1997 California Freshwater Shrimp (*Syncaris pacifica*) Surveys Within Point Reyes National Seashore and Golden Gate National Recreation Area

Darren Fong
Aquatic Ecologist
Golden Gate National Recreation Area

April 1999

Prepared for the

Golden Gate National Recreation Area
Division of Resource Management and Planning

U.S. Fish and Wildlife Service
Endangered Species Permits
Ecological Services
Portland Regional Office

INTRODUCTION

The California freshwater shrimp (*Syncaris pacifica*) is listed by the U.S. Fish and Wildlife Service as endangered (55 FR 43884) and is the only extant member of the genus. The shrimp is endemic to 17 coastal streams in Marin, Sonoma, and Napa counties north of San Francisco Bay, California.

The shrimp is found in low elevation (<116 meters), low gradient (generally <1 percent), perennial freshwater streams where banks are structurally diverse with undercut banks, exposed roots, overhanging woody debris, or overhanging vegetation. Existing populations are threatened by introduced fish, deterioration or loss of habitat because of water diversions, impoundments, livestock and dairy activities, agricultural activities and developments, flood control activities, gravel mining, timber harvesting, migration barriers, and water pollution.

Within Point Reyes National Seashore and Golden Gate National Recreation Area (hereafter referred to as "Parks"), the shrimp is found within the Lagunitas Creek watershed. The current range of the shrimp within Lagunitas Creek extends from Shafter Bridge in Samuel P. Taylor Park to roughly 1.6 km below the confluence with Nicasio Creek (Serpa 1991). Shrimp habitat along mainstem Lagunitas Creek within the Parks is generally protected from agricultural activities that are present within the watershed.

National Park Service Policy

It is a policy of the National Park Service (NPS) that the primary management objective in natural zones will be the protection of natural resources and values for appropriate types of enjoyment while ensuring their availability to future generations. Furthermore, the NPS will identify and promote the conservation of all federally listed threatened, endangered, or candidate species.

Objectives

The objectives of the study are as follows:

1) Determine the distribution of California freshwater shrimp within streams of Golden Gate National Recreation Area and Point Reyes National Seashore;

2) Evaluate the effectiveness of three survey methods for the shrimp; and

3) Provide recommendations for long-term monitoring.

Permits

Because sampling activities would deliberately “take” an endangered species, a permit under section 10(a)(1)(A) of the Endangered Species Act was obtained from the U.S. Fish and Wildlife Service (subpermit no. GGNRA-2).

Project Area

Two streams within the Lagunitas Creek drainage: mainstem Lagunitas Creek and Olema Creek, Marin Co. (Figure 1) were sampled in August 1997 to assess sampling techniques. Inventory activities occurred in Tennessee Valley Creek, Oakwood Creek, Nyhan Creek, lower Pine Gulch, and Redwood Creek (Marin Co.) (Figures 2-5). During 1997 and 1998, Larry Serpa, The Nature Conservancy, conducted a comprehensive survey of shrimp in Lagunitas Creek.

METHODS

Presence-Absence Inventory Method

Shrimp inventories were conducted using a single pass through suitable habitats. The sampling methods followed procedures described by Serpa (1991) and permitted by the U.S. Fish and Wildlife Service. A standard butterfly net was used to sweep riparian vegetation overhanging into the creek as well as undercut banks. Both banks were sampled during a single pass. Nets were frequently emptied into a shallow pan and sorted for shrimp or other unusual invertebrates. Survey distance and descriptive information on habitat conditions were recorded on data sheets (Appendix I).

Population Estimation:

We evaluated the following methods to estimate shrimp densities: 1) mark-recapture, 2) multiple pass removal (without replacement), and 3) snorkel techniques. One pool sampled in 1996 was resampled in 1997. We evaluated these three methods in pools within lower Lagunitas Creek and Olema Creek.

<u>Direct observation</u>: Direct observation methods are typically the least intrusive and disruptive of the available aquatic sampling techniques. Mask and snorkel techniques have been used successfully to determine the abundance and distribution of atyid shrimp in streams on the island of Guam (T. Leberer, Univ. of Guam, pers. comm., 1996). Atyids have been amenable to visual surveys because they are undisturbed by the presence of observers and easy to count.

Snorkeling was conducted by a single observer moving from the downstream most end of the habitat unit upstream. Observed shrimp were separated into two general age classes (juvenile and adults) based on estimated lengths (juveniles <25 mm, adults >25 mm). Dive lights were used to search dark and inaccessible areas (e.g. undercut banks). Undercut banks and overhanging vegetation were carefully searched. Because the waters were easily clouded with fine sediments, only one snorkel pass was conducted per habitat unit.

Multiple pass removal: After snorkeling activities, units were sampled with aerial sweep nets to provide data for multiple pass and mark-recapture models. We recorded the number of shrimp and general age class (juvenile and adults) captured per pass to provide a determination of population densities by age groups. Typically, we conducted 3-4 passes per habitat unit. Equal effort was applied for all passes. To estimate numbers of adults and juveniles per sampling unit, two different models were used: DeLury (linear regression) (Hellawell 1978) and the maximum likelihood (Van Deventer and Platts 1988). The maximum likelihood model was run on the software program, Microfish (Van Deventer and Platts 1988).

Mark-recapture: Mark-recapture methods are routinely used to estimate fish populations. They have also been used to estimate shrimp densities as well. Atyid shrimp densities in Puerto Rico have been successfully estimated using mark-recapture techniques (K. Buzby, Univ. of Syracuse, pers. comm., 1996). In 1996, we used two different means of marking shrimp: indelible ink tattoos and metallic glitter. However, because of the messiness and potential injury concerns by marking shrimp with a tattoo, only metallic glitter was used in 1997 sampling. Juveniles less than 25 mm in length (tip of rostrum to telson) were not marked; therefore, mark-recapture estimates are based solely on adults.

