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Title
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Permalink
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Journal
San Francisco Estuary and Watershed Science, 5(1)

Authors
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Publication Date
2007

DOI
10.15447/sfews.2007v5iss1art1

Peer reviewed

SAN FRANCISCO
ESTUARY&WATERSHED SCIENCE
Published by the California Bay-Delta Authority Science Program and the John Muir Institute of the Environment

Introduced Yellowfin Goby, *Acanthogobius flavimanus*: Diet and Habitat Use in the Lower Mokelumne River, California

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ABSTRACT

The introduced yellowfin goby (YFG) is now common throughout the tidal portion of the Sacramento-San Joaquin River system. We investigated its habitat use, size, and diet in the Mokelumne River, an eastern tributary to the system. Catch per unit effort (CPUE) by boat electrofishing was significantly higher in the fall than all other seasons sampled over four years. Habitat type, turbidity, and dissolved oxygen were not significantly related to CPUE between years and seasons. Temperatures were negatively related to CPUE in fall sampling only. Delta outflow and CPUE showed a significant negative relationship. Fish captured ranged from 27 mm SL (standard length) (33 mm TL [total length]) to 155 mm SL (196 mm TL) (mean 113 mm SL (138 mm TL)), with largest fish captured during the fall. Seasonal and annual analysis showed a diet composed of a variety of macroinvertebrates, including chironomids, gammarids, aquatic isopods, and ephemeropterans with no difference in composition among seasons or years. The YFG's generalist diet gives it an advantage as a successful invader, but salinity requirements appear to limit its expansion potential.

KEYWORDS

yellowfin goby; *Acanthogobius flavimanus*; alien fishes; invasives; diet; habitat use

INTRODUCTION

The Sacramento San Joaquin River basin is a highly manipulated ecosystem with structural impacts including levees, land conversion, and water diversions (Herren and Kawasaki 2001; Kimmerer 2002; Micheli et al. 2004). Large amounts of money are currently being and will be spent to mediate these structural modifications (Nichols et al. 1986; Hunter 1999; van Geen and Luoma 1999; Jacobs et al. 2003; Kimmerer et al. 2005). However, an important aspect of ecosystem restoration is the consideration of invasive species. Invasive species are perhaps the largest biological impact to ecological function within this sys-

tem (Kimmerer and Orsi 1996; Jassby et al. 2002). Invaders can cause extinctions of vulnerable native species through predation, competition, and habitat alteration, and can even alter nutrient cycling and energy budgets in an ecosystem, greatly diminishing the abundance or survival of native species. Therefore, invasive species can strongly influence the outcome of restoration projects (Mack et al. 2000). Successful invaders typically have a history of past invasions (Kolar and Lodge 2001), often thrive in highly disturbed areas (McKinney and Lockwood 1999), or have been released from a previous constraint (e.g. predators) (Marchetti et al. 2004). Habitat destruction, fragmentation, and short-term disturbances may all favor invasion by habitat generalists, despite the inferior competitive abilities of these species (Marvier et al. 2004). As exotics in late stages of invasion eliminate native species and replace their functional roles, it is becoming increasingly important to understand the context within which invasives operate in these ecosystems to avoid unwanted ecological effects from their management or eradication (Zavaleta et al. 2001). Here, we provide data on the invasive yellowfin goby (*Acanthogobius flavimanus*) within a portion of the Sacramento San Joaquin River system. Specifically, we discuss information on diet, habitat use and correlations between density and general physical parameters of this successful invader at the periphery of its present range.

Yellowfin gobies (YFG) are native to northern Asia and Japan (Akihito et. al. 2002). Inhabiting bays, estuaries, and lower tidal reaches of rivers within their native range, YFG have been described as ambush or search feeders, eating small crustaceans and fish (Kikuchi and Yamashita 1992). YFG were first observed in the Sacramento San Joaquin System in 1963 (Brittan et al. 1963). Believed to have been introduced via ballast water (Carlton 1985; Dill and Cordone 1997), they have continued to expand their range and are now one of the most abundant bottom fishes in San Francisco Bay and the Delta (Baxter et al. 1999; Moyle 2002; Feyrer and Healey 2003). Within the San Francisco Estuary, they spawn in late winter and early spring (Wang 1986, Baker 1979) and have an average longevity of three years, although there have been examples of older specimens (Moyle 2002). Males mature after their first year and females

at the end of their second year (Hoshino et al. 1993). They move from fresh to saline waters to spawn from December to July (Wang 1986). Eggs are attached to the walls of Y-shaped burrows dug by males, and are guarded by the males until hatching after 28 days (Dotu and Mito 1955). Pelagic larvae have been reported to use tidal currents to maintain their position within the Estuary or to ascend into fresher water areas during spring (Wang 1986). Dege and Brown (2004) observed YFG larvae concentrations of 0 to 51,985 fish per 10,000 m^3 at individual plankton tow stations within the upper San Francisco Estuary. Larvae were consistently captured between March and April and the mean position of the population was closely associated with the Delta X2. The X2 is measured as the distance up the axis of the Estuary to the location where the daily average near-bottom salinity is 2 practical salinity units (psu) (Jassby et al. 1995, Dege and Brown 2004). At about 15 mm, young gobies begin a benthic existence (Dotu and Mito 1955). Juveniles apparently prefer shallow water and can tolerate both low salinity and high temperature (Wang 1986). The YFG has been documented as a dominant prey item for the harbor seal (*Phoca vitulina*) in San Francisco Bay, indicating how well this species has integrated into this system (Torok 1994). Although YFG can live in freshwater, they require salinities of at least 5 ppt to breed, suggesting they are limited in their potential expansion (Wang 1986). Some general dietary trends have been documented for the YFG in the San Francisco Estuary and Suisun Marsh (Feyrer et al. 2003), although little is known about their diets within California inland waters.

