A Review of the Exotic Species Inhabiting the Upper San Marcos River, Texas, U.S.A

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A Review of the Exotic Species Inhabiting the Upper San Marcos River, Hays County Texas, U.S.A.

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Abstract.—The occurrence and current status of aquatic and semi-aquatic exotic species and their real or potential impacts on native species are assessed for the San Marcos River, Texas. Exotic species were found to be abundant in the river including 16 species of plants, four species of invertebrates, and 28 species of vertebrates. These species were introduced through a variety of means, but released aquaria specimens and stocking for the purpose of supplementing the sport fishery of the river are the primary sources. The geographic origin of the species reported here is diverse with most being native to tropical and subtropical areas of Asia, Central and South America, and other areas of the southern United States outside of central Texas. Solutions to address the problem of exotic species introductions are presented including some management and control options, regulatory mechanisms, and public education and outreach. Public education, and, when possible, management and removal of exotic species are proposed as the best means of alleviating threats to the native fauna and flora of the river.

There has been a continual increase in the rate of species invasions into freshwater habitats in the United States (U.S.), and the rate that mankind is intentionally introducing species to new habitats also is increasing (Lachner *et al*. 1970; Courtenay and Hensley 1980; Schwartz 1997). Introductions of non-native species may seem harmless in some circumstances, or even desirable in the case of certain sport fishes. Indeed, certain introduced species play major roles in our culture and many have socioeconomic benefits (*e.g.*, sport fishes, aquacultural enterprises). However, introductions of many non-native species can have severe negative effects on ecosystem structure and functioning and ultimately result in the loss of biological diversity (Lodge 1993). Exotic species compete with native species for food and space, serve as predators, introduce disease and parasites, modify habitats, and sometimes interbreed with native species. There also are aesthetic considerations associated with introduced species such as recreational and sport value degradation. For instance, lakes and streams clogged with *Hydrilla* are not popular for swimming and other aquatic sports because the abrasive texture of this invasive weed scratches the skin, and its voluminous growth habits make movement by swimmers and watercraft difficult. Other activities such as hunting and fishing also can be impacted. Exotic species can cause serious economic losses when they detrimentally impact recreational, commercial and agricultural enterprises, or pose risks to human health and welfare (Pimentel *et al*. 2000). To confound this issue further, invasive aquatic species are particularly problematic because they are difficult, if not impossible, to control or manage once established (Courtenay and Robins 1975; Simberloff 1996).

The upper San Marcos River, from its source at San Marcos Springs (impounded as Spring Lake) in the City of San Marcos, Hays County, Texas to its confluence with the Blanco River some 11 km downstream (Fig. 1), has been impacted by exotic species for over 100 years. San Marcos Springs are the second largest spring system in Texas producing some 4,500 liters per second average flow (Brune 1981). The San Marcos River is an ecologically unique system that serves as habitat to several threatened, endangered, and endemic species (United States Fish and Wildlife Service 1995). The warm subtropical to Mediterranean climate of central Texas and the thermally constant (~23°C) flows of the San Marcos Springs and River provide an excellent medium for establishment of non-native species. No previous attempt has been made to fully address the extent to which exotic species have invaded the river.

In this paper, we present a list of the known exotic species that have been reported from the San Marcos River ecosystem and address the current status of these species and their real and potential impacts on the native flora and fauna. A survey of the exotic flora and fauna of the San Marcos River is an important step toward developing relevant management plans for protecting and conserving rare, threatened and endangered species that naturally occur in the river (U.S. Fish and Wildlife Service 1995).

Methods

The terminology for exotic species used herein follows Shafland and Lewis (1984), and we thus define exotic species as those entering an ecosystem from beyond their historic range through non-natural means. The scope of this paper is restricted to aquatic and semiaquatic species, but we recognize that there are numerous terrestrial and riparian exotic species in the San Marcos River watershed that may have impacts on the ecology of the river. To the extent known, we also assess the current relative population status of these species and consider their potential impacts on native species and habitats. Based on this information, we have assigned a relative ecological impact (high, medium, low) to each species. Known or suspected ecological impacts are based on published information and our own observations. We also discuss the geographic origin of each species, their probable means and dates of introduction, and summarize pertinent literature relating to their biology and management in the river.

Results and Discussion

The exotic species that presently occur or have been reported from the San Marcos River are presented in Table 1. Forty-eight species including 16 plants, four invertebrates, 18 fish, one reptile, eight birds, and one mammal are listed. Thirty-two of these species are established in the river and have breeding populations while the remaining 14 species either have localized populations or apparently did not become established following introduction. The geographic origins of the species reported here are diverse with most coming from Asia, Central and South America, and from other locations within North America north of Mexico. Under Texas law, possession, sale, and distribution of several of the species discussed here are prohibited due to the real or potential risks they pose to native species (Howells 1999).

Aquatic Vegetation

We found 16 species of aquatic and semi-aquatic plants have been introduced into the river and its headwaters at Spring Lake, and most of these have established populations. Many of these species are considered noxious weeds in Texas and elsewhere in the world (Barrett 1989). Introduction of aquatic vegetation into large spring ecosystems in Texas presents several potentially significant problems. For example, invasive aquatic vegetation can impact human activity and safety, interfere with navigation, increase risk and severity of flooding, and disrupt ecosystem structure and functioning (Gurnell and Midgley 1994; Madsen 1997). The many threats to aquatic ecosystems from invading hydrophytes were addressed by Cronk and Fuller (1995) and Barrett (1989). Common names for plants presented here follow Brako *et al*. (1995) and Correll and Correll (1975).

***Arundo donax* L., giant reed.** —This species apparently was introduced from the Mediterranean and is now widely naturalized in the southern U.S. (Correll and Correll 1975). Giant reed commonly

grows along the banks of the river and on elevated, partially dewatered areas and sandbars within the stream channel. Once established, giant reed grows to several meters in height and produces considerable shading. In addition, the "islands" formed by giant reed can cause accumulation of debris and sediments ultimately forming larger islands that alter stream channel morphology. The date of introduction of this species to the river is unknown, but the most probable time was before 1900 given that it was widely distributed in the southern U.S. in the 1800s.

***Ceratopteris thalichtroides* (L.) Brongn., floating fern**.—Cook *et al*. (1974) stated this species is a native of Asia where it is commonly cultivated for food in Japan. The first report of this species from the river was by Morton (1967) from a collection made in 1963, who further reported the plant to be native to South America in addition to Asia. Hannen [sic. Hannan] (1969) followed Morton's work documenting the establishment of *C. thalichtroides* in the river, and he stated that this species was intentionally introduced for purposes of commercial production by the now defunct Texas Aquatic Plants Company. This species is common along the shoreline areas of Spring Lake and backwater areas of the river. Floating fern subsequently has been introduced into other large spring systems in Texas (Lemke 1994).

***Colocasia esculenta* (L.) Schott, elephant ear**.—Elephant ear is native to southeast Asia and Indonesia (Cook *et al*. 1974). Akridge and Fonteyn (1981) first reported *C. esculenta* to be naturalized along the upper river although the species has been present there for nearly 100 years. The species apparently was introduced sometime after 1907, and the first herbarium record is dated 1929 (Akridge and Fonteyn 1981). Elephant ear dominates the shoreline areas of Spring Lake and the shallow, near bank zone of the river to well downstream of its confluence with the Blanco River. Elephant ear is considered highly detrimental to the ecological functioning of the river (Akridge and Fonteyn 1981; U.S. Fish and Wildlife Service 1995).

