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Research Article

Imported Asian swamp eels (Synbranchidae: *Monopterus*) in North American live food markets: Potential vectors of non-native parasites

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Abstract

Since the 1990s, possibly earlier, large numbers of Asian swamp eels (Synbranchidae: *Monopterus* spp.), some wild-caught, have been imported live from various countries in Asia and sold in ethnic food markets in cities throughout the USA and parts of Canada. Such markets are the likely introduction pathway of some, perhaps most, of the five known wild populations of Asian swamp eels present in the continental United States. This paper presents results of a pilot study intended to gather baseline data on the occurrence and abundance of internal macroparasites infecting swamp eels imported from Asia to North American retail food markets. These data are important in assessing the potential role that imported swamp eels may play as possible vectors of non-native parasites. Examination of the gastrointestinal tracts and associated tissues of 19 adult-sized swamp eels—identified as *M. albus* "Clade C"—imported from Vietnam and present in a U.S. retail food market revealed that 18 (95%) contained macroparasites. The 394 individual parasites recovered included a mix of nematodes, acanthocephalans, cestodes, digeneans, and pentastomes. The findings raise concern because of the likelihood that some parasites infecting market swamp eels imported from Asia are themselves Asian taxa, some possibly new to North America. The ecological risk is exacerbated because swamp eels sold in food markets are occasionally retained live by customers and a few reportedly released into the wild. For comparative purposes, *M. albus* "Clade C" swamp eels from a non-native population in Florida (USA) were also examined and most (84%) were found to be infected with internal macroparasites. The current level of analysis does not allow us to confirm whether these are non-native parasites.

Key words: fish, LEMIS, macroparasites, *Monopterus albus*, species complex, pathways

Introduction

A serious threat posed by the introduction of non-native fishes results from their role in the transfer of new or non-native parasites (Bunkley-Williams and Williams 1994; Škoriková et al. 1996; Font 2003; Salgado-Maldonado and Pineda-López 2003; Gozlan et al. 2006; Peeler et al. 2011). The numbers and diversity of potential fish-borne parasites is quite large and many are considered harmful to vertebrates, including humans (Chai et al. 2005). The risk of parasites being introduced has increased over recent decades due to the wide diversity and high numbers of live fishes being shipped internationally. The increase in the transport of live fish is generally linked to expanding international markets, improved transportation systems, and changes in human demographics (Gozlan et al. 2010; Kolar et al. 2010).

In North America, fish imports have long been associated with the aquarium and aquaculture industries, but since about the mid-1980s an increasing number of live fish have been transported and distributed to food markets in the USA and Canada. Among these are certain fishes introduced from Asia to North America known or suspected of having aided in the introduction and spread of non-native parasites (Alcaraz et al. 1999; Salgado-Maldonado and Pineda-López 2003). Despite expansion of the international live food trade, little attention has been given to live food markets in North America and their role as a pathway for introduced foreign fishes and fish-borne parasites.

Many live fishes (e.g., certain tilapias) sent to food markets in the United States and Canada are propagated at aquaculture facilities in North America, mainly the southern United States (Watanabe et al. 2002; Rixon et al. 2005).

However, some live fish and other aquatic animals destined for North American food markets originate in Asia where they are either cultured or, in some cases, taken from the wild (Courtenay and Williams 2002; L.G.Nico, unpublished data). Most North American recipients are ethnic food markets, businesses catering to a clientele that prefer to shop where the fish are displayed live, a clear indication of freshness. During a market transaction, some consumers elect to have their purchased fish slaughtered (e.g., gutted/filleted) while others choose to depart with their newly purchased fish still alive (Myers et al. 2010; L.G.Nico, personal observations).

Although many or most of the purchased live fish carried from markets are later killed and then consumed as food, a few are not. For example, some live fish are obtained by groups participating in religious ceremonial practices calling for release of captive animals into the wild (Severinghaus and Chi 1999; Henry 2007a; Shiu and Stokes 2008). Even though the relative numbers of fish purchased live in North American food markets and then liberated may be small, any release carries the risk that a non-native fish previously not present will become established in the wild. Moreover, parasites harbored by released non-native fish may also be introduced and potentially infect native species.