The Mokelumne River delta, including the North Fork and South Fork Mokelumne River, a tributary to the Sacramento-San Joaquin Delta, has been highly modified by human activity (Figure 1). Its upper watershed has been described extensively elsewhere (Merz and Setka 2004a; Pasternack et al. 2004; Holloway et al. 1998). Tidal influence begins at or slightly downstream of Woodbridge Irrigation District Dam (WIDD) (rkm 62). The tidal river portion flows through mostly agricultural and pastoral lands, bordered by earthen levees and a thin ribbon of riparian vegetation, including native Fremont cottonwood, *Populus fremonti*, valley oak, *Quercus lobata*, California sycamore, *Platanus racemosa*, California box elder, *Acer negundo*
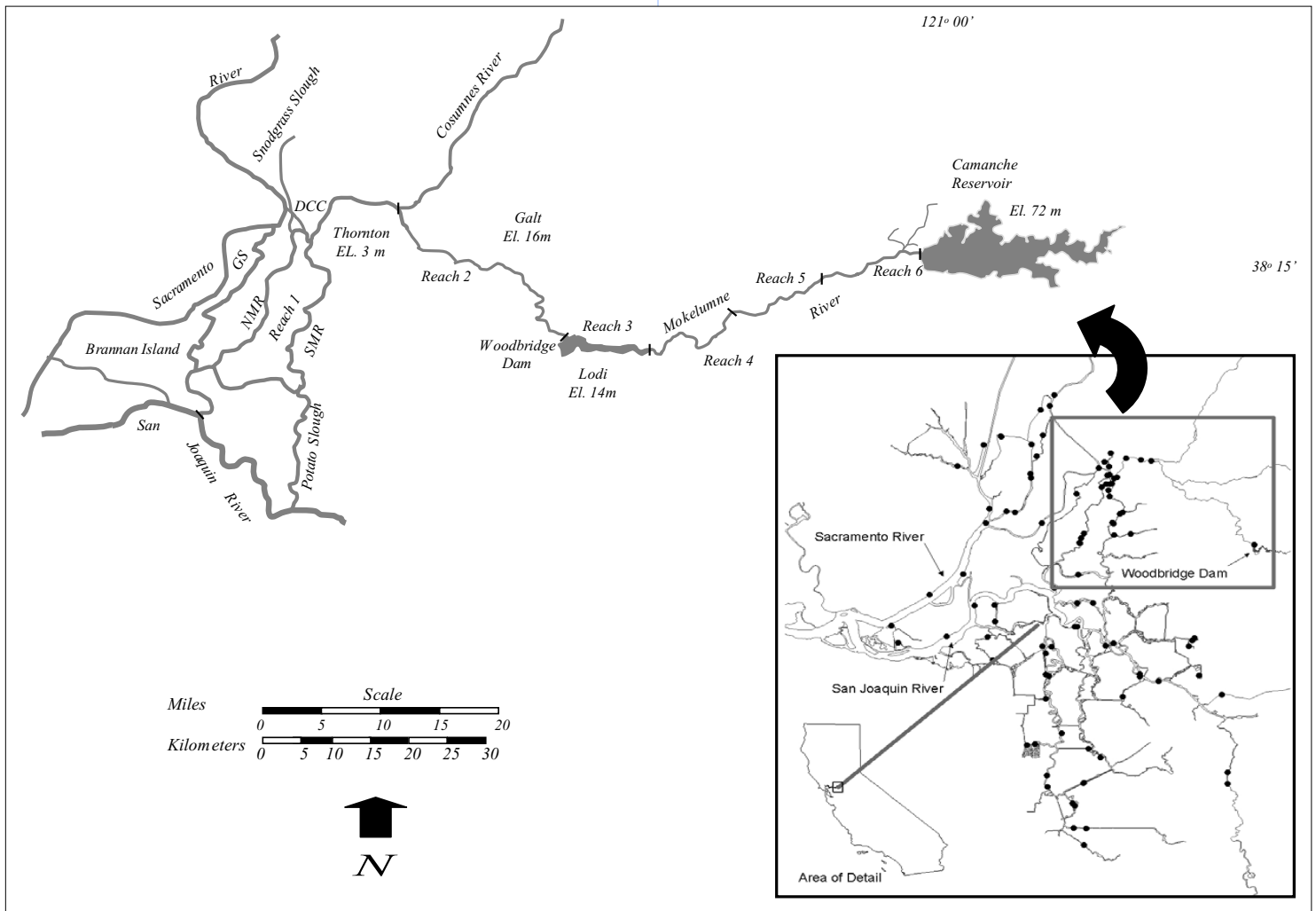
Figure 1. Lower Mokelumne River sampling reaches and yellowfin goby distribution in the Sacramento San Joaquin Delta (inset). DCC=Delta Cross Channel; GS=Georgiana Slough; NMR-North Mokelumne River; SMR=South Mokelumne River. Black dots (inset) indicate sample locations where yellowfin gobies were observed.

