. Existing coordinated resource management plans or watershed management plans may serve as participation plans. The development of Habitat Conservation Plans, under section 10 of the Endangered Species Act, may also provide a means to develop and manage watersheds.

8.2. Support, produce, or conduct public outreach programs.

The public should be informed about the biology and ecology of the shrimp as well as habitat requirements. The U.S. Fish and Wildlife Service should offer periodic updates to the press and general public regarding the shrimp's population status and recovery efforts. Public awareness and participation is needed to facilitate implementation of recovery efforts. Creation of live exhibits containing natural, stream habitat as well as shrimp should be encouraged if exhibits are also used to gather pertinent research information such as toxicology, feeding ecology, and captive propagation techniques. Other forms of outreach include educational programs, tours, and informational brochures.

9. Assess effects of various conservation efforts on cohabiting, native species.

Population data on sensitive species would aid in their preservation. Increased populations of species of concern and improved habitat conditions may forestall the need to list these species in the future. Also, increased populations of listed species and improved habitat conditions may help achieve recovery objectives for those species.

Although it is assumed that enhancement of habitat conditions for shrimp would benefit other native species, the impacts of enhancement efforts on cohabiting, native species should be assessed.

9.1. Monitor cohabiting, native species.

There must be sufficient monitoring of populations and reproduction to detect any detrimental effects that may arise from habitat improvements directed at improving conditions for shrimp; salmon spawning is of particular interest.

No separate task is proposed for the monitoring of habitat conditions for cohabiting, native species. Habitat information collected for the shrimp such as water quality, presence of undercut banks, and the extent and quality of riparian corridors should also be suitable data for assessing habitat conditions for cohabiting, native species. Species-specific habitat information should be collected on an as needed basis.

9.2. Implement remediation, where appropriate.

If conservation efforts cause declines in populations of native, cohabiting species, remediation efforts should be developed and implemented as long as actions would not adversely affect shrimp populations. These remediation efforts may results in additional costs that would not be required if projects only met the needs of the shrimp.

10. Assemble a California freshwater shrimp recovery team.

A recovery team comprising technical experts, resource managers, and public representatives should be established to track the progress of the recovery program and to provide assistance in the identification of site-specific actions. Additionally, the recovery team could prepare research perspectives to be used by universities to attract faculty researchers and graduate students to conduct needed research. In this capacity, the recovery team could prepare proposals and seek research funds.

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IV. IMPLEMENTATION SCHEDULE

The implementation schedule that follows outlines actions and estimated costs for this recovery plan. It is a guide for meeting the objectives discussed in Part II of this recovery plan. This schedule describes and prioritizes tasks, provides an estimated time table for performance of tasks, indicates the responsible agencies, and estimates costs of performing tasks. These actions, when accomplished should recover the species and protect its habitat as well as enhance conditions for co-occurring native organisms.

Key to Acronyms used in the Implementation Schedule

Definition of task priorities:

Priority 1 - An action that must be taken to prevent extinction or prevent the species from declining irreversibly in the foreseeable future.

Priority 2 - An action that must be taken to prevent a significant decline in species population or habitat quality, or some other significant negative impact short of extinction.

Priority 3 - All other actions necessary to meet the recovery objectives.

Definition of task durations:

Continuous - A task that will be implemented on a routine basis once begun.

Ongoing - A task that is currently being implemented and will continue until action is no longer necessary.

Unknown - Either task duration or associated costs are not known at this time.

Responsible parties:

BRD- Biological Resources Division, U.S. Geological Survey (was National Biological Service)
CCC - California Coastal Conservancy
CDFG - California Department of Fish and Game
CDF - California Department of Forestry
CDPR - California Department of Parks and Recreation
CITY - Local city government agencies
CMG - California Department of Mines and Geology
COE - U.S. Army Corps of Engineers (San Francisco District)
COUN - County Planning and Public Works agencies
EPA - U.S. Environmental Protection Agency
FWS - U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Endangered Species Division
NPS - National Park Service
NRCS - Natural Resources Conservation Service (was Soil Conservation Service)
OWN - Local landowners
RCD - Local resource conservation districts
RWQCB - Regional Water Quality Control Board
SLC - State Lands Commission
SWRCB - State Water Resources Control Board
UC - University of California Cooperative Extension Service
VARIOUS - multiple agencies and landowners

