A Brief History of the Use of Grass Carp to Manage Vegetation in Iowa Lakes

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Introduction

Grass Carp (*Ctenopharyngodon idella*), a species native to eastern Asia, was first imported into the United States in 1963 for biological control of aquatic vegetation (Mitchell and Kelly 2006). State and federal agencies enthusiastically promoted their use, and by the early 1970s up to 40 states had introduced this species (Pflieger 1978; Mitchell and Kelly 2006). As of 2017, Grass Carp had been stocked or become established in 45 states - only Alaska, Maine, Montana, Rhode Island, and Vermont remain undocumented (USGS 2017). Since the early 1980s, sterile triploid Grass Carp were used in an effort to prevent natural reproduction by this species (Cassani and Caton 1986; Thompson *et al.* 1987; Mitchell and Kelly 2006). Triploids match diploids closely in behavior, metabolism, growth, and longevity, consuming only about 10% less plant biomass and initiate feeding at water temperatures ≈1°C higher than diploids (Wiley and Wilke 1986; Wiley and Gorden 1984; Leslie *et al.* 1996; Stich *et al.* 2013; Kirk *et al.* 2014).

In Iowa, 90% of significant public lakes (n = 140) are classified as eutrophic or hyper-eutrophic. As a result, extensive submerged aquatic vegetation (SAV) necessitated frequent management attention. Grass Carp stockings initially were viewed as an effective method to control SAV; however, managers noted that this approach often triggered opportunistic algal blooms that were detrimental to biodiversity, water quality, and recreation, and sometimes produced harmful cyanotoxins (Smith *et al.* 1999; Heisler *et al.* 2008; Paerl and Paul 2012). Given the longevity of Grass Carp and propensity for vegetation eradication - and Iowa's relatively simple fish communities - managers grew concerned about long-term impacts on sport fisheries and ecosystem health (Hill 1986; Stich *et al.* 2013; Kirk *et al.* 2014). Consequently, although Iowa stocked numerous public water bodies since 1974, Grass Carp were removed from its approved species list for public waters in 2010 to safeguard water quality and ecological integrity.

The purpose of this review is to examine Grass Carp's biological traits, their historical use in Iowa lake management, documented ecological effects of past stockings, alternative vegetation-control methods, and current policy governing Grass Carp in Iowa.

Grass Carp Biology

Feeding Dynamics

Understanding Grass Carp feeding dynamics is critical when considering this method of aquatic plant management. These fish exhibit exceptionally high consumption rates and low metabolic demands. Their bioenergetic assimilation efficiency is low (≈29%), a trait attributed to their relatively short gut length (Wiley and Gorden 1984; Van der Lee *et al.* 2017). Adult diploids and triploids exhibit similar feeding behaviors (Standish and Wattendorf 1987).

Grass Carp are selective herbivores and will prioritize preferred species before less desirable ones (Table 1; Edwards 1974; Colle *et al.* 1978; Fowler and Robson 1978; Mitzner 1978; Mitchell 1980; Van Dyke *et al.* 1984; Wiley and Gorden 1984; Blackwell and Murphy 1996; Leslie *et al.* 1996a; Dick *et al.* 2016). Local conditions and fish age influence selectivity. For example, Wild Celery (*Vallisneria americana*) was not preferred by adult fish in Florida (Leslie *et al.* 1996a) or Texas (Dick *et al.* 2016) but was highly preferred by juvenile triploid Grass Carp in the Pacific Northwest (Bonar *et al.* 1993a). Plant nutrient content also affects preference; Grass Carp consumption showed positive correlations with calcium and lignin concentrations and negative correlations with iron and cellulose (Bonar *et al.* 1990).

Several other factors influence consumption, including handling time (the time it takes to consume a plant), geographical location, and plant chemical composition - each of which can vary with plant species and site conditions (Leslie *et al.* 1996a). In laboratory studies, handling time was identified as the primary determinant of species preference (Wiley and Gorden 1984b). Grass Carp generally prefer soft, succulent submersed species over tougher emergent or floating-leaved vegetation (Stewart and Boyd 1999; Pipalova 2006).

