Draft National Control and Management Plan
for
Members of the Snakehead Family (Channidae)

Drawing by: Susan Trammell

Submitted to the Aquatic Nuisance Species Task Force
Prepared by the Snakehead Plan Development Committee

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Committee Members

Paul Angelone, U.S. Fish and Wildlife Service
Kelly Baerwaldt, U.S. Army Corps of Engineers
Amy J. Benson, U.S. Geological Survey
Bill Bolen, U.S. Environmental Protection Agency - Great Lakes National Program Office
Lindsay Chadderton, The Nature Conservancy, Great Lakes Project
Becky Cudmore, Centre of Expertise for Aquatic Risk Assessment, Fisheries and Oceans Canada
Barb Elliott, New York B.A.S.S. Chapter Federation
Michael J. Flaherty, New York Department of Environmental Conservation, Bureau of Fisheries
Bill Frazer, North Carolina BASS Conservation
Katherine Glassner-Shwayder, Great Lakes Commission
Jeffrey Herod, U.S. Fish and Wildlife Service
Lee Holt, U.S. Fish and Wildlife Service
Nick Lapointe, Carleton University, Ottawa, Ontario
Luke Lyon, District of Columbia Department of the Environment, Fisheries Research Branch
Tom McMahon, Arizona Game and Fish Department
Steve Minkkinen, U.S. Fish and Wildlife Service, Maryland Fishery Resources Office
Meg Modley, Lake Champlain Basin Program
Josh Newhard, U.S. Fish and Wildlife Service, Maryland Fishery Resources Office
Laura Norcutt, U.S. Fish and Wildlife Service, Branch Aquatic Invasive Species
John Odenkirk, Virginia Department of Game and Inland Fisheries
Scott A. Sewell, Maryland Bass Federation Nation
James Straub, Massachusetts Department of Conservation and Recreation, Lakes and Ponds Program
Michele L. Tremblay, Naturesource Communications
Martha Volkoff, California Department of Fish and Wildlife, Invasive Species Program
Brian Wagner, Arkansas Game and Fish Commission
John Wullschleger, National Park Service, Water Resources Division, Natural Resources Stewardship and Science

Executive Summary

The introduction of northern snakehead (*Channa argus*) into waterways of the United States has received a great deal of media, public, and political attention. Unfortunately, this awareness has not served to prevent further spread of northern snakehead into other waterways. The northern snakehead is a popular food fish throughout its native distribution in Asia, and was imported into the U.S. for the live-food fish market until 2002, when the U.S. Fish and Wildlife Service (USFWS) prohibited importation and interstate transport under the Lacey Act, 18 U.S.C. 42.

Prior to 2002, the occurrence of northern snakehead in the United States was limited and consisted of low numbers of individuals in California, Florida, Massachusetts, and North Carolina with no evidence of self-sustaining populations. However, self-sustaining populations of blotched (*Channa maculata*) and bullseye (*Channa marulius*) snakehead were known to exist in Hawaii and Florida, respectively. Then in 2002, a northern snakehead population was discovered and later eradicated in a small pond in Crofton, Maryland. Just two years later, in 2004, an additional northern snakehead population was discovered in the tidal freshwater Potomac River in the vicinity of Mount Vernon, Virginia. This population increased rapidly in range and abundance. By 2011, the fish occurred in the main stem and tributaries from Great Falls, Virginia (above Washington, D.C.) downstream to the mouth of the river. It was initially thought that higher salinity in the lower Potomac River and Chesapeake Bay would prevent snakehead species from escaping the river into other Bay tributaries. This assumption no longer appears valid as northern snakehead have been captured in several other tributaries of the Chesapeake Bay as of June 2012. Other northern snakehead populations have been found in the states of New York, Arkansas, Delaware, New Jersey and Pennsylvania. Because many eradication attempts have been unsuccessful, a goal of this management plan is to help guide management of invasive snakehead species where present and to prevent further introductions.

Initially, Congress requested that the USFWS address concerns about the introduction of northern snakehead. Senate Report 108-341, Department of the Interior and Related Agencies Appropriations Bill (2005) of the 108th Congress states, "the Committee is concerned by the recent discoveries of northern snakehead in the Potomac River and its potential impact on native fish populations through predation, food and habitat competition, or the introduction of diseases and parasites. The Committee directs the USFWS to submit a report to Congress on steps the Agency is taking to identify, contain, and eradicate the species." In response to this Congressional mandate, the USFWS assembled a Northern Snakehead Working Group (NSWG) to provide input on the development of a Northern Snakehead Control and Management Plan (SCMP). This SCMP was developed with the input of the NSWG and other northern snakehead experts to guide the USFWS and other interested parties in managing and controlling existing populations, and preventing the spread and introduction of this species into additional areas of the United States. In 2012, the Mississippi River Basin Panel requested that the Aquatic Nuisance Species Task Force (ANSTF) update the SCMP to include, based on

Herborg et al., (2007,) 10 potential invasive snakehead species. However, due to a lack of available information on all 10 species, only three are included in this management plan. They include the northern snakehead, giant snakehead (*Channa micropeltes*), and bullseye snakehead. A new working group of experts coordinated by the ANSTF was formed, and this group incorporated ng existing research and plans with the most relevant information about snakehead management and control to create this management plan.

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Purpose of Management Plan

The purpose of this Snakehead Control and Management Plan (SCMP) is to guide the U.S. Fish and Wildlife Service (USFWS) and other interested parties in managing invasive snakehead already established in U.S. waters as well as prevent the further spread and introduction of this fish into other waterways.

Snakehead are popular food fish native to Asia. Over the past two decades, they have been imported into certain ethnic markets in the U.S. for the live-food fish market. In 2002 the USFWS prohibited their importation and interstate transport under the Lacey Act. Prior to 2002, there had been sporadic single occurrences of northern snakehead in California, Florida, Massachusetts, and North Carolina that appear to be the result of releases of single fish. There was no indication of established, reproducing populations. However, in 2002, a self-sustaining population was discovered and later eradicated in a small pond in Crofton, Maryland. Subsequently, in May 2004, northern snakehead were discovered in the main stem tidal freshwater Potomac River near Mount Vernon, Virginia. Since this discovery, the population has increased rapidly in range and abundance.

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In response to this Congressional mandate, the USFWS assembled a Northern Snakehead Working Group (NSWG) in 2006 to provide input on the development of a SCMP. The intent of the SCMP was to identify action items to guide agency activities and funding priorities in addition to focus efforts of stakeholders and non-governmental organizations (NGO's). The plan's focus was on specific control priority action items needed in the Potomac River and northeast region as well as general prevention, early detection and rapid response, control, research, and education and outreach priorities for the rest of the nation, should additional snakehead populations be discovered.

A draft SCMP report was completed in February of 2007. An update to the report was completed in March 2011. Because of the spread of the northern snakehead and risk of other snakehead species entering the country, the Mississippi River Basin Panel requested that the Aquatic Nuisance Species Task Force (ANSTF) update the SCMP to address the primary species at risk for surviving in the U.S. These species include the Chinese (*Channa asiatica*), blotched, giant, spotted (*Channa punctata*), golden (*Channa stewartii*), bullseye, chevron (*Channa striata*), Niger (*Parachanna africana*), northern, and rainbow (*Channa bleheri*) snakehead species. Due to little or no information

available on seven of these species, only three (the giant, bullseye, and northern snakehead) are discussed in detail in this management plan.

Twenty-seven individuals from federal, state, academia, and non-governmental organizations (NGOs) volunteered to serve on a committee to develop a SCMP. The SCMP Development Committee first met by teleconference on February 9, 2012. The following six subcommittees were established:

1. Biology, Natural History, Ecological, and Economic Impacts
2. Pathways, Early Detection, Rapid Response, and Preventing Spread
3. Control and Management
4. Research
5. Education, Outreach, and Data Management
6. Regulatory Authorities and Scope

The goal of this SCMP is to use sound science and management to prevent the future introduction of snakehead into new areas, contain and where possible remove all newly established and localized outlying populations, and minimize impacts in areas where they are established and eradication not is feasible. The following is a list of goals set forth by the SCMP Development Committee:

1. Prevent importation into the U.S. by refining the Lacey Act and other regulations and improving compliance and enforcement.
2. Contain the expansion of northern snakehead within the U.S. by establishing an effective snakehead surveillance program that can detect new introductions at a stage where populations are able to be eradicated.
3. Develop long-term adaptive management options to mitigate potential impacts of snakehead in U.S. waters where eradication is not possible.
4. Conduct research to better understand the pathways of spread and impacts of snakehead on native and beneficial naturalized aquatic organisms and to develop more effective surveillance, control, and eradication methods.
5. Develop outreach or education plans and tools to help prevent new introductions of snakehead within the U.S. and control the anthropogenic spread of established populations.
6. Review and assess progress of the SCMP.

Biology, Natural History, Ecological and Environmental Impacts of Snakehead

Snakehead (family Channidae) are air-breathing, freshwater fishes containing two genera, *Channa*, native to Asia, Malaysia, and Indonesia, and *Parachanna*, endemic to tropical Africa. Courtenay and Williams (2004) compiled a document containing summaries of known information for all snakehead species as of publication date. Readers are encouraged to view this document for additional information, as this work has been, and will be,, cited heavily throughout this plan. We have attempted to update Courtenay and Williams (2004) with more recent studies when applicable and have addressed "major" *Channa* species below which either (1) have new findings since 2004 and/or (2) have potential implications based on current presence in North America or historical occurrence. Most snakehead have limited colonization potential in the United States due to their thermal tolerances (Herborg et al., 2007). Northern snakehead is the exception, and the majority of the following narrative will be allocated to this species due to the existence of several established populations and its wide thermal tolerance, making it the species of greatest concern.

Of the 28 species of snakehead listed as injurious under the Lacey Act only 10 have a high likelihood of becoming established in the U.S. However, this SCMP emphasizes the northern snakehead because it is most adapted to surviving in the U.S. and has already established populations in the U.S.

Northern Snakehead (*Channa argus*)

Figure 1. Northern snakehead caught in Virginia.Photo Credit: Steve Chaconas

Northern snakehead is native to rivers and estuaries of China, Russia, and Korea (Courtenay and Williams, 2004). This species was brought from Korea and intentionally released by culturists in Japan in the early 1900s (Okada, 1960). However, its subsequent release and establishment in ponds, rivers, and reservoirs of present day Kazakhstan, Turkmenistan, and Uzbekistan in the early 1960s may have been accidental, as hitchhikers in contaminated shipments of Asian carps (Courtenay and Williams, 2004). Within its native (Berg, 1965) and introduced range and with the exception of Japan, snakehead is considered a desirable and sought after food fish (Baltz, 1991 as cited in Courtenay and Williams, 2004; Dukravets, 1992; FAO, 1994; Okado, 1960). In China, this species is raised in ponds, rice paddies, and reservoirs (Atkinson, 1977; Sifa and Senlin, 1995 as cited in Courtenay and Williams, 2004; Liu et al., 1998) and is considered most important snakehead species cultured (Courtenay and Williams, 2004)

In major cities such as Calcutta, Bangkok, Singapore, and Hong Kong, northern snakehead are a specialty food item, available alive in aquaria for customer selection at finer restaurants. They also provide easily caught food for less affluent people (Wee, 1982). Northern snakehead are usually killed just prior to preparation and cooked in a variety of ways. They can be cooked whole or prepared as filets or steaks, fried or steamed, or put in soups (Courtenay and Williams, 2004). Wee (1982) and Balzer et al. (2002), cited by Courtenay and Williams (2004), documented that excess catches in Thailand and Cambodia are often dried for storage and future use. Some Asian cultures, such as in Myanmar, believed that because snakehead can remain alive outside of water for periods of time, the fish have healing properties, which makes them prized as food for people that are ill (Lee and Ng, 1991). In such situations, the fish are killed just before cooking because of the belief that the healing properties will be lost if the fish are killed sooner (Lee and Ng, 1991).

The northern snakehead is most readily identified by long dorsal and anal fins; pelvic fins located beneath the pectorals; a truncate caudal fin; and, a large mouth extending far beyond the eye with large canine-like teeth on the upper and lower jaws. Adult northern snakehead are golden tan to pale brown or olive in color with a series of dark, irregular patches on the sides and saddle-like blotches across the back interrupted by the dorsal fin. Coloration of juveniles is similar to the adults, which is atypical of most snakehead species (Courtenay and Williams, 2004).

The northern snakehead can grow to at least 850 mm total length (TL) (Okada, 1960); however, in Russia there have been reports of captured specimens reaching 1.5 m TL (Courtenay and Williams, 2004), while the largest individual documented in Virginia waters was at least as large as 864 mm TL mm TL (Odenkirk et al. 2013). Recent evaluations suggested Potomac River fish grow faster than previously determined. For example, age-3 fish averaged 357 mm in an early study (Odenkirk and Owens, 2007), which was commensurate with growth rates found in China (Uchida and Fujimoto 1933); however, otolith evaluations and growth of recaptured tagged fish in 2011 implied faster growth. In that study, age-3 fish averaged 644 mm, and the resulting growth increment was similar to that of recaptured tagged fish of similar size (Odenkirk and Lim, 2012).

Northern snakehead typically reach sexual maturity at two to three years of age and approximately 300-350 mm TL but may mature at an earlier age in North America (Odenkirk et al. 2013). Females produce eggs 1 to 5 times per year and release 22,000-51,000 eggs per spawning (Frank, 1970; Nikol'skii, 1956). Dukravets and Machulin (1978) documented fecundity rates that ranged from 28,600-115,000 eggs per spawning for northern snakehead introduced to the Syr Dar'ya basin in Turkmenistan and Uzbekistan. Their eggs float and take approximately 28 hours to hatch at 31^{o}C and 45 hours at 25^{o}C. At lower temperatures, the eggs take much longer to hatch. Parents guard the young in a nest until yolk sac absorption is complete at approximately 8 mm TL (Uchida and Fujimoto, 1933).

In the lower reaches of the Amu Dar'ya basin of central Asia, Guseva and Zholdasova (1986; as cited by Courtenay and Williams 2004) reported that an accidentally introduced population of northern snakehead fed on crustacean zooplankton and chironomid larvae in their first month of life. At 40 mm TL, they began to feed on fish and by 130-150 mm, fish comprised 64-70 percent of the diet. Juveniles up to 300 mm TL fed almost exclusively on fish. Juvenile northern snakehead feed in schools with most of the activity during early evening and again in early morning, usually in vegetation close to shore (Courtenay and Williams, 2004). In addition to fish, adult food items include frogs, crayfish, dragonfly larvae, beetles, and plant material that is probably incidentally ingested along with the prey (Dukravets and Machulin, 1978). According to Odenkirk and Owens (2007), food items observed in the stomachs of 219 northern snakehead collected from the Potomac River between 2004 and 2006 consisted mostly of banded killifish (*Fundulus diaphanous*), white perch (*Morone americana*), bluegill (*Lepomis macrochirus*), and pumpkinseed sunfish (*Lepomis gibbosus*). Saylor et al. (2012) found similar food habits among northern snakehead in the Potomac River with fundulid and centrarchid fish species consumed most frequently and non-fish taxa consumed rarely. In the Syr Dar'ya basin of central Asia, Dukravets and Machulin (1978) reported that northern snakehead fed on 17 species of fish, including fish measuring up to 33 percent of the predator's total body length.

