

Research Article

Discovery of the invasive Mayan Cichlid fish “*Cichlasoma*” *urophthalmus* (Günther, 1862) in Thailand, with comments on other introductions and potential impacts

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Abstract

We report on the occurrence and possible establishment of a non-native cichlid fish in a brackish-water system in the lower Chao Phraya River delta region, Thailand. Although, the possibility of some degree of introgressive hybridization can not be ruled out, Thailand specimens agree best with Mayan Cichlid “*Cichlasoma*” *urophthalmus* (Günther 1862). Our collections represent the first records of this New World, highly-invasive, euryhaline fish from Thailand and coincides with recent collections from Singapore. Positive identification of specimens as “*C.*” *urophthalmus* requires caution due to the diversity of the Cichlidae (>1,300 species), widespread introduction of many family members, variation within species, extensive interspecific overlap in characters, and proliferation of artificial cichlid hybrids (e.g., Flowerhorns). We first became aware of the Thailand population in 2005 when “*C.*” *urophthalmus* began appearing in the catches of local fishermen. We visited the site in November 2006 and obtained and examined voucher specimens. The abundance and wide size range of juveniles and adults in local ponds and an adjacent canal is evidence of natural reproduction. Because water bodies throughout the Chao Phraya delta are interconnected and subject to flooding, it is likely that “*C.*” *urophthalmus* is already established and is dispersing, but surveys and monitoring are needed to determine their exact geographic range. The Thailand population is compared to “*C.*” *urophthalmus* introduced into Florida (USA). Based on what is known about Florida “*C.*” *urophthalmus*, it is predicted that this cichlid will further invade coastal and inland waters in Thailand and elsewhere in Southeast Asia. This cichlid has a long history in the aquarium trade in Europe. However, there are no records from the wild in European waters and, because of the colder climate, the possibility of establishment in that region is relatively low.

Key words: introduced fishes, Cichlidae, Flowerhorn hybrids, invasive species, Thailand, Singapore, Malaysia, Chao Phraya River

Introduction

Similar to trends observed in other world regions, the number of non-native fish species introduced and established in Southeast Asia has increased considerably over recent decades (De Silva 1989, Pallewatta et al. 2003, Welcomme and Vidthayanon 2003). However, the geographic distributions and biology of many southeast Asian non-native fishes are poorly documented in the scientific literature. The situation is gradually improving as evidenced by recent peer-reviewed publications detailing the occurrence and identification of a few species (e.g., Liang et al. 2005, Chavez et al. 2006, Dudgeon and Smith 2006, Page and Robins

2006). Still, most information on the region’s non-native fishes is largely limited to the grey literature, much of it consisting of species listings (some partially annotated), and usually with few references to primary sources. Moreover, because of the lack of published field data and apparent paucity of museum voucher specimens, the non-native geographic ranges of many introduced fishes in Southeast Asia remain unclear and their specific identifications inadequately confirmed.

In recent years the sport-fishing guide Jean-Francois Helias, of Fishing Adventures Thailand, has periodically sent us photographs of fishes that he and colleagues caught in Southeast Asia. Some photographs were of fishes that Mr. Helias



Figure 1. Specimen (>100 mm TL) identified by us as "*Cichlasoma*" *urophthalmus*. Fish was collected 26 September 2005 by Jean-Francois Helias while angling in the lower Chao Phraya River delta, Thailand. Photograph by J.-F. Helias.

was unable to positively identify and, among these, a few were images of non-native fishes either not previously reported or poorly documented for the region. Of particular interest were photographs sent to us in September 2005 showing a fish that we identified as the Mayan Cichlid "*Cichlasoma*" *urophthalmus* (Günther, 1862) (Figure 1). This cichlid is native to the New World tropics and introduced populations in Florida (USA) appear to be highly invasive. Mr. Helias informed us of the existence of a population in a brackish water canal system south of Bangkok in the lower Chao Phraya River delta near the Gulf of Thailand. He first became aware of its presence in 2005 when specimens began appearing in the catch of a local fisherman employed to provide live bait fish. In November 2006, responding to our desire to examine actual specimens and learn more about the wild population's status, Mr. Helias kindly agreed to guide us to the site in Thailand where the cichlid had been found. He also arranged for the local fisherman who trapped the first specimens to capture additional individuals for our inspection.

"*Cichlasoma*" *urophthalmus* is native to the Atlantic slope of Middle America within a latitudinal range of about 13°30'N to 21°39'N (Miller et al. 2005). As is the case with many cichlids, there is uncertainty concerning this species' generic placement (Kullander 2003). Due to this continued taxonomic confusion, many name combinations still appear in technical and popular publications, including *Amphilophus urophthalmus*, *Parapetenia urophthalma*, *Nandopsis urophthalmus*, and *Cichlasoma urophthalmus*. We follow recent authorities, Kullander (2003) and Miller et al. (2005), in referring to this species as "*Cichlasoma*" *urophthalmus* to indicate uncertainty of generic name assignment. Largely because of its mixed importance as an

ornamental, food, and sport species, many common names have also been used for this species. Some of the names most frequently used by English speakers are Mayan Cichlid, Mexican Mojarra, Orange Tiger, and False Red Terror, and those used by Spanish speakers, Catarrica and Mojarra del Sureste.

"*Cichlasoma*" *urophthalmus* is a medium-sized fish, adults typically range from 8 to 20 cm standard length (SL) (Loftus 1987, Faunce et al. 2002, Chávez-Lopez et al. 2005). Kullander (2003) reported a maximum size of 30 cm total length (TL); Miller et al. (2005) gave a maximum of 22 cm SL and 600g weight. It has the teeth and short intestine of a carnivore and diet studies have confirmed that adults are highly opportunistic predators, taking fish and a wide variety of macro-invertebrates (e.g., shrimp, gastropods, annelids, sponges) (Caso-Chávez et al. 1986, Martínez-Palacios and Ross 1988, Bergmann and Motta 2005). Marked trophic flexibility is further evidenced by the high proportion of plant material and detritus in the diets of some populations (Caso-Chávez et al. 1986, Loftus 1987, Chávez-Lopez et al. 2005). In terms of behavior, "*C.*" *urophthalmus* is highly aggressive and territorial, being most pronounced in adults during mating, spawning, nesting, and guarding of young (Martínez-Palacios et al. 1993).

Although basically a shallow-water fish usually found in lentic habitats, "*C.*" *urophthalmus* is highly adaptable ecologically, occurring in a diverse array of natural and artificial inland and coastal environments, including small and large streams, canals, ditches, lakes, ponds, limestone sinkholes and connected caves, marshes, coastal lagoons, and mangrove swamps (Hubbs 1938, Loftus 1987, Faunce and Lorenz 2000, Miller et al. 2005, Nico 2005; L.G. Nico, personal observations). The species can survive abrupt changes in salinity and naturally-reproducing populations have been documented as inhabiting freshwater, brackish, and even marine environments (Stauffer and Boltz 1994, Greenfield and Thomerson 1997, Chávez-Lopez et al. 2005). Although in its native range this species is limited to tropical latitudes (Miller et al. 2005), introduced populations in Florida extend far into the subtropical zone (Nico 2005). "*Cichlasoma*" *urophthalmus* is tolerant of a wide temperature range (14 to 39 °C) and is also capable of surviving low-oxygen conditions (Martínez-Palacios and Ross 1986, Stauffer and Boltz 1994).