We marked shrimp by gluing small uniquely colored glitter to the carapace of the shrimp (Figure 6). First, shrimp were removed from the water. The carapace was blotted dry, then glue and glitter were placed quickly thereafter. Different colored glitter was used for each pool. This marking technique has been used successfully to mark atyid shrimp (Genus *Atya* and *Xiphocaris*) in northeastern Puerto Rico (K. Buzby, Univ. of Syracuse, pers. comm., 1996). She uniquely marked atyid shrimps with bits of numbered flagging glued to the upper carapace.

Following marking, shrimp were released at their sites of capture. No block nets were used to cordone off the upstream and downstream ends of the sampled units. Because sampling activities occurred during the fall, any block nets placed in the creek would likely be dislodged because of the large amounts of leaf debris combined with the small mesh size required to exclude shrimp. It is unlikely that any detectable migration occurred. In 1996, Larry Serpa sampled sites downstream of the release of marked shrimp. No marked shrimp were found.

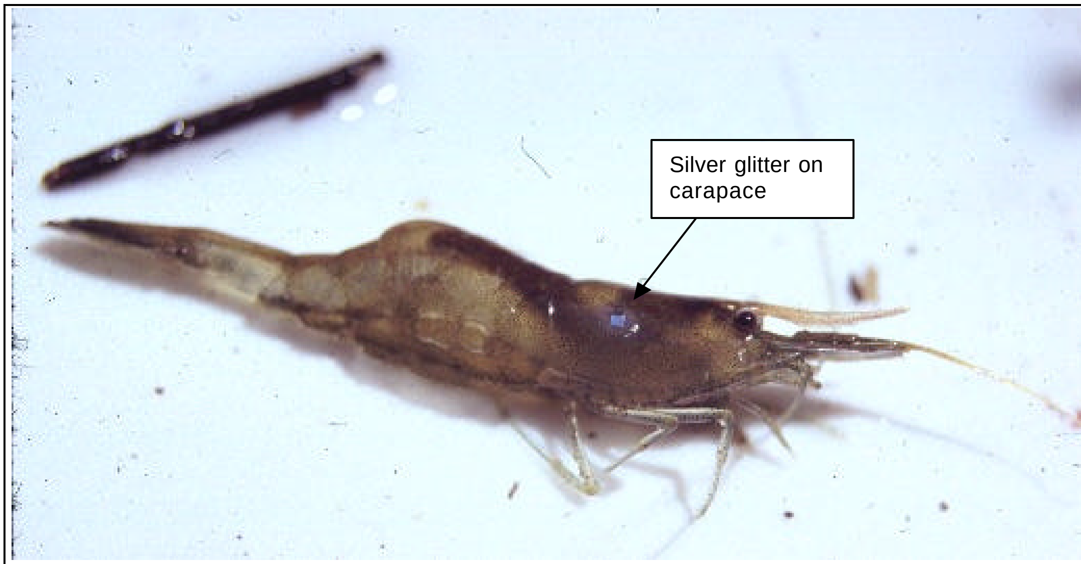

Figure 6: California freshwater shrimp marked with glitter, Lagunitas Creek, Marin Co., August 11, 1997

Pools with the marked shrimp were resampled using the same level of effort within 4 days. Shrimp were examined for marks, mark retention, and injuries. Possible injuries associated with marking and sampling activities were recorded along with a statement of the probable cause.

The Seber modification of the Petersen method was chosen to analyze the mark-recapture data (Krebs 1989). I inappropriately used the Bailey's modification of the Petersen method for the 1996 mark-recapture data; it assumes that individuals can be observed or captured more than once in the second sample. The Seber modification assumes sampling without replacement for the second samples (e.g., individuals can only be counted once). Our multiple pass removal sampling efforts meet the assumptions of the Seber modification.

(from Krebs 1989)

$$\hat{N} \; ? \; \frac{(M \; ? \; 1)(C \; ? \; 1)}{R \; ? \; 1} \; ? \; 1$$

where

$\hat{N}$? Estimate of population size at time of marking
M ? Number of marked individuals in first sample
C ? Total number of individuals captured in second sample
R ? Number of recaptured marked inviduals

Field Data Collected:

Listed below are the types of shrimp and habitat data collected.

Shrimp data:

Abundance:	Number of collected shrimp by age class and pass
Age class:	Juveniles or adults
Sex:	Male or female for adults. Females distinguished by presence of eggs, deepened body, or long pleura on sides.
Length:	Measured from tip of rostrum to telson (mm)
Injury/Mortality:	Notes on any injuries (e.g. broken spine) or moralities
Marks:	Type and presence/absence of marks

Habitat data:

Habitat type:	California Department of Fish and Game classification: pool, riffle, or flatwater. Pools further identified as scour, backwater, or main channel units.
Habitat unit length:	Length along thalweg in meters
Habitat unit width:	Water surface widths are measured on three transects using a meter tape at roughly 1/4, 1/2, and 3/4 habitat length.
Average depth:	Along each of the three width transects, depth measurements are taken at 1/4, 1/2, and 3/4 widths. We calculated average depth by transect by summing depths and dividing by 4 to account for assumed zero depth at transect corners.
Residual pool depth:	The residual pool depth is calculated by subtracting minimum pool depth (at tail or downstream end) from the deepest part of pool.
Average shoreline depth:	Average water depths at the edge of banks for each of the transects

RESULTS

Sampling Unit Descriptions

We sampled three sites, ranging from 41 to 88.0 m in length, as part of our evaluation of various survey techniques. One location, milepost (MP) 19.94 on Sir Francis Drake Highway, was sampled in the previous year. Photos of habitat conditions found in MP 19.94 and Below Gallager sites are provided in Appendix II. Table 1 provides the physical habitat descriptions.

