GUT CONTENT AND STABLE ISOTOPE ANALYSIS OF EXOTIC SUCKERMOUTH CATFISHES (*HYPOSTOMUS*) IN THE SAN MARCOS, TX: A CONCERN FOR SPRING ENDEMICS?

THESIS

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I dedicate this thesis to my mother, Judy Cohen, who first saw in me the strength and tenacity to overcome obstacles and accomplish my dreams. Her wisdom, savvy, fun-loving nature, and faith in Jesus Christ were always my greatest inspiration, and she lives on in the hearts of many who knew her. Together we remain in the Father's hands.

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ABSTRACT

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Introduced suckermouth catfishes (Family Loricariidae) are established in a number of spring-influenced streams in North America. Impacts to native flora and fauna are predicted, but these predictions have not been tested. Purposes of this study were to quantify gut contents of suckermouth catfishes from the San Marcos River in central Texas and to assess degree of dietary overlap between the suckermouth catfish and native herbivorous fishes by comparing gut contents and by analyzing stable isotopes. Suckermouth catfishes ($N = 36$) primarily consumed amorphous detritus (87% in biovolume), filamentous red algae (5.4%), and picoplankton (4.1%). Stable isotopes analysis indicated a more omnivorous trophic level. An endangered macrophyte, macroinvertebrates, and fish eggs were not found in the gut contents. Suckermouth catfish gut contents were similar ($P > 0.05$) to those of a sympatric native herbivore,

Guadalupe roundnose minnow *Dionda nigrotaeniata*, but differed (P <0.01) from another sympatric native herbivore, central stoneroller *Campostoma anomalum*. Gut content assessments of two additional *Dionda* species suggest high dietary overlap between the *Dionda* complex and suckermouth catfish. Consequently, occurrences of suckermouth catfishes in spring-influenced streams are potential direct competitors with only a few native taxa in spring-influenced streams of central and west Texas.

CHAPTER I

INTRODUCTION

Homogenization of fauna, or the replacement of rarer species by cosmopolitan invaders, is an increasing concern in the conservation of aquatic environments (Rahel 2000; Scott and Helfman 2001). The process of homogenization is highly evident in spring environments of the Edwards Plateau and Trans Pecos regions of central and west Texas, where thermally-stable spring habitats and associated endemic fauna are bombarded by aquarium releases of tropical plants, mollusks, fishes, and incidentally digenetic trematodes (Hubbs et al. 1991; Howells 1992; McDermott 2000; Mitchell et al. 2000). Establishment and persistence of these tropical invaders likely are benefited from anthropogenic modifications to these spring environments (Brune 1981; Ono et al. 1983), which alter community structure and biotic interactions and make flora and fauna less resistant to biotic invaders (Baltz and Moyle 1993).

Suckermouth catfishes (Loricariidae. *Hypostomus* and *Pterygoplichthys*) are native to Central and South America and have been introduced to North America. Reproducing populations exist in tropical waters of Hawaii, Florida, and Puerto Rico, and spring-influenced streams of Texas, Nevada, and Mexico (Courtney et al. 1974; Courtney et al. 1979; Ludlow and Walsh 1991; Page 1994; Edwards 2001; Hoover et al. 2004, Hoover et al. 2006). In Texas, suckermouth catfishes in the genus *Hypostomus* are established in the San Antonio River (Bexar County, Hubbs et al. 1978), Comal River (Comal County,

Whiteside and Berkhouse 1992), San Marcos River (Hays County), and San Felipe Creek (Val Verde County, Lopez-Fernandez and Winemiller 2005). These spring-influenced streams, except the San Antonio River, are critical habitats for a number of federal and state-listed threatened and endangered plants, macroinvertebrates, fishes, and amphibians (Bowles and Arsuffi 1993). As such, established populations of grazing, herbivorous suckermouth catfishes potentially impact critical habitats of native flora and fauna by consuming native plants and macroinvertebrates, competing with herbivorous macroinvertebrates and fishes, and consuming adhesive eggs of phytophilic-spawning fishes (Hoover et al. 2004, Hoover et al. 2006).

Purposes of this study were to examine several hypotheses about the impact of suckermouth catfishes on native flora and fauna in a spring-influenced stream. The main objective of this study was to assess gut contents of suckermouth catfishes taken monthly from the upper San Marcos River and to quantify consumption of native vegetation, such as the federally-listed Texas wild rice *Zizania texana*, native macroinvertebrates, and fish eggs. In addition, I assessed potential dietary overlap between suckermouth catfishes and spring-endemic fishes by quantifying gut contents of four herbivorous fishes, and to confirm trophic position of suckermouth catfish determined by gut content analysis with stable isotope analysis.

CHAPTER II

METHODS

Fishes within the Genus *Hypostomus* were collected from upper reaches of the San Marcos River (Figure 1). Taxonomic uncertainty precluded identification to the species level (Hoover et al. 2004). Suckermouth catfishes were collected with gigs from January to December 2005 during daytime and nighttime hours. Guadalupe roundnose minnow *Dionda nigrotaeniata* and central stoneroller *Campostoma anomalum* were collected with seines in March 2007. Immediately upon collection, suckermouth catfishes were pithed, and Guadalupe roundnose minnows and central stonerollers were anaesthetized in MS-222 Total lengths of all fish were measured to the nearest 0.01 mm. For each fish, the abdomen region was cut from the pectoral girdle to anus, and the entire alimentary canal from esophagus to anus was removed. With the aid of a dissecting scope, gut contents were removed from the stomach and foreguts, washed into containers with 4% formalin, and stored in the dark for later identification.

Nueces roundnose minnow *Dionda serena* and roundnose minnow *Dionda episcopa* were acquired from fish collections held at Texas State University-San Marcos. Nueces roundnose minnows were taken from upper reaches of the Nueces River (Edwards County) in February 2005 Roundnose minnows were taken from Independence Creek (Pecos River drainage, Terrell County, TX) in July 2003. When collected, fishes were anesthetized with MS-222 and fixed in 10% formalin. For this

study, gut contents were removed from the stomach and foreguts, washed into containers with 4% formalin, and stored in the dark.

