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Multiple records of aquatic alien and invasive species in diets of native predators in Singapore

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Abstract

We report for the first time the diversity of known aquatic alien species in the diets of four piscivorous predators in Singapore through a review of published and unpublished studies, and our empirical data. Of 15 aliens identified to the species level, 11 were fish, including the highly invasive tilapia (*Oreochromis mossambicus* [Peters, 1852]). Other alien species include the abundant red-eared slider (*Trachemys scripta elegans* [Wied-Neuweid, 1839]) and the American bullfrog (*Lithobates catesbeiana* [Shaw, 1802]). We hypothesize that the diversity of established alien species in Singapore's aquatic habitats allows for novel ecological interactions, one of which is predation by native species. Our study provides preliminary evidence that alien and invasive species may benefit some native piscivores as a source of prey although it is not possible to infer relative composition of these alien species given our limited data. Future studies should investigate the ecological dynamics of these interactions, including the relative importance of these alien prey to diets and survival of predators.

Key words: aquatic, piscivore, fish, Southeast Asia, predator-prey, novel ecosystems

Introduction

The threat posed by alien and invasive species to native and endemic biodiversity in Southeast Asia remains poorly understood despite the fact that many alien species across multiple taxonomic groups are now established in many Southeast Asian countries (Pallewatta et al. 2003; Tan et al. 2010; Wanger et al. 2011). One example is the city state of Singapore where a bustling pet trade (Goh and O'Riordan 2007; Ramsay et al. 2007) and aquaculture industry (see also Naylor et al. 2001; Ng et al. 1993; Liew et al. 2013), together with deep-rooted religious (Tan 2004) and culinary traditions (Tan et al. 2010), continue to act as conduits for arrival of alien species into Singapore's natural environments. This is further supplemented with accidental introductions arising from biological control projects (Sodhi and Sharp 2006; Tan et al. 2010) and marine transportation (Yeo et al. 2009).

There is a well-established body of literature, particularly from temperate Europe and North America that documents the detrimental ecological interactions and impacts of invasive species on native species and communities (Pysek et al. 2008). Invasive species are widely known to out-compete or become predators of native species (Ehrlich 1989; Carlsson et al. 2009). However, there is increasing evidence that invasive species can develop novel interactions which benefit native species (Hobbs et al. 2006); particularly as prey consumed by native predators (see Ward-Fear et al. 2010; Beckmann et al. 2011). In one of few examples from tropical Asia, Wanger et al. (2011) highlighted the novel predation of an endemic anuran, the Celebes toad (*Ingerophrynus celebensis* [Gunther, 1859]), on the alien yellow crazy ant (*Anoplolepis gracilipes* [F. Smith, 1857]) in Sulawesi, also a notorious invasive. Ultimately, predation of invasive or potentially invasive alien species may help limit or even control the invasion of these species (Madenjian et al. 2011).

Given its diversity of established alien species (see Ng and Tan 2010; Tan et al. 2010; Jaafar et

al. 2012; Liew et al. 2012), some of which are invasive, Singapore offers an excellent setting to investigate the spatial extent, rate and impacts of biological invasions in multiple terrestrial and aquatic habitats. Of particular interest are Singapore's aquatic ecosystems, many (e.g. reservoirs, streams in open country) of which are now dominated by alien fish partly due to releases from the ornamental fish trade (Ng and Tan 2010; Liew et al. 2013). Since many of Singapore's aquatic habitats are artificial or have been modified historically and presently do not support many native species (Tan et al. 2010), it is difficult to assess the impacts of alien fish on other native aquatic organisms. However, the occurrence of many piscivorous predators, some which are locally common (e.g. water monitor) provides a unique opportunity to assess whether many of these newly-arrived alien species could benefit these natives as prey, at least at short timescales.

Here, we review the dietary diversity of four facultative, piscivorous predators (one bird, one mammal and two reptiles) (Table 1) and document all records of prey species known to be non-alien or alien to Singapore. Two of these, the grey-headed fish eagle (*Icthyophaga ichthyaetus* [Horsfield, 1821]) and smooth-coated otter (*Lutrogale perspicillata* [Saint-Hilaire, 1826]), are in Singapore's list of threatened species (Davison et al. 2008), with the latter also globally threatened (Hussain et al. 2008), although increasing frequency of records in Singapore (Theng 2011) suggests at least a localized increase in abundance at the well-watched Sungei Buloh Wetland Reserve. In contrast, the Malayan water monitor (*Varanus salvator* [Laurenti, 1768]) and the dog-faced water snake (*Cerberus schneiderii* [Schlegel, 1837]) remain common in suitable habitats (Baker and Lim 2008). We briefly discuss how dietary adaptations of these predators to exploit alien prey may offer insights into novel ecological dynamics of some of Singapore's aquatic ecosystems.

Materials and methods

Data were compiled from a review of published work and unpublished theses (2000–2012) on the life history of native piscivores (i.e. opportunistic, facultative) in Singapore from library databases. Additional data were collected based on field work conducted by the authors. We chose to examine prey species richness, rather than abundance, relative composition of prey items or prey frequencies given that sampling effort and methods across the reviewed studies were spatially and temporally variable. During a national survey of nesting sites of the grey-headed fish-eagle from 2009 to 2011, we also collected data on prey items whenever the species was observed foraging (see Yong 2011) from two sites (1.3559°N, 103.7549°E; 1.3436°N, 103.8311°E), and which continued to mid-2012. Prey species that could not be positively identified in the field were photographed at high magnification and sent to a colleague (Lim, KKP pers comm.) for identification.