Table 1: Physical habitat characteristics at shrimp sampling sites, Lagunitas and Olema Creeks

Station	***MP 19.94 (Tocaloma)***	***MP 12.91 (Below Gallager)***	***Olema Above Dam***
Date	8/11/97	8/12/97	8/16/97
Air temp (^oC)	25.0	25.0	25.5
Surface water (^oC)	17.5	20.5	19.0
Pool Type	SC	MC/SC	MC/SC/BW
Mean width (m)	6.7	10.3	8.9
Mean depth (m)	0.25	0.36	0.43
Length (m)	41.5	88.0	62.6
Area (m^2)	277.6	902.7	555.3
Max depth (m)	0.60	0.90	1.00
Min depth (m)	0.10	0.20	0.15
Residual pool depth (m)	0.50	0.70	0.85
Mean shoreline depth (m)	0.05	0.12	0.14
Cover Type (% Area)	OV (15), LWD (10), UCR (5)	OV (5), UCR (5), RWD (<1), EV (<1)	OV (15), UC (5), EV (<1)

*Note: **EV**-emergent vegetation, **LWD**-large woody debris, **OV**-overhanging vegetation,*
***RW**-rootwad, **UC**-undercut without fine roots, **UCR**-undercut with fine roots*

Sampling Technique Evaluation:

We were only able to sample three pools in 1997. Similar to 1996, the mark-recapture method provided the highest estimate of adult shrimp followed by multiple pass removal estimates, and snorkeling (Table 2). Estimates of juvenile abundance were higher with the multiple pass removal estimates than snorkel counts. Appendix III includes the raw, uncooked shrimp data. Appendix IV provides the catch of shrimp per pass for each sample site using the Microfish maximum likelihood removal estimate.

Table 2: Estimated numbers of California freshwater shrimp at sample sites in Lagunitas and Olema Creeks , Marin Co., 1997. Note: Values in parentheses are standard error units
.

Site- Sample Date	Estimation Method	Adult	Juvenile	All
MP 19.94 (Tocaloma)				
Aug. 11,1997	-snorkel	33	6	*39*
	-mark-recapture (Seber)	186		
	-max. likelihood	61 (8.5)	151 (4.9)	*211 (7.8)*
	-DeLury	67	149	*211*
Aug. 12,1997	-max. likelihood	43 (1.7)	101 (2.6)	*147 (3.6)*
	-DeLury	45	102	*147*
MP 12.91 (Below Gallager)				
Aug. 12,1997	-snorkel	0	0	*0*
	-mark-recapture (Seber)	31		
	-max. likelihood	9 (1.2)	16 (3.6)	*27(5.1)*
	-DeLury	11	19	*29*
Aug. 16,1997	-max. likelihood	22 (11.4)	17 (1.0)	*37 (5.3)*
	-DeLury	33	19	*41*
Olema Above Dam				
Aug. 18,1997	-snorkel	N.A.	N.A.	*N.A.*
	-mark-recapture (Seber)	N.A.	N.A.	*N.A.*
	-max. likelihood	3 (0.7)	3 (0.7)	*6 (1.0)*
	-DeLury	error	error	error

Injury and Mortality

No shrimp mortalities occurred during sampling or marking. However, one shrimp was injured during sampling activities on Lagunitas Creek.

Shrimp Inventory:

Olema Creek. The California freshwater shrimp population is extremely small in Olema Creek. It is not widely distributed, nor is it abundant where present. In 1996, a single female was captured. This individual was found within the lower section of Olema Creek which "backs up" because of a seasonal impoundment in Lagunitas Creek (Giacomini dam). It was suspected that this sole shrimp represented a stray rather than a sustaining population. No juveniles were captured in 1996.

In 1997, Olema Creek was surveyed just above the confluence with Lagunitas Creek to the confluence with the Olema Cemetary tributary- a distance of 4 km (Figure 2). Shrimp were found in two discrete locations- and at very low numbers (Table 3). The presence of adult shrimp for the second consecutive year and the additional presence of juveniles suggests that a small, reproducing shrimp population may be present in Olema Creek.

The "Old dam" site was revisited to sample more intensively for density estimates. Density estimates at one pool (using multiple pass removal depletion) were 4.75 juvenile and 4.75 adults per 100 m. For comparison, the pool below Gallager in Lagunitas Creek had 19.3 juveniles and 13.6 adults per 100 m. The sampling site below Gallager is generally considered one of the sparsest locales with shrimp in Lagunitas Creek.

The lower portion of Olema Creek has adequate habitat for shrimp. Long main channel pools were present with infrequent riffles. Although little undercut was present, there were areas with California and Himalayan blackberry overhanging into the water. In fact, the shrimps captured during inventory sampling were associated with areas with blackberry (Photo 3, Appendix II). In addition, aquatic invertebrates typical of slow-moving waters were captured during sweep surveys for shrimp including water scorpion (Family Nepidae), giant waterbug (Family Belostomatidae), scuds (Order Amphipoda), damselfly larvae (Suborder Zygoptera), dragonfly larvae (Suborder Anisoptera), and water striders (Family Gerridae). Fish taxa captured included sculpins (Family Cottidae), California roach (*Hesperoleucus symmetricus*), and three-spine stickleback (*Gasterosteus aculeatus*).

Table 3: 1997 inventory of shrimp in Olema Creek, Marin Co.

Stream Reach	Date	Sample Distance	No. of shrimp
-Pasture Above Lagunitas Confluence to Old Dam	Aug. 15, 1997	350 m	1 adult
-Old Dam to Olema Pasture	Aug. 15, 1997	750 m (approx)	2 adults
-Olema Pasture to Bear Valley Bridge	Aug. 15, 1997	1,770 m (approx)	
-Bear Valley Bridge to Vedanta (MP 26.00)	Aug. 20, 1997	570 m	0
-Vedanta to Olema Cemetary Trib. Confluence	Aug. 20, 1997	505 m	0
TOTAL		3,955 m	3 adults

Pine Gulch Creek. Two sections of lower Pine Gulch Creek adjacent to Marin County Open Space and two farms operated by Don Merch and Peter Martinelli (Paradise Valley Ranch) were surveyed during a single day (Table 4, Figure 3). Permission to access other portions of lower Pine Gulch was not granted and therefore, not surveyed. The creek adjacent to Don Merch's farm and Marin County Open Space contained a riparian corridor primarily of young willows and alders with some areas of California blackberry. As with lower Olema Creek, pools comprised the predominant habitat type. Very little root structure was present within the pools. Fish taxa captured included sculpins, juvenile steelhead (*Oncorhynchus mykiss*) and three-spine stickleback.