Okado (1960), cited by Courtenay and Williams (2004), reported this species was a voracious feeder. It is an ambush predator that lies on the bottom waiting for prey (Guseva, 1990). In the Amu Dar'ya basin, northern snakehead only feed from late March to October with 45.1 percent of their annual food consumption completed by May, another 46.4 percent of annual consumption occurring in June and July, and only 4.6 percent between September and October (Guseva, 1990). No food was found in their stomachs during the winter months (Guseva, 1990). Prey items considered valuable as human food fish were common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), bream (*Abramis brama*), zander (*Sander lucioperca*), and catfish (*Ictalurus* spp.) (Guseva, 1990). Snakehead assumed vacated predator niches due to anthropogenic factors and displaced native pike and catfish in the basin (Guseva, 1990).

Northern snakehead prefer stagnant shallow ponds or swamps with mud substrate and vegetation, and slow muddy streams (Okada, 1960), but are also found in canals,

reservoirs, lakes, and rivers (Dukravets and Machulin, 1978; Dukravets, 1992). In the Potomac River, northern snakehead are typically found in shallow water with floating and emergent vegetation (Odenkirk and Owens, 2005; Lapointe et al., 2010). They have a broad temperature range of 0 to 31°C (Okada, 1960) and as high as 40°C in water without oxygen (Frank, 1970; Nikol'skii, 1961). The species is an obligate air-breather; therefore, survival in poorly-oxygenated waters is possible (Courtenay and Williams, 2004). Air respiration is absolutely necessary except in the hibernation period when the respiratory function almost ceases (Uchida and Fujimoto, 1933). Northern snakehead have survived acclimatization experiments in outside ponds in Czechoslovakia where severe winter temperatures dipped below -30°C for up to 4 weeks (Frank, 1970). During cold temperatures, northern snakehead have a reduced metabolism and oxygen demand, which allows them to survive under ice (Frank, 1970).

The USFWS and Maryland Department of Natural Resources (MDNR) conducted several experiments at the Joseph Manning Hatchery (Maryland) to examine salinity tolerances of northern snakehead. In trials that were conducted at lower temperatures (15-20^{o}C), snakehead exhibited increased tolerance to salinity. However, the upper tolerance level remained at 18 ppt (S. Minkkinen, USFWS, personal communication, 2012). The capture of a snakehead in a pound net in Chesapeake Bay near St. Jerome's Creek (Maryland) in May 2010 confirmed northern snakehead's tolerance of elevated salinity (at least temporarily), as surface salinities at the mouth of the Potomac River ranged between 10 and 12 ppt. Snakehead have also colonized Potomac River tributaries down to the mouth of the river, which required migration through the lower river where salinities typically range from 6-20 ppt. The salt wedge in the lower Potomac River has apparently not prevented the spread of snakehead into the Chesapeake Bay and other tributaries.

There is little information in the scientific literature about effects of northern snakehead on other aquatic organisms. The predatory nature of northern snakehead suggests their introduction could affect populations of fish, amphibians, and invertebrates through direct predation, competition for food resources, and alteration of food webs (Courtenay and Williams, 2004). Through predation, ecosystem balance could be modified if northern snakehead became established in waters with low diversity of native and naturalized fishes and low abundance or absence of other predatory species. These effects could include adversely alter endangered and threatened species populations. Of the taxa listed as endangered and threatened in U.S. aquatic habitats, 16 amphibians, 115 fish, and 5 crustaceans (surface-dwelling crayfish and shrimp), would be the most likely affected (Courtenay and Williams, 2004). Based on habitat requirements and life history of northern snakehead, fish species are most likely to be affected. However, the addition of a predator in the aquatic community could pose a significant threat to with any listed amphibian or crustacean species (USFWS, 2002).

The northern snakehead's native range (24-53°N) and water temperature range (0-31°C) indicate a species that, if introduced, could establish populations throughout most of the United States (Courtenay and Williams, 2004; Herborg et al., 2007) with the highest likelihood for colonization may be the mid and northeast Atlantic slope (Poulos et al.,

2012). The northern snakehead could potentially compete with commercially and recreationally important fish species through predation and competition for food and habitat in ponds, streams, canals, reservoirs, lakes, and rivers. In the Potomac River, northern snakehead appeared to have similar habitat and feeding preferences as recreationally important species such as largemouth bass (*Micropterus salmoides*). Analysis of stomach contents of northern snakehead collected in the Potomac River included white perch (*Morone americana*), a recreationally and commercially important fish species caught in the Chesapeake Bay, and killifish, an important prey for both white perch and yellow perch *(Perca flavescens)* (Odenkirk and Owens, 2005). Saylor et al. (2012) concluded that northern snakehead in the Potomac River displayed dietary overlap with largemouth bass, but they could not infer competition between the two species because they lacked estimates of prey abundance. However, Love and Newhard (2012) showed that largemouth bass abundance could decrease if co-occurrence (resulting in competition) of largemouth bass and northern snakehead increased.

A small population of northern snakehead established in two connected lakes in New York City has remained at low abundance since a study began in 2006. This study found that and the abundances of coexisting fish populations were unchanged (Cohen et al. 2012). Thus, it may be difficult to predict the short-term ecological and economic effects of the northern snakehead on recreational and commercial fisheries.

Giant Snakehead (*Channa maculata*)

Figure 2. Giant snakehead caught in Wisconsin.
Photo Credit: Wisconsin Department of Natural Resources.

The giant snakehead has been caught in the U.S. and could potentially become established in Florida or Hawaii. The native range of the giant snakehead is extremely

noncontiguous. It is native to rivers of Southeast Asia in Cambodia, Indonesia, Laos, Malaysia, Thailand, Vietnam, and possibly Myanmar (Courtenay and Williams, 2004). It has also been found in the southwestern region of India, restricted to the Kerala State (Roberts, 1989) as a result of a very early introduction (Courtenay and Williams, 2004). In its native range it is considered a highly prized food fish with multiple cage culture operations raising giant snakehead for market (Courtenay and Williams, 2004).

This species can grow to 1 m in (TL) and weigh over 20 kg (Roberts, 1989; Lee and Ng, 1991; Talwar and Jhingran, 1992, as cited by Courtenay and Williams, 2004). It is believed to be one of the fastest growing snakehead species along with bullseye snakehead by Wee (1982; as cited by Courtenay and Williams, 2004).

Giant snakehead reproduction is similar to that of other *channids*. This species removes vegetation in a circular area to spawn. Once spawned, their pelagic eggs rise to the surface and are guarded by parents (Lee and Ng, 1991).

Giant snakehead are mainly daytime feeders (Ng and Lim, 1990, cited by Courtenay and Williams, 2004). It is a vicious predator of other fish and is described by several sources of Courtenay and Williams (2004) as being "known to kill more fish than it consumes in its natural habitat." The knife-like shape of their teeth allows prey to be sheared in pieces. This species is primarily piscivorous but does have a diet that includes frogs, birds, and crustaceans (Courtenay and Williams, 2004).

This tropical and subtropical species is extremely limited in where it could potentially establish a viable population in the United States. There are no specific temperature requirements in the literature. However, the native range for this species is between 20° N and 7° N (Courtenay and Williams, 2004). Freshwater habitats in southern Florida and Hawaii are likely suitable climates for giant snakehead in the United States (Herborg et al., 2007; Courtenay and Williams, 2004). This species' large size, along with its propensity to kill more fish than it consumes, makes it a potentially serious threat in southern Florida. This species can be more than twice the weight of the heaviest largemouth bass ever caught in Florida. Their aggressive nature could allow them to out-compete native and naturalized fish species for food and habitat. The potential impact to the Florida economy could be significant. According to a USFWS report (2006), freshwater fishing is a 2.4 billion dollar per year industry in Florida and the introduction and establishment of this species could have serious detrimental economic effects.

Bullseye Snakehead (*Channa marulius*)

Figure 3. Bullseye snakehead caught in South Florida.
Photo Credit: US Fish and Wildlife Service.

The bullseye snakehead is established in Florida and is an invasive threat in other tropical states. The bullseye snakehead is a freshwater fish with an elongate body shape, very long dorsal and anal fins, a rounded caudal fin, and tubular nostrils. It is native to Pakistan, India, Bangladesh, southern Nepal, Thailand, Myanmar, Laos, Cambodia, and southern China (Courtenay and Williams, 2004). In juvenile fish less than 180 mm TL, there is a distinctive orange ocellus near the caudal peduncle (J. Galvez, USFWS, personal communication, 2012; Kottelat, 2001). They have a broadly flattened head, with anteriorly placed eyes, in a dorsolateral position. There is a series of dark blotches along the sides of the body of juvenile fish, which are outlined by a row of white scales. The pectoral fin length is approximately one-half of the head length (Courtenay and Williams, 2004).

Reported to be the largest species in the snakehead family, bullseye snakehead often reach 300 mm TL in year one, and a maximum of 1200 to 1220 mm TL (Bardach et al. 1972; Talwar and Jhingran, 1992 as cited by Courtenay and Williams, 2004). Maximum sizes have been reported up to 1800 mm TL with a weight of 30 kg in the Maharashtra State of western India (Talwar and Jhingran, 1992 as cited by Courtenay and Williams, 2004). Young bullseye snakehead are facultative air breathers, whereas this behavior is obligatory among adults. They prefer sluggish or standing water in rivers, canals, lakes, and swamps that are characterized by submerged aquatic vegetation. Snakeheads may

also occupy areas of flooded forests and deep riverine pools (Courtenay and Williams, 2004). They are often found in deep, clear water with sand or rocky substrate (Talwar and Jhingran, 1992 as cited by Courtenay and Williams, 2004). Thermal preferences are tropical, subtropical, and warm temperate climates (Courtenay and Williams, 2004) with average temperatures of 24°C to 28°C (Pethiyagoda, 1991, as cited in Courtenay Williams, 2004). Mean air temperature was identified as the most significant environmental variable with respect to habitat suitability (Herborg et al., 2007), and may explain the more tropical distribution of bullseye snakehead compared to other species of snakehead, such as northern snakehead, in the United States.

Gut-content analysis of adult bullseye snakehead in West Bengal, India reported stomach contents consisting primarily of fish (40 percent), followed by crustaceans (30 percent), macrophytes (15 percent), larval insects (10 percent), and algae (5 percent) (Dasgupta, 2000). Other dietary analysis of the bullseye snakehead from the River Kali in northern India indicated that more than 60 percent of prey consumed was represented by fish, with the remainder being comprised of crustaceans, gastropods, insects, and larval chironomids (Ahmad et al., 1990).

The bullseye snakehead is an important aquaculture, game, commercial, and aquarium fish (FishBase, 2011). It has been cultured in ponds, rice fields, and other water bodies that do not typically support aquaculture, such as irrigation wells. It is reported that they are highly suitable for cage aquaculture. Because of their aggressive fighting behavior when angled, their popularity as a game species in Thailand may promote intentional introduction into natural water bodies (Courtenay and Williams, 2004). They are a valued species in the live food industry (Herborg et al., 2007) and have been observed as part of the live food fish industry in New York City (L. Smith, personal communication, 2002, in Courtenay and Williams, 2004).

Bullseye snakehead are known in the aquarium trade as both “giant snakehead” and “cobra snakehead.” Due to U.S. federal legislation prohibiting the importation and transportation of snakehead, it is not common in the U.S. aquarium trade. However, in the past, there have been discussions from aquarist-oriented online forums that indicate an interest in the species and suggest it may be as popular as the giant snakehead among aquarium enthusiasts (Schmidt, 2001). The introduction of bullseye snakehead into Broward County, Florida, may be the result of an intentional release of an aquarium specimen into a water body. Specimens of bullseye snakehead have been found at aquarium stores in the United States and Canada, indicating that the species can be obtained commercially despite restrictions in the U.S. and in some Canadian provinces (Courtenay and Williams, 2004).

The invasion of bullseye snakehead into the U.S. could negatively affect native and naturalized fish populations, crustaceans, insects, and other aquatic species through predation. Increased predation could disrupt existing commercial and recreational fisheries, although new recreation and commercial fisheries could develop. Negative environmental and economic effects are possible with the introduction of the bullseye snakehead. However, since establishment in south Florida in 2000, no negative effects to

aquatic species have been attributed to its presence (K. Gestring, Florida Wildlife Commission, personal communication).

Regulation of Snakehead in the U.S.

In October 2002, the USFWS listed the family Channidae, which includes the northern, bullseye and giant snakehead, as injurious wildlife under the Lacey Act (18 U.S.C. 42). This listing prohibits the import and interstate transportation of these species. Maximum penalties for injurious wildlife violation under the Lacey Act (18 USC 42) are 6 months in prison and a $5,000 fine for an individual and a $10,000 fine for an organization. Importation and interstate transport may be allowed with a permit for scientific, educational, or zoological purposes (50 CFR 16.22). The USFWS has additional import declaration requirements under 50 CFR 14.61, which requires among that all wildlife be declared to the USFWS upon importation. The injurious wildlife listing (Title 18) under the Lacey Act does not regulate intrastate possession, transportation, or sale. Additional Lacey Act Wildlife Trafficking (16 USC 3372) charges may be filed against individuals and organizations violating State laws prohibiting importing and transporting of snakehead species at the State level. Title 16 violations are a maximum of 5 years in prison and a $250,000 fine for individuals and $500,000 fine for organizations.

To help prevent the introduction and spread of federally listed injurious wildlife, the USFWS has expanded surveillance and enforcement of illegal transportation of federally listed invasive species. The USFWS has acquired a van equipped with x-ray equipment to improve the effectiveness and efficiency of wildlife inspectors' search for invasive species at international ports of entry. In addition, the USFWS is working with state partners to control the spread of invasive species, including snakehead, through domestic interstate investigations.

Canada does not have federal regulations prohibiting the import of snakehead but some provincial regulations do prohibit import. Ontario is the only province to ban possession, transportation and sale of live snakehead. British Columbia and Quebec are the only Canadian provinces that currently import live snakehead for retail and institutional uses. There is no legislation preventing the importation of snakehead into Mexico (See the [Tri-national Risk Assessment Guidelines for Aquatic Alien Invasive Species, Test Cases for the Snakehead (Channidae) and Armored Catfishes (Loricariidae) in North American Inland Waters (Commission for Environmental Cooperation (CEC) Project Report. April 2009].