Regional acclimation influences the temperature at which feeding begins. In warmer climates with longer growing seasons (e.g., Florida), Grass Carp initiate feeding at slightly higher temperatures than in cooler regions (Leslie *et al.* 1996a). Generally, feeding begins around 50°F, with optimal intake occurring between 68°F and 86°F (Wiley and Gorden 1984b). Therefore, more northerly latitudes with shorter optimal feeding periods require higher stocking rates to achieve effective SAV control (Wiley *et al.* 1985; Swanson and Bergersen 1988; Bonar *et al.* 1993a). Plant selectivity tends to decline as water temperature increases (Leslie et al. 1996a).

Fish size also affects feeding dynamics. Grass Carp under 7 lb may consume over 100% of their body weight per day. Although daily intake rate declines with size, larger fish consume greater total amounts of vegetation (Clugston and Shireman 1987). Additionally, older and larger fish exhibit less selectivity in feeding than smaller, younger individuals (Catarino *et al.* 1997; Pipalova 2006).

Table 1. Common names of Grass Carp aquatic macrophyte preference.
Superscripts denote author (Wiley et al. 1987[1], Mitzner 1978[2], Stewart and Boyd 1999[3]).

Preferred	Moderately Preferred	Not Preferred
Brazilian and Canada Elodea[3]	Bladderwort[3]	Coontail[1,2,3]
Chara spp.[1,3]	Canada Elodea[2,3]	Fanwort[1]
Duckweed spp.[3]	Pondweeds, All[3]	Lotus[3]
Hydrilla[3]	Pondweed, Curlyleaf[1]	Wild Celery[3]
Fanwort[3]	Pondweed, Longleaf[1]	Watermilfoil spp[1,3]
Naiads; Slender, Southern, Brittle[1,2,3]	Pondweed, Sago[1]	Water Shield[3]
Pondweeds, Narrow-leaved[1,2]	Spikerush[3]	White Water Lily[3]
		Yellow Water Lily[3]

Growth and Mortality
Grass Carp growth varies regionally, with documented growth rates ranging from 4.5-6.5 lb/year.Growth rates are generally lower in cooler climates (Pauley *et al.* 1994) and faster in tropical waters (Shireman and Maceina 1981; Cudmore and Mandrak 2004). Growth is also inversely proportional to stocking density (Shelton *et al.* 1981), with growth slowing in vegetation-free ponds (Rottmann and Anderson 1976). Triploid Grass Carp generally grow more slowly than diploid Grass Carp as juveniles (Cassani and Caton 1986), but these differences were not noted in adults (Standish and Wattendorf 1987). Hill (1986) observed a growth rate of almost 5 lb/year under favorable conditions in Iowa.

Mortality is difficult to estimate and contributes to variability in vegetation control outcomes. Factors influencing mortality include fish size at stocking (Gasaway 1978, as cited in Leslie *et al.* 1996b), transport stress (Mitzner 1978), mismatches in water quality between hatchery and lake, plant density, fish or avian predator presence (Kirk 1992), and escapement (S. Grummer, Iowa DNR, pers. comm.). In South Carolina's Santee Cooper system, triploid Grass Carp showed annual mortality rates of 22-39%, with the oldest fish reaching 11 years (Kirk and Socha 2003). Similarly, Florida recorded triploid Grass Carp up to 15 years old (FWC 2024). In Iowa, diploid Grass Carp generally exhibited low annual mortality (i.e., 2.2-7.7%; Hill 1986), and their longevity resulted in long term effects. For example, Grass Carp stocked into Red Haw Lake in 1973 effectively prevented vegetation growth until the lake was renovated 29 years later. Similar mortality and longevity were reported elsewhere by Iowa DNR personnel (C. Larson, G. Sobotka, B. Hayes, pers. comm.).

Reproductive Physiology and Movement
Diploid Grass Carp (2n) have 2 sets of chromosomes, are fertile and reach maturity at about age-4, spawning when water exceeds 68°F. Their eggs require flowing water to remain suspended during incubation (Chilton and Muoneke 1992). Temperature and flow requirements for spawning typically occur in Iowa when rivers are rising. Fecundity is high, with females producing over one million eggs per season. Triploid Grass Carp (3n) have 3 sets of chromosomes, though sterile, still produce gametes, but fertility is extremely low.

