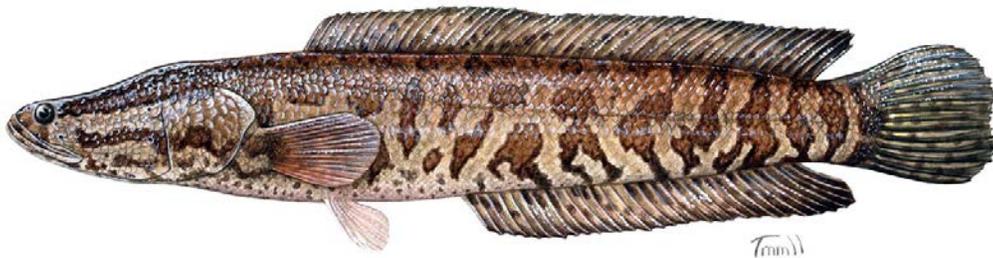


**National Control and Management Plan
for
Members of the Snakehead Family (Channidae)**



Drawing by: Susan Trammell

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

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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 snakeheads into other waterways. The northern snakehead is a popular food fish in its native Asia that 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 are known to exist in Hawaii and Florida, respectively. Then in 2002, a population of northern snakeheads was discovered and later eradicated in a small pond in Crofton, Maryland. Just two years later, in 2004, an additional population of northern snakeheads 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 (above Washington, D.C.) downstream to the mouth of the river. It was initially thought higher salinity in the lower Potomac River and Chesapeake Bay would prevent snakeheads from escaping the river into other Bay tributaries. This assumption no longer appears valid as northern snakeheads have been captured in several other tributaries of the Chesapeake Bay as of June 2012. Other populations of northern snakeheads have been found in the states of New York, Arkansas, Delaware, New Jersey and Pennsylvania. Because eradication attempts have had varying degrees of success, a goal of this management plan is to help guide management of invasive snakehead species where present and 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 (2006) of the 109th 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 ANSTF update the SCMP to include, based on Herborg et Al., 2007, pp1727, 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 building off of existing research and plans: the most relevant information about snakehead management and control is included in this document.

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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 snakeheads already established in U.S. waters as well as prevent the further spread and introduction of this fish into other waterways.

Snakeheads are a popular food fish in its native Asia. Over the past two decades, they have been imported into certain ethnic markets in the U.S. for the live-food fish market. This potential pathway for introduction to the wild was largely overlooked. Then 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 but there was no indication of reproducing populations. However, in 2002, a self-sustaining population was discovered and later eradicated in a small pond in Crofton, Maryland. Subsequently, northern snakeheads were discovered in the main-stem tidal freshwater Potomac River in the vicinity of Mount Vernon, Virginia, in May 2004 where the population has since increased rapidly in range and abundance.

Congress requested that the USFWS address concerns about the introduction of the northern snakehead. Senate report 108-341, Department of the Interior and Related Agencies Appropriations Bill of the 109th Congress states, “The Committee is concerned by the recent discoveries of northern snakeheads 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 U.S. Fish and Wildlife Service 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) in 2006 to provide input on the development of a SCMP. The intent of the SCMP is 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 is 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. In addition to the report, 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 Chinese, blotched, giant, spotted, golden, bullseye, chevron, Niger, northern, and rainbow snakeheads. Due to little or no information available on seven of these species, only three are focused on here and they include: giant, bullseye, and northern snakeheads.

Twenty-seven individuals from federal, state, academia, and NGO's volunteered to serve on a committee to develop a SCMP. The SCMP Development Committee first met by teleconference February 9, 2012. The following six subcommittees were established:

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

The goal of this SCMP is to use sound science and management to prevent future introduction of snakeheads into new areas, contain and where possible remove all newly established and or 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. Prevent further range expansion of northern snakeheads within the U.S. by controlling the spread of established populations, and eradicating outlying established populations.
3. Conduct research to better understand the pathways of spread (i.e. cultural, black market, and food fish) and impacts of snakeheads on native and/or beneficial naturalized aquatic organisms.
4. Conduct research to develop more effective surveillance, control and eradication methods.
5. Establish an effective surveillance program for snakeheads in U.S. waters to detect new introductions while populations are able to be contained and removed.
6. Develop long-term adaptive management options to mitigate potential impacts of snakeheads in U.S. waters where eradication is not possible.
7. Develop outreach or education plans and tools to prevent new introductions of snakeheads within the U.S. and control the anthropogenic spread of established populations.
8. Review and assess progress of the SCMP.

Biology, Natural History, Ecological and Environmental Impacts of Snakeheads

Snakeheads (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 (to date) for all snakehead species. 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 and/or historical occurrence. Most snakeheads have limited colonization potential in the United States due to their thermal tolerances. The northern snakehead is the exception, and the majority of the following narrative will be allocated to this species due to its established populations and 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 established populations in the U.S. There is limited information on most other species and they are less likely to become established in the U.S. Consequently, they are not covered in this document.

Northern Snakehead

The 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 establishment in ponds, rivers, and reservoirs of present day Kazakhstan, Turkmenistan, and Uzbekistan in the early 1960s may have been accidental, with shipments of Asian carps contaminated with snakeheads (Courtenay and Williams, 2004). Within its native (Berg, 1965) and introduced range, with the exception of Japan, it 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, it is the most important snakehead species cultured (Courtenay and Williams, 2004) where it is grown in ponds, rice paddies, and reservoirs (Atkinson, 1977; Sifa and Senlin, 1995 as cited in Courtenay and Williams, 2004; Liu et al., 1998).



In major cities such as Calcutta, Bangkok, Singapore, and Hong Kong, northern snakeheads 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 snakeheads are usually killed just prior to preparation and cooked 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 snakeheads 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 snakeheads are golden tan to pale brown in color with 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 is 870 mm TL (J. Odenkirk, unpublished data). 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 and 2012).

Northern snakeheads reach sexual maturity at 2 to 3 years of age and approximately 300-350 mm TL but may mature at an earlier age in North America (J. Odenkirk, VDGIF, personal communication). Females produce eggs 1 to 5 times per year and release 22,000-51,000 eggs per spawn (Frank, 1970; Nikol'skii, 1956). Dukravets and Machulin (1978) documented fecundity rates that ranged from 28,600-115,000 for northern snakeheads introduced to the Syr Dar'ya basin of Turkmenistan/Uzbekistan. Their eggs float and take approximately 28 hours to hatch at 31°C and 45 hours at 25°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), cited by Courtenay and Williams (2004), reported that an accidentally introduced

population of northern snakeheads fed on crustacean zooplankton and chironomid larvae in their first month of life. At 40 mm TL, they began to feed on fish and then at 130-150 mm, fishes comprised 64-70% of the diet. Juveniles up to 300 mm TL fed almost exclusively on fish. Juvenile northern snakeheads 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, and beetles as well as 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 219 northern snakehead stomachs 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 snakeheads in the Potomac River with fundulid and centrarchid species consumed most frequently. In the Syr Dar'ya basin, Dukravets and Machulin (1978) reported that northern snakehead fed on 17 species of fish, including young and fish 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 snakeheads only feed from late March to October with 45.1% of their annual food consumption completed by May, another 46.4% of annual consumption occurring in June and July, and only 4.6% in 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 carp, grass carp, bream, zander, and catfish (Guseva, 1990). Snakeheads assumed vacated predator niches due to anthropogenic factors and displaced native pike and catfish in the basin (Guseva, 1990).