californicum, several species of willow, *Salix sp,* and non-native Himalaya blackberry, *Rubus discolor.* Substrates consist of mostly sand and mud, with occasional clay outcroppings and very little habitat heterogeneity (Merz and Setka 2004b). Flows in this section of river are regulated and over the 10-year period before the conclusion of this study, have ranged from 0.62 to 142.15 $m^3 \bullet sec^{-1}$ with a mean flow of 20.02 $m^3 \bullet sec^{-1}$ and exceedence flows of Q20, 50 and 80 equal to 30.58, 7.93 and 3.57 $m^3 \bullet sec^{-1}$, respectively (e.g., 20% of the time flows exceed 30.58 $m^3 \bullet sec^{-1}$). The Cosumnes River joins the Mokelumne River at rkm 37. Below the confluence, river banks are leveed and

rip-rapped with very little remaining native riparian vegetation. Downstream of this area, the aquatic littoral zone is dominated by non-native submerged aquatic vegetation, primarily Brazilian waterweed (*Egeria densa*). The river splits into the North and South delta forks with several large sloughs, including the Delta Cross Channel and Georgiana Slough providing as much as 99.1 $m^3 \bullet sec^{-1}$ and 402 $m^3 \bullet sec^{-1}$, respectively from the Sacramento River to the North fork (maximum since monitoring began in 2003). Dead-end sloughs, such as Hog, Sycamore and Beaver join the Mokelumne River Delta on the South Fork with an unknown amount of inflow from agricultural

sources. The two forks presently have a channel capacity of ~ 1,132.67 m³• sec⁻¹ and rejoin at rkm 5.6 before emptying into the San Joaquin River. Since EBMUD began a monitoring program, 40 fish species, including 14 native and 26 invasive species, have been documented in this portion of the Mokelumne River (Merz and Saldate 2004; Workman 2001). Beyond this, the Sacramento-San Joaquin Delta has been described extensively in the literature (Davis et al. 2003; Feyrer and Healey 2003; Jassby and Cloern 2000; Toft et al. 2000).

METHODS

General Habitat Use

Habitat Delineation

The lower Mokelumne River (LMR), from Camanche Dam (rkm 103) to the confluence with the San Joaquin River, was separated into six reaches based on stream confluences, gradient, tidal influence, and substrate characteristics (Figure 1). The reaches are further stratified into habitat types. Habitat types were identified and assigned to one of six habitats (Merz and Setka 2004a): 1) channel pools (unbroken surface, slow velocity, deep water); 2) glides (moderately shallow water with an even flow lacking pronounced turbulence); 3) runs (rippled surface, fast velocity, shallow water); 4) riffles (stream bed substrate protruding through water surface); 5) island complexes (sections of river dominated by longitudinal bars of bed material that typically split the channel during normal flow periods; and 6) off-channel pools (slow, deep water adjacent and contiguous to the main channel). Specific sites representative of major habitats present in each reach were selected for fish community sampling.

Fish Sampling

Mokelumne River fish monitoring includes sampling representative habitat types for each reach using a combination of seining in reaches 6 through 2 from January to July annually, and boat electrofishing in reaches 6 through 1 seasonally, and operation of a rotary screw trap from December through July at rkm 63 in river reach 2 (Figure 1). YFG analyzed for this study were all collected via boat electrofishing.

Boat electrofishing was used to conduct seasonal sampling annually during January (Winter), early-May (Spring), late-July (Summer), and October (Fall) between January 2000 and December 2004. Seasonal sampling was performed with a Smith-Root SR-18E electrofishing boat with a 130 horsepower outboard jet engine following the methods described in Meador et al. (1993). The jet allowed for sampling water > 40cm deep. An automatic timer was used to measure the total length of time a specific site was sampled to calculate a catch per unit effort (CPUE=fish • sec⁻¹).

For this study, sampled YFG were measured and released, with a sub-sample from each site kept for dietary analysis (see below). Three environmental variables were recorded with each sampling event: Water temperature (°C) and dissolved oxygen (mg • L⁻¹) were recorded with a YSI 550 handheld dissolved oxygen (DO) and temperature probe (accuracy: ±0.3 mg • L⁻¹ ±0.2°C); turbidity (NTU) was measured from a 100 ml water sample with a Hach 2100P Turbidimeter. All samples were collected at 18 cm below the water surface.

To compare YFG parameters with stream discharge, we accessed flow data from the California Department of Resources Data Exchange Center (http://cdec.water.ca.gov/).

Occurrence data from our fish community sampling, the California Department of Fish and Game's Delta sampling (Michniuk and Silver 2002), and the University of California at Davis' work on the Cosumnes River (Moyle and Crain, unpublished data) were combined to generate a YFG range map for the Sacramento-San Joaquin Delta (Figure 1).

Size Distribution

YFG standard length and total length were measured to the nearest millimeter (mm) in the field. Data on length frequency collected in field samples were organized by river kilometer, season, and year to assess age structure and seasonal size distribution related to river distribution patterns.

