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Flathead catfish population estimate and assessment of population characteristics, Diamond Valley Lake, California

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Flathead catfish (*Pylodictis olivaris*) were inadvertently introduced to Diamond Valley Lake, Riverside Co., California, where their population has become well-established. The species is highly piscivorous, extremely opportunistic, and is the least gape-limited of North American piscivores. Flathead catfish can exhibit extreme predatory pressure on existing fish populations in waters where they are introduced. Multiple mark-recapture methods were used to estimate the flathead catfish population in Diamond Valley Lake. Population characteristics including proportional stock distribution (PSD), relative stock distribution (RSD) and relative weight (Wr) were evaluated. Anchor tag retention was also evaluated. Understanding the status and characteristics of the flathead catfish populations will aid fisheries management decisions for the reservoir.

Key words: California, demography, Diamond Valley Lake, flathead catfish, piscivory, population estimate, *Pylodictis olivaris*

Flathead catfish (FCF; *Pylodictis olivaris)* is a piscivorous ictalurid catfish native to central North America that have been introduced throughout the United States (Jackson 1999). They are capable of achieving very large sizes in excess of 1.4 m and 27 kilograms (Moyle 2002). The least gape-limited of North American freshwater piscivorous fishes, evidence suggests FHC are highly opportunistic, mostly nocturnal feeders which prey upon any fish species encountered (Ashley and Buff 1988, Quinn 1988a, Eggleton and Schramm 2004, Pine et al. 2005). Flathead catfish may be detrimental for fishery management if their numbers escalate to a level where they affect other managed fish populations. For instance, many California reservoirs support salmonid or centrarchid fisheries that may be negatively impacted by introduction of this species. The expansion of FCF outside their native range has led to dramatic declines in native fish populations through predation and competition in other states (Guier et al. 1981, Quinn 1988a, Marsh and Brooks 1989, Bart et al. 1994, Marsh 1996).

Little documentation exists about the absolute predation pressure FCF exert on existing host systems, but evidence suggests that their predatory activities can decimate entire populations in a short amount of time (Guier et al. 1981, Minkley 1982, Quinn 1988a, Marsh and Brooks 1989, Marsh 1996), even when other large-bodied species are present (Bart et al. 1994). Barr and Ney (1993) estimated that FCF annually consumed 20–35% of the centrarchid population of a Virginia reservoir. FCF are the least-studied of the three predominant catfish species in North America, and very little if any information exists regarding their populations in California reservoirs. Given California regulations that mostly prohibit methods of take traditionally used in their native range (i.e., noodling, trot lines, jugging, etc.), FCF are largely unavailable to California's angling public. Without exploitation or natural predators, FCF populations may grow unchecked and can negatively affect the management of fisheries of other species in California (Moyle 2002).

Diamond Valley Lake (DVL) is a relatively new, no-body-contact reservoir in Riverside County, California, managed as a two-tiered fishery for both warm-water and cold-water species. DVL was constructed to receive water from both the Colorado River Aqueduct (CRA) and California State Water Project (CSWP) and opened to the public in October 2003. Fish species that have been stocked in the lake and are managed by the California Department of Fish and Wildlife (CDFW) include Florida-strain largemouth bass (*Micropterus salmoides floridanus*), smallmouth bass (*Micropterus dolomieu*), bluegill (*Lepomis macrochirus*), redear sunfish (*Lepomis microlophus*), channel catfish (*Ictalurus punctatus*), blue catfish (*Ictalurus furcatus*), rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). Inadvertently introduced fish species have become established within the reservoir through the water inflows from both the CRA and CSWP, and include striped bass (*Morone saxatilis*), black crappie (*Pomoxis nigromaculatus*), Wakasagi (*Hypomesus nipponensis*), threadfin shad (*Dorosoma petenense*), inland silverside (*Menidia beryllina*), prickly sculpin (*Cottus asper*), bigscale logperch (*Percina macrolepida*) and flathead catfish. The CSWP has no recorded FCF; however FCF were introduced into the Colorado River in 1962 (Bottroff et al. 1969) and are now well-established there (Moyle 2002). Hence, the Colorado River is the likely source for introduction of FCF into DVL. The lake stopped receiving CRA water in late 2006, prior to the discovery of quagga mussels (*Dreissena bugensis*) in Lake Mead in January 2007. DVL has not received CRA water since that time to prevent the establishment of mussels in the reservoir. The first FCF was sampled in DVL during a CDFW electrofishing survey in October 2007. Since that initial sample the number of FCF sampled or observed during annual electrofishing surveys at DVL has steadily increased.