Prior to the recent records from Southeast Asia, the only documented non-native populations of "*C.*" *urophthalmus* were all within tropical and subtropical North America. In southeastern Mexico, reproducing populations in the Papaloapam River drainage (Atlantic Slope) are considered non-native (Obregon-Barbosa et al. 1994, Contreras-Balderas 1999, S. Contreras-Balderas, personal communication). A few Yucatan cenote populations were also rumored to be the result of introductions (Hubbs 1938). In the USA, populations of "*C.*" *urophthalmus* were discovered in 1983 in southern Florida and the species persisted during those early years in spite of adverse environmental conditions, including severe cold spells, a drought, floods, and wide annual salinity fluctuations (Loftus 1987). Over the past two decades their range in Florida has greatly expanded and the species now occupies a significant portion of the peninsula's southern half (Faunce and Lorenz 2000, Matamoros et al. 2005, Nico 2005; L.G. Nico, personal observations). The mechanism of introduction in non-native parts of its range in Mexico is believed to be linked to its use as a food or forage fish, whereas the origin of the Florida population is unknown, although likely associated with the ornamental fish trade (Loftus 1987, Contreras-Balderas 1999, S. Contreras-Balderas, personal communication).

In this paper we report on the results of a field excursion to the Chao Phraya River delta and provide evidence for the occurrence of a reproducing nonindigenous population of "*C.*" *urophthalmus*. We also present information on other Southeast Asia records of "*C.*" *urophthalmus*. Lastly, we assess the risks associated with the introduction of "*C.*" *urophthalmus* in Asia and other regions of the world and list the non-native fishes considered established or possibly established in Thailand.

Materials and Methods

In Thailand, fish specimens were collected by a local fisherman who used different types of gear, including traps, nets, and hook-and-line. We visited the Chao Phraya River delta on 12 November 2006 and observed the fisherman sample shoreline habitat with a long-handled dip net to catch "*C.*" *urophthalmus* juveniles and several other small non-native and native fishes. During our visit, we were able to document collections of fishes and their habitat with digital

cameras and digital video. We also observed live fishes collected prior to our visit. At one area along the shoreline where "*C.*" *urophthalmus* had just been netted, we measured and recorded water temperature, pH, and conductivity using recently-calibrated Hanna meters (models HI 98127 and HI 8733C). To determine salinity (ppt), we applied the conductivity-salinity relationship equation of Williams (1986).

All "*C.*" *urophthalmus* specimens and a few other species caught during our visit were preserved immediately in the field, some placed in 10% formalin and others in 70% ethanol. After several weeks, formalin-preserved specimens were transferred to 70% ethanol. The standard length (SL) of each preserved specimen was measured to the nearest mm with dial calipers. Diet was determined by removing the entire gastrointestinal tract and examining the contents from 15 field-preserved specimens that had been collected on 12 November 2006. Gut contents were examined and identified to lowest practical taxon under a dissecting microscope. Frequency of occurrence and relative percent volume of each food type was recorded. An estimate of relative gut fullness was made using scores ranging from 0 (empty) to 3 (full, or almost full). Following Nico and Taphorn (1988), this information was used to calculate relative importance (adjusted percent volume) of each food category. The length of the gut, from beginning of the esophagus to anus, was measured for 10 of the dissected specimens. Most preserved voucher specimens are deposited in the collection of the research laboratory of Ichthyology of Kasetsart University, Chatuchak, Bangkok, and registered under the catalogue numbers RLIKU 1450, 1451, and 1452. Two additional specimens are deposited in the Florida Museum of Natural History Ichthyology Collection (UF) under catalogue number UF 167281.

For purposes of identification, we compared Thailand specimens to native-range "*C.*" *urophthalmus* specimens collected in Guatemala and Mexico and non-native specimens from Florida (USA). Comparative material examined included: Guatemala (all from Lake Petén Itzá, Department of Petén): UF 39364 (19), 20 July 1980. UF 39378 (8), 14 Jul 1980. UF 166859 (6), August 1993. UF 167026 (6), 10 January 1993. UF 167030 (3), Summer 1992. Mexico: UF 15949 (7) Laguna Isleta, WSW of Tenochtitlán, Veracruz State, 5 February 1968. Florida (all UF uncataloged): Field Number LN99-77 (1) South



Figure 2. Adjacent water bodies in the lower Chao Phraya River delta, Thailand, found to be inhabited by “*Cichlasoma urophthalmus*”. Photographs by Leo G. Nico (13 Nov 2006).

New River Canal, Broward County, 29 May 1999. JJH00-03 (2) Canal L-31W, Dade County, 11 January 2000. LGN00-19 (5) Canal L-31W, Dade County, 25 April 2000. LGN00-35 (2) Imperial River, Lee County, 13 December 2000. LGN01-22 (10) Rim Canal of Lake Okeechobee, Okeechobee County, 1 September 2001. LGN03-42 (1), main canal in Golden Gate Estates, Collier County, 5 December 2003. LGN06-82 (1) Crane Creek, Brevard County, 8 August 2006.

Our investigation of the possible occurrence of wild and captive introduced “*C.*” *urophthalmus* in other parts of Asia and other regions of the world consisted of an intense search of the literature and internet sources, supplemented by inquiries to museum fish curators and other experts.

Site Description

The Chao Phraya basin drains about 160,000 km² or nearly one-third of Thailand’s land area. Its

delta, one of the largest in Southeast Asia (about 40,000 km²), is on the Gulf of Thailand (Molle and Srijantr 2003, Szuster 2003). The deltaic plain is low lying, with little relief and a tropical wet savannah climate. The lower delta region has been highly modified by humans, with much of the floodplain’s water compartmentalized by low artificial levees. In combination with other modifications, the result has been the creation of a mosaic of aquatic habitats consisting of numerous small and large ponds or reservoirs, small and large ditches, and numerous canals. Most aquatic habitats are interconnected and water can be easily transferred into different sub-basins during periods of exceptionally high or low flows. Extensive shrimp and fish farming are practiced throughout the delta (Szuster 2003; B. Szuster, personal communication).

The capture site (Figure 2) was a brackish-water system of interconnected ponds and canals (approx. 13°33'38.5"N; 100°32'57"E) in the lower Chao Phraya River delta of the Amphoe Pra Samut Chedi district, southeastern Samut Prakan province, Thailand. The area, situated about one kilometer west of the main-stem of the lower Chao Phraya River and within one or a few kilometers of the Gulf of Thailand, is exposed to marked tidal influence. At approximately 11:30 h on 12 December 2006, water along the shore area at one of the capture sites was 27.5°C, pH 7, electrical conductivity 32,500 µS/cm, and salinity 20.5 ppt.