***Cryptocoryne beckettii* Thw. ex R. Trim.**—This hydrophyte is a native of southeast Asia (Cook *et al*. 1974). A population of *Cryptocoryne becketti* occurs in the river near the outfall of the San Marcos Wastewater Treatment Facility. The occurrence of this species in the river likely resulted from an unintentional release by an aquarist given the popularity of this plant in the aquarium industry. The year of introduction of *C. becketti* into the river is unknown, but biologists with the Texas Parks and Wildlife Department first observed this species at its current location in 1993 (DEB, personal observation).

***Egeria densa* Planch., leafy elodea**.—This native of South America (Cook *et al*. 1974) has been widely sold as an aquarium plant suggesting its probable source of introduction into the river. *Egeria densa* was not listed by Watkins (1930), but Devall (1940) reported it as *Elodea canadensis* suggesting it was introduced into the river between 1930 and 1940. Leafy elodea is particularly

abundant in the area immediately upstream of Rio Vista Dam (Fig. 1). However, given its limited distribution in the river, ecological impacts caused by this species probably are not significant.

***Eichhornia crassipes* (Martinus) Solms., water-hyacinth**.—Barrett (1989) reported that water hyacinth is native to the tropical lowlands of South America, but it has now spread to more than 50 countries on five continents. Around 1884, popular interest in water hyacinth began increasing, and plants imported from Venezuela were distributed as gifts by a Japanese delegation at a cotton exposition in New Orleans (Penfound and Earle 1948; Williams 1980). The beautiful purple flowers associated with this plant quickly led to its popularity and dispersal throughout the southern U.S. The exact year of introduction into the San Marcos River is unknown, but photographs of the river taken in the early 1920s clearly show water hyacinth in the background. The first written record of this species from the river was by Devall (1940). Water hyacinth is considered to be to be among the 10 worst invasive weeds in the world (Williams 1980; Barrett 1989), and it also is considered to be among the most serious nuisance species in the southern U.S. (Madsen 1997). However, water hyacinth primarily occurs along the margins of Spring Lake and backwater areas of the river, and its population densities in these locations are relatively small. Penfound and Earle (1948) and Gopal (1987) gave detailed accounts of the biology of *E. crassipes*, and Barrett (1989) discussed aspects of the biology of *E. crassipes* that make this species such a noxious weed. A "wetland" restoration program associated with San Marcos Springs recently was initiated by Southwest Texas State University and water hyacinth is now being actively removed from the Spring Lake area. Water hyacinth is listed as a prohibited species in Texas (Howells 1999).

***Hydrilla verticillata* (L. f.) Royle, hydrilla**.—This hydrophyte has become so widely introduced around the world that its native distribution is uncertain. For instance, Tiner (1993) reported that hydrilla is native to Africa, but Langeland (1996) stated it is native to the warmer parts of Asia. Regardless, hydrilla is considered among the most serious nuisance species of aquatic vegetation in the U.S. (Langeland 1996; Madsen 1997). This species is well established in the river where it now dominates the macrophyte community in some areas and eliminates habitat for native plants (Poole and Bowles 1999), fish, and invertebrates. Hydrilla was first introduced into the U.S. in the late 1950s for use in aquariums (Williams 1980). Neither Hannan and Dorris (1970) or Bruchmiller (1973) reported hydrilla in their studies of the river's vegetation, but it was first reported from the river by Flook (1975). Lemke (1989) noted that this species was among the most dominant macrophytes present. *Hydrilla verticillata* is on the Texas prohibited species list (Howells 1999).

***Hygrophila polysperma* (Roxb.) T. Anderson, Indian hygrophila.**—This species is native to Malaysia and India. Angerstein and Lemke (1994) first reported *H. polysperma* from the San Marcos River. However, based on collection data from herbarium specimens,

it appears that *H. polysperma* has been established in the river for well over 25 years (Angerstein and Lemke 1994). This species is now naturalized in the upper river where it constitutes a significant portion of the hydrophyte community, and it appears to have taken over much of the habitat formerly occupied by native species. Such impacts ultimately may be shown to have significant impacts on endangered and endemic species living in the river (U.S. Fish and Wildlife Service 1995). *Hygrophila polysperma* has several characteristics that make it a serious threat to the native flora and fauna of the river. These characteristics include having a high growth potential, vigorous vegetative reproduction, the ability to live in shaded areas, and plasticity with respect to habitat choice (Botts *et al.* 1990; Kovach *et al*. 1992; Spencer and Bowes 1985). *Hygrophila* is a popular aquarium plant and likely was introduced into the river by aquarists. The U.S. Department of Agriculture (1983) placed this species on the federal list of noxious weeds.

***Limnophila sessiliflora* (Vahl) Blume, limnophila**.—This hydrophyte is native to India and Southeast Asia (Lemke 1994). The first record of limnophila in the river was by Bruchmiller (1973). Lemke (1994) stated that he could find no evidence that this species is having any deleterious effects on the growth of native hydrophytes in the river, but he warned that the spread of this species should be closely monitored. However, Lemke (1999) later reported that he had not observed *L. sessiliflora* in the river since 1984. Spencer and Bowes (1985) reviewed the physiological characteristics of *Limnophila* that contribute to the success of this species as a weed.

***Myriophyllum aquaticum* (Vell.) Verdc., parrot's feather**.—Nelson and Couch (1985) discussed the introduction and distribution of this South American native in North America. The first report of parrot's feather from the upper San Marcos River was by Hannan and Dorris (1970), but Nelson and Couch (1985) reported that *M. aquaticum* was present in central Texas by the 1940s. This species is restricted to Spring Lake and backwater areas of the river, and it occurs at very low densities. Sutton (1985) reviewed the biology and ecology of parrot's feather, and he suggested that this species is not a major noxious weed.

***Myriophyllum spicatum* L., Eurasian water-milfoil**.—A native of North Africa and Eurasia, this species is considered to be among the worst nuisance aquatic weeds in the U.S. (Madsen 1997). Couch and Nelson (1985) reported on the introduction and distribution of *M. spicatum* in North America, and they indicated that, based on herbarium records, this species was first introduced into Hays County, Texas during the 1950s. However, the specific year of its introduction into the San Marcos River is unknown. Lemke (1989) reported *M. spicatum* in his survey of aquatic vegetation of the river, but the species was not reported by Hannan and Dorris (1970) suggesting that it may not have been introduced at the time of their study. Lemke (1999) later reported that he had not observed Eurasian water-milfoil in the river in recent years. The production biology and ecology of Eurasian water-milfoil were reviewed by Grace and

Wetzel (1978) and Smith and Barko (1990), respectively. *Myriophyllum spicatum* is on the Texas prohibited species list (Howells 1999).

***Pistia stratiotes* L., water lettuce**.— This species may be native to the southern gulf coastal plain of the U.S., but apparently it is not native to central Texas (Bailey 1949). However, Dray *et al*. (1993) argued water lettuce is not native to the U.S. because there is a paucity of phytophagous specialists associated with it in this country compared to South America. Lemke (1999) considers *P. stratiotes* to be transplanted into the San Marcos River from eastern or southern Texas. The first known record of this species from the river was by Watkins (1930), indicating that it had been introduced no later than the 1920s. Water lettuce is poorly represented in the river where it is restricted to Spring Lake and backwater areas.

***Potamogeton crispus* L., curled pondweed**.— This native of Europe was first recorded from the San Marcos River by Bruchmiller (1973). *Potamogeton crispus* was well established in some areas of the river by 1984 (DEB, personal observation). However, Lemke (1999) reported that he had not observed curled pondweed in the river since 1984, and Poole and Bowles (1999) likewise did not report finding any examples of this species in their study. The source of introduction is likely from aquarists as this species is commonly used in aquariums.