Due to a combination of restrictive fishing and access regulations, the population of FCF is subject to minimal angling pressure. With a lack of natural predation or other sources of mortality, DVL provides an ideal environment for an invasive species like FCF to expand unchecked. The present study was initiated over the concern for the potential effects of FCF on other managed species in DVL, as well as a scarcity of prior research on this species. The objectives of this study were to estimate FCF population size, population characteristics, and tag retention in Diamond Valley Lake, California.

Methods

Study area.—Diamond Valley Lake (33° 41' N, 117° 02' W) is an off-stream storage reservoir built by Metropolitan Water District of Southern California and is located 6.4 kilometers (km) southwest of Hemet in western Riverside County, California. The mean depth at full pool (elevation 535 m) is 61 m, 49 m at the East Dam, and 79 m at the West Dam with 1,990 ha of surface area. At full pool the lake has approximately 40 km of shoreline including the three dams. DVL is subjected to annual water level fluctuations of approximately 10 m with the maximum drawdown to the emergency supply level at 27 m below full pool.

Methods.—FCF were collected from 17 July to 27 August 2014 using two electrofishing boats from 0530 to 1000. Sampling efforts were concentrated along the three earthen dams covered with rip-rap and large chunk-rock habitat where FCF were more likely to be concentrated (Hale et al. 1987, Quinn 1988b, Cunningham 1995, Daugherty and Sutton 2005, Travnichek 2011). This habitat represents 20–25% of the DVL shoreline at full pool and is where all FCF have been sampled or observed during prior electrofishing surveys. One boat was actively electrofishing moving parallel to the shoreline using low frequency, pulsed direct current (30–60 pps) in 1–3 m of water. Low frequency electrofishing provides the most efficient and precise sample for FCF compared to other gears (Cunningham 1995). A chase boat followed behind, collecting FCF outside the range and behind the active electrofishing boat. Both boats had a boat operator, two forward netters, and two personnel handling fish and recording data. To avoid resampling fish, the lead electrofishing boat applied a partial left pelvic fin clip to all FCF sampled and a red numbered Floy FD-68D tag to those larger than 350 mm total length (TL). The tags were applied just below and behind the dorsal fin (Guy et al. 1996, Buckmeier and Irwin 2000).

During the initial sampling effort all FCF were collected, measured for TL to the nearest mm, and weighed to the nearest gram. During additional sampling efforts only FCF larger than 350 mm were checked for a partial left pelvic fin clip and the presence of a red numbered Floy tag. If neither fin clip nor tag were present, they were applied and the fish was tallied as a new mark. If both fin clip and tag were present, the fish was tallied as a recapture. If the left pelvic fin clip was present but the tag absent, a different colored un-numbered Floy tag was applied to the dorsal fin and the fish was tallied as a recapture with a lost tag. All fish collected were released following measuring, marking, and tagging. Schnabel and Schumacher-Eschmeyer mark-recapture estimates with 95% confidence intervals were calculated for a closed population. Since DVL is an off-stream storage reservoir with no natural inflows and there are no fish removed by anglers, the population was considered closed.