Results and Discussion

Identification of the Thailand Population

During our visit to the site in the lower Chao Phraya delta on 12 November 2006, a few short passes along the shore-line with a single dip net yielded 46 small “*C.*” *urophthalmus* (Figure 3). These ranged in size from 17 to 87 (mean = 47) mm SL. At the same site, we also photographed (still and video) a few large “*C.*” *urophthalmus* (estimated to be between 130 and 180 mm SL, Figure 4) and other non-native species that locals had collected prior to our arrival. All or most of the large “*C.*” *urophthalmus* were caught angling with hooks baited with small shrimp. Some of these cichlids were caught on 12 November 2006 and others were presumably captured during preceding days or months. These fish were being maintained live in an outdoor concrete tank and none were preserved.



Figure 3. Preserved "*Cichlasoma*" *urophthalmus* (40 and 64 mm SL), part of the voucher specimen sample netted at site in lower Chao Phraya River delta on 13 November 2006. Smaller specimen (A) is missing part of caudal fin. Based on size, absence of gonadal tissue, and typical size at first maturity, these fish were both determined to be juveniles. Photographs by H.L. Jelks.



Figure 4. "*Cichlasoma*" *urophthalmus* (143 mm SL), probably an adult, taken from the lower Chao Phraya River delta site in Thailand. This specimen shows a color pattern and body shape different from introduced Florida "*C.*" *urophthalmus*, but is similar to some individuals reportedly captured in their native range in Mexico. It was captured either on 13 November 2006 or shortly before but was not preserved, therefore we were unable to determine reproductive status, but body size indicates it is an adult. Photograph by J.-F. Helias.

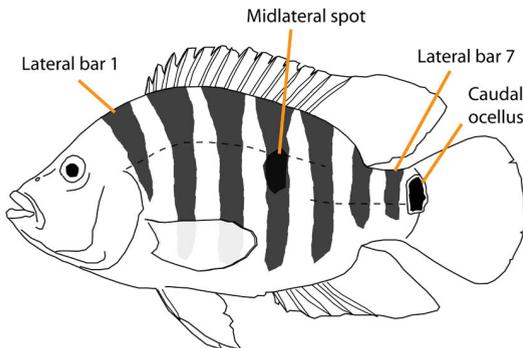


Figure 5. Diagrammatic representation of melanistic coloration of "*Cichlasoma*" *urophthalmus* highlighting primary distinguishing patterns. Also note the divided lateral line, a characteristic of many cichlids. Illustration based on an adult fish from Florida (USA).

Identification of these specimens as "*C.*" *urophthalmus* was based on the literature (Günther 1862, Hubbs 1936, Martinez-Palacios and Ross 1988, Greenfield and Thomerson 1997, Miller et al. 2005), comparison with live and preserved specimens from native and other non-native populations (Table 1), and discussions with other ichthyologists familiar with the species. Several of the more important traits useful in distinguishing "*C.*" *urophthalmus* are: 1) seven (rarely 8) prominent dark bars on body (the first an oblique along nape that crosses near the lateral line origin, and the seventh or posterior-most bar positioned on the caudal peduncle); 2) conspicuous, dark blotch centered above the caudal fin base and often outlined by a light halo (this blotch may be nearly round, oval square, or vertically elongate, and is noticeably blacker than the dark body bands); 3) caudal fin rounded; 4) anal-fin spines 5-7 (usually 6); 5) dorsal-fin spines 14-18 (usually 16); and 6) well-developed canine, unicuspid teeth in both jaws. Some of these characters are illustrated in Figure 5. Males and females are similar in appearance and difficult to distinguish even during the reproductive season when breeding adults of both sexes develop intense red on the ventral part of body (Martinez-Palacios et al. 1993, Martinez-Palacios and Ross 1992).

We noted that "*C.*" *urophthalmus* specimens from the Chao Phraya delta exhibited variation in color patterns and body shapes. In particular, one of the larger specimens (143 mm SL) was slightly unusual in color pattern and shape (Figure 4). This fish may simply represent an odd "*C.*" *urophthalmus* specimen, but we cannot discount the possibility of introgressive hybridization (see later discussions concerning hybrids and Flowerhorn cichlids). The scientific and aquarium literature clearly reveals that "*C.*" *urophthalmus* is highly variable in color and certain anatomical features (e.g., body proportions). Based on a combination of field and laboratory research, Hubbs (1936, 1938) reported finding consistent variations among different native populations leading him to recognize as many as nine separate subspecies. Kullander (2003) concluded that "*C.*" *urophthalmus* is one of the more enigmatic cichlid taxa. He treated a few of Hubbs' taxa as different species, and also noted that some highly localized subspecies from the Yucatán of Mexico merit further review. In contrast, Miller et al. (2005) stated that use of Hubbs' trinomials was unwarranted, but provided no details. Barrientos-

Table 1. Frequency distributions of selected characters in "*Cichlasoma*" *urophthalmus*, comparing specimens (17-87 mm SL) caught in the Chao Phraya Delta, Thailand to non-native specimens (20-185 mm SL) from Florida (USA) and native-range specimens (24-170 mm SL) from Guatemala and Mexico (see Materials and Methods section for sources of material examined).

Population	Number of anal-fin spines					Number of dorsal-fin spines					
	5	6	7	Mean	SD	15	16	17	18	Mean	SD
Thailand (n = 37)	3	34		5.9	0.28	2	30	5		16.1	0.43
Florida (n = 22)	5	16	1	5.8	0.50	1	21			16.0	0.21
Guatemala and Mexico (n = 49)	2	38	9	6.1	0.46	2	24	22	1	16.4	0.61

Population	Number of lateral bars				Midline blotch on 4th lateral bar		
	7	8	Mean	SD	Present (distinct)	Present (faint)	Absent
Thailand ^{a,b}	43	1	7.0	0.15	7	34	4
Florida (n = 22)	20	2	7.1	0.29	4	9	9
Guatemala and Mexico (n = 49)	47	2	7.0	0.20	10	11	28 ^c

a/ lateral bar counts based on 44 specimens; midline blotch observations on 45 specimens.

b/ Lateral bar counts and observations on midline blotch were based on left side of fish. In some individuals there were eight lateral bars present on one side, but seven bars on the right side of same specimen. Similarly, in some species a midline blotch was present on one side but absent on opposite side of same specimen.

c/ Preservation may have resulted in loss or degradation of the midline blotch pigmentation in some specimens.

Medina (2003) has been investigating the morphological variation among the different native "*C.*" *urophthalmus* populations, but his findings have not been published.