Dietary Examination

YFG were collected during seasonal electrofishing of the LMR in 2001 and 2002. YFG were measured to SL and TL (mm), weighed (0.1 g), labeled, and immediately preserved in an 80 to 85% ethanol solution, packed in

ice in the field, and transported to the laboratory for storage and analysis. Stomach contents were sorted in the laboratory under a dissecting microscope and magnifying illuminator. Food items were identified to Family for aquatic organisms and Order for terrestrial organisms; life stages (i.e. larva, pupa, or adult) were determined. Adult Ephemeroptera, Trichoptera, Plecoptera, and Diptera were classified as terrestrial. Food items were further categorized into the following size classes: class 1 = <2 mm; class 2 = 2-7 mm; class 3 = 8-13 mm; class 4 = 14-20 mm; class 5 = >20 mm. Prey lengths were then estimated using the mean length for each size class. Sorted food items were oven-dried at 70° C for 24 h to constant weight and then weighed to the nearest 0.0001 g, and percent composition of stomach contents was determined (Bowen 1983). Major food items by season were determined by calculating an Index of Relative Importance (IRI), following methods described in Hyslop (1980) and modified by Merz and Vanicek (1996).

IRI= (FN+FW)FO

Where,

FN=% of total number of organisms ingested

FW=% of total weight

FO=% frequency of occurrence in all stomachs examined that contained food.

Stomach fullness was calculated as:

$W \bullet 100 \bullet w^{-1}$.

Where: W = stomach contents dry weight and w = individual fish weight.

Data Analysis

Three main statistical tests were used to analyze data collected: one way analysis of variance (ANOVA), linear regression with associated ANOVA, and chi square analysis (Sall et al. 2001). We used ANOVA to analyze the following: 1) seasonal variation in YFG abundance and habitat use within the LMR with CPUE as the dependent variable; 2) the relationship of YFG abundance to environmental variables by comparing CPUE with dissolved oxygen, temperature, and turbidity; 3) the size of YFG by season; and 4) the fullness of stom-

achs across seasons. Linear regression analysis, and associated ANOVA were used 1): to analyze size of YFG compared to distance upstream from the LMR mouth; 2) to compare mean prey item size, weight of prey item, and number of items ingested to the size (SL) of YFG by season; and 3) to look at seasonal variation in the amount of food ingested (dry weight; g) by season for YFG. We used a chi square contingency table to 1) compare IRI of the five most common orders present in diets between seasons and years; 2) assess seasonal and annual diet shifts; and 3) compare the ratio of full to empty stomachs to assess seasonal variations in feeding activity.

RESULTS

General Habitat Use

Distribution

The YFG is widely distributed throughout the Sacramento-San Joaquin Delta: in the Sacramento River and its tributaries as far inland as rkm 56; in the San Joaquin River and its tributaries as far inland as rkm 76 (Michniuk and Silver 2002); on the lower Mokelumne River inland to rkm 62 (Workman 2001); and well into Snodgrass Slough within the central Delta (Moyle and Crain unpublished data) (Figure 1).

Within the lower Mokelumne River, we captured 419 YFG between January 2000 and December 2004 by boat electrofishing. YFG were first observed during these surveys in July of 2000. YFG were observed between rkm 1, the lowest monitoring station (Reach 1) and rkm 62, the base of WIDD and the upstream extent of tidal influence (Reach 2). No YFG were observed above WIDD. Depending on season and year, YFG comprised as much as 11% of the total fish captured by electrofishing within reach 1 of the LMR. For the entire study period combined they comprised 2% of catch.

Mean CPUE (measured as number of fish $\bullet$ sec^{-1}) ranged from 0.0044 fish $\bullet$ sec^{-1} to 0.0241. Seasonal CPUE was significantly higher in fall in each year sampled on the LMR (F = 13.4925; df = 14; P = 0.0002). For each year sampled there is an upward trend in CPUE from winter through fall.
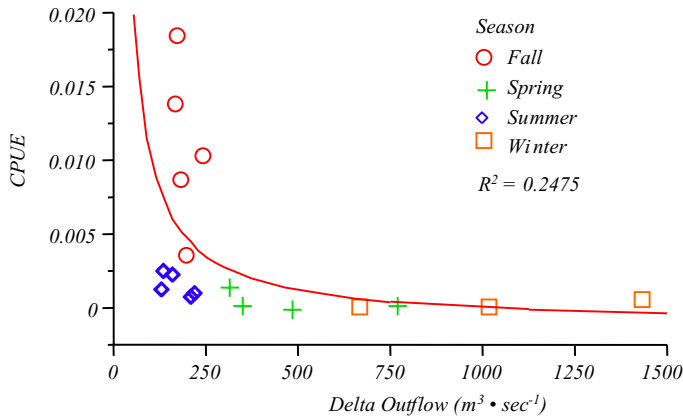
Figure 2. The relationship between mean Delta outflow and mean yellowfin goby catch per unit effort (CPUE) in the lower Mokelumne river, 2000 through 2004. Mean CPUE= -0.001077+1.1793922 Reciprocal (Delta Outflow).
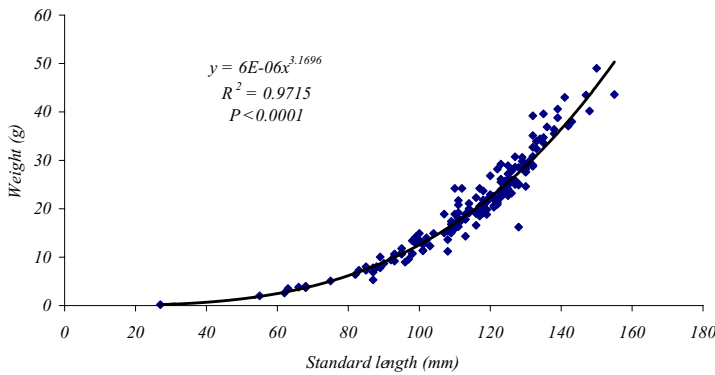

Figure 3. The relationship between standard length (mm) and weight (g) of yellowfin gobies sampled from the lower Mokelumne River and delta, January 2000 through November 2004.