Northern snakeheads prefer stagnant shallow ponds or swamps with mud substrate and vegetation, 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 snakeheads are typically found in shallow water with floating and emergent vegetation (Odenkirk and Owens, 2005; Lapointe et al., 2010) and 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). Northern snakehead survived acclimatization experiments in outside ponds in Czechoslovakia where severe winter temperatures dipped below -22°F for some 4 weeks (Frank, 1970). The species is an obligate air-breather; therefore, survival in low oxygen waters is possible (Courtenay and Williams, 2004). During cold temperatures, northern snakeheads have a reduced metabolism and oxygen demand, which allow them to survive under ice (Frank, 1970).

The USFWS and Maryland Department of Natural Resources (MDNR) conducted several experiments at the Joseph Manning Hatchery to examine salinity tolerances of northern snakehead. In trials that were conducted at lower temperatures (15-20° C), snakeheads exhibited increased tolerance to salinity. However, the upper tolerance level remained at 18 ppt (S. Minkinen, USFWS, personal communication, 2012). The capture of a

snakehead in a pound net in Chesapeake Bay near St. Jerome's Creek in May 2010 confirmed northern snakehead's tolerance of elevated salinity, as surface salinities at the mouth of the Potomac ranged between 10 and 12 ppt. Snakeheads 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 snakeheads into the Chesapeake Bay and other tributaries.

There is little information in the scientific literature about effects of northern snakeheads on other aquatic organisms. The predatory nature of northern snakeheads suggests their introduction could affect other 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 snakeheads became established in waters with low diversity of native and/or naturalized fishes and low abundance or absence of other predatory species. These impacts could include adverse effects on endangered and threatened species. Of the taxa listed as endangered and threatened in U.S. aquatic habitats, 16 amphibians, 115 fishes, and 5 of the 21 crustaceans (surface-dwelling crayfish and shrimp), would be the most likely affected (Courtenay and Williams, 2004). Based on habitat requirements and life history, fishes are most likely to be affected. However, the addition of a predator in the aquatic community with any listed amphibian or crustacean could represent a significant threat to a listed 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), although 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 snakeheads appeared to have similar habitat and feeding preferences as recreationally important species such as largemouth bass (*Micropterus salmoides*). Analysis of stomach contents of northern snakeheads 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 (i.e., competition) of largemouth bass and northern snakehead increased.

A small population of northern snakeheads established in two connected lakes in New York City remained at low levels since a study began in 2006, and abundances of coexisting fish populations were unchanged (Cohen et al. 2012). Thus, it currently seems

impossible to predict ecological and economic impacts of northern snakeheads on recreational and commercial fisheries, although they could prove substantial over time.

Giant Snakehead

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), but believed to be 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 growing giant snakeheads 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, 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 other *channids*; they clear out vegetation in a circular area to spawn and their pelagic eggs then rise to the surface and are guarded by parents (Lee and Ng, 1991).

The giant snakeheads are mainly a daytime feeder (Ng and Lim, 1990, cited by Courtenay and Williams, 2004). It is a vicious predator of fishes 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/subtropical species is extremely limited to where it could potentially establish a viable population in the United States. Freshwater habitats in southern Florida and Hawaii are the only suitable climates for giant snakeheads 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 (*Micropterus salmoides*) ever caught in Florida. Their aggressive nature could allow them to out compete native and/or naturalized fishes for food and habitat. The potential impact to the Florida economy is significant. According to a U.S. Fish and Wildlife Service report (2006), freshwater fishing is a 2.4 billion dollar per year industry in Florida.

Bullseye Snakehead

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 18 cm TL, there is a

distinctive orange ocellus spot 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 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 reaches 30 cm TL in one year, and a maximum TL of 120 to 122 cm (Bardach et al. 1972; Talwar and Jhingran, 1992 as cited by Courtenay and Williams, 2004). Although maximum sizes have been reported up to 180 cm TL and weight of 30 kg (reported from Maharashtra State, western India) (Talwar and Jhingran, 1992 as cited by Courtenay and Williams, 2004), this has been disputed (Pethiyagoda and Musikasinthorn, personal communication, 2002, in Courtenay and Williams 2004) as the bullseye snakehead is fast-growing, identified as one of the two fastest growing snakehead species (Wee, 1982), with the greatest increase in weight occurring in year two and slowing with increasing age. While young bullseye snakeheads are facultative air breathers, 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 and may also occupy areas of flooded forests and deeper 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 snakeheads, such as northern snakehead into the United States.

Gut content analysis of adult bullseye snakehead in West Bengal, India reported stomach contents consisting primarily of fishes (40%), followed by crustaceans (30%), macrophytes (15%), larval insects (10%), and algae (5%) (Dasgupta, 2000). Other dietary analysis of the bullseye snakehead from the River Kali in northern India indicated that more than 60% of prey consumed was represented by fishes, 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, 2006). It has been cultured in ponds, rice fields, and other water bodies that do not typically support fishes, 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); it has 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 snakeheads are known in the aquarium trade as both “giant snakehead” and “cobra snakehead.” However, 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 *C. marulius* into Broward County, Florida, may be the result of an intentional release of an aquarium specimen into a water body. Specimens of bullseye snakeheads have been found at aquarium stores in the United States and Canada, which indicates that the species is able to be obtained commercially despite restrictions in the U.S. and in some Canadian provinces (Courtenay and Williams, 2004).

The invasion of the bullseye snakehead could produce negative impacts to native fishes through predation. It also could impact native and naturalized populations of fishes, as well as crustaceans, insects and other biota. Social impacts could include disruption of existing commercial and recreational fisheries, although new recreation and/or commercial fisheries could develop. Negative environmental and social impacts are possible with the introduction of the bullseye snakehead, but after a decade of establishment in south Florida, no negative impacts to aquatic species have been attributed to its presence (K. Gestring, Florida Wildlife Commission, personal communication).

Regulation of Snakeheads in the U.S.

In October 2002, the USFWS listed 28 species of snakeheads, including the northern snakehead, as injurious wildlife under the Lacey Act (18 U.S.C. 42). That listing prohibits the importation and interstate transportation of the 28 snakehead species. However, because the Lacey Act is a federal law, it does not regulate intrastate possession, transportation, or sale. Maximum criminal penalties under the Lacey Act are five years in prison and a \$250,000 fine for an individual and a \$500,000 fine for an organization. The USFWS also has import declaration requirements under 14 CFR 14.61, which requires among other things that wildlife listed as injurious must be declared to the USFWS when imported.

The USFWS has expanded surveillance and enforcement of illegal transportation of federally listed invasive species. Wildlife inspectors have increased their efforts to target and interdict federally listed invasive species at border locations. In addition, 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 snakeheads, through domestic interstate investigations.

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

Snakeheads are legally managed to some extent in every state in the U.S. 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 snakeheads in 1983 and most recently the District of Columbia specifically restricted the possession of the snakeheads 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 snakeheads 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 snakeheads in fish markets or pet shops. Nebraska has not had any snakehead incidents since.

Introduction of Snakeheads into U.S. Waters

Northern snakeheads 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, snakeheads 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 snakeheads imported into the U.S. until 2001 (Courtenay and Williams, 2004). Other species imported since 1999 include Chinese (*Channa asiatica*), dwarf (*Channa gachua*), blotched (*Channa maculata*), chevron (*Channa striata*), giant (*Channa micropeltes*), striped (*Ophicephalus striatus*), and Congo (*Parachanna insignis*), (USFWS, 2012). These species were most likely imported for the live food fish market, fish farming, 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 snakeheads was illegal. Although import records are incomplete and not detailed, it is evident that from 1997 to 2002, imports of live snakeheads into the U.S. increased (Table 1) and that China was the biggest exporter of live snakeheads (Table 2).

