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Memorandum

To: Katrina Grantz, Bureau of Reclamation, HFE Technical Team Lead

From: David Ward, Grand Canyon Monitoring and Research Center, Research Fish Biologist

CC: Vineetha Kartha, GCDAMP Technical Work Group, Chair

Date: Sept 30, 2015

Subject: Green Sunfish *Lepomis cyanellus;* Risk Assessment for the Colorado River ecosystem (CRe)

The detection of large numbers of Green Sunfish *Lepomis cyanellus* in Glen Canyon has repercussions for the management of fisheries and other resources in the Colorado River below Glen Canyon Dam. The risk of dispersal of this invasive species must be taken into consideration as the Environmental Assessments (EA) for Nonnative Fish Control and High-Flow Experiments (HFE) are implemented. Experimental floods are of particular concern since this species is adapted to using floods as a means of dispersing to new habitats and colonizing them. Eradication of Green Sunfish from Glen Canyon prior to any HFE would eliminate the risk of dispersal and subsequent establishment of this harmful nonnative in the Colorado River or any of its tributaries in Grand Canyon. Potential methods to eradicate Green Sunfish from Glen Canyon include mechanical approaches like electrofishing, netting, or concussive methods and chemical treatments such as piscicides or carbon dioxide. Of the methods evaluated to remove these fish, chemical treatments provide the greatest likelihood of success.

Below, I summarize available literature concerning Green Sunfish life history and the risks they present to native fishes as well as describe and evaluate methods available to remove these fish from Glen Canyon.

Background

The continued decline of native fish populations in the southwestern USA is largely attributed to interactions with invasive aquatic species, with repeated studies demonstrating the inability of native fishes to persist in environments where nonnative fish have become established (Marsh and Pacey, 2005). Warm-water nonnative fish such as Green Sunfish, commonly dominate the small ponds and streams of the desert Southwest (Schade and Bonar, 2005). Once established, these invasive species prey upon and compete with native fishes, ultimately jeopardizing the existence of native fish populations (Minckley and Marsh, 2009). Attempts to eradicate established populations of nonnative aquatic species are common, but success is often limited because very few effective tools are available for managing invasive aquatic species (Marking 1992; Dawson and Kolar, 2003; Tyus and Saunders, 2000). This creates the need to prevent introductions and to identify and remove threats quickly before they become established.

Green Sunfish are native to the Great Lakes and the Mississippi River Basin. In low gradient rivers such as the Mississippi with large floodplains, dispersal during flood events is an effective survival strategy because the likelihood that a dispersing individual will encounter suitable habitat to colonize and reproduce is high. Fish that evolved in these systems commonly use this type of dispersal/colonization strategy, unlike native southwestern fish which typically avoid displacement during flood events (Minckley and Meffe, 1987). Juvenile Green Sunfish actively seek to disperse during flood events leading to movement downstream (Dudley and Matter, 2000) and colonization of new environments (Cochran and Stagg, 2011). Green Sunfish are prolific spawners producing up to 10,000 eggs per female (Wang, 1986). They also tolerate extremely high densities among themselves and reproduce at small sizes under crowded conditions (Minckley, 1973), allowing them to reach very large population sizes quickly. Green Sunfish have demonstrated rapid invasion and expansion potential in both riverine and pond environments throughout the southwestern United States indicating the sunfish currently located in Glen Canyon are very likely to disperse downstream during HFEs designed to conserve sandbars within Grand Canyon. Bathymetric maps of the slough area (located approximately 12.2 miles upstream of Lees Ferry, hereafter designated RM -12) indicate the area becomes a flowing side channel at flows between 20,000 and 30,000 cubic feet per second (cfs) (Figure 1), while the minimum flows for HFEs are 31,500 cfs.