Despite reproductive differences, diploid and triploid Grass Carp exhibit similar spawning movement patterns in large reservoirs (Hessler *et al.* 2023). As riverine species, they seek flowing water and can escape impoundments through just a few inches of current (Masser 2002). Migration tends to occur during high-discharge events in April and May, with temperatures between 59°F and 82°F. Movement is often upstream into tributaries, with reported distances ranging from 1.9 to 67.0 river miles (Hessler *et al.* 2023). When preferred vegetation like Hydrilla is present, movement is localized (Kirk *et al.* 2001), suggesting escapement risk may be lower when adequate food sources are available. However, emigration remains a concern under conducive environmental conditions.

Grass Carp Stocking Strategies and Case Studies

Iowa's experience with Grass Carp followed two primary strategies: stocking Grass Carp alone at rates based purely on surface area, or integrating lower Grass Carp densities with targeted chemical or mechanical treatments. Historically, Iowa managers favored the former, aiming for rapid and substantial SAV reduction.

The pilot program at Red Haw Lake in 1974 exemplifies this approach. Fisheries biologists introduced 813 diploid Carp (≈12 in, 0.9 lb) at 10.7 fish/acre (Mitzner 1978). Initial monitoring detected no adverse changes in water quality (e.g., organic/inorganic phosphorus, turbidity, BOD, or temperature) nor in sport-fish populations (Mitzner 1980), prompting replication of the ≈10 fish/acre stocking rate in subsequent impoundments, sometimes adjusting fish size slightly (Mitzner 1980).

Mitzner's detailed evaluation of Red Haw Lake (71 acres; max depth 36 ft; D_V = 1.09, mean slope = 16.4) found that Grass Carp reduced SAV by 91% from 1973-1976 and eliminated all vegetation by 1979. SAV species included pondweeds (*Potamogeton* spp.), Bushy Pondweed (*Najas flexilis)*, Coontail (*Ceratophyllum demersum)*, and Canada Waterweed (*Elodea canadensis*)(Mitzner 1980).

Other case studies varied in outcome:

- Mormon Trail Lake (33 acres; max depth 32 ft; D_V = 1.29): A 1980 stocking of 9.7 Grass Carp/acre achieved complete vegetation removal and the sport fishery declined (Cashatt and Bruce 2008). Water clarity values also declined as did primary production.
- Greenfield Lake (55 acres; max depth 26 ft; D_V = 1.26): Incremental stockings totaling 1,080 Grass Carp (22.5 fish/acre over 14 years) suppressed but did not eradicate SAV. Water clarity and the sport fishery were not affected during the study.
- Cold Springs Lake (15 acres; max depth 15 ft; D_V = 1.30): From 1974-1980, 428 Grass Carp fully removed SAV until a 2006 fishery renovation with rotenone and the sport fishery declined. Water clarity was significantly improved post-renovation. It should also be noted Common Carp, known to have a negative impact on sport fish populations, were also eradicated during the renovation. Therefore, negative impacts to the sport fish were most likely caused by multiple sources.
- Southwest Iowa lakes: Multiple impoundments stocked with Grass Carp from 1979-1994 maintained <10% SAV coverage through 2016 (Table 2).

Most studies report a three-to-four-year lag between Grass Carp introduction and maximal SAV clearance.

Table 2. Lakes stocked with Grass Carp and received minimal Grass Carp removal efforts had <10% vegetation coverage.

Lake	Size (ac)	Years stocked	Sizes (in)	No/ac
Greenfield*	55	'80, '82, '94	8, 8, 8	11, 4.4, 4.4
Meadow	38	'79, '81, '94	9, 4-8, 8	10.5, 10.5, 11
Nodaway Lake	29	'80, '92, '94	8, 8, 8	12, 4.4, 4.3

Because actual annual mortality of Grass Carp in these trials was unknown, early programs assumed a 33% per-year loss - mirroring rates for native Bigmouth Buffalo *Ictiobus cyprinellus* (Mitzner 1978). Fisheries managers restocked every four to five years to maintain vegetation suppression. Later studies revealed that diploid Grass Carp mortality in Iowa ranged only 2.2-7.7% annually (Hill 1986), indicating that earlier models overestimated losses and underestimated longevity, leading to unexpected long-term high-density populations and frequent vegetation elimination.

