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Risk Assessment for Northern Snakehead (*Channa argus*) in Canada

Évaluation des risques posés par le poisson à tête de serpent (*Channa argus)* au Canada

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Abstract

There are at least 29 species in the snakehead (Channidae) family and are found in cold temperate to tropical areas. The cold temperate snakehead, northern snakehead (*Channa argus*), is found in areas in Russia, China, and Korea. Northern snakehead is highly favoured as a food fish and is commercially fished and exported. Historically, it has been found in the live food trade in the United States, and is currently only imported into North America into British Columbia. This species has a broad range of environmental tolerances and is extremely hardy. Its voracious predation on other fish species, ability to migrate over land and ability to withstand freezing and no water is well known. Concern for this species to enter Canadian natural waters prompted the provincial government of Ontario to ban live possession of this species. The Canadian federal government conducted a biological risk assessment to determine the risk of northern snakehead in Canada. This assessment included evaluating the risk of survival, reproduction and spread of these species, as well as their pathogens, parasites or fellow travelers (e.g. other invasive species) should northern snakehead be introduced into Canada. These components were assessed using best available information on its biology, potential vectors of introduction, and impacts in both native and introduced ranges. The potential distribution in North America was also modeled as part of the risk assessment. The biological risk assessment concluded that the risk of impact was high in, at least, some parts of Canada, including the southern Great Lakes basin by northern snakehead.

Résumé

Il existe au moins 29 espèces de channas, ces poissons à tête de serpent de la famille des channidés qu'on observe dans les eaux froides tempérées et jusque dans les régions tropicales. *Channa argus*, un membre de cette famille vivant dans les eaux froides tempérées, se trouve en Russie, en Chine et en Corée. Cette espèce est hautement prisée comme poisson de consommation et fait l'objet d'activités de pêche et d'exportation. Par le passé, on la retrouvait parmi les espèces du commerce de poissons de consommation vivants aux États-Unis et elle est présentement importée en Amérique du Nord uniquement en Colombie-Britannique. Elle a une grande tolérance à des conditions environnementales très diversifiées et elle est extrêmement robuste. On connaît bien sa voracité en tant que prédatrice d'autres espèces de poissons, sa facilité à migrer sur terre et sa capacité de tolérer le gel et l'absence d'eau. Les préoccupations relatives à la pénétration de cette espèce dans les eaux naturelles du Canada ont amené le gouvernement provincial de l'Ontario à bannir la possession de spécimens vivants de cette espèce. Le gouvernement canadien a entrepris une évaluation des risques biologiques, afin de déterminer les risques posés par *Channa argus* au Canada. Cet exercice comprenait une évaluation des risques de survie, de reproduction et de propagation de l'espèce, de même que de ses pathogènes, parasites ou compagnons de route (d'autres espèces envahissantes), au cas où elle s'introduirait au Canada. Ces facteurs ont été évalués à l'aide de la meilleure information disponible sur sa biologie, ses vecteurs d'introduction possibles et ses effets, aussi bien dans son territoire indigène que dans les zones où elle s'est introduite. Sa répartition possible en Amérique du Nord a aussi été modélisée dans le cadre de l'évaluation des risques biologiques. Celle-ci a permis de conclure que les risques de répercussions posées par *Channa argus* étaient élevés, tout au moins dans certaines parties du Canada, notamment dans le sud du bassin des Grands Lacs.

Introduction

This document summarizes the results of a risk assessment conducted to evaluate the risk posed by one species, northern snakehead (*Channa argus*), in the snakehead family (Channidae) (Table 1) if introduced into Canadian waters. The risk assessment is adapted from the process outlined in the Canadian *National Code on Introductions and Transfers of Aquatic Organisms*. The code outlines a two-part process that evaluates:

- Part I - the probability of establishment and consequence of establishment of an aquatic organism; and,

- Part II - the probability of establishment and consequence of establishment of a pathogen, parasite or fellow traveler of the aquatic organism.

Each part contains two sets of component ratings (two each for probability and consequences of establishment) and are assigned ratings of high (risk is likely, or very likely, to occur), medium (there is a probability of negative impact), or low (risk is considered to be insignificant). In addition, a level of certainty is also assigned as a gradient from very certain (scientific basis), reasonably certain, reasonably uncertain, to very uncertain ("best guess"). An overall risk potential is then determined separately for both parts.

The risk assessment process requires the best available biological information for the species of interest. This information was obtained mainly from a report on the biological synopsis and risk assessment for snakehead in the United States (Courtenay and Williams 2004), and other information published since the collection of information for that report. As noted by Copp *et* al. (2005), risk assessments of invasive species are not static. New research may require modification and refinement of the risk assessment in order to ensure that the risk posed by the species reflects the available information. This may result in a change in the level of risk previously assigned, as well as a change in the certainty level.

A draft risk assessment document was prepared and peer-reviewed by international aquatic invasive species experts who attended a two-day workshop on the Canadian Asian carp risk assessment (for workshop proceedings and resulting Asian carp risk assessment see Rice *et al.* 2004 and Mandrak and Cudmore 2004, respectively).

This document is a synthesis of the draft document and input from the reviewers. A brief summary of the snakehead family is provided, as well as specific information on the northern snakehead's general biology, native and non-native distribution, potential Canadian distribution, potential vectors and pathways of introduction, and the risk assessment with rationale.

Snakehead Family (Channidae)

Although the systematics of snakeheads have not been fully studied, authorities currently recognize two genera in the Channidae family, *Channa* (26 species) and *Parachanna* (3 species) (Table 1) (Courtenay and Williams 2004). It is possible, in some cases likely, that species complexes and forms exist within the family and a taxonomic revision of the family is currently underway (W. Courtenay, retired USGS, pers. comm.). The current view is there may be 36 snakehead species, as several subspecies within the species complexes of *C. gachua*, *C. marulius* and *C. striata* may be elevated to the species level (W. Courtenay, pers. comm.). For the purposes of this report, we deal with the 29 species as listed in Courtenay and Williams (2004).

These freshwater fishes range in native distribution from Asia, Malaysia, Indonesia, and, for the *Parachanna* spp. only, Africa (Courtenay and Williams 2004). Fifteen species are characterized as tropical-subtropical, 12 as subtropical-warm temperate, and one species as warm-cold temperate (Table 2).

The following general biological information on the snakehead family comes from the biological synopsis compiled by Courtney and Williams (2004).

The body of snakeheads is torpedo-shaped, which tapers towards the tail. They have a single, long dorsal fin, a long anal fin, and a small head with a large mouth.