Table 4: 1997 inventory of shrimp in Pine Gulch Creek, Marin Co.

Stream Reach	Date	Sample Distance	No. of shrimp
-Marin County OS footbridge to Bolinas Road car bridge	Sept. 9, 1997	400 m	0
-Paradise Valley (Martinelli reach)	Sept. 9, 1997	400 m	0
TOTAL		800 m	0

Redwood Creek. Bill Cox (CDFG, pers. comm. 1997) and Larry Serpa (pers. comm. 1997) both indicated that Redwood Creek has suitable habitat for shrimp. We focused our shrimp surveys at sites with potential for stream restoration activities and suitable habitat.. Survey activities were conducted within Franks Valley and the Big Lagoon/Muir Beach area (Table 5, Figure 4). No shrimp were captured during surveys. Potential habitat for shrimp is present in these lower reaches of Redwood Creek. However, the lower reaches of Redwood Creek are intermittent with isolated pools during the drier summers. In terms of habitat structure, lower Redwood Creek by the Muir Beach parking lot contained much overhanging willow with fine root structure as well as herbaceous plants (sedges, water hemlock, and grasses) that were hanging into the water. Many pools in this area had abundant wood. Fish species either seen or captured included three-spine stickleback, prickly sculpin (*Cottus asper*), juvenile steelhead, and juvenile coho (*O. kisutch*).

Table 5: 1997 inventory of shrimp in lower Redwood Creek, Marin Co.

Stream Reach	Date	Sample Distance	No. of shrimp
-Confluence with Big Lagoon backwater to Pacific Way Bridge	Mar. 19, 1997, Aug. 8, 1997	325 m	0
-Banducci ballfield to MBCC foot bridge	Aug. 14, 1997	700 m	0
-MUWO road bridge to 1st foot bridge	Mar. 19, 1997	325 m	
-@ Miwok foot bridge	Aug. 8, 1997	100 m	0
-Above State Park housing @ MP 2.67	Aug. 14, 1997	500 m	0
Total		1,950 m	0

<u>Nyhan/Oakwood/Tennessee Valley Creeks</u>. Shrimp surveys were suggested by the U.S. Fish and Wildlife Service (M. Vandenburg, pers. comm., 1997) prior to initiation of any pond draining activities for bullfrog control. The survey locations are provided in Table 6 and Figure 5. No shrimp were caught during the surveys. Habitat for shrimp is extremely marginal in Oakwood Valley and Nyhan Creeks primarily because of intermittent flows. Tennesse Valley Creek was difficult to survey because of the small channel and extensive riparian vegetation.

Table 6: 1997 inventory of shrimp in Oakwood and Tennessee Valleys, Marin Co.

Stream Reach	Date	Sample Distance	No. of shrimp
-Nyhan Creek (above confluence with Oakwood Valley Creek)	Mar. 21, 1997, Aug. 14, 1997	500 m	0
-Oakwood Valley Creek (dry)	Aug. 14, 1997	approx. 300 m	0
-Tennessee Valley Creek (below TV Cove Pond)	Mar. 21, 1997	100 m	0
-Tennessee Valley Creek (above TV trail @ TV Cove Pond)	Mar. 21, 1997, Aug 14, 1997	200 m	0
-Tennessee Valley Creek (@ Coastal trail foot bridge)	Apr. 3, 1997	50 m	0
Total		1,150 m	0

DISCUSSION

This project had three objectives. The first objective required the completion of a comprehensive inventory of streams within GOGA and PORE for shrimp. This was only partly completed. Further inventories are needed on perennial, low gradient streams that have not been surveyed. These include Bear Valley Creek (PORE), tributaries to Bolinas Lagoon (GOGA, private lands), tributaries to Lagunitas Creek (GOGA),and Rodeo Creek (GOGA). In addition, the lower portion of Lagunitas Creek below Gallagher Ranch should continue to be surveyed for the presence or absence of shrimp.

The second objective looked at the effectiveness of three survey methods for determining shrimp abundance: direct observation, mark-recapture, and multiple pass removal. Our study design was limited because we had no means of determining the actual number of shrimp in sampled pools. Complete removal of shrimp could only be accomplished by a toxicant. Alternatively, we could have stocked shrimp-less habitat units with known number of shrimp. However, those shrimp-less habitat units were typically poor habitats and transplanting shrimp could expose them to predation and yield results not characteristic of shrimp-bearing habitat units. Also, conditions of the Park's Section 10 permits from the U.S. Fish and Wildlife Service did not permit such activities.

So, rather than identifying the most accurate means of estimating shrimp abundance, this short-term study was only able to point out the pluses and minuses of the three survey methods. A summary of these comparisons are provided below (Table 7).

Table 7: Evaluation of three survey techniques for the estimation of California freshwater shrimp abundance in Lagunitas Creek, Marin Co., CA.

Method	Demographic Info	Estimate Adults?	Estimate Juve's?	Degree of Handling	Level of Effort	Obtains Behavior Data?	Misc.
Direct Observation	Poor	Poor	Poor	None	Medium	Yes	Hard to detect at low density
Multiple Pass Removal	Yes, sex, size, repro. status	Yes	Yes	Medium	Medium (If 2-3 passes)	No	Problems with depletion at low density and woody habitats
Mark-Recapture	Yes, sex, size, repro. status	Yes	Yes	High	High	No	Mark-recap. assumptions not always met

Direct Observation. There were definitely a few drawbacks with using direct observation to count shrimp. On Lagunitas Creek, snorkel efforts did not detect shrimp at low densities when they were present. Snorkel sampling was not much "cheaper" in terms of sampling time per habitat unit. A single pass snorkeling effort could take as long as 2-3 passes with a net. Also, even with a 6.5 mm wetsuit, only a few pools could be snorkeled by a single diver per day because of the cold waters. Finally, snorkel observations did not collect useful demographic data.