Whole and sub-samples of gut contents were quantified based on linear measurements of individual items (percent biovolume; Hyslop 1980; Hillebrand et al. 1999) of the following categories: amorphous detritus, filamentous red algae, filamentous bluegreen algae, filamentous green algae, picoplankton (i.e., algae <2 μm in diameter), diatoms, plant material, fungi, insects, and sand. Whole stomach contents were visually inspected with a dissecting scope to detect and remove any large macrophyte fragments, macroinvertebrates, and fish eggs. Large macrophyte fragments and sand were found in only one of the suckermouth catfishes; therefore, percent biovolume of stomach contents for this individual was estimated by taking linear measurements (μm^3) of the macrophyte fragments and collective volume of the sand. All other stomach contents were sub-sampled three times each to determine percent biovolume. Standardized biovolumes were determined for the most common algal taxa (Hillebrand et al. 1999). Once linear measurements of at least 50 algae in a taxonomic category were measured, I calculated the individual biovolumes and used the mean as the standardized biovolume for all algae in that category.

Containers containing whole stomach contents were shaken on a vortex mixer until contents were thoroughly suspended. Each sub-sample was taken with a micropipetter and placed in a Palmer-Maloney Counting Cell (Palmer and Maloney 1954; Wildco, Saginaw, MI). The 0.1 ml sub-sample was scanned at 40X to determine the presence of at least 10 algal cells per field of view (Eaton et al. 2005). If it contained <10 algal cells per field of view, the sub-sample was allowed to resettle for 24 h, and the

supernatant was decanted to a lower concentration. At times, the sub-sample was too crowded for algal cells to be counted. On these occasions, more preservative was added. Once the number of algal cells per field of view was adjusted appropriately, microalgae and other small items were identified, enumerated, and measured at 40X. This was repeated for a total of 30 fields of view. In sub-samples containing larger filamentous algae, enumeration was underestimated at 40X. Therefore, all filamentous algae of macroscopic size in a sub-sample was identified, enumerated, and measured at 10X. Distinguishable algal taxa and other items were identified to the lowest practical taxonomic level. Complex aggregates of amorphous material were listed as amorphous detritus.

To determine the overall count of items in a category, total count per milliliter was calculated using the following equation (Wetzel and Likens 2000):

$$\text{Count/ml} = \frac{C \times 1000 \text{ mm}^3}{\text{A} \times \text{D} \times \text{F}}$$

Where, C is the average number of times an item was counted in the three sub-samples, A is the area of the field in which the item was measured (calculated in mm^2 at both the 10X and 40X objective powers), D is depth of the field (0.4 mm), and F is the average number of fields counted for an item among the three sub-samples, which equaled 30 for items measured at 40X and was variable for macroscopic filamentous algae measured at 10X. The count/ml for an item was then multiplied by the volume of preservative in the sample container to calculate the total count per sample. The mean biovolume of a category counted in the three sub-samples was multiplied by the count per sample to calculate biovolume per sample.

Biovolume of each category was expressed as a percentage of the total sample volume. Mean percent biovolume of each food category was calculated for each fish taxa. Analyses of Similarity (ANOSIM; Bray and Curtis 1957) were used to assess similarities of percent biovolume of stomach contents among suckermouth catfishes and used to assess similarities of percent biovolume of stomach contents among suckermouth catfishes and sympatric Guadalupe roundnose minnow and central stoneroller using PRIMER 6.1.6 (Clark 1993, Clark and Warwick 2001). Multi-dimensional scaling (MDS) plots were generated to illustrate degree of dissimilarity for both ANOSIM tests. In addition, percent occurrence of food categories in guts of suckermouth catfishes was calculated based on the presence or absence of a category.

Stable Isotope Analysis

In July 2007, coarse particulate organic matter (CPOM), periphyton, macroinvertebrates, and fishes were collected from the upper San Marcos River. Duplicate samples of CPOM were collected as composites of terrestrial plant material gathered throughout the water column and placed into plastic bags. Periphyton collections consisted of both microalgae and filamentous algae collected from slow and fast-flowing habitats. Duplicate samples of microalgae were collected from each habitat type as composite samples brushed from several rocks, rinsed into acid-washed polyethylene centrifuge tubes, placed into a cooler, and transported to the laboratory. Filamentous algae were also collected from rocks in each habitat type and placed into acid-washed high density polyethylene vials. Macroinvertebrates were collected from fast and slow-flowing habitats with a combination of kick-netting and picking from

rocks, placed into plastic bags with stream water, kept for about 2 h to allow excretion, and preserved in 70% EtOH Fish were collected by seining or spear-fishing at night, pithed in the field, placed into plastic bags and frozen.

In the laboratory, samples were prepared for stable isotope analysis. Microalgae were filtered onto pre-combusted glass fiber filters. Filamentous algae were rinsed with deionized water, and obvious detritus was removed. Macroinvertebrate samples were sorted into taxonomic groups and rinsed of attached algae or detritus. Foot regions were removed from snails (*Melanoides*) with a scalpel. Macroinvertebrate samples were prepared as composite samples of multiple organisms within a taxon (76 *Hyallela*, 29 Baetidae, 3 Naucoridae, and 5 snails). Only taxonomic groups collected in adequate numbers for stable isotope analysis were assessed. Fish were identified, total length and wet mass were determined, and fillet muscle was removed. Larger fish were individually analyzed, and western mosquitofish *Gambusia affinis* were analyzed as a composite sample of 6 individuals.

All samples were dried at 60°C for 48 h. Since the San Marcos River is a spring-fed system that drains a limestone karst aquifer, there is a large amount of calcium carbonate in river water, which affects signatures of epilithic algae (W.H. Nowlin, unpubl data). Therefore, dried microalgae filters were placed in a fuming HCl chamber for 24 h to remove inorganic carbon from microalgal samples. All samples except microalgae were homogenized with a mortar and pestle. Samples were sent to University of California-Davis Stable Isotope Laboratory for analysis. Samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$ and duplicates were run approximately every 10 samples with a mean standard error of <0.15%. Carbon isotope mixing models were used to estimate contributions of potential

food sources (algae and CPOM) to consumers (Fry 2006). Mean and error estimates for the mixing model were made according to equations from Phillips and Greg (2001). $\delta^{13}C$ values for fish and macroinvertebrates were corrected for trophic enrichment of +0.5% (Finlay et al. 2002).