***Ranunculus sceleratus* L., cursed buttercup**.— Cursed buttercup is native to Europe, but it has become widely naturalized in the U.S. (Abrams 1964). This semi-aquatic plant is uncommon, but it is established in the Spring Lake area where it inhabits shallow and wetted areas around the lake margins. The date of introduction is unknown, and this is the first report of this species from the San Marcos River ecosystem. Correll and Correll (1975) reported that this species has an acrid sap that can raise blisters on human skin.

***Rorippa nasturtium-aquaticum* (L.) Hayek, water cress**.—A native of Europe, this species probably was introduced prior to 1900 by Europeans who settled in central Texas. However, the first report of water cress at San Marcos Springs was by Watkins (1930). Some argue that water cress is native to North America (Whitley *et al*. 1990). Water cress is uncommon in the river.

***Xanthosoma sagittifolium* (L.) Schott., elephant ear**.—This species of elephant ear is native to tropical America from the West Indies through South America (Bailey 1949). Presently, *X. sagittifolium* is restricted to small areas immediately downstream of the spillways of Spring Lake Dam and Rio Vista Dam. Although the date of introduction of *X. sagittifolium* to the river is unknown, Lemke and Schneider (1988) first reported its occurrence there. *Xanthosoma sagittifolium* is commonly used as an ornamental, and it has become sporadically naturalized in the southern U.S. (Godfrey and Wooten 1979).

Invertebrates

Four species of exotic invertebrates have

been recorded from the San Marcos River. All four species are mollusks that are considered highly detrimental to the ecological functioning of the river.

***Corbicula fluminea* (Müller), Asian clam**.—This species was introduced into the U.S. from southeast Asia prior to the early 1920s (Britton 1982; McMahon 1982; Counts 1986). Asian clam is well established in the upper San Marcos River. In some areas of the river, accumulations of shells from dead specimens constitute a large portion of the surface substrate. The exact year of introduction of *C. fluminea* into the river is unknown. However, this species was well established throughout much of Texas by the early 1970s (Metcalf 1966; Murray 1971b, Metcalf and Smartt 1972; Murray 1972; Britton and Murphy 1977; Britton 1982; McMahon 1982), and it was common in the river by 1982 (DEB personal observation). How *C. fluminea* was introduced into the river is unknown, but probable sources include discarded fishing bait (Britton 1982; McMahon 1982), released aquarium specimens, and accidental transport. However, as noted by McMahon (1982), *C. fluminea* has remarkable inherent dispersal abilities and may well be responsible for its own rapid spread throughout Texas and elsewhere. A considerable body of literature has been amassed on Asian clam largely due to its invasive nature and the negative ecological impacts it creates in aquatic ecosystems (*e.g.*, Sinclair 1971; McMahon 1982, 1983; Britton and Prezant 1986; McMahon and Williams 1986; Strayer 1999). The introduction and spread of *C. fluminea* in the U.S. has been thoroughly documented (*e.g.*, Dundee 1969; McMahon 1982). Britton (1982) briefly reviewed several ecological and biological studies pertaining to the Asian clam in Texas. Ecological studies for Texas populations of this species were conducted by Horne and McIntosh (1979) and Bushek and Cameron (1992). The Asian clam is no longer listed as a prohibited species in Texas primarily because it already occurs statewide (Howells 1999).

***Marisa cornuarietis* (L.), giant ramshorn snail**.—This large snail is a native of tropical America from Panama southward into South America (Neck 1984). Ramshorn snail was first reported from the San Marcos River in 1983 (Neck 1984) where it is now established. Release by aquarists is the presumed source of introduction. The voracious appetite of this herbivorous species suggests it has significant potential for disrupting the ecological functioning of the river by feeding on native aquatic vegetation (Seaman and Porterfield 1964; Horne *et al*. 1992; Howard 1998). Among this vegetation is the federally-endangered Texas wild-rice (*Zizania texana* Hitchcock). Robins (1971) reported that grackles (*Quiscalis* sp.) in Florida preyed heavily on *M. cornuarietis* occupying shallow waters suggesting that similar predation may occur along areas of the San Marcos River that are frequented by these birds. *Marisa cornuarietis* is listed as a prohibited species in Texas (Howells 1999).

***Melanoides tuberculatus* (Müller), red-rimmed melania**.—This thiarid snail is a native of southern Asia and it has been commonly sold in the aquarium industry (Murray 1971a). The date of introduction

to the San Marcos River is unknown, but this species was reported (as *Thiara tuberculata*) from neighboring counties in the 1960s (Murray 1964). Lindholm (1979) first reported its occurrence in the river. Murray (1971a) indicated that *M. tuberculatus* has high reproductive rates and can displace native snails. However, we have observed that this species, although established, occurs in fairly low densities in the river. Pointier *et al*. (1994) found that this species along with *Tarebia granifera* (see below) effectively excluded the native snail *Biomphalaria glabrata* (Say) from the streams to which they were introduced. The impacts of thiard snails on the native snail *Biomphalaria obstructus* Morelet in the river are unknown. The red-rimmed melania apparently serves as an intermediate host in the life cycle of a fluke (Trematoda) that parasitizes the gills of certain percid fishes including the federally-endangered fountain darter (*Etheostoma fonticola* Jordan and Gilbert) (Mitchell *et al*. 2000). Murray and Haines (1969) similarly reported the red-rimmed melania to be the intermediate host of a trematode in Texas with adult flukes being parasites of waterfowl, and Murray (1971a) noted that it is an intermediate host of the human lung fluke (*Paragonimus westermani*).

***Tarebia granifera* (Lamarck), quilted melania**.—The means by which this Asian species was introduced to the San Marcos River is unknown although it has been commonly sold in the aquarium industry (Murray 1971a) and may have originated from released aquarium stocks. Murray (1964) reported this species (as *Thiara granifera*) from nearby Bexar and Comal counties suggesting a corresponding timeframe for introduction into the river. Lindholm (1979) first reported this species from the river in his study of the gastropods of that system. However, the actual date of introduction is unknown. Murray (1971a) noted that, much like *M. tuberculatus*, quilted melania has high reproductive rates and can displace native snails. Indeed, wherever this species is introduced, its populations become quickly established and grow to enormous densities (Abbott 1950; Murray 1971a). Recent collections from the San Marcos River show this species constitutes to up to 60% of the benthic invertebrate density in some areas (DEB, personal observation), and shells from dead individuals litter the stream bottom. *Tarebia granifera* appears to be rapidly displacing native snails such as *Elimia comalensis* Pilsbry in the river. Abbott (1950) discussed aspects of the biology of the quilted melania, and it has been shown to be an intermediate host of various flukes (Trematoda), including the human lung fluke (*P. westermani*) (Abbott 1952; Murray and Stewart 1968; Murray and Haines 1969).

Fish

We report here 18 species of fish that have been introduced into the San Marcos River. Some of the species presented here are known only from single occurrences and are not thought to have breeding populations in the river. Nevertheless, we list these records because of their potential for possible reintroduction and establishment into the river. Other species, primarily gamefishes, that perhaps could be considered introduced

species are not listed here, including the Florida subspecies of the largemouth bass (*Micropterus salmoides* Lacépède) which has been widely introduced for recreational sport fishing in Texas. This strain now occurs in the river although its impacts, exclusive of genetic dilution of native largemouth bass (Morizot *et al*. 1991), are probably negligible. Hubbs (1982) gave an excellent account of the various exotic fishes introduced to Texas at that time. In addition, Howells and Garrett (1992) reported that a wide variety of non-native species of fish have been imported and stocked in Texas waters over the past century, but most of these introductions failed to establish. The former two papers illustrate that there is a significant potential for additional introductions of exotic fishes into Texas waters including the San Marcos River drainage. Although there are many potential environmental impacts of introduced fishes on aquatic ecosystems, they are rarely documented (Courtenay and Taylor 1982; Courtenay and Stauffer 1984).