Since the addition of the Channidae family of snakeheads under the prohibitions of the Lacey Act in 2002, the USFWS Office of Law Enforcement has continued to seize illegal shipments of snakeheads imported to the United States. As recently as August 2010, 2800 snakeheads were seized and destroyed at a New York port, and in February 2011 a shipment of over 350 Chinese snakeheads (*Channa asiatica*) were seized at an airport in New York (USFWS, 2011). The Lacey Act does allow permitted access of snakeheads for medical, scientific, educational and zoological reasons. Since 2002, seven permits have been issued allowing snakeheads 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 snakeheads (Channidae, Ophicephalus, Parachanna, all species) during 1997-2010.

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	<i>725</i>	<i>3</i>	<i>--</i>	<i>445</i>
2004	<i>172</i>	<i>3</i>	<i>--</i>	<i>1,031</i>
2005	<i>601</i>	<i>4</i>	<i>--</i>	<i>4,731</i>
2006	<i>0</i>	<i>0</i>	<i>--</i>	<i>0</i>
2007	<i>0</i>	<i>0</i>	<i>--</i>	<i>0</i>
2008	<i>6</i>	<i>1</i>	<i>--</i>	<i>8</i>
2009	<i>276</i>	<i>2</i>	<i>--</i>	<i>484</i>
2010	<i>2,800</i>	<i>3</i>	<i>--</i>	<i>796</i>
Totals	86,058	316	40,554	\$177,927

Note: Values in italics for years since late 2002 were seized and not allowed into the U.S. (USFWS, 2012).

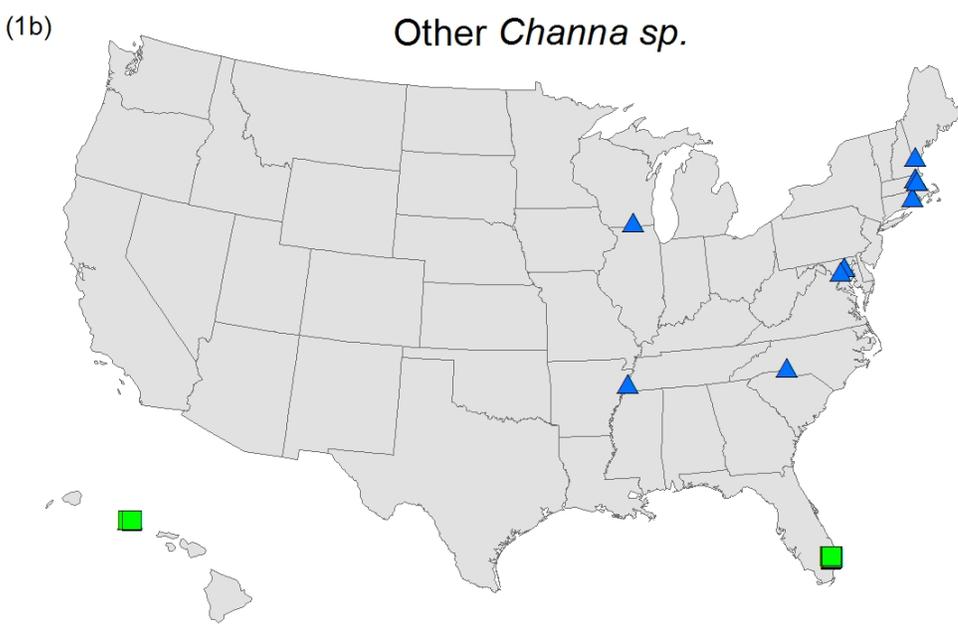
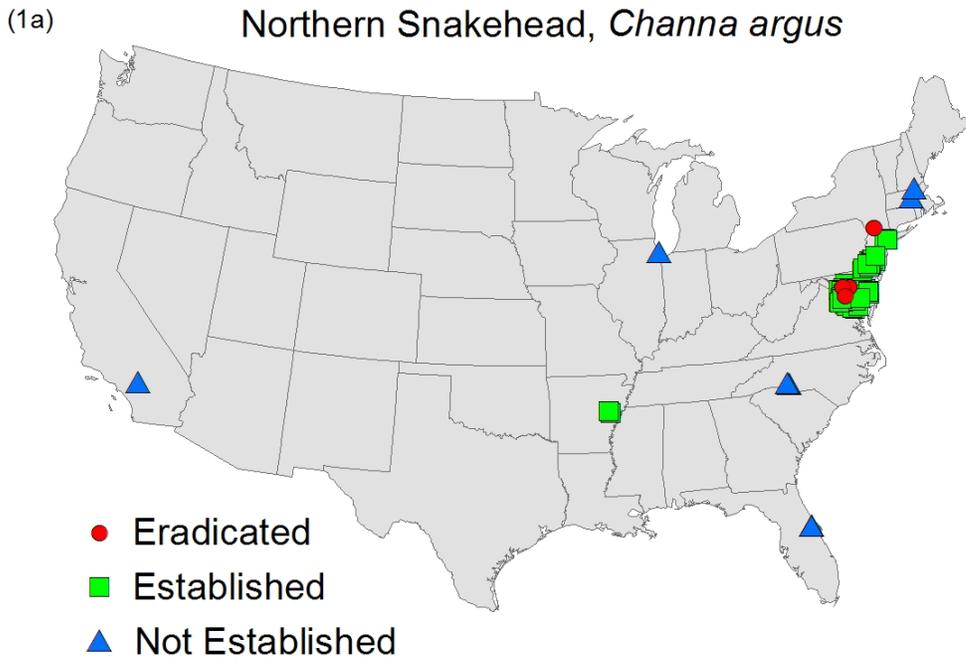
Table 2. Origin of snakehead shipments (Channidae, all species) for 1997-2010.

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

Note: This includes seized shipments (USFWS, 2012).

Northern snakeheads are the most widely cultured snakehead species in China and live fish were imported for sale in Asian live food fish markets in New York City, New York, and St. Louis, Missouri, (Courtenay and Williams, 2004) until they were prohibited by the Lacey Act in 2002. Courtenay and Williams (2004) obtained live specimens from fish markets in New York City, New York; Houston, Texas; Pembroke Pines, Florida; and Orlando, Florida. Prior to the prohibitions under the Lacey Act, live snakeheads were purported to have been available in live fish food markets and restaurants in Washington, D.C., northern Virginia, and Maryland.

The first report of a northern snakehead in the U.S. was in Silverwood Lake, California, on October 22, 1997, (Figure 1a and 1b). The fish was collected by California Department of Fish and Game personnel by electrofishing (Courtenay and Williams, 2004). It is unknown whether the 71 cm specimen was purposefully released in the lake or whether it arrived through the California aqueduct. No more have been documented in California to date. Both the bullseye snakehead in Florida and the blotched snakehead in Hawaii are believed to be the result of food fish releases from live fish markets.



Source: U.S. Geological Survey, October 2012

Figure 1a and 1b. Snakehead locations in the United States. Source: U.S. Geological Survey

Figure 1a and 1b. Figure 1a 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 1b 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 snakeheads were caught in 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-inch northern snakehead was caught by an angler in a small pond in the town of Crofton (Figure 2). 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 was later confirmed by an expert. On June 30, 2002, another angler caught a 26-inch snakehead from the same pond and dip netted eight juvenile snakeheads on July 7 and 8. MDNR personnel then captured in excess of 100 young-of-the-year snakeheads by electrofishing the pond. They were positively identified as northern snakehead. Subsequently, the pond was treated with rotenone in September 2002 to eradicate the established population. During the eradication effort, over 1,200 snakeheads 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.