Greenfield and Thomerson (1997) reported "*C.*" *urophthalmus* as having 5-6 vertical dark bars, presumably ignoring the first (oblique) bar. Nearly all (110 of 115) specimens we examined, including material from Thailand, Florida, and native populations, had 7 dark bars (Table 1; counts included the first, oblique bar), the number most commonly reported. Although the bars were prominent in our Thailand specimens, Hubbs (1936, 1938) noted substantial variation in the width and intensity of these bars in different native populations he studied. The blotch on the base of the caudal fin, often described as an "ocellus," also exhibits considerable variation in shape and size, and intensity. In most specimens we examined, the caudal spot was usually a large oval, but in some the blotch was nearly round or even slightly square. In contrast, some "*C.*" *urophthalmus* have this tail marking vertically elongate (Figure 1; also see photographs in Axelrod 1993: 609; Staeck and Linke 1995). These lateral bars and the caudal fin blotch are present in both juveniles and

adults, including specimens 30 mm TL or smaller (see photographs appearing in Řičan et al. 2005). During our examination of preserved specimens from different populations (Table 1), we observed that the light halo surrounding the caudal spot was prominent in most large specimens (Figure 1), but less distinct or even absent in some smaller preserved specimens.

Miller et al. (2005) noted the presence of another large dark blotch, one centered on the fourth vertical bar which they considered a key character in Mexican "*C.*" *urophthalmus*. This marking, when present, is quite faint in many Thailand and Florida specimens and absent in some of the older preserved material (Table 1). In a few Thailand and Florida and native-range specimens additional midline blotches also are present on fifth, and in some, on the sixth and seventh lateral bars. In some specimens, a midline blotch is present on one side, but less distinct or even absent on the other side of the same fish.

Positive identification of introduced cichlids requires caution due to the diversity of the Cichlidae (>1,300 species), unresolved taxonomy of many genera and species, widespread introduction of many species, morphological and

color variation within species, marked overlap in color patterns and morphological characters among different taxa, and the proliferation of natural and artificial cichlid hybrids (Lever 1996, Fuller et al. 1999, Kullander 2003, Miller et al. 2005). Minor differences in color pattern, in particular, are not always useful as a distinguishing trait because of the intra-specific variation in cichlid colors, differences often related to ontogeny, breeding condition, gender, behavior, and ecology (Neil 1984, Řičan et al. 2005). In addition to "*C.*" *urophthalmus*, there are many cichlids, especially those from Middle America, that have lateral bars on the body, a dark spot near base of caudal fin, and simple, unicuspid teeth (see Bussing 2002, Miller et al. 2005). Among these are certain non-native cichlids already present in Southeast Asia, such as "*Cichlasoma*" *festae* (Boulenger 1899) (= *Parapetenia festae*), *Archocentrus octofasciatus* (Regan 1903), and *Vieja synspila* (Hubbs 1935) (= *Cichlasoma synspilum*). The young and even adults of some artificially created hybrid cichlids (e.g., a few Flowerhorn varieties) in the ornamental fish trade also resemble "*C.*" *urophthalmus*. Although the literature is sparse, most of these non-native cichlids are not known to occur in brackish or marine waters, reducing the likelihood of misidentifications with "*C.*" *urophthalmus* occurring in estuarine habitats. Many cichlids are euryhaline, for example, some tilapia and "*C.*" *trimaculatum* (Günther 1867) (Trewavas 1983, Miller et al. 2005); however, the salinity tolerance of some taxa (e.g., hybrid Flowerhorn cichlids) is uncertain.

"*Cichlasoma*" *festae* is reportedly established in Singapore (Tan and Tan 2003) and some individuals of this species are remarkably similar to "*C.*" *urophthalmus* (see Axelrod 1993:739-740; Staeck and Linke 1995). The aquarium literature and aquarium-fish internet sites include mention of a few traits useful in distinguishing the two (e.g., Danforth 1995, Leibel 1996, Staecker and Linke 1995), but we have been unable to verify these supposed differences in the scientific literature and even aquarists report exceptions or character overlap. Both species have an ocellated spot at the base of the caudal fin, but in "*C.*" *festae* the spot is usually smaller and, in most specimens, restricted to the upper half of the caudal peduncle (as opposed to extending downward onto the midline). In addition, the first two dark body bars (located immediately behind the head

or nape) are joined to form a "Y" or "V" although the marking is somewhat irregular and commonly broken into segments. This joining of the first two bars is not known to occur in "*C.*" *urophthalmus*. However, oddities in the pattern of a few of the more posterior bars have been reported (Hubbs 1938) in this species. In terms of color, "*C.*" *festae* is usually, but not always, a more brightly pigmented fish, especially in terms of the extent and intensity of red or red-orange on the head and body. However, some "*C.*" *urophthalmus* show much red, primarily on the throat. Red on the abdomen and other ventral areas is reportedly typical of both male and female "*C.*" *urophthalmus* during the breeding season (Martinez-Palacios et al. 1993, Martinez-Palacios and Ross 1992). Aquarists also note that "*C.*" *festae* tends to be a larger fish, attaining 30 cm TL or more, whereas "*C.*" *urophthalmus* is often less than about 20 cm (Danforth 1995, Staeck and Linke 1995). In the ornamental fish trade, "*C.*" *festae* is often marketed as the "Red Terror" and "*C.*" *urophthalmus* as the "False Red Terror," but many of the so-called "Red Terrors" offered by pet shops are true "*C.*" *urophthalmus* and the name is even sometimes misapplied in aquarium fish publications (see Axelrod et al. 2005).

Although certain Old World tilapias are the most widespread introduced cichlids in Southeast Asia (Annex; Lever 1996), the only member of this group in the region having some resemblance to "*C.*" *urophthalmus* is the African *Tilapia buttikoferi* (Hubrecht 1881). This species is reportedly established in Singapore (Tan and Tan 2003) and it also recently has been taken in Thailand (Figure 6). *Tilapia buttikoferi* has a series of prominent bars, broad and dark, but unlike "*C.*" *urophthalmus* they consistently number eight and the first bar passes directly through the eye (Figure 6; Lamboj 2004). Moreover, all or most of the tilapia species found in Southeast Asia can easily be distinguished from "*C.*" *urophthalmus* by their dentition (i.e., teeth in jaw with notched crowns) and the number of anal fin spines (typically only three) (Trewavas 1983, Miller et al. 2005).

Among hybrids, the young and some adults of certain varieties of Flowerhorn cichlid resemble those of "*C.*" *urophthalmus*. We investigated two cases in Southeast Asia involving cichlids of uncertain identity that we initially suspected were "*C.*" *urophthalmus* or its hybrid. However, after reviewing the literature and unpublished information and consultation with other cichlid



Figure 6. *Tilapia buttikoferi* specimen captured in Thailand in November 2006. Their bar pattern is distinct from that of "*Cichlasoma*" *urophthalmus*, consisting of eight dark bars, the first passing directly through the eye. Deposition of specimen is unknown. The capture site, Bung Sam Lan is a small (20-hectare), artificial reservoir. Privately-owned, the site is used for sport fishing and, reportedly, commonly stocked with non-native fishes. Photograph by Jean-Francois Helias.