***Amblopities rupestris* (Rafinesque), rock bass**.—Rock bass were transplanted to Texas from Missouri as a food and sport fish (Hubbs *et al*. 1991), and they are now established in many areas of the state. The date of first introduction of this species into the river is thought to be 1897 (Brown 1953). Rock bass are now common in the river where they have been found in several locations (Kelsey 1997). The ecological impacts associated with this species are unknown. Rock bass are a popular sport fish among fishermen.

***Astyanax mexicanus* (Fillippi), Mexican tetra**.—Mexican tetras are native to the Rio Grande and possibly Nueces River drainages in Texas. However, this species was widely introduced into the Guadalupe River Basin between 1908 and 1930 (Brown 1953; Hubbs *et al*. 1978). The first record of Mexican tetra from the San Marcos River is 1938 (Brown 1953). This species is established and common in the river where it is particularly abundant in heavily vegetated areas (Jurgens 1951). Ecological impacts associated with Mexican tetra introductions are unknown.

***Carrasius auratus* (L.), goldfish**.—This species is native to Asia. Goldfish occasionally can be observed in the San Marcos River (Kelsey 1997) where they likely originated from released aquarium stock. The species does not appear to be established in the river. However, goldfish have been reported as established in other areas of Texas (Courtenay *et al*. 1984, 1986). Ecological impacts associated with goldfish in the San Marcos River probably are negligible.

***Cichlasoma cyanoguttatum* (Baird and Girard), Rio Grande cichlid**.—This cichlid is native to the Rio Grande and Pecos River drainages in Texas and Mexico, and it has been widely introduced into other river drainages in Texas for the purpose of sport fishing (Brown 1953). Rio Grande cichlids were first brought to the San Marcos area in 1928, and subsequent releases were made into the Guadalupe River Basin, including the San Marcos River (Brown 1953). This species is now established and common in the river. Rio Grande cichlid is a predatory species and likely competes with or preys on other species, including the endangered fountain darter (*E. fonticola*), threatened

San Marcos salamanders (*Eurycea nana* Bishop), and benthic invertebrates. Hubbs (1968) reported that the transplantation of this species into areas of Texas to which it is not native has resulted in rigorous, albeit unsuccessful, attempts to remove it.

***Cichlasoma nigrofasciatum* Günther, convict cichlid**.—This native of Central America was first collected from the San Marcos River in 1989 with additional collections being made in 1991 (Whiteside and Berkhouse 1992). Convict cichlid may be established in the river though this has not yet been confirmed. The impacts of this species on the ecological functioning of the river are unknown. However, Courtenay and Hensley (1980) suggested this species competes with native sunfishes for spawning sites in areas where it is introduced. Convict cichlids likely were introduced by aquarists.

***Colosomma* sp., pacu**.—Howells *et al*. (1991) reported a 1990 collection of pacu from the San Marcos River. In addition, Texas Parks and Wildlife Department staff biologists have observed two large unidentified pacu (ca. 30-40 cm in length) swimming about Spring Lake on several occasions during 1997-1999 (DEB, personal observation). These specimens likely were released into Spring Lake by aquarists. Several species of pacu are commonly sold in the aquarium trade, and some of these have been reported escaped in other Texas aquatic systems (Howells *et al*. 1991). Pacus are generally distributed in South America.

***Cyprinus carpio* L., common carp**.—Carp are native to Eurasia and were introduced and widely propagated in Texas between 1879 and 1900. According to Kuehne (1955), they probably were stocked into the Guadalupe River Basin several times during this period. However, the date of the first occurrence of this species in the San Marcos River is unknown. State supported stocking of this species ended in 1885 when the Texas legislature abolished the Texas Fish Commission (Cox 1999). Whiteside and Berkhouse (1992) reported on a collection of Koi carp, a variety of *C. carpio*, taken at the intake screen for the A.E. Wood Fish Hatchery in 1990. They speculated these fish had probably escaped from the hatchery because at that time Koi carp were used as prey for sport fish being reared at the hatchery. However, release by aquarists cannot be entirely ruled-out as a source for these fish. Large (/30 cm) Koi carp can occasionally be seen in the upper river. The ecological impacts of carp on aquatic ecosystems are substantial and well documented (Taylor *et al*. 1984; Lever 1996).

***Hypostomus* sp., suckermouth catfish, Armadillo del Río (Hubbs *et al*. 1991)**.—These fish are native to Central America and the Amazon Basin in South America. Barron (1964) found that suckermouth catfish could overwinter in central Texas. Whiteside and Berkhouse (1992) first reported this species from the upper San Marcos River. Suckermouth catfish are now established and reproducing in the river (DEB, personal observation), but ecological impacts associated with this species probably are negligible. According to Burgess (1989), *Hypostomus* species feed mainly on algae and other vegetable matter, but they also

will occasionally eat small invertebrates.

***Lepomis auritus* (L.), redbreast sunfish**.—This species was introduced from the Atlantic slope of the U.S. as a food and sport fish. However, the date of first introduction into the San Marcos River is unknown. Jurgens (1951) did not report redbreast sunfish in his study, but Kuehne (1955) found them to be widespread in the Guadalupe River Basin thus indicating the species was introduced well before 1955. Presently, it is established and abundant in the river where it is a popular sport fish. Wallace (1984) studied the food habits of this species in the river.

***Menidia beryllina* (Cope), inland silversides**.—This species is native to estuaries along the Atlantic and Gulf coasts of the U.S. and was transplanted into the river through an unknown source. In 1993, U.S. Fish and Wildlife Service biologists collected several examples of this species from the river near the A.E. Wood State Fish Hatchery outfall. The current status of this species in the river is unknown, but it probably is not established. However, Tilton and White (1969) documented the spread of this species in the nearby Colorado River Basin of Texas, suggesting it potentially could become established in the San Marcos River.

***Micropterus dolomieu* Lacépède, smallmouth bass**.—Smallmouth bass have been widely transplanted from other areas of the U.S. into the Guadalupe River Basin, including the San Marcos River. Hubbs and Peden (1968) reported a single specimen of *M. dolomieu* collected from the river in 1967, and Kelsey (1997) also collected representatives of the species showing its continued presence there. Edwards (1979) reported the ability of this species to hybridize with native Guadalupe bass (*Micropterus treculi*). Faraquhar (1995) reported hybrids of these two species from the Blanco River near its confluence with the San Marcos River, and he also presented data to show that smallmouth bass compete with native black basses for available habitat.

***Oncorhynchus mykiss* (Walbum), rainbow trout**.—Rainbow trout are native to the Pacific Northwest slope of North America from California to Alaska, but they have been widely introduced throughout Texas for the purpose of sport fishing. In the spring of 1983, a fisherman caught a rainbow trout (approximately 15 cm total length) while fishing downstream of the San Marcos Fish Hatchery outfall (DEB, personal observation). This fish certainly had escaped from the hatchery where this species was being reared at the time for eventual stocking elsewhere in Texas. We are unaware of any additional records of rainbow trout from the river, but we suspect that other specimens escaped from the hatchery before it was renovated during the late 1980s.

***Oreochromis aureus* (Steinachner), blue tilapia**.—This cichlid is a native of the Middle East and the Mediterranean coast of Africa. Blue tilapia are established and have a breeding population in the San Marcos River. The source of introduction of blue tilapia in the river is unknown, but most introductions of this species stem from escaped aquaculture specimens, efforts aimed at controlling aquatic

vegetation, or escaped baitfish. Lever (1996) stated that large populations of blue tilapia cause increases of turbidity due to their rolling behavior, and they may displace and compete with other species. Nonetheless, there is no conclusive evidence to this end, and most ecological impacts associated with this species are largely anecdotal and contradictory (Lever 1996). Muoneke (1988) reviewed the occurrence and ecology of tilapia in Texas waters. All species of tilapia are on the Texas prohibited species list (Howells 1999).