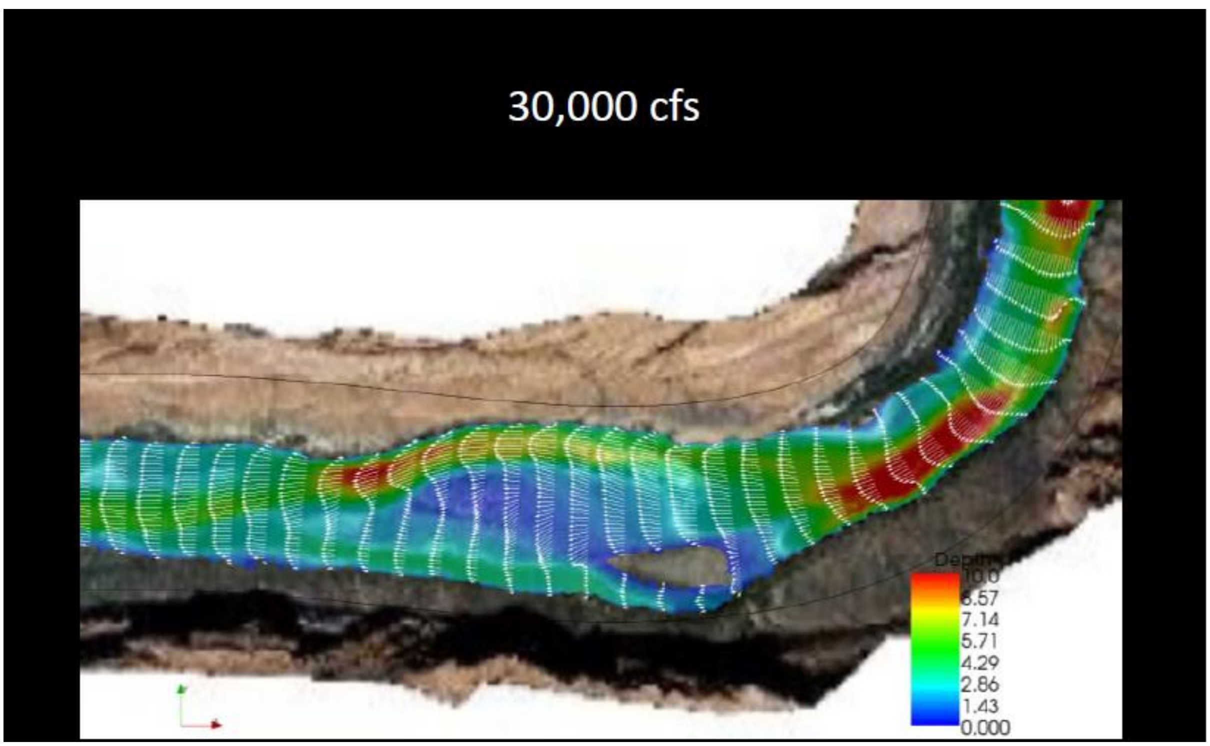

Figure 1. Two-dimensional streamflow model of predicted water surface extent and depths in

Lees Ferry, RM -12 showing full connection at modelled flows of 30,000 cfs. (Scott Wright, US Geological Survey, written commun., 2015).

Green Sunfish are the most piscivorous member of its genus (Dudley and Matter, 2000). They are highly predaceous with documented negative impacts to native fish and amphibian populations throughout the Southwest (Moyle and Nichols, 1974; Moyle, 1976; Rosen and others, 1995; Karp and Tyus, 1990). Green Sunfish also compete with and prey on the eggs and larvae of other fishes (Moyle, 1976; Lemly, 1985; Cochran and Stagg, 2011). Their large mouth relative to their body size allows them to consume both larval and juvenile native fish and have adverse impacts on juvenile native fish for extended time periods, particularly in environments where growth rates of native fish are reduced because of low water temperature. Young life stages of chub do not persist in streams occupied by Green Sunfish. No recruitment of young-of-year Gila Chub *Gila intermedia* occurred in the presence of sunfish in Sabino Creek, Arizona (Dudley and Matter, 2000). Even small Green Sunfish are highly predacious on young-of-year chub with 140 mm sunfish readily consuming chub half of their size (70 mm) in laboratory predation experiments (David L. Ward, US Geological Survey, unpublished data).