Very little is known about the life span of snakeheads, but it is suspected that some of the smaller species may live for only a few years, while larger species may reach sexual maturity within two years. Most species are small as adults at about 170 mm, but some can grow to larger sizes, reaching 1.8 m. Snakeheads are highly evolved and many species are obligate airbreathers, others are facultative airbreathers. Snakeheads possess suprabranchial chambers for aerial respiration, and the ventral aorta is divided into two parts to permit aquatic and aerial respiration. Therefore, some snakehead species are capable of surviving hypoxic conditions and can remain out of water for considerable periods of time, as long as they remain moist. Their metabolism and oxygen demand reduces in cold temperatures, allowing for survival under ice. Several species also have the ability to move overland as a result of wriggling motions in search of food resources, escape from drying habitats, or both.

Spawning in their native ranges occurs during the summer months with spawning pairs reported to be monogamous for at least the spawning season. Some species are nest builders, constructing a vertical column of vegetation filled with water.

Fry feed on zooplankton with diet changing to small crustaceans and insects. All snakehead species are carnivorous thrust predators as adults, consuming mainly fishes.

Some snakehead species are the target of fisheries in their native ranges, and are also utilized in aquaculture. They are highly valued as food fishes, and are also used as biological control to manage tilapiine fish densities in aquaculture facilities. Many snakeheads have been exported to other nations and sold live in fish markets. There have also been instances of accidental releases in these nations, resulting in subsequent establishment (Courtenay and Williams 2004, FIGIS 2005).

Snakeheads are also available in the aquarium trade, particularly the smaller species and the brightly coloured juveniles of the larger species. However, these species are incompatible with other fishes, require expensive food, and quickly outgrow their aquaria. As a result, many individuals have been released into natural waters outside their native range (Courtenay and Williams 2004).

As most snakeheads are tropical to warm temperate in their thermal preferences (Table 2), these species would likely not be able to survive for long in Canadian waters. It was decided to assess the risk posed by the snakehead family into the three thermal groups (Table 2). This risk assessment was conducted for the northern snakehead, the only cold temperate species. Risk assessments for the other two thermal groups are currently being conducted (Cudmore and Mandrak, unpubl. data).

Northern snakehead (*Channa argus*)

Other common names used: Amur snakehead, eastern snakehead, ocellated snakehead (ISSG 2005).

1. General Biology

Young northern snakehead are golden brown to pale grey in colour, changing to darker brown with black splotches with age. They are similar in appearance to the following native North American fishes: bowfin (*Amia calva*), burbot (*Lota lota*) or American eel (*Anguilla rostrata*) (Figure 1). They can grow to 1.8 m and weigh up to 6.8 kg (Courtney and Williams 2004, ISSG 2005). They are found in slow moving waters, usually close to shore with vegetated or muddy substrate (ISSG 2005). Spawning occurs in June or July in their native range when the species matures at about two years (or 30 cm in length) (ISSG 2005). This species builds cylindrical nests using pieces of macrophytes in shallow aquatic vegetation. These nests can be up to one metre in diameter (Courtenay and Williams 2004). Between 1 300 – 1 500 pelagic, nonadhesive, buoyant eggs (about 1.8 mm diameter) can be laid per spawn, with up to five spawns occurring within a year (Courtenay and Williams 2004). Northern snakehead are most active at dusk and dawn. They feed close to shore, typically under aquatic vegetation, and only when water temperatures are above 10°C (ISSG 2004). As an obligate airbreather, this species is capable of surviving up to four days out of water. Overland migration is limited; however, juveniles can somewhat move on land if there is some water available (Courtenay and Williams 2004).

2. Native Distribution

The northern snakehead is a warm to cold temperate species, but can also be found in subtropical areas (Courtenay and Williams 2004). It is native to the middle and lower Amur River basin, including the Ussuri River basin and Khanka Lake; the Sungari River in Manchuria; and, the Tungushka River at Khaborovsk, Russia. It is also native to Korea, except for the northeastern regions, as well as the rivers of China, southward and southwestward to the upper tributaries of the Yangtze River basin in northeastern Yunnan Province (Figure 2) (Courtenay and Williams 2004).

There is a broad range of climatic conditions within the native range of the northern snakehead. Mean annual air temperatures range from 18°C in the southernmost part of its range to -7^{o}C in the northernmost part (Figure 3). The distribution of mean annual air temperatures within its range is trimodal, with modes centred on 0^{o}C, 6 ^{o}C and 16^{o}C (Figure 4).

3. Non-native Distribution

a. China

Although the northern snakehead is native to some areas of China, they have been reported from non-native areas where current status has not been documented (ISSG 2005).

b. Eurasia

The northern snakehead was introduced into eastern Europe and western Asia (vector unknown) during the 20th century; current status has not been documented (ISSG 2005).

c. Japan

The northern snakehead was introduced in 1923 to Japan from Korean populations to establish a recreational fishery. These populations have since become established through natural reproduction (Chiba *et al.* 1989, FIGIS 2005).

d. Kazakhstan

The northern snakehead was accidentally introduced to Kazakhstan in 1961 as a stock contaminant with shipment of other fish species; current status has not been documented (ISSG 2005).

e. Korea (Democratic People's Republic of, and Republic of,)

This species has been introduced into northeastern Korea; although date, means of introduction and current status is unknown (FishBase 2005, ISSG 2005).

f. Russia

Northern snakehead was intentionally introduced in eastern Russia, although reason, date of introduction and current status is unknown (ISSG 2005). This species was also introduced into western Russia in 1949 (vector unknown), but it is suspected that the species is not established (Holcik 1991, Elvira 2000, ISSG 2005).

g. Turkmenistan

In 1961, the northern snakehead was imported accidentally into Turkmenistan in a shipment of another species; current status has not been documented (ISSG 2005).

h. Uzbekistan

The northern snakehead is now established in Uzbekistan after being introduced to the country in 1961 for aquaculture purposes (FIGIS 2005, ISSG 2005).

i. United States

The northern snakehead was first found in the wild in the United States in California in 1977. It was not found again until 2000, when it was found in Florida. In 2002, the first established population found was in a Maryland retention pond, which has since been treated with rotenone, eradicating the population (Orrell and Weigt 2005). Two specimens were also angled in North Carolina in 2002. Beginning in April 2004, several fish were found from the Potomac River in Maryland and Virginia (USGS 2004). It has been determined that these populations were the result of several independent introductions and that the populations are reproducing naturally (Odenkirk and Owens 2005, Orrell and Weigt 2005) Several individuals were also captured from a pond in a park in Philadelphia, Pennsylvania (USGS 2004). One northern snakehead was also captured in downtown Chicago in Burnham Harbor, Lake Michigan in 2004 (USGS 2004). Follow-up sampling in the area did not detect any more individuals. In July 2005, officials found five northern snakeheads of two different year classes in a lake in a New York City park (W. Courtenay, pers. comm.).

j. Canada

The northern snakehead has not been found in any natural waters in Canada.

