Striped Bass Predation on Juvenile Chinook Salmon in the Mokelumne River

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Abstract
Juvenile Chinook salmon were identified in the stomachs of striped bass collected in the Mokelumne River between Woodbridge Dam and the confluence of the North and South Mokelumne Rivers, from June 1993 through January 2001. The number of juvenile Chinook salmon per striped bass was far higher from bass collected in the afterbay below Woodbridge Dam (1.6) than in the 58km of river below the afterbay (0.03). Juvenile Chinook salmon were the largest component in the diets of striped bass collected in the afterbay, making up 50.6% of the number of all prey items identified and 75.5% of the volume, but were the 6th and 5th largest components by frequency (1.3%) and volume (1.9%) respectively, in all river reaches downstream of the afterbay. The catch-per-unit of sampling effort for striped bass was over an order of magnitude higher in the Woodbridge Afterbay (0.027fish/s) than in any of the survey sites below the afterbay (0.0019fish/s). Striped bass abundance was estimated between 200 and 500 fish in the afterbay from SCUBA surveys conducted in May of 1993. Juvenile salmon losses associated with striped bass predation in the afterbay were estimated from a model based on striped bass densities, stomach contents, digestion rates and associated water temperatures. A model run using only positively identified salmon from striped bass stomachs collected in 1993 indicates between 19,824 and 49,560 salmon were lost in the afterbay that year (11% to 28% of the estimated natural production in the Mokelumne River). Adding prey items suspected of being salmon increased the loss estimate by 53.8%, where up to 92,120 salmon (51% of the natural production) could have been lost. Striped bass were first documented above Woodbridge Dam in 2007, indicating striped bass have found a way past the new dam. Annual video monitoring indicates a few striped bass enter the new fish ladder each year, but suggests upstream passage may only be occurring through the bays of the dam and only under certain operating conditions.

INTRODUCTION

The seaward migration of Fall-run Chinook salmon *Oncorhynchus tshawytscha* smolts from the major Central Valley tributaries each spring coincides with the spawning migration of striped bass *Morone saxatilis* (STB) from the ocean and the San Francisco Estuary into these tributaries (Moyle 2002), providing the opportunity for STB to prey on salmon smolts. Relatively little is known about the rate of predation so it is unclear how serious this problem is for salmon populations in Central Valley tributaries, including the Mokelumne River.

The STB is native to the east coast of North America, and was introduced into California in 1879 and 1882. They are now widely distributed on the west coast from northern Mexico to southern British Columbia, though the main breeding population is still in the San Francisco Estuary (Moyle 2002). Striped bass became abundant enough to support a sizable commercial fishery for many years and still supports a large sport fishery (White 1986). This predatory species tends to form and move in groups, which apparently aids them in locating and capturing prey. Striped bass eat a wide variety of invertebrates and fishes (Schaefer 1970; Rulifson and McKenna 1987) including salmonids (Shapovalov 1936; Morgan and Gerlach 1950; Thomas1967). Striped bass predation on Atlantic salmon smolts has been documented in Chesapeake Bay and Hudson River by Blackwell and Juanes (1998); on Chinook salmon smolts on the Pacific Coast by Morgan and Gerlach (1950) and Johnson et al. (1992), in the Sacramento River, at Red Bluff Diversion Dam by Villa (DFG internal memo 1985) and in the Mokelumne River by Boyd (1994). Adult STB on the east coast spend most of their lives foraging in the ocean, which is in contrast to California STB that spend most of their lives foraging in San Francisco and San Pablo bays (Moyle 2002). Adult STB generally move into freshwater in the fall, spend winter in the Delta, and migrate up Central Valley tributaries (including the Mokelumne River) in the spring. The spawn in freshwater before moving back to salt water bays (Moyle 2002).

The first major impoundment of the Mokelumne River was completed in 1888 near the present site of Woodbridge Dam. The dam has since then been rebuilt in 1901, 1910 and 2001. Historically the river was backed up each spring to meet demand for irrigating crops and drawn down each fall when demand ceased. The dam had no fish ladder until 1925. This was replaced 23 years later in 1948 with a more effective structure. This was later modified to provide ladder passage when the reservoir was drawn down. A Denil fishway was added in 1972 to aid steelhead passage. Both the dam and the fish ladder were replaced in 2001.

The ladders and fishway provided access to the river above Woodbridge Dam for salmon, steelhead and other resident fishes, but despite frequent reports of striped bass seen or caught below the dam, no documented instances of STB occurring above the dam have been found prior to 2006. It seems likely all these structures were barriers to STB passage for most if not all years prior to 2006, when East Bay Municipal Utility District (EBMUD) staff collected 7 from 5 electro-fishing sites located upstream of the dam, in

May. No other STB have been collected above the dam in the quarterly electro-fishing surveys to date.

EBMUD began monitoring fish passage at Woodbridge Dam in 1993 and reported STB actively feeding on juvenile Chinook salmon in the Woodbridge Dam Afterbay that year. A preliminary angling survey was conducted by EBMUD staff, followed up by a series of angling surveys conducted by CDFG. The results sparked interest in STB predation in the lower river, and resulted in a series of angling and electro-fishing surveys at multiple sites in the study area.

The study area includes the Mokelumne River from Woodbridge Dam downstream for about 56km to the confluence of the South and North Mokelumne Rivers (Figure 1), and is located in Northern San Joaquin and Southern Sacramento Counties. From Woodbridge Dam the river runs northwest for 25.3 km to the Cosumnes River Confluence near the town of Thornton, then west 6.9 km to New Hope Landing where it splits into the North (16.1 km) and South (25.3 km) Mokelumne Rivers. The rivers turn south and reunite about 1.6 km upstream of the Highway 12 Bridge.