Green Sunfish in the Colorado River Ecosystem

Green Sunfish have been present at low levels within the Colorado River ecosystem for at least 35 years. For the purposes of this memorandum and as previously defined by the Glen Canyon Dam Adaptive Management Program (GCDAMP), the Colorado River ecosystem (CRe) is defined as the segment from the forbay of Glen Canyon Dam downstream to westernmost boundary of Grand Canyon National Park, including tributaries. Long- term fish monitoring in this area routinely documents a few Green Sunfish each year, but few very have ever been captured in the Lees Ferry reach. From 1980 to 2014 there were 80 Green Sunfish captured in the CRe (Figure 2), with more than half of those fish caught near the confluence of Kanab Creek (river mile (RM) 125 [as measured from Lees Ferry, AZ]) or downstream (Figure 3). However, in July 2015, the Arizona Game and Fish Department collected 43 sunfish during routine monitoring at Lees Ferry in the backwater at RM - 12 (hereafter the slough) and in an associated pool directly upstream of the slough (Lisa Winters, AZGFD, written communication, date?). In response to the unusually high number of sunfish, two removal efforts were conducted, in accordance with the Comprehensive Fish Management Plan (NPS, 2013). In two subsequent removal trips, a total of 3,528 sunfish were captured and removed using standardized boat mounted /backpack electrofishing and netting techniques (Winters, 2015). The relatively large numbers of small sunfish caught indicate a significant infestation in this small area. The numbers of sunfish captured did not decline between passes or trips, indicating that these methods are unlikely to be successful in eradicating sunfish from this area.

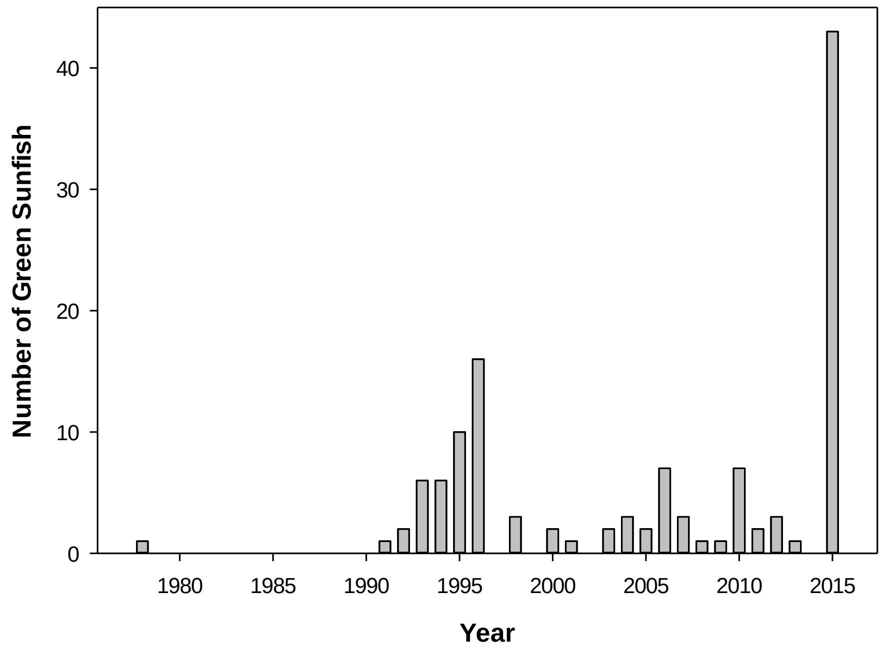

Figure 2. Number of Green Sunfish caught in the CRe during standardized monitoring by year from 1978-2015.