On the positive side, snorkeling efforts provided information regarding the location of shrimp and type of underwater habitat. Except when vegetation was overhanging into the water, shrimp were typically located along the periphery of pools in undercut banks with roots or overhanging vegetation. Rarely were any shrimp seen swimming in the water column or on the bottom of surveyed habitat units. Also, because no handling was involved, no injury or mortality to shrimp occurred. In addition, snorkeling efforts at the Gallager site resulted in the discovery of a native freshwater mussel (*Anodonta californiensis*), the California floater.

<u>Mark-Recapture</u>. This was the most time consumptive survey technique. While the multiple pass removal sampling could be done with a single netter per habitat unit, mark-recapture activities required at least 2 individuals-one netter and one individual to mark the shrimp and record the data. In addition, the mark-recapture sampling activities required sampling the same habitat units on two separate days.

This sampling technique had other limitations. The sampling activity could also increase the risk of handling injury because the shrimp have the potential for being captured twice. Also, our marking technique was not used on juveniles; therefore, we were unable to estimate the number of juveniles. Also, some of the assumptions required for mark-recapture estimates such as a closed population could not be validated.

<u>Multiple Pass Removal</u>. This survey technique seems to hold the most promise. It does not subject the sampler to hypothermia (as in snorkeling) and requires similar sampling effort if just 2-3 passes are done. It provides the added benefit of obtaining demographic information that snorkeling cannot accurately provide. However, multiple pass removal estimates were difficult when the rate of depletion was poor because of complex habitats (particularly those with instream woody materials) or when low densities of shrimp were present.

<u>Assessment of two-pass removal sampling</u>. The Marin Municipal Water District (MMWD) is required under the State Water Resources Control Board water rights decision (Order WR95-17) to implement several measures to protect sensitive aquatic life including the California freshwater shrimp in Lagunitas Creek. Stemming from this decision, MMWD prepared a long-term monitoring plan which includes monitoring provisions for the shrimp. This monitoring plan calls for the continuation of monitoring index reaches for shrimp using two-pass removal efforts (Trihey & Assoc. 1996).

Two-pass removal efforts might provide a reliable estimate of the total number shrimp found in the index reaches. The main advantages include reduced disturbance to listed shrimp and their habitat and reduced sampling time per habitat unit (when compared to >2 pass sampling and mark-recapture efforts). Just for the purposes of illustration (using data from 1997 and 1996), we can see how the shrimp estimates for 2 passes compare with the 3-5 pass efforts. Again, estimates have been generated by the Microfish program (Van Deventer and Platts 1988). The poor correspondence between the estimates for Site Serpa 6 result from poor depletion between 1st and 2nd passes. With the exception of this one site, most of the 2 pass estimates were within 20% of the estimate generated by >2 passes.

Site Name	Year	Passes	Estimate	Passes	Estimate	% Difference
Serpa 1	1996	2	20	4	22	-9
Serpa 2	1996	2	107	5	122	-12
Serpa 5	1996	2	24	5	22	9
Serpa 6	1996	2	169	5	87	94
Below Gallager	1997	2	21	3	25	-16
MP 19.94	1997	2	174	4	212	-18
Olema Creek above dam	1997	2	Undefined; total 2 pass catch=4	3	6	N.A.

Improved estimates could be developed by using a two-staged sampling design similar what is being used to obtain basin-wide estimates of fish abundance (Dollof *et al*, 1996).

RECOMMENDATIONS

1. Complete inventory of perennial low gradient streams within PORE and GOGA that could support the California freshwater shrimp including Bear Valley Creek, tributaries to Bolinas Lagoon and Lagunitas Creek, and Rodeo Creek.

2. Obtain technical review of MMWD's long-term monitoring plan to establish monitoring objectives for shrimp demographics, to determine abundance/distribution of shrimp over time within Lagunitas Creek drainage, and to establish a labor-efficient sampling program (e.g., two-staged sampling design).

ACKNOWLEDGEMENTS

Technical advice and field work was expertly provided by Larry Serpa, The Nature Conservancy. Field assistance was provided by Jeremy Clark, Bill Cox, CDFG, and Danette Woo, NPS (Pacific Great Basin Support Office).

LITERATURE CITED:

Dollof, C.A., D.G. Hankin, and G.H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. Gen. Tech. Rep. SE-83. USDA Forest Service Southeastern Forest Experiment Station, Asheville, NC. 25 p.

Donnelly, M.A. and C. Guyer. 1994. Mark-recapture. Pages 183-200. *In*: W.R. Heyer, M.A. Donnelly, R.W. McDiarmid, L.C. Hayek, and M.S. Foster (eds.). Measuring and monitoring biological diversity-standard methods for amphibians. Smithsonian Institution.

Fong, D. 1996 California Freshwater Shrimp (*Syncaris pacifica*) surveys within Point Reyes National Seashore and Golden Gate National Recreation Area. Unpublished report prepared for the U.S. Fish and Wildlife Service-Endangered Species Permits. 11 p.

Hellawell, J.M. 1978. Biological surveillance of rivers: a biological monitoring handbook. National Environment Research Council, Stevenage, England. 332 p.

Krebs, C.J. 1989. Ecological methodology. Harper & Row, New York, 654 p.

Li, S. 1981. Survey of the California freshwater shrimp, Syncaris pacifica, in Lagunitas Creek, Marin Co., California. Unpublished report prepared for the Marin Muncipal Water District.

Serpa, L. 1991. Survey of the California freshwater shrimp, Syncaris pacifica, in Lagunitas Creek, Marin Co., California. Unpublished report prepared for the Marin Municipal Water District. 28 pp.