The entire study area is a low gradient, sand bed, alluvial river channel. Most of the river in the study area is confined by levees that severely limit the amount of flood plain. Rip rap is a common bank feature in the reach between Woodbridge Dam and the Cosumnes River confluence, and is the dominant bank feature in the study reach below the Cosumnes River confluence. The study reach downstream of Peltier Road Bridge is under year-round tidal influence, though tidal influence extends upstream to Woodbridge Dam during the winter months.

OBJECTIVES:

(1) Assess the relative abundance of all prey items found in the stomachs of STB in the Lower Mokelumne River.

(2) Determine whether the contribution of smolts to the diet of STB captured in the Woodbridge Dam afterbay (Figure 2), differs from the contribution of smolts to the diets of STB captured elsewhere in the lower river and Delta.

(3) Determine whether STB abundance differs spatially among various sites in the lower river and/or seasonally within sampling sites in the lower river.

(4) Estimate salmon smolt losses in the afterbay below Woodbridge Dam associated with STB predation.

METHODS

The data used for these analyses was the product of 98 fisheries surveys conducted by East Bay Municipal Utility District (EBMUD) and California Department of Fish and Game (CDFG) biologists on the Mokelumne River between May, 1993 and August, 2001. Collection methods include angling (n = 15), electro-fishing (n = 82), and gill netting (n = 1). Sampling sites included Woodbridge Dam Afterbay, Feiste property, Cosumnes River mouth, upstream of New Hope Landing, Deadhorse Cut, combined sites in the North Mokelumne River, and combined sites in the South Mokelumne River. All sampling occurred between 0900 and 1500hr. Captured fish were identified and fork lengths (FL) were measured to the nearest mm. Striped bass captured during early surveys were killed to allow removal of the entire stomach for analysis, and to determine the sex ratio of the bass population. Gastric lavage was used to collect stomach contents during later surveys. Stomach samples were drained through a 0.246mm mesh sieve, placed into plastic sample bags, labeled and preserved in an 80 to 85% solution of ethanol. The bags were packed in ice in the field and taken to the laboratory for storage and analysis.

Electro-fishing surveys were conducted using a 5.5 m electro-fishing boat manufactured by Smith Root, Inc. (Vancouver, WA). Representative habitats from each reach were sampled quarterly from 1998 through July 2001. The catch-per-unit-effort (CPUE) was calculated for all electro-fishing surveys as the count of striped bass captured on a particular survey divided by the sampling time, in seconds.

Random surveys were conducted with hook and line at all sample sites in the study area by 2-3 anglers using 7.5 cm to 15.3 cm lures resembling small fish. The duration of angling surveys was from 0.5 h to 2 h.

The contents of 278 stomachs were analyzed in the lab following procedures established by Bowen (in Nelson and Johnson 1983). All prey items were keyed to species when possible. Prey organisms and parts thereof, were identified and sorted into the lowest taxonomic groupings possible and enumerated based on the number of like parts of a given organism type found in the sample. Prey volume was determined by blotting surface moisture from prey organisms with paper towels and measuring to the nearest ml, the volume of water displaced by prey items in a graduated cylinder.

The food habits analyses used data from angling and electro-fishing surveys conducted between 1998 and 2001. Catch-per-unit-effort was calculated using only the electro-fishing data. Visual inspection of gonads was used to determine sex ratio from angling data collected in June of 1993.

Daily losses of juvenile salmon were estimated as the product of the estimate of STB abundance and numbers of salmon smolts consumed per STB. Logistical constraints limited the variety and effectiveness of available methods to precisely estimate STB abundance at any of the sample sites. A realistic range of abundance was developed for the Woodbridge Dam afterbay based on a SCUBA survey conducted on 27 May 1993, and supported by harvest rates recorded during an angling survey, daily observation of anglers catching STB in the afterbay and from 7 angling surveys conducted in 1993 on 27 May and 3, 4, 10, 13, 15, 16 June, by California Department of Fish and Game, with help from EBMUD Fisheries and Wildlife staff.

The daily predation rate estimated in the Woodbridge Dam afterbay and reported by Boyd (1994), followed methods developed by Johnson et.al. (1992) to estimate the consumption of juvenile salmon per predator: C = KA, where (C) is the daily consumption, (K) is the turnover coefficient (24h/n, the number of hours for complete gastric evacuation based on average monthly water temperature), and (A) is the average stomach content. Turnover coefficients were developed by Bajkov (1935) by measuring stomach evacuation rates of Chinook salmon smolts in the stomachs of STB at various water temperatures. The coefficient was shifted from 33h to 24h, at 15˚C, to reflect that identification of a food item ceases to be possible before complete evacuation has occurred. Water temperatures were recorded hourly in the afterbay using a Ryan Model RTM 2000 thermograph (Ryan Instruments, Inc., Redmond Washington). Average consumption of salmon/STB was determined from stomach samples collected during all angling, electro-fishing and gill net surveys at this site.

Daily juvenile salmon abundance was estimated from data generated by Vogel Environmental Services (VES) using an Archimedes rotary screw trap operating in the pool at the base of Woodbridge Dam (Vogel and Marine 1994).

RESULTS
The 98 surveys conducted in the study area consisted of 31 surveys in the afterbay at the base of the old Woodbridge Dam, and 67 surveys at various locations in the lower river. Sampling in the afterbay yielded 376 STB and sampling at various locations in the lower river yielded 97 STB.

The fork lengths of STB caught in the Woodbridge Dam Afterbay is distributed fairly normally around the mean of 438 mm (Figure 3). The fork lengths of STB caught at all sites downstream of the afterbay are skewed toward juvenile fish with a mean of 360 mm (Figure 4).