Figure 7. Examples of other non-native cichlids present in Southeast Asia that superficially resemble "*Cichlasoma*" *urophthalmus*. These are likely hybrids of "*C.*" *trimaculatum* and presumably represent varieties of the ornamental hybrid group known as Flowerhorns. Upper image shows live individuals for sale as food outside a restaurant in the Bang Rak district of Bangkok, early February 2006 (Photograph by Leo G. Nico). Lower image is a juvenile (about 80 mm TL) captured at Tasik Biru (Blue Lake), northwest Borneo, Malaysia on 24 June 2006. In addition to the one fish captured, the collector observed about 20 additional cichlids of the same type swimming in the lake. (Photograph by Michael Lo). Note the red iris of these fish, a character rare or absent in "*C.*" *urophthalmus*.

experts, it was eventually concluded that all were likely hybrids of "*C.*" *trimaculatum*, or possibly of *Vieja synspila*, genetic forms that presumably can be assigned to the hybrid group known as Flowerhorns. Among these were live adults that one of us (LGN) observed being sold outside a restaurant in Bangkok and the other a juvenile cichlid recently collected from a site in Malaysia (Figure 7).

Because of absence of information on Flowerhorn hybrids in the scientific literature, their widespread commercial use as ornamentals, and close or superficial resemblance to other cichlids, there is value in providing details concerning these unusual fish. In particular, over the past few years a number of news stories have appeared that reported their release and occurrence in open waters in Southeast Asia, but their introduction into nature remains poorly documented. One official report indicated that wild Flowerhorn populations, at least in Malaysia, are either uncommon or have not persisted (NACA 2005:293).

The history of these ornamental fish is short, but interesting. Flowerhorns, also referred to as Luohan and Kirin cichlids, were first developed by the ornamental fish industry in Malaysia during the mid-1990s (Lutz 2004). The parental taxa used by breeders to create these hybrids are all New World cichlids, but the species have supposedly never been divulged. Nevertheless, it is widely believed that a range of species have been crossed consequently, Flowerhorns is a group of many varieties, essentially a hybrid complex. Some aquarists have suggested that these hybrids have been back crossed to create some of the Flowerhorn hybrid varieties that now exist. "*Cichlasoma*" *urophthalmus* supposedly is not involved, but some suspect "*C.*" *festae* has been used in some crosses, along with "*C.*" *trimaculatum*, *Amphilophus citrinellus* (Günther 1864) (= "*C.*" *citrinellum*), *Vieja synspila*, and others (Miller and Midgley 2002, Lutz 2004, Axelrod et al. 2005). The different Flowerhorn varieties are often marketed under a variety of names (e.g., Red Dragon, Super Red Dragon, Rainbow Dragon, Blue Dragon, and Kamfa or Kampa) and fish breeders reportedly continue to experiment, so the situation is dynamic.

Biology of the Thailand Population

Although none of the 15 small "*C.*" *urophthalmus* from Thailand that we dissected included

individuals with mature eggs, first maturity of females of this species is variable, reportedly occurring anywhere between 60 and 120 mm SL (Caso-Chávez et al. 1986, Martinez-Palacios and Ross 1992, Faunce and Lorenz 2000). Our preliminary analysis of the diet of the Thailand population indicated a generalized, omnivorous diet, agreeing with what has been reported for other "*C.*" *urophthalmus* populations (Caso-Chávez et al. 1986, Loftus 1987, Martinez-Palacios and Ross 1988, Bergmann and Motta 2005, among others). We found food items in all 15 of the "*C.*" *urophthalmus* (36-87 mm SL) gastrointestinal tracts examined. Estimated fullness ranged from 1 to 3 (mean = 1.7). In terms of frequency of occurrence (%O) and relative importance (adjusted %V), the predominant food items were fish (%O = 20, adjusted %V = 36), multi-cellular algae (53, 20), other plant material (47, 20), and detritus (73, 24). Only three specimens had preyed on fish, but their gastrointestinal tracts were full with these remains. Unfortunately, fish remains were highly digested and unidentifiable. Eight of the fish had fed on algae, with the most common being two genera of filamentous Chlorophyta, *Oedogonium*, a group normally associated with freshwater habitats, and *Chaetomorpha*, a genus restricted to brackish and salt-water environments. Presence of these environmentally distinct algae in the diet suggests that these fish were moving between fresh water and brackish or salt-water habitats or that there was a local inflow from a freshwater source.

In addition to the identified genera, the digestive tract of one specimen contained large fragments of an unidentified multi-cellular marine alga. Detritus was a broad food category that included inorganic debris and any organic material that could not be identified as either plant or animal. It is possible that the detritus and certain other small food items found in the guts had been ingested incidentally by "*C.*" *urophthalmus* while targeting other larger, intended prey. The only other food items identified, each of these found in the gut of single individuals, consisted of a piece of a shrimp, and some insect and snail remains. In one case, the alimentary tract of a 64-mm SL "*C.*" *urophthalmus* contained shell fragments of three small conical-spire gastropods (0.5 mm diameter), a few insect parts, and a small amount of vascular debris of an unidentified flowering plant (Monocotyledon), most likely a tidal grass.

We measured the length of the gastrointestinal tract of 10 "*C.*" *urophthalmus* (58-87 mm, SL). Resulting measures ranged from 111 to 188 (mean = 139) mm. Relative intestine lengths (gut length divided by standard length) ranged from 1.8 to 2.1 (mean = 2.0). This relationship approximates the findings of others. In their study of a population inhabiting a brackish-water lagoon in Mexico, Martinez-Palacios and Ross (1988) noted that the alimentary tract of "*C.*" *urophthalmus* averaged approximately 2.2 times the SL (figures erroneously reported in article as total length, but see Martinez-Palacios et al. 1993).

Co-habiting fishes were typically euryhaline species. Other non-native fishes taken with "*C.*" *urophthalmus* on the day of our visit included adult and juvenile Mozambique Tilapia *Oreochromis mossambicus* (Peters 1852) and a poeciliid tentatively identified as the Yucatan Molly *Poecilia velifera* (Regan 1914). Native fishes in shoreline dip-net samples included *Rasbora cf. aurotaenia* Tirant 1885 (Cyprinidae), *Oryzias javanicus* (Bleeker 1854) (Adrianichthyidae), *Brachygobius* sp. (Gobiidae), a small cryptic fish tentatively identified as a gobioid species, and juvenile *Scatophagus argus* (Linnaeus 1766) (Scatophagidae).