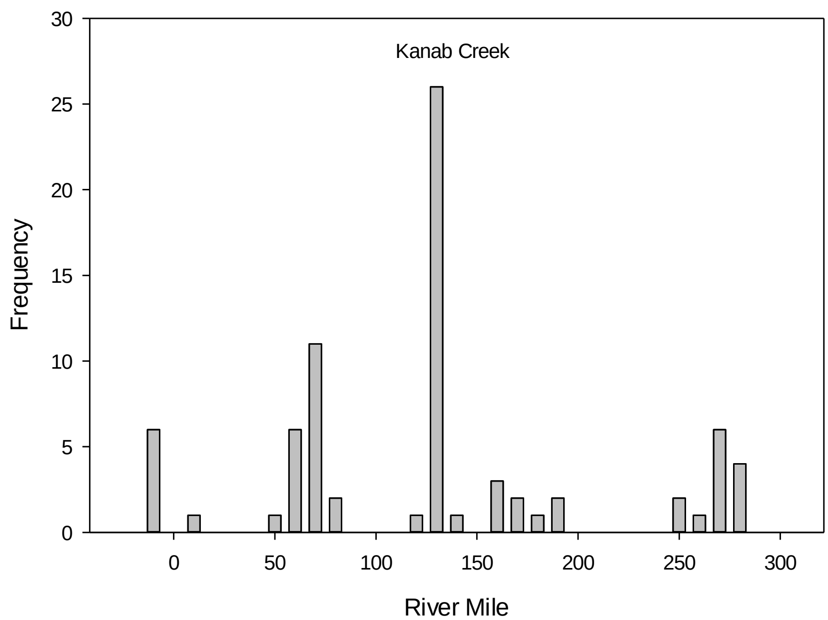

Figure 3. Location of Green Sunfish captured in the CRe from 1978-2014.

Source of Green Sunfish at Lees Ferry

Glen Canyon Dam uses Francis style turbines to generate power (Hilwig and Andersen, 2011 draft). Survival of small fish through Francis turbines, which pass large volumes of water, is commonly 70 percent or higher (Cada, 2001). Occasional captures of fish common in Lake Powell downstream, near the dam, such as Smallmouth Bass *Micropterus dolomieu* and Channel

Catfish *Ictalurus punctatus*, suggest that both juvenile and adult life stages can pass through Glen Canyon Dam turbines and survive (Hilwig and Anderson, 2011, administrative report). Smallmouth Bass were first discovered in Grand Canyon in 2003 with the capture of a 348-mm adult fish 3.2 km (1.9 miles) downstream of Glen Canyon Dam. In 2004, a 70-mm juvenile smallmouth was also captured 8 km downstream of the dam. Both of these fish likely passed through the dam. It is likely that the sunfish which spawned in the backwater at Lees Ferry also came through the turbines. The large number of very small juvenile sunfish currently occupying the slough at Lees Ferry (Figure 3) indicates spawning has occurred at that location. At full pool, penstock intakes are located at 230 feet below the water surface reducing the number of fish that become entrained, but fish passage likely increases during drought conditions when reservoir levels are reduced and intakes are much closer to the surface.

Temperature Tolerance

Even though Green Sunfish are considered a warm-water species they can tolerate a wide range of environmental conditions (Wallus and Simon, 2008). Their thermal optimum is similar to that of the native Colorado River fishes (20 °C). Current conditions throughout much of the CRe in the mainstem Colorado River are sub-optimal for sunfish (similar to the native fish) but they can survive at current river temperatures. It has been generally estimated that water temperatures increase about 1°C for every 48 km (30 miles) traveled downstream within the CRe (U.S. Department of the Interior, 1999). At this rate of warming, mainstem temperatures do not reach levels suitable for good growth and reproduction of sunfish until about Kanab Creek (RM 125), but backwater areas and tributaries do provide the thermal environment sunfish need for reproduction (Table 1). These are the same environments that are sought out by native Colorado River fishes, which increase the likelihood that sunfish will adversely impact native fishes. A large source population of sunfish at Lees Ferry increases the likelihood of widespread establishment of sunfish within the CRe, especially if drought conditions continue causing reduced water levels in Lake Powell and warm downstream release temperatures.