***Oreochromis mossambicus* (Peters), Mossambique tilapia**.—This cichlid is a native to Africa. Brown (1961) first reported this species from the San Marcos River, and Hubbs (1982) and Courtenay *et al*. (1984) reported its continued occurrence there. Lever (1996) reported that in 1958 the Texas Game and Fish Commission (now Texas Parks and Wildlife Department) introduced Mossambique tilapia into Spring Lake, and additional specimens escaped into the river from the outflow drain of the A. E. Wood State Fish Hatchery. Hubbs (1968) warned of the possible ecological consequences assoc-iated with the introduction of this species. Muoneke (1988) reviewed the occurrence and ecology of tilapia in Texas waters. All species of tilapia are listed on the Texas prohibited species list (Howells 1999).

***Poecilia formosa* (Girard), Amazon molly**.—Amazon mollies are native to the Rio Grande drainage and southward into Mexico. They were accidentally released from the San Marcos State Fish Hatchery into the river in 1955 from stocks obtained at the Lula B. Sams State Fish Hatchery in Olmito, Texas (Hubbs 1964). Drewry *et al*. (1958) first reported the Amazon molly from the river, where it is now established. Amazon mollies are aggressive fish and will harass and chase other fishes that enter their territory. The ecology of this species is discussed in Meffe and Snelson (1989).

***Poecilia latipinna* (Lesueur), sailfin molly**.—Sailfin mollies are native to the Atlantic and Gulf coasts of the U.S. and Mexico. The source of introduction of the sailfin mollies in the river is unknown, but released aquarium specimens is the most probable source. Sailfin mollies apparently were introduced into the river in 1944 (Brown 1953) and are now abundant in shallow and backwater areas. Sailfin mollies also harass other fishes that enter their territory.

***Pseudotropheus* sp., rift-lake cichlid**.—A single specimen of this species was captured by a fisherman in 1991 downstream of the Spring Lake Dam (Whiteside and Berkhouse 1992). The source of introduction probably was an aquarist who released the fish. The species apparently is not established in the river. Rift-lake cichlids are native to Africa.

***Pterygoplichthys disjunctivus* (Weber), vermiculated sailfin catfish**.— Examples of this were captured from the San Marcos River during 1996 (Edwards 2001). Burgess (1989) reported that this genus is distributed in South America with examples being known from Brazil, Paraguay and Peru. Sailfin catfish are closely related to *Hypostomus* and they

have similar ecological characteristics. The source of introduction likely is from released aquarium specimens.

Reptiles

***Pseudemys nelsoni* Carr, Florida red-bellied turtle.—**The only known exotic reptile occurring in the upper San Marcos River (Spring Lake) is the Florida red-bellied turtle. The first occurrence of this species in the river was reported by Rose *et al*. (1998) who reported that it probably is established there based on the occurrence of large fecund females and hatchlings in Spring Lake. However, this species is localized and potentially could be eliminated from Spring Lake through standard capture methods. Although the source of introduction for *P. nelsoni* is not known, the population likely was founded by escaped or released pets. The Florida red-bellied turtle is a native of Florida and southeastern Georgia (Ernst *et al*. 1994). Impacts caused by this species on native species or their habitats are not known. However, potential impacts may include hybridization with native turtles, and competition for food resources.

Birds

Eight species of exotic waterfowl have been introduced to the San Marcos River. Some of these, such as the domestic mallard duck, *Anas platyrhynchos* (L.), and Canada goose, *Branta canadensis* (L.), could be considered marginal exotics. However, we consider the non-migratory, domesticated forms of these species as exotic because naturally occurring representatives of these species normally occur in the watershed only during periods of migration. The waterfowl we report here do not leave the upper river and are considered permanent residents, but the respective population sizes for each of these species are small and do not exceed one dozen animals. The impacts these species have on the native species and their habitats in the upper river are unknown, but they feed on and among aquatic vegetation causing physical damage to plants. Tupa and Davis (1976) reported various waterfowl to feed on aquatic moss and the alga *Lyngbya* sp. and they may have localized impacts on such vegetation. Long (1981) provides an exhaustive review of exotic birds, including the species presented here, and notes on the types of damage they are known to cause.

***Alopochen aegyptiacus* (L.), Egyptian goose**.—This species is native to the southern two-thirds of Africa (Long 1981), and it has been widely distributed throughout the world for domestic purposes. We observed a pair of these birds at Spring Lake during June 2000. They likely escaped from a domestic source.

***Anas platyrhynchos* (L.), mallard duck**.—Included here is the domestic white duck which is a variant of the mallard. The range of the mallard has increased in North America due in part due to captive-reared birds reverting to the wild (Long 1981). This species occurs naturally in the U.S. and migratory forms overwinter along the river, but domesticated individuals can be found throughout the year, particularly around Spring Lake.

***Anser anser* (L.), domestic goose**.—Several domestic geese frequent the upper San Marcos River and occasionally Spring Lake. These geese apparently are domesticated varieties of the Greylag goose, a species common to Europe and northern Africa (Brown *et al*. 1982). The date of first introduction of this species to the river is unknown, but likely dates to the first arrival of Europeans to central Texas.

***Anser cygnoides* (L.), Chinese or African goose**.—Several of these distinctly marked domestic geese have been observed along the upper San Marcos River since 1998. African geese actually are domesticated descendants of the Asiatic or Chinese goose (Brown *et al*. 1982). Both white (Chinese goose) and brown (African goose) forms have been seen on the river. The date of introduction is unknown, but it is presumed to be recent.

***Branta canadensis* (L.), Canada goose**.—This species occurs naturally in the U.S, but domesticated individuals can be found throughout the year along the upper San Marcos River, particularly around Spring Lake and the various parks along the river.

***Cairina moschata* (L.) Muscovy duck**.—This duck is a native of southern Texas (Hildago, Starr and Zapata counties) (Eitniear *et al*. 1998) and southward from Mexico to South America (Long 1981). It has been introduced locally as a domestic form and a few individuals occasionally can be observed at Spring Lake.

***Cygnus olor* (Gmelin), mute swan**.—This native of Eurasia has been widely introduced in the U.S. including the upper San Marcos River where they are semi-domesticated. However, the original date of introduction is unknown. Mute swans are established and actively nest and reproduce at Spring Lake.

***Cygnus atratus* (Latham), black swan**.—This large swan is a native of Australia and Tasmania. Individuals occasionally have been observed along the San Marcos River, but no specimens have been seen recently. Observed specimens likely originated from domestic sources, but the date of first introduction is unknown.

Mammals

***Myocaster coypus* (Molina), nutria.—** The only introduced mammal known from the upper San Marcos River is the nutria. No specific population estimate has been made for the river, but the species is abundant along this stretch of river. This large rodent is native to the temperate portions of South America including Argentina, Bolivia, Chile, Paraguay, and Uruguay. Schmidly (1983) reported that the nutria was first introduced into the U.S. in the late 1930s to Avery Island, Louisiana. They were later introduced to the mainland in 1940 during a hurricane, and the species subsequently has spread throughout most of Texas (Hollander *et al.* 1992). Other introductions have occurred from releases of animals for the proposed purpose of controlling aquatic vegetation and by disillusioned fur farmers who found no market for nutria fur (Smith 1969). The primary impacts to aquatic systems, including the San Marcos River, attributed to the nutria include

destab-ilization of stream banks associated with burrowing, and eating aquatic vegetation (Atwood 1950; Davis 1974). Relatively little is known about the specific impacts nutria may have on the river and its native vegetation. However, Emery (1967) reported observing nutria feeding on endangered Texas wild-rice. Atwood (1950) presented a detailed life history study of the nutria.