<u>Diets</u>
Food items were found in 215 of 278 (77.3%) stomach samples collected. Several stomachs contained prey items too digested to identify to species. Some could be keyed to Family and others to Order. Plant matter was not uncommon in stomach samples and was treated as an incidental item STB swallowed while foraging for target species. A fair number of zooplankton (mostly daphnia) was observed in one STB stomach. The zooplankton appeared to be the stomach contents of a prey item that were regurgitated shortly after the prey item was swallowed by the STB.

Juvenile Chinook salmon were the most frequent prey item in the diets of STB captured in the Woodbridge Dam Afterbay, comprising 51.3% of all organisms. They were followed by unidentified fish suspected of being salmon (20.6%), other unidentified fish

(12.3%), crayfish (8.0%), insects (3.4%), centrarchids (2.1%), cottids (1.0%), with Pacific lamprey, cyprinids, steelhead/rainbow trout, and juvenile STB combined (1.2%). Juvenile salmon also ranked first in importance by volume, making up 75.7% of the total volume (Figure 5).

Unidentified fish were the most numerous prey item found in STB stomachs collected from all survey sites except the Woodbridge Afterbay, making up 28.6% of all prey items, followed by clams (20.8%), unidentified shad (15.6%), threadfin shad (11.7%), crayfish (9.1%), Chinook salmon (5.2%), STB (2.6%), Sacramento sucker (2.6%), Pacific lamprey (2.6%). Juvenile salmon ranked 6^{th} in importance by frequency and 5^{th} in importance by volume, making up 1.9% of the total volume (Figure 6).

Mean STB catch-per-unit-effort (CPUE) for electro-fishing surveys conducted between Jan 99 and Jul 01 was an order of magnitude greater in the Woodbridge Dam Afterbay than at any of the other sample sites (Table 1). The highest CPUE rates were observed in the second and third quarters of the year, when water temperatures were highest with survey temperatures ranging between 13˚ and 24.4˚ C.

In 2007, a small number of STB were observed in the fish ladder, passing back and forth in the front of the camera. It appears none used the ladder to pass the dam in the upstream direction, but the number of STB passing the camera in the downstream direction exceeded the number passing in the upstream direction by two fish, indicating STB can pass the new dam using the ladder in the downstream direction. The low numbers of STB seen in the new ladder and captured in electro-fishing surveys above the dam indicate the new dam and fish ladder greatly impede STB passage.

No STB fry have been reported caught in Archimedes screw traps annually deployed at the base of Woodbridge Dam, so it's unlikely that any spawning activity has occurred upstream of the dam.

<u>Smolt Losses</u>

The stomach content data of 153 STB, collected from the afterbay in April and May, 1993 were used to estimate the mean number of salmon consumed per striped bass. Food items were found in 120 (78.4%) of the stomachs. Juvenile salmon were positively identified in 79 (51.6%) of the stomachs examined (n = 250). The occurrence of salmon ranged from 0 to 28 per stomach, with a mean consumption of 1.77 juvenile salmon/STB. This consumption rate produces a range of estimated juvenile salmon losses of 19,824 to 49,560 fish, representing between 11% and 27.5% of the total natural production estimate for that year. Nine stomachs contained 214 partially digested fish strongly suspected of being salmon as well. Inclusion of these data increases mean consumption to 3.29 salmon/STB and pushes the loss estimate to 92,120 fish (Figure 7). This represents 51.1% of the natural production and is comparable to salmon losses reported by Hallock (1987) associated with Sacramento pikeminnow and STB predation at the Red Bluff Diversion Dam.

Four angling surveys were conducted between 3 June 1993 and 19 June 1993 where 59 STB were collected in the Woodbridge Dam Afterbay, including 35 females (mean FL =

640 mm), 20 males (mean FL = 610 mm), and 4 unknown (mean FL = 450 mm). Nearly all were in spawning condition. The average monthly water temperature was nearly optimal for STB spawning at 15.5˚C, though there have been no reports of spawning activity in the afterbay.

DISCUSSION

Juvenile Chinook salmon are being preyed upon by STB throughout the study area and predation rates in the afterbay below the old dam at Woodbridge were elevated to extreme levels. It appears STB quickly move upstream to the base of Woodbridge Dam when outmigrating fish are present. The latest Dam at Woodbridge includes features designed to reduce potential predation problems there. Parts of the afterbay were filled to reduce the potential for STB to use it for cover. The new fish friendly bladder dam design is expected to reduce predation by reducing the potential for outmigrating salmon to be injured or disoriented as they pass the dam. The outfall for the bypass pipe was relocated so that fish being diverted away from the front of the diversion screens are shunted to an area in the river below the dam thought to be less conducive to predation than the old outfall located within the old fish ladder.

The higher CPUE of STB captured in the Woodbridge Dam Afterbay indicates STB congregate there. The larger mean size, of STB found in the afterbay, indicates adult fish tend to congregate there more often. The STB presumably congregate in the afterbay for three reasons: 1) Woodbridge Dam impedes upstream progress to spawning or feeding areas, 2) The afterbay provides cover for large fish in an otherwise shallow, exposed reach of the river above tidal influence, and 3) The seasonal abundance of outmigrating juvenile salmon and steelhead in the river coupled with downstream passage problems associated with the old dam create conditions that make it easy for STB to catch juvenile salmonids there (see Vogel 2000). The smaller mean size and year-round presence of STB in the river below tidal influence suggests juvenile STB use this area for some portion of their juvenile life stage.

The first documented evidence of STB above Woodbridge Dam came in 2007 during an Electro-fishing survey. Their presence indicated some STB found a way past the new dam this year. Annual video monitoring indicates a few STB enter the new fish ladder each year, but suggests upstream passage is only possible through the bays of the dam and only under certain operating conditions.