Status and Origin of the Thailand Population

The population status of the "*C.*" *urophthalmus* in the lower Chao Phraya River delta is unclear. It is almost certainly reproducing and likely established. The area is typical of environments where "*C.*" *urophthalmus* is known to thrive. Over the past few years this species has been collected repeatedly from ponds and an adjacent canal. Additional evidence for reproduction is the broad range of adult and juvenile sizes present and report by locals that the species has become increasingly common. During our visit, juvenile "*C.*" *urophthalmus* were common in the qualitative dip-net samples of near-shore habitats. Surveys are needed to determine its actual distribution in the delta, but "*C.*" *urophthalmus* is probably not restricted to the immediate area of our capture site. The local water bodies are large and the complex area has multiple interconnections with surrounding pond and canal habitats. Extensive dispersal of this fish has probably already occurred because the site is situated in the lowland deltaic tidal plain. The fact that "*C.*" *urophthalmus* has opportunity



Figure 8. “*Cichlasoma*” *urophthalmus* netted from the Punggol River of Singapore: (A) 124 mm SL captured 27 June 2006; and (B) 66 mm SL taken 4 July 2006. These preserved specimens are deposited at the Raffles Museum of Biodiversity Research (RMBR) at the National University of Singapore. The dark spot centered on 4th bar is most evident in the smaller specimen. Photographs courtesy of Tan Heok Hui.

to easily disperse was evident during our November visit when we witnessed gradual flooding of local roadways and other high ground by incoming tide. According to Umitsu (2000), elevation of the Chao Phraya’s deltaic tidal plain is only 1-2 m, about the same as the high tide level of the Gulf of Thailand. Moreover, the area is subject to dramatic flooding during the rainy season.

The local fisherman informed us that “*C.*” *urophthalmus* appeared in his catch a few years before, probably in 2004. The first specimens were netted from a small ditch at the point where it enters into a large reservoir. These initial collections included only adult fish. Juveniles began appearing in his catch in about 2006 and “*C.*” *urophthalmus* is now considered common in the area. In contrast, the fisherman stated that the first *Oreochromis mossambicus* were taken in about 2003, approximately one year before the first “*C.*” *urophthalmus*. According to locals, the observed recent increase in the number of “*C.*” *urophthalmus* corresponded to a decline in the number of *O. mossambicus* collected.

The origin of the Thailand “*C.*” *urophthalmus* population is a mystery. This species has been in the ornamental fish trade many decades (Staeck and Linke 1995) and Mr. Helias suspects that the Thailand population resulted from an aquarium release. Welcomme and Vidthayanon (2003:14) reported that Thailand is an important regional center for the aquarium fish trade and that

hatcheries breeding and rearing aquarium fishes exist near Bangkok. They also commented that the trade in Thailand (and in other parts of Southeast Asia) is uncontrolled and that some ornamental species had already appeared in the natural environment. A number of cichlid varieties are available in pet markets and shops in Bangkok (e.g., Chatuchek weekend market) and in other Thai cities.

“*Cichlasoma*” *urophthalmus* has been cultured as a food fish in Mexico since at least the 1980s (Martinez-Palacios et al. 1993, Martinez-Palacios and Ross 2004, Miller et al. 2005). However, we have no information indicating the species has been cultured for food in Asia. Our observation in early 2006 that live “*Cichlasoma*” were being sold at a Bangkok restaurant (Figure 7) is evidence that New World cichlids are being exploited, at least in a minor way, as a food fish in Thailand. We do not know the source for these market specimens and we have not yet observed live or dead “*C.*” *urophthalmus* in Thailand fish food markets. It is notable that the underlying reason for many introductions of aquatic species in Thailand and most other Southeast Asia countries is aquaculture (Welcomme and Vidthayanon 2003, NACA 2005:130).

Other Southeast Asia Records

In addition to our Thailand collections, the only other confirmed population of “*C.*” *urophthalmus* in Southeast Asian open waters is based on a report and specimens collected in Singapore. Tan and Tan (2003) included it in that country’s list of “established alien species,” but provided no additional information. In January 2007, we contacted personnel of the Raffles Museum of Biodiversity Research (RMBR) at the National University of Singapore to determine if museum voucher specimens existed to support the Singapore record. Dr. Tan Heok Hui (personal communication) of RMBR provided photographs and collection information for two “*C.*” *urophthalmus* specimens in their possession (RMBR uncatalogued) (Figure 8). These fish were taken by cast net from the estuarine area of Punggol River, along the northern coast of Singapore, the first in June and the other in July 2006. The July collection also included introduced *O. mossambicus* and various native brackish-water species. According to Tan, “*C.*” *urophthalmus* is more common along the estuarine northern coast of Singapore on both

sides of the causeway which links Singapore to Johor via a land bridge, possibly throughout the Johor Straits estuaries. The Punggol River is a relatively short, narrow and shallow estuary that flows into the Straits of Johor near the Singapore community of Punggol (approx. 1°22'41"N; 103°52'31"E). The river exhibits a mesohaline to polyhaline environment (Thia-Eng 1973).

Ecological Threat to Southeast Asia

To our knowledge the records from Thailand and Singapore represent the first documented cases of "*C. urophthalmus*" in open waters of Southeast Asia and the only reproducing wild populations of this species outside the New World. Considering its life-history attributes (see Introduction) and given the successful establishment and rapid dispersal of "*C. urophthalmus*" in Florida, this species will likely persist and gradually expand its range in Southeast Asia, invading inland systems and shallow coastal habitats in surrounding lowland areas. Of particular importance is the fact that "*C. urophthalmus*" is euryhaline and naturally occurs and maintains reproducing populations in inland freshwater environments and coastal marine habitats. In Florida introduced populations have invaded and become established and are relatively abundant in fresh- and brackish water habitats, including coastal mangroves and estuaries as well as in a variety of artificial and some natural inland habitats.

Much of what we know about "*C. urophthalmus*" as an invader is based on information on introduced populations in North America. Results of these past introductions provide perspective on possible outcomes for Southeast Asia. The first reported collections and observations of wild populations of "*C. urophthalmus*" in the USA were made in 1983 in Everglades National Park, Florida (Loftus 1987). The fish were found at two sites, an estuarine creek system and some freshwater ponds. Since that first discovery, the range of this cichlid in Florida has greatly expanded and it now occupies nearly the entire southern half of the peninsula from mangrove systems of Florida Bay north to the upper Kissimmee River basin and the Indian River lagoon system (Faunce and Lorenz 2000, Matamoros et al. 2005, Nico 2005, L.G. Nico, unpublished data; museum specimens). The area covered extends from about 25°09' N to 28°11' N. As of 2006, the straight-line distance between the site in Everglades

National Park, where the species was first encountered, and the approximate northern edge of its expanding front (i.e., Tohopekaliga Lake in the upper Kissimmee River basin and Crane Creek the Indian River Lagoon), is about 350 kilometers. This equals a rate of invasion dispersal of nearly 15 km per year over the 23-year period (1983-2006). Based on unpublished data on the pattern of geographic distribution and the chronology of occurrence, it is likely that "*C. urophthalmus*" has dispersed in Florida via both coastal habitats as well as by way of inland waterways (e.g., canals). In addition to continued marketing of this species in the USA as an ornamental fish, "*C. urophthalmus*" has become moderately popular as a sport fish in Florida. Consequently, although not confirmed, the rapid dispersal northward by this species has possibly been facilitated by humans (e.g., transport and illegal release of live fish by anglers or others).