Highest CPUE of YFG occurred at the confluence of the Mokelumne and Cosumnes rivers (0.0740). However, we found no significant difference in the CPUE of YFG when comparing habitat types sampled (F = 0.3542; df = 62; P = 0.8041). YFG were captured in turbidities ranging from 2.9 to 23.9 NTU (mean = 8.1; SD = 4.5), DO ranging from 6.8 to 11.4 mg • L^{-1} (mean = 8.4; SD = 0.8), and water temperatures ranging from 7.8 to 23.6o C (mean = 18.0; SD = 2.2). We found no significant relationship between YFG CPUE and turbidity (NTU) (F = 0.2039; df = 18; P= 0.6570) or DO (F = 0.2982; df = 65; P = 0.5869) during sea-

sonal electrofishing surveys. However, YFG CPUE was negatively related to sampled water temperature during the fall period (F = 4.8168; df = 32; P = 0.0356). We also observed a negative relationship between the Delta outflow index and YFG CPUE (F = 5.2635; df = 16; P = 0.0356) (Figure 2).
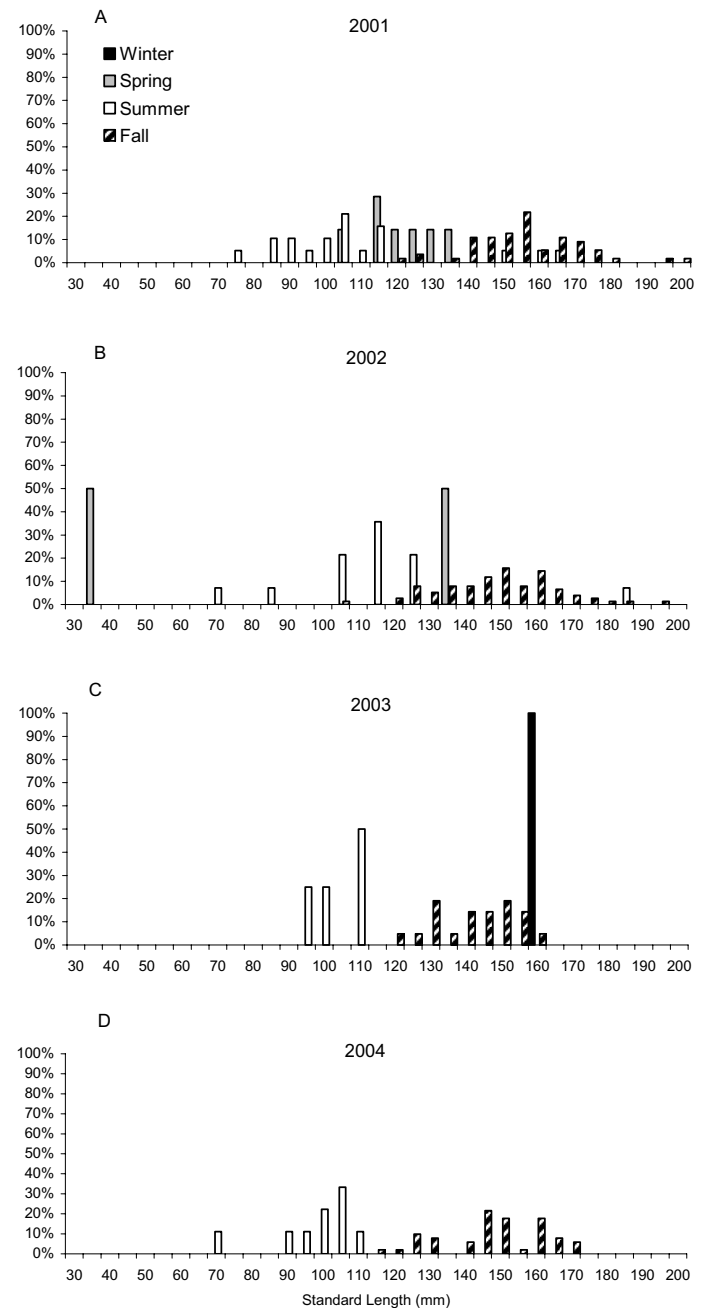

Figure 4. Seasonal length frequencies of yellowfin gobies captured by boat electrofishing on the lower Mokelumne River and delta, 2001 through 2004.