4. Potential Distribution in Canada

Using nine environmental variables in the native range of northern snakehead (wet day index, maximum, mean and minimum air temperatures, annual river discharge, precipitation, compound topographic index, slope, and frost frequency), potential distribution in North America was modeled using genetic algorithm for rule set production (GARP) analysis. This type of analysis has been used by others to predict potential distribution of invasive species (e.g. Drake and Lodge 2006). The model was developed for the native distribution of northern snakehead and used to predict the potential distribution in North America based on the environmental layers. The analyses create random rules (algorithms) and repeatedly analyze their accuracy until a maximum prediction of accuracy is reached. The environmental layers used to identify potential distribution are tested for their relevance for, and contribution to, the prediction of the distribution.

The results of the GARP modeling suggest that the distribution of northern snakehead could be widespread in Canada, north to about 60^{o}N (Figure 6). Of the nine environmental layers used in the modeling, maximum air temperature, frost frequency and mean air temperature were the top three contributors to the prediction (Figure 6a). Wet day index, precipitation and slope did not contribute to the model's prediction (Figure 6a).

As previously mentioned, risk assessments for invasive species should not be static (Copp *et al.* 2005). Therefore, analyses are ongoing to refine the potential distribution of northern snakehead in Canada. Analyses are being conducted at a regional level by adding environmental variables and propagule pressure estimates based on potential location and magnitude of introduction. At a local scale, potential distribution could be refined by modeling the physical, biological and chemical attributes of lakes and streams.

5. Potential Vectors and Pathways of Introduction

Potential distribution will also depend on the vectors and pathways of introduction through which northern snakehead could be introduced into the natural waters of Canada. The most likely of these would include colonization from the United States, deliberate and accidental releases from the live food fish trade.

There are several established populations of northern snakehead in the United States (Figure 5), which may soon place them in close proximity to the Great Lakes and Lake Champlain basins, and other Canadian waters.

In their native range, the northern snakehead contributes significantly to both commercial and recreational fisheries, and is used in aquaculture. It is highly valued as a food fish. In the United States, it is the most widely available snakehead species sold live in food fish markets (Courtenay and Williams 2004). These live food fish markets provide a source for deliberate release for ceremonial or animal rights reasons. It is suspected that these may be the sources for the occasional capture of Asian carps in the Canadian Great Lakes basin (Mandrak and Cudmore 2004).

The northern snakehead is not favoured for the aquarium or water garden trade as they are not very colourful and rapidly attain very large sizes (Courtenay and Williams 2004, Orrell and Weigt 2005).

6. Northern Snakehead Risk Assessment

Table 3 summarizes the northern snakehead risk assessment.

Part I – Aquatic Organism Ecological and Genetic Risk Assessment Process

Step 1. Determining the Probability of Establishment

(1) Estimate of probability of the organism successfully colonizing and maintaining a population if introduced. **Survival – High, very certain; Reproduction – High, reasonably certain.**

Vectors of northern snakehead introduction may include natural colonization from established populations in the United States (Figure 5), deliberate (e.g. prayer fish (see Severinghaus and Chi 1999), animal rights activism) or accidental (e.g. tanker spill) release related to the availability of northern snakehead in the live food fish industries. The probability of introduction of northern snakehead through these vectors is largely unknown; however, the natural range extension and release of northern snakeheads experienced in the United States is as likely to occur in Canada.

It has been suggested to Ontario conservation officials that snakeheads are more preferable than Asian carps for ceremonial release as a prayer species as they are a highly resilient species, giving stronger "karma" for the afterlife of the releaser (B. Ingham, Ontario Ministry of Natural Resources, pers. comm.). The potential for unauthorized release of northern snakehead for recreational fishing reasons also exists.

Accidental release during transport could also occur with the live fish food market trade. In 2001, a driver for a Canadian fish wholesaler bound for Seattle, WA was stopped in Blaine, WA. He declared his shipment to be three boxes of live ling cod (proper common name is burbot). The fish were, in fact, pond-raised northern snakeheads, which were shipped from China without water to Canada (Courtenay and Williams 2004).

According to Goodchild (1999) and Crossman and Cudmore (2000), snakeheads have not been imported live into Ontario; however, Canadian Food Inspection Agency (CFIA) data suggests this may not be the case. In 2003, 541 kgs of “fresh water snake fish” entered Ontario via the Niagara Falls port of entry (CFIA, unpubl. data). Positive identification of this import as snakeheads is not possible, but the authors presume that this is likely the case. Provincial prohibitions now exist in Ontario that makes it illegal to possess and sell live snakeheads. The province that historically and currently imports the most live snakeheads for retail and institutional uses into Canada is British Columbia. These snakeheads (species unknown) arrive at three ports of entry: Vancouver International Airport; Vancouver Marine and Rail; and, Pacific Highway (CFIA, unpubl. data) (Figure 7). The countries of origin for these imports are Hong Kong, Vietnam and China. Snakeheads are also imported in a fresh/frozen and dried/paste state into Canada (Figures 8 and 9). From 2000-2005, 43 893 kgs of fresh or frozen snakeheads were imported into three CFIA areas (Western, Ontario and Quebec) (Figure 8), while from 2003-2005, 24 859 kgs were imported into the Western and Ontario CFIA areas in a dried or paste state (CFIA, unpubl. data) (Figure 9) .

If the northern snakehead does successfully colonize Canada, there is a high probability of it maintaining populations based on its thermal requirements (Figure 6). In addition, feeding, spawning and nursery habitat exists in the Great Lakes basin in the nearshore, vegetated areas (Figure 10).

(2) If the organism escapes from the area of introduction, estimate the probability of its spreading. **High, reasonably certain.**

If the northern snakehead does successfully colonize the Great Lakes basin, there is a high probability that it could spread throughout the basin based on the presence of natural and man-made connections, and on the widespread distribution of suitable thermal (Figure 5), feeding, spawning and nursery habitat (Figure 10). The probability of spreading outside of the Great Lakes basin is unknown largely as a result of the unknown availability of suitable feeding, spawning and nursery habitats elsewhere. The northern snakehead is also very tolerant of a wide range of environmental conditions as evidenced by the rapid spread and establishment in Asian and Japanese populations (USGS 2004).

(3) Final Rating. **High, reasonably certain.**

Step 2. Determining the Consequences of Establishment of an Aquatic Organism

(1) Ecological impact on native ecosystems both locally and within the drainage basin. **High, reasonably certain.**

Based on the results of its introduction throughout the world (Courtenay and Williams 2004), there is little doubt that the northern snakehead has the potential to significantly impact on native fish populations due to their voracious predatory feeding style and strong competition with other fishes for resources. They are also highly fecund and resilient to a wide range of environmental conditions (ISSG 2005). After a purposeful introduction to develop a recreational fishery, Japan reported adverse ecological impacts from predation on native species. No further information on specific impacts or species was mentioned (Chiba *et al.* 1989, ISSG 2005).

(2) Genetic impacts on local self-sustaining stocks or populations. **Low, very certain.**

As the northern snakehead is not closely related to any native fish species in Canada, it is highly unlikely to have any direct genetic impact on the native fauna.