Fish condition was calculated using relative weight (Wr). Length-specific standard weights (Ws) were derived from the standard weight equation, $\log_{10}(Ws) = -5.542 + 3.23 \log_{10}TL$ (Bister et al. 2000). Relative weight was not calculated for FCF less than 150 mm in length due to the Ws equation excluding smaller individuals that produced variance-to-mean errors larger than 0.02 (Bister et al. 2000). Proportional stock distribution (PSD) and relative stock distribution (RSD) indices were calculated based on length categories proposed by Quinn (1991) and Bister (2000).

Results

A total of 1,871 FCF larger than 350 mm were captured during the four mark-recapture efforts and of those, 10% (n=187) were recaptures. The Schnabel point estimate was 6,295 stock-size FCF (5,107–8,205, P<0.05), and the Schumacher-Eschmeyer point estimate was 6,660 stock-size FCF (3,707–32,747, P<0.05). Applying the mean weight of all tagged fish (1.096 g) to the estimated number of fish yielded total biomass estimates of 6,899 kg and 7,299 kg with the Schnabel and Schumacher-Eschmeyer estimators, respectively. The Schnabel and Schumacher-Eschmeyer methods indicate 3.6 to 3.8 fish per surface hectare respectively, at the lake level when the study was initiated. Retention of the FD-68D Floy tags from the 187 FCF recaptured during the duration (41 days) of the sampling was 98.25%.

A total of 707 FCF were collected during the first sample; all FCF were collected, weighed and measured to assess population structure. Flathead catfish sizes ranged from 133 to 790 mm TL with 421 being ≥350 mm (i.e., stock size; Figure 1). PSD and RSD-P were both low (16 and 1, respectively), and no FCF of memorable or trophy size were captured, nullifying any ability to calculate RSD-M or RSD-T.

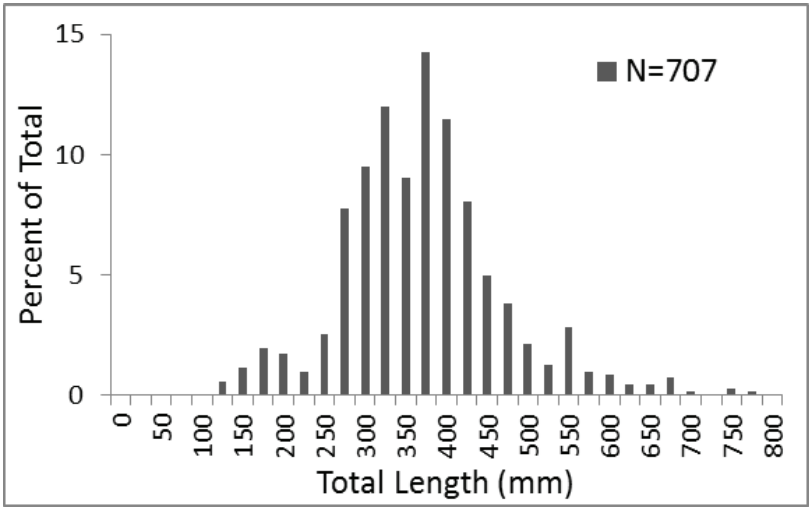

Figure 1.—Frequency distribution of lengths of flathead catfish (*Pylodictis olivaris*) collected from Diamond Valley Lake, Riverside County, California, during July 2014.

A length-weight regression yielded a model similar to the expected weights generated from the regression slope equation described by Bister et al. (2000; Figure 2). Relative weights were averaged across all proposed size classes, with mean values of Wr between 89 and 102 (Figure 3).