An additional electro-fishing survey conducted in the afterbay on 11/5/98 was aborted after 29s to avoid negative impacts to adult salmon and yearling salmon that were present. The survey was conducted while the hatchery was releasing about 4 loads of yearling salmon per day, below the dam. The sampling was done at the plant site, shortly after a release of fish. Fish netted during the sampling include 1 adult salmon (78cm FL), 11 yearling salmon (7cm to 21cm FL), 8 STB (30cm to 90cm FL) and two largemouth bass (12cm and 28 cm FL). Additionally, an estimated 3000 juvenile salmon, 20 adult salmon and 49 adult STB were observed but not netted. Complete surveys were conducted at 5 sites downstream of the afterbay that week and only 2 STB were captured.

This fall-time congregation of STB in the afterbay indicates the predation is more than the result of coincidental encounters between these two species during the STB spawning migration and the salmon outmigration. It suggests STB in the Delta are sensitive to juvenile salmon outmigrating from the Mokelumne River and are quickly drawn up river following the “trail” of outmigrating fish. Woodbridge impedes their upstream progress so they collect at the base of the dam and stay as long as sufficient food, water quality and cover are available.

Elevated predation rates on outmigrating salmonids are not uncommon at engineered structures in other river systems (Warner and Kynard 1986; Liston et.al.1994). The entire range of estimated losses of Mokelumne River natural salmon production in 1993, at a single location in a river system, is very high and warrants looking at measures to reduce these losses. Striped bass predation at the base of the new dam should be evaluated to document any reduction in predation associated with the new dam, and to identify any opportunities to reduce predation further.

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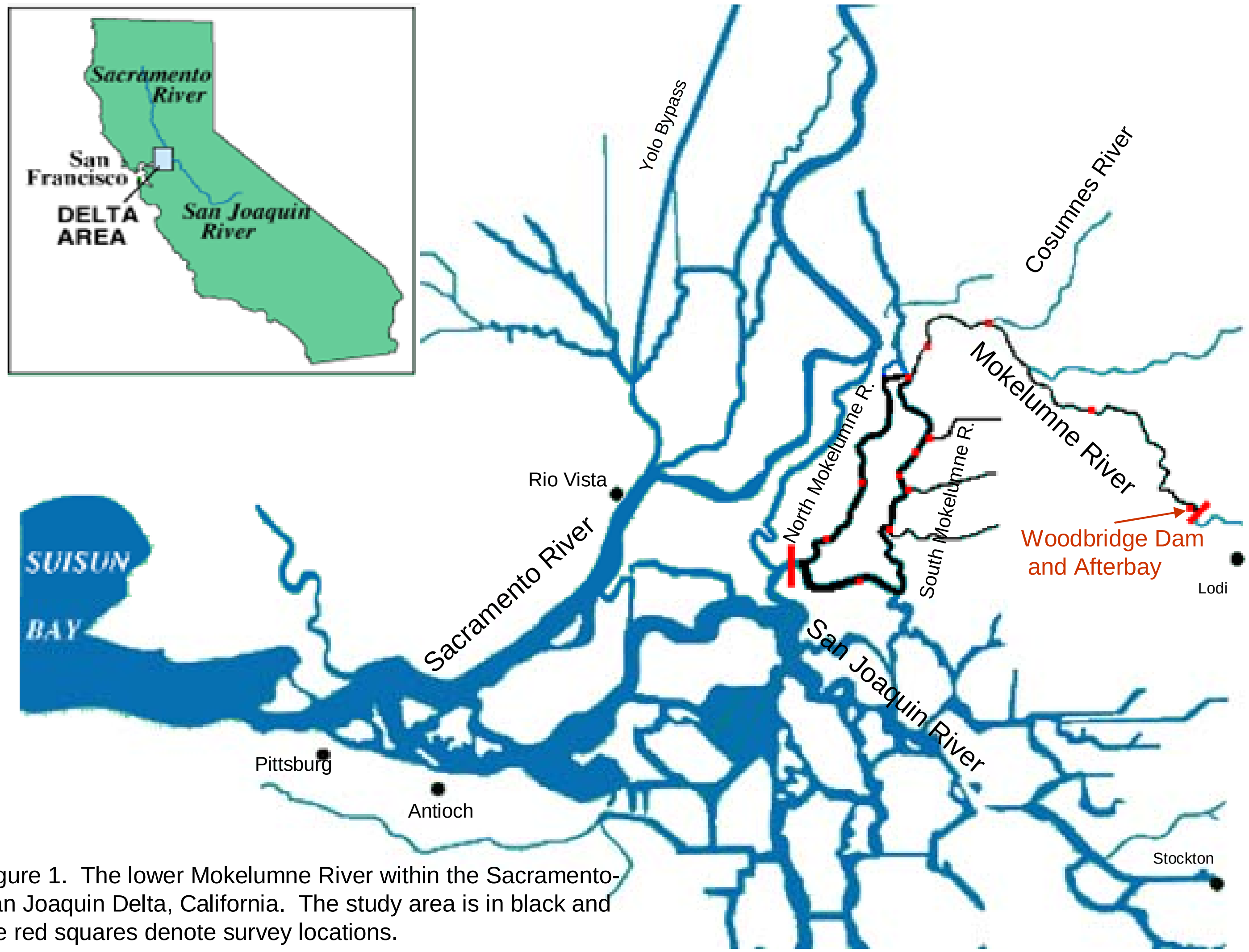


Figure 1. The lower Mokelumne River within the Sacramento-San Joaquin Delta, California. The study area is in black and the red squares denote survey locations.