Size Distribution

Fish captured in electrofishing surveys ranged from 33mm TL (27 mm SL) to 196 mm TL (155 mm SL) (Figure 3). Average size was 113 mm SL (138mm TL). From fish collected for stomach samples, weight ranged from 0.2 to 54.5 g (mean = 22.0 g). Fish observed in spring all appeared to be young-of-year. Of the 288 fish measured, only 13 (<5%) were over 170 mm TL. All but one of the fish in this size class was observed in the fall. Length frequencies suggest at least two year classes coexisted during spring and summer of 2001 and 2002 (Figures 4B and 4C). By comparing peak length frequencies between summer and fall, YFG length appeared to increase 45-60 mm (SL) within this three-month period.

YFG were significantly larger in fall than all other seasons sampled (F = 77.0784; df = 277; P <0.0001). There was a significant inverse relationship between YFG length and distance upstream from the LMR mouth (F = 2.6179; df = 202; P = 0.0098).

Diet

General composition

YFG sampled for diets ranged from 27 to 155 mm SL (mean: 114.2). YFG ate a variety of prey items including chironomids, gammarids, aquatic isopods and ephemeropterans (Table 1). No difference in diet composition existed between seasons (U = 0.0075; df = 4; P > 0.1506) or between years (U = 0.0069; df = 4; P > 0.3788). Dipterans, primarily chironomid pupae, made up the largest portion of the diet for all seasons, followed by amphipods, primarily *Gammarus sp.,* pelycopods, primarily Asian clams, *Corbicula fluminea,* and Ostracods (Figure 5). Detritus was also a common stomach item.

Fullness

Of 165 stomachs examined, 13% were empty. An insufficient number of YFG were sampled in spring and winter to compare stomach fullness. The percent of empty YFG stomachs was lower in summer (5.9%) than fall (16.3%). However, this was not statistically significant (X2 = 2.804; df = 155; P = 0.0984). YFG stomachs were significantly more full in summer (mean IF = 0.10515) than fall (Mean IF = 0.0445) (F =
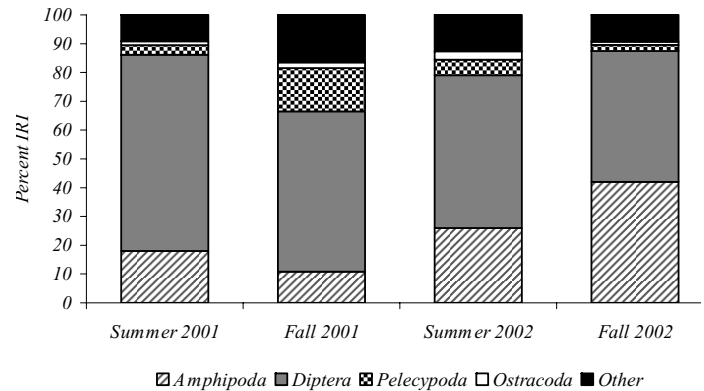

Figure 5. Seasonal IRI (Index of Relative Importance) of food items found in the stomachs of yellowfin goby on the lower Mokelumne River, 2001-2002.
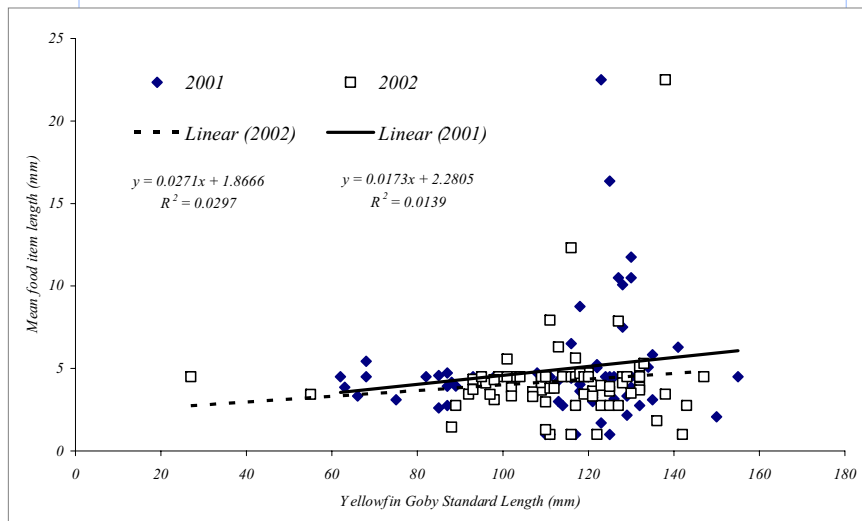

Figure 6. The relationship of yellowfin goby standard length and mean food size ingested, 2001 and 2002.

4.5138; df = 150; P = 0.0353). A significant relationship between YFG SL and mean food item size consumed was observed in summer 2001 (R2 = 0.3470; F = 2.7655; df = 17; P = 0.0079). However, this was not a significant pattern over either of the two years sampled (Figure 6). Overall, YFG length had no significant influence on the number of food items in (R2 = 0.0153; F =2.3224; df =149; P =0.1296) or the weight of stomach contents sampled (R2 = 0.0082; F =1.2342; df =149; P =0.2684). No significant difference was observed between season for number of food items per stomach (F = 0.0648; df =152; P = 0.9373) or dry weight of stomach contents (F = 0.0768; df = 152; P = 0.9261).