In addition to its rapid geographic expansion, "*C. urophthalmus*" has established reproducing populations in most areas in Florida where it has invaded and has become increasingly common or abundant at many of these sites. The situation continues to be dynamic. For example, it was reported that "*C. urophthalmus*" comprised 90% of the total fish biomass in samples collected from estuarine mangrove habitats off Florida Bay (Faunce and Lorenz 2000), although it was later found that these populations exhibited wide fluctuations in abundance over time (Trexler et al. 2000; W. F. Loftus, personal communication). In a recent review paper, Simberloff and Gibbons (2004) stated that "*C. urophthalmus*" in the Florida Everglades was an example of an introduced species whose populations initially peaked (in 1993) but later crashed and did not recover. However, their conclusion was an erroneous representation of the general situation, relying mostly on data presented by Trexler et al. (2000) from a single habitat type. In reality, there is little evidence of a general decline of this species in Florida, and if anything, their continued range expansion and occurrence in samples argues against a general population crash in the state (W. F. Loftus, personal communication; L.G. Nico, unpublished data).

Although "*C. urophthalmus*" will most likely persist and continue to colonize new areas in Southeast Asia, the ecological threat that introduced populations pose to the region is difficult to predict. Similar to the situation in Florida, the mere presence and relative abundance of "*C. urophthalmus*" changes in the

composition and structure of local fish communities. It is uncertain, however, if "*C. urophthalmus*" is displacing native fishes through predation or competition. Results will likely depend on the species composition of the site invaded. In south Florida, the situation is somewhat unique and may not apply to other parts of the world. Most south Florida fish communities include multiple non-native fish species, including many other New World cichlids. Moreover, native Florida fishes are relatively hardy, opportunistic, and widespread species, unlikely to disappear or be seriously threatened by the introduction of one more foreign fish. Consequently, ecological effects of "*C. urophthalmus*" and other introduced fishes on indigenous aquatic communities are extremely difficult to quantify and assess (Trexler et al. 2000). This gap in scientific knowledge is not surprising, given that the measurement of impacts has long been considered a major challenge for ecologists interested in ecological effects of invaders (Parker et al. 1999).

One subject requiring attention is the relationship between introduced fishes and their importance as vectors of diseases and parasites. The parasite load of the Thailand "*C. urophthalmus*" population needs investigation. A recent study has documented that Florida "*C. urophthalmus*" is an intermediate host to an unidentified member of the genus *Contracaecum*, a group of anisakid nematodes known to infect birds and mammals, including humans (Bergmann and Motta 2004). Studies in Mexico have reported "*C. urophthalmus*" as host to a diverse assortment of parasites, including as many as 71 different helminth species (Salgado-Maldonado 2006) and a tapeworm of the genus *Bothriocephalus* (Scholz et al. 1996). Moravec et al. (1998) reported occurrence of *Serpinema trispinosum* (Leidy 1852) larvae in "*C. urophthalmus*", the first record of this nematode in a fish. Adults of this parasite commonly infect turtles consequently, the researchers suggested that "*C. urophthalmus*" probably play a role in its transmission and are a source of infection for turtles.

The presence of multiple non-native fishes in a habitat adds to the difficulty of assessing possible ecological effects. As mentioned earlier, at least two other non-native fishes were present at the site in the Chao Phraya delta where "*C. urophthalmus*" was found, *Oreochromis*

mossambicus and a *Poecilia* species, tentatively identified as Yucatan Molly *Poecilia velifera*. Vidthayanon and Premcharoen (2002) reported that *O. mossambicus* and a *Poecilia* species (identified by them as the Mexican Molly *P. sphenops* Valenciennes 1846) were flourishing in the inner Gulf of Thailand.

The discovery of "*C. urophthalmus*" in Thailand brings the total number of non-native fishes documented as established or possibly established in the entire country up to 19 (Annex). The actual number is likely greater. Some non-native species, such as *Tilapia buttikoferi* (Figure 6), are limited in distribution and likely not established in Thailand. The distribution and reproductive status of a number of other non-native fishes are unknown.

Surveying and monitoring are required to fully assess the status and impact of "*C. urophthalmus*" in Thailand and other regions in Southeast Asia where it may occur. In Thailand, field work is necessary to determine this species' exact distribution in the Chao Phraya delta. Based on native populations in Mexico and on the dispersal of introduced populations in Florida, it is likely that over time the Thailand population will invade much of the delta eventually dispersing along the coast, potentially even colonizing nearby islands. In addition, based on its pattern of invasion in Florida, we suspect the species will eventually move a considerable distance up the Chao Phraya River.

Potential Risk for Europe

"*Cichlasoma*" *urophthalmus* has a long history as an ornamental fish and has occasionally been imported into Europe. Staeck and Linke (1995) reported that this species was kept by aquarists in Germany during the early 1900s. After a long hiatus, import of "*C. urophthalmus*" began anew in the 1980s. W. Staeck (personal communication) informed us that a few specimens were imported into Germany in 1985, 1989, and 1991 by aquarists and that this cichlid was very popular among German, Dutch, and French hobbyists during the 1980s and 1990s. In recent years the interest in "*C. urophthalmus*" in Europe has declined, as evidenced by its absence in European aquarium stores and wholesale facilities (S. O. Kullander, A. Ploeg, and W. Staeck, personal communications). Nevertheless, continued imports of this cichlid into Europe may not be necessary given that it is commonly

and easily bred in captivity, thereby maintaining a potential source for introduction into the wild.

Because this species is presently uncommon in the European ornamental fish trade, and most likely not being held in outdoor facilities, currently the risk is minor that "*C. urophthalmus*" will be introduced into the wild within Europe. Other than the aquarium trade, there are presumably no other functioning pathways of introduction into Europe. For example, although "*C. urophthalmus*" is a food and sport fish in other parts of the world, there is no evidence that it is being imported or cultured for these purposes in Europe or adjacent countries. In the event of an introduction into the wild, survival of this species would depend heavily on where in Europe a release or escape might occur. As previously described, "*C. urophthalmus*" is a tropical-subtropical species. Its lower temperature tolerance limit is reportedly around 14°C (Martinez-Palacios and Ross 1986, Stauffer and Boltz 1994) and spawning is known to occur only above about 24°C (see Martinez-Palacios and Ross 1992). During occasional harsh winters in Florida, "*C. urophthalmus*" populations suffer extensive mortality, but populations have consistently demonstrated an ability to persist (Loftus 1987, Trexler et al. 2000; L.G. Nico, personal observation).