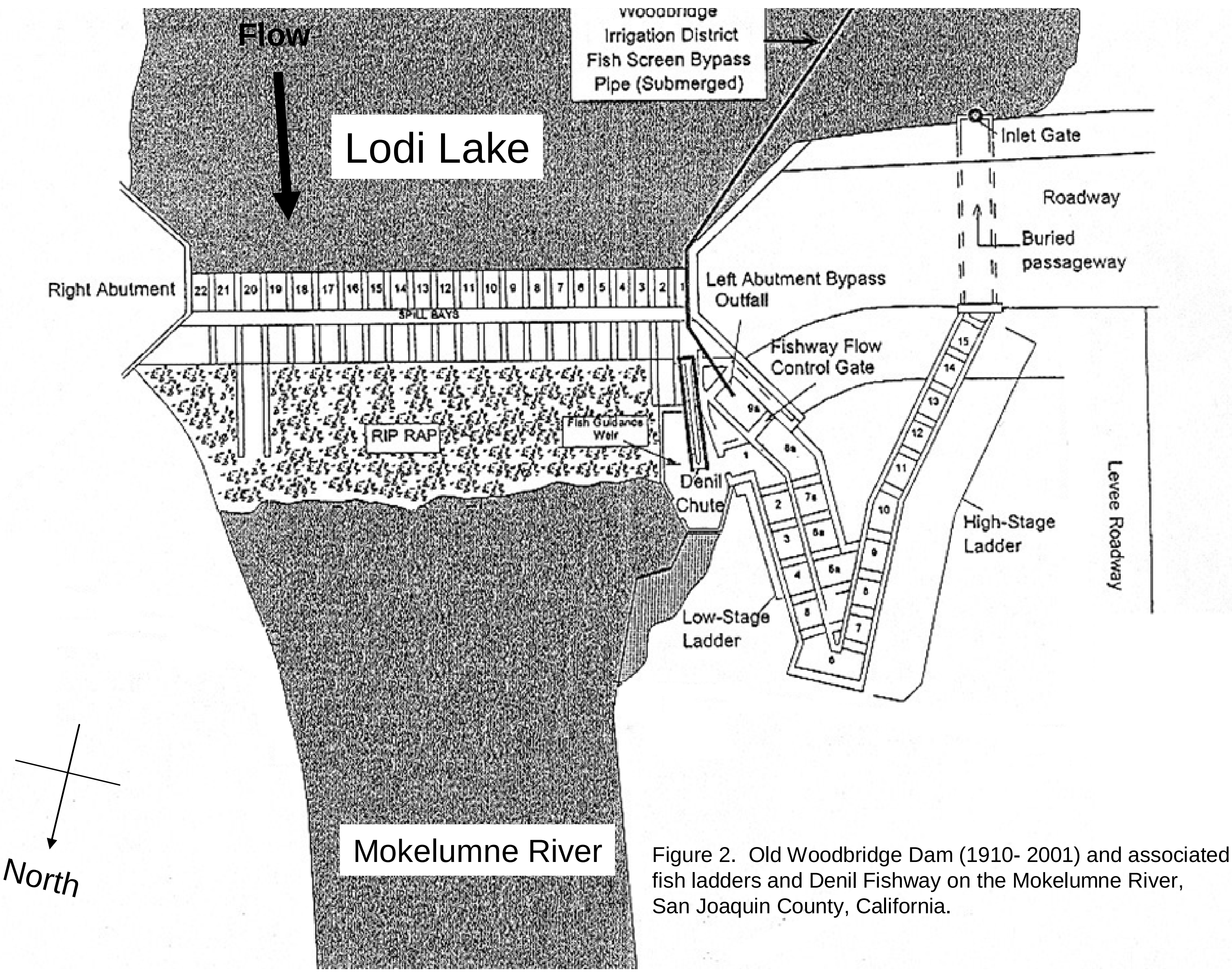


Figure 2. Old Woodbridge Dam (1910- 2001) and associated fish ladders and Denil Fishway on the Mokelumne River, San Joaquin County, California.

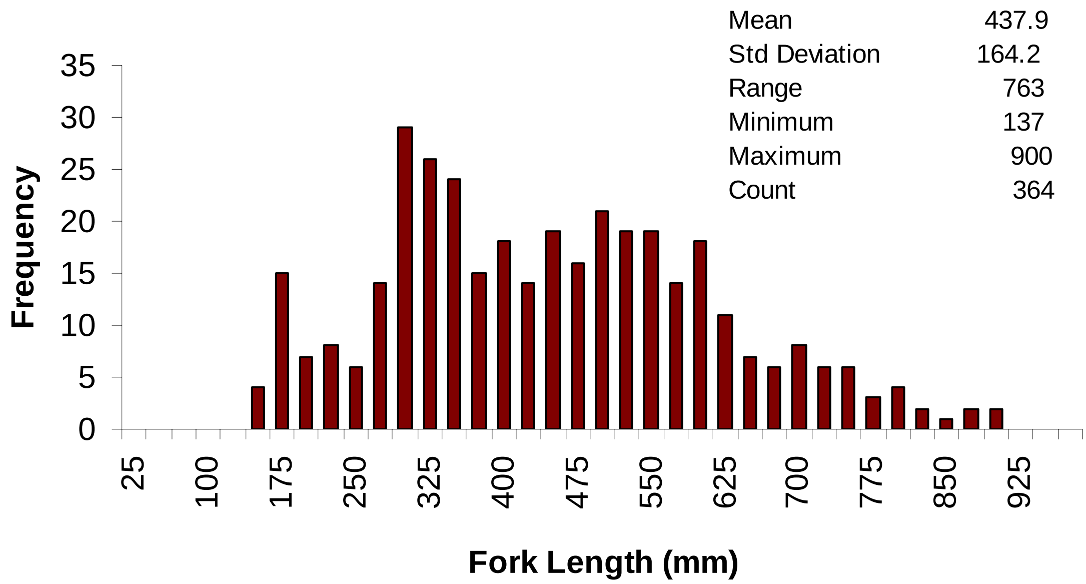


Figure 3. Fork lengths of striped bass captured in the Woodbridge Dam afterbay on the Mokelumne River between June 1993 and August 2001.