DISCUSSION

Distribution

The specific salinity requirements for YFG spawning and California's Mediterranean climate and flow runoff regimes may restrict YFG by seasonal shifts in salinity based on inflow to the Bay and Delta. Dege and Brown (2004) found yellowfin goby populations in the San Francisco Estuary closely related to 2 psu salinity (X2) during spring and summer surveys with the population centered farther upstream during lower flows. Similarly, we observed this pattern occurring farther upstream. This suggests that salinity may not be the only factor influencing seasonal variation in YFG densities. Additional factors may include species longevity, spawning requirements, gradient, and flows.

In Suisun Marsh YFG show little inter-annual response to environmental changes presumably because the range of environmental variation over the course of a year stays within their physiological limits. Seasonally, however, young of year are more abundant in trawls and seine catch in spring and summer than in fall and winter (Matern et al. 2002). This is not the case farther inland on the lower Mokelumne River where we saw peak abundance in YFG in the summer and fall and very few in winter and spring. These inland peaks in abundance could be the result of dispersal of young of year from nursery areas like Suisun Marsh in conjunction with downstream migration of reproductive age fish to spawn in the Estuary.

In the San Francisco Bay and Delta region, high flows that reduce salinities coincide with the winter/spring YFG spawning season, and salinities increase during the reduced flow coinciding with summer and fall (Dettinger and Cayan 2003). This salinity regime potentially allows YFG to expand their range upstream seasonally. Anthropogenic factors such as freshwater exports from the system may also drive salinity based distribution (Cayan et al. 2003), increasing salinities farther inland allowing YFG to move farther up the river. This salinity requirement may ultimately limit the further spread of the YFG. High flows may either dislodge YFG from steeper gradient portions of the system, causing annual reductions on a seasonal basis, or larger fish may simply move downstream to spawn. This

appears to be supported by our general observation of larger fish farther downstream. Interestingly, WIDD (rkm 62) is at the upper limit of tidal habitat. The fact that only one specimen has been observed in the after-bay and none upstream of the dam in over four years of monitoring (Workman 2001) suggests that tidewater may be the upper extension of YFG habitat. Fish ladder passage at WIDD may impede movement upstream.

Diet

Within their native environments the YFG diet includes polychaete worms, benthic crustaceans and fish (Kikuchi and Yamashita 1992, Hironouchi and Sano 2000). In Japan's Tamu River Estuary, Kanou et al. (2005) found that for juvenile YFG up to 20 mm SL the major prey item was harpacticoid copepods, and as fish got larger they switched to errant and sedentary polychaetes. It appears from these studies that YFG have successfully shifted their diets from their native range, which has led to their success as an invader in the San Francisco Estuary. In the Estuary and surrounding Delta they appear to have already accomplished another successful dietary shift. Feyrer et al. (2003) observed a shift in YFG diets from mysids to amphipods with the decline in mysid shrimp caused by the spread and increased density of the alien over-bite clam, *Corbula amurensis*, (formerly *Potamocorbula amurensis*) in the San Francisco Estuary and clustered YFG in a feeding group identified as primarily amphipod eaters. These diet shifts suggest the YFG is an opportunistic predator and is taking advantage of the most numerous and/or easily available food source. This trait is optimal for a species invading a new area where the food base may differ from their native range (Kostrzewa and Grabowski 2003). Within the lower Mokelumne River, diptera, primarily chironomid pupae, made up the largest portion of the diet for all seasons; amphipods (mainly Gammarus) comprised the second largest portion of the diet in inland waters. These food items also appear in the diets of Delta smelt *(Hypomesus transpacificus)* and juvenile Chinook salmon *(Oncorhynchus tshawytscha)*, two special-status species studied within the same geographic region (Moyle 2002; Kjelson and Raquel 1981). It appears from these data that the diet of YFG in the Estuary and inland waters may be quite similar

Table 1. Major food items of yellowfin gobies in the lower Mokelumne River and delta, 2001 and 2002. Data presented as percent frequency of number (%FN), percent frequency of occurrence (%FO), index of relative importance (IRI), and percent index of relative importance (%IRI).