Implementation Schedule for the California Freshwater Shrimp Recovery Plan

Task Priority	Task Number	Task Description	Task Duration	Responsible Parties	Cost Estimate (in $1,000 units) Total Costs	FY 1	FY 2	FY 3	FY 4	FY 5
1	1.1.1.	Continue to determine the extent, nature, and trend of agricultural threats.	10 years	FWS, NRCS, CDFG, UC, COUN, RWQCB, RCD, OWN	197	17	20	20	20	20
1	1.1.2.	Develop and implement best management practices to maintain riparian communities	Continuous	FWS, NRCS, CDFG, UC, COUN, RWQCB, RCD, OWN	1,170	100	110	120	120	120
1	1.1.3.	Develop and implement best management practices to prevent impacts to shrimp from agricultural chemicals.	Continuous	FWS, EPA, NRCS, CDFG, UC, COUN, RWQCB, RCD, OWN	260	25	30	30	25	25
1	1.1.4.	Develop and implement measures to ensure agricultural diversions do not take shrimp or result in loss of habitat.	Continuous	FWS, COE, CDFG, SWRCB, SLC, OWN	350	25	40	40	35	35
1	1.1.5.	Develop and implement measures to reduce unnatural rates of sediment deposition in streams.	Continuous	FWS, NRCS, CDFG, UC, COUN, RWQCB, RCD, OWN	275	25	35	35	30	25
1	1.2.1.	Continue to the determine extent and nature of threats to shrimp from livestock grazing and dairy operations.	10 years	FWS, NPS, NRCS, CDFG, UC, COUN, RWQCB, RCD, OWN	320	50	30	30	30	30
1	1.2.2.	Develop and implement best management practices for livestock operations.	Continuous	FWS, NPS, NRCS, CDFG, UC, COUN, RWQCB, RCD, OWN	7,800	700	700	800	800	800

Implementation Schedule for the California Freshwater Shrimp Recovery Plan

Task Priority	Task Number	Task Description	Task Duration	Responsible Parties	Cost Estimate (in $1,000 units)					
					Total Costs	FY 1	FY 2	FY 3	FY 4	FY 5
1	1.5.1.	Continue to determine the extent and nature of water development threats.	10 years	FWS, CDFG, SWRCB, COUN, OWN	895	75	80	100	100	90
1	1.5.2.	Mitigate adverse impacts of water development activities on shrimp habitat and populations.	10 years	FWS, CDFG, SWRCB, COUN, OWN	2,100	200	200	300	200	200
1	1.6.	Remove existing summer impoundments in streams with shrimp and prevent future instream impoundments.	Continuous	FWS, COE, CDFG, SLC, COUN, OWN	0	0	0	0	0	0
1	1.7.1.	Continue to determine the extent and nature of urban runoff and wastewater threats to shrimp.	10 years	FWS, EPA, CDFG, COUN, RWQCB, RCD, CITY, OWN	660	50	60	60	70	70
1	1.7.2.	Develop and implement best management practices for wastewater discharge.	Continuous	FWS, EPA, CDFG, COUN, RWQCB, RCD, CITY, OWN	8,200	800	800	900	900	800
1	1.8.1	Continue to determine the extent and nature of flood control and bank protection threats to shrimp.	10 years	FWS, COE, CDFG, SLC, COUN, RWQCB, CITY, OWN	230	15	20	20	25	25
1	1.8.2.	Develop and implement mitigation measures for flood control and bank protection projects.	Continuous	FWS, COE, CDFG, SLC	8,000	700	700	900	900	800
1	3.1.	Obtain long-term habitat protection.	Unknown	FWS, NPS, CDFG, CPR, SLC, SWRCB, COUN, OWN	270	50	50	50	60	60
1	3.2.	Enforce applicable local, State, and Federal laws, regulations, and policies to protect the shrimp and its habitat.	Continuous	FWS, COE, EPA, CDFG, SLC, SWRCB, COUN	200	10	10	10	10	10

Implementation Schedule for the California Freshwater Shrimp Recovery Plan

Task Priority	Task Number	Task Description	Task Duration	Responsible Parties	Cost Estimate (in $1,000 units)					
					Total Costs	FY 1	FY 2	FY 3	FY 4	FY 5
1	6.1.1.	Determine characteristics of refugia for shrimp.	2 years	FWS, BRD, CDFG	50	30	20			
1	6.1.2.	Obtain information regarding feeding ecology.	2 years	FWS, BRD, CDFG	30	20	10			
1	6.2.	Identify population characteristics and reproductive ecology.	2 years	FWS, BRD, CDFG	70	40	30			
2	1.3.1.	Continue to determine the extent and nature of timber harvest threats to shrimp.	10 years	FWS, CDF, CDFG, OWN	78	5	5	7	7	9
2	1.3.2.	Develop and implement best management practices for timber harvest.	Continuous	FWS, CDF, CDFG, OWN	660	50	60	60	70	70
2	1.4.	Prevent adverse impacts to shrimp from gravel mining operations.	Continuous	FWS, COE, CMG, CDFG, COUN, OWN	290	10	10	15	15	15
2	1.9.	Develop and implement measures to remove unnatural barriers, where feasible , to facilitate upstream and downstream passage of shrimp.	10 years	FWS, COE, CDFG, SLC, COUN, RWQCB, CITY, OWN	340	20	20	30	30	40
2	1.10.1.	Identify locations with high concentrations of introduced predators.	1 year	FWS, NPS, CDFG, OWN	5	5				
2	1.10.2.	Develop and implement measures to reduce predation on shrimp.	Continuous	FWS, NPS, CDFG, OWN	225	20	15	15	15	10
2	2.1.	Identify locations for habitat restoration.	1 year	FWS, NPS, EPA, CDFG, CCC, COUN, RCD, OWN	20	20				
2	2.2.	Develop and implement habitat restoration plans.	Continuous	FWS, NPS, EPA, CDFG	1,040	100	120	120	100	100