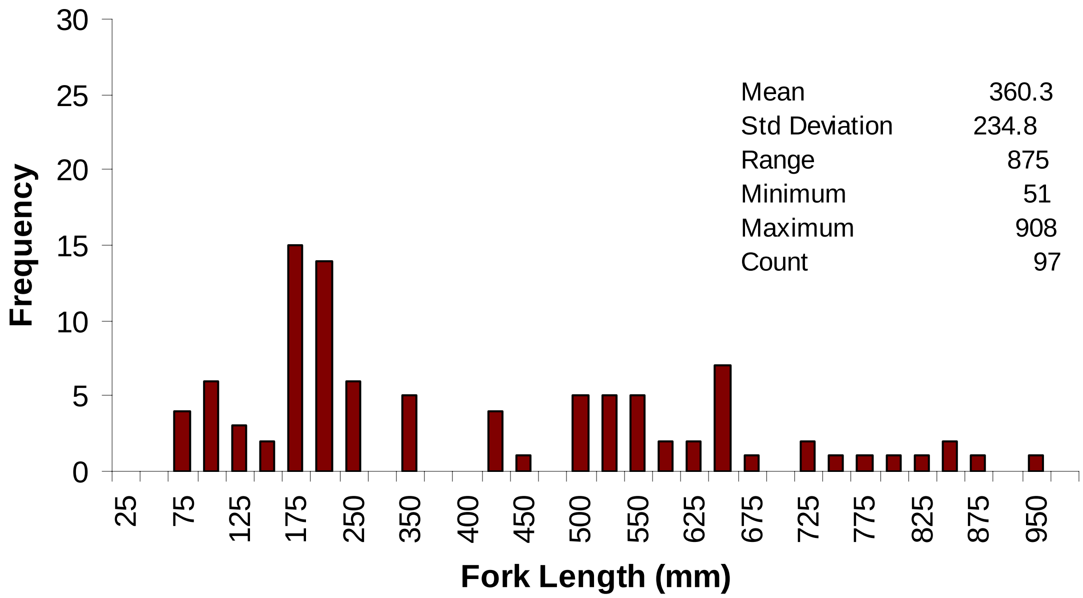
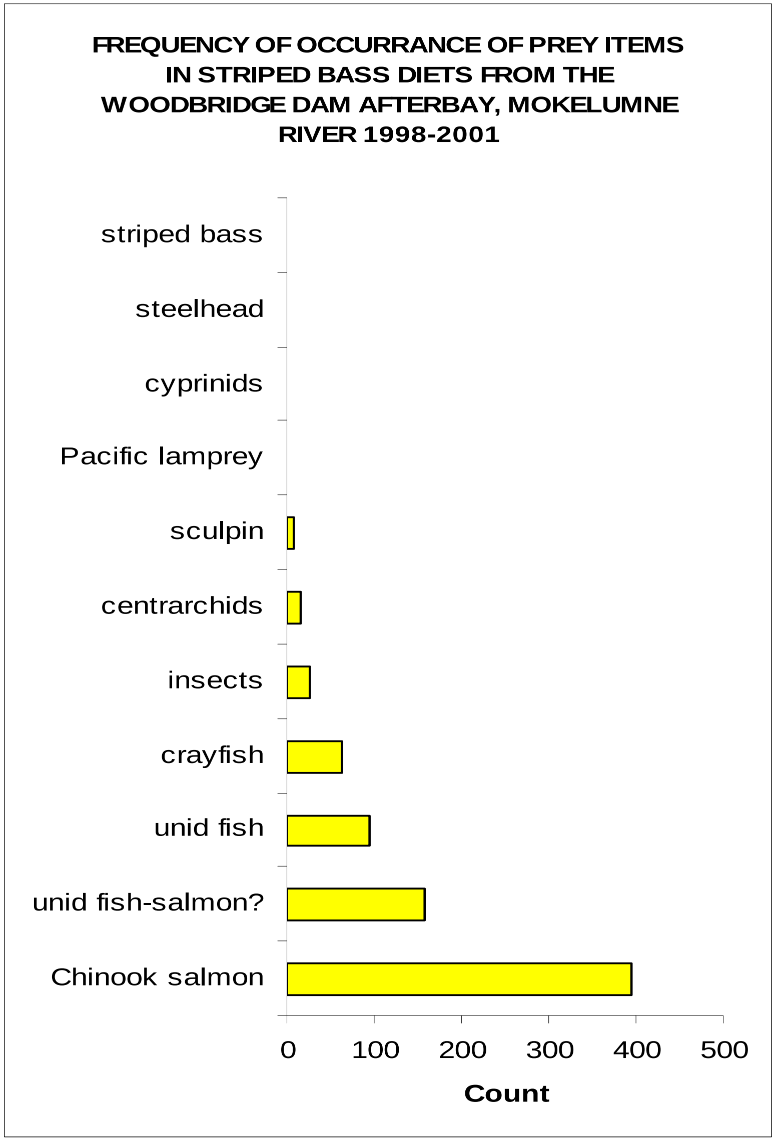


Figure 4. Fork lengths of striped bass caught at various sample sites downstream of the Woodbridge Dam afterbay in the Mokelumne River between June 1993 and August 2001.