There have been several captures of either one or two northern snakeheads in the U.S. that appear to be releases of individual fish, with no indication of a reproducing population. Capture sites include the states of California (1), Florida (2), Illinois (1), and Massachusetts (2). In North Carolina, two anglers reported catching two northern snakeheads 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 snakeheads (Courtenay and Williams, 2004). However, anglers caught another northern snakehead in the same reservoir in 2007 and a blotched snakehead (*C. maculata*) was caught in 2009.

In May 2004, northern snakeheads 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 2), 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 snakeheads 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 snakeheads from Meadow Lake, a 17-acre park lake in Philadelphia, Pennsylvania (Figure 2). The fish were later identified as northern snakeheads and a total of six were captured from the lake. In 2005, sampling efforts resulted in the capture of several size-classes of snakeheads, including juveniles (R. Horwitz, Pennsylvania Academy of Natural Sciences, personal communication). Meadow Lake is part of a maze of interconnected embayment's and tidal sloughs. Given the openness of the system, Pennsylvania Fish and Boat Commission (PRBC) biologists concluded that the fish had probably accessed adjoining waters of the nearby lower Schuylkill and Delaware rivers. As a result, PRBC biologists decided that they would monitor the pond and surrounding waters but would not attempt to eradicate the species (Pennsylvania Fish and Boat Commission press release, July 23, 2004). There have been confirmed reports of snakeheads from the Schuylkill River and the Delaware River and its tributaries in New Jersey.

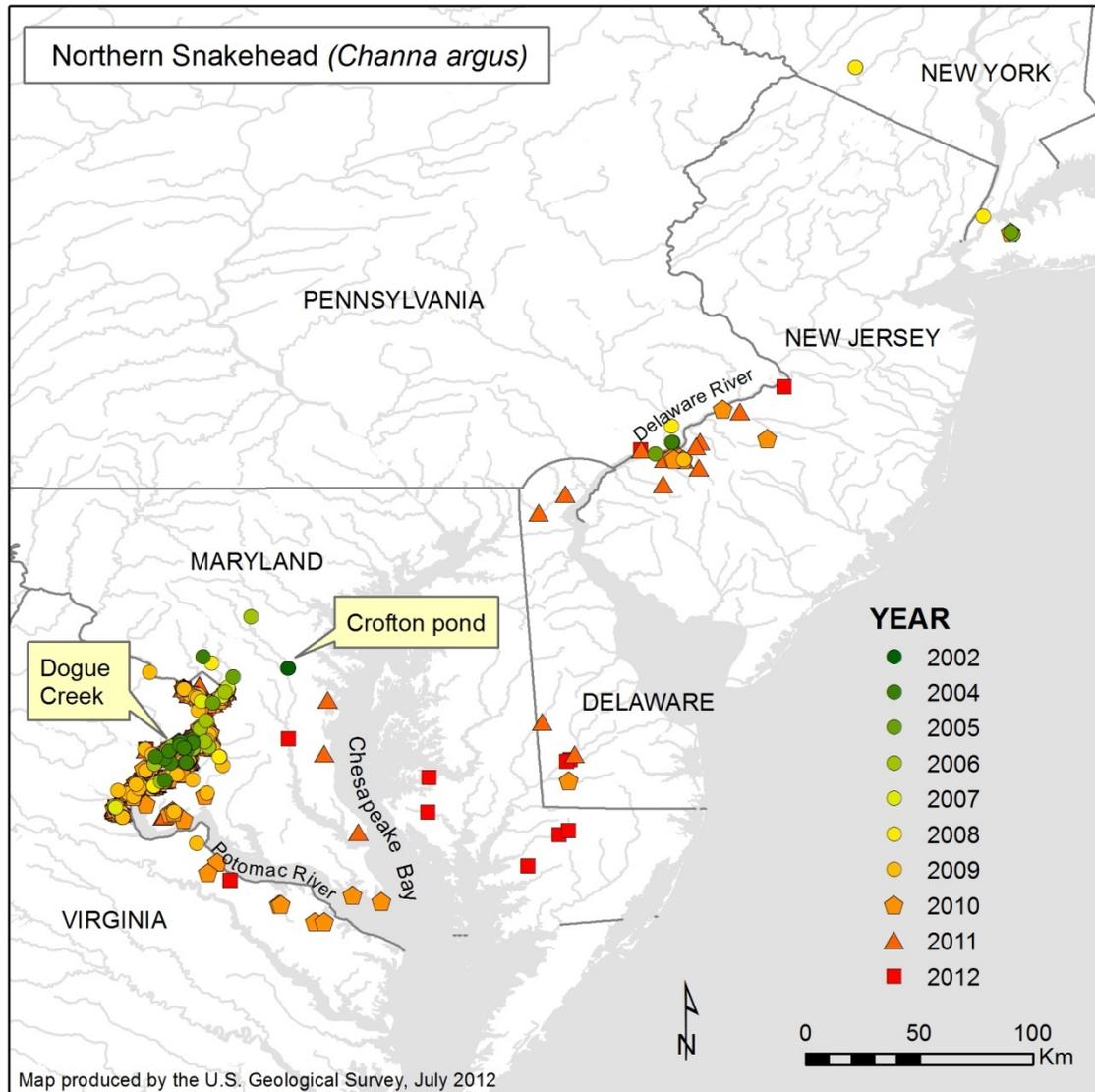


Figure 2. Locations of northern snakehead collections and observations in the Mid-Atlantic region of the U.S. Crofton pond in Maryland was the first documented location of northern snakehead in the region. Dogue Creek in Virginia is believed to be the point of introduction of the Potomac River population.

In 2005, four northern snakeheads were found in two park ponds in Queens, New York (Figure 2). These ponds appear to have an established population of northern snakehead that has been contained to prevent infiltration to other waterways. About 50 miles to the northwest in upstate New York, more northern snakeheads 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, a fish toxicant. More than 200 northern snakeheads 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 snakeheads 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 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 snakeheads 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 snakeheads 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 snakeheads 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 illegal stocking, but genetic testing may yield some insight.

In the U.S., three fish farms in Arkansas cultured northern snakeheads until importation, culture, sale, and possession of snakeheads 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 1a), 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 50,000 acres of the watershed. The area was resampled after the massive eradication attempt and additional live northern snakeheads were found. Currently, northern snakeheads still inhabit the Big Piney Creek watershed, and several have been found outside of this watershed. Widespread flooding in the spring/summer of 2009, 2010 and 2011 has 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 snakeheads. However, at this time due to the new labeling of powdered rotenone by the EPA, the relative ease of use is compromised and has greatly slowed and restricted their control efforts.

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 snakeheads. 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 snakeheads were reported from Delaware in 2011 and 2012. In 2011, two snakeheads 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 snakeheads are spreading throughout much of the Chesapeake Bay. In 2012, confirmed reports of northern snakeheads 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 snakeheads were confirmed by Virginia Division of Game and Inland Fisheries (VDGIF) in from July to September 2012 (J. Odenkirk, VDGIF, personal communication, 2012).

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

Snakeheads 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 snakeheads 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 snakeheads were smuggled into the country to supply a live fish food market. In addition, snakeheads 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 snakeheads 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 snakeheads could increase the potential for introductions into interconnected 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 would be by humans considering that larger species of snakeheads are popular with anglers in several locations within their native and introduced ranges (Courtenay and Williams, 2004) or 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.