Snakehead are legally managed to some extent in every state in the U.S and the regulations are expanded or clarified as new information is obtained. Maine was the first state to enact regulations restricting the importation of exotic wildlife into the state in 1979. Oklahoma was the first state to specifically restrict the importation of snakehead in 1983 and most recently the District of Columbia specifically restricted the possession of snakehead in 2012. Fourteen states, including the District of Columbia, Iowa, Indiana, Kansas, Louisiana, Maryland, Mississippi, North Carolina, Pennsylvania, South Dakota, Tennessee, Texas, Virginia and West Virginia, allow harvest of snakehead as long as the fish is immediately killed.

Violations to the state regulations vary greatly from state to state. The minimum fine is $10 in both Oklahoma and North Carolina while the maximum fine charged by a state is $10,000 in Michigan. In Wyoming, violators may lose hunting and fishing privileges in all other Interstate Violators Compact member states for life and be responsible for civil penalties in an amount not to exceed the costs incurred by the commission in removing the illegally stocked fish.

The Nebraska Game and Parks Commission instituted a snakehead buy-back program in 2004 for fish held in private aquaria. One snakehead was purchased through the buy-back program. The Nebraska Game and Parks Commission also initiated undercover visits to both fish markets and the 84 licensed pet shops in the state and found no snakehead in fish markets or pet shops. Nebraska has not had any snakehead incidents since these visits.

Introduction of Snakehead into U.S. Waters

Northern snakehead likely arrived in U.S. waters by importation for the live food fish market and to a lesser degree in the aquarium trade. For the last two decades, snakehead have been imported to the U.S. for sale in some ethnic markets that sell live food fish and some restaurants that hold fish live in aquaria for customer selection. The northern snakehead comprised the greatest volume and weight of live snakehead imported into the U.S. until 2001 (Courtenay and Williams, 2004). Other species imported since 1999 include Chinese,, dwarf (*Channa gachua*), blotched, chevron, giant, striped (*Ophicephalus striatus*), and Congo (*Parachanna insignis*), (USFWS, 2012). These species were most likely imported for the live food fish market, aquaculture, and as pets.

Prior to 2002, importation and sale of the species was legal in most states, but there were violations in at least six states where possession and sale of live snakehead was illegal. Although import records are incomplete and not detailed, it is evident that from 1997 to 2002, imports of live snakehead into the U.S. increased (Table 1) and that China was the biggest exporter of live snakehead (Table 2).

Since the addition of the Channidae family of snakehead under the prohibitions of the Lacey Act in 2002, the USFWS Office of Law Enforcement has continued to seize illegal shipments of snakehead imported into the United States. As recently as August 2010, 2,800 snakehead were seized and destroyed at a New York port, and in February 2011 a shipment of over 350 Chinese snakehead were seized at an airport in New York (USFWS, 2011). The Lacey Act does allow permitted access of snakehead for medical, scientific, educational and zoological reasons. Since 2002, seven permits have been issued allowing snakehead into the United States. Five permits were for educational display to zoos and two for scientific research to governmental agencies.

Table 1. U.S. importations of live snakehead (Channidae, Ophicephalus, Parachanna, all species) during 1997-2010.
Values in italics for years since late 2002 were seized and not allowed into the U.S. (USFWS, 2012).

Year	Number of individuals	Number of Shipments	Total mass (kilograms)	Total declared value (U.S. dollars, individuals and weight combined)
1997	372	--	892	5,085
1998	1,488	--	1,883	12,632
1999	13,059	74	7,645	23,393
2000	8,408	86	9,657	41,087
2001	22,827	90	20,035	41,255
2002	35,324	50	442	46,980
2003	*725*	*3*	--	*445*
2004	*172*	*3*	--	*1,031*
2005	*601*	*4*	--	*4,731*
2006	*0*	*0*	--	*0*
2007	*0*	*0*	--	*0*
2008	*6*	*1*	--	*8*
2009	*276*	*2*	--	*484*
2010	*2,800*	*3*	--	*796*
Totals	86,058	316	40,554	$177,927

Table 2. Origin of snakehead shipments (Channidae, all species) for 1997-2010.
Number of individuals includes seized shipments (USFWS, 2012).

Country	Number of individuals	Total mass (kilograms)	Total declared value (U.S. dollars, individuals and weight combined)
China	68,038	36,784	203,248
Thailand	917	--	4,941
Vietnam	809	995	2,348
India	572	--	1,498
Indonesia	638	--	1,190
Nigeria	1,760	--	949
Macao	2,800	--	796
Congo	250	--	480
Korea	5	--	160
Switzerland	50	--	100
Taiwan	400	--	56
Hong Kong	150	--	24

Northern snakehead are the most widely cultured snakehead species in China. Until the 2002 injurious wildlife listing, this snakehead species was imported for sale in Asian live food fish markets in Houston, Texas; New York, New York; Orlando, Florida; Pembroke Pines, Florida; and St. Louis, Missouri (Courtenay and Williams 2004). Additionally, live snakeheads were purported to have been available in fish markets in Maryland, northern Virginia, and Washington DC. Both the Florida bullseye snakehead population established in 2000 and the Hawaii blotched snakehead population established prior to 1900 (http://fl.biology.usgs.gov/Snakehead_circ_1251/html/introduction.html) are believed to be the result of releases from live fish markets.

There have been several captures of either one or two northern snakehead fish in the U.S. that appear to be releases of individual fish, with no indication of a reproducing population. One fish was captured in California, two in Florida, one in Illinois and two in Massachusetts.

The first report of a northern snakehead in the U.S. was in Silverwood Lake, California, on October 22, 1997, (Figure 4a and 4b). The fish was collected by California Department of Fish and Game personnel by electrofishing (Courtenay and Williams, 2004). It is unknown whether the 710 0m specimen was purposefully released in the lake or whether it arrived through the California aqueduct. No more have been documented in California to date.

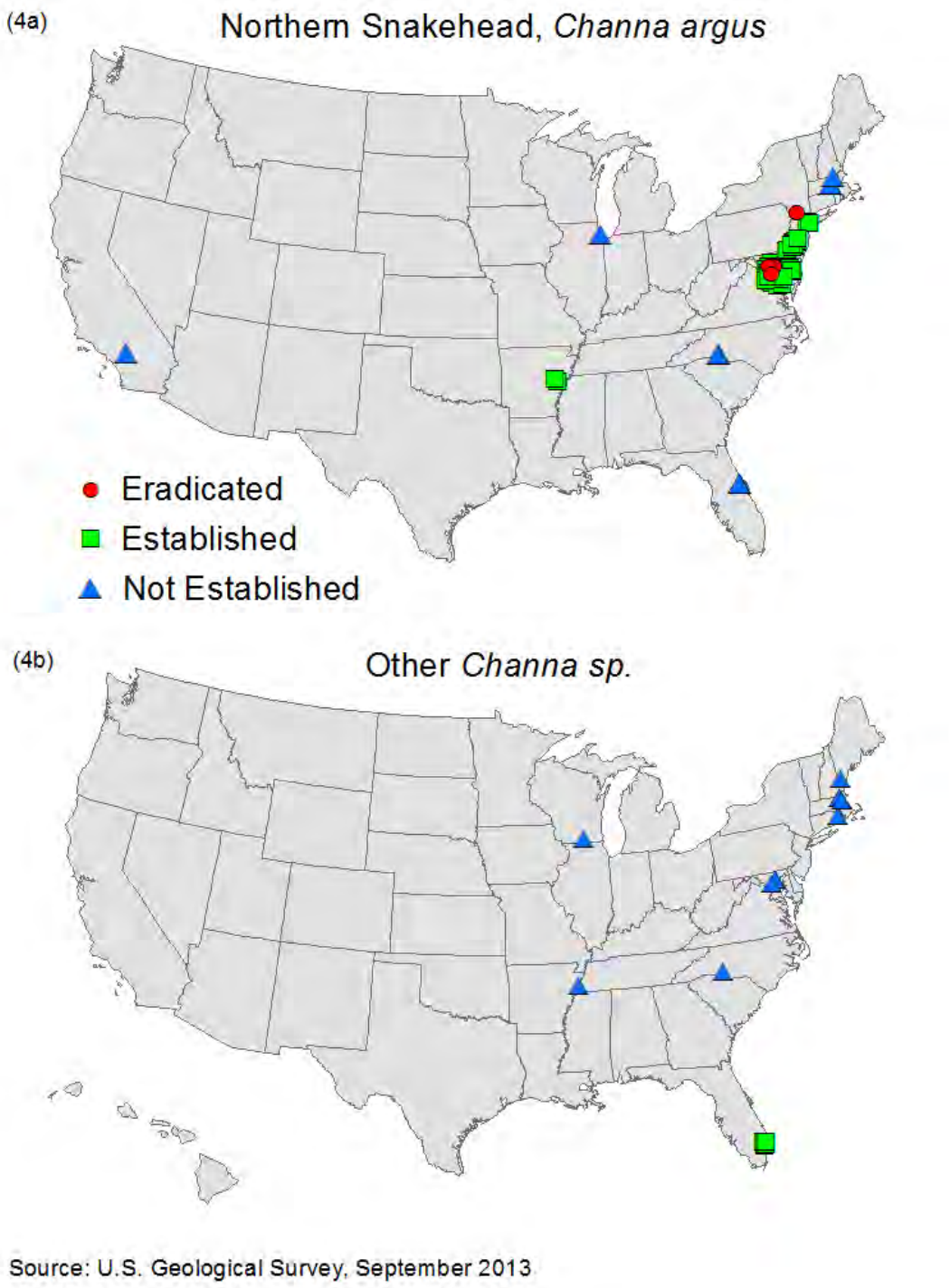

Figure 4a and 4b. Figure 4a shows locations of established northern snakehead populations (green squares) in the Potomac-Susquehanna-Delaware rivers region. Red circles represent eradicated populations in Catlin Creek, New York, two small water bodies in Crofton and Wheaton, Maryland, and a park pond in the District of Columbia. Figure 4b shows established populations (green squares) of bullseye snakehead in Florida and blotched snakehead in Hawaii. Blue triangles on both U.S. maps represent no more than two fish collected at a location and are not considered established.

In Florida, two northern snakehead fish were caught in the St. Johns River below Lake Harney, Seminole and Volusia counties in 2000, with unconfirmed reports of an additional three individuals caught nearby. Reproduction and establishment in this area has not been confirmed. The fish may have been intentionally introduced from the live food fish trade to establish a local source of fish as a live northern snakehead was purchased in a live fish food market in Orlando, Florida, in March 2002, even though possession of the species in that state was illegal (Courtenay and Williams, 2004).

The first known established population was discovered in Maryland in May 2002 when an 18 in northern snakehead was caught by an angler in a small pond in the town of Crofton (Figure 5). The angler took several pictures of the fish and then released it back in the pond. After examining the pictures, MDNR identified the fish as a species of snakehead and this was later confirmed by an expert. On June 30, 2002, another angler caught a 26 in snakehead from the same pond and dip netted eight juvenile snakehead on July 7 and 8. MDNR personnel then captured in excess of 100 young-of-the-year snakehead by electrofishing the pond. They were positively identified as northern snakehead. Subsequently, the pond was treated with rotenone, a fish toxicant, in September 2002 to eradicate the established population. During the eradication effort, over 1200 snakehead were recovered. MDNR police determined the source of the introduction as a local resident who purchased the fish at a live food fish market in New York and released fish sometime during 2000 (Boesch, 2002).

In North Carolina, two anglers reported catching two northern snakehead fish snakehead from Lake Wylie, a reservoir of the Catawba River, in July 2002. The following month, North Carolina Wildlife Resources Commission personnel sampled the lake by electrofishing but failed to find any snakehead (Courtenay and Williams, 2004). However, anglers caught another northern snakehead in the same reservoir in 2007 and a blotched snakehead was caught there in 2009.

In May 2004, northern snakehead of multiple year classes were collected within a 23 km reach of the tidal freshwater Potomac River in Virginia and Maryland downstream of Washington, D.C., indicating a self-sustaining population. Genetic analysis of a subset of fish from 2004 suggested most were offspring of either a single pair of breeding adults or multiple female siblings that had been deliberately or unintentionally released (Orrell and Weigt, 2005). Ten of the original 20 fish collected during 2004 were collected from Dogue Creek (Figure 5), and multiple collections occurred in adjacent creeks both to the north and south of Dogue Creek suggesting an epicenter or point of introduction. By the end of 2010, the population had expanded rapidly in range and abundance inhabiting the main stem and all tributaries of the Potomac River from Great Falls down to the river mouth. While northern snakehead were occasionally found in the main stem of the Potomac River, they were more abundant in shallower tributaries.

In July 2004, an angler caught and preserved two snakehead from Meadow Lake, a 6.9 hectare park lake in Philadelphia, Pennsylvania (Figure 5). The fish were later identified as northern snakehead and a total of six were captured from the lake. In 2005, sampling efforts resulted in the capture of several size-classes of snakehead, including juveniles (R.

Horwitz, Pennsylvania Academy of Natural Sciences, personal communication). Meadow Lake is part of a maze of interconnected embayments and tidal sloughs. Given the openness of the system, Pennsylvania Fish and Boat Commission (PFBC) biologists concluded that the fish had probably accessed adjoining waters of the nearby lower Schuylkill and Delaware rivers. As a result, PFBC biologists decided that they would monitor the pond and surrounding waters but would not attempt to eradicate the species (PFBC press release, July 23, 2004). There have been confirmed reports of snakehead from the Schuylkill River and the Delaware River and its tributaries in New Jersey.