Trihey & Associates, Inc. December 17, 1996. Aquatic resources monitoring workplan for the Lagunitas Creek drainage, Marin County, California. Unpublished final report prepared for the Marin Municipal Water District. 19 pp. +appendices.

Van Deventer, J.S. and W.S. Platts. 1988. User's guide for Microfish 3.0: a software package for processing electrofishing data obtained by the removal method. 40 p.

Appendix I: DATASHEET FOR INVENTORIES

Photo 1: Sampled shrimp pool, Lagunitas Creek at MP 19.94 (above Tocaloma), 11 Aug. 1997

Photo 2: Sampled shrimp pool, Lagunitas Creek at MP 12.91 (below Gallager), 12 Aug. 1997

Picture 3: Shrimp-bearing pool on Olema Creek (approx. 600 m above confluence with Lagunitas Creek), 15 Aug. 1997. Shrimp found in overhanging blackberry

Date	Location	Pass	Morph cond	No.	Length (mm)*	Recap?	Date	Location	Pass	Morph cond	No.	Length (mm)*	Recap?
8/12/97	MP 12.91	1	j	7	0	n	8/11/97	MP 19.94	1	j	1	15	n
8/12/97	MP 12.91	1	f	1	44	n	8/11/97	MP 19.94	1	j	1	15	n
8/12/97	MP 12.91	1	f	1	43	n	8/11/97	MP 19.94	1	j	1	14	n
8/12/97	MP 12.91	1	m	1	38	n	8/11/97	MP 19.94	1	j	1	16	n
8/12/97	MP 12.91	1	m	1	44	n	8/11/97	MP 19.94	1	j	1	17	n
8/12/97	MP 12.91	1	m	1	36	n	8/11/97	MP 19.94	1	j	1	14	n
8/12/97	MP 12.91	2	j	4	0	n	8/11/97	MP 19.94	1	j	1	14	n
8/12/97	MP 12.91	2	m	1	44	n	8/11/97	MP 19.94	1	j	1	14	n
8/12/97	MP 12.91	2	m	1	37	n	8/11/97	MP 19.94	1	j	1	14	n
8/12/97	MP 12.91	3	j	3	0	n	8/11/97	MP 19.94	1	j	1	15	n
8/12/97	MP 12.91	3	f	1	51	n	8/11/97	MP 19.94	1	j	1	15	n
8/12/97	MP 12.91	3	m	1	38	n	8/11/97	MP 19.94	1	j	1	17	n
8/16/97	MP 12.91	1	m	2	0	n	8/11/97	MP 19.94	1	j	1	14	n
8/16/97	MP 12.91	1	f	3	0	n	8/11/97	MP 19.94	1	j	1	14	n
8/16/97	MP 12.91	1	f	1	0	y	8/11/97	MP 19.94	1	j	1	17	n
8/16/97	MP 12.91	1	j	10	0	n	8/11/97	MP 19.94	1	j	1	14	n
8/16/97	MP 12.91	2	m	2	0	n	8/11/97	MP 19.94	1	j	1	18	n
8/16/97	MP 12.91	2	m	1	0	y	8/11/97	MP 19.94	1	j	1	12	n
8/16/97	MP 12.91	2	f	1	0	n	8/11/97	MP 19.94	1	j	1	9	n
8/16/97	MP 12.91	2	f	1	0	y	8/11/97	MP 19.94	1	j	1	11	n
8/16/97	MP 12.91	2	j	6	0	n	8/11/97	MP 19.94	1	j	1	16	n
8/16/97	MP 12.91	3	m	2	0	n	8/11/97	MP 19.94	1	f	1	48	n
8/16/97	MP 12.91	3	f	1	0	n	8/11/97	MP 19.94	1	f	1	53	n
8/16/97	MP 12.91	3	f	1	0	y	8/11/97	MP 19.94	1	f	1	51	n
8/16/97	MP 12.91	3	j	1	0	n	8/11/97	MP 19.94	1	f	1	43	n
8/11/97	MP 19.94	1	j	1	16	n	8/11/97	MP 19.94	1	f	1	54	n
8/11/97	MP 19.94	1	j	1	16	n	8/11/97	MP 19.94	1	f	1	46	n
8/11/97	MP 19.94	1	j	1	16	n	8/11/97	MP 19.94	1	f	1	50	n
8/11/97	MP 19.94	1	j	1	17	n	8/11/97	MP 19.94	1	f	1	51	n
8/11/97	MP 19.94	1	j	1	14	n	8/11/97	MP 19.94	1	f	1	46	n
8/11/97	MP 19.94	1	j	1	14	n	8/11/97	MP 19.94	1	m	1	41	n
8/11/97	MP 19.94	1	j	1	16	n	8/11/97	MP 19.94	1	m	1	41	n
8/11/97	MP 19.94	1	j	1	17	n	8/11/97	MP 19.94	1	m	1	46	n
8/11/97	MP 19.94	1	j	1	17	n	8/11/97	MP 19.94	1	m	1	36	n
8/11/97	MP 19.94	1	j	1	15	n	8/11/97	MP 19.94	1	m	1	43	n
8/11/97	MP 19.94	1	j	1	15	n	8/11/97	MP 19.94	1	m	1	41	n
8/11/97	MP 19.94	1	j	1	14	n	8/11/97	MP 19.94	1	m	1	49	n
8/11/97	MP 19.94	1	j	1	13	n	8/11/97	MP 19.94	1	m	1	39	n
8/11/97	MP 19.94	1	j	1	18	n	8/11/97	MP 19.94	1	m	1	38	n