Swamp eels (family Synbranchidae) are not native to the USA or Canada. However, at least five separate wild populations of Asian swamp eels are established in North American open waters, including three in peninsular Florida, one in northern Georgia, and another recently discovered in New Jersey (Collins et al. 2002; L.G.Nico, unpublished data). Biologists initially assigned all non-native wild populations to *Monopterus albus* (Zuiew, 1793), a taxa with a broad natural geographic distribution in eastern and southeastern Asia. However, the taxonomy and systematic of synbranchids are unresolved, partly because external morphology is nearly featureless (Rosen and Greenwood 1976). Analysis of mitochondrial DNA supported the opinion that "*M. albus*" is a species complex, revealing that introduced and native populations of "*M. albus*" were composed of at least three separate, genetically distinct clades (Collins et al. 2002; Matsumoto et al. 2010). Based on the large numbers of swamp eels imported live to North America as food, we suspect that all or most of these non-native wild populations likely originated from live food market specimens. *Monopterus* and certain other swamp eels have a number of attributes that ensure their survival during international transport as cargo and while being held live in food markets awaiting purchase. These same attributes also augment the risk that individuals introduced into the wild will survive and reproduce. For example, most members of the family Synbranchidae are air breathers and able to survive weeks or months out of water (if kept moist) and without food (Liem 1967; L.G.Nico, unpublished data).

The aim of this paper is to present original data documenting the occurrence and abundance of internal macroparasites infecting live swamp eels imported from Asia and held live and for sale in ethnic food markets in North America. For comparison, we also recovered macro-parasites from a non-native population of Asian swamp eels inhabiting a drainage in the southeastern United States. Resulting data provide an important preliminary step in assessing the extent to which imported Asian swamp eels may serve as vectors of foreign parasites, information critical to the completion of a biological synopsis and risk assessment of introduced swamp eels.

Methods

Asian swamp eels examined for parasites were obtained from two sources: 19 individuals purchased live from an ethnic food market in the Atlanta metropolitan area (Georgia, USA) on 7 August 2003 (Figure 1); and 50 specimens captured by electrofishing in a freshwater lake in Manatee County within the Tampa Bay drainage of Florida, on 28 July 2003. Based on a combination of air-bill information on a shipping container at the Atlanta market and recently-obtained U.S. Fish and Wildlife Service Law Enforcement Management Information System (LEMIS) live animal shipment records, we determined that the market swamp eels originated in Vietnam and had been shipped a day or two prior to our market visit. LEMIS records also indicated our market specimens came from the wild as opposed to being captive-reared or bred.

Market swamp eels purchased for this study were adult-sized individuals, ranging from 595 to 875 (mean 688) mm total length [TL]. Wild-caught specimens from Florida waters included juveniles and adults, ranging from 137 to 625 (mean 320) mm TL. Based on genetic analysis of

Figure 1. Left: Young customer inspecting tub of live Asian swamp eels for sale in an ethnic food market in a large U.S. city, 7 August 2003. These animals—*Monopterus albus* "Clade C"—were the source of the market specimens used in the study (Field# LGN03-35b). Information derived from cargo container labels and customs records indicated these swamp eels were part of larger air shipments originating in Vietnam and that the fish were from the wild. Right: Tub of live Asian swamp eels for sale in same market, 1 June 2004 (Field# LGN04-07) (photographs by L. G. Nico).

muscle tissues and certain morphological characteristics (e.g., body color pattern), we determined that all swamp eels examined in our study, both the market specimens and those captured in Florida waters, belonged to the group designated as "Clade C" within the *Monopterus albus* species complex (Collins et al. 2002; T.M.Collins and L.G.Nico, unpublished data).

Market and wild-caught specimens were held live, without food, at the U.S. Geological Survey laboratory in Gainesville, Florida for several days before being anesthetized in cold water and then frozen (see Blessing et al. 2010). Frozen material was deemed necessary at the time to expedite transport, although its use over fresh has limitations in parasitological studies (see Pence et al. 1988). In early August 2003, the frozen specimens were transported to Florida International University (Miami) where they were thawed and necropsies performed following procedures detailed in Daily (1996). Focus was on recovery of internal parasites associated with gastrointestinal tracts and connected organs. This involved removal and separation of the stomach, intestines, and liver as well as retention of the contents and lining scrapings from the stomach and intestines. Each organ (stomach, intestine, liver and muscle) was separately placed atop a series of sieves for the recovery of parasites. Sieve contents were separately examined at 40x under a Leica MZ6 dissecting microscope with vertical illumination.