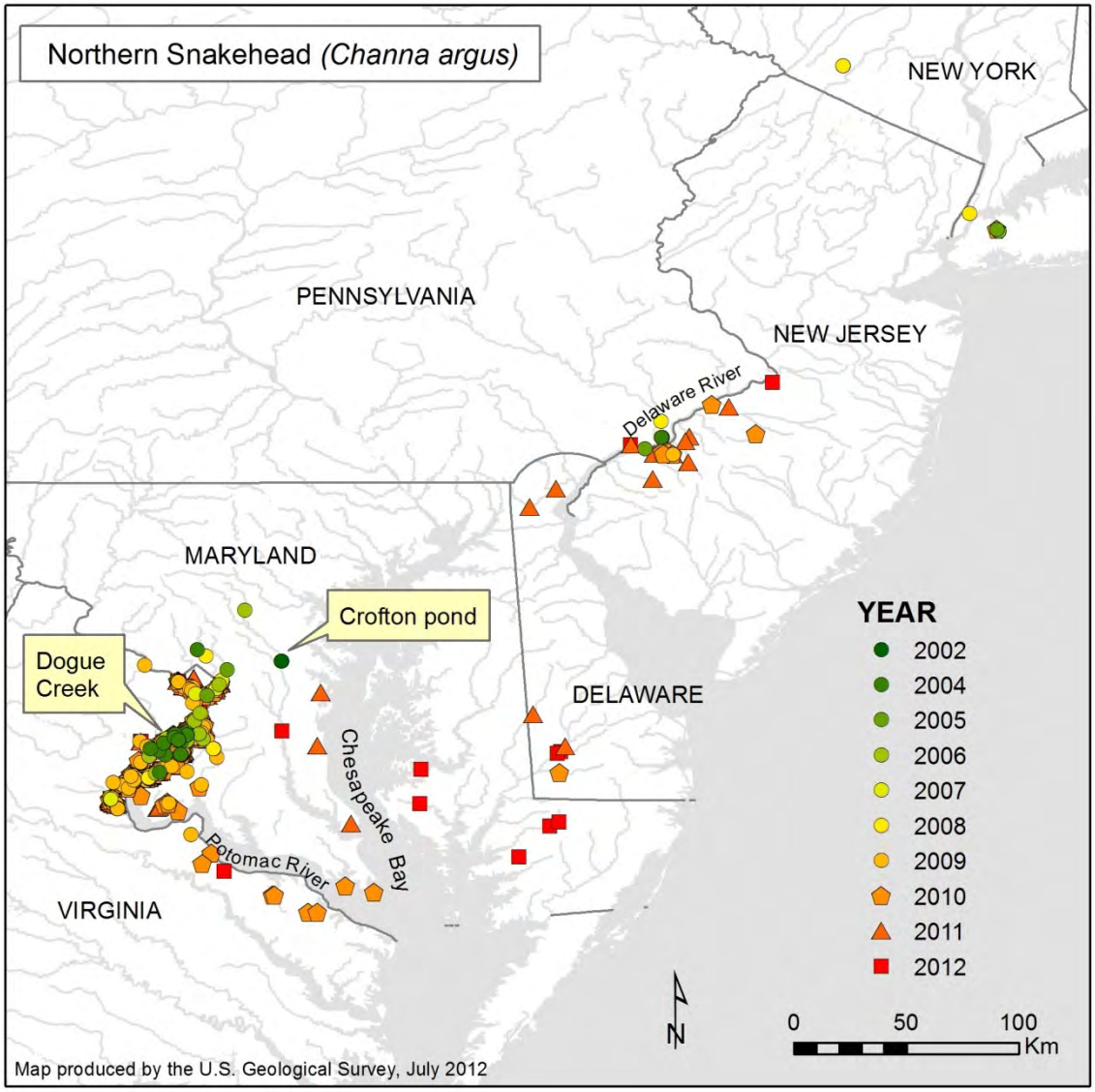

Figure 5. Locations of northern snakehead collections and observations in the Mid-Atlantic region of the U.S. Crofton pond in Maryland was the first documented location of northern snakehead in the region. Dogue Creek in Virginia is believed to be the point of introduction of the Potomac River population, March 2013.

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In 2005, four northern snakehead fish were found in two park ponds in Queens, New York (Figure 5). These ponds appear to have an established population of northern snakehead that has been contained to prevent infiltration to other waterways. About fifty miles to the northwest in upstate New York, more northern snakehead were found in May 2008 in Ridgebury Lake, part of the Wallkill River drainage, a tributary to the Hudson River. In August 2008, Ridgebury Lake, Catlin Creek and adjacent ponds downstream were treated with rotenone. More than 200 northern snakehead were recovered following treatment and almost all were juveniles suggesting that the species was successfully reproducing. Two adults were caught in Valentine Pond, downstream from Ridgebury Lake in 2009, but the system was retreated and subsequent monitoring has failed to detect any snakehead in the pond. This population is thought to have been eradicated, and in 2012 the New York Department of Environmental Conservation (NYDEC) discontinued monitoring for snakehead in Catlin Creek (L. Wilson, NYDEC, personal Communication, 2012).

In Arkansas, three fish farms cultured northern snakehead until importation, culture, sale, and possession of snakehead were prohibited by the Arkansas Game and Fish Commission (AGFC) in August 2002 (Courtenay and Williams, 2004). However, in 2008 the AGFC discovered a population of northern snakehead in the Big Piney Creek watershed (Figure 4a) and associated tributaries, part of the White River system in Arkansas and a tributary of the Mississippi River. These were fish that likely escaped from farm ponds. An attempt was made to eradicate the Piney Creek northern snakehead population and rotenone was applied to 20,234 hectares of the watershed. The area was resampled after the massive eradication attempt and additional live northern snakehead were found. Currently, northern snakehead fish still inhabit the Big Piney Creek watershed, and several have been found outside of this watershed. Widespread flooding in the spring and summer of 2009, 2010 and 2011 resulted in further lateral and downstream spread. Extensive delimitation surveys are required to determine the full extent of this population. Preliminary trials are underway to test the efficacy of environmental DNA detection methods, as this approach may enable large areas to be surveyed rapidly, and with greater detection sensitivity than traditional fisheries tools (Jerde et al., 2011, L. Holt, AGFC, personal communication, 2012). AGFC is still considering feasibility and practicality of using rotenone to monitor, assess, and control the spread of northern snakehead. However, at this time due to the new labeling of powdered rotenone by the EPA, the relative ease of use is compromised and this has greatly slowed and restricted their control efforts.

In June 2010, a snakehead was captured in a pound net in the Chesapeake Bay near St. Jerome's Creek just north of the mouth of the Potomac River in Maryland. Later, another snakehead was caught by an angler in St. Jerome's Creek on May 4, 2011. It was initially thought that higher salinity in the lower river and Chesapeake Bay would prevent snakehead from escaping into other tributaries of the Chesapeake Bay. However, subsequent colonization of downstream tributaries in the Chesapeake suggests that conditions in the lower Bay have not deterred snakehead movement and range expansion continues. The falls at Great Falls are blocking the upstream movement of snakehead in the Potomac, but there is concern that the adjacent C&O Canal could allow fish to bypass

the falls. In Virginia during the summer 2012, northern snakehead were caught by anglers in Massaponax Creek, a Rappahannock River tributary, and then by biologists sampling the tidal Rappahannock River near Port Royal. The origins of these fish are unclear, and it is unknown if they emigrated from the Potomac River or were introduced by illegal stocking, but genetic testing may yield some insight.

In October 2010, a large northern snakehead was collected by Delaware Department of Natural Resources biologists in Broad Creek near the town of Laurel during an electrofishing survey. The fish was found in shallow waters at the mouth of the stream coming from Horseys Pond. Subsequent sampling in Broad Creek and in Horseys Pond failed to find more snakehead. However, at least eight fish have been collected from Delaware portions of the Nanticoke River from 2010 to 2012. It is not yet known if this indicates another established population. In addition, more snakehead were reported from Delaware in 2011 and 2012. In 2011, two snakehead guarding a nest were reported from Becks Pond in Bear, and another was caught in Nonesuch Creek, a tributary to the Christina River in New Castle, both in Delaware. In June 2012 another adult northern snakehead was captured in Becks Pond.

Northern snakehead are spreading throughout much of the Chesapeake Bay. In 2012, confirmed reports of northern snakehead in new waterways increased dramatically. During spring 2012, multiple fish were caught in the Wicomico River near Salisbury in the Little Choptank River near Cambridge, and another was confirmed from the Blackwater River located on Blackwater National Wildlife Refuge, also near Cambridge. An angler caught and killed a northern snakehead in a pond directly connected to the Patuxent River near Croom. In the upper Rappahannock River drainage, four northern snakehead were confirmed by Virginia Division of Game and Inland Fisheries (VDGIF) from July to September 2012 (J. Odenkirk, VDGIF, personal communication, 2012).

Potential for the Spread of Snakehead in U.S. Waters

Snakehead may be introduced to watersheds via intentional or unintentional release of captive fish, or by natural dispersal of fish from established populations in interconnected watersheds. Although importation and interstate transport of snakehead have been prohibited under the Lacey Act since October 4, 2002, live snakehead imports continue to be seized by USFWS agents as recently as February 2010 in New York. In this case, live northern snakehead were smuggled into the country to supply a live fish food market. In addition, snakehead may be intentionally released into the environment when they are no longer wanted as pets, or as part of a religious ceremony (Severinghaus and Chi, 1999).

The desire for wider availability of live northern snakehead could potentially increase the probability of introductions to create a localized source of live fish for the live food fish market (Courtenay and Williams, 2004). In the Potomac River, where the northern snakehead is established, there is concern that interest in developing fisheries for snakehead could increase the potential for introductions into new waterways. Because this species is an obligate air-breather, it is easily transported alive out of water as long as it is kept moist (Courtenay and Williams, 2004). The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay and Williams, 2004; Herborg et al., 2007). The most probable source of spread is by humans considering that larger species of snakehead are popular with anglers in several locations within their native and introduced ranges (Courtenay and Williams, 2004) and that markets exist creating demand for them. This concern is increased by the fact that it appears only a small number of fish were released in the Crofton Pond and Potomac River introductions, but high populations were discovered suggesting that the species can establish even when propagule pressure (how many snakehead are likely to be introduced and how often) is low.

Mitochondrial sequence variation was examined in northern snakehead taken from the Potomac River tributaries; Crofton Pond in Maryland; Pine Lake in Wheaton, Maryland; Newton Pond in Massachusetts; and FDR Park in Philadelphia, Pennsylvania. There were seven unique haplotypes in the twenty nine specimens studied, with no haplotype shared between areas of introduction. This indicates that there were several separate introductions of northern snakehead into these waters, and that no two introductions came from the same source. In the Potomac River, one haplotype was shared by all of the fish less than 480 mm TL, indicating that these fish are the offspring of either a single breeding pair or the offspring from multiple adult female siblings (Orrell and Weigt, 2005).

To prevent further spread of snakehead, it is a matter of urgency that the status of all snakehead occurrences is determined. Uncertainty still appears to exist over the status of sites where single or small numbers of individual fish have been collected, namely Florida, California, North Carolina, Illinois, and Massachusetts. Only eight fish across

the five states have been collected since 1997. Subsequent sampling and monitoring after each collection has led to no further specimens. Surveys have relied upon traditional sampling methods that may have a low detection sensitivity, which raises the potential that detection efforts have failed to detect rare fish in the earliest phases of establishment. The amount of fishing pressure in these states' waters over the years would almost certainly have given rise to additional specimens if present. It is also widely assumed that the snakehead recovered from Burns Harbor (Chicago) in southern Lake Michigan was a single fish as subsequent fisheries surveys and recreational fishing in the area have not found any further specimens. However, if snakehead were to become established in waterways in the Chicago area they may have the potential to invade the upper Mississippi and Great Lakes systems. The bullseye snakehead has been collected only in Florida and is well established in the canal system of Broward and Palm Beach counties. The potential is present for this warm water species to spread further into connecting canals and natural areas of southern Florida. New environmental DNA (eDNA) detection tools (Jerde et al., 2011; Ficetola et al., 2008) may provide a secondary more sensitive detection method to confirm population status of outlying records.

Potential Dispersal of Recently Established Populations in the Mississippi River

In regards to the Arkansas northern snakehead population, and subsequently the dispersal into Mississippi River Basin, the potential for natural spread is great. Since the initial 2008 discovery of northern snakehead in Arkansas, the state has had three years (2008, 2009, and 2011) of high-water events in the Arkansas Delta Region, producing excessive flooding. These flood events have provided the opportunity for northern snakehead to disperse to other waters in which they had not been found previously. Based on the presumption of where the initial specimens originated, most of the dispersion has been in an upstream fashion. While there is no definitive evidence regarding the Arkansas population that confirms upstream spread, preliminary analysis and general observations do appear to show that these fish will migrate upstream more readily than downstream, consistent with dispersal behavior in the Potomac River (Lapointe et al. 2013). However, occasional specimens have been documented downstream of the presumed point of origin. The distribution of additional specimens that have been documented outside of the original drainage, Piney Creek, appear to have no definitive preference or pattern for upstream or downstream dispersal. Currently, specimens have been confirmed outside of the original drainage in waters to the north, northeast, east and southeast (L. Holt, AGFC, personal communication, 2012).

At present, potentially all waters are vulnerable to invasive snakehead species. The greatest limiting factors for snakehead dispersal are river currents and availability of backwater areas, although movements of northern snakehead in the Potomac watershed have shown high gradients and swift currents are not migration barriers (Lapointe et al. 2013). With an abundance of backwater sloughs, ditches, and canals, these fish are afforded an opportunity to disperse while avoiding strong currents as those found in the Arkansas and Mississippi Rivers. Unfortunately, Arkansas has numerous backwater areas, and during the high water conditions, there are multiple interconnected waterways in which these fish can travel and disperse into previously unconnected waters (L. Holt, AGFC, personal communication, 2012).

Currently, the most immediate threat to waters in the Mississippi River drainage, and outside of Arkansas, is to the neighboring states of Missouri and Louisiana. Based on observations of the population in Arkansas, northern snakehead prefer stagnant, vegetated back-water areas and do not readily reside in the main channel of streams and rivers. The most-used waters by northern snakehead in Arkansas are the interconnected irrigation ditches found throughout the farmlands in the east central part of the state. Consequently, any similar type waters within Missouri and Louisiana may be at risk, should a pathway to those waters become available (L. Holt, AGFC, personal communication, 2012).

Eradication and Control

The potential for eradication of snakehead depends on the aquatic system in which they are found. This species was successfully eradicated in two Maryland locations: from a small storm water pond (1.6 hectares) in Crofton with the use of rotenone, and from Pine Lake (2 hectares) in Wheaton by draining with a pump. Eradication will be nearly impossible and control efforts challenging in larger lakes or riverine systems where snakehead have become established. Control in smaller systems depends on the amount of vegetation, access to the water body, and effectiveness of available control methods, as was the case with the eradication efforts in Arkansas. If eradication is not possible, the next approach to consider is control and containment, although these strategies may be met with limited success. Options for control include the use of general piscicides, such as rotenone, or physical removal methods such as electrofishing, or nets and traps. Limitations of these existing control methods mean eradication is only likely to be effective in small to medium sized isolated water bodies and small order streams with limited riparian wetlands and will be extremely demanding of resources (labor, equipment, etc.). Populations will likely surge given diminished suppression effort. Rotenone, for example, is a nonspecific piscicide that has been used to remove problematic fish in North America for over fifty years. Rotenone works by preventing fish from utilizing the dissolved oxygen in the water and also exhibits a neurological effect on certain species. Chemical control using rotenone and other similar toxins could, in some cases, be ineffective to air-breathing snakehead at low concentrations in open systems; however, it has killed northern snakehead in most applications. Electrofishing and netting can also provide some level of control, but because collection gear are not effective at capturing all size and age classes; it is unlikely to result in eradication of a population, except perhaps in the earliest phases of establishment (USFWS, 2002). As technology advances, more options for detecting and thus controlling and ultimately, eradicating snakehead may be available. For example, the use of eDNA may aid in the detections of snakehead within a system where sampling for snakehead presence is impractical.