In general, the risk that "*C. urophthalmus*" will successfully survive the winter in most regions of Europe is low. Some artificially heated waters (e.g., outlets of power plants) could conceivably allow a small population to persist. In terms of natural areas, there are a few areas in or adjacent to southern Europe with climate and temperatures that may be suitable for their survival and reproduction. There are recent reports that some subtropical aquatic organisms, including a few fishes, are expanding their ranges in the Mediterranean in response to water warming (Grau and Riera 2001, Addis et al. 2006, Diaz-Almela et al. 2007). These findings indicate "*C. urophthalmus*" might also find suitable habitat somewhere in the region, if not now, then possibly in the near future. Based on recent sea surface temperature data and general warming trends in the basin (Marullo et al. 2006, Miró et al. 2006), sites seemingly most vulnerable to colonization by this species include certain shallow coastal areas in the far eastern Mediterranean. An introduced population of another New World cichlid, the Chanchito *Australoheros facetus* (Jenyns 1842) (formerly

recognized as "*Cichlasoma facetum*") from southern Brazil, has persisted in the Guadiana River basin on the Iberian Peninsula since the 1980s (Elvira 1995; Elvira and Almodovar 2001). The only other cichlids, all Old World tilapia species, introduced into Europe never established or their establishment has never been confirmed (Lever 1996).

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Supplementary material

The following supplementary material is available for this article:

Annex. Foreign non-native fishes reported to have reproducing populations in open waters of Thailand.

Annex. Foreign non-native fishes reported to have reproducing populations in open waters of Thailand, with supporting references. Included are species considered established and those probably or possibly established.

Family/Species - Common name	Year of introduction	Origin/Donor area	Pathway	References/Comments
Cyprinidae				
1. <i>Carassius auratus</i> (Linnaeus 1758)- Goldfish	before 1700	Asia (China and Japan)	ornamental	NACA 2005, Welcomme and Vidthayanon 2003:18, Vidthayanon 2005
2. <i>Cirrhinus cirrhosus</i> (Bloch 1795) – Mrigal	1980	southern Asia (Bangladesh)	aquaculture	Welcomme and Vidthayanon 2003:19, but see Vidthayanon 2005:116 (probably not established)
3. <i>Ctenopharyngodon idella</i> (Valenciennes 1844) - Grass Carp	1932	eastern Asia (China)	aquaculture	Welcomme and Vidthayanon 2003, Vidthayanon 2005 (probably established)
4. <i>Cyprinus carpio</i> Linnaeus 1758 - Common Carp	1913 and later	Eurasia (China, Japan, Israel and Germany)	aquaculture	Smith 1945:117, Piyakarnchana 1989, de Iongh and Zon 1993, Welcomme 1988, Welcomme and Vidthayanon 2003, NACA 2005, Vidthayanon 2005
5. <i>Hypophthalmichthys nobilis</i> (Richardson 1845) - Bighead Carp	1932	eastern Asia (China)	aquaculture	Welcomme and Vidthayanon 2003, Vidthayanon 2005 (probably established)
6. <i>Labeo rohita</i> (Hamilton 1822) - Rohu	1968	southern Asia (India)	aquaculture	de Iongh and Zon 1993 (spawning in open waters but no successful reproduction), Welcomme and Vidthayanon 2003, Vidthayanon 2005 (as possibly established)
Characidae				
7. <i>Gymnocorymbus ternetzi</i> (Boulenger 1895) - Black Tetra	1950s	South America (unknown?)	aquarium	Piyakarnchana 1989: 121, Welcomme and Vidthayanon 2003
Loricariidae				
8. <i>Hypostomus</i> spp. -Plecostomus	unknown	South America (unknown)	aquarium	Yakupitiyage and Bhujel 2005, Welcomme and Vidthayanon 2003, Vidthayanon 2005
9. <i>Pterygoplichthys</i> sp. - Sailfin Catfish	unknown	South America (unknown)	aquarium	Vidthayanon 2005
Clariidae				
10. <i>Clarias gariepinus</i> (Burchell 1822) - African Walking Catfish	about 1987	Africa and Middle East (Laos)	aquaculture	Welcomme and Vidthayanon 2003, Vidthayanon 2005, De Silva et al. 2006
Poeciliidae				
11. <i>Gambusia affinis</i> (Baird and Girard 1853) - Western Mosquitofish	unknown	North America (unknown)	mosquito control	Smith 1945 [as <i>G. holbrooki</i>], Myers 1965, Piyakarnchana 1989, Welcomme and Vidthayanon 2003, Vidthayanon 2005

Annex (continued)

Family/Species - Common name	Year of introduction	Origin/Donor area	Pathway	Reference/Comments
12. <i>Poecilia reticulata</i> Peters 1859 - Guppy	unknown	South America (unknown)	mosquito control and aquarium	Thiemmedh 1966, Welcomme and Vidthayanon 2003
13. <i>Poecilia velifera</i> (Regan 1914) - Yucatan Molly	1960	Central America (Taiwan)	algae control	Vidthayanon and Premcharoen 2002 [as <i>Poecilia sphenops</i>], Welcomme and Vidthayanon 2003, Vidthayanon 2005, present paper. Some populations may be the closely-related Mexican Molly <i>Poecilia sphenops</i> Valenciennes 1846. Also see reference to <i>Poecilia latipinna</i> (Lesueur 1821) in Thiemmedh 1966.
Cichlidae				
14. <i>Archocentrus octofasciatus</i> (Regan 1903) - Jack Dempsey	1950s	Central and North America (unknown?)	aquarium	Piyakarnchana 1989:121 [as <i>Cichlosoma biocellatum</i>], Welcomme and Vidthayanon 2003 [as <i>Cichlasoma octofasciatum</i> and indicates introduced from "Brazil"]
15. " <i>Cichlasoma</i> " <i>urophthalmus</i> (Günther 1862) - Mayan Cichlid	after 2000	Central America (unknown)	probably aquarium	Present paper. Locals report that species was first taken in wild in about 2004.
16. <i>Oreochromis aureus</i> (Steindachner 1864) - Blue Tilapia	1970	Africa and Middle East (Israel)	aquaculture	Welcomme and Vidthayanon 2003, Vidthayanon 2005
17. <i>Oreochromis mossambicus</i> (Peters 1852) - Mozambique Tilapia	1949	Africa (Malaysia)	aquaculture	Atz 1954, Welcomme 1988, Piyakarnchana 1989, Vidthayanon and Premcharoen 2002, Welcomme and Vidthayanon 2003, Vidthayanon 2005, present paper
18. <i>Oreochromis niloticus</i> (Linnaeus 1758) - Nile Tilapia	1965	Africa and Middle East (Japan)	aquaculture	Welcomme 1988, Piyakarnchana 1989, de Iongh and Zon 1993, Rainboth 1996, Welcomme and Vidthayanon 2003, Vidthayanon 2005, Yakupitiyage and Bhujel 2005
19. <i>Tilapia rendalli</i> (Boulenger 1897) - Redbreast Tilapia	1955	Africa (Belgium)	aquaculture	Welcomme and Vidthayanon 2003, Vidthayanon 2005