(3) Final Rating. **High, reasonably certain.**

Step 3. Estimating Aquatic Organism Risk Potential

(1) Probability of establishment estimate. **High, reasonably certain.**

(2) Consequences of establishment estimate. **High, reasonably certain.**

(3) Final Risk Estimate. **High, reasonably certain.**

Part II – Pathogen, Parasite or Fellow Traveler Risk Assessment Process

Step 1. Determining the Probability of Establishment

(1) Estimate the probability that a pathogen, parasite or fellow traveler may be introduced along with the potential invasive species. Note that several pathways may exist through which pathogens or accompanying species can enter fish habitat. Each must be evaluated. **Medium, reasonably uncertain.**

The diseases and parasites of snakeheads have not been well studied. However, mortality of snakeheads under intensive culture, such as northern snakehead, but particularly chevron snakehead (*C. striata*) and spotted snakehead (*C. punctata*), has been known to occur from epizootic ulcerative syndrome (EUS), a disease which involves several pathogens. Several other species can also be affected by EUS; however, only one cyprinid genera (*Cyprinus*) is native to Canada (Courtenay and Williams 2004). Snakeheads have also been shown to suffer from gnathostomiasis, a disease caused by the helminth parasite, *Gnathostoma spinigerum*, which can affect humans. At this point, however, only one snakehead species, chevron snakehead, has been shown to be an intermediate host of the parasite (Courtenay and Williams 2004).

A paper by Chiba *et al.* (1989) mentions that northern snakehead introduced in 1923/24 from Korea had parasites, but provides no further detail.

Snakeheads are also imported into Canada in the fresh and frozen state (i.e. not live) (CFIA, unpubl. data) (Figure 8). These may potentially be a source for the introduction of pathogens if the water or ice used during shipment or for washing is not treated properly. Hong Kong is the country of origin for fresh snakeheads, while Vietnam, Bangladesh, China and Thailand are countries of origin for frozen snakeheads (CFIA, unpubl. data). Dried and paste product likely present little, if any, risk for introduction of pathogens. These products are imported from Thailand, Philippines, Myanmar, Sri Lanka and China (CFIA, unpubl. data).

(2) Estimate the probability that the pathogen, parasite or fellow traveler will encounter susceptible organisms or suitable habitat. **Medium, reasonably uncertain.**

It is unknown what other species would be affected by any disease or parasites carried by northern snakehead; however, *Cyprinus* spp. may be at risk.

(3) Final Rating. Medium, reasonably uncertain.

Step 2. Determining the Consequences of Establishment of a Pathogen, Parasite or Fellow Traveler

(1) Ecological impacts on native ecosystems both locally and within the drainage basin including disease outbreak, reduction in reproductive capacity, habitat changes, etc. **Medium, very uncertain.**

There is not enough information presently available to predict impacts.

(2) Genetic impacts on local self-sustaining stocks or populations (i.e. whether the pathogen, parasite, or fellow traveler affects the genetic characteristics of native stocks or species). **Medium, very uncertain.**

Nothing is known about the potential genetic impacts on local populations.

(3) **Final Rating. Medium, very uncertain.**

Step 3. Estimating Aquatic Organism Risk Potential

(1) Probability of establishment estimate. **Medium, reasonably uncertain.**

(2) Consequences of establishment estimate. **Medium, very uncertain.**

(3) Final Risk Estimate. **Medium, very uncertain.**

7. Knowledge Gaps

It is important to identify areas where knowledge required to more accurately identify risk, increase our certainty about risk, or to refine potential distribution is lacking.

More information is required concerning the imports of northern snakehead into Canada. This requires thorough searching of all databases of live fishes entering Canada. Bioenergetics modeling could be used to refine potential distribution based on spatial results concerning the inability of northern snakehead to feed below 10°C. Work is currently being undertaken by the authors to address these data gaps, and to refine potential distribution of northern snakehead based on availability of required ecological resources.

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Table 1. Scientific and common names of the species found in the snakehead family (Channidae) (Courtenay and Williams 2004).

Scientific Name	Common Name
Channa amphibeus	Chel snakehead
Channa argus	northern snakehead
Channa asiatica	Chinese snakehead
Channa aurantimaculata	orangespotted snakehead
Channa bankanensis	Bangka snakehead
Channa baramensis	Baram snakehead
Channa barca	barca snakehead
Channa bleheri	rainbow snakehead
Channa burmanica	Burmese snakehead
Channa cyanospilos	bluespotted snakehead
**Channa gachua*	dwarf snakehead
Channa harcourtbutleri	Inle snakehead
Channa lucius	splendid snakehead
Channa maculata	blotched snakehead
Channa marulioides	emperor snakehead
**Channa marulius*	bullseye snakehead
Channa melanoptera	blackfinned snakehead
Channa melasoma	black snakehead
**Channa micropeltes*	giant snakehead
Channa nox	night snakehead
**Channa orientalis*	Ceylon snakehead
Channa panaw	panaw snakehead
Channa pleurophthalma	ocellated snakehead
**Channa punctata*	spotted snakehead
Channa stewartii	golden snakehead
**Channa striata*	chevron snakehead
Parachanna africana	Niger snakehead
Parachanna insignis	Congo snakehead
Parachanna obscura	African snakehead

* possible/likely species complex

Table 2. Thermal characterizations of snakeheads (adapted from Courtenay and Williams 2004).

Tropical-Subtropical Species	Subtropical-Warm Temperate Species	Warm-Cold Temperate Species
Bangka snakehead Baram snakehead bluespotted snakehead Inle snakehead splendid snakehead emperor snakehead blackfinned snakehead black snakehead giant snakehead Ceylon snakehead panaw snakehead ocellated snakehead Niger snakehead Congo snakehead African snakehead	Chel snakehead Chinese snakehead orangespotted snakehead barca snakehead rainbow snakehead Burmese snakehead dwarf snakehead blotched snakehead bullseye snakehead night snakehead spotted snakehead golden snakehead chevron snakehead	northern snakehead

Table 3. Summary of risk assessment for northern snakehead in Canada.