Mitochondrial sequence variation was examined in northern snakeheads 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 29 specimens studied, with no haplotype shared between areas of introduction. This indicates that there were several separate introductions of northern snakeheads 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 snakeheads, 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 delimitations 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 snakeheads 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 (e.g. Jerde et al., 2011; Ficetola et al., 2008 as cited in Courtenay and Williams, 2004) may provide a secondary more sensitive detection method to confirm population status of outlying records.

Dispersal of Recently Established Populations in the Mississippi River

In regards to the Arkansas northern snakehead population, and subsequently the Mississippi River Basin, the potential for natural spread is great. Considering that since the initial 2008 discovery of northern snakeheads 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 snakeheads 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 indicates that this is entirely true, preliminary analysis and general observations do appear to show that these fish will migrate upstream more readily than downstream. However, occasional specimens were 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. 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 snakeheads prefer stagnant, vegetated back-water areas and do not readily reside in the main channel of streams and rivers. The most utilized waters by northern snakeheads 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 snakeheads 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 in Crofton with the use of rotenone, and from Pine Lake in Wheaton by dewatering using a pump. Eradication will be nearly impossible and control efforts challenging in large lakes or riverine systems where snakeheads 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. 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 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 50 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 snakeheads at low concentrations in open systems; however, it has killed northern snakeheads 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 snakeheads may be available. For example, the use of eDNA may aid in the detections of snakeheads within a system where sampling for snakehead presence is impractical.

In the absence of control, snakeheads are likely to spread, depending on the hydrology of the system. Within the Potomac River drainage, northern snakeheads spread rapidly throughout most of the drainage within 7 years. This is roughly the same timeframe that Arkansas Game and Fish Commission estimate that snakeheads colonized approximately 700 km of streams and ditches within the Big Piney Creek watershed. Control should be a priority 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 snakeheads 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. 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 snakeheads 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 snakeheads. Therefore, each instance where snakeheads are managed will be unique as to whether the costs of control outweigh the presence of snakeheads.

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 the 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 snakeheads are more easily captured by electrofishing due to limited movement of adults (Lapointe et al., 2010). More specifically, snakeheads 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 snakeheads 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 snakeheads are prohibitive, then encouraging commercial fisheries harvest could be an alternate option. However, some states do not allow the possession or sale of snakeheads, dead or alive. In Maryland, the commercial sale of snakeheads 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 snakeheads 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 snakeheads is becoming popular. In June 2012, a recreational fishing tournament was held, and in only 18 hours, over 200 snakeheads 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 snakeheads, 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 snakeheads need to be eradicated or controlled, especially in areas where endangered species or other federal interests may be encountered. Public outreach and education should also be a key component in any management effort.

Early Detection and Rapid Response (EDRR)

Surveillance and Site selection

Vander Zanden and Olden (2008) provide guidance on how to identify priority sites for snakehead surveillance. Because importation is prohibited and there is an effective pre-border import surveillance program, it can be assumed that there is a low probability for further introductions into the U.S. Accordingly, site selection should focus on the potential for secondary spread, habitat suitability, and likelihood of adverse impacts. The later not only needs to consider the presence of vulnerable high value species (e.g. threatened species or commercial fisheries), communities or ecosystem services, but also whether that site could facilitate or accelerate secondary spread (Worrall, 2002). Forecasting the potential for secondary spread will require a spatial assessment of human mediated pathways of invasion, the snakeheads ability for natural spread, and data on site suitability and values.

The identification of high priority sites for snakehead surveillance requires identification of the likely pathway points of greatest probability of introduction. The identification of high priority sites would also necessitate the compilation and location of sites vulnerable to invasion that contain irreplaceable assets (e.g., fisheries, threatened species).

Sampling effort – and periodicity

Detecting an incipient invasion is often challenging when the target species is often rare or elusive; however this action is best achieved by either increasing sampling effort or adopting highly sensitive surveillance methods (McDonald, 2002). How often a site should be sampled will also require an understanding of the propagule pressure, (how many snakehead are likely to be introduced and how often), 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 snakeheads and help guide response actions.

Current detection methods for snakeheads 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 snakeheads are rare (*someone, personal Communication, or report*). Spot treatment of sites suspected to contain snakeheads 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 as cited in Courtenay and Williams, 2004; 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 it is able to detect the presence of eDNA in the water when fish populations are at very low levels (Jerde et al., 2011). However, while there is increasing evidence that the rate of detection is correlated with fish abundance (Thomsen et al., 2012), there can still be a lack of acceptance and agreement on how the positive detection of eDNA should be interpreted (see Darling and Mahon, 2011). A positive eDNA result is still largely an indication of presence/absence, and repeated sampling that produces positive detections, and systematic consideration of potential alternate sources of eDNA is required to determine whether the results indicates the presence of live fish. 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, all methods of eDNA should be considered in conjunction with other surveillance methods.

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 any action taken or operation implemented in response to a trigger being met as defined by the lead jurisdiction authority. One potential 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 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 being brought to bear 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.

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

One or more of the above thresholds may illicit various levels of response 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 shall begin 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, rapid response operations phase, will be 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 response may be necessary 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. Increased 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 as time allows.
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. Initial follow-up monitoring of area for snakeheads utilizing electrofishing, netting, eDNA analysis, and/or sentinel fish.

Other actions may be necessary in conjunction with a rapid response operation to ensure control and halt of the spread of snakeheads. These actions may include but are not limited to the following:

- Seine/block off netting during operations to further isolate treatment area
- Closing of structures such a sluice gates, dams, or navigable waterways where possible to prevent escape of fish during treatment
- Sentinel monitoring to ensure treatment efficacy.

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 dose achieved
- Dose timeline complete
- Negative result of sentinel monitoring within the treatment area for snakeheads
- 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. Components of the Recovery Phase are as follows:

1. Continued follow-up monitoring efforts
2. Cleanup and disposal of all recovered fish and bio-mass from the treatment area
3. Demobilization
4. Determination of capture and document costs
5. Preparation of an AAR
6. Preparation for future rapid response based on AAR, lessons learned, and continued training and exercises.

Mobilization 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 program Improvement Plan (IP)
3. Personnel training and rapid response exercises
4. Increase response capacity and capabilities.

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 snakeheads will be valuable to any agency in charge of snakehead management.

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

Creel surveys along the Potomac River tributaries were conducted in 2008 in Virginia 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 snakeheads, and examine catch rates of species that may be negatively impacted by the presence of snakeheads such as largemouth bass. Catch rates of northern snakeheads 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 snakeheads 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 snakeheads 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 snakeheads 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 1,133 northern snakeheads were tagged in the Potomac River. Of these tagged fish, 96 were recaptured by both state or federal agencies and recreational anglers. The majority of recaptured northern snakeheads (approximately 90%) remained in the creeks where they were initially tagged. This suggests that many individuals in the population do not move far 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).

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 for 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 opportunities for stakeholder involvement. This website offers information regarding all aspects of the snakehead management actions and includes links to other important federal, state, and other relevant actions and information. Outreach and communication actions should focus on establishing primary contacts, web links, news releases, and media events.

Efforts start with engaging key outlets and audiences. This plan discusses utilizing the media (newspapers, radio stations, website) to effectively communicate what penalties are associated with introduction, transport, and live possession of snakeheads. Although there are many potential audiences, this plan encourages the most outreach effort to target angler and enforcement officer audiences. This starts with engaging key outlets and audiences. In the table below, key outlets and audiences for outreach activities are included. These outlets are not ranked.

