The Northern Snakehead, *Channa Argus*, as an Invasive Species

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The northern snakehead, Channa argus, is a large freshwater fish native to Eastern Russia, China, and North Korea (Lapointe et al. 2010, Landis et al. 2011). This highly piscivorous species poses a serious threat to a broad new range of environments and has become a concern for fisheries along its invaded range (Love and Newhard 2012, Saylor et al. 2012). Several control methods have been considered to keep the effect of the northern snaked to a minimum (Simberloff et al. 2005, Lazur et al. 2006). The northern snakehead has characteristics that are beneficial to its invasion, has a high potential to negatively affect the native species, and has several possible prevention methods that may help control future populations.

From their native range in eastern Asia, the northern snakehead has been found in Uzbekistan, Kazakhstan, Turkmenistan, and the United States (Landis et al. 2011). The northern snakehead was most likely introduced through the live fish markets (Herborg et al. 2007). Originally discovered in the United States in Maryland in 2002, The northern Snakehead has spread to Virginia, Pennsylvania, New York, and Arkansas (Love and Newhard 2012). In North America, the northern snakehead has been observed to tolerate a wider range of temperatures than it experiences in its native habitat (Herborg et al. 2007). Combined with its ability to live in water with salinity levels between 0-10 ppt, the northern snakehead is predicted to have a large habitable range through most of the United States, down the center of Mexico, as well as southern Canada and Alaska (Herborg et al. 2007, Lapointe et al. 2013).

Many characteristics are often considered when evaluating the introduction of non-native species, especially the ability to disperse and establish in new areas after an introduction (Lapointe et al. 2013). The northern snakehead has demonstrated a high ability to disperse long distances (Lapointe et al. 2013). Dispersal occurs during the pre-spawn months, April to June, most likely due to the snakehead's desire to find a habitat or a mate (Lapointe et al. 2013). Nearly a third of the snakeheads in an observed population had dispersed up to 39km from their primary habitat (Lapointe et al. 2013). Dispersal was only restricted by physical barriers, occurred across unsuitable habitats, and tended to be in the direction of lower salinity, despite the ability to live in higher salinity habitats (Lapointe et al. 2013). Once dispersed or introduced to a new environment, the species has a high ability to colonize and increase in population size (Odenkirk and Owens 2007, Lapointe et al. 2013). Within the Potomac River, the catch rate of the northern snakehead increased by 950% across the span of a year (Odenkirk and Owens 2007). In large, open water systems the northern snakehead's dispersal ability will be highly effective, and rapid population growth is predicted to continue in invaded environments (Landis et al. 2011, Lapointe et al. 2013). As the population of the northern snakehead expands, the invaded areas will be increasingly exposed to its predatory characteristics (Saylor et al. 2012, Lapointe et al. 2013).

The northern snakehead's diet consists of, on average, 97% other fish species, which classifies it as a generalist piscivorous predator (Saylor et al. 2012). The northern snakehead has not been connected to any declines in native fish species, but possess a high potential to cause negative effects on native species through predation (Odenkirk and Owens 2007, Landis et al. 2011). Analysis of stomach contents found 15 native species, with banded killifish occurring with a 27% frequency (Odenkirk and Owens 2007). Predation effects could extend to other commonly found prey species such as Lepomis spp. and Fundulus spp. (Lapointe et al. 2010). The northern snakehead's diet has a large potential to become a competitor with several other predatory species that have already become established in the Potomac River, but is likely to affect some species more than others (Saylor et al. 2012).

The introduction of the northern snakehead is predicted to have the highest impact on the largemouth bass, Micropterus salmoides, through competition (Saylor et al. 2012). The largemouth bass has a diet that overlaps with the northern snakeheads diet to a biologically significant level, causing a high potential for the two species to become direct competitors (Saylor et al. 2012). Compounding with the overlapping diet, the northern snakehead and largemouth bass share suitable habitat types, causing the two species to hunt for a single source of prey (Love and Newhard 2012). This competition has not caused a significant impact on the largemouth bass because the abundance of prey for the two predators is not a limiting factor (Saylor et al. 2012). If the prey becomes limited, because of their highly piscivorous diets and shared habitat, the northern snakehead and the largemouth bass are highly likely to become competitors (Saylor et al. 2012).

The diet of the northern snakehead, as a piscivore, has the potential to affect the population of the largemouth bass through predation, as well as competition (Love and Newhard 2012, Saylor et al. 2012). Despite both species being considered top predators, age-0 largemouth bass are highly vulnerable to predation from the northern snakehead, due to their small size (Love and Newhard 2012). As the co-occurrence of these two species increases, the potential for the negative impact on the largemouth bass increases as well (Love and Newhard 2012). Currently, in the Potomac River, the co-occurrence, at 10.6%, is considered minimal, and no declines in abundance have been observed (Love and Newhard 2012). Even though the current levels of co-occurrence and impact of the northern snakehead are considered minimal, these trends may change as the population of the northern snakehead increases and expand (Crooks 2009, Love and Newhard 2012, Saylor et al. 2012).

The invasive effects of a new species are normally reliant on their population size and inhabited area. The northern snakehead is no different (Crooks 2009, Love and Newhard 2012). The lack of observed decline in abundance of prey species, including the largemouth bass, may be due to lag (Crooks 2009). If the population of the northern snakehead continues to rapidly expand and grow as predicted, the strain placed on prey species will increase, and despite current trends, could begin to cause an observable decline in native fish species (Crooks 2009, Landis et al. 2011, Saylor et al. 2012). This pressure could over time press prey into limited abundance, and pit the northern snakehead against the largemouth bass as competitors (Saylor et al. 2012). This growth and spread also has the potential to surpass the 30% co-occurrence threshold that predicts a minimal effect of the northern snakehead on the largemouth bass through predation (Love and Newhard 2012). To prevent the northern snakehead's abundance from reaching a point where the potential effects of its invasion shifts to an observable one, it is recommended that prevention methods against the northern snakehead are taken (Love and Newhard 2012).