Items	Summer					Fall				
	%FN	%FW	%FO	IRI	%IRI	%FN	%FW	%FO	IRI	%IRI
Amphipoda	21.9	18.7	52.6	2139.9	18.0	15.5	6.2	44.2	958.3	10.8
Coleoptera	1.0	1.0	10.5	21.6	0.2	1.1	0.1	4.7	6.0	0.1
Coleoptera	0.0	0.0	0.0	0.0	0.0	0.6	0.1	2.3	1.5	0.0
Copepoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Decapoda	0.0	0.0	0.0	0.0	0.0	0.6	13.0	2.3	31.5	0.4
Detritus	3.1	11.4	47.4	687.4	5.8	6.9	24.5	27.9	877.1	9.9
Diptera	58.6	37.8	84.2	8117.5	68.2	37.4	25.0	79.1	4934.1	55.7
Dipterd[t]	0.3	0.0	5.3	2.1	0.0	0.0	0.0	0.0	0.0	0.0
Ephemeroptera	1.0	11.0	15.8	190.1	1.6	1.1	2.0	4.7	14.5	0.2
Gastropoda	1.4	3.3	21.1	98.7	0.8	1.7	0.1	7.0	12.6	0.1
Hemiptera	0.3	0.6	5.3	4.8	0.0	0.0	0.0	0.0	0.0	0.0
Hydracarina	0.0	0.0	0.0	0.0	0.0	1.1	0.1	4.7	5.9	0.1
Isopoda[a]	0.3	0.6	5.3	4.9	0.0	0.6	0.1	2.3	1.5	0.0
Nematoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odonata	0.3	5.8	5.3	32.5	0.3	0.6	0.7	2.3	2.9	0.0
Oligochaeta	0.3	0.1	5.3	2.1	0.0	1.7	0.6	7.0	16.0	0.2
Ostracoda	5.1	1.1	26.3	162.9	14	6.3	0.5	25.6	175.6	2.0
Pelecypoda	4.8	4.5	42.1	389.5	3.3	16.1	12.6	46.5	1333.4	15.0
Plecoptera	0.0	0.0	0.0	0.0	0.0	0.6	0.0	2.3	1.3	0.0
Trichoptera	1.0	0.5	15.8	24.2	0.2	2.3	0.1	9.3	22.5	0.3
Vegetation	0.3	3.5	5.3	20.3	0.2	5.7	14.4	23.3	467.5	5.3
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002										
Amphipoda	28.0	16.1	63.6	2807.9	26.0	33.5	32.0	62.7	4110.6	42.0
Cladocera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coleoptera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copepoda	0.0	0.0	0.0	0.0	0.0	0.1	0.0	1.7	0.2	0.0
Decapoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Detritus	3.0	18.9	36.4	799.0	7.4	1.4	12.0	23.7	318.4	3.3
Diptera	47.7	22.5	81.8	5747.5	53.1	44.3	18.3	71.2	4453.7	45.5
Dipterd[t]	0.0	0.0	0.0	0.0	0.0	0.9	0.4	1.7	2.2	0.0
Ephemeroptera	1.5	3.0	9.1	41.5	0.4	1.0	1.0	11.9	24.2	0.2
Gastropoda	3.8	2.3	36.4	222.7	2.1	0.6	0.6	6.8	8.5	0.1
Hemiptera	0.0	0.0	0.0	0.0	0.0	3.1	1.5	10.2	47.7	0.5
Hydracarina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda[a]	0.0	0.0	0.0	0.0	0.0	0.2	0.5	1.7	1.1	0.0
Nematoda	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.7	0.5	0.0
Odonata	0.8	6.2	9.1	63.5	0.6	0.0	0.0	0.0	0.0	0.0
Oligochaeta	0.0	0.0	0.0	0.0	0.0	7.5	8.9	18.6	305.9	3.1
Ostracoda	7.6	1.2	36.4	319.0	29	3.6	0.8	23.7	104.8	1.1
Pelecypoda	5.3	10.6	36.4	577.5	5.3	1.3	14.1	13.6	209.1	2.1
Plecoptera	0.0	0.0	0.0	0.0	0.0	0.1	0.1	1.7	0.3	0.0
Trichoptera	1.5	3.7	18.2	95.6	0.9	0.9	0.2	11.9	12.7	0.1
Vegetation	0.8	15.3	9.1	146.1	1.4	1.1	9.1	18.6	189.6	1.9
Other	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.7	0.8	0.0

[t]Terrestrial; [a]Aquatic

but varies slightly in the order of importance for specific food items. More work on the relative proportions of food items available in the Estuary versus inland waters related to proportions in YFG stomachs may serve to answer the question of whether opportunistic feeding plays a major role in YFG expansion potential farther inland.

Seasonality of stomach fullness was dissimilar to that found in the Estuary. We found a higher percentage of empty stomachs in the fall than summer, and Feyrer (2003) found the opposite to be true with more empty stomachs in the spring/summer over fall.

CONCLUSIONS

The success of an invader in California estuaries and streams hinges largely on how well it can tolerate the abiotic components of that environment, specifically the local hydrograph (Moyle and Light 1996). By the completion of this study, YFG had already invaded and been established in the Sacramento-San Joaquin river system for at least 41 years (Brittan et al. 1963), thus indicating that the Sacramento-San Joaquin Delta and San Francisco Estuary provide a salinity and temperature regime favorable to supporting YFG. Opportunistic feeding may also contribute to the species' success within the Delta, Estuary, and inland waters. These features which make the YFG such a successful invader appear to be offset by the limitations of spawning requirements, and this may limit further expansion into peripheral waters that do not meet their reproductive needs. The apparent expansion of YFG range into the lower Mokelumne River in 2001 with a single observation at rkm 62, a full 25 rkm higher than previously encountered, encouraged us to investigate this successful invader's ability to expand on its current range and try to assess how it fits into these relatively freshwater inland habitats in habitat use and dietary interactions in this highly altered system. Our data suggest that even at the fringe of their current range, well into the freshwater portion of the Sacramento San Joaquin System, the YFG is a common component of the fish community although this appears to be only a seasonal trend. Specific salinity spawning requirements and delta outflow levels appear to influence this seasonal variation. The YFG

has coexisted with a number of special status species, including delta smelt and Chinook salmon. Although dietary overlap appears minimal between YFG collected in this study and the two species listed (Kjelson and Raquel 1981; Moyle et al. 1992) the observed ability of YFG to shift its diet to accommodate changing environments, paired with the highly altered state of the Delta and Estuary would suggest dietary overlap should be further investigated as system conditions change. Further exploration into potential mechanisms for expansion of this and other invasive species will also be important as future introductions are likely, and as habitat restoration and native species recovery continue to dictate Delta and Estuary management.

ACKNOWLEDGMENTS

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