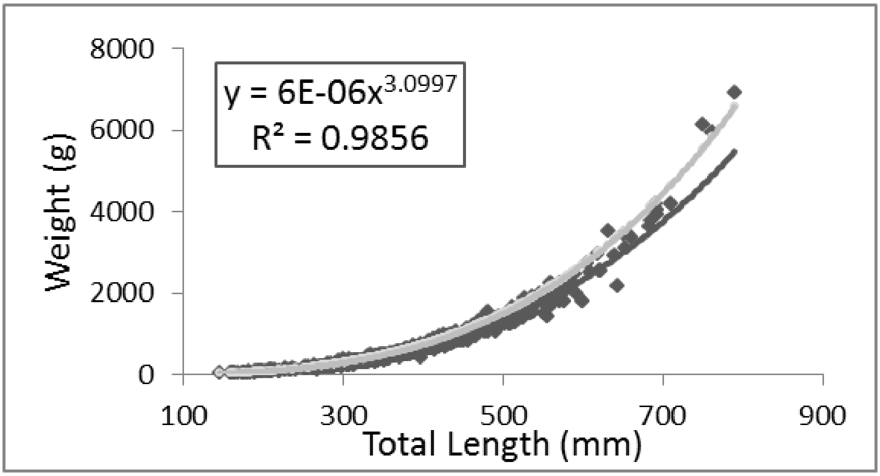

FIGURE 2.—Length-weight scatter plot with power regression line, slope equation and R^2 for flathead catfish (*Pylodictis olivaris*) collected from Diamond Valley Lake, Riverside County, California, during July 2014. The light gray line is the expected weight-at-length power regression line taken from the slope equation of Bister et al. 2000.

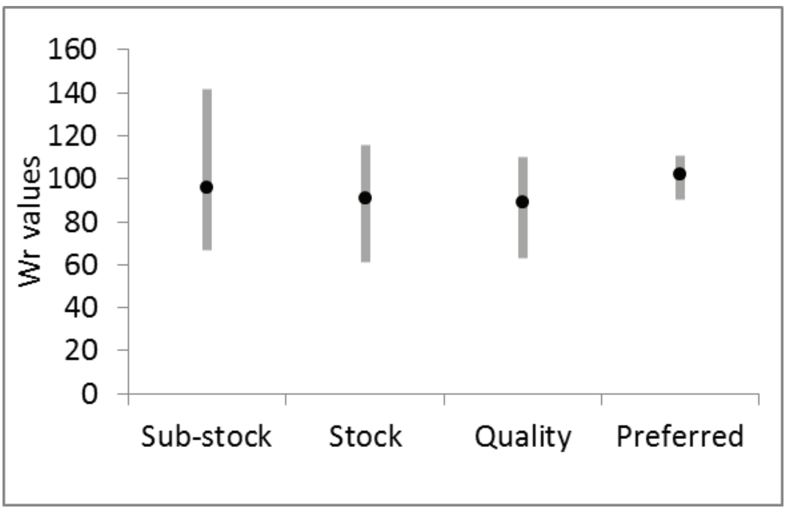

FIGURE 3.—Relationship between mean relative weights (Wr) and proposed stock distribution length categories for flathead catfish (*Pylodictis olivaris*) collected from Diamond Valley Lake, California, during July 2014. The shaded lines represent the range of Wr values of individuals sampled with the dark circle representing the mean Wr value.

Reservoir elevation dropped 3 m during the 41-day duration of sampling and has fallen 10.66 m since 1 January 2014. Reservoir surface water temperatures ranged from 24°C to 28°C during sampling. Stratification of the lake resulted in an epilimnion reaching a depth of only 9 m throughout sampling. Dissolved oxygen was 8 mg/liter down to 9 m, beyond which it dropped to 1 mg/liter in the metalimnion (11 m) and became anoxic throughout the hypolimnion.

Discussion

Ninety-eight percent of the Floy FD-68D anchor tags applied were retained during the sampling period. Though the retention rate was high for the Floy tags, using them for a FCF mark-recapture population estimate is not recommended, as any tag loss can lead to lost marks. Lost marks violate one of the basic, yet critically important, assumptions of mark-recapture population estimators (Krebs 1999). This study utilized a partial pelvic fin clip as a secondary mark to identify FCF that would have been adequate on its own for the purpose of these population estimates.