Component Rating	Element Rating	Level of Certainty
Part I – Aquatic Organism Ecological and Genetic Risk Assessment Process		
Probability of establishment estimate	High	Reasonably Certain
Consequences of establishment estimate	High	Reasonably Certain
Final Risk Estimate	**High**	**Reasonably Certain**
Part II – Pathogen, Parasite or Fellow Traveler Risk Assessment Process		
Probability of establishment estimate	Medium	Reasonably Uncertain
Consequences of establishment estimate	Medium	Very Uncertain
Final Risk Estimate	**Medium**	**Very Uncertain**

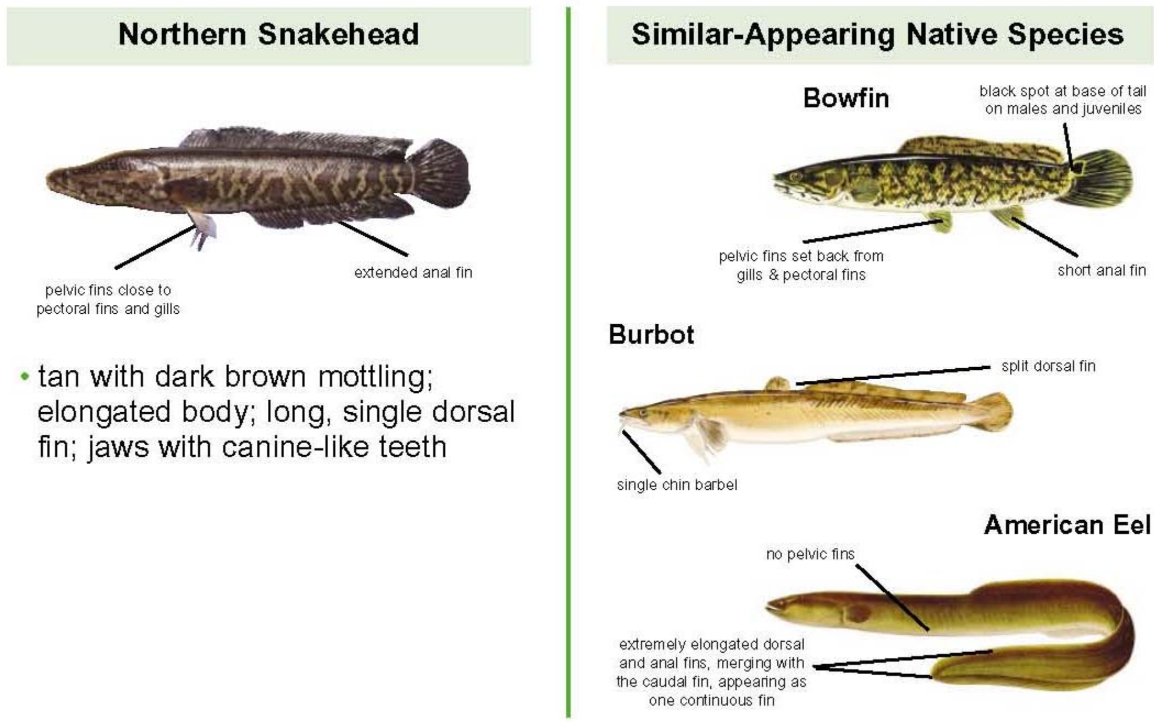

Figure 1. Distinguishing characteristics of northern snakehead and similar-appearing native species. (from: Illinois Department of Natural Resources (http://dnr.state.il.us/fish/digest/Page%2045.pdf))

Figure 2. Native distribution of northern snakehead (modified from Courtenay and Williams 2004).

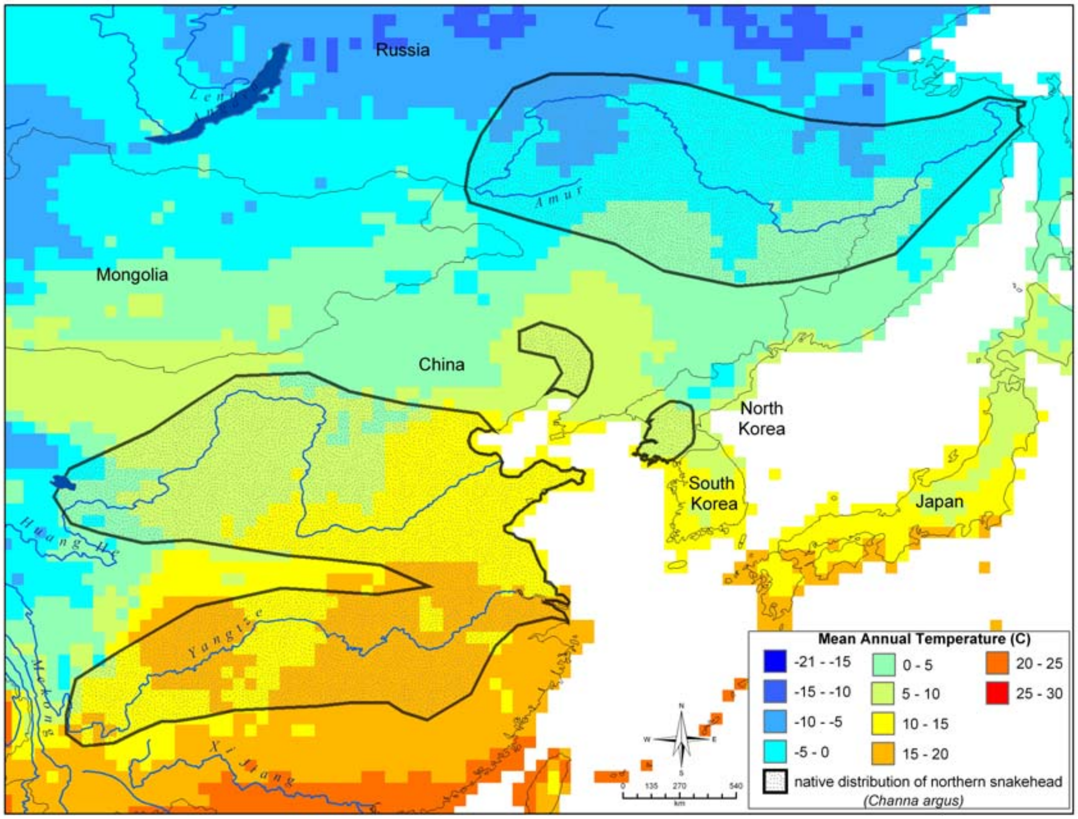

Figure 3. Native distribution of northern snakehead overlaid onto mean annual air temperature (based on 0.5° latitude x 0.5° longitude grid cells; data from Intergovernmental Panel on Climate Change (IPCC) data distribution center (http:// ipcc.ddc.cru.uea.ac.uk)).