Table 1. August 2015 surface water temperatures recorded by Arizona Game and Fish Department personnel with a handheld thermometer (Winters, 2015)

Location	Temperature (°C)
Mainstem (Ferry Swale Camp, RM -11.4)	12.9
Midpoint Slough	16.3
Upper Slough (multiple readings)	22.8

Green Sunfish are known to be displaced by large flood events (Dudley and Matter, 2000) and thus are unlikely to maintain large populations in tributaries such as the Paria River and the Little Colorado River. They are also likely to be displaced by high flow events in the mainstem Colorado River. Green Sunfish may temporarily be displaced into colder more unfavorable environments where survival is lower, but fish that survive will seek out warm backwaters and tributaries after moving downstream. An upstream source that continues to allow new individuals to disperse downstream and colonize tributaries, when they are not in flood stage, greatly increases the likelihood of sunfish establishment in tributaries of the CRe.

Statement of the problem

Green Sunfish are a leading cause of native fish declines in the Southwestern US, and the large population of Green Sunfish established in Lees Ferry represents a significant threat to Colorado River native fish populations in Grand Canyon. Immediate eradication of Green Sunfish from Glen Canyon seems prudent and may prevent this invasive warmwater species from colonizing downstream reaches in Grand Canyon that are managed for native fish. Below is a list of potential options for control and a comparison among options (Table 2).

Control/Eradication Options

No Action

If no further action is taken, there is a high risk of sunfish spreading downstream and becoming established in and near other tributaries, primarily the Little Colorado River, where negative impacts to the endangered humpback chub will occur. This risk is increased by expected warmer than usual temperature of water released from Glen Canyon Dam, due to low reservoir elevation in Lake Powell. The risk would be further increased if the sunfish are not eliminated prior to implementation of an HFE.

Electrofishing

Electrofishing is often used to remove non-native fishes from streams as part of mechanical removal projects designed to aid native fish. Use of electrofishing to remove predatory fishes from large rivers such as the Colorado River has been shown to be largely ineffective (Mueller, 2005; Breton and others, 2012), but managers still commonly use electrofishing to attempt removal of invasive aquatic species from small streams or pond environments. Commonly used electrofishing methods are unlikely to remove all of the fish even in small shallow streams exhibiting conditions ideal for electrofishing (Penczak and others, 2003; Meyer and others, 2006). In Bonita Creek, a small warm-water stream (<2 cfs) in southern Arizona, three-pass electrofishing on consecutive days removed an average of 45 percent of the fish present, as revealed by a subsequent rotenone treatment (Ward and others, 2015). Effectiveness has been shown to decrease with stream size and habitat complexity (Bayley and Dowling, 1993), suggesting that complete eradication of nonnative warm-water fishes using standard electrofishing techniques to be highly unlikely even with repeated effort.

Netting

Various types of nets have been used in the upper Colorado River basin to remove nonnative fishes (Martinez and others, 2014; Trammell and others, 2004). Gill nets, trammel nets, seines, and both baited and unbaited trap nets continue to be used to remove nonnative fishes in both lotic and lentic environments both in the upper basin (Martinez and others, 2014) and the CRe (Persons and others, 2013). In the clear water typically present from Glen Canyon Dam downstream to Lees Ferry, entanglement nets are less effective than in areas with turbid water because the fish can see the nets and avoid capture. Fishing nets at night does improve capture rates, but some species still avoid capture. Repeated seining in backwaters has been shown to be less than 100 percent effective at removing small bodied nonnative fish (Trammell and others, 2004), particularly when seines are impeded by uneven substrate (large cobble) or rooted vegetation, both of which occur in the slough.

Experimental Mechanical Removal Methods

Pulse pressure generated from a water gun has been shown to be effective at controlling Northern Pike *Esox lucius* (Gross and others, 2013) and Asian Carp *Hypophthalmichthys nobilis* (Layhee, 2013) in experimental settings. Use of pulsed-DC electric fields have also shown promise at moving fish out of areas where they are unwanted (Stewart-Malone and others, 2014). These new tools, although experimental and unproven on Green Sunfish, warrant further investigation.