Early Iowa evaluations noted that stocking fish >14 inches reduced predation losses and that fall or early spring stockings (water <65°F) minimized handling stress-related mortality (Mitzner 1978). Accurate pre- and post-stocking measures of SAV biomass and percent coverage were essential for refining predictive stocking models (Wiley et al. 1985; Stewart and Boyd 1999).

In most cases, Grass Carp stocking strategies in other states also noted two potential outcomes: inadequate vegetation control or complete elimination of SAV. Grass Carp stocking rates were determined by total surface acres of the lake (number of fish/ac) or vegetated acres of a lake (number of fish/VA). In a controlled Texas study, triploid adults (≈21 in) were stocked at 1.6, 3, and 5 fish/acre aiming for 10-40% SAV coverage. The lowest rate failed in two ponds, 3 fish/acre eradicated all vegetation in one pond, and 5 fish/acre reduced but did not meet coverage targets in the last pond - indicating that both plant biomass and species composition confound outcomes (Blackwell and Murphy 1996). Similarly, 38 Florida lakes monitored for 3-10 years exhibited near-complete vegetation removal when stocking exceeded 10-12 fish/VA, below the target 14% area coverage (Hanlon et al. 2000). In a 1,735-acre Florida lake, 4.2 diploid fish/acre (8.1 fish/VA) reduced Hydrilla within two years without markedly affecting other species; however, Hydrilla rebounded by year 10, necessitating additional stockings of 1.6 triploid fish/acre (2.3 fish/VA) (Leslie et al. 1994). In Oregon, stocking at 73 fish/VA (5.5 fish/wet ton vegetation) decreased surface coverage and biovolume by 30%, yet overall biomass rose due to resistant species like Brazilian Elodea (*Egeria densa)*, Eurasian Watermilfoil (*Myriophyllum spicatum)*, and Coontail (Bonar et al. 1993a). Overall, low rates (2.4 fish/ac) in the southern U.S. often removed all macrophytes (Leslie et al. 1996b), whereas temperate and colder regions with less frequent >80°F exposures and seasonal ice cover typically required higher densities to achieve similar impacts (Wiley et al. 1985; Swanson and Bergersen 1988; Bonar et al. 1993a).

Ecological and Water Quality Issues

In Iowa and many U.S. case studies, high stocking rates routinely led to complete SAV elimination within one to three years (Stott and Robson 1970; Bailey 1978; Mitchell 1980; Shireman and Maceina 1981; Van Dyke et al. 1984; Small et al. 1985; Bates and Webb 1987; Hestand et al. 1987; Maceina et al. 1991), and low stocking rates alone were not enough to achieve desired control. More often than not, use of Grass Carp resulted in SAV eradication, and this usually caused ecological and water quality issues that drastically limited fishery potential.

Shifts in Plant Community Composition

Grass Carp preferentially consume the most palatable SAV, often allowing less palatable or emergent species to dominate (Van Dyke et al. 1984; Leslie 1996a). For example, a higher rate was required to control a non-preferred invasive species, Eurasian Watermilfoil (Van Dyke et al. 1984), otherwise expansion of the more aggressive unpalatable species may occur (Leslie 1996a). In lakes retaining any vegetation after stocking, non-palatable emergent and floating-leaved species dominate; these species comprised <10 % of aquatic plants treated chemically by the Iowa DNR Fisheries Bureau in 2024 (J. Euchner, Iowa DNR, personal communication).