In the absence of control, snakehead are likely to spread, depending on the hydrology of the system. Within the Potomac River drainage, northern snakehead spread rapidly throughout most of the drainage within seven years. This is roughly the same timeframe that Arkansas Game and Fish Commission estimate that snakehead colonized approximately 700 km of streams and ditches within the Big Piney Creek watershed. Control should be considered for established populations, even if negative impacts are not yet determined. There can be lag times between an invasive species' establishment and any observed impacts from that invader (Crooks, 2005). Given there is a high amount of suitable habitat for some snakehead species throughout the U.S. (Herborg et al., 2007), there is a potential for snakehead to negatively interact with endangered freshwater species.

The costs associated with control will need to be balanced with the potential monetary loss caused by the invading species. Costs for removing invasive species are almost

always high, and, in some instances, may be prohibitive (Allendorf and Lundquist, 2003; Pimentel et al., 2005). For example, in recent years an average of $50 million has been spent annually on Asian carp control including monitoring, scientific research, operation of the electric barriers, eradication measures, and other population control and establishment prevention measures. The benefits of control may be difficult to measure in a monetary value, but include things such as, reducing the potential spread to nearby watersheds and limiting potential of a national or regional problem (i.e. Asian carp). In Arkansas, the costs associated with snakehead eradication attempts reached nearly $750,000. While snakehead still reside in the Big Piney Creek drainage, the overall goal of protecting resources in the nearby White River National Wildlife Refuge and adjacent waters was achieved by preventing and slowing the spread of snakehead. Therefore, each instance where snakehead are managed will be unique as to whether the costs of control outweigh the presence of snakehead.

Typically, little is known about a potential invasive species' life history and behavior patterns, making physical removal difficult. As more is learned about snakehead behavior in U.S. waters, managers can more easily target them when capture efficiency is high, hopefully reducing costs as well. Demographic models have shown that removal of northern snakehead should occur during pre-spawn periods or prior to juvenile dispersal in order to be the most efficient in limiting population growth (Jiao et al., 2009). This is also the time period when northern snakehead are more easily captured by electrofishing due to limited movement of adults (Lapointe et al., 2010). More specifically, snakehead appear to be most active during peak daylight times, so targeted removal should occur during early morning/late evening hours when fish are less active. Based on data collected by USFWS, it is least costly for agencies to target northern snakehead in the spring and fall, when catch per unit effort (CPUE) is highest. This can be used as guidance for managers to use resources at times of greatest capture efficiency.

If costs associated with control of snakehead are prohibitive, then encouraging commercial fisheries harvest could be an alternate option. However, some states do not allow the possession or sale of snakehead, dead or alive. In Maryland, the commercial sale of snakehead is in its infancy, and it remains to be seen if this will help control the population or not. Fishing mortality may need to be relatively high in order to control snakehead populations. Moreover, if the value for snakehead becomes high, then there is incentive for releases outside of currently established ranges. These issues would need to be examined in test areas where a commercial fishery could be an option for controlling snakehead. Recreational fisheries are another potential control method. In the Potomac River, bowfishing for northern snakehead is becoming popular. In June 2012, a recreational fishing tournament was held, and in only 18 hours, over 200 snakehead were caught, weighing over 1400 pounds. If angling pressure can safely be increased, it can be included with agencies control methods and aid in management of invasive species.

With any control effort, public health and welfare concerns will need to be addressed. This can include any potential issues with the public, whether through direct or indirect interactions with snakehead, electrofishing efforts, or rotenone application. During control efforts carried out by AGFC, public health issues were addressed, especially in

regards to the use of rotenone. They provided fact sheets and made contact with landowners to address their concerns. In addition to public health concerns over the application of rotenone, AGFC also addressed potential negative interactions with non-target organisms. Prior to the Arkansas control efforts in 2009, an Environmental Assessment (EA) evaluating the effects of snakehead control was completed by the USFWS. The results of the EA provided a Finding of No Significant Impact (FONSI) for the Big Piney Creek drainage. Once the FONSI was accepted, AGFC was able to obtain full assistance from the USFWS in the control effort. Such assessments will probably be necessary in many instances where snakehead need to be eradicated or controlled, especially in instances when natural or cultural interests; public health; or safety or violation of federal, state, local or tribal regulation may be encountered (43 CFR 46.215).

Early Detection and Rapid Response (EDRR)

Early detection of snakehead invasions and rapid response to eradicate is key to preventing their establishment in new areas and further spread. Effective early detection and rapid response depends on several steps that are explained in this section.

Surveillance and Site selection

Vander Zanden and Olden (2008) provide guidance on how to identify priority sites for snakehead surveillance recommending that site selection should focus on the potential for introduction, habitat suitability and the likelihood of adverse impacts. The probability of future introductions into the U.S. should be low considering that the importation of snakehead is prohibited. However, this is depending on the effectiveness of import surveillance programs and the ability of inspectors to detect illegal imports of snakehead. The success of such prevention programs needs to be determined. In, in the interim, forecasting the probability of new introductions should focus on the potential for secondary spread from established populations. This will require a spatial assessment of both human-mediated pathways of spread,, and the likelihood for natural dispersal and intersection with suitable habitats. Priority should then be given to those high probability sites with suitable habitat where adverse impacts are likely. An impact assessment of needs to consider both the presence of vulnerable high-value species (e.g. threatened species or commercial fisheries), communities or ecosystem services, and whether that site could facilitate or accelerate secondary spread (Worrall, 2002).

Sampling effort – and periodicity

Detecting an incipient invasion is often challenging when the target species is rare or elusive; however, this action is best achieved by either increasing sampling effort or adopting highly sensitive surveillance methods (McDonald, 2004). How often a site should be sampled will also require an understanding of the propagule pressure and the lag time between establishment and abundant populations that are likely to drive or promote spread. Data from the Potomac population suggest that population growth and spread is the result of high fecundity, early age of maturation and occurrence of multiple spawning events per year. These data suggest sites with a high vulnerability to invasion (sensu Vander Zanden and Olden, 2008) and will require annual monitoring efforts in order to maximize the probability of detecting new snakehead incursions while they can still be contained and eradicated.

Sampling methods

Surveillance monitoring should incorporate a range of capture methods including electrofishing, traditional sampling gear, high-tech detection, contract fishermen, eDNA analysis, as available, and be tailored to habitat conditions. A discussion of these methods is provided in this section. The efficacy of each method may vary across habitats, therefore multiple methods may be required to sample a full range of habitats and maximize the probability of detection. Sampling results and data collected will contribute to the understanding of snakehead and help guide response actions.

Current detection methods for snakehead rely on standard fisheries methods (traps, nets, electrofishing, etc.) that can be effective in shallow (< 1m), clear and slow flowing water, but these methods appear to have limited detection sensitivity in deep, turbid waters or when snakehead are in low densities (L. Holt, AGFC, personal communication, 2012). The AGFC has found that spot treatment of sites suspected to contain snakehead with rotenone has been an effective method to survey short river reaches or ponds. However, widespread application of rotenone is not possible because of potential non-target species impacts and associated difficulties in obtaining use permits.

Indirect genomic detection tools (e.g. environmental DNA; Ficetola et al., 2008 ; Jerde et al., 2011) offer potential as an effective early detection surveillance method. Various initiatives are underway to design and test genetic markers for snakehead species and quantify relative sensitivity and efficacy of environmental DNA analysis compared with standard fisheries methods.

Surveillance methods

Methods utilizing eDNA have been used extensively throughout the Upper Mississippi River Basin and parts of the Great Lakes Basin to monitor for the possible presence of Asian carp. This technique could prove useful for the early detection of snakehead species as well because given the methods ability to detect the presence of eDNA in the water when fish populations are at very low levels (Jerde et al., 2011). Positive detection of target eDNA is indication of presence only although there is increasing evidence that detection rate is correlated with fish abundance (Thomsen et al., 2012). Nevertheless, interpretation of a positive detection can still be open to interpretation (see Darling and Mahon, 2011) but greater certainty that the results indicates the presence of live fish is provided by repeated sampling that produces positive detections and systematic consideration of potential alternate sources of eDNA (Jerde et al. 2011, 2013). Methods, understanding and data interpretation are evolving rapidly (Lodge et al., 2012; Thompson et al., 2012), and while genetic laboratory capacity is limited, sample processing and analysis time can be variable and results may not be available for days to weeks. Additionally, eDNA methods should be considered in conjunction with other surveillance methods for accurate verification of Asian carp presence.

To maintain a responsive program, efforts for surveillance should focus on the tools available now and continue to develop additional tools to increase effective monitoring and early detection. The following initiatives are recommended to increase snakehead surveillance and early detection:

Incursion Response (Rapid Response)

Rapid response is a systematic effort to eradicate, or contain invasive species while infestation are still localized (NISC, 2008). Rapid response can be implemented through the Incident Command System (ICS), a standardized, on-scene, all-hazards incident management approach. The ICS is a subcomponent of the National Incident Management System (NIMS), as released by the U.S. Department of Homeland Security in 2004.

One potential response trigger in the case of snakehead may be the observation or capture of a live snakehead in a new area or ecologically sensitive area. The goal of the rapid response is to mitigate the potential adverse effects of an invading invasive species through containment, control or eradication of the target population. Advanced planning and preparations are crucial to the success of a rapid response for agency collaboration, stakeholder and public buy-in of the potential actions, resource management, and to fulfill all regulatory requirements. Rapid response involves four key elements; a Response Trigger, Rapid Response Operations, a Recovery Phase, and a Reverse Trigger. Each of these key elements is outlined below:

Response Triggers

The lead jurisdictional authority determines what the response trigger should be as well as the extent of response. This could range to a great degree depending on the potential risk posed. For example, if a very small population is detected, containment and capture by local authorities may be sufficient. If, however, a larger self-sustaining and spreading population is detected, a much larger scale response may be warranted. This could then result in additional response assets from differing jurisdictional authorities to contain and then eradicate the population. The decision to implement a rapid response action should account for the efficacy and capabilities of each trigger threshold met.

The following thresholds or a combination of two or more threshold limits should be considered as triggers to invoke a rapid response or rapid removal action in a given area. However the final decision to initiate a rapid response action and the type and extent of the action ultimately will be based on the best professional judgment of representatives from involved agencies with jurisdictional authority. One or more of the following thresholds may illicit various levels of response:

1. Observation or capture of one or more live snakehead specimen in a section of waterway and/or;
2. Multiple reports of sightings for snakehead from a single location of waterway and/or;
3. Consecutive positive eDNA results for snakehead from a single location.

These responses are dependent on a variety of factors including the connectivity of the affected waterway, potentially affected species, and level of threshold met. The level of response is to be determined by the involved agencies in the impacted area with jurisdiction authority. A trigger/tiered response matrix should be developed to assist stakeholder agencies in the decision making process.

Rapid Response Operations

Implementation of a rapid response operation consists of four phases: preparedness, response, recovery, and mitigation. Specific operational procedures will be dependent upon the treatment selected at the time of plan initiation.

Preparedness Phase. This phase begins well in advance of implementing operations in response to the threat of snakehead introductions or expansion into new waterway

systems. It signals the threat is imminent and shall conclude when the actual response is triggered. This phase includes planning functions necessary to carry out a rapid response and includes the following:

- Selection of a rapid response planning team from stakeholder and partner agencies or organizations
- Review of current legislation regarding AIS authorities and proposed treatment options
- Request of information, support, and resources from stakeholder representatives to implement a rapid response
- Assurance that Memoranda of Understanding (MOU) or other agreements are in place for efficient operations
- Site selection for treatment and staging
- Selection of potential treatments or response actions, ranging from increased monitoring to piscicidal treatments, best suited for various locations

Response Phase. This phase of rapid response operations, is initiated by the pre-established triggers, and will extend into the process of follow-up monitoring. The following functions occur within this phase:

1. Plan implementation and initiation.
2. Treatment selection – A tiered, integrated treatment response based on the severity of the threat and the potential for increases and sustained spread of snakehead species into new areas of waterway and the native species potentially affected. Response actions may include the following:
    a. Increase and sustained monitoring for a specified amount of time including netting, commercial fishing, electrofishing, etc.
    b. Initiate level I response actions with increased personnel, resources, and time devoted to response actions. Consider the use of piscicidal agent to further mitigate spread of snakehead fish present.
    c. Initiate level II response with use of piscicide application and all associated actions including a threatened and endangered species assessment and live capture of sport fish and other critical species. Other actions may include but are not limited to the following:
        i. Seine/block off netting during operations to further isolate treatment area
        ii. Closing of structures such as sluice gates, dams, or navigable waterways where possible to prevent escape of fish during treatment
        iii. Snakehead sentinel fish monitoring to ensure treatment efficacy
3. Stakeholder notification – Stakeholder agencies should be notified of potential response actions and involved in the planning and response, if applicable.
4. Mobilization – Implement a National Incident Management System, Incident Command System (ICS).
5. Treatment application

6. Detoxification if necessary – If a piscicide is employed, a detoxicant should be used to neutralize the agent so that it does not persist in the water and cause harm to additional native species in the area.
7. Follow-up monitoring utilizing electrofishing, netting, eDNA analysis, or sentinel fish for snakehead presence

Reverse Trigger. The reverse trigger is the point at which the lead jurisdictional agency and/or its' response partners agree that whatever may have necessitated the response has now been addressed. One or all of the following may signal conclusion of response activities, depending on response actions implemented:

- Completed detoxification of treatment area
- Conclusion of cleanup actions
- Maximum piscicide dose achieved
- Dose timeline complete
- Negative monitoring result of snakehead sentinel fish
- Catastrophic event within treatment area

Recovery Phase. The recovery phase follows the water treatment and/or termination of the threat of snakehead species within the treatment area. This phase may begin during follow-up monitoring activities, and may continue well into recovery efforts. This phase ends with the After-Action Report (AAR) and dissemination of lessons learned. The AAR typically intended to assist agencies by analyzing results and identifying strengths to be maintained and built upon, identifying potential areas for further improvement, and recommending follow-up actions. The suggested actions in this report should be viewed as recommendations only. The components of the Recovery Phase are as follows:

1. Continue treatment follow-up monitoring efforts.
    a. Determine capture from response operations and monitoring activities.
2. Cleanup and dispose recovered fish and bio-mass from the treatment area.
3. Demobilization
    a. When the reverse trigger has been met, demobilize personnel and resources until recovery is complete.
    b. Demobilize according to the demobilization plan.
    c. Responders should not leave the site until they are formally demobilized.
4. Document costs associated with operations.
    a. Compile costs expended by each agency including man-hours, equipment usage costs, consumables, and all other associated costs.
5. Preparation of an AAR
    a. Compile responder debriefs, lessons learned, and recommendations for future planning and response work.
6. Preparation for future response
    a. Based future response on AARs, and lessons learned.
    b. Continue to train and exercise potential responding staff.