Angling Harvest/Monetary Incentives

The removal of bag and possession limits for non-salmonid sport fish has been used in the upper basin to promote the harvest of nonnative fishes and reduce their population sizes (Martinez and others, 2014). Incentives that entice anglers to remove invasive species and reward them for removing problematic fishes has also been used in the upper Colorado River Basin (Martinez and others, 2014) and in other systems like the Columbia River to remove Northern Pikeminnow (Radtke and others, 2004), but these programs have yet to show marked effectiveness and diminishing populations of target fishes. Green Sunfish are highly vulnerable to angling methods (Minckley, 1973), but rarely reach more than 178 mm (7 inches) in length (Johnson, 2008). Green Sunfish caught in 2015 averaged less than 65 mm TL (Figure 4; Winters, 2015), indicating a majority of the sunfish present at Lees Ferry would not be vulnerable to angling techniques, or desired by anglers. Limited numbers of anglers willing to pursue small sunfish and the remote location of the infestation make removal using angling techniques unfeasible.

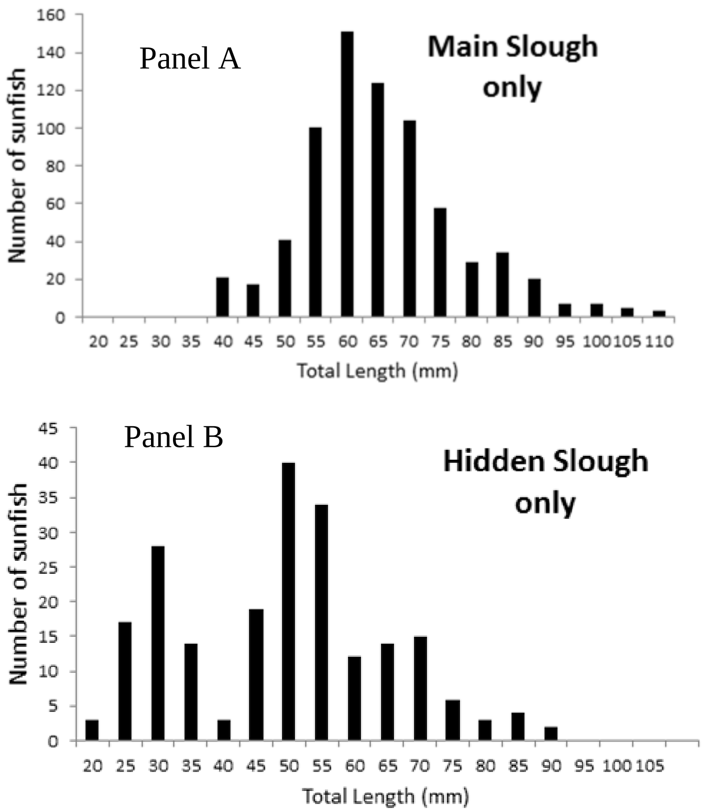

Figure 4. Sizes of Green Sunfish caught in 2015 at Lees Ferry. Panel A Main backwater (slough). Panel B – Isolated backwater at upstream end of slough (Graphs created by Lisa Winters, Arizona Game and Fish Department).

Explosives

Metzger and Shafland (1986) used detonating cord to create a concussive blast and kill fish in small lakes and ponds. Explosives were effective at sampling fish and reducing fish biomass by almost 90 percent but were not effective at eradicating all fish. Use of detonating cord to eradicate sunfish from the slough area at Lees ferry may be possible if strands of cord are laid less than 7 m apart.