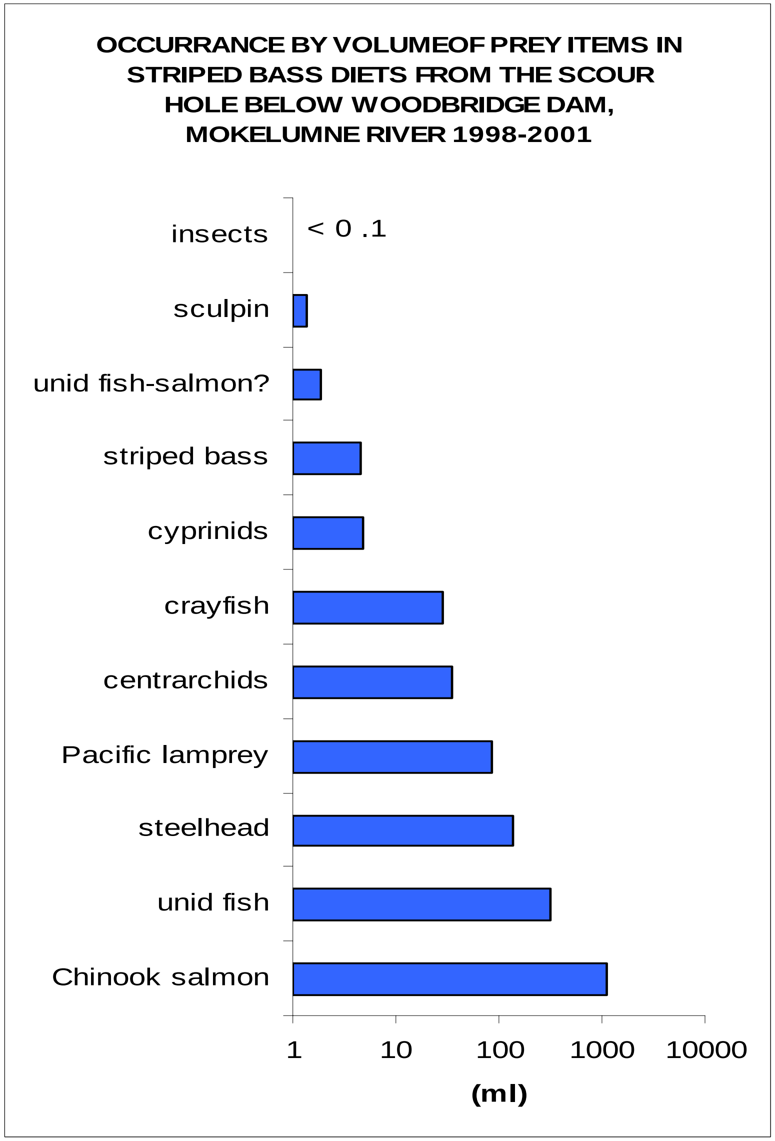


Figure 5. Number and volume of prey items found in the stomachs of striped bass captured in the Woodbridge Dam afterbay in the Mokelumne River between June 1993 and August 2001.

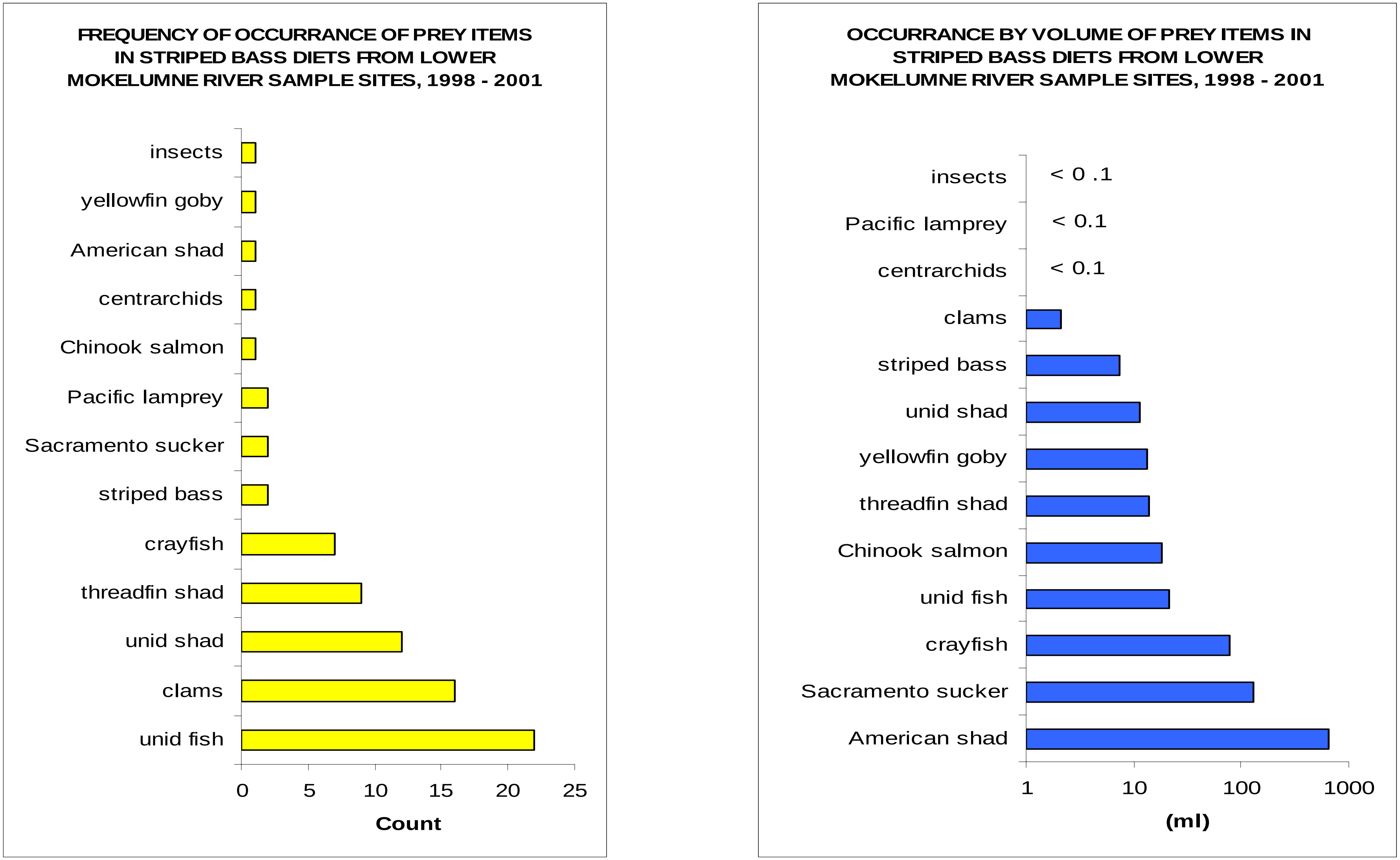


Figure 6. Number and volume of prey items found in the stomachs of striped bass captured at sample sites in the Mokelumne River downstream of the Woodbridge Dam afterbay between June 1993 and August 2001.