Mitigation Phase. The mitigation phase should begin following rapid response and recovery. During this phase improvement plans should be developed and implemented from the response After-Action Report and identified areas for improvement. The mitigation phase includes any efforts that work to reduce the threat of snakehead species and the need to implement rapid response operations. It may include of the following:

1. Long-term monitoring efforts
2. Development and implementation of a program Improvement Plan (IP)
3. Personnel training and rapid response exercises
4. Increase response capacity and capabilities

The steps to detect snakehead fish and respond to their presence require coordination with multiple agencies and organizations. These steps are a guide that should be followed and any lessons learned can be applied to improve the process.

Research

Research is required to develop more effective snakehead control methods. Current methods of controlling snakehead populations may not offer complete control or eradication and can be extremely costly. Research leading to more efficient ways to control snakehead will be valuable to any agency in charge of snakehead management.

For example, in 2006, Lapointe et al. (2010) radio-tagged adult northern snakehead in Virginia tributaries of the Potomac to determine seasonal habitat selection. They found that snakehead in the Potomac tributaries generally preferred shallow habitats that provided cover. In the spring (pre-spawning period), snakehead moved upstream within their respective tributaries and remained there throughout the spawning period. During the spawning season snakehead almost exclusively chose habitats along the shoreline that provided macrophyte cover for spawning. During the post-spawn period, from September to November, snakehead were found in offshore habitats with vegetative cover such as Eurasian milfoil and hydrilla. However, during winter, snakehead preferred offshore habitats with deep water (Lapointe et al., 2010).

Creel surveys along the Potomac River tributaries in Virginia were conducted in 2008 by VDGIF and again in 2009 in both Maryland and Virginia tributaries by the VDGIF and USFWS. Creel surveys can provide data regarding how often recreational anglers catch snakehead, and examine catch rates of species that may be negatively impacted by the presence of snakehead such as largemouth bass. Catch rates of northern snakehead more than doubled from 2008 to 2009, even though catch rates were extremely low for both years (0.0025 and 0.0057 snakehead per angler hour, respectively). Largemouth bass catch rates were approximately one fish per angler hour for each year. This shows that anglers are more commonly encountering northern snakehead while fishing on the Potomac River, suggesting that the population could be expanding in range and/or growing in numbers. Creel surveys should continue every 2-3 years to monitor recreational catch rates of northern snakehead and other species.

In spring 2009, a cooperative tagging program of state and federal agencies, including the District of Columbia Department of the Environment's Fisheries and Wildlife Division, MDNR, VDGIF, and USFWS for northern snakehead began on the Potomac River. In this program, northern snakehead were tagged with an external tag and released where they were captured. Tagged fish are subsequently captured and killed by recreational anglers, and the tag is reported to USFWS. These tag returns provide essential information on northern snakehead distribution and movement within the Potomac River.

By April 2011, over 1133 northern snakehead were tagged in the Potomac River. Of these tagged fish, ninety-six were recaptured by both state or federal agencies and recreational anglers. The majority of recaptured northern snakehead (approximately 90%) remained in the creeks where they were initially tagged. This suggests that many individuals in the population do not move great distances. However, those individuals that did move outside the creek where they were initially tagged were capable of moving

relatively large distances. One tagged fish was captured approximately a year after it was tagged, and had moved 47 river kilometers upstream. Most northern snakehead movement appears to be during the pre-spawning months of April and May and during high flow events (USFWS, unpublished data, 2012).

Education and Outreach

The effectiveness of the actions summarized in this SCMP can be significantly enhanced through effective communication and increased public participation. Communication between agencies and outreach to the general public, commercial and recreational users, media, legislators, and local officials is critical to success of snakehead control and management. An informed public is an essential component for improving the chances of preventing or minimizing impacts of the snakehead.

USDA's National Invasive Species Information Center, snakehead page at http://www.invasivespeciesinfo.gov/aquatics/snakehead.shtml provides information for the public and stakeholder's outreach use. This website offers information regarding all aspects of the snakehead management actions and includes links to important federal, state, and other relevant actions and information. Access to scientific literature on pathways, non-native fish species, and scientific research will enhance improved development of outreach materials to prevent future introductions of snakehead or other invasive species, improve our understanding of snakehead populations and control methods, and improve our ability to implement the actions in this SCMP and future plans. A central location for information on scientific literature on pathways and non-native fish species is important for coordinated management of snakehead. The National Invasive Species Information Center, snakehead page, USGS NAS database, or another website should be designated as the central information source and reliably funded and maintained to support snakehead control and management.

Preventing invasion and detecting snakehead starts with public education, specifically fishermen. Angler and public education could include providing a short, concise and easily understood poster, brochure, or information card. These cards and brochures could be distributed to the public and fishermen each time a fishing license is sold or a boat is registered.

Educational material should notify anglers and the public of the potential for snakehead to invade local waters and give the angler the capability to identify a snakehead should one be caught. Materials should include phone numbers and contact information for the agencies involved with invasive species management. An explanation of natural resources stewardship, environmental and human health issues related to the introduction of snakehead, and regulations and penalties associated with live possession of snakehead should be included on outreach materials. It is critical to inform the public and all appropriate stakeholders of appropriate actions to be taken if a live snakehead is detected. Educational programs and materials should be updated if regulatory status changes or new pathways are identified. The public may report invasive species sightings, including snakehead at 1-800-STOP-ANS and http://nas.er.usgs.gov/sightingreport.aspx.

Such outreach materials should be in several different languages and be distributed to fishing license holders and posted at boat ramps, cultural festivals, and bait and tackle shops. Public education targeting every ethnic group is very important, especially since people may transport fish not realizing the environmental risks and legal penalties. Larger species of snakehead are popular with anglers in their native and introduced ranges; therefore, the possibility of anglers transporting snakehead to new locations is real. Research to identify ethnic groups that purchase and release species as part of their cultural practices could be used to develop targeted multilingual outreach products.

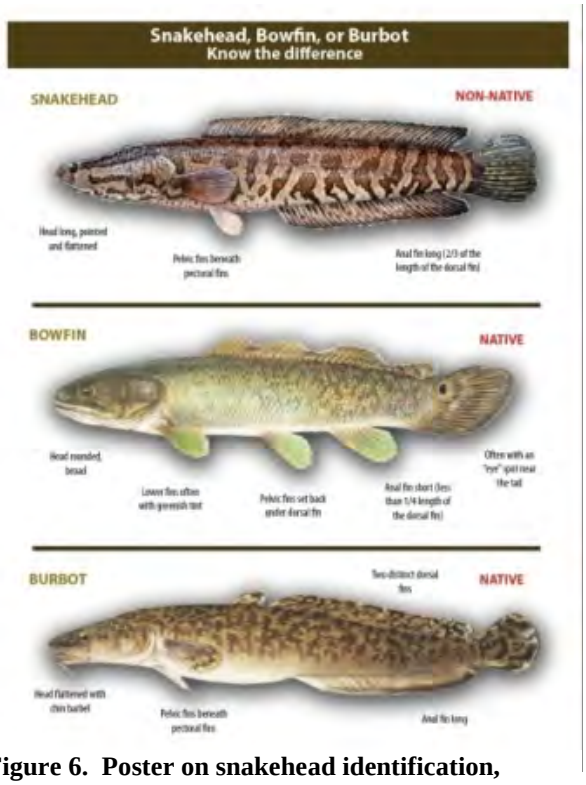

Figure 6. Poster on snakehead identification, including contact information, New York Department of Environmental Conservation (NYDEC)

Education programs and materials should be further tailored to inform inspection agents and state and federal wildlife officers about identification of live juvenile and adult snakehead, applicable laws, and high risk pathways.

Proactively working with the press can effectively spread a message to a wide population. Regular news releases and media events about the snakehead and other regional invasive species will bring attention to invasive species issues and highlight the activities of the Aquatic Nuisance Species Task Force. Each jurisdiction should have one point of contact for the press to ensure an accurate and consistent message. Points of contact and other general information about snakehead could be posted on the snakehead website as part of a press kit for developing news releases and hosting media events.

Outreach efforts start with engaging key outlets and audiences. This plan discusses utilizing the media (newspapers, radio stations, and websites) to effectively communicate the threats to the ecosystem and economy; what can be done to prevent snakehead movement; and what penalties are associated with introduction, transport, and live possession of snakehead. Although there are many potential audiences, this plan encourages primary outreach efforts targeting angler and enforcement officer audiences. Effective outreach starts with engaging key outlets and audiences. The table below identifies key outlets and audiences for outreach activities. These outlets are not listed in any priority.

Table 3. Key Outlets and Audiences for Outreach Activities Involving Snakehead.

Key Outlets and Audiences for Outreach Activities	
Outlet	**Audience**
Academia and Research Community	Schools / Students Universities
Community Groups	Angler groups Community organizations Ethnic and multilingual groups
Consumers	Food consumers Recreational and farm pond owners
Elected Officials	Federal State Local
Enforcement	US Fish and Wildlife Service US Border Patrol Homeland Security US Coast Guard
Marketers	Fish farms Live haulers Retail sales (grocers and pond stockings) Wholesalers
Media	Applications Blogs Magazines Newspapers Radio Television Widgets
Natural Resources Management Agencies/Organizations	Land Grant institutions Local municipalities National Park Service Non-governmental organizations Regional Aquatic Nuisance Species Panels NOAA Sea Grant institutions State commerce agencies State DNR/DEC/DEP/AGR agencies State/County DOT agencies Tribal natural resources management agencies U.S. Army Corps of Engineers U.S. Department of Agriculture U.S. Environmental Protection Agency U.S. Fish and Wildlife Service U.S. Geological Survey U.S. Department of Transportation U.S. Forest Service
Pet Trade Industry	Aquarium and water garden owners and hobbyists Internet trade Retail store owners

	Wholesalers
Producers and Growers	Grow-out facilities Hatcheries
Recreational Anglers and Boaters	BASS groups Boating and sailing clubs Division of Motor Vehicles Large- and small-scale bait/tackle shops Marinas Trout Unlimited
Trade Associations	Commercial Fishers Commercial and Recreational Baitfish Harvesters Marine Trade Associations
Transporters	Consumers Fish farms Live haulers Retail sales Wholesalers

Appendix A. Objectives and Action Items for SCMP Implementation

Action Items	
Objective	**Item**
Objective 1. Prevent new introductions of snakehead within the U.S. by refining the Lacey Act and other regulations and improving compliance and enforcement.	1.1) Work with federal agencies, states, the District of Columbia, and jurisdictions to promulgate regulations or statutes that would prohibit possession, transportation, sale, acquisition, and introduction of all snakehead species nationally. 1.2) Develop approaches to prevent importation from vector source, including improved border surveillance methods. 1.3) Promote the enactment of consistent and enforceable regulations and statutes among bordering or shared jurisdictions that include substantial penalties for violating those statutes. 1.4) Identify, understand and characterize all vectors of spread and quantify / assess their relative risk of contributing to range expansions of snakehead. 1.5) Identify management, outreach, and enforcement options available to reduce the risks associated with each identified vector. 1.6) Through genetic analysis determine source regions of established populations. 1.7) Determine the status of all historic records of snakehead outside the known established range. 1.8) Sources of snakehead in the U.S. are contained (and where possible, eradicated) and the risk of natural and anthropogenic spread is minimized.
Objective 2.0. Contain the expansion of northern snakehead within the U.S. by establishing an effective snakehead surveillance program to detect new introductions at a stage where populations are able to be removed.	2.1) Develop an information system via the web or protocol to notify other jurisdictions of sightings of snakehead. 2.2) Identify legal and administrative barriers in jurisdictions that would prevent rapid response efforts from occurring. 2.3) Enact legislation in jurisdictions that allow the appropriate agency access on public/private property and inter-jurisdictional waters to assess a potential introduction and implement control methods. 2.4) Recommend that jurisdictions develop a rapid response plan for snakehead. 2.5) For those jurisdictions that have developed rapid response plans, obligate funding or identify sources of funding for rapid response. 2.6) Identify trained individuals to respond to new introductions of snakehead within their jurisdictions. 2.7) Incorporate monitoring for snakehead into other

	existing aquatic surveys in jurisdictions. 2.8) Establish a network of surveillance monitoring stations at priority sites highly vulnerable to northern snakehead invasion. 2.9) Develop containment guidelines to prevent spread from infested areas. 2.10) Ensure all outlying established populations (e.g. Queens New York) are fully contained, and, where possible, eradicate these to eliminate these potential sources of spread. 2.11) Compile a list of existing control options and summary of regulatory use requirements and develop best practice guidelines. 2.12) Test the efficacy of eDNA detection methods. 2.13) Petition EPA to develop a special use permit for the new rotenone label to address snakehead control. 2.14) Evaluate ecological and economic impacts of eradication.
Objective 3. Mitigate impacts of snakehead in U.S. waters where eradication is not possible.	3.1) Determine ecological and economic impacts of control methods on other species. 3.2) Determine effectiveness of control options for long-term management in different systems. 3.3) Continue effective law enforcement to stop supply routes, sources, and markets in order to prevent further introductions.
Objective 4. Conduct research to understand pathways and to develop more effective surveillance, control, and eradication methods.	4.1) Conduct research on biology,natural history, behavior, ecological, and economic impacts to inform long-term control options. 4.2) Obtain information on life history and biology of snakehead in their native environment and in U.S. waters to better predict where the species could become established. 4.3) Conduct research to understand impacts of snakehead on native aquatic organisms. 4.4) Evaluate each snakehead species using a risk assessment method to determine potential establishment, impact, and pathways for introduction. 4.5) Establish and maintain comprehensive population genetics baseline that describes complete genetic variation across all established populations of snakehead in the U.S. to aid identification of the source of new introductions and whether there is successful illegal importation of snakehead into the U.S. 4.6) Identify the most effective snakehead surveillance methods and develop guidelines and best management practices. 4.7) Determine the effectiveness of all containment methods

	that prevent spread from infested areas. 4.8) Conduct research to develop additional control methods including integrated approaches using multiple methods. 4.9) Conduct comprehensive review and translation of non-English literature on snakehead where the species is either native or naturalized. 4.10) Conduct a symposium to compile and publish scientific information pertaining to snakehead.
Objective 5. Develop outreach tools to help prevent new introductions of snakehead within the U.S. and control the spread of established populations.	5.1) Develop outreach tools for target groups to reduce risks associated with each identified pathway including information on regulations and penalties for possession and introduction. 5.2) Develop a press kit for jurisdictions to use for rapid response and containment of new introductions. 5.3) Develop outreach materials in each jurisdiction to educate the public on identification of snakehead and who to contact to report sightings. 5.4) Train state and federal wildlife officers, U.S. Customs and Border Protection Inspectors on species identification of all live juvenile and adult snakehead. 5.5) Coordinate outreach efforts with those for other non-native fish species in order to provide greater effectiveness in preventing future introductions of new species**.**
Objective 6. Review and assess progress of the SCMP.	6.1) Annually review progress with implementation of actions in the SCMP. 6.2) Coordinate reporting and communications between state and other stakeholder agencies. 6.3) Incorporate information associated with implementation of actions in the SCMP into the national clearinghouse.