Fish Community Responses

Short-term enhancements in growth and catch rates of Largemouth Bass (*Micropterus salmoides*), White Crappie (*Pomoxis annularis*), and Black Crappie (*P. nigromaculatus*) have been observed following SAV removal (Maceina et al. 1991; Bettoli et al. 1992). However, three years post-stocking, fish communities often shift to favor Channel Catfish (*Ictalurus punctatus*) and White Bass (*Morone chrysops*), with significant declines in eight of 17 species (including sunfish, crappie, and Spotted Gar *Lepisosteus oculatus*), increases in cyprinids, and higher gillnet CPUE for White and Yellow Bass (*M. mississippiensis*) (Bettoli et al. 1993). In Texas reservoirs, Largemouth Bass standing crop and recruitment to >10 in were positively related to SAV coverage up to 20 % (Durocher et al. 1984).

The potential for decline of Largemouth Bass is particularly concerning in Iowa, given their top-down control on fish communities and angling quality, but also for sport fish in general. In Iowa's Red Haw Lake, 10.9 Grass Carp/acre led to higher angling pressure but no immediate sport fish biomass changes (Mitzner 1980). Stocking Grass Carp in Mormon Trail Lake was harmful to the sport fish population, with a reduction in sport fish biomass measured within a few years. Sport fish standing stock in 1999 was estimated at 238 lb/ac, and the lake was nearly devoid of vegetation (Cashatt and Bruce 2008). After removing 58 lb/acre of Grass Carp between 1999 and 2001, aquatic vegetation returned to the littoral zone and sport fish standing stocks increased to 473 lb/acre (Cashatt and Bruce 2008).

Other studies report mixed outcomes for the fish community: two Florida urban lakes stocked over 14 years saw increased shad but inconsistent centrarchid responses (Cole and Shireman 1994). One lake lost six species entirely; the other maintained total standing crop and species richness (Cole and Shireman 1994). A different set of Florida lakes lost Largemouth Bass and seven native species following complete SAV removal, with Bluegill shifting to stunted populations (Ware and Gassaway 1976; Rottmann and Anderson 1976). In Louisiana's Caney Creek Reservoir, a stocking of 2.4 triploid fish/acre eliminated Hydrilla in one year, depressed Largemouth Bass catch rates by 25-45% over five years, and reduced SAV to <10 % for floating-leaved species (Wood and Dugas 2000). Some Arkansas lakes showed no significant centrarchid changes post-stocking of Grass Carp; however, variability among lakes may have masked effects in that analysis (Bailey 1978).

Impacts on Water Quality

Vegetation removal commonly triggers increased algal blooms, elevated nutrients, and reduced clarity. Florida lakes had higher total phosphorus, total nitrogen, chlorophyll a, and lower Secchi transparency following plant elimination (Canfield and Hoyer 1992 as cited in Leslie et al. 1996b). Indiana ponds experienced increased turbidity and potassium and decreased dissolved oxygen without significant nutrient shifts (Lembi et al. 1978). Lake Conroe, Texas, displayed decreased clarity and increased chlorophyll a and nutrients, initiating a trophic cascade: more planktivorous Threadfin Shad (*Dorosoma petenense*), fewer zooplankton, and rising phytoplankton (Maceina et al. 1992). Fourteen- to sixteen-year studies in two Florida lakes documented progressive declines in water quality metrics post-stocking (Cole and Shireman 1994). Similar patterns of heightened turbidity and chlorophyll a emerged in other Florida systems, wherein lakes retaining some vegetation exhibited greater stability in nutrient and clarity parameters (Leslie et al. 1983; Small et al. 1985; Cassani 1995). In 98 Washington lakes, mean turbidity was significantly higher (11 NTU vs. 4-5 NTU) when SAV was eradicated, though chlorophyll a remained unchanged (Bonar et al. 2002).