Key Outlets and Audiences for Outreach Activities	
Outlet	Audience
Academia and Research Community	Schools / Students Universities
Commercial and Recreational Baitfish Harvesters	Trade associations
Commercial Fishers	Trade associations
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 Nongovernmental 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 Marine Trade Associations Trout Unlimited
Transporters	Consumers Fish farms Live haulers

Posters or brochures should focus on stewardship, health issues, and regulations and penalties associated with live possession of snakeheads. Such outreach products should be in several different languages and target boat ramps, fishing license holders, cultural festivals, and bait and tackle shops. There should be added research to identify ethnic groups that purchase and release species as part of their cultural practices. This research will assist in the development of targeted multilingual outreach products.

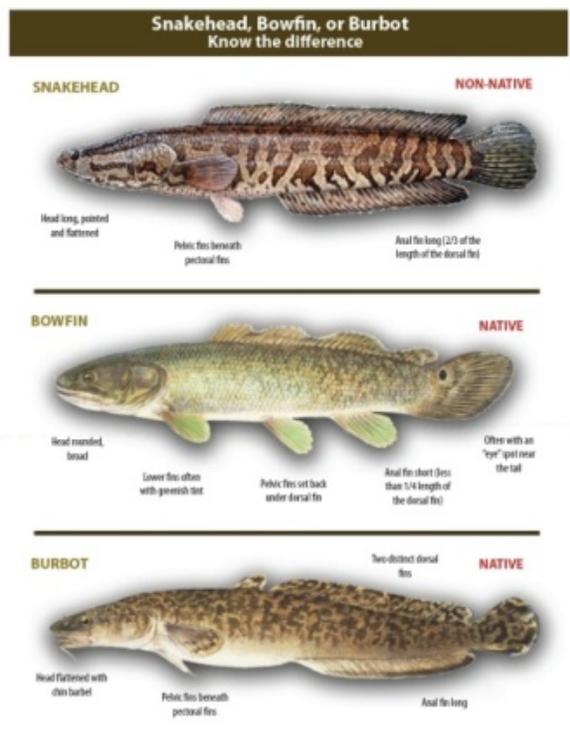
It is critical to notify the public and all appropriate stakeholders if there is detection of a live snakehead. Each jurisdiction should have one point of contact for the press to ensure a correct and consistent message. Contact information and other general information about snakeheads could be developed and posted on the snakehead website as part of a press kit for jurisdictions. The public can report a sighting at 1-800-STOP-ANS.

There should be regular news releases and media events about the snakehead and other regional invasive species. These actions will bring attention to invasive species issues and highlight the activities of the Aquatic Nuisance Species Task Force.

Preventing and detecting the invasion of snakeheads into native waters starts with education of the public, specifically fishermen. Education of anglers and the public could be undertaken with a short, concise and easily understood pamphlet or information card. These cards and pamphlets could be made available to the public, and handed out to fishermen each time a fishing license is sold or a boat is registered.

This education material would notify anglers of the potential for snakeheads to invade native waters and give the angler the capability to identify a snakehead should one be caught. Included on the pamphlet should be phone numbers and contact information for the agencies involved with non-indigenous species management. As an example, the New York Department of Environmental Conservation has created a poster with this information including contact information.

Educating the public is very important, especially because people often move and transport fish. Larger species of snakeheads are popular with anglers in their native and introduced ranges; therefore, the probability of anglers



transporting snakeheads to new locations is real. The ability to breathe air and survive transport by air overland in moist conditions facilitates intentional introductions by anglers.

Outreach materials created to assist the public with identification of snakeheads should be developed in a simple, effective way so that the public can easily identify snakeheads from other similar looking native species. All of these materials should be posted on the snakehead website.

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

There should be an increased network to distribute scientific literature on pathways and non-native fish species. Sharing scientific research results will improve our understanding of snakehead populations and control methods and improve our ability to implement the actions in this SCMP and future plans. This will support further development of outreach materials that focus on introduction through specific pathways to prevent future introductions of snakeheads or other new species.

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 the snakeheads, 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://glmr.is.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. Snakeheads 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 authorize USFWS personnel); and
- USGS' Nonindigenous Aquatic Species database (NAS) is a national database providing real-time occurrence data within the United States of nonindigenous 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.

Objectives and Action Items for SCMP Implementation

Action Items	
Objective	Item
<p>Objective 1. Prevent new introductions of snakeheads within the U.S. and control the spread of established populations.</p>	<p>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.</p> <p>1.2) Promote the enactment of clear, effective, consistent, and enforceable regulations and statutes among bordering or shared jurisdictions that include substantial penalties for violating those statutes.</p> <p>1.3) Identify, understand and characterize all vectors of spread and quantify / assess their relative risk of contributing to range expansions of snakehead. .</p> <p>1.4) Identify management, outreach, and enforcement options available to reduce the risks associated with each identified vector.</p> <p>1.5) Obtain information on life history and biology of snakeheads in its native environment and in U.S. waters to better predict where the species could become established.</p> <p>1.6) Through genetic analysis determine source regions of established populations.</p> <p>1.7) Develop approaches to prevent importation from source regions, including improved border surveillance methods.</p> <p>1.8) Establish status of all historic records of snakeheads outside known established range.</p> <p>1.9) 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.</p> <p>1.10) Ensure all sources of snakeheads in the U.S. are contained and the risk of natural and anthropogenic spread is minimized.</p>
<p>Objective 2. Establish an effective snakehead surveillance program within the U.S.</p>	<p>2.1) Develop an information system via the web or protocol to notify other jurisdictions of sightings of snakeheads.</p> <p>2.2) Identify legal barriers in jurisdictions that would prevent rapid response efforts from occurring.</p> <p>2.3) Enact legislation in jurisdictions that allow the appropriate agency access on public/private property and interjurisdictional waters to assess a potential introduction, implement control methods.</p> <p>2.4) Recommend that jurisdictions develop a rapid response plan for snakeheads.</p> <p>2.5) For those jurisdictions that have developed rapid</p>

	<p>response plans, obligate funding or identify sources of funding for rapid response.</p> <p>2.6) Undertake research to identify the most effective and sensitive surveillance methods and develop guidelines for snakehead detection and surveillance programs including descriptions of monitoring methods best practice.</p> <p>2.7) Undertake research to quantify effectiveness of all containment methods that prevent spread from infested areas and develop containment guidelines to prevent spread from infested areas.</p> <p>2.8) Identify trained and knowledgeable individuals to respond to new introductions of snakeheads within their jurisdictions.</p> <p>2.9) Incorporate monitoring for snakeheads into other existing aquatic surveys in jurisdictions.</p> <p>2.10) Establish a network of surveillance monitoring stations at priority sites highly vulnerable to northern snakehead invasion.</p>
<p>Objective 3. Contain and eradicate newly discovered populations of snakeheads.</p>	<p>3.1) Compile a list of existing control options for eradication; develop guidelines of best practice and regulatory requirements.</p> <p>3.2) Test the efficacy of eDNA detection methods,</p> <p>3.3) Petition EPA to develop special use permit for new rotenone label to address snakehead control.</p> <p>3.4) Conduct research to develop additional control strategies for eradication.</p> <p>3.5) Evaluate ecological and economic impacts of eradication.</p>
<p>Objective 4. Mitigate impacts of snakeheads in U.S. waters where eradication is not possible.</p>	<p>4.1) Determine ecological and economic impacts of control methods on other species.</p> <p>4.2) Determine effectiveness of control options for long-term management in different systems.</p> <p>4.3) Conduct studies to understand life history traits, biology, and behavior to inform long-term control options.</p> <p>4.4) Conduct research to develop additional control methods including integrated approaches using multiple methods.</p> <p>4.5) To prevent further introductions continue effective law enforcement to discontinue supply routes, sources, and markets.</p>
<p>Objective 5. Conduct research to understand impacts of snakeheads on native aquatic organisms.</p>	<p>5.1) Conduct research on biology/natural history/ecological and economic impacts.</p> <p>5.2) Evaluate each snakehead species using a risk assessment method to determine potential establishment, impact, and pathways for introduction.</p> <p>5.3) Establish and maintain comprehensive population genetics baseline that describes complete genetic variation</p>