$\delta^{15}N$ values were used to estimate trophic position of consumers where each organism is considered ~1 trophic position above its direct prey. The organism with the lowest $\delta^{15}N$ was chosen as the baseline indicator for trophic position (Anderson and Cabana 2007). Baseline $\delta^{15}N$ was used to estimate trophic position for other consumers using the equation:

$$\text{Trophic position}_{\text{Consumer}} = ([\delta^{15}N_{\text{Consumer}} - \delta^{15}N_{\text{Baseline}}]/f) + 2$$

Where, $\delta^{15}N_{\text{Consumer}}$ is the $\delta^{15}N$ value for consumer for which trophic position is estimate, $\delta^{15}N_{\text{Baseline}}$ is the $\delta^{15}N$ value of baseline organism, 2 is the expected trophic position of the organism used to estimate baseline $\delta^{15}N$, and f is the $\delta^{15}N$ fractionation factor expected between a predator and its direct prey (3.4‰).

CHAPTER III

RESULTS

Thirty-six suckermouth catfishes were collected for gut content analysis. Amorphous detritus and picoplankton were the most common food items consumed (occurrence in catfish = 100%), followed by diatoms (83%), filamentous bluegreen algae (50%), and filamentous red algae (30%; Batrachospermaceae) (Table 1). Other items (i.e., filamentous green algae, plant material, and sand) were each found in <10% of the catfishes. Amorphous detritus was the most abundant food item consumed (mean ± SE; 87% ± 3.3) by biovolume, followed by filamentous red algae (5.4% ± 2.7), and picoplankton (4.1% ± 0.9). All other food items comprised <2% of the total biovolume in catfishes.

Three Guadalupe roundnose minnows and three central stonerollers were collected for gut content analysis (Table 2). Mean percent biovolumes (±1 SE) of abundant gut contents in Guadalupe roundnose minnows were algal detritus (66% ± 29.8), filamentous green algae (31% ± 31.2) and picoplankton (2.6% ± 1.6). Mean percent biovolumes (±1 SE) of abundant gut contents in central stonerollers were filamentous green algae (50% ± 27.3), algal detritus (38% ± 19.6), diatoms (6% ± 4.2), and picoplankton (6% ± 3.2).

Percent biovolumes of gut contents were dissimilar (ANOSIM, Global R = 0.46; $P < 0.01$) among suckermouth catfishes, Guadalupe roundnose minnows, and central

stonerollers. Among pairwise comparisons, gut contents were similar between suckermouth catfishes and Guadalupe roundnose minnows (Global R = 0.17; $P = 0.22$) and Guadalupe roundnose minnows and central stoneroller (Global R = 0 15; $P = 0.60$) but differed (Global R = 0.75; $P < 0.01$) between suckermouth catfish and central stoneroller. Two Guadalupe roundnose minnows and one central stoneroller, all with large amounts of amorphous detritus in their guts, were within the score range of suckermouth catfishes (Figure 2a) One Guadalupe roundnose minnow and two central stonerollers, all with large amounts of filamentous green algae in their guts, formed a distinct cluster separate from catfish scores. Four suckermouth catfishes had larger positive scores on MDS axis I and larger negative scores on MDS axis II. These catfishes had greater amounts of filamentous red algae in their guts than the other catfishes.

Three Nueces roundnose minnows and three roundnose minnows were selected for gut content analysis (Table 3) Amorphous detritus was the most abundant food item consumed (54% ± 27.4 of biovolume) by Nueces roundnose minnow, followed by picoplankton (21.3% ± 12.6), diatoms (19% ± 8.9), and plant material (6.1% ± 6.1). Amorphous detritus was the most abundant food item consumed (87% ± 4.9) by the roundnose minnow, followed by filamentous algae (9.3% ± 6.4), and fungi (1.4 ± 1.4). Percent biovolumes of Nueces roundnose minnow and roundnose minnow diets were compared to those of suckermouth catfishes, Guadalupe roundnose minnow, and central stoneroller, and a second MDS plot was generated. Nueces roundnose minnows and roundnose minnows grouped closely with suckermouth catfishes and Guadalupe roundnose minnow because of the prevalence of amorphous detritus within the diet of

each taxa and individuals (Figure 2b). An exception was noted in one Nueces roundnose minnow, which did not contain any amorphous detritus in its gut tract.

Stable Isotope Analysis

Four macroinvertebrate taxa and eight fish taxa were collected for stable isotope analysis (Figure 3). Baetidae had the lowest $\delta^{15}N$ value of all consumers. Consequently, baetids were selected as the baseline indicator and assigned a trophic position of 2.0. Trophic positions of Naucoridae and *Hyallela* were slightly >2.0, followed by snails (2.7) and suckermouth catfishes (2.8 ± 0.4). Trophic position of Rio Grande cichlid (*Cichlasoma cyanoguttatum*), rock bass (*Ambloplites rupestris*), western mosquitofish (*Gambusia affinis*), Mexican tetra (*Astyanax mexicanus*), and sunfishes (*Lepomis* spp.; <200 mm) ranged between 3 and 4. Trophic positions of top predators were 4.1 for redbreast sunfish and 4.1 ± 0.5 for largemouth bass. Unfortunately, Guadalupe roundnose minnows were not collected after exhaustive sampling.

Mean (± 1 SE) $\delta^{13}C$ was -34.8 (±1.1) for algae and -29.4 (±0.2) for CPOM. Taxa with mean $\delta^{13}C$ less than that of algae were baetids, naucorids, Mexican tetra, Rio Grande cichlids, and suckermouth catfishes. Taxa with mean $\delta^{13}C$ greater than that of algae but less than the mean $\delta^{13}C$ for CPOM were snails, rock bass, western mosquitofish, sunfish (<200m), redbreast sunfish, and largemouth bass. Carbon source, based on the two-source mixing model analyses, was primarily algal for naucorids, baetids, snails, Mexican tetra, suckermouth catfishes, and Rio Grande cichlid (Table 4). Carbon sources were algal and terrestrial for others: *Hyalella*, western mosquitofish, sunfish (<200 mm), largemouth bass, and rock bass.