Any parasites recovered were then counted and identified to class or phylum taxonomic level and life stage based on presence or absence of an oral sucker, acetabulum, cecum, alimentary canal, proboscis, scolex and proglottids. Although parasites were not identified to lower taxonomic levels (i.e., family, genus or species), all parasites recovered from individual swamp eel specimens were isolated and examined under a microscope in an attempt to distinguish the number of different morphotypes or lower-level taxa present. This was accomplished by distinguishing parasites based on gross morphological characteristics, mainly body size, shape, armature, pigmentation, and number and location of gonads. Parasites recovered were also photographed and then preserved (without staining) in 70% ethanol. Some of the recovered parasites were subsequently discarded, a few because the specimens were damaged during recovery and others because the specimens later dried out due to ethanol evaporation.

Results

Most market and wild-caught swamp eels examined were infected with macroparasites. The 865 parasite specimens recovered included an array of encysted and unencysted nematodes, acanthocephalans, cestodes, and digeneans, and a few pentastomes (Table 1, Figures 2 and 3). Of 19 swamp eels purchased live from the Atlanta market, 18 (95%) contained macroparasites, with necropsies yielding a total of 394 individual parasites. Of 50 wild swamp eels from a Florida lake, 42 (84%) contained macroparasites, with a yield of 471 individual parasites (Figures 2 and 3).

Because the recovered parasites were not stained during initial preservation or were otherwise in poor condition, it was not possible during later re-examination of material to reliably distinguish non-native taxa or determine whether any of the taxa had been previously recovered from fish inhabiting North American waters. However, obvious differences in the gross anatomy of parasites removed from individual swamp eels allowed us to infer that many were infected with several different types of macroparasites. Based on apparent morphological differences, it was estimated that the number of different parasite taxa per individual swamp eel ranged from 0 to 9 (mean = 4.2) in market samples, and from 0 to 7 (mean = 2.3) for wild-caught specimens examined. The heaviest parasite load, 136 individual parasites, was found in a wild-caught swamp eel (420 mm TL). The heaviest load among market swamp eels was associated with a specimen (595 mm TL) yielding 77 individual parasites. In both of these fish, most parasites counted consisted of encysted or immature acanthocephalans. The swamp eel specimen with the most diverse macroparasite infection was a gravid female (713 mm TL) obtained from the food market. During dissection of that fish, we recovered 20 individual parasites, tentatively concluding that it was infected with as many as four different types of nematodes, four different acanthocephalans, and a single digenean taxon.

Discussion

The present study provides the first documented evidence that imported swamp eels available in North American ethnic food markets harbor a variety of macroparasites. The findings raise concern because of the likelihood that some, perhaps most of the parasites infecting market swamp eels imported from Asia are themselves Asian taxa, some possibly new to North America. The ecological risk is exacerbated because non-native fish, including swamp eels, sold in food markets are occasionally retained live by customers and a few of these later released into the wild, establishing wild populations (Courtenay and Williams 2002; Henry 2007a, b).

Studies conducted on *Monopterus albus* collected in Asia indicate the taxa is host to a variety of parasites (Lu 1991; Moravec and Wang 2002; Moravec et al. 2003). Some are harmful to humans and other vertebrates. For example, live swamp eels sold in markets in Southeast Asia are commonly infected with nematodes of the genus *Gnathostoma*, organisms known to infect humans and various domestic animals who consume raw or inadequately cooked fish containing the larval stage of the parasite (Setasuban et al. 1991; Sugaroon and Wiwanitkit 2003; Herman and Chiodini 2009; Sieu et al. 2009). All of the preserved parasites recovered from our market and wild-caught swamp eels were recently re-examined but no *Gnathostoma* species were found. However, our use of frozen rather than fresh swamp eels was likely inappropriate for recovery of these particular parasites. Consequently, even if

Figure 2. As a measure of parasite prevalence, histogram displaying percent frequency occurrence of the different macroparasite groups and their life stages recovered during necropsy of the digestive tracts and associated organs of introduced Asian swamp eels. Included in samples were market swamp eels (n = 19) imported from Asia and purchased live from an ethnic market in the United States. Wild-caught swamp eels (n = 50) were taken from an established non-native population in Florida.