For the northern snakehead, the main pathways of movement around the world are through live fish markets (Herborg et al. 2007). To reduce the propagule pressure of the northern snakehead into new environments, laws around the transport of the species have already been tightened (Simberloff et al. 2005, Herborg et al. 2007). Even though the northern snakehead has established itself as a species in the United States, there are several methods to prevent the spread of invasive species: physical and mechanical control, chemical control, biological control, and ecosystem management (Simberloff et al. 2005). Out of these, chemical control and biotic control have been considered to control the population of the northern snakehead (Lazur et al. 2006, Iwanowicz et al. 2013).

The use of chemical control is found to be effective, but has many collateral effects on the ecosystem (Simberloff et al. 2005, Lazur et al. 2006). One chemical that is considered for the control of the northern snakehead is rotenone, and is expected to be used for eradication efforts (Lazur et al. 2006). It has been found that a rotenone concentration of 0.075 mg/L is strong enough to kill all northern snakehead in an enclosed area after 24 hours (Lazur et al. 2006). Along with the complete eradication of northern snakehead, this concentration can also kill other species, including the largemouth bass (Lazur et al. 2006). When used in a small pond, the complete mortality of reintroduced fish continued for several days after the treatment (Lazur et al. 2006). While the use of rotenone as a chemical control would cause a complete eradication of the northern snakehead, this eradication would include any coexisting native fish species (Simberloff et al. 2005, Lazur et al. 2006).

Growing in popularity, biotic control is considered an effective control that is safe for most ecosystems (Simberloff et al. 2005). For the northern snakehead, biotic control may come as a virus discovered in a few individuals of the northern snakehead population (Simberloff et al. 2005, Iwanowicz et al. 2013). Strains of the largemouth bass virus (LMBV) have been found in northern snakehead adults (Iwanowicz et al. 2013). The LMBV in the northern snakehead has the potential to cause disease and act as an effective biotic control against the rapidly growing population (Simberloff et al. 2005, Iwanowicz et al. 2013). Future research could find a specialized pathogen that causes disease in northern snakehead, becoming ideal biotic control (Simberloff et al. 2005, Iwanowicz et al. 2013).

Mechanical control of the northern snakehead through fishing has been in effect since its discovery in the Potomac River (Odenkirk and Owens 2007, Iwanowicz et al. 2013). Fishermen are told to report and kill any northern snakehead caught (Odenkirk and Owens 2007, Iwanowicz et al. 2013). Identifying northern snakehead nests could expand the target of mechanical control from adults to their eggs (Gascho Landis and Lapointe 2010). Recently, the nest of a pair of northern snakeheads had been discovered (Gascho Landis and Lapointe 2010). The nest consisted of floating vegetation in areas with a minimal current flow (Gascho Landis and Lapointe 2010). The floating vegetation acts to camouflage the nest, but using the known characteristics of the nests, an active search and eradication program may provide an effective method to reduce the population (Simberloff et al. 2005, Gascho Landis and Lapointe 2010). By targeting the nests, individuals would be removed from the ecosystem before becoming highly mobile and reproductively active (Simberloff et al. 2005, Gascho Landis and Lapointe 2010).

Each potential control method has its benefits and downfalls, and could be more effective in different environments (Simberloff et al. 2005). The use of rotenone as a chemical control is the most effective control method, but it also includes the most devastating collateral damage (Simberloff et al. 2005, Lazur et al. 2006). The collateral damage to some ecosystems may not be worth the removal of the northern snakehead, making this form of control best for isolated environments where restoration is a future possibility (Simberloff et al. 2005, Lazur et al. 2006). The use of a virus as a biotic control against the northern snakehead would be highly effective in controlling the northern snakehead and have a lower impact on coexisting species than chemical controls (Simberloff et al. 2005, Lazur et al. 2006, Iwanowicz et al. 2013). A developed biotic control may be best for large, diverse ecosystems where maintenance of the northern snakehead is the goal (Simberloff et al. 2005, Iwanowicz et al. 2013). The mechanical control of the northern snakehead would not have a large impact on the population size and could be expensive to maintain (Simberloff et al. 2005, Iwanowicz et al. 2013). Mechanical control may only be beneficial, combined with other control methods, if a specific population of northern snakehead becomes detrimentally large (Simberloff et al. 2005, Iwanowicz et al. 2013). In the Potomac River, where the invasion of the northern snakehead is predicted to have the greatest negative effect, biotic control would be the best method due to its permanent, targeted effect (Simberloff et al. 2005, Iwanowicz et al. 2013).

The northern snakehead, as a large piscivorous predator, is predicted to rapidly expand its invaded range into most of North America (Herborg et al. 2007, Lapointe et al. 2013). Any ecosystems it invades are very likely to be affected negatively by competition and predation from the northern snakehead (Love and Newhard 2012, Saylor et al. 2012). The largemouth bass is expected to be the most affected by the northern snakehead, possibly causing detrimental affects to the largemouth bass fishery (Love and Newhard 2012). To avoid the consequences of the northern snakehead's expansion, several control methods have been considered (Simberloff et al. 2005, Lazur et al. 2006, Iwanowicz et al. 2013). Due to their different benefits and drawbacks, the circumstances of the environment will need to determine which control method will be used (Simberloff et al. 2005, Lazur et al. 2006, Iwanowicz et al. 2013). The northern snakehead is an invasive species that, without proper control, is expected to cause detrimental effects on the ecosystems it invades.

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