Date	Location	Pass	Morph cond	No.	Length (mm)*	Recap?
8/11/97	MP 19.94	2	j	27	0	n
8/11/97	MP 19.94	2	f	1	53	n
8/11/97	MP 19.94	2	f	1	51	n
8/11/97	MP 19.94	2	f	1	47	n
8/11/97	MP 19.94	2	m	1	43	n
8/11/97	MP 19.94	2	m	1	47	n
8/11/97	MP 19.94	2	m	1	42	n
8/11/97	MP 19.94	2	m	1	44	n
8/11/97	MP 19.94	2	m	1	37	n
8/11/97	MP 19.94	2	m	1	42	n
8/11/97	MP 19.94	2	m	1	49	n
8/11/97	MP 19.94	2	m	1	42	n
8/11/97	MP 19.94	2	m	1	39	n
8/11/97	MP 19.94	2	m	1	41	n
8/11/97	MP 19.94	2	m	1	38	n
8/11/97	MP 19.94	2	m	1	40	n
8/11/97	MP 19.94	2	m	1	39	n
8/11/97	MP 19.94	2	m	1	37	n
8/11/97	MP 19.94	3	f	1	59	n
8/11/97	MP 19.94	3	f	1	55	n
8/11/97	MP 19.94	3	f	1	47	n
8/11/97	MP 19.94	3	f	1	44	n
8/11/97	MP 19.94	3	m	1	45	n
8/11/97	MP 19.94	3	m	1	43	n
8/11/97	MP 19.94	3	m	1	46	n
8/11/97	MP 19.94	3	m	1	39	n
8/11/97	MP 19.94	3	m	1	43	n
8/11/97	MP 19.94	3	m	1	43	n
8/11/97	MP 19.94	3	j	28	0	n
8/11/97	MP 19.94	4	f	1	54	n
8/11/97	MP 19.94	4	f	1	45	n
8/11/97	MP 19.94	4	f	1	54	n
8/11/97	MP 19.94	4	u	1	0	n
8/11/97	MP 19.94	4	j	8	0	n
8/11/97	MP 19.94	4	m	1	41	n
8/12/97	MP 19.94	1	f	1	47	n
8/12/97	MP 19.94	1	f	1	45	n
8/12/97	MP 19.94	1	f	1	47	n
8/12/97	MP 19.94	1	f	1	50	n
8/12/97	MP 19.94	1	f	1	46	n

Date	Location	Pass	Morph cond	No.	Length (mm)*	Recap?
8/12/97	MP 19.94	1	f	1	45	n
8/12/97	MP 19.94	1	f	1	44	n
8/12/97	MP 19.94	1	f	1	50	n
8/12/97	MP 19.94	1	f	1	48	n
8/12/97	MP 19.94	1	f	1	52	y
8/12/97	MP 19.94	1	m	1	40	n
8/12/97	MP 19.94	1	m	1	36	n
8/12/97	MP 19.94	1	m	1	40	n
8/12/97	MP 19.94	1	m	1	43	n
8/12/97	MP 19.94	1	m	1	45	n
8/12/97	MP 19.94	1	m	1	46	n
8/12/97	MP 19.94	1	m	1	42	n
8/12/97	MP 19.94	1	m	1	44	n
8/12/97	MP 19.94	1	m	5	0	y
8/12/97	MP 19.94	1	j	57	0	n
8/12/97	MP 19.94	2	f	1	0	y
8/12/97	MP 19.94	2	f	1	43	n
8/12/97	MP 19.94	2	f	1	49	n
8/12/97	MP 19.94	2	f	1	49	n
8/12/97	MP 19.94	2	f	1	43	n
8/12/97	MP 19.94	2	m	2	0	y
8/12/97	MP 19.94	2	m	1	37	n
8/12/97	MP 19.94	2	m	1	39	n
8/12/97	MP 19.94	2	m	1	40	n
8/12/97	MP 19.94	2	m	1	41	n
8/12/97	MP 19.94	2	m	1	41	n
8/12/97	MP 19.94	2	m	1	40	n
8/12/97	MP 19.94	2	j	23	0	n
8/12/97	MP 19.94	3	f	1	50	n
8/12/97	MP 19.94	3	f	1	0	y
8/12/97	MP 19.94	3	m	1	42	n
8/12/97	MP 19.94	3	j	13	0	n
8/12/97	MP 19.94	4	f	1	43	n
8/12/97	MP 19.94	4	f	1	41	n
8/12/97	MP 19.94	4	m	1	0	y
8/12/97	MP 19.94	4	j	5	0	n
8/18/97	Olema Crk above dam	1	j	1	19	n

APPENDIX III: RAW SHRIMP DATA BY LOCALE (LENGTH=ROSTRUM TO TELSON)

Date	Location	Pass	Morph cond	No.	Length (mm)*	Recap ?
8/18/97	Olema Crk above dam	1	j	1	18	n
8/18/97	Olema Crk above dam	1	f	1	44	n
8/18/97	Olema Crk above dam	1	m	1	39	n
8/18/97	Olema Crk above dam	3	m	1	45	n
8/18/97	Olema Crk above dam	3	j	1	17	n

APPENDIX IV - MICROFISH (VERS 3.0) OUTPUT

Stream: olema above old dam
Species: adult 8/18/97

Removal Pattern: 2 0 1
Total Catch = 3
Population Estimate = 3

Chi Square = 2.516
Pop Est Standard Err = 0.709
Lower Conf Interval = 3.000
Upper Conf Interval = 6.050

Capture Probability = 0.600
Capt Prob Standard Err = 0.354
Lower Conf Interval = -.925
Upper Conf Interval = 2.125

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was -5.002093E-02 .

Stream: olema above old dam
Species: juvenile 8/18/97

Removal Pattern: 2 0 1
Total Catch = 3
Population Estimate = 3

Chi Square = 2.516
Pop Est Standard Err = 0.709
Lower Conf Interval = 3.000
Upper Conf Interval = 6.050

Capture Probability = 0.600
Capt Prob Standard Err = 0.354
Lower Conf Interval = -.925
Upper Conf Interval = 2.125

The population estimate lower confidence interval was set equal
to the total catch. Actual calculated lower CI was -5.002093E-02 .

Stream: olema above old dam
Species: total shrimp 8/18/97

Removal Pattern: 4 0 2
Total Catch = 6
Population Estimate = 6

Chi Square = 5.031
Pop Est Standard Err = 1.002
Lower Conf Interval = 6.000
Upper Conf Interval = 8.577

Capture Probability = 0.600
Capt Prob Standard Err = 0.251
Lower Conf Interval = -.044
Upper Conf Interval = 1.244

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 3.422797 .