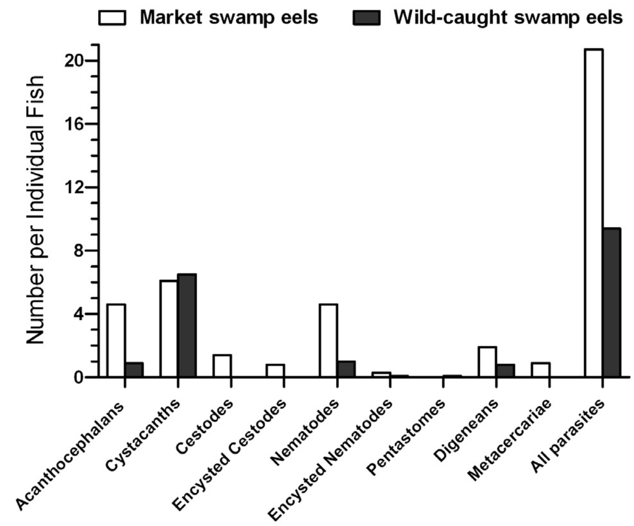

Figure 3. Mean abundance of macroparasites based on the numbers of recovered individual parasites, by major taxonomic group and life stage, per Asian swamp eel specimen. Included in samples were market swamp eels (n = 19) imported from Asia and purchased live from an ethnic market in the United States. Wild-caught swamp eels (n = 50) were taken from an established non-native population in Florida. Note: because a few swamp eels were without parasites, mean intensity of infection (not displayed) would be slightly higher than the mean abundance (see Bush et al. 1997 for definition of terms).

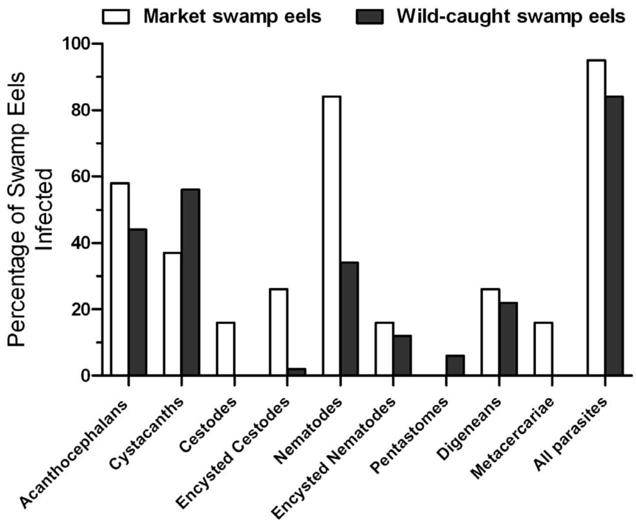

Table 1. Descriptive statistics of major groups of macroparasites recovered from swamp eels (n = 19) imported from Asia and purchased live from an ethnic market in the United States. See Bush et al. (1997) for definitions of the terms prevalence, abundance, and intensity.

Taxon/Life Stage	Site	Prevalence (%)	Mean Abundance (± SE)*	Mean Intensity (± SE)*
Acanthocephalans	Intestine, stomach	58	4.6 ± 2.0	8.0 ± 3.1
Cystacanths	Intestine, stomach	37	6.1 ± 3.8	16.4 ± 9.4
Cestodes	Intestine	16	1.4 ± 1.2	8.7 ± 7.2
Encysted cestodes	Intestine	26	0.8 ± 0.3	3.2 ± 0.4
Nematodes	Intestine, stomach, liver	84	4.6 ± 0.9	5.5 ± 1.0
Encysted nematodes	Intestine, stomach	16	0.3 ± 0.2	1.7 ± 0.7
Digeneans	Intestine, stomach, liver	26	1.9 ± 0.9	7.4 ± 2.1
Metacercariae	Muscle	16	0.9 ± 0.6	6.0 ± 1.8
All parasites	(above organs)	95	20.7 ± 4.2	21.8 ± 4.2

*SE = standard error

present these parasites may not have been detected. We are now in the process of procuring additional market swamp eel specimens which will be examined using methods suitable for detection and recovery of *Gnathostoma* spp. and other potentially harmful parasites.