In our review of life history studies of piscivorous species, we were able to obtain dietary data of three other focal organisms, namely the smooth-coated otter (Theng 2011), the Malayan water monitor (Abdur Rashid 2004) and the dog-faced water snake (Chim 2009), from which we extracted specific records. All three studies were carried out at the Sungei Buloh Wetland Reserve (1.4467°N, 103.7302°E). We only included prey organisms if they were identifiable to species level, which allowed us to determine unequivocally if it was alien in the Singapore context unless we are certain that the genus is non-native. Identification of alien species was based on published checklists of alien fish (Ng and Tan 2010), or checklists of reptiles and fish (e.g. Baker and Lim 2008). However, most of the alien species in our review were readily identifiable as a number are well-known invasives with wide global distributions (see Lowe et al. 2000).

Results

A total of 15 alien species are identified from the diets of the four predators examined, including 11 fish species (Table 2) from five families: Characidae, Cichlidae, Cyprinidae, Pangasiidae and Poecilidae. Cichlids were the dominant family, with six species reported in one or more of the predators. The invasive tilapia *Oreochromis mossambicus* was the most frequently encountered cichlid, being identified in the diets of three of four species. Despite its known abundance in the water bodies surveyed for grey-headed fish eagle, we did not record it in the diet of that species. Four species of cichlids were reliably identified from the diet of the smooth-coated otter, the highest dietary diversity of alien species among the four predators compared although the spraint remains did not allow species-level identification for many prey items (Theng 2009).

Table 1. Ecological background of four native predators in Singapore. All species are either opportunistic or facultative piscivores.

Latin name	Common name	Taxonomic group	IUCN status	Habitat
Icthyophaga ichthyaetus (Horsfield, 1821)	Grey-headed fish-eagle	Bird	Near-threatened	Forest and woodland adjoining water bodies
Lutrogale perspicillata (Saint-Hilaire, 1826)	Smooth-coated Otter	Mammal	Vulnerable	Mangroves, woodland near water
Varanus salvator (Laurenti, 1768)	Malayan water monitor	Reptile	Least concern	Mangroves, woodland, scrub near water
Cerberus schneiderii (Schlegel, 1837)	Dog-faced water snake	Reptile	Least concern	Mangroves

Table 2. Diversity of alien and/or invasive prey species consumed by indigenous aquatic predators. All prey items were identified to species-level if possible.

Alien species	Common name	Taxonomic Group	Smooth-coated Otter	Grey-headed Fish-Eagle	Water Monitor	Dog-faced Water Snake
Trachemys scripta elegans (Wied-Neuweid, 1839)[1]	Red-eared slider	Reptile		+	+	
Calotes versicolor (Daudin, 1802)	Changeable lizard	Reptile			+	
Pelodiscus sinensis (Weigmann, 1835)	Chinese softshell turtle	Reptile			+	
Lithobates catesbaiena (Shaw, 1802)[1]	American bullfrog	Amphibian			+	
Geophagus altifrons (Heckel, 1840)	Eartheater cichlid	Fish		+		
Cichla orinocensis (Humboldt, 1821)	Orinoco peacock bass	Fish		+		
Oreochromis niloticus (Linnaeus, 1758)	Nile tilapia	Fish	+			
Oreochromis mossabicus (Peters, 1852)[1]	Common tilapia	Fish	+		+	+
Cichlosoma urophthalmus (Gunther, 1862)	Mayan cichlid	Fish	+			+
Etroplus suratensis (Bloch, 1790)	Green chromides	Fish	+			+
Pangasius hypophthalmus (Sauvage, 1878)	Iridescent shark	Fish		+		
Pangasius sp. 1	NA	Fish		+		
Poecilia sphenops (Valenciennes 1846)	Mexican molly	Fish				+
Hyphessobrycon anisitsi (Eigenmann & Ogle, 1907)	Buenos Aires Tetra	Fish				+
Poecilia latipinna (Lesueur, 1821)	Sailfin molly	Fish				+
Cyprinus carpio (Linnaeus, 1758)[1,2]	Common carp	Fish			+	
Total alien prey species	-		4	5	6	6
Total prey identified to genus-level	-		c.18	7	18	15

[1]Listed in Lowe et al. (2000) as one of the worst 100 invasive species globally

[2]Likely to occur as newly released individuals, and is not known to be established (see Ng et al. 1993)

Of 15 prey identified to species level in the diet of the dog-faced water snake (Chim 2009), six were alien, of which three were cichlids. A common species of estuarine streams and drainage canals (Ng and Tan 2010), the alien Mexican molly (*Poecilia sphenops*) was one of two dominant prey items for that species based on total biomass, the other which is the native Javanese ricefish (*Oryzias javanicus*) (Chim 2009) while cichlids only formed a small proportion of its diet.

Three species of alien reptiles (families Agamidae, Emydidae, Trionychidae) and one amphibian (family Ranidae) were identified in the diets of the four predators. Among alien reptiles, the red-eared slider (*Trachemys scripta elegans* [Wied-Neuweid, 1839]) occurred in the diets of two predators. The remaining species all originated from dietary analysis of the water monitor (Abdur Rashid 2004).

Discussion

The ornamental fish trade is considered to be a major source of alien aquatic species worldwide, with studies highlighting that up to one third of the world's worst alien species originate from releases from this trade (Padilla and Williams 2004; Semmens et al. 2004). Singapore is no exception (Ng et al. 1993), with cichlids particularly well represented (Liew et al. 2013). In a recent survey of