Stream: lagunitas below gallager
Species: adult 8/12/97

Removal Pattern: 5 2 2
Total Catch = 9
Population Estimate = 9

Chi Square = 1.574
Pop Est Standard Err = 1.228
Lower Conf Interval = 9.000
Upper Conf Interval = 11.831

Capture Probability = 0.600
Capt Prob Standard Err = 0.205
Lower Conf Interval = 0.128
Upper Conf Interval = 1.072

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 6.168925 .

Stream: Lagunitas below Gallager

Species: juvenile 8/12/97

Removal Pattern: 7 4 3
Total Catch = 14
Population Estimate = 16

Chi Square = 0.404
Pop Est Standard Err = 3.564
Lower Conf Interval = 14.000
Upper Conf Interval = 23.595

Capture Probability = 0.467
Capt Prob Standard Err = 0.195
Lower Conf Interval = 0.051
Upper Conf Interval = 0.882

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 8.404965 .

Stream: lagunitas below gallager
Species: total shrimp 8/12/97

Removal Pattern: 12 6 5
Total Catch = 23
Population Estimate = 27

Chi Square = 0.564
Pop Est Standard Err = 5.077
Lower Conf Interval = 23.000
Upper Conf Interval = 37.438

Capture Probability = 0.451
Capt Prob Standard Err = 0.154
Lower Conf Interval = 0.133
Upper Conf Interval = 0.769

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 16.5622 .

Stream: lagunitas below gallager
Species: adult 8/16/97

Removal Pattern: 6 5 4
Total Catch = 15
Population Estimate = 22

Chi Square = 0.288
Pop Est Standard Err = 11.442
Lower Conf Interval = 15.000
Upper Conf Interval = 45.800

Capture Probability = 0.306
Capt Prob Standard Err = 0.229
Lower Conf Interval = -.171
Upper Conf Interval = 0.783

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was -1.799635 .

Stream: lagunitas below gallager
Species: juvenile 8/16/97

Removal Pattern: 10 6 1
Total Catch = 17
Population Estimate = 17

Chi Square = 1.689
Pop Est Standard Err = 1.028
Lower Conf Interval = 17.000
Upper Conf Interval = 19.180

Capture Probability = 0.680
Capt Prob Standard Err = 0.129
Lower Conf Interval = 0.407
Upper Conf Interval = 0.953

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 14.81965 .

Stream: lagunitas below gallager
Species: total shrimp 8/16/97

Removal Pattern: 16 11 5

Total Catch = 32
Population Estimate = 37

Chi Square = 0.470
Pop Est Standard Err = 5.297
Lower Conf Interval = 32.000
Upper Conf Interval = 47.742

Capture Probability = 0.471
Capt Prob Standard Err = 0.127
Lower Conf Interval = 0.213
Upper Conf Interval = 0.729

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 26.25781 .

Stream: Lagunitas MP19.94
Species: Adult 8/11/97

Removal Pattern: 18 17 10 5
Total Catch = 50
Population Estimate = 61

Chi Square = 1.431
Pop Est Standard Err = 8.523
Lower Conf Interval = 50.000
Upper Conf Interval = 78.047

Capture Probability = 0.342
Capt Prob Standard Err = 0.090
Lower Conf Interval = 0.163
Upper Conf Interval = 0.522

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 43.95326 .

Stream: Lagunitas MP 19.94
Species: juvenile 8/11/97

Removal Pattern: 79 27 28 8
Total Catch = 142

Population Estimate = 151

Chi Square = 7.822
Pop Est Standard Err = 4.886
Lower Conf Interval = 142.000
Upper Conf Interval = 160.674

Capture Probability = 0.498
Capt Prob Standard Err = 0.045
Lower Conf Interval = 0.408
Upper Conf Interval = 0.588

The population estimate lower confidence interval was set equal
to the total catch. Actual calculated lower CI was 141.326 .

Stream: Lagunitas MP19.94
Species: total shrimp 8/11/97

Removal Pattern: 97 44 38 13
Total Catch = 192
Population Estimate = 211

Chi Square = 4.828
Pop Est Standard Err = 7.845
Lower Conf Interval = 195.546
Upper Conf Interval = 226.454

Capture Probability = 0.450
Capt Prob Standard Err = 0.041
Lower Conf Interval = 0.369
Upper Conf Interval = 0.530

Stream: Lagunitas MP19.94
Species: Adult 8/12/97

Removal Pattern: 23 13 4 3
Total Catch = 43
Population Estimate = 44

Chi Square = 1.038

Pop Est Standard Err = 1.801
Lower Conf Interval = 43.000
Upper Conf Interval = 47.633

Capture Probability = 0.558
Capt Prob Standard Err = 0.078
Lower Conf Interval = 0.401
Upper Conf Interval = 0.716

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 40.36652 .

Stream: Lagunitas MP 19.94
Species: juvenile 8/12/97

Removal Pattern: 57 23 13 5
Total Catch = 98
Population Estimate = 101

Chi Square = 0.581
Pop Est Standard Err = 2.647
Lower Conf Interval = 98.000
Upper Conf Interval = 106.251

Capture Probability = 0.563
Capt Prob Standard Err = 0.051
Lower Conf Interval = 0.462
Upper Conf Interval = 0.665

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 95.7486 .

Stream: Lagunitas MP19.94
Species: total shrimp 8/12/97

Removal Pattern: 80 36 17 8
Total Catch = 141
Population Estimate = 147

Chi Square = 0.040
Pop Est Standard Err = 3.602

Lower Conf Interval = 141.000
Upper Conf Interval = 154.131

Capture Probability = 0.544
Capt Prob Standard Err = 0.043
Lower Conf Interval = 0.459
Upper Conf Interval = 0.630

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 139.869 .