Degree of risk – that introduced swamp eels will become established and serve as vectors of non-native parasites – is likely linked to the source and numbers of swamp eels imported, the frequency of imports, and the number and distribution of receiving markets, among other factors. Surveys of ethnic retail food markets conducted over a ten year period (2001-2010) revealed that multiple varieties and species of Asian swamp eels are in the live food trade pathway and available, either regularly or intermittently, in select food markets across the USA and parts of Canada (L.G.Nico, unpublished data). In addition, LEMIS shipment records for live fish imports obtained from the U.S. Fish and Wildlife Service (USFWS) indicate that large numbers of live swamp eels have been regularly shipped into the United States for food or other commercial purposes since at least the mid-1990s. The most commonly listed countries of origin over the period 1996-early 2010 were Vietnam (443 shipments), Bangladesh (388), and China (36). For that 15-year period, LEMIS records register well over 500,000 live swamp eels shipped from Asia to the United States (although one or few specific shipment records, those documenting extremely large swamp eel numbers, are suspect). The occur-ence of swamp eels in the live food trade closely parallels the pattern observed for other imported live Asian fishes, for example, Asian snakeheads of the genus *Channa*, a group now banned from U.S. import (Courtenay and Williams 2002; L.G.Nico, personal observations).

Although market surveys and currently available USFWS-LEMIS import records indicate the distribution of live Asian swamp eels among North American food markets has continued for at least 15 years, it is likely that such imports began earlier, possibly in the 1980's, the decade when ethnic retail food markets on the continent reportedly began to commonly receive and display live fish (Sediva 2001). Other than LEMIS records and information gleaned from market surveys, little is known and almost nothing published on the live food trade and their targeted North American markets, especially with regard to possible ecological risks associated with imported live fish. Most information on U.S. live food markets is typically available only in reports resulting from economic studies of consumers or research related to expansion or improvement of the aquaculture and food industries (Gorman 2009; Myers et al. 2010). Although non-native swamp eel populations are now established in several drainages in the USA, many states have no laws barring the import of live swamp eels for the live food market.

In North American markets, Asian swamp eels typically are displayed under the names "yellow eel", "Chinese yellow eel" or "Vietnam eel", distinguishing them from "white eels" or anguillid eels, an unrelated groups of fishes also commonly seen live in many of the same food markets (L.G.Nico, unpublished data). In Southeast Asia, swamp eels distributed to food markets may include individuals propagated or raised in aquaculture facilities as well as individuals collected in the wild or open waters, including rice paddies (Sieu et al. 2009; Weimin 2010). According to USFWS-LEMIS records for the period 1996-2010, different shipments of live swamp eels from Asia to North America may include either cultured/captive-reared or wild-caught individuals. Such information may have relevance in terms of the types and numbers of parasites harbored by internationally-shipped swamp eels. Nevertheless, even if certain non-native parasites associated with imported live fish are found in new environments, the actual pathway of introduction may remain unknown or only suspected (Sterud and Jorgensen 2006). Absence of evidence means that invasion pathways remain open, often inadequately monitored or poorly regulated. An analysis of live fish imported directly from known foreign sources and available in food markets provides information helpful in identifying likely pathways of introduction.

In summary, we have shown that in a sample of wild-caught live swamp eels imported from Vietnam and sold in a food market in the US, the majority were infected with one or more macroparasites. Since these swamp eels are from a native-range population in Asia, their parasites are also likely to be native-range (i.e., of Asian origin), presenting the risk of introduction of new parasites into US waters. In addition, the majority of swamp eels sampled from a non-native population of swamp eels in Florida

(USA) were also infected with macroparasites, although our current level of analysis does not allow us to determine whether introduced populations contain non-native parasites. The parasites sampled from the imported market swamp eels and from swamp eels collected in Florida waters included acanthocephalans, trematodes, cestodes, and nematodes. Further study based on better-preserved specimens will allow us to definitively determine the numbers of species involved, the proportion of parasites that are not native to the US, and whether any of these parasites might present a risk to human health or native species.

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