The FCF population in Diamond Valley Lake appears to be abundant and consisting of mostly stock (350 mm) and quality (510 mm) sized fish. Typically, unexploited fish stocks are characterized by high population abundance, a low rate of annual mortality and a broad range of fish age and length classes (Clady et al. 1975, Goedde and Coble 1981). Although abundant, FCF of the larger memorable (860 mm) and trophy (1020 mm) sizes in DVL were not sampled as compared to other FCF populations in the U.S. (Bister et al. 2000). This is due to this population becoming established relatively recently, not permitting enough time for many FCF to achieve larger sizes. Since DVL is recently impounded (2000) and the FCF population is recently established, the growth rates should be high (Buck 1956, Pisano et al. 1983, Sakaris et al. 2006). Sneed et al. (1961) suggested that FCF growth is faster in reservoirs than in rivers, although more recent data suggest that growth rates in reservoirs are variable and are generally similar in range to riverine based populations (Guier et al 1984). Although age data were not available, fish captured likely ranged from 1 to 7 years old, with the majority 2–4 years old based on length-at-age data collected from the Colorado River or Coachella Canal (Pisano et al. 1983, Young and Marsh 1990). Water from the Colorado River imported into DVL is the most likely source of FCF. Also, given the geographical proximity of DVL to the Colorado River and Coachella Canal, growth rates are expected to be similar. Daugherty and Sutton (2005) suggested thermal gradient and length of growing season associated with geographic location are reliable indicators of FCF growth rates. The length-weight results from DVL appear very similar to pooled data collected (Bister et al. 2000), with DVL FCF larger than 600 mm generally weighing less (Figure 2). Although the DVL population appears to lack older fish the population appears to be growing at a typical rate and may develop higher RSD-P, RSD-M, and RSD-T over time.

There are likely larger specimens within the lake that were not sampled as part of this study, as a few have been reported caught by anglers or have been seen during other CDFW electrofishing efforts. The first recorded FCF was sampled in 2007 and was 495 mm TL, likely 3–4 years old at that time, based on work by Pisano et al. (1983). By 2014, this individual may be greater than 1000 mm (Pisano et al. 1983, Marsh and Young 1990, Moyle 2002) and able to ingest a largemouth bass up to 604 mm TL (Slaughter and Jacobson 2008). Thomas (1993) noted it took 10 years for the FCF population in the Altamaha River, Georgia to increase from relative obscurity to the dominant predator present in mainstream habitat. It appears the FCF population in DVL is progressing in a similar manner given a single FCF was sampled in 2007 and up to 2.24 fish/minute larger than stock size were sampled during this study.

The abundance of approximately 2–4 year old fish coincides with a dramatically increased, and then relatively stable, water level in DVL from 2010 to 2012, which also

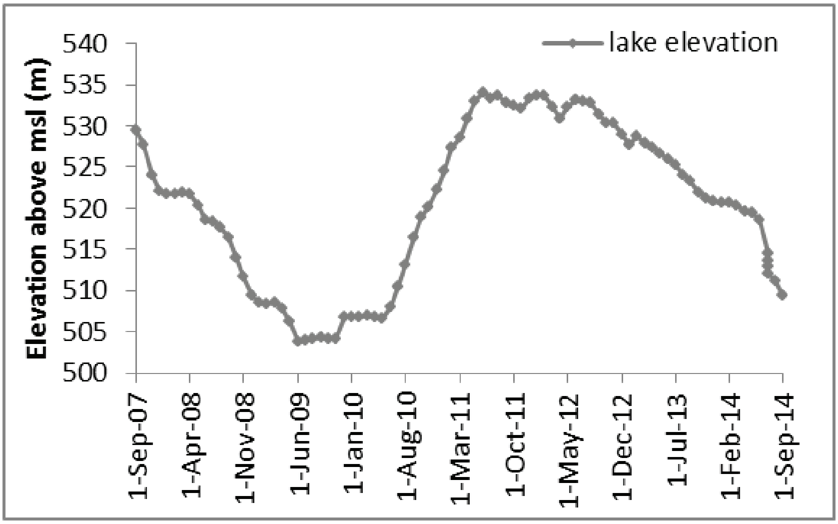

FIGURE 4.—Monthly pool elevation above mean sea level at Diamond Valley Lake, California, from September 2007 to July 2014.