Limnological studies have documented the nutrient buffering and phytoplankton mediating capacity of aquatic vegetation in lakes (e.g. Wetzel 1983, Jeppesen et al. 1990, Moss 1990, Van Donk et al. 1993, Phillips et al. 2016). Aquatic plants are central to providing the positive feedback necessary to maintain lakes in a clear water state over a phytoplankton-dominated turbid water state (Jeppesen et al. 1997). Small, dense stands of SAV have been found to provide daytime refugia for cladoceran zooplankton, which then migrate to open water at night to graze on phytoplankton (Lauridsen et al. 1996). Even 3% coverage by small, dense SAV beds could lead to a doubling of cladoceran density in open water at night. In shallow lakes, which have a larger portion of the lake area as SAV-amenable littoral zones, the mediating effects of vegetation on water quality have been found to be of greater importance (Moss 1990). This is of special significance to water quality in Iowa lakes, which generally have large littoral areas. Overall, rapid or complete SAV removal tends to provoke more severe water-quality degradation than partial control.

In Iowa's Red Haw Lake, 10.9 Grass Carp/acre stocking coincided with significant decreases to mean nitrites, nitrates, biological oxygen demand and turbidity, an increase in alkalinity and non-significant increases in organic and inorganic phosphorus (Mitzner 1980). The Cold Springs Lake renovation saw Secchi depth recover from a mean of 2.0 ft (2000-2005) to 4.6 ft (2007-2012), with SAV returning to 90% surface coverage (C. Larson, Iowa DNR, personal communication).

Regional and Climatic Considerations

Climatic factors influence Grass Carp performance: warmer, southern U.S. waters generally see more drastic vegetation loss at low stocking densities, while cooler northern and intermountain climates - characterized by less frequent >80°F events and seasonal ice cover - may require higher densities for similar impacts (Wiley et al. 1985; Swanson and Bergersen 1988; Bonar et al. 1993a). Plant community composition, vegetation biomass, Grass Carp size and mortality, and initial waterbody conditions further dictate outcomes, yielding highly variable results across latitudes and reservoir sizes. In summary, substantial negative impacts to fish populations, water quality, and plant communities may result from the use of Grass Carp as a plant management tool in Iowa.

Alternative Management Strategies

Integrated Management

Preventing or delaying nuisance SAV establishment is often more sustainable - and cost-effective - than reactive control. Key preventive and integrated strategies include:

- Reservoir design and habitat modification: Steep shoreline slopes and controlled littoral zone excavation reduce favorable macrophyte habitat (Jeppesen et al. 2000; MN DNR 2010). Regular sediment management maintains deeper shorelines and limits expansion of colonizable area.

- Invasive species prevention and early detection: Programs that emphasize aquatic invasive species (AIS) education, boat inspection, and rapid response to new infestations can curb introduction and spread of nuisance plants (Lodge et al. 2006; Wittenberg and Cock 2001).
- Monitoring and adaptive planning: Routine vegetation surveys, aerial imagery, and biomass/coverage metrics inform timely interventions and refine integrated management plans (Iowa DNR 2013; Madsen and Wersal 2012).
- Chemical controls: Targeted herbicide applications remain a flexible tool for spot treatments or interim control when integrated with biological or mechanical methods. Although initial costs can exceed stocking (Mackey and Wuellner 2025), herbicides allow precise, localized treatments with predictable efficacy.
- Mechanical removal: Harvesters, cut-and-draw, and benthic barriers offer short-term vegetation reduction without the ecological risks associated with biocontrol (Madsen et al. 1991).
- Biological agents: Beyond Grass Carp, specialist invertebrates (e.g., weevils, moths) can target specific AIS without broad-scale habitat impacts (Cuda 2002; Lockwood et al. 2013). Where triploid Grass Carp are used, strict ploidy verification and containment protocols prevent unwanted reproduction and spread (Chilton and Muoneke 1992; USACE 2003).

Adopting an integrated management framework - tailoring combinations of these tools to site-specific goals, budgets, and ecological constraints - yields resilient, long-term control of aquatic vegetation while minimizing unintended consequences.

Stocking Models and Predictive Approaches

To mitigate the long-term environmental risks of overstocking, several predictive models have been developed to inform appropriate Grass Carp stocking rates. The Illinois Natural History Survey (INHS) model segments the U.S. into north-south climate zones and incorporates Grass Carp bioenergetics, seasonal plant dynamics, and feeding constraints (Wiley et al. 1985; Wiley and Wilke 1986). A public-facing circular (Wiley et al. 1987) presents a conceptual serial stocking strategy - adding cohorts every five to six years as needed - versus a single (batch) stocking, with serial approaches offering finer control over vegetation suppression.