CHAPTER IV

DISCUSSION

This study is the first quantification of diet for non-native suckermouth catfishes in semi-tropical spring environments. Gut content assessment and stable isotope analysis collectively indicated that suckermouth catfishes are herbivorous and consumed algal-derived, amorphous detritus in the San Marcos River. Trophic position, as determined by stable isotope analysis, suggested a more omnivorous feeding strategy than gut content assessment, which yielded only amorphous detritus and no animal parts. Aquatic detritus typically is an amalgam of organic matter, consisting of algal, invertebrate, and vertebrate materials (Ray and Straskraba 2001; Moore et al. 2004). Therefore, my results suggest that higher trophic position of suckermouth catfishes likely is attributed to consumption of amorphous detritus enriched with indistinguishable animal material rather than selective or incidental consumption of live invertebrates, vertebrates, or vertebrate eggs.

Gut contents of suckermouth catfishes taken from the San Marcos River were similar to those reported for loricariids taken from native environments (Bowen 1983; Fugi et al. 1996; Delariva and Agostinho 2001) Percent volume of amorphous detritus range from 10% to 96% among three genera and six species (*N* per species: 18 to 26) of loricariids taken from the Parana River of Brazil, whereas percent volume range from 0% to 7% for morphous plant detritus, and from 0% to <0.01% for aquatic insects, gastropods, and Hydracarina (Delariva and Agostinho 2001). Detritivorous fishes usually

ingest smaller detrital particles (<100 μm), which are amorphous in structure as opposed to larger, morphous fragments, because amorphous detritus contains less refractory organic matter, is more digestible, and supports higher growth production in detritivores than morphous plant detritus (Bowen 1984; Sinsabaugh and Linkins 1990).

Ingestion of small, amorphous detrital particles is consistent with feeding-associated morphologies of detritivorous fishes, in general, and of detritivorous loricariids, specifically. Long and thin branchial filaments and wide oral cavity of the San Marcos River suckermouth catfishes enable them to strain detrital particles or to suction flocculent detrital matter from substrate, trapping the particles in mucous on the gillrakers (Odum 1968; Bowen 1983; Ahlgren 1996; Delariva and Agostinho 2001). In addition, the San Marcos River suckermouth catfishes have less developed pharyngeal teeth and poorly developed stomachs, which are characteristic of detritivorous fishes that consume amorphous detritus, instead of well-developed pharyngeal teeth for grinding and tearing and well-defined stomachs for chemical and mechanical digestion, which are characteristic of fishes that consume living plants (Bowen 1983; Delariva and Agostinho 2001).

Introduced suckermouth catfishes are predicted to negatively impact native herbivorous fishes (Hubbs et al. 1978), such as the roundnose minnow and central stoneroller through competition for food. Results from this study suggested a high degree of dietary overlap with roundnose minnows. Amorphous detritus was the predominant item found in Guadalupe roundnose minnow, Nueces roundnose minnow, roundnose minnow, and likely in other species within the *Dionda* complex. Consequently, these results support Lopez-Fernandez and Winemiller (2005) prediction that the presence of

introduced suckermouth catfishes is related to the population decline of the federally-listed Devils River minnow *Dionda diaboli* in San Felipe Springs (Rio Grande drainage, Texas). Impacts of suckermouth catfishes on the Guadalupe roundnose minnow, the only other population of *Dionda* in sympatry with suckermouth catfishes, are not currently known. Results of this study, however, suggested little dietary overlap between suckermouth catfishes and central stonerollers. Gut contents of central stonerollers in this study consisted primarily of filamentous green algae, which typically are the predominant food items, along with amorphous detritus and macroinvertebrates (Fowler and Taber 1985; Evans-White et al. 2001; Evans-White et al 2003).

Currently, suckermouth catfishes are likely the largest component of the ichthyofaunal biomass in the upper San Marcos River. This conclusion is based on underwater observations and observations made during repairs of a low-head dam in 2005, where >150 kg of suckermouth catfish were removed from a 100-m stretch of the dewatered river channel (V. Cantu, National Fish Hatchery and Technology Center-San Marcos). Consequently, competition with native fishes is not the only problem associated with the introduction of suckermouth catfishes in the San Marcos River and likely other thermally-stable spring environments. As a large component of faunal biomass, suckermouth catfishes likely play an important role in ecosystem processes such as nutrient cycling, which is strongly influenced by detritivorous fishes (Hood et al. 2005; Higgins et al. 2006; Zimmer et al. 2006). The rate and ratios by which nutrients are recycled is a function of detritivore body nutrient composition (i.e., stoichiometry) and nutrient composition of their food (Schindler and Eby 1997; Vanni et al. 2002). Armor-plated suckermouth catfishes are rich in phosphorous, resulting in high retention and low

excretion of the nutrient (Vanni et al. 2002; Hood et al. 2005). Suckermouth catfishes likely are phosphorous sinks with the potential to limit primary productivity, to alter algal community composition, and to diminish the quality of periphyton as a food source (Hood et al. 2005). Top-down controls regulate detritivore abundances and limit impacts on nutrient cycling (Ray and Straškraba 2001); however, nutrient availability, trophic interactions and fauna and flora abundances will change with the introduction of a functional feeding group without biological controls (Elton 1958).

Illegal aquarium releases are responsible for the establishment of suckermouth catfishes and other exotic species in the San Marcos River and elsewhere. Releases of exotics have ecological consequences and have diverted federal and state conservation funds to pay for eradication. The spread of tropical exotic snail *Melanoides tuberculatus* is one example, because of its potential negative impact on native mollusk populations and because it is the first intermediate host of exotic Asian trematode *Centrocestus formosanus* (Mitchell and Brandt 2005). The Asian trematode infects several imperiled fishes in Texas (McDermott 2000; McDonald et al. 2006), and fishes in spring-influenced streams of Oregon and Utah (Mitchell et al. 2000; Mitchell and Brandt 2005). In another example, USFWS solicited proposals in 2004 to remove water trumpet (*Cryptocoryne becketti*), a popular aquarium plant and potential competitor to the endemic Texas wildrice (Rosen 2000; Doyle 2001), from the San Marcos River. Estimated cost for the project was US$250,000 to $500,000 (Solicitation Notice #201814R040).