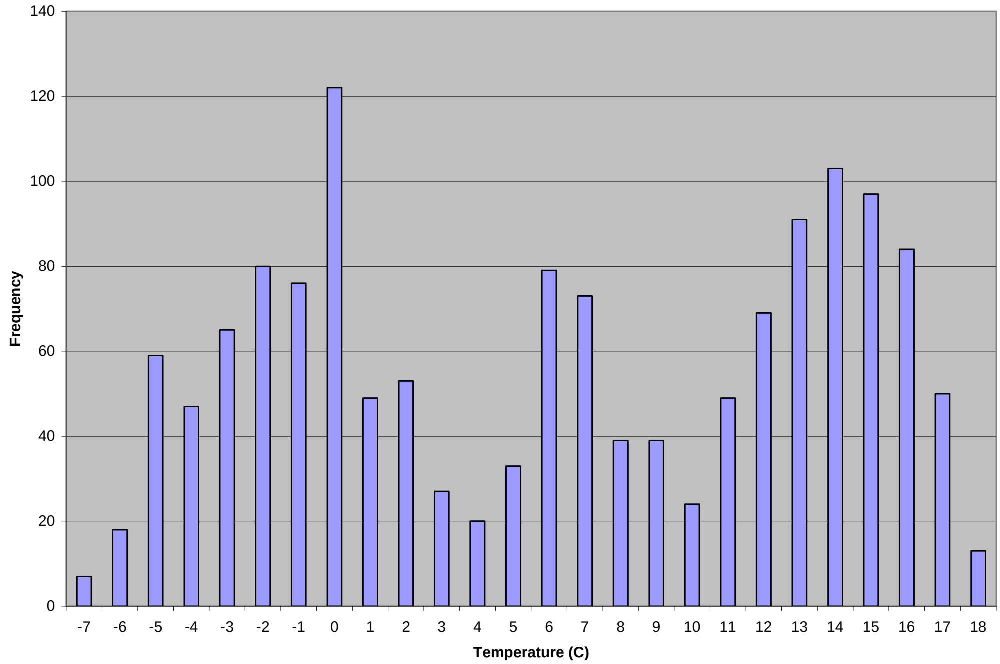

Figure 4. Frequency distribution of mean annual air temperature within the native distribution of northern snakehead as represented in Figure 3.

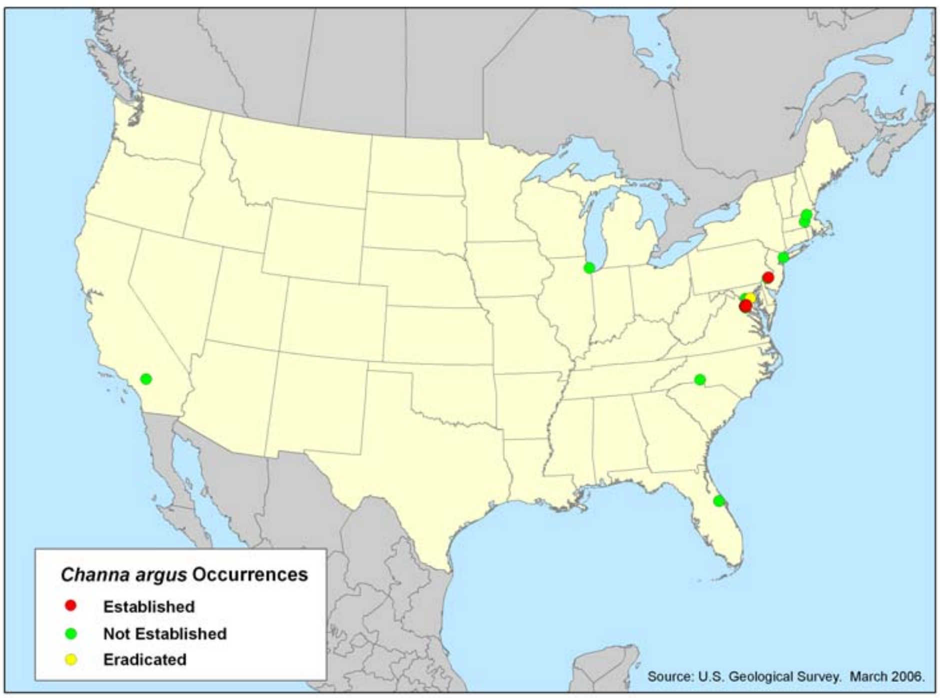

Figure 5. Distribution of northern snakehead in the United States as of March 2006. (Courtesy of Amy Benson, United States Geological Survey)

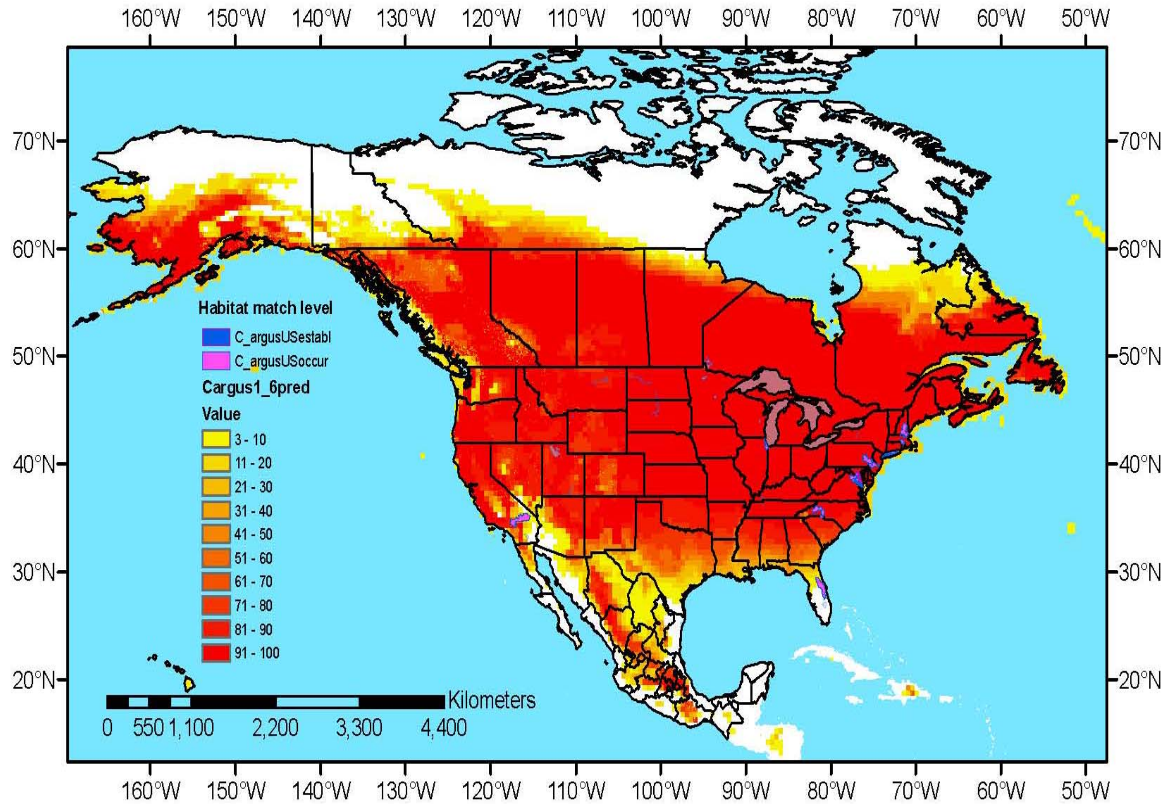

Figure 6. Potential distribution of northern snakehead in North America using GARP modeling. See Figure 6a for contribution of environmental layers to model prediction.