Solutions to the Problem

Introductions of non-native species into the San Marcos River ecosystem have occurred for well over 100 years. Our interpretation of available data on the approximate year or decade of exotic species known to have been introduced into the river show that new introductions have occurred steadily throughout the past century (Fig. 2). While the 1960s exhibited the greatest documented number of introductions for any decade, the 1980s and 1990s also show substantial numbers of species were introduced. Based on this relatively recent surge of introductions, an argument can be made that past and present attempts to prevent introductions of exotic species have largely failed. Such introductions call into question the potential solutions that are available or must be developed to resolve this problem.

Numerous proposals have been made concerning the management and control of exotic species, especially aquatic vegetation (Madsen 1997). However, most management and control techniques are not completely effective, and they can present unacceptable problems themselves (Gallagher and Haller 1990). For example, various insects have been proposed as biological control agents of such invasive species as *Hydrilla verticillata*, (*e.g.*, Del Fosse *et al*. 1976). However, such intro-ductions must be carefully evaluated given that some introduced insects can have severe consequences with respect to native species and the environment (Sailer 1978, Howarth 1992). Similarly, grass carp (*Ctenopharyngodon idella* Cuvier and Valenciennes) are commonly used to control aquatic vegetation, but these voracious, non-discriminant herbivores often produce adverse environmental impacts to systems in which they are introduced (Courtenay and Stauffer 1984), and their management can be problematic (Prentice *et al*. 1998). Mechanical harvesting of aquatic vegetation also can be an effective tool in some circumstances, but it generally requires multiple harvests, and disposal of harvested material can be problematic (Langeland 1996; Madsen 1997). Moreover, hydrilla fragments can sprout entire new plants (Langeland 1996) and failure to remove cuttings of hydrilla may result in a larger population of this weed. As Barrett (1989) noted, mechanical methods cannot destroy plants at a rate fast enough to eliminate them, and herbicides often have harmful side effects, such as impairing water quality, killing fish and disrupting ecosystem functioning. The occurrence of the federally-endangered Texas wild-rice in the San Marcos River precludes the use of any herbicides in that system. Management of invertebrate and vertebrate exotic species poses even more problems than those noted for aquatic vegetation (Courtenay and Stauffer 1984). These species often are highly fecund and are capable of

movement and escape thus making their management a difficult, if not impossible, process. In addition, management activities may conflict with sport and recreational uses and legal water rights. Once these species become established, they essentially become permanent residents.

Regulations applicable to the introduction of exotic species in Texas waters were reviewed by Howells (1999). These regulations include 31 TAC §§57.111-57.130 concerning harmful or potentially harmful exotic fish, shellfish and aquatic plants, and 31 TAC §57.251, §§57.257-57.260 concerning the introduction of fish, shellfish, or aquatic plants into public waters. Comparable laws apply at the federal level (Peoples *et al*. 1992; U.S. Office of Technology Assessment 1993; Clugston 1986). Both the Executive Order 11987 (42 USC 4321) and Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (P.L. 101-646) address the import and export of exotic species of plants and animals. In February 1999, President Bill Clinton signed Executive Order 13112 that tasks federal agencies to prevent the introduction of invasive species and provide for their control in order to minimize undesirable impacts. Although such regulations may appear to be efficacious at face value, few people are even vaguely familiar with these state and federal laws. Moreover, such laws often are not enforced because violators are seldom caught. Exotic species introductions have originated as escapees from aquacultural sources, released pets and plants by aquarists, released and escaped bait by fishermen, releases from attempts to supplement sport fishing, and intentional, non-malicious releases by ill-informed individuals who want to beautify or supplement the biotic diversity of an aquatic ecosystem. Given these many sources of introduction, regulatory action alone clearly cannot be completely effective in stopping the flow of non-native species into ecosystems.

Relatively few efforts are made to educate the general public on the potential environmental and legal ramifications of introducing exotic species into public waters. Many people view the introduction of exotic species as serving a positive benefit, and they are generally unaware that such actions seldom produce a desirable outcome. In our view, one of the most important means for eventually halting the spread and introduction of exotic species is public education. Educational efforts relating to the dangers of exotic species can be achieved through mass media announcements, development of educational kiosks, developing programs for presentation to schools, and providing information pamphlets and posters for dissemination through pet shops and other sources. Two educational kiosks previously have been erected along the upper San Marcos River in recent years that address, in part, the potential impacts of exotic species. A greater effort also must be made to properly address exotic species in the popular literature. Presently, educational articles on exotic species for the benefit of the general public are only infrequently published. In addition, popular literature addressing exotic species sometimes presents conflicting information that the lay public must decipher. For instance, an Texas Parks and Wildlife article (Shook 1997) heralds the presence of Rio Grande

cichlids in non-native habitats for their sport fishing value, while in the same issue readers are alerted to the highly invasive and deleterious nature of water hyacinth and other exotic species (Castillo 1997). Clearly, educational efforts regarding exotic species must not only be more unified in their message to the public, but they must be more widely disseminated and placed in a broader variety of mass media if they are to reach and effectively influence the target audience. Environ-mentally conscious groups, such as The Nature Conservancy, have been at the forefront in educating the general public on exotic species. Recently, nearly an entire issue of Nature Conservancy magazine was devoted to exotic species issues (Nature Conservancy 1999). Similarly, an informative article on exotic species recently was published in the San Antonio (Texas) Express-News (Verrengia 1999).

Beyond the obvious necessity of public education and legal enforcement is addressing the physical functioning of ecosystems themselves. For instance, as stated by Vitousek *et al*. (1996), damming and impoundment of streams alters natural disturbance cycles, such as flooding and scouring, that normally occurs in these ecosystems. As a result, construction of dams often can be correlated with the successful invasion of non-native species into lotic ecosystems (Vitousek *et al*. 1996). The upper San Marcos River has three dams upstream of its confluence with the Blanco River, and three flood control dams have been constructed in the tributaries that feed the river (Poole and Bowles 1999). The impounded areas behind these dams provide habitat for many of the exotic species listed herein. The situation may well exist that exotic species will never be successfully managed or controlled in the river as long as such dams alter the normal ecological functioning of this unique aquatic ecosystem. Exotic species occur in many other aquatic systems in Texas including some of the other large-volume springs (Bowles and Arsuffi 1993). Many of the non-native species introduced into the San Marcos River also occur in these systems. Thus, the information presented in this paper can be used as a model for comparison with other spring systems in Texas in an effort to better understand the magnitude of the existing exotic species problem.

The arguments against introducing non-native species into freshwater ecosystems, recommendations for increased enforcement of existing regulations, and emphasis on public education and vigilance are not new (Shaffland 1986; Clugston 1986; Kohler and Courtenay 1986). However, we find our-selves still making these same arguments as we venture into a new millennium. Clearly, we have far to go in fully addressing the problem of exotic species. Although the number of exotic species we report here is high for a single aquatic ecosystem, there is a realistic possibility of additional species being introduced into the San Marcos River ecosystem. The trend reported in this paper substantiates this prediction, and the problem could become worse if steps are not taken to prevent future introductions. The ultimate solution must include a combination of a wide range of educational programs, funded research into potential and actual impacts to ecosystem structure and functioning, enforcement of existing

regulations at all governmental levels, and removal and management of offending species when possible and practical. Regrettably, such solutions are not readily at hand and ultimately resolving the problem of exotic species introductions will not be accomplished soon.