	<p>across all established populations of snakeheads in the U.S. to aid identification of the source of new introductions and whether there is successful illegal importation of snakeheads into the U.S.</p> <p>5.4) 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.</p> <p>5.5) Conduct research on control and management.</p> <p>5.6) Conduct comprehensive review and translation of non-English literature on snakeheads where the species is either native or naturalized.</p> <p>5.7) Conduct a symposium to compile and publish scientific information pertaining to snakeheads.</p>
<p>Objective 6. Develop outreach tools to prevent new introductions of snakeheads within the U.S. and control the spread of established populations in new areas.</p>	<p>6.1) Develop outreach tools for target groups to reduce risks associated with each identified pathway including information on regulations and penalties for possession and introduction.</p> <p>6.2) Develop a press kit for jurisdictions to use for rapid response and containment of new introductions.</p> <p>6.3) Develop outreach materials in each jurisdiction to educate the public on identification of snakeheads and who to contact to report sightings.</p> <p>6.4) Train state and federal wildlife officers, U.S. Customs and Border Protection Inspectors on species identification of all live juvenile and adult snakeheads.</p> <p>6.5) Coordinate outreach efforts with those for other non-native fish species in order to provide greater effectiveness in preventing future introductions of new species.</p>
<p>Objective 7. Review and assess progress of the SCMP.</p>	<p>7.1) Annually review progress with implementation of actions in the SCMP.</p> <p>7.2) Coordinate and increase reporting and communications between state and other stakeholder agencies.</p> <p>7.3) Incorporate information associated with implementation of actions in the SCMP into the national clearinghouse.</p>

Objective 1. Prevent new introductions of snakeheads within the U.S. and control the spread of established populations.

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.

Some states prohibit possession of only those snakehead species that could become established in their waters. As long as the source of the snakeheads was not through

interstate or foreign commerce, the Lacey Act does not prohibit possession of live snakeheads if states do not have regulations to prohibit their possession. Without state law prohibiting possession of live snakeheads, wildlife law enforcement officers would find it difficult to prove a violation of state or federal law. Even though certain species of snakeheads 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.

Establish enforcement Standard Operating Procedures (SOP) for snakehead violations pertaining to the Lacey Act. Develop practices for collecting samples that are rigorous and can meet legal standards for chain of custody, etc. Establish pilot work at the border to start to assess levels of contaminants or 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.

1.2. Promote the enactment of clear, effective, 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 snakeheads into new areas. Each jurisdiction should prohibit possession transportation, sale, acquisition, and introduction of live snakeheads.

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

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 snakeheads 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. The Great Lakes and Mississippi River basins have implemented awareness campaigns and can serve as a model for future snakehead activities.

Anglers fishing for snakeheads 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 distributors. Similar efforts in conjunction to snakeheads could be implemented on a larger scale in areas where snakeheads 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 snakeheads.

Continued interception of illegal snakehead imports into and within the U.S. and Canada (N. Mandrak, personal communication, *date?*) by the USFWS raises the possibility that there may be an active underground or black market for this fish (Table 1).

The scale of both legal and illegal movement and sale of snakeheads 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 snakeheads.

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

Suspected pathways include live food markets, live bait trade, aquarium trade, etc.

1.5. Obtain information on life history and biology of snakeheads 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 in English to provide information on life history and biology of snakeheads in their native ranges. In addition it will be important to obtain spatial records across snakehead native range to inform development of niche models that represent the full U.S. distribution potential.

1.6. Through genetic analysis determine source regions of established populations.

To perform this analysis, research is needed on the genetic makeup of all populations of snakeheads 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 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.

1.7. Develop approaches to prevent importation from source regions, including improved border surveillance methods.

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 import of live snakehead species. Determine other means of importing live snakeheads, 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. eDNA screening may offer potential to improve accuracy of screening that presumably currently relies upon visual inspections.

1.8. Establish status of all historic records of snakeheads outside known established range.

As a matter of urgency, the status of all new discoveries of snakeheads outside their established range (including all historic outlying records of snakeheads e.g. Florida, North Carolina, California, Illinois and Massachusetts) needs to be determined. Standard fisheries survey methods may have low detection sensitivity especially in deep (>2m) or turbid water or habitats with large amounts of cover using the most sensitive detection tools.

1.9. Ensure all outlying established populations are fully contained, and, where possible, eradicate these to eliminate these 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, and all efforts should be made to eradicate these irrespective of whether they have the potential to naturally spread. Even where a population may be fully contained, they have the potential to act as a source for human dispersal.

1.10. Ensure all sources of snakeheads in the U.S. are contained and the risk of natural and anthropogenic spread is minimized.

In the Lower Mississippi River Basin, snakeheads appear to have established in the Big Piney river system in Arkansas. Extensive flooding in 2009, 2010 and 2011 has likely spread these fish downstream beyond the point where they can be contained and 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.

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 snakeheads are detected as soon as they invade. Control and containment measures should be instigated as soon as snakeheads 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. Establish an effective snakehead surveillance program within U.S. waters

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

It is critical to notify bordering or shared jurisdictions when a snakehead is found. The use of a notification system via the web is suggested as an effective mechanism for prompt notification. NAS alerts from USGS are an effective communication tool.

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

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/private property and interjurisdictional 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, restrict access, etc. 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 snakeheads.

A rapid response plan would examine and address factors that may result in a delay in eradication efforts such as acquiring the proper permits for different control methods, establishing safety protocol for the different 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; identifies regulatory requirements for each management action; and lists contacts and key experts. All model rapid response plans document relevant containment, control and eradication measures; their relative effectiveness; and the relevant legal requirements, acquisition of required permits (e.g. enabling dewatering, rotenone application).

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. The Great Lakes states should include planning and developing response capabilities, which could also include planning for snakehead. Further the USFWS has a program to stockpile rotenone for state use if needed for AIS rapid response. Agencies should work together to develop a rapid response fund that could be used for emergencies similar to Federal Environmental Management Agency (FEMA). Establish a federal call in process if state agency does not have resources or interest in addressing the issue.

2.6. Undertake research to identify the most effective and sensitive surveillance methods and develop guidelines for snakehead detection and surveillance programs including descriptions of monitoring methods best practice.

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 the best practice to maximize the likelihood that new introductions will be detected early, while they are still localized and can be contained and ideally eradicated.

2.7. Undertake research to quantify effectiveness of all containment methods that prevent spread from infested areas and develop containment guidelines to prevent spread from infested areas.

Research is required to develop barriers to prevent upstream spread of snakeheads 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. In areas where eradication is possible, containment guidelines should be developed based on the type of aquatic system in which introduction has occurred. These guidelines should be incorporated into the rapid response plan.