Preventing releases through laws and public education (Hodge 2006) evidently are ineffective in the San Marcos River. Limiting types of organisms across state lines, such as Harmful or Potentially Harmful Fish, Shellfish, and Aquatic Plants legislation (21

TexReg 12414), seem more likely to prevent illegal introductions by limiting the types of plants and animals readily available to the public. Alternatives to suckermouth catfish commerce could include selling dwarf species in the genus *Otocinclus* that grow only to a maximum length of 50 mm (Britto and Moreira 2002), which would prevent release of up to 500 mm suckermouth catfish that outgrow most household fish tanks, or exploring the potential to produce non-viable suckermouth catfish, similar to triploidy in grass carp (Allen et al. 1987). Regardless of the alternatives, protecting the biotic integrity of spring-influenced aquatic systems from current and future exotic taxa is essential to long-term sustainability of the native flora and fauna and to reversing the current trends of biotic homogenization.

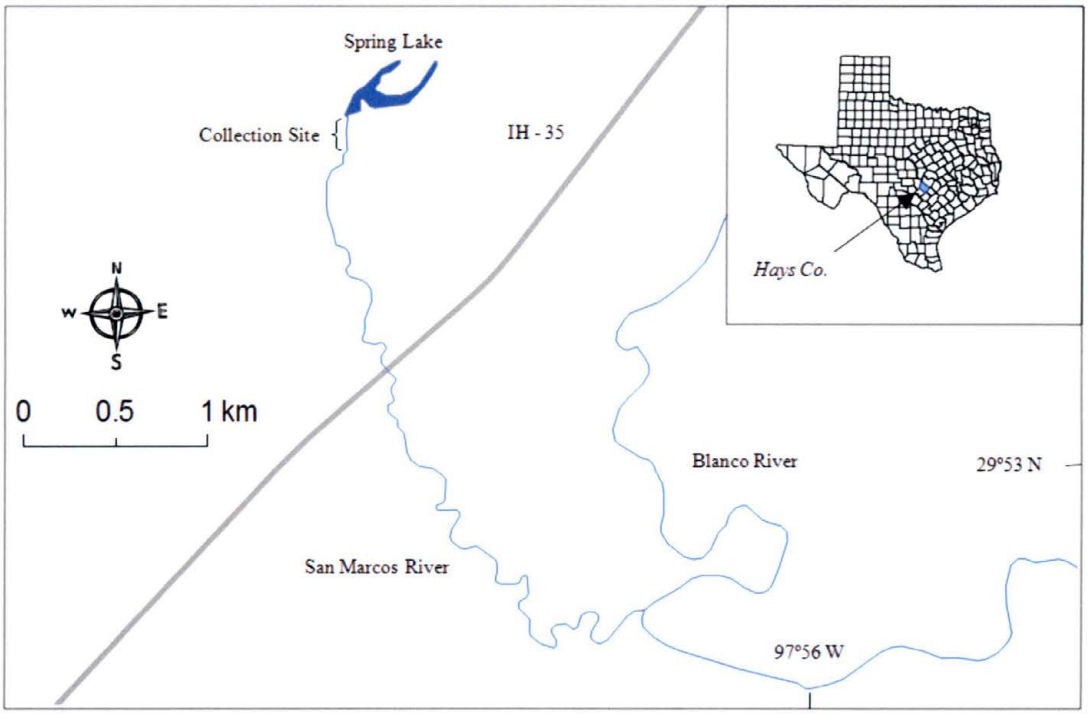

Figure 1. San Marcos River (Hays County, Texas) and collection location of suckermouth catfishes.

Table 1. % Occurrence and mean % biovolume (± 1 SE) of food items found in suckermouth catfish guts.

Taxa	% Occurrence	% Biovolume
Amorphous Detritus	100	86.5 ± 3 3
Filamentous Red Algae	30.6	5.4 ± 2 7
Filamentous Bluegreen Algae	50 0	< 1.0
Filamentous Green Algae	8 3	< 1 0
Picoplankton	100	4.1 ± 0 9
Sand	2 8	1.5 ± 1.5
All Diatoms	83 3	1 3 ± 0 3
Cocconeis	58 3	< 1 0
Fragilariaceae	72 2	< 1.0
Naviculoids	83 3	< 1 0
Aulacoseira	25 0	< 1.0
Plant Material	5 6	< 1.0

Table 2. Mean % biovolume (± 1 SE) of food items in guts of Guadalupe roundnose minnow and central stoneroller.

Taxa	Guadalupe Roundnose Minnow	Central Stoneroller
Amorphous Detritus	65 6 ± 29.8	35.0 ± 19.5
Filamentous Green Algae	31 2 ± 31 2	53 6 ± 27 3
Cladophora	-	53 6 ± 27 3
Other	31 2 ± 31 2	-
Picoplankton	2 6 ± 1 6	5 4 ± 3.3
All Diatoms	<1 0	5 7 ± 4 4
Cocconeis	< 1.0	< 1 0
Naviculoids	< 1 0	< 1 0
Fragilariaceae	< 1.0	3 3 ± 1.9
Aulacoseira	-	2 0 ± 2 0