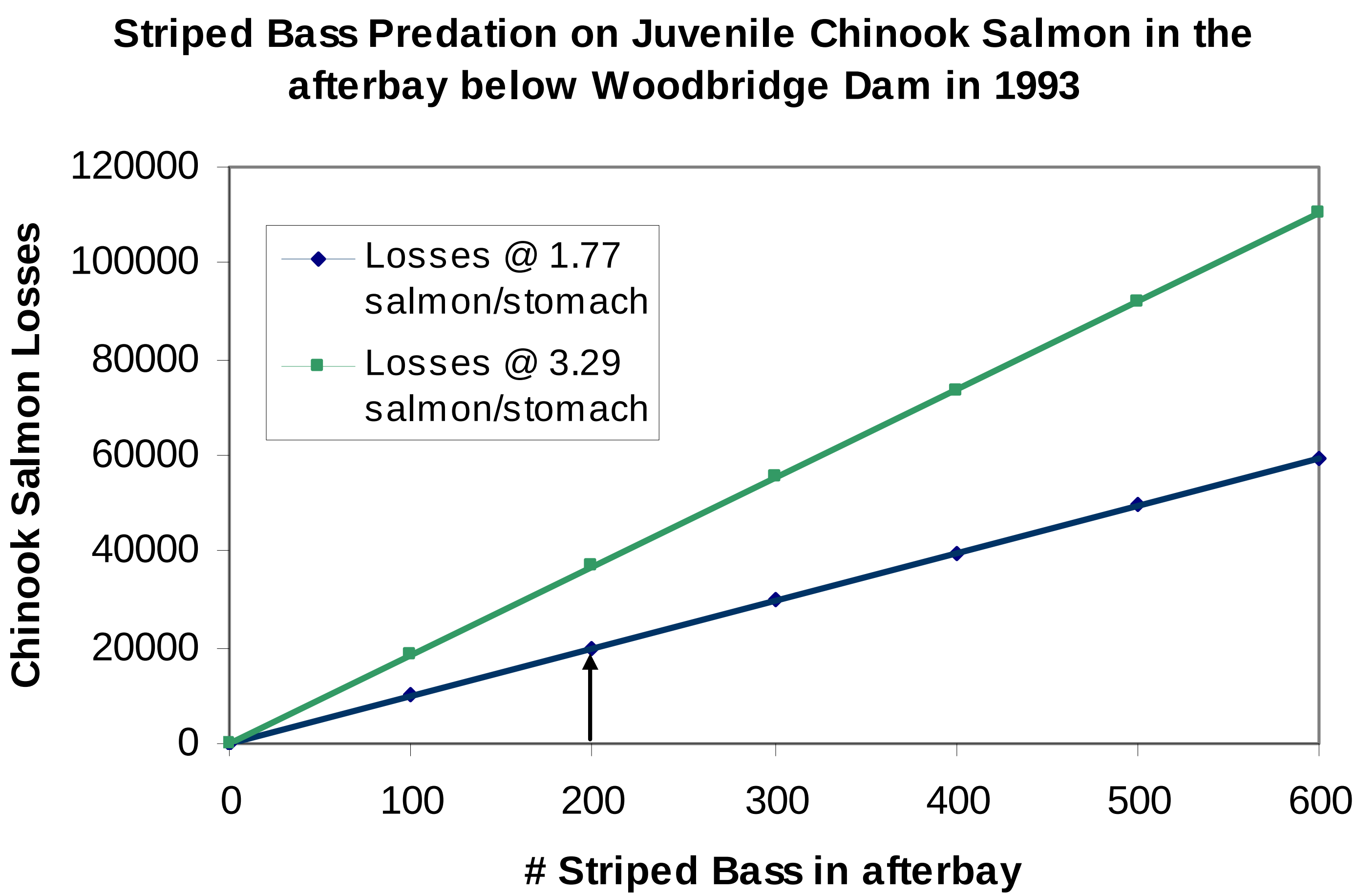


Figure 7. Graphical model of estimated juvenile Chinook salmon losses associated with striped bass predation in the Woodbridge Dam afterbay on the Mokelumne River in 1993. The blue line depicts losses based on positively identified salmon from STB stomachs and the green line depicts losses that include fish found in STB stomachs strongly suspected of being salmon.

Sample Sites	Sample Count	CPUE Sum	CPUE Mean	CPUE Variance
Woodbridge Afterbay	**15**	**0.3995188**	**0.0266346**	**0.00108162**
Feiste Property	**15**	**0.0432285**	**0.0028819**	**4.8271E-05**
Cosumnes Mouth	**16**	**0.0419433**	**0.0026215**	**1.8135E-05**
Above New Hope	**7**	**0.0097314**	**0.0013902**	**5.9586E-06**
Dead Horse Cut	**7**	**0.0165073**	**0.0023582**	**6.6768E-06**
South Mokelumne	**11**	**0.0061361**	**0.0006818**	**1.4516E-06**
North Mokelumne	**9**	**0.0108186**	**0.0009835**	**5.6222E-06**

Table 1. A summary of striped bass catch-per-unit-effort (STB/s) for electro-fishing surveys conducted at listed sites between 1993 and 2001in the Mokelumne River.