increased the availability of suitable spawning and residential habitat (Figure 4). Relatively stable water levels with some spring flooding improve FCF reproduction and survival in hydropower storage reservoirs (Plosky et al 1984). Flathead catfish have habitat requirements that vary with age. Juveniles in rivers prefer riffles and runs with complex structure, and adults prefer deep pools with large rocks and woody debris in areas of strong flow (Moyle 2002). In reservoirs, the availability of rock rip-rap limits FCF populations more than the availability of suitable forage, where they use the habitat type for cover, spawning, and foraging (Layher and Boles 1980). Weller and Winter (2001) reported that FCF total abundance may be limited to the amount of rock and wood habitat available in a reservoir. Their results showed FCF used rocky substrate the majority of the time (61.4%–62.6%) in Buffalo Springs Lake, Texas, where that type of habitat accounted for only 16% of the available substrate.

The amount of habitat suitable for FCF spawning or residence within DVL is mostly limited to the rip-rap areas on the three dams and other smaller areas intermittently spaced around the inlet-outlet tower and marina at higher water levels. Areas of rip-rap with larger interstitial spaces for fish to use are also more abundant at higher water levels in DVL. Large water fluctuations cause erosion and deposition of sediments, which fills interstitial spaces at lower water levels. This was evident during the last sampling effort when the water level dropped rapidly, revealing rip-rap devoid of interstitial spaces as a result of silting. The number of fish sampled during the final effort was much lower (n=156) than in weeks prior ($\bar{x}$=572). In addition to the rip-rap areas, possible spawning habitat includes 2,500 PVC pipe caves that were placed on the lake shoreline prior to filling; however, all of these caves were in 8–30 m of water for the last 2–4 years of higher water, and away from the rocky areas of the lake. At this depth, FCF are unlikely to use the caves for spawning, as FCF rarely occupy deeper water during spawning (Weller and Winter 2001). Summerfelt

(1971) reported FCF in reservoirs prefer to spawn at depths of 2-5 m. The PVC spawning caves, thus, are unlikely to have contributed to FCF spawning success over the last 2–4 years.

Recruitment of juvenile FCF (114–318 mm) to adults increased in years when reservoir surface area is higher than average in spring and followed by a more extensive than usual summer drawdown (Lee and Terrel 1987). Diamond Valley Lake has been higher in the spring with drawdowns in the summer or fall over the last 2 years, which likely improved recruitment of the 2–4 year classes observed in this study.