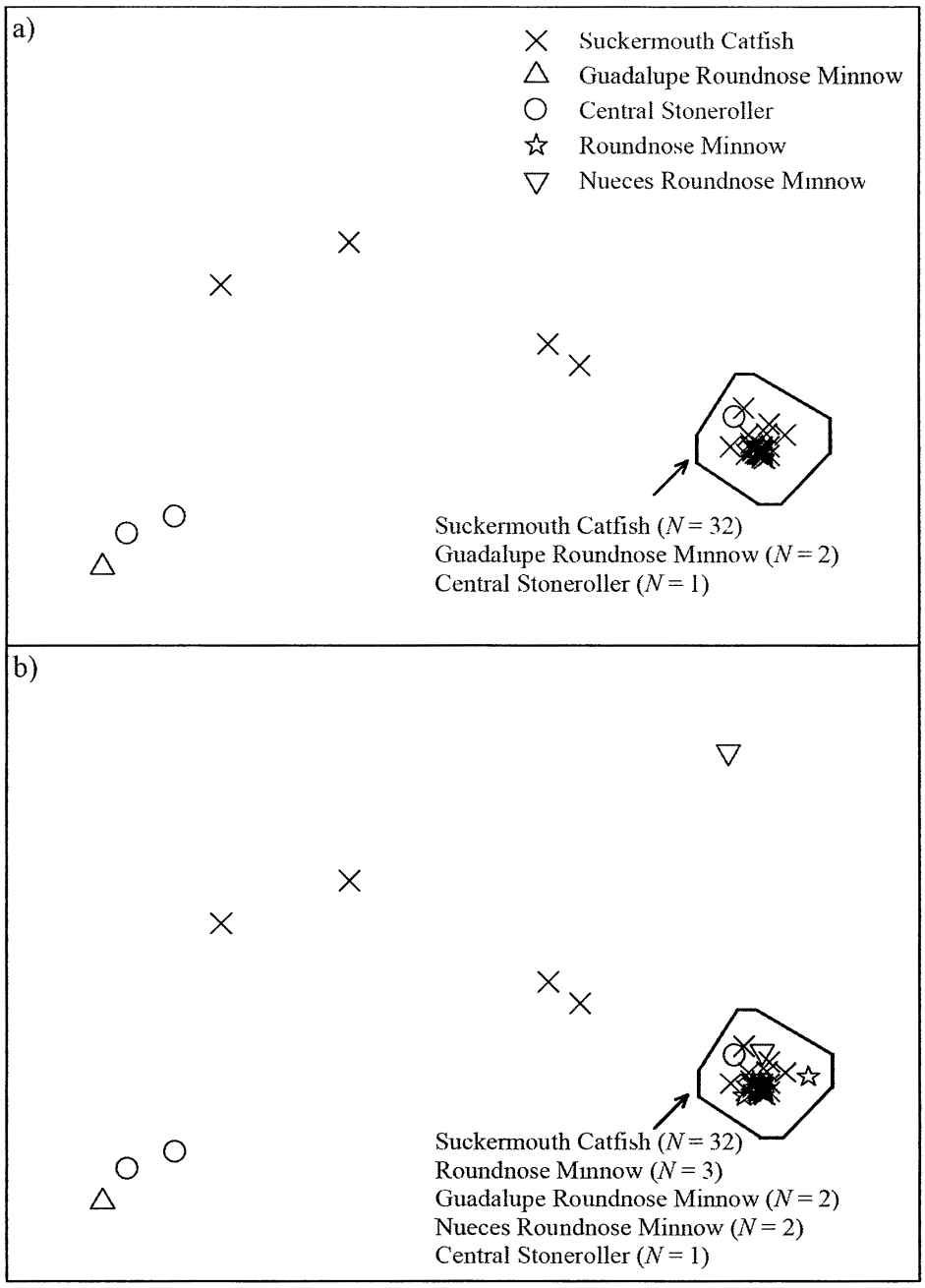

Figure 2. MDS plots of similarities and differences in gut contents of fishes. a. Suckermouth catfishes, Guadalupe roundnose minnow, and central stoneroller collected from the San Marcos River. b. Three fishes collected from the San Marcos River, roundnose minnow collected from Independence Creek, and Nueces roundnose minnow collected from the Nueces River.

Table 3. Mean % biovolume (± 1 SE) of food items in guts of Nueces roundnose minnow and roundnose minnow.

Taxa	Nueces Roundnose Minnow	Roundnose Minnow
Amorphous Detritus	53 7 ± 27.4	86 5 ± 4.9
Filamentous Algae	-	9.3 ± 6.4
Green	-	2.1 ± 2 1
Bluegreen	-	7 2 ± 7 2
All Diatoms	18.7 ± 8.9	1.2 ± 0.4
Cymbelloids	14.5 ± 7.6	< 1.0
Naviculoids	3.2 ± 1.4	< 1.0
Gomphonema	<1 0	-
Fragilariaceae	-	<1 0
Plant Material	6.1 ± 6.1	< 1.0
Fungi	-	1 4 ± 1.4
Picoplankton	21 3 ± 12.6	1.3 ± 0.6
Insect Part	< 1.0	-