Stewart and Boyd's AMUR/STOCK model (1999) adapts these principles for the southeastern U.S., integrating variables such as winter and summer peak biomass, plant composition, water temperature, Grass Carp size, and ploidy to calculate stocking needs. Bonar's Pacific Northwest model (1990) emphasizes vegetated acreage and species characteristics, while the GRASCARP model (Swanson and Bergersen 1988) uses three years of data from six Colorado lakes to link stocking rate predictions to plant density, distribution, species composition, water temperature, human use, and management objectives.

All these models aim for vegetation reduction - not complete eradication - and acknowledge that full control may take three to four years post-stocking. They highlight the necessity of adaptive management by refining stocking rates and strategies in response to measured SAV biomass, percent coverage, and environmental conditions. Cassani (1995) noted that failure to account for these multiple factors has largely driven the historical unpredictability of Grass Carp for vegetation control.

Application Example: Red Haw Lake

Using the INHS framework, Red Haw Lake's vegetated acreage in 1973 (8.2 of 71 acres) illustrates model versus practice:

- <u>Historical stocking (1973-74):</u> 780 diploid Grass Carp (≈15 in, 380 g) at 11 fish/acre (95 fish/vegetated acre) removed 91% of SAV in three years and eradicated all vegetation in four - exceeding desired suppression.
- <u>INHS model recommendation</u>: 123 triploid Grass Carp (≈10 in, 200 g) at 1.7 fish/acre (15 fish/vegetated acre), with reevaluation after five to six years to maintain desired suppression levels.

By comparing model outputs with actual outcome in the Red Haw example, it is clear that overstocking resulted in excessive aquatic vegetation suppression.

Grass Carp Removal Techniques

When Grass Carp stockings overshoot vegetation suppression targets - leading to SAV levels that impair fish populations or degrade water quality - removal efforts become necessary. Passive capture methods (e.g., fyke nets or baited traps) proved largely ineffective and exceptionally labor-intensive in Iowa trials (Hestand 1996; Boucher, pers. comm.). Active gears, such as gillnets and seines used within herded aggregations, achieved higher catch per unit effort (CPUE) but still yielded diminishing returns over time. In small (<25 acre) lakes with dense vegetation, netting removed only 0.8-8.2% of the original Grass Carp populations at CPUE rates of 0.17-0.56 fish/hr (Bonar et al. 1993b).

Night-time electrofishing has emerged as the most effective technique for population estimation and removal in Iowa. In Cold Springs Lake (15 ac), biologists captured and recaptured 250 and 150 Grass Carp, respectively, over a 14-day study (Hill 1986). Mormon Trail Lake removals of 50 fish via electrofishing required two years of effort under optimal temperatures (45-50°F) (Cashatt and Bruce 2008; Hestand 1996).

Chemical removal using low-dose rotenone offers another option. Pond trials indicated 8 µg/L rotenone removed ≈35% of Grass Carp but also risked comparable losses of centrarchid sport fish; reducing the concentration to 7 µg/L predicted 20% carp removal with less non-target mortality (Flammang and Sobotka 2014). Field tests on Wilson Lake (17 ac) at 8 µg/L eliminated 13 Grass Carp and facilitated SAV regrowth the following year (Jansen, pers. comm.). Although rotenone can be effective, its non-selective toxicity and regulatory constraints limit widespread application.

Overall, removal of established Grass Carp populations is both time- and resource-intensive. Gear selection, effort duration, lake size, vegetation density, and seasonal water temperatures critically influence success. As such, proactive stocking strategies and adaptive management are essential to avoid the need for extensive removal campaigns.

Iowa's Current Management Strategy

Reflecting on past challenges - unpredictable SAV control and unintended ecological impacts - Iowa DNR maintains a prohibition on stocking Grass Carp in public waters. Nonetheless, these fish persist in Iowa's rivers where they are supported by natural reproduction and immigration, and private ponds, where diploid and triploid Grass Carp are available from private hatcheries and continue to serve as a de facto biocontrol tool.