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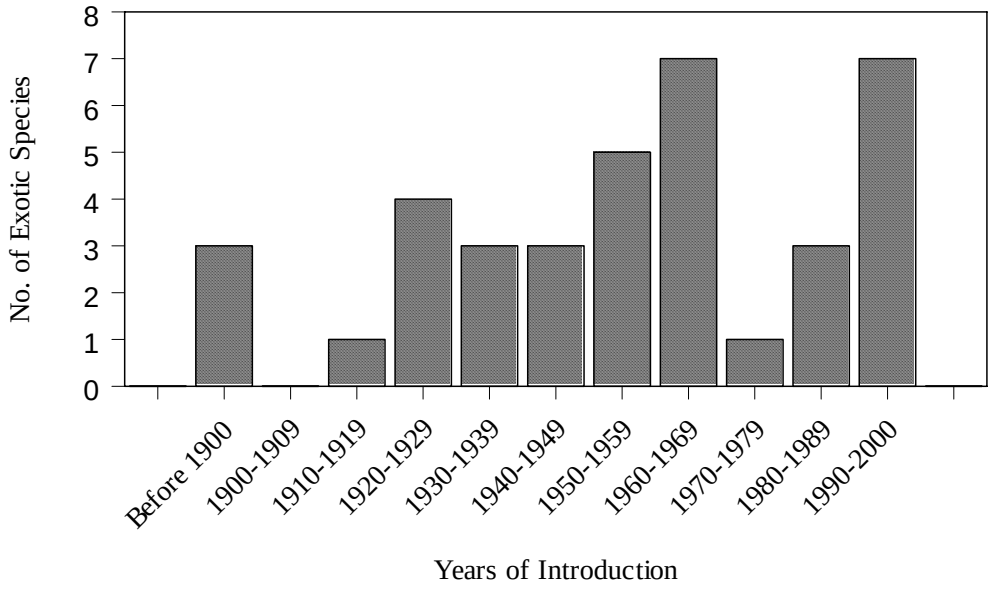


Figure 2. Exotic species introductions in to the San Marcos River, Texas by decade of occurrence.

Table 1. Exotic species of the upper San Marcos River, Texas.

Species	Common Name	Status[1]	Origin	Source	Known/Probable Date Introduced	Relative Ecological Impact
Plants						
Arundo donax	giant reed	E	Mediterranean	Agricultural	Before 1900	Medium
Ceratopteris thalictroides	floating fern	E	Southeast Asia	Aquarists	1963	Medium
Colocasia esculenta	elephant ear	E	Southeast Asia, Indonesia	Ornamental	1920s	High
Cryptocoryne beckettii	cryptocoryne	E	Southeast Asia	Aquarists	1993	High
Egeria densa	giant elodea	E	South America	Aquarists	1930s	Medium
Eichhornia crassipes	water-hyacinth	E	South America	Ornamental	1930s	Medium
Hydrilla verticillata	hydrilla	E	Africa/Asia?	Aquarists	1970s	High
Hygrophila polysperma	Indian hygrophila	E	Asia, Malaysia	Aquarists	1940s	High
Limnophila sessiliflora	limnophila	E	India, Southeast Asia	Aquarists	1960s?	Low
Myriophyllum aquaticum	parrot's feather	E	South America	Aquarists	1940s?	Low
Myriophyllum spicatum	Eurasian water-milfoil	E	North Africa, Eurasia	Aquarists	1950s?	Medium
Pistia stratiotes	water lettuce	E	South/East Texas	Ornamental	1920s?	Low
Potamogeton crispus	curled pondweed	E	Europe	Aquarists	1960s?	Low
Ranunculus sceleratus	cursed buttercup	E	Europe	Ornamental	Unknown	Low
Rorippa nasturtium-aquaticum	water cress	E	Europe?	Food crop?	Before 1900	Low
Xanthosoma sagittifolium	elephant ear	E	Central/South America	Ornamental	Unknown	Low

Table 1. Exotic species of the upper San Marcos River, Texas.

Species	Common Name	Status	Origin	Source	Known/Probable Date Introduced	Relative Ecological Impact
Invertebrates						
Corbicula fluminea	Asian clam	E	Asia	Invasive/ Bait bucket?	1960s?	High
Marisa cornuarietis	giant rams-horn snail	E	Central/South America	Aquarists	1983	High
Melanoides tuberculatus	red-rimmed melania	E	Southeast Asia	Aquarists	1960s	High
Tarebia granifera	quilted melania	E	Southeast Asia	Aquarists	1960s	High
Fish						
Amblopities rupestris	rock bass	E	Central U.S.	Sport fish	1897	Medium
Astayanax mexicanus	Mexican tetra	E	South Texas	Bait bucket	1920s	Medium
Carrasius auratus	goldfish	R	Asia	Aquarists	Unknown	Low
Cichlasoma cyanoguttatum	Rio Grande cichlid	E	South Texas	Sport fish	1928	High
Cichlasoma nigrofasciatum	convict cichlid	R	Central America	Aquarists	1980s	Low
Colosomma sp.	pacu	R	South America	Aquarists	1990	Low
Cyprinus carpio	common carp	E	Eurasia	Sport fish/ Accidental release	Before 1900	Low
Hypostomus sp.	suckermouth catfish	E	Cental/South America	Aquarists	1980s?	Low
Lepomis auritus	redbreast sunfish	E	Southeastern U.S.	Sport fish	1950s?	High
Menidia beryllina	inland silversides	R	Atlantic/Gulf Coast	Bait bucket?	1990s?	Low

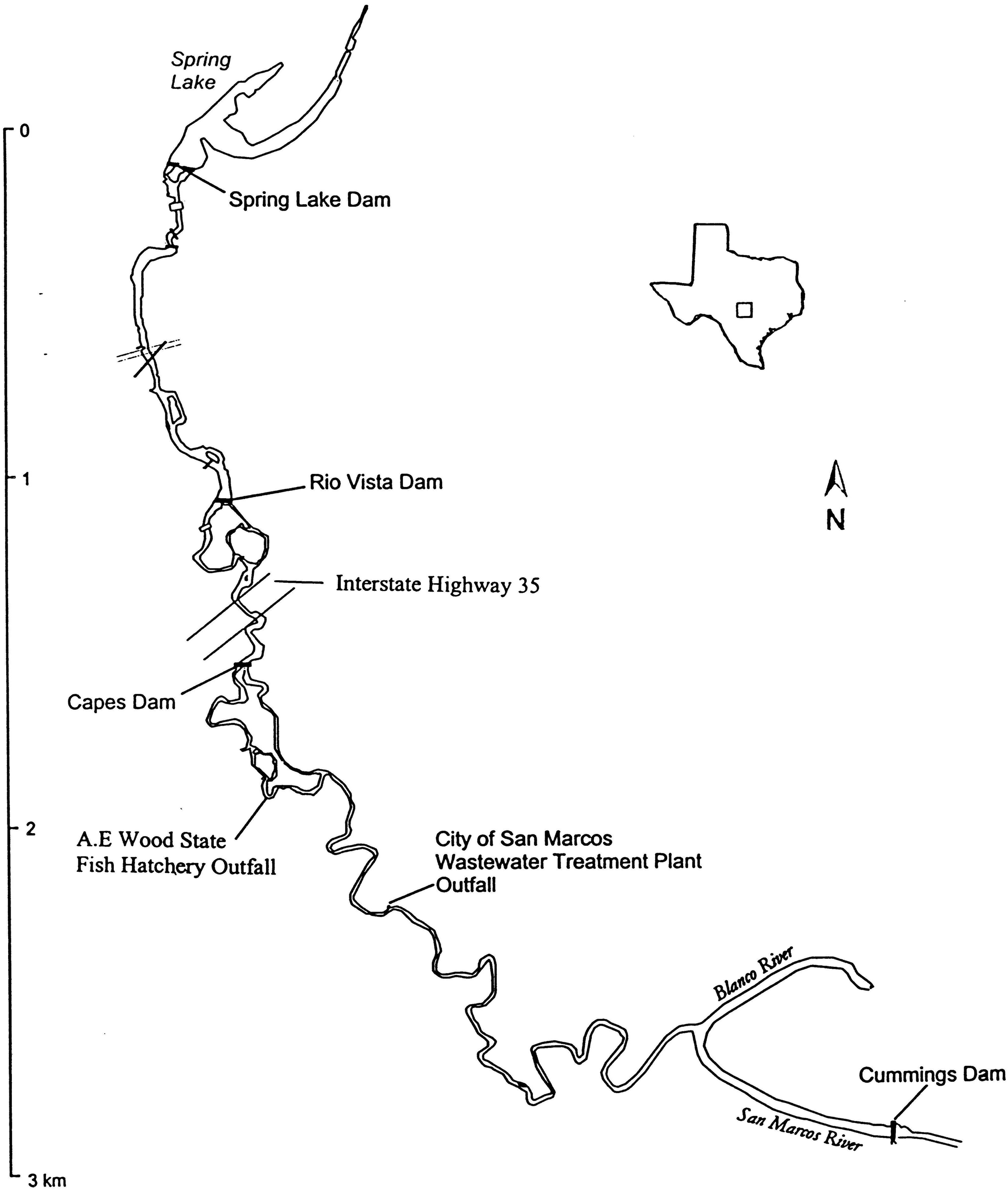
Table 1. Exotic species of the upper San Marcos River, Texas.