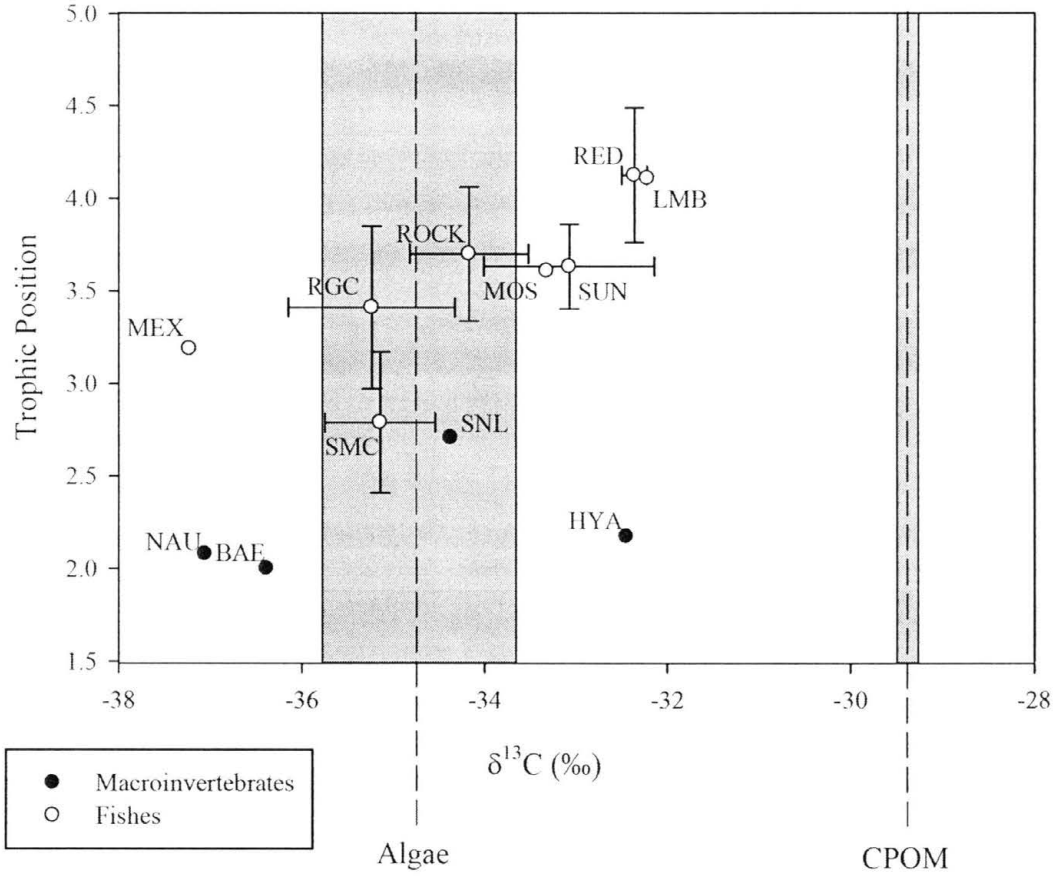

Figure 3. Dual isotope plot of consumer $\delta^{13}C$ and trophic position for samples collected from the San Marcos River in late July 2007. Values for macroinvertebrates and fishes represent mean values and ± SE for replicated samples. Staggered vertical lines represent mean algal $\delta^{13}C$ and mean CPOM $\delta^{13}C$ with ± 1 SE shown in gray. Abbreviations are: NAU, naucoridae; BAE, baetidae; HYA, *Hyalella*; SMC, suckermouth catfishes; SNL, snails; MEX, Mexican tetra; RGC, Rio Grande cichlid; ROCK, rock bass; MOS, western mosquito fish; SUN, sunfishes (<200m); RED, Redbreast sunfish; and LMB, largemouth bass.

Table 4 Results of the two-source carbon mixing model for contributions of algal and CPOM derived food sources for macroinvertebrates and fishes collected from the San Marcos River. Mean values and ± 1 SE are reported for replicated samples.

Species	*N*	Percentage algae	Percentage CPOM
Naucoridae	1	100	0
Baetidae	1	100	0
Melanoides	1	92 8	7.2
Hyalella	1	56.9	43 1
Western Mosquito Fish	1	73 1	26.9
Mexican tetra	1	100	0
Suckermouth Catfishes	5	98.6 ± 2.1	1.4 ± 2.1
Sunfishes <200mm	4	68 6 ± 2.4	31.4 ± 2 4
Redbreast sunfish >200mm	1	52.7	47.3
Largemouth bass	2	55 3 ± 1.8	44 7 ± 1 8
Rock bass	4	84 7 ± 2.3	15.3 ± 2.3
Rio Grande Cichlid	2	96.7 ± 3 5	3.3 ± 3 5

LITERATURE CITED

Ahlgren, M. O. 1996. Selective ingestion of detritus by a north temperate omnivorous fish, the juvenile white sucker, *Catastomus commersoni.* Environmental Biology of Fishes 46:375-381.

Allen, Standish K., and Robert J. Wattendorf. 1987. Triploid Grass Carp: status and management implications. Fisheries 12(4):20-24.

Anderson, C., and G. Cabana. 2007. Estimating the trophic position of aquatic consumers in river food webs using stable nitrogen isotopes. Journal of North American Benthological Society 26(2):273-285.

Baltz, D. M., and P. B. Moyl. 1993. Invasion resistance to introduced species by a native assemblage of California stream fishes. Ecological Applications 3(2):246-255.

Baxter, C. V., C. D. Fausch, M. Murakami, and P. L. Chapman 2004. Fish invasion restructures stream and forest food webs by interrupting reciprocal prey subsidies. Ecology 85(10):2656-2663.

Bowen, S. H. 1983. Detritivory in neotropical fish communities. Environmental Biology of Fishes 9:137-144.

Bowen, S. H. 1984. Evidence of a detritus based food chain based on consumption of organic precipitates. Bulletin of Marine Science 35(3):440-448.

Bowles, D. E., and T. L. Arsuffi. 1993. Karst aquatic ecosystems of the Edwards Plateau region of central Texas, USA: A consideration of their importance, threats to their existence, and efforts for their conservation Aquatic Conservation: Marine and Freshwater Ecosystems 3:317-329.

Bray, J. R., and J. T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs 27·325-349.

Britto, Marcelo R., and Cristiano R. Moreira. 2002. *Otocinclus tapirape*: A new Hypoptopomatine catfish from central Brazil. (Siluriformes: Loricariidae). Copeia 2002(4) 1063-1069.

Brune, G. 1981. Springs of Texas. Branch-Smith, Inc, Fort Worth, TX.

Clark, K. R. 1993. Non-parametric multivariate analysis of changes in community structure. Australian Journal of Ecology 18:117-143.

Clark, K. R., and R. M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER E: Plymouth Marine Lab, U.K.

Courtenay, W. R., Jr., and D. A. Hensley. 1979. Survey of introduced non-native fishes. phase I report. Introduced exotic fishes in North America: Status 1979. Report Submitted to National Fishery Research Laboratory, U.S. Fish and Wildlife Service, Gainesville, FL.

Courtenay, W. R., Jr., H. F. Sahlman, W. W. Miley II, and D. J. Herrema. 1974. Exotic fish in fresh and brackish waters of Florida. Biological Conservation 6(4):292-302.

Delariva, R. L., and A. A. Agostinho. 2001. Relationship between morphology and diets of six neotropical fishes. Journal of Fish Biology 58:832-847.

Doyle, Robert D. 2001. Expansion of the exotic aquatic plant *Cryptocoryne beckettii* (Araceae) in the San Marcos River, Texas. Sida 19(4):1027-1038.

Eaton, A. D., L. S. Clesceri, E. W. Rice, A. E. Greenberg, and Mary Ann H. Franson. editors. 2005. Standard Methods for the Examination of Water and Wastewater. 21st edition. American Public Health Association, American Water Works Association, Water Environment Federation, Washington, D.C.

Edwards, R. J. 2001. New additions and persistence of the introduced fishes of the upper San Antonio River, Bexar County, Texas. Texas Journal of Science 53(1):3-10.

Elton, C.G. 1958. The ecology of invasions by animals and plants, University of Chicago Press edition. University of Chicago Press, Chicago. (2nd printing, 2000)

Evans-White, M. A., and W. K. Dodds. 2003. Ecosystem significance of crayfishes and stonerollers in a prairie stream: Functional differences between co-occurring omnivores. Journal of North American Benthological Society 22(3):423-441.

Evans-White, M., W. K. Dodds, L J. Gray, and K. M. Fritz. 2001. A comparison of the trophic ecology of the crayfishes (*Orconectes nais* and *Orconectes neglectus*): Omnivory in a tallgrass prairie stream. Hydrobiologia 462:131-144.

Fowler, J. F., and C. A. Taber. 1985. Food habits and feeding periodicity in two sympatric central stonerollers (Cyprinidae) American Midland Naturalist 113:217-223.

Fry, B. 2006. Mixing mechanics. Pages 139-142 *in* Mixing mechanics. Stable isotope ecology. Springer Science, New York, New York.