Objective 1. Prevent new introductions of snakehead within the U.S. by refining the Lacey Act and other regulations and improving compliance and enforcement.

1.1. Work with federal agencies, states, the District of Columbia, and jurisdictions to promulgate regulations or statutes that would prohibit possession, transportation, sale, acquisition, and introduction of all snakehead species nationally.

Some states prohibit possession of only those snakehead species that could become established in their waters. As long as the source of the snakehead was not through interstate or foreign commerce, the Lacey Act does not prohibit possession of live snakehead if States do not have regulations prohibiting possession. Without state law prohibiting possession of live snakehead, wildlife law enforcement officers would find it difficult to prove a violation of state or federal law. Even though certain species of

snakehead may not be capable of reproducing in the wild in certain climates in the U.S., they could be transported to another state where a viable reproducing population could be established if introduced. Improve border protection from AIS Pathways by import and individuals and propose post border surveillance program.

1.2. Develop approaches to prevent importation from vector source, by improving border surveillance methods.

The following actions are recommended:

- Establish enforcement Standard Operating Procedures (SOP) for snakehead violations pertaining to the Lacey Act to improve international border surveillance.
- Develop practices for collecting samples that are rigorous and can meet legal standards for chain of custody, etc.
- Determine which agencies are involved in inspecting shipments of imported live aquatic organisms at ports of entry and make sure they are aware of the laws pertaining to the import of live snakehead species.
- Determine other means of importing live snakehead, such as purchase through websites or hobbyist groups.
- Develop improved border inspection methods to determine whether snakehead are being imported as contaminants and/or hidden within larger live fish importation.
- Offer eDNA screening to improve accuracy of visual inspections screening.
- Assess levels of illegal importation, relative efficacy of genomic screening compared to current surveillance methods, and practical consideration in terms including sample collection, and required process times.
- Consider a statutory requirement for reporting new records of injurious wildlife to USFWS.

1.3 Promote the enactment of consistent and enforceable regulations and statutes among bordering or shared jurisdictions that include substantial penalties for violating those statutes.

Each state jurisdiction should have the same regulations to prevent further spread or introduction of snakehead into new areas. Each jurisdiction should prohibit the possession transportation, sale, acquisition, and introduction of live snakehead and establish state border surveillance programs.

1.4 Identify, understand, and characterize all vectors of spread and quantify/assess their relative risk of contributing to range expansions of snakehead.

The scale of both legal and illegal movement and sale of snakehead needs to be assessed, and reasons for these behaviors understood before effective prevention measures can be developed. Assessing the risk of introduction associated with each identified pathway

will assist states and jurisdictions in prioritizing enforcement and outreach efforts to prevent additional introductions of snakehead.

The live food fish market has been identified as the main vector for introduction of snakehead into areas. Prayer animal release was also mentioned as a possible vector for introduction of snakehead species, but work is needed to assess whether this pathway is real. Northern snakehead are thought to have been introduced to the Potomac River and several New York locations to establish a local wild food source. If further evidence supports this pathway, community action can be initiated to increase public awareness, surveillance, and enforcement. Continued interception of illegal snakehead imports into and within the U.S. and Canada by the USFWS raises the possibility that there may be an active underground or black market for this fish (Table 1). The Great Lakes and Mississippi River basins have implemented awareness campaigns and can serve as a model for future snakehead activities.

Anglers fishing for snakehead in established populations could also introduce the fish in new areas unknowingly through catch and release or the release of live bait. Illinois Department of Natural Resources commenced a study throughout Illinois to assess the bait trade as a vector of spread for Asian carp. Their efforts included site visits, visual inspections, eDNA sampling, and questionnaires to local bait shops and distributers. Similar efforts in conjunction to snakehead could be implemented on a larger scale in areas where snakehead threaten waterways.

Snakehead establishment in Arkansas is thought to have arisen from fish that escaped from an aquaculture facility. This could be prevented in the future by closer monitoring of state regulations prohibiting the importation, transportation or possession of snakehead.

1.5 Identify management, outreach, and enforcement options available to reduce the risks associated with each identified pathway.

Agencies and organizations should conduct regular reviews of their invasive species programs to identify improvements needed to management, outreach and enforcement activities. The program reviews should consider pathways of introduction such as live food markets, live bait trade, aquarium trade, etc.

1.7 Through genetic analysis determine source regions of established populations.

To perform this analysis, research is needed on the genetic makeup of all populations of snakehead worldwide. This would provide information for agencies involved in inspections and enforcement at ports of entry to determine which countries are importing these fish illegally.

Nevertheless, it is also important to fully characterize the genetic origin of all snakehead populations and single records presently within the U.S. as well as Canada and Mexico to

provide a population genetics baseline that will enable the source of future introductions to be assessed. These data will help determine whether new introductions represent spread within the U.S. from known populations, or either illegal importation from outside U.S. or that there is an unknown established population within the U.S.

1.8. Determine the status of all historic records of snakehead outside known established range.

To prevent further spread of snakehead, the status of all snakehead occurrences should be determined. Uncertainty still appears to exist over the status of sites where single or small numbers of individual fish have been collected, namely Florida, California, North Carolina, Illinois, and Massachusetts.

Snakehead range is unknown in many of these areas areas because standard fisheries survey methods have low detection sensitivity, especially in deep (>2m) or turbid water or habitats with large amounts of cover. Other tools need to be employed to determine the status of snakehead outside their established range.

1.9 Ensure all sources of snakehead in the U.S. are contained (and where possible, eradicated) and the risk of natural and anthropogenic spread is minimized.

Snakehead are established in several areas of the U.S. and steps should be taken to prevent their spread to other locations. Snakehead have been established in the Potomac River Basin since 2002.

In the Lower Mississippi River Basin, snakehead appear to have established in the Big Piney Creek system in Arkansas. Extensive flooding in 2009, 2010 and 2011 has likely spread these fish downstream beyond the point where they can be contained or eradicated. There is a significant risk that this population will spread into the lower Mississippi over the coming decade. While downstream invasion may not be preventable, it may be possible to prevent access to tributaries that flow into the lower Mississippi by establishing barriers, similar to those used to protect the Great Lakes Basin from Asian carp. It is urgent that an assessment is undertaken to examine the development of barriers to upstream dispersal and their potential collateral impact on native species.

In the Great Lakes Basin, aquatic invasive species risks are occurring at an alarming rate. Since the beginning of the 19th century, more than 180 non-native species have been introduced into the Great Lakes. Some of these species have become ‘invasive’ (causing ecological or economic damage or threatening human health). These invasive fish, invertebrates, viruses, bacteria, and parasites can devastate native communities, as well as cause great economic damage to the Great Lakes commercial, sport, and tribal fisheries. The geographic range of snakehead species is expanding in the Mississippi River Basin and other waterway systems threatening invasion to the Great Lakes.

Sites that contain rare or threatened taxa that will be highly vulnerable to snakehead predation or competition also need to be identified. These sites should be priorities for surveillance to ensure that snakehead are detected as soon as they invade. Control and containment measures should be instigated as soon as snakehead are detected to slow establishment and minimize impacts.

The ecological and economic damage in the Mississippi River watershed that followed Asian carp invasion was an early warning of potential impacts of other invasive species such as snakehead on these threatened waterway systems. This warning has resulted in the formulation of this SCMP and corresponding efforts for prevention or eradication.

Objective 2.0. Contain the expansion of northern snakehead within the U.S. by establishing an effective snakehead surveillance program to detect new introductions at a stage where populations are able to be removed

2.1. Develop an information system via the web or protocol to notify other jurisdictions of sightings of snakehead.

To insure improved international border protection from AIS Pathways by import and individuals, it is critical to notify bordering or shared jurisdictions when a snakehead is found. A notification system via the web should be developed for prompt notification. NAS alerts from USGS are an example of an effective communication tool that may be expanded for snakehead

2.2. Identify legal and administrative barriers in jurisdictions that would prevent rapid response efforts from occurring.

Federal actions that may affect the environment must be evaluated through the NEPA process. This includes any federal assistance to state, local agencies or organizations. The USFWS should consider developing a categorical exclusion for future snakehead control programs inin instances where snakehead need to be eradicated or controlled, especially in instances when natural or cultural interests; public health; or safety or violation of federal, state, local or tribal regulation may be encountered (43 CFR 46.215).

Processes to streamline the Endangered Species Act (ESA) evaluations in advance of rapid response operations should be developed.

The lack of access to private property to control snakehead creates a legal barrier that may prevent rapid response efforts from occurring. All potential legal barriers that may prevent rapid response occurring in a timely manner should be identified along with corresponding solutions.

2.3. Enact legislation in jurisdictions that allow the appropriate agency access on public and private property and inter-jurisdictional waters to assess a potential introduction, implement control methods, or eradicate snakehead.

Several states have early detection and rapid response legislation enabling state agencies to enter private lands and take action, and restrict access. Virginia legislation authorizes the VDGIF to control any nuisance species populations and gives the Department authority to obtain a warrant to conduct such operations on private property. In Maryland, there is legislation that authorizes the MDNR to enter and inspect property to determine if a "state of nuisance" exists, and establishes provisions related to abatement. Legislation was prompted in both of these states due to legal access issues that agency personnel were confronted with when trying to initiate rapid response on private property. Similar legislation could be drafted in other states.

2.4. Recommend that jurisdictions develop a rapid response plan for snakehead.

A rapid response plan would establish a protocol to prevent factors that may result in a delay in eradication efforts. Protocols would include acquiring the proper permits for control methods, establishing safety protocol for the control methods, developing an outreach plan to work with the media and a plan for containment, and providing contact information for agencies if a snakehead is found. Develop (or update) a web based "model" response plan that describes containment, control and eradication best management practices; their relative effectiveness; identifies regulatory requirements including acquisition of required permits (e.g. enabling dewatering, rotenone application); and lists contacts and key experts.

2.5. For those jurisdictions that have developed rapid response plans, obligate funding or identify sources of funding for rapid response.

States at high risk for introduction of snakehead should obligate or identify sources of funding for rapid response. States should include planning and developing response capabilities, which could also include planning for snakehead introduction. Agencies should work together to develop a rapid response fund that could be used for emergencies. The system by which agencies should respond is via the incident command system (ICS). ICS provides a standardized yet flexible system for response management so that multiple agencies can coordinate and respond together under one organization. The ICS process coordinates planning and shared resources and personnel to carry out the overall mission. A federal ICS activation process should be established in the event that a state agency does not have resources or interest in addressing the issue.

2.6 Identify trained individuals to respond to new introductions of snakehead within their agency jurisdictions.

There is a need to identify trained individuals to respond to new introductions. This could consist of a directory of agency personnel, scientists, and certified pesticide and herbicide applicators that can identify the fish species and recommend containment, eradication, and control options. This directory could be posted on a central website that contains information on snakehead. Incursion response experts who can advise and peer review rapid response plans should also be identified.

If the ICS is used to respond to invasive species detection, the rapid response personnel directory is essential. The ICS includes training for partners, drills and exercises to test response capacity, and provides reviews of lessons learned from past eradication projects resulting in developing improved emergency response plans.

2.7 Incorporate monitoring for snakehead into other existing aquatic surveys within agency jurisdictions.

Monitoring programs for snakehead should be established in states where they have been introduced or could become introduced. Monitoring for the fish should occur even if it is incorporated into existing monitoring or survey efforts for other species. Creel surveys should continue every 2-3 years to monitor recreational catch rates of northern snakehead and other species.

2.8 Establish a network of surveillance monitoring stations at priority sites highly vulnerable to northern snakehead invasion.

Identify priority sites and systems for snakehead interstate surveillance on the basis of the risk of invasion (because of their proximity to established populations and or pathways of spread), habitat suitability and, presence of vulnerable taxa or ecosystems. Snakehead surveillance programs should be established in areas at greatest risk of invasion and in systems containing irreplaceable values (threatened taxa or ecosystems) that are vulnerable to snakehead impacts. Priorities for monitoring can be identified on the basis of an analysis of proximity to established populations and presence of vectors or pathways of spread. Surveillance of pathways of spread should include monitoring fish haulers (bait, fish stocks) or plants arising from areas with established snakehead populations within the U.S.

Incorporate eDNA into surveillance and monitoring of high-risk pathways for snakehead introductions and inland waterways with the highest risk of introductions. New environmental DNA (eDNA) detection tools (e.g. Jerde et al., 2011; Ficetola et al., 2008) may provide a secondary more sensitive detection method to confirm population status of outlying records.

2.9. Develop containment guidelines to prevent spread from infested areas.

In areas where eradication is possible, containment guidelines should be developed and based on the type of aquatic system in which the introduction has occurred. These guidelines should be incorporated into the rapid response plan and implemented.

2.10. Ensure all outlying established populations are fully contained, and, where possible, eradicate these to eliminate them as potential sources of spread.

All established populations have the potential to act as sources of propagules for spread within the U.S. All new populations should be contained to prevent natural spread irrespective of whether they have the potential to naturally spread, and all efforts should be made to eradicate these. Even where a population may be fully contained, they have the potential to act as a source for human dispersal.

2.11. Compile a list of existing control options and summary of regulatory use requirements and develop best practice guidelines.

A list of different control options that could be used in the environments in which this species could be introduced should be developed. To maintain a responsive program, surveillance efforts should focus on using tools available now and continue to develop additional monitoring and early detection tools. Review past failed attempts and identify reasons for lack of success. To complement the list of control tools, regulations and best management practices that apply to their use should be compiles. The lists should be developed in part with input from members of the NSWG. As information on eradication strategies develops, the eradication tool list, regulatory requirements, and best practice guidelines should be periodically updated.

2.12. Test the efficacy of eDNA detection methods.

Evaluate field efficacy of eDNA for early detection of incipient populations of all species of snakehead Develop and test primers standardized protocols and SOPs for field sampling, laboratory analysis, and data validation. Analysis must be rapid, accurate, and reliable and consistent with an overall nationally approved program. This is particularly important for data comparability.

2.13. Petition EPA to develop special use permit for new rotenone label to address snakehead control.

Currently the Rotenone label does not allow the legal treatment of water bodies for snakehead. If biologists determine rotenone is the most effective control method for a project, they must apply for a special use permit from the EPA and state pesticide bureaus. This can be expensive and time consuming and risk further establishment of snakehead. The NSMP committee should initiate the process for EPA to amend the rotenone label to allow the treatment of water bodies for snakehead.