Approximately 6.44 km of rip rap were sampled resulting in an estimated density of 977 to 1,034 fish/km for this habitat in DVL. Studies in the lower Colorado River, Arizona, and St. Joseph River, Michigan, estimated FCF densities of 155 to 229 fish/km (Marsh et al. 1988) and 145 fish/km (Daugherty and Sutton 2005), respectively. The numbers of FCF per km in DVL are much higher than those found in either river, although only the St. Joseph River investigators focused on selectively sampling preferred habitat. However, Weeks and Combs (1981) estimated the total FCF population in a 4,050 ha Oklahoma reservoir at 4.1 fish/ha, which compares to 3.6-3.8 fish/ha within DVL. Given the behavioral tendency of FCF to maintain and defend a home range and populations that are generally regulated by the availability of rip-rap habitat, it is surprising that only 10% of the FCF marked were recaptured during this study. Many investigators have documented FCF to be solitary in nature, to have a propensity for site fidelity, and to be extremely aggressive toward other FCF, which implies they are unwilling to leave their established home ranges (Funk 1957, Swingle 1964, Hackney 1965, Hart and Summerfelt 1974, Gholson 1975, Skains and Jackson 1995, Weller and Winter 2001, Gelwicks and Simmons 2011). Each sampling effort at DVL was conducted while a drastic reduction in water level occurred (3.96 m over 41 days; Figure 4) and a strong thermal stratification limited the usable habitat (i.e., conditions were anoxic below 11 m). These factors confined FCF to shallower zones in the rip-rap areas where they were more vulnerable to the electrofishing sampling method used in this study. Rip-rap habitat is fairly homogenous and the large number of unmarked fish sampled at a high catch rate may indicate FCF population saturation within the preferred habitat. Even though rip-rap habitat on the dams extends much deeper than was habitable due to the thermal stratification, the rapidly decreasing water level may have crowded FCF and forced some of them to move laterally and away from preferred habitat to find other areas in which to forage or reside, particularly during the last sampling effort when the number of FCF sampled was much less than prior efforts.

Weller and Winter (2001) also reported a reduced amount of FCF habitat availability in a reservoir due to anoxic conditions below 7.9 m. During lake stratification they reported FCF utilized rock substrates only 47% of the time, rarely in shallow (0.1–0.9 m) or deep water (6.0–7.9 m), although their findings were not affected by changing lake levels. It is possible that fish collected were displaced from their home range by physical relocation due to sampling efforts. However, radio telemetry studies have documented homing tendencies of FCF with individuals returning to the same area in as little as 1.7 days (Hart and Summerfelt 1974, Duncan and Meyers 1978, Dobbins et al. 1999, Pugh and Schramm 1999).

Due to their nocturnal nature and restrictive regulations on lake use, FCF are not generally available to anglers in DVL. Methods of take typically used for targeting FCF are not legal in Riverside County, further inhibiting an anglers' ability to target FCF. Annual creel surveys conducted at DVL showed only seven FCF caught by anglers in 2013 and four in 2014 (Q. Granfors, CDFW, unpublished data). The fish were reported as being caught on artificial lures by anglers targeting other species, which indicates they were incidental catches.

Low fishing pressure increases the potential of the FCF population in DVL to grow unchecked and negatively affect the management of the other fisheries. Thomas (1993) reported a significant increase in CPUE for FCF by electrofishing, but without a discernable increase in the number of FCF reported to creel surveys and observed a decline in abundance of red breast sunfish (*Lepomis auritus*) and bullhead (*Ameiurus* sp.) over the same time period. Also, 50% of the FCF sampled for this study are at, or just below, the size or age of reaching sexual maturity (Turner and Summerfelt 1971, Moyle 2002), which could result in a future population eruption. Because of this potential, methods for controlling the FCF population may be needed. FCF are long-lived and have relatively low fecundity, resulting in altered population size and age structure with excessive harvest (Jenkins and Burkhead 1994, Stauffer et al. 1996, Jackson 1999). Given population estimates of 6,295-6,660 FCF, a removal similar to our first sampling effort (i.e., 1,871 FCF over 350 mm) would be equivalent to removing 28–30% of the population. Sakaris et al. (2006) predicted that an intensive electrofishing removal plan, coupled with minimal protection from anglers, would considerably reduce the biomass of FCF in the Satilla River, Georgia, where invasive FCF were introduced in the mid-1990s. Bonvechio et al. (2011) evaluated the use of intensive electrofishing to remove FCF from the Satilla River, Georgia, resulting in 65% of the total FCF biomass being removed from the river. Bonvechio et al. (2011) recommended periodic removal of FCF as a reasonable method to manage FCF where they have been introduced. Reducing the predatory and competitive potential of FCF should provide other sport-fish populations in DVL a greater opportunity to flourish, resulting in a better fishery overall for anglers in California.

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