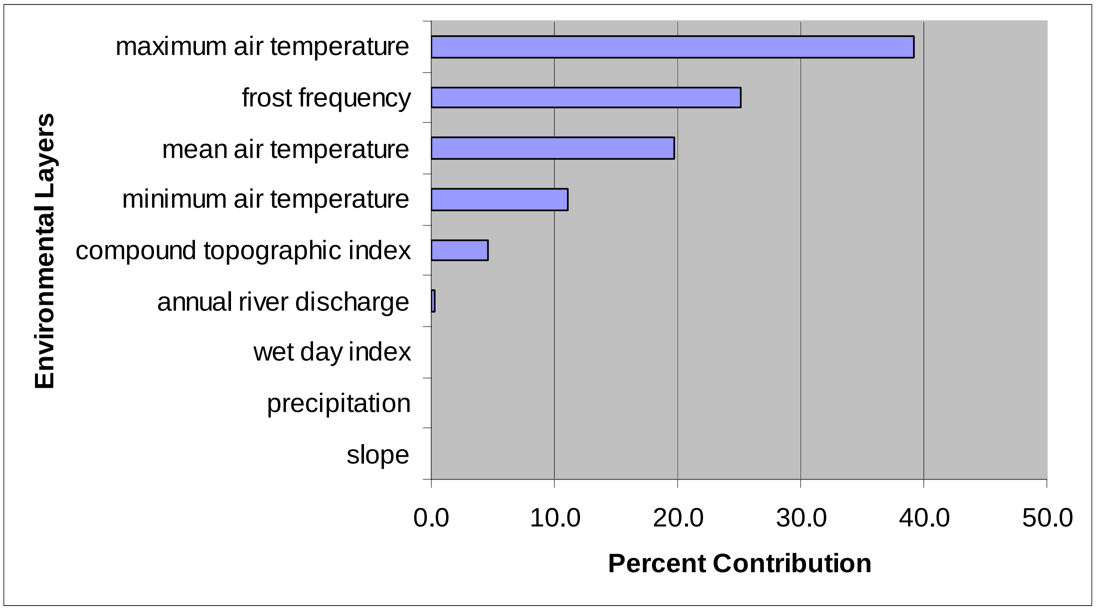

Figure 6a. Percent contribution of the environmental layers used in modeling the potential distribution of northern snakehead in North America (Figure 6).

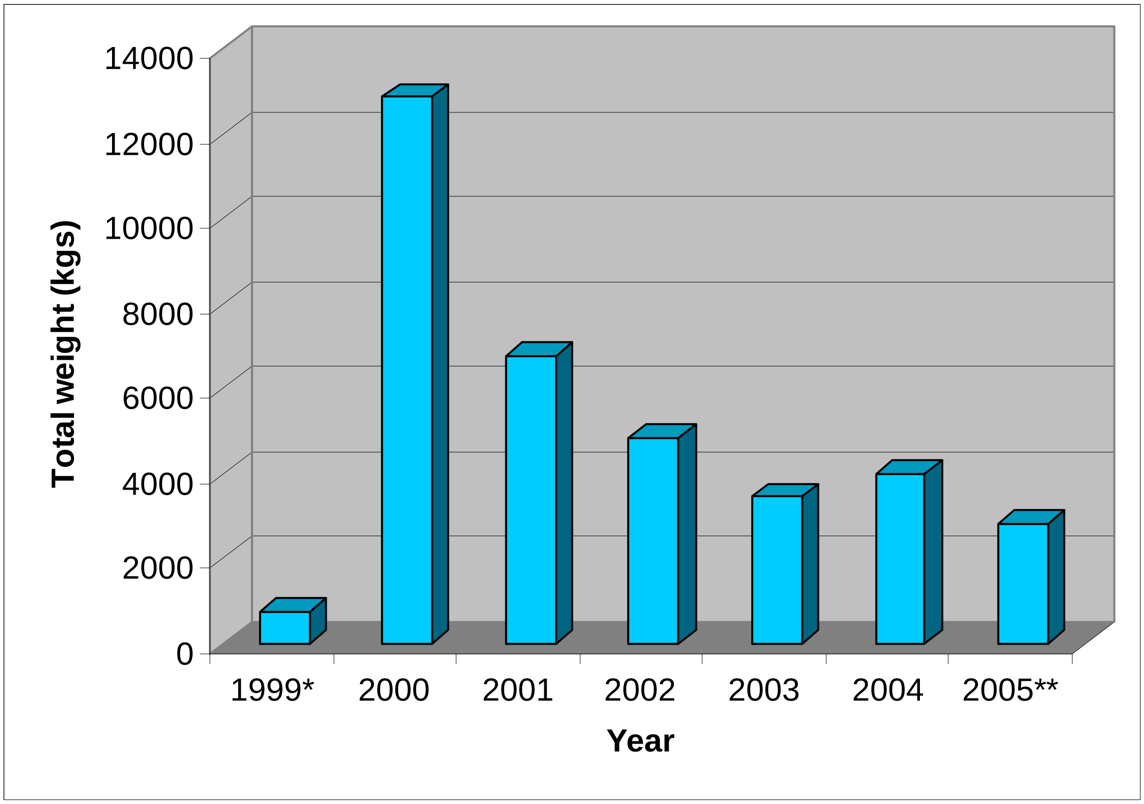

Figure 7. Weight (kg) of live snakeheads imported into British Columbia from December 1999* (1 month) to mid-August 2005** ($6^{1/2}$ months). Data from the Canadian Food Inspection Agency.

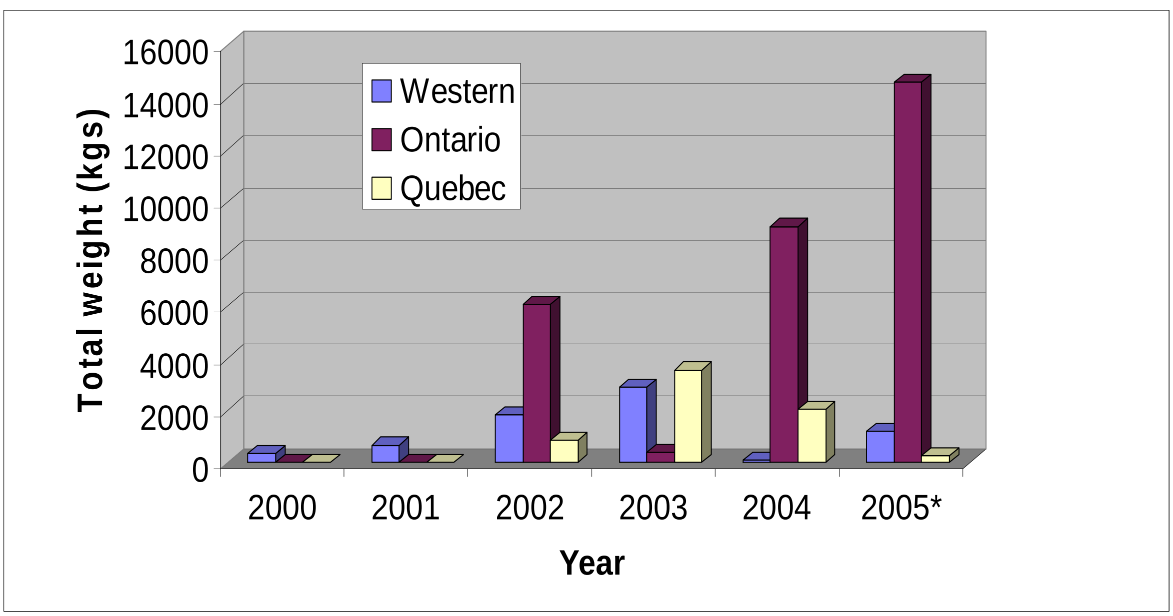

Figure 8. Weight (kg) of fresh (not live) or frozen snakeheads imported into Canada from 2000 to July 2005* (7 months). Data from the Canadian Food Inspection Agency.