Implementation Schedule for the California Freshwater Shrimp Recovery Plan

Task Priority	Task Number	Task Description	Task Duration	Responsible Parties	Cost Estimate (in $1,000 units) Total Costs	FY 1	FY 2	FY 3	FY 4	FY 5
2	4.1	Develop a routine and comprehensive habitat monitoring plan.	1 year	FWS, NPS, BRD, CDFG	50	50				
2	4.2.	Implement a habitat monitoring plan.	Continuous	FWS, NPS, BRD, CDFG, OWN	600	50	75	50	25	25
2	4.3.	Develop a routine and comprehensive population monitoring plan for shrimp.	1 years	FWS, NPS, BRD, CDFG	50	50				
2	4.4.	Implement a population monitoring plan.	Continuous	FWS, CDFG, COUN, CDPR, BRD, RCD	1,630	90	90	90	80	80
2	4.5.	Develop a database to collect, store, analyze, and exchange monitoring information.	Continuous	FWS, NPS, BRD, CDFG	515	30	30	30	25	25
2	5.	Assess effectiveness of various conservation efforts for shrimp.	Continuous	FWS, CDFG	800	40	40	40	40	40
3	4.6.	Develop and implement survey training programs for biologists.	Continuous	FWS	50	10	5	5	5	5
3	6.3.	Characterize shrimp dispersal capabilities and the environmental and habitat characteristics necessary for movement.	2 years	FWS, BRD, CDFG	50	30	20			
3	6.4.	Develop protocol for a captive propagation program.	2 years	FWS, BRD, CDFG	25	15	10			
3	7.	Restore and maintain viable shrimp populations at extirpated localities.	Unknown	FWS, CDFG, OWN	420	90	90	80	80	80
3	8.1.	Develop and implement participation plans to protect, enhance, and restore stream and riparian habitats.	Continuous	FWS, VARIOUS	1,000	100	100	100	100	100
3	8.2.	Support, produce, and conduct public outreach programs.	Continuous	FWS	77	20	3	3	3	3

Implementation Schedule for the California Freshwater Shrimp Recovery Plan										
					Cost Estimate (in $1,000 units)					
Task Priority	Task Number	Task Description	Task Duration	Responsible Parties	Total Costs	FY 1	FY 2	FY 3	FY 4	FY 5
3	9.1.	Monitor cohabiting, native species.	Continuous	FWS, NPS, BRD, CDFG, OWN	510	35	25	25	25	25
3	9.2.	Implement remediation where appropriate.	Unknown	FWS, VARIOUS	220	50	50	40	40	40
3	10.	Assemble a California freshwater shrimp recovery team.	1 year	FWS	15	2	1	1		1
					39,747	3824	3714	4126	3985	3778

V. APPENDIX: SUMMARY OF THE AGENCY AND PUBLIC COMMENTS ON THE DRAFT RECOVERY PLAN FOR THE CALIFORNIA FRESHWATER SHRIMP

On July 21, 1997, the U.S. Fish and Wildlife Service announced the availability for public review of a draft recovery plan for the California freshwater shrimp (*Syncaris pacifica* Holmes 1895) listed as an endangered species on October 30, 1988 (53 FR 43889). On September 29, 1997, the U.S. Fish and Wildlife Service extended the public review and comment period for this draft recovery plan and stated that comments on the draft recovery plan received by October 29, 1997, would be considered by the U.S. Fish and Wildlife Service. Larry Serpa, Larry Eng, and Bill Cox were requested to peer review the draft recovery plan.

A total of seven letters were received, each containing varying numbers of comments. Some specific comments reoccurred in letters. A complete index of the commenters, by affiliation, is available from the U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, 3310 El Camino Avenue, Suite 130, Sacramento, California 95821-6340. All letters of comment on the draft recovery plan are kept in the Sacramento Field Office.

The following is a breakdown of the number of letters received from various affiliations:

Federal agencies	1 letter
State agencies	4 letters
local governments	1 letter
business industry	1 letter

The comments received from the various affiliations mentioned above, and incorporated into this Recovery Plan, provided valuable insight that aided the U.S. Fish and Wildlife Service in preparation of the final Plan. The comments broadened the depth and scope of the Recovery Plan and improved the document overall. Some of the more significant comments received and incorporated into the Recovery Plan were those that provided evidence of shrimp in Olema Creek, detailed a more realistic approach to downlisting and delisting, and suggested forming a Recovery Team to track progress of the shrimp in accordance with this Recovery Plan.