2.14. Evaluate ecological and economic impacts of eradication.

Ecological and economic impacts of eradication must be considered for different aquatic systems. The effectiveness and feasibility of different control options in different systems should be evaluated. For example, piscicides would not be able to be used in a reservoir that is a drinking water source or a large, open aquatic system.

Objective 3. Mitigate impacts of snakehead in U.S. waters where eradication is not possible.

3.1. Determine ecological and economic impacts of control methods on other species.

Controlling snakehead may impact other species or habitats in negative or positive ways. Evaluate ecological risks and benefits to native flora and fauna and economic costs and benefits to determine which control strategies should be employed for long-term management. This is usually conducted as a part of the NEPA evaluation of a project.

3.2. Determine effectiveness of control options for long term management in different systems.

Current methods of controlling snakehead populations may not always offer complete control or eradication and can be extremely costly. Research leading to more efficient ways to control snakehead will be valuable to any agency in charge of snakehead management. Conduct research to determine effectiveness of different control options for long-term management in different systems. Using an adaptive management framework will provide flexibility in case the control effectiveness changes. Also, integrated control strategies that use multiple methods to target vulnerable life stages or behaviors will improve the control program effectiveness.

3.5. Continue to implement effective law enforcement activities to discontinue supply routes, sources, and markets.

As we gain more knowledge about the risk from different pathways, it is important that natural resource managers coordinate with law enforcement to implement the most effective tools to prevent new introductions the spread of established populations into new areas.

Objective 4. Conduct research to understand pathways and to develop more effective surveillance, control, and eradication methods.

4.1. Conduct research on biology, natural history, behavior, ecological, and economic impacts to inform long-term control options.

Biotelemetry and tagging studies of established populations in both the Potomac River and the Mississippi River basin in Arkansas are needed to examine spatial and temporal distribution, and understand the environmental drivers and limits of dispersal. Studies of the dispersal limits imposed by saltwater will be critical to understand the potential for dispersal in the lower Mississippi delta and Gulf region. Information on spawning, feeding, and guarding behavior is also needed to inform long-term control options. Research into snakehead vulnerability to parasites and disease within their native and introduced range may inform potential biological control mechanisms.

Research should:

- Determine baseline histology of snakehead to better understand the risk and mechanism of these species spreading parasites and diseases to native organisms. Support ongoing research and assist with initiating new research to develop clearer understanding of snakehead taxonomy as it relates to species identification (cryptic species, hybrids, and larvae) and life history.
- Determine methods for aging otoliths or scales and sexing snakehead to better understand population dynamics. This includes investigating possible sexual dimorphism, histology of testes in males, and examining non-gravid females.
- Conduct studies to investigate spawning behavior.
- Conduct studies with snakehead in closed systems to determine potential effects at the ecosystem and species level. This includes food web shifts, reduction in sport fish abundance, and impacts to native species.
- Conduct studies to determine environmental and behavioral cues to movements to colonize new habitats.
- Assess research needs for other snakehead species.
- Conduct studies to determine the economic impacts of snakehead.

4.2. Obtain information on life history and biology of snakehead in their native environment and in U.S. waters to better predict where the species could become established.

An extensive literature review has already been conducted by Courtenay and Williams (2004) but additional literature on snakehead is available in Japanese, Chinese, and Korean. This literature will have to be translated into English to provide information on life history and biology of snakehead in their native ranges. In addition it is important to obtain spatial records across snakehead native range to inform development of niche models that represent the full U.S. distribution potential.

Tag returns provide essential information on northern snakehead distribution and movement within the Potomac River and agencies should consider continuing these studies.

4.3. Conduct research to understand effects of snakehead on native aquatic organisms.

Snakehead have not been methodically studied in their native habitat. Very little is known about the potential effects of snakehead introductions in the U.S. Information concerning the biology, behavior, movement, and stock dynamics of this fish are needed to determine effects. This information would also serve to suggest control and management measures to reduce effects. Studies on northern snakehead populations in the Potomac River would provide useful information on abundance, growth, prey preference, parasite loads, salinity tolerance, and habitat use.

4.4. Evaluate each snakehead species using a risk assessment method to determine potential establishment, impact, and pathways for introduction.

4.5 Establish and maintain comprehensive population genetics baseline that describes complete genetic variation across all established populations of snakehead in the U.S. to aid identification of the source of new introductions and whether there is successful illegal importation of snakehead into the U.S.

4.6. Identify the most effective snakehead surveillance methods and develop guidelines and best management practices.

Undertake research to identify the most effective and sensitive surveillance methods that maximize the likelihood that those new introductions will be detected early, while they are still localized and can be contained and ideally eradicated. Guidelines for snakehead surveillance programs should be written to include descriptions of monitoring methods and best management practices to maximize the likelihood that new introductions will be detected early, while they are still localized and can be contained and ideally eradicated.

4.7. Determine effectiveness of all containment methods that prevent spread from infested areas.

Research is required to develop barriers to prevent upstream spread of snakehead to prevent colonization of tributaries flowing into the lower Mississippi and Chesapeake Bay. Effective barriers to upstream spread could be used to prevent reinvasions and help facilitate eradication of some populations in short streams flowing into the Chesapeake.

4.8. Conduct research to develop additional control methods including integrated approaches using multiple methods.

At this time, control options are extremely limited for snakehead, and successful control is likely restricted to small to medium sized shallow slow flowing water bodies.

Successful control of the impacts of snakehead requires that new control options are developed and tested for effectiveness in different aquatic systems. This need is likely to become critical in the lower Mississippi River System over the coming decade.

Develop additional or enhanced collection and control methods. These could include new capture methods, species specific toxins, diseases or parasites, genetic detection methods, attractants or methods to exploit behaviors and life history traits. Research should:

- Evaluate the effectiveness of different field collection techniques for snakehead. In the Potomac River, it has been difficult for natural resource managers to assess the effectiveness of different field collection techniques because they are still unsure where the fish are distributed temporally and spatially. Once that information is understood, we can more readily assess the effectiveness of different field collection techniques.

- Conduct studies to determine optimal exploitation or removal strategies designed to reduce snakehead abundance.
- Conduct analysis to determine if developing fisheries and markets for snakehead could reduce established populations.
- Identify the most effective electrical waveforms, current, and voltage required to capture, kill or damage all snakehead life stages may improve electrofishing control snakehead because of the snakehead' propensity to favor shallow, slow river margins.
- Improve traps
- Develop baits or pheromone attractants to improve catch efficiency of nets and traps
- Similarly a better understanding of the effectiveness of rotenone (liquid versus powder formulations) might also help improve success of eradication attempts.
- Long term research is required to develop species specific biocides or delivery mechanisms that could enable targeted control or eradications with limited non-target impacts.
- The use of biological control by parasites or disease in native or introduced range or enhanced predation by native U.S. species
- Selective biocides or delivery mechanisms
- Methods that interfere with adult nest guarding behavior and increase the vulnerability of larvae and eggs to native predators.
- Genetic control tools including daughterless, sterile male approaches, or lethal genetic control tools

4.9. Conduct comprehensive review and translation of non-English literature on snakehead where the species is either native or naturalized.

Snakehead species information is available in the countries of origin but have not been translated into English. Information on snakehead within their native range will help us to understand their biology and life history traits, which in turn will help us predict potential ecological and economic impacts and inform long-term control and eradication options**.**

4.10. Conduct a symposium to compile and publish scientific information pertaining to snakehead.

A symposium with published proceedings would be an efficient means for effectively communicating and cataloging research results in a timely manner to natural resource managers throughout the country. A national symposium sponsored by the American Fisheries Society would be one possible venue.

Objective 5. Develop outreach tools to help prevent new introductions of snakehead within the U.S. and control the spread of established populations into new areas.

5.1. Develop outreach tools for target groups to reduce risks associated with each identified pathway including information on regulations and penalties for possession and introduction.

Various types of media (newspapers, radio stations, websites,) can be used to effectively communicate what penalties are associated with introduction, transport, and live possession of snakehead. Jurisdictions should create a poster or brochure that focuses on stewardship, health issues, and regulations and penalties associated with live possession of snakehead. This poster or brochure should be in several different languages. The jurisdictions could target boat ramps, fishing license holders, cultural festivals, and bait and tackle shops. A liaison should be designated to communicate with ethnic communities that may consume or utilize snakehead. Stewardship could be emphasized by citing examples where the introductions of other species have had high costs to communities and ecosystems.

5.2. Develop a press kit for jurisdictions to use for rapid response and containment of new introductions.

One of the most important components of rapid response is communication with the public. Each jurisdiction should have one point of contact for the press to ensure a correct and consistent message. Contact information and other general information about snakehead could be developed and posted on the national snakehead website (Action Item 6.2).

5.3. Develop outreach materials in each jurisdiction to educate the public on identification of snakehead and who to contact to report sightings.

Outreach materials created to assist the public with identification of snakehead should be developed in a simple, effective way so that the public can easily identify snakehead from other similar looking species. These materials could be posted on the national snakehead website (Action Item 6.3).

5.4. Train state and federal wildlife officers, U.S. Customs and Border Protection Inspectors on species identification of all live juvenile and adult snakehead.

Education programs and materials should be developed to inform inspection agents and state and federal wildlife officers about identification of live juvenile and adult snakehead, applicable law, and high-risk sources. Educational programs and materials should be regularly updated if regulatory status changes or new pathways are identified.

5.5 Coordinate outreach efforts with those for other non-native fish species in order to provide greater effectiveness in preventing future introductions of new species.

Create outreach materials that focus on introduction through specific pathways of non-native fish species to prevent future introductions.

Objective 6. Review and assess progress of the SCMP.

6.1. Annually review progress with implementation of actions in the SCMP.

The working group members should meet on an annual basis to review progress of implementation of management actions identified in the SCMP to prioritize actions and to discuss potential funding sources.

Measures of success should be developed in order to assess implementation progress. Measures should include key milestones of success and or failure. In addition, they should determine how success is defined (i.e. all populations are contained, range has contracted, key outlying populations are eradicated, or few new populations have been detected).

6.2. Coordinate reporting and communications between state and other stakeholder agencies.

Implement a centralized national reporting system (USGS – Non-indigenous Aquatic Species (NAS) Database). Consider coordinating existing databases and websites into one single centralized database that provides all the information needed to manage AIS. USGS could get a snakehead URL, expand their database to include research and cited literature, and coordinate with states to collect data on a national scale.

6.3. Incorporate information associated with implementation of actions in the SCMP into a national clearinghouse.

Information associated with implementation of management actions should be collected on a national website, such as the USGS NAS database, in a timely manner.

Appendix B. Literature Cited

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Appendix C. Information Access and Data Management

Information access and data management are important components of a species management plan. To effectively manage aquatic invasive species like snakehead, fish and wildlife managers need information on their biology, distribution, effective control methods, state and federal management regulations, and education and outreach materials.

Several data collection systems have been developed but the information is not universally available or consistent. A national level database for access by researchers, managers and even the public is needed. Several have been developed but need a lead manager and funding to make the information useable. Current information systems that collect snakehead data include:

- BugwoodApps are available for iOS and Android systems and enable users to have access to electronic field guides and to report sightings of invasive species with their smartphone. Georeferenced reports with images are incorporated into EDDMapS;
- Early Detection and Distribution Mapping System (EDDMapS) is a web based mapping system for documenting invasive species distribution by the Center for Invasive Species and Ecosystem Health at the University of Georgia. EDDMapS combines data from other databases, organizations and citizen scientists to create a national network of invasive species distribution data. Users enter observation information and images into the standardized web form or with regional smartphones apps. All data are reviewed by state verifiers to ensure all data is accurate. The data are made available to scientists, researchers, land managers, landowners, educators, conservationists, ecologists, farmers, foresters, state and national parks, www.eddmaps.org;
- FishBase is a global relational database with information on practically all fish species known to science to cater to different professionals such as research scientists, fisheries managers, zoologists and many more, (http://www.fishbase.org/search.php);
- Global Registry of Invasive Species Database, (GISD), collects information on worldwide invasive alien species that threaten native biodiversity and covers all taxonomic groups from micro-organisms to animals and plants in all ecosystems, http://www.issg.org/database/welcome/;
- Great Lakes and Mississippi River Interbasin Study, (GLMRIS), has developed an inventory of available control methods for ANS of concern, http://glmris.anl.gov/index.cfm;
- Great Lakes Restoration Initiative, (GLRI), database tracks the progress of projects that prevent the introduction of new invasive species and provides an invasive species risk assessment database, http://greatlakesrestoration.us/index.html;
- Invasive Species Compendium, (CABI) is a constantly developing encyclopedic resource containing datasheets on over 1500 invasive species and animal diseases, basic datasheets on further species, countries, habitats and pathways, and

bibliographic database of over 75,000 records (updated weekly), http://www.cabi.org/isc/;

- Mid Atlantic Early Detection Network (MAEDN) is the result of a cooperative effort between the National Park Service (National Capital Region, Integrated Pest Management and Invasive Species Program) and the University of Georgia's Center for Invasive Species and Ecosystem Health (CISEH) and utilizes their widely used Early Detection Distribution Mapping System (EDDMapS) to report highly invasive and early detection invasive plant species. Snakehead and other species will continue to be added as appropriate. http://apps.bugwood.org/mid_atlantic.html
- National Exotic Marine and Estuarine Species Information System, (NEMESIS), relational database compiles detailed information on approximately 500 different non-native species of plants, fish, invertebrates, protists and algae that have invaded coastal U.S. waters. The database identifies which species have been reported, their current population status (i.e., whether established or not), as well as when, where, and how they invaded; it also summarizes key information on the biology, ecology, and known impacts of each invader, http://invasions.si.edu/nemesis/databases.html;
- Northeast Aquatic Nuisance Species, (NEANS), Online Guide provides information about invasive species that threaten northeastern North America to allow the creation of customized field guides, http://www.northeastans.org/online-guide/;
- PetWatch provides consumers with a science-based list of the Best, Fair and Worst choices of exotic pets based on extensive research aimed at protecting native wildlife and resources, global biodiversity and public health, http://www.petwatch.net/browse_animals/;
- USDA National Invasive Species Information Center is a reference gateway to information, organizations, and services about invasive species including summaries of state laws and regulations, http://www.invasivespeciesinfo.gov/laws/statelaws.shtml;
- USFWS Law Enforcement Management Information System, (LEMIS), investigative case tracking system collects AIS information (link available to authorized USFWS personnel); and
- USGS' Non-indigenous Aquatic Species database (NAS) is a national database providing real-time occurrence data within the United States of non-indigenous aquatic species observations and collections, http://nas.er.usgs.gov/.

All of these databases have valuable features but there is no single centralized database that provides all the information needed to manage AIS. It would be valuable to have one central location for the information.