Dewatering

Drying of fish habitats can be an effective tool for controlling fish. However, the slough cannot be fully dewatered. Water levels in the hidden slough appear to be maintained by subsurface flow, and the main slough/backwater is too deep to completely dewater without going below established minimum flow levels (5,000 cfs). Construction of a physical barrier to isolate the slough at typical flows and facilitate removal of the sunfish using chemical methods may also be needed. Physical modification to the area to prevent a ponded area, or modification that would allow for continuous flow-through after a successful sunfish removal is completed may be warranted to prevent continuing infestation of warm water invasive fishes.

Chemical Piscicides

Piscicides such as rotenone[1] and antimycin A[1] are effective toxicants for Green Sunfish. Chemical piscicides, when applied properly under favorable environmental conditions, have been shown to effectively eradicate localized populations of sunfish in environments similar to the infestation at Lees Ferry. Rotenone is readily available and widely used, (Finlayson and others, 2010), and is the only chemical fish toxicant currently approved (Dawson and Kolar, 2003). Antimycin A is no longer being manufactured and unavailable at the current time. Small-scale spot treatments using piscicides such as rotenone have proven effective in the Upper Colorado River Basin (Martinez and others, 2014). Rotenone was successfully used recently in the Old Charlie Wash wetland – a large shallow pond adjacent to the Green River in Utah (Monroe and Hedrick, 2008). Rotenone is toxic to most fish, and non-target species may be incidentally killed, creating the need for extreme caution, and careful dosing (and neutralization) in a location such as Lees Ferry, where valuable angling resources are in close proximity to the treatment location.

Other chemicals such as carbon dioxide (Gross and others, 2010) or liquid ammonia (Ward and others, 2013) have also emerged as potential tools for local eradication of invasive fish. These methods are experimental and lack a current mechanism for regulatory approval. Although this localized infestation could provide an opportunity to further explore these new tools, use of these experimental methods may be controversial in a high profile location like the Colorado River.

[1] Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Table 2. Matrix of removal methods and likelihood of successful eradication

Removal Method	Cost	Likelihood of Eradication	Comments
Electrofishing	High	Low	High personnel costs
			Repeated effort needed
Netting	High	Low	High personnel costs
			Repeated effort needed
Pulse Pressure Gun/Pulsed DC fields	Moderate	Unknown	Effectiveness unknown for Green Sunfish
			Effective for other species
Angling/harvest incentives	*Low	Low	* High for paid incentive programs
			Not feasible for the sizes of fish present
Dewatering	N/A	Low	Not possible - given the location
Explosives	Low	Unknown	Effective to reduce density, but eradication effectiveness unknown
Rotenone	*Low	High	Known to be effective, but repeated effort if re-invasions occur
			Environmental compliance is needed *low cost for materials, but potentially high costs for planning and compliance.
Carbon Dioxide	Moderate	Unknown	High personnel costs to dispense and mix
			Experimental; lacks regulatory approval
Ammonia	Low	High	Known effectiveness for Green Sunfish
			Experimental; lacks regulatory approval

Conclusions and Treatment Recommendations

Eradication should be the goal of invasive fish management because it removes the need for further control and ongoing environmental or economic costs (Martinez and others, 2014). The best time to eradicate invasive species is when they are first detected and their numbers are low and distribution is limited (Myers and others, 2000). Once invasive fish become established, the damage is often irreversible. The chemical piscicide [1]rotenone or the experimental use of ammonia appear to be the best options for complete eradication of Green Sunfish from the backwater area at Lees Ferry. The application of mechanical options have low likelihood of success, even in combination. Life history characteristics of sunfish (high reproductive potential, and propensity to move with flood events) indicate that without complete eradication, sunfish are likely to persist and spread downstream. The use of rotenone or ammonia in the CRE presents environmental compliance hurdles, but will have the highest likelihood of success at the lowest cost provided the appropriate approvals for application can be obtained, that this is a one-time action, and the area can be modified to prevent further re-invasion. To eradicate Green Sunfish from Lees Ferry we recommend a two phased approach involving an initial mechanical treatment using electrofishing and pulse pressure water guns (Gross et al. 2013), followed by chemical treatment with either rotenone or ammonia, once appropriate regulatory approvals have been secured.

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