Recreational users consistently cite water quality as their top motivation for choosing a lake (Azevedo et al. 2003; Evans et al. 2011; Jeon et al. 2016; Wan et al. 2021). Concern over declining water quality in the 1990s spurred the 2006 Infrastructure Bill and the launch of the Lake Restoration Program, which funded extensive watershed and in-lake improvements. During post-renovation phases, carp removals were prioritized to reestablish aquatic vegetation and meet water-quality targets.

Alternative Control Tools

- **Herbicides:** Licensed applicators deploy targeted chemical treatments under detailed plans (Iowa State University 2024; Euchner, pers. comm.), using modern GPS/GIS and UAV technologies to enhance precision (Madsen *et al.* 2012; Netherland 2008).
- **Mechanical Methods:** From floating harvesters and cut-and-draw techniques for shoreline access to large-scale dredging, drawdowns, benthic barriers, and nutrient removal, the Lake Restoration Program employs mechanical controls to improve access and water quality (Madsen 2000; WDNR 2020; Sperry *et al.* 2021; Verhofstad *et al.* 2017; Steinman *et al.* 2018).
- **Preventive Design & Education:** Recent shoreline construction and renovation grants emphasize steep slopes, sediment management, AIS outreach, and early-detection protocols to preempt nuisance plant establishment (Lodge *et al.* 2006; MN DNR 2010).
- **Monitoring & Adaptive Planning:** A dedicated vegetation management biologist coordinates systematic surveys, aerial imagery analysis, and integration of chemical, mechanical, and biological tactics to achieve balanced SAV levels - maintaining 10-40% coverage for optimal ecosystem function and recreational use.
- By prioritizing integrated, site-specific strategies over reliance on a single biocontrol agent, Iowa DNR seeks to sustain healthy aquatic ecosystems, preserve water quality, and support diverse recreational opportunities.

For private waters and those managed by partners, the Iowa DNR discourages the use of Grass Carp whenever possible. However, some still express concerns regarding the environmental footprint of herbicides and ongoing treatment costs. When partners or the public want to use Grass Carp, the Iowa DNR advises conservative stocking of 3-5 triploid Grass Carp per acre - paired with strict verification of ploidy and containment measures.

Chemicals have become a preferred choice to control aquatic plants in Iowa because Grass Carp are currently not an option (B. Hayes, personal communication, Iowa DNR). Not everyone is receptive to the idea of applying herbicides to aquatic ecosystems, nontarget organisms and beneficial vegetation may suffer, yet others are supportive to see the issue of excessive plants being addressed (Henderson 1996, Slipke et al. 1998). Chemical applications require applicators to obtain a pesticide applicators license and attend annual continuing education training (Iowa State University 2024). Applicators are also required to obtain permits when applying chemicals to public waters in Iowa. Chemical applications provide immediate results, an ability to target specific aquatic plant species and specific areas in a waterbody, and the ability to respond quickly to nuisance stands of aquatic plants. Chemical applications targeting large areas are more cost-effective than mechanical harvesting. Safety can also be a concern for both recreational users and infrastructure. Chemical applications can provide immediate reductions of plant biomass inhibiting swimming areas, plugging water intakes, or reducing flow through outlet structures. Native species management can also benefit from targeted chemical applications by removing dense stands of invasive species to improve light penetration and dissolved oxygen. All chemicals used for aquatic plant control are regulated by the EPA. Therefore, chemicals and application rates have undergone toxicological testing. Iowa DNR has an active aquatic plant monitoring program and chemical treatment is an important tool for quick suppression of new AIS infestations (J. Euchner, personal communication, Iowa DNR). Chemical applications used to treat aquatic vegetation require a detailed application plan including environmental conditions at the time of application, volume or surface area of treatment zones, calibrated application equipment, and appropriate personal protective equipment. New technologies, unmanned aerial vehicles, global positioning systems and geographical information systems, have improved chemical application precision and accuracy (Madsen et al. 2012, Netherland 2008). Chemical applications have positive attributes but the public perception of potential negative effects to the environment can impact their use as an aquatic plant management method.

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