Fugi, R., N. S. Hahn, and A. A. Agostinho. 1996. Feeding styles of five bottom-feeding fishes of the high Parana River. Environmental Biology of Fishes 46:297-307.

Garrett, G. P., R. J. Edwards, and A. H. Price. 1992. Distribution and status of the Devils River minnow, *Dionda diaboli*. The Southwestern Naturalist 37(3):259-267.

Higgins, K. A., M. J. Vanni, and M. J. Gonzalez. 2006. Detritivory and the stoichiometry of nutrient cycling by a dominant fish species in lakes of varying productivity. Oikos 114:419-430.

Hillebrand, H., C. Durlselen, D. Kirschtel, U. Pollingher, and T. Zohary. 1999. Biovolume calculation for pelagic and benthic microalgae. Journal of Phycology 35:403-424.

Hodge, L. D. 2006. Don't don't dump that aquarium – cute aquarium fish become ugly monsters in springs and streams. Texas Parks and Wildlife Magazine 64 (8):10.

Hood, J. M., M. J. Vanni, and A.S. Flecker. 2005. Nutrient recycling by two phosphorous-rich grazing catfish: The potential for phosphorous-limitation of fish growth. Oecologia 146:247-257.

Hoover, J., K. J. Killgore, and A. F. Confrancesco. 2004. Suckermouth catfishes: Threats to aquatic ecosystems in the United States? Aquatic Nuisances Species Research Bulletin 4·1-9.

Hoover, J. J., C. E. Murphy, and J. Killgore. 2006. Environmental impacts of suckermouth catfishes (Loricariidae) in North America: A conceptual model. US Army Engineer Research and Development Center, draft report, Vicksburg, MS.

Howells, R. G. 1992. Annotated list of introduced non-native fishes, mollusks, crustaceans and aquatic plants in Texas waters. Texas Parks and Wildlife Department, Management Data Series 78, Austin, TX

Hubbs, C., T. Lucier, G. P. Garrett, R. J. Edwards, S. M. Dean, E. Marsh, and D. Belk. 1978. Survival and abundance of introduced fishes near San Antonio, Texas. Texas Journal of Science 30:369-376.

Hubbs, C., R. J. Edwards, and G.P. Garrett 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. Texas Journal of Science 43: 1-56.

Hyslop, E. J. 1980. Stomach contents analysis-a review of methods and their application. Journal of Fish Biology 17:411-429.

Lopez-Fernandez, H., and K. O. Winemiller. 2005. Status of *Dionda diaboli* and report of established populations of exotic fish species in lower San Felipe Creek. Southwestern Naturalist 50(246):251.

Ludlow, M. E., and S. J. Walsh. 1991. Occurrence of a South American armored catfish in the Hillsborough River, Florida. Florida Scientist 54:48-50.

McDermott, K. S. 2000. Distribution and infection relationships of an undescribed digenetic trematode, its exotic intemediate host, and endangered fishes in springs of West Texas. Master of Science. Southwest Texas State University, San Marcos, TX.

McDonald, Dusty L., and Timothy H. Bonner. 2006. Size susceptibility to trematode induced mortality in the endangered fountain darter (*Etheostoma fonticola*). Journal of Freshwater Ecology 21(2):293-299.

Mitchell, Andrew J., Robin M. Overstreet, Andrew E. Goodwin, and Thomas M. Brandt. 2000. Spread of an exotic fish-gill trematode: a far-reaching and complex problem. Fisheries 30(8):11-16.

Mitchell, Andrew J., and Thomas M. Brandt. 2005. Temperature tolerance of red-rim melania *Melanoides tuberculatus*, and exotic aquatic snail in the United States. Transactions of the American Fisheries Society 134 126-131.

Moore, J. C., E. L Berlow, D. C. Coleman, Peter C. de Ruiter, Q. Dong, A. Hastings, N. C. Johnson, K. S. McCann, K. Melville, P. J. Morin, K. Nadelhoffer, A. D. Rosemond, D. M Post, J. L. Sabo, K. M. Scow, M. J. Vanni, and D. H. Wall. 2004. Detritus, trophic dynamics, and biodiversity. Ecology Letters 7:584-600.

Odum, W E. 1968 The ecological significance of fine particle selection by the striped mullet *Mugil cephalus*. Limnology and Oceanography 13:92-98.

Office of the Secretary of State. 1996. Harmful or potentially harmful fish, shellfish, and aquatic plants, (Rule §57.111). Texas Register 21:95(24 December 1996):12414.

Ono, R. D., J. D. Williams, and A. Wagner. 1983. Vanishing fishes of North America. Stone Wall Press, Inc., Washington.

Page, L. M. 1994. Identification of sailfin catfishes introduced to Florida. Florida Scientist 57:171-172.

Palmer, C. M., and T. E. Maloney. 1954. A new counting slide for nannoplankton. American Society of Limnology and Oceanography Special Publication 21·6.

Phillips, D. L., and J. W. Greg. 2001. Uncertainty in source partitioning using stable isotopes. Oecologia 127:171-179.

Rahel, F. J. 2000. Homogenization of fish faunas across the United States. Science 288:854-856.

Ray, S., and M. Straškraba. 2001. The impact of detritivorous fishes on a mangrove estuarine system. Ecological Modelling 140:207-218.

Rosen, David J. 2000. *Cryptocoryne becketti* (Araceae), a new aquatic plant in Texas. Sida 19(2):399-401.

Schindler, D. E., and L. A. Eby. 1997. Stoichiometry of fishes and their prey: implications for nutrient recycling. Ecology 78·1816-1831.

Scott, M. C., and G. S. Helfman. 2001. Native invasions, homogenization, and the mismeasure of integrity of fish assemblages. Fisheries 26(11):6-15.

Sinsabaugh, R. L., and A. E. Linkins. 1990. Enzymic and chemical analysis of particulate organic matter from a boreal river. Freshwater Biology 23:301-309.

Whitesıde, B. G., and C. Berkhouse. 1992. Some new collection locations for six fish species. Texas Journal of Science 44(4):494.

Zimmer, K. D , B. R. Herwig, and L. M. Laurıch. 2006. Nutrıent excretion by fish in wetland ecosystems and its potential to support algal production. Limnology and Oceanography 51(1):197-207.

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