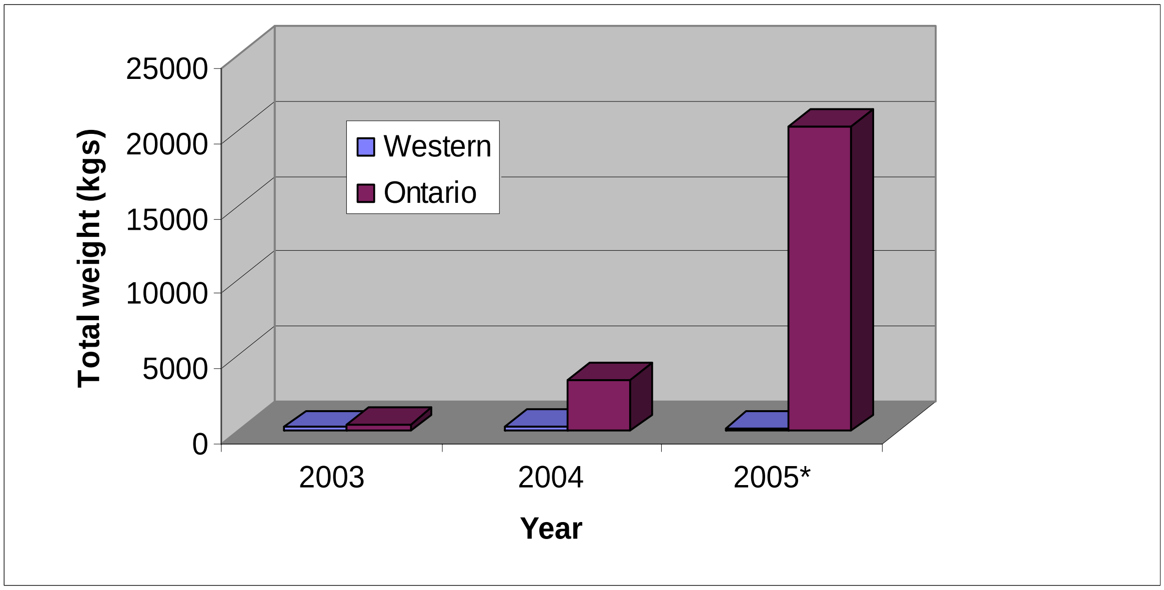

Figure 9. Weight (kg) of dried or paste form snakeheads imported into Canada from 2003 to February 2005* (2 months) (data from the Canadian Food Inspection Agency)

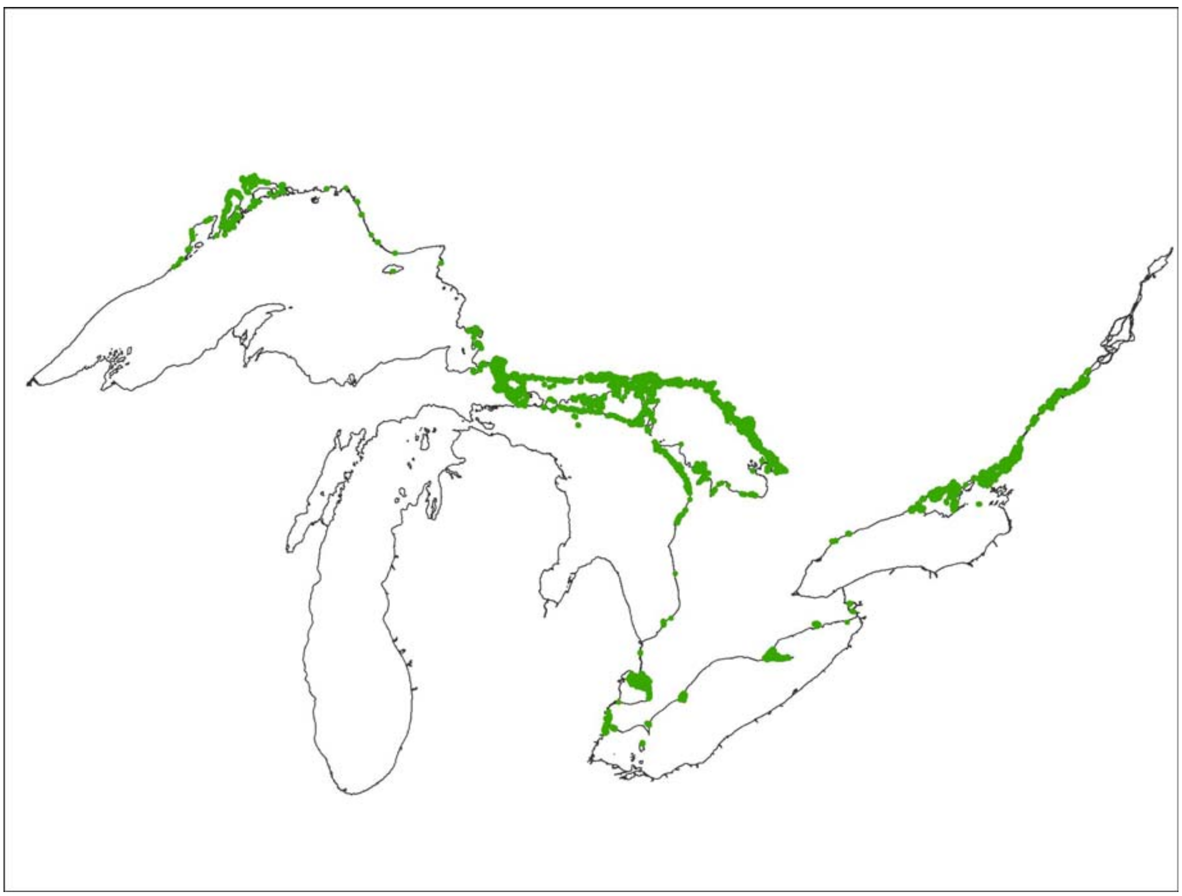

Figure 10. Distribution of vegetated shorelines in the Canadian Great Lakes basin (Shoreline Classification, Environment Canada)