Species	Common Name	Status	Origin	Source	Known/Probable Date Introduced	Relative Ecological Impact
Micropterus dolomieu	smallmouth bass	E	Eastern North America	Sport fish	1960s	High
Oncorhynchus mykiss	rainbow trout	R	Pacific Northwest U.S	Sport fish Accidental release	1983	Low
Oreochromis aureus	blue tilapia	E	Middle East, Africa	Aquaculture	1958	High
Oreochromis mossambicus	Mossambique tilapia	E?	Africa	Aquaculture	1958	Low
Poecilia formosa	Amazon molly	E	Rio Grande Basin, Central/South America	Aquarists	1955	Low
Poecilia latipinna	sailfin molly	E	Atlantic/Gulf Coast	Aquarists	1944	Medium
Pseudotropheus sp.	Rift-lake cichlid	R	Africa	Aquarists	Early 1990s	Low
Ptergoplichthys disjunctivus	vermiculated highfin catfish	R	South America	Aquarists	1990s	Low
Reptiles						
Pseudemys nelsoni	Florida red-bellied turtle	E	Florida	Aquarists	1990s?	Low
Birds						
Alopochen aegyptiacus	Egyptian goose	L	Africa	Domestic	2000	Low
Anas platyrhynchos	Mallard/domestic duck	L	North America	Domestic	Unknown	Low
Anser anser	domestic goose	L	Europe/North Africa	Domestic	Unknown	Low

Table 1. Exotic species of the upper San Marcos River, Texas.

Species	Common Name	Status	Origin	Source	Known/Probable Date Introduced	Relative Ecological Impact
Anser cygnoides	Chinese/African Goose	L	Asia	Domestic	1990s?	Low
Branta canadensis	Canada/domestic goose	L	North America	Domestic	After 1930	Low
Cairina moschata	Muscovy duck	L	South Texas, Mexico	Domestic	Unknown	Low
Cygnus atratus	black swan	L	Australia/Tasmania	Domestic	Unknown	Low
Cygnus olor	mute swan	E	Eurasia	Domestic	After 1910	Low
Myocaster coypus	nutria	E	South America	Invasive	1950s?	High

[1] E = established, R = reported, L = localized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Spring Lake Dam
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Rio Vista Dam
Interstate Highway 35
Capes Dam
A.E Wood State Fish Hatchery Outfall
City of San Marcos Wastewater Treatment Plant Outfall
Blanco River
San Marcos River
Cummings Dam
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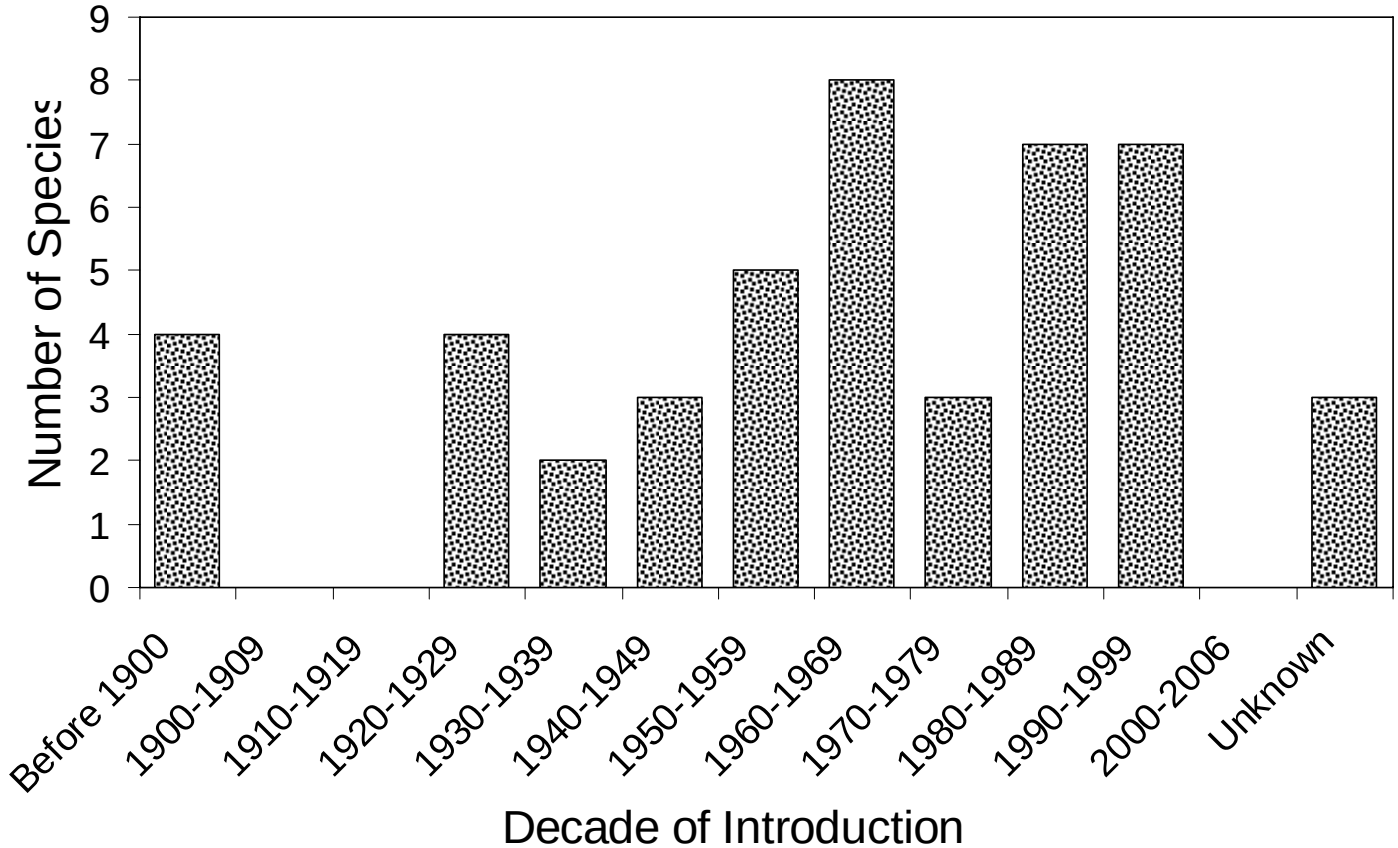

Figure 2. Exotic species introductions into the San Marcos River, Texas by decade of occurrence.