2.8. Identify trained and knowledgeable individuals to respond to new introductions of snakeheads within their agency jurisdictions.

There is a need to identify trained and knowledgeable 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.

Implement agency response capacity and capability such as the Incident Command System (ICS) that includes training for partners, drills and exercises to test response capacity and past eradication projects lessons learned reviews resulting in developing improved plans.

Conduct National Environmental Policy Act (NEPA), Endangered Species Act (ESA), etc. evaluations in advance of rapid response operations.

2.9. Incorporate monitoring for snakeheads into other existing aquatic surveys within agency jurisdictions.

Monitoring programs for snakeheads 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.

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

Identify priority sites and systems for surveillance on the basis of the risk of invasion by snakeheads (because of their proximity to established populations and or pathways of spread) and or presence of vulnerable taxa or ecosystems. Snakehead surveillance programs should be established in areas at greatest risk of invasion by snakeheads and in systems containing irreplaceable values (threatened taxa or ecosystems) that are vulnerable to snakeheads. 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. Incorporate eDNA into surveillance and monitoring of high-risk pathways for snakehead introductions that includes both border and inland waterway surveillance.

Objective 3. Contain and eradicate newly discovered populations of snakeheads.

3.1. Compile a list of existing control options for eradication, and develop guidelines of best practice and summarize regulatory use requirements.

A list of different control options should be developed for snakeheads in a range of environments in which this species could be introduced. Review past failed attempts and identify reasons for lack of success. 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. The list should be developed in part with input from members of the NSWG. As information on eradication strategies develops, the eradication list should be periodically updated. Best practice guidelines should be developed to facilitate uptake and development of rapid response plans and deployment of methods.

3.2. Test the efficacy of eDNA detection methods.

Evaluate field efficacy of eDNA for early detection of incipient populations of snakeheads (all species). Develop and test primers, facilities need to agree on approach and standardized protocols and SOPs for field sampling, laboratory analysis, and data validation. The analysis should be done rapidly and the Quality Assurance/Quality Control program needs to be consistent with an overall nationally approved program. This is particularly important for data comparability. Testing must be rapid, accurate, and reliable.

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

3.4. Conduct research to develop additional control strategies for eradication.

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

Successful control of the impacts of snakeheads 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.

Some initial priorities for investigation would include development of baits or pheromone attractants to improve catch efficiency of nets and traps. In addition, research to identify the most effective electrical wavelengths, current, and voltage required to kill or damage all snakehead life stages may improve electric fishing control snakeheads because of the snakeheads' propensity to favor shallow slow river margins. 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. Methods that interfere with adult nest guarding behavior and increase the vulnerability of larvae and eggs to native predators should be investigated also. This will require a better understanding of guarding behavior, role of pheromones, and chemical cues and alarm pheromones.

Finally, the potential effects of sterile male releases, or daughterless or lethal genetic control tools should also be investigated, as these may offer the most effective control methods for recently established and expanding populations of snakehead in the Mississippi River basin.

3.5. Evaluate ecological and economic impacts of eradication.

Ecological and economic impacts of eradication must be considered for different aquatic systems. For example, it may not be economically or ecologically beneficial to use piscicides in a large, open aquatic system.

Objective 4. Mitigate impacts of snakeheads in U.S. waters where eradication is not possible.

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

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.

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

Conduct research to determine effectiveness of different control options for long-term management in different systems. Using an adaptive management framework also investigate integrated control strategies that use multiple methods to target vulnerable life stages or behaviors.

4.3. Conduct studies to understand life history traits, biology, and behavior to inform long-term control options.

Biotelemetry and tagging studies of established populations in both the Potomac River and Arkansas/Mississippi 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.

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

Research should consist of:

- 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
- Improved traps or use of attractants to improve trap CPUE
- Genetic control tools including daughterless or sterile male approaches

4.5. To prevent further introductions, continue effective law enforcement to discontinue supply routes, sources, and markets.

As we gain more knowledge about the risk of different pathways, it is important that the natural resource managers communicate with law enforcement to effectively prevent new introductions from occurring and prevent spread of established populations into new areas.

Objective 5. Conduct research to understand impacts of snakeheads on native aquatic organisms.

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

5.1. Conduct research on biology/natural history/ecological and economic impacts:

Research should consist of:

- Determine baseline histology of snakeheads to better understand the risk of this species spreading parasites and disease to native organisms. Very little is known about diseases and parasites of snakeheads in their native range; baseline histology of snakeheads is warranted to determine whether the fish carry introduced parasites or pathogens that could potentially affect native species.
- Determine methods for aging and sexing snakeheads to better understand population dynamics. Natural resource managers in the Potomac River have had a difficult time determining the sex of non-gravid northern snakeheads

they have captured. Otolith interpretation for aging also has been difficult, especially with the absence of known-age comparative specimens.

- Conduct studies to investigate spawning behavior and strategies.
- Determine if there is external sexual dimorphism in snakeheads.
- Examination of dissected fish has not been effective in identifying testis in males. Histological analysis is needed to determine the location and shape of testis.
- Conduct studies to evaluate the impact of snakehead on other fish species and ecosystems. This includes food web shifts, reduction in sport fish abundance, and impacts to native species.
- Conduct studies with snakeheads in closed systems to understand life history traits, biology, and behavior to determine impact at the ecosystem and species level and to inform long-term control options. A better understanding of the biology and life history traits of snakeheads in its introduced range is needed. Also, ecological impacts of other snakehead species are largely unknown at this time. Carefully controlled studies in a contained aquatic system (e.g., isolated pond) could contribute to a better understanding of this species that could inform long-term control and eradication options.
- Conduct studies to understand nesting behavior and parental protection of early life history stages.
- Conduct age validation studies.
- Conduct studies to determine daily and seasonal movement patterns.
- Conduct studies to determine environmental and behavioral cues to movements to colonize new habitats.
- Conduct additional studies to evaluate the environmental (salinity, temperature, D.O., etc.) tolerance and preferences of snakeheads.
- Assess research needs for other snakehead species.
- Conduct studies to determine the economic impacts of snakeheads.

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

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

5.4. 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.

5.5. Conduct research on control and management:

Research should consist of:

- Evaluate the effectiveness of different field collection techniques for snakeheads. 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.
- 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.
- Conduct studies to determine optimal exploitation or removal strategies designed to reduce snakehead abundance.
- Determine pathways for establishment of additional populations.
- Conduct analysis to determine if developing fisheries and markets for snakeheads could reduce established populations.

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

Information on snakeheads 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.

5.7. Conduct a symposium to compile and publish scientific information pertaining to snakeheads.

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 6. Develop outreach tools to prevent new introductions of snakeheads within the U.S. and control the spread of established populations into new areas.

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

Traditional media (newspapers, radio stations, website, etc.) can be used to effectively communicate what penalties are associated with introduction, transport, and live possession of snakeheads. Jurisdictions should create a poster or brochure that focuses on stewardship, health issues, and regulations and penalties associated with live possession of snakeheads. 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 snakeheads. Stewardship could be

emphasized by citing examples where the introductions of other species have had high costs to communities and ecosystems.

6.2. 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 snakeheads could be developed and posted on the national snakehead website (Action Item 7.2).

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

Outreach materials created to assist the public with identification of snakeheads should be developed in a simple, effective way so that the public can easily identify snakeheads from other similar looking species. These materials could be posted on the national snakehead website (Action Item 7.2).

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

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

6.5. 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 7. Review and assess progress of the SCMP.

7.1. 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).

7.2. Coordinate and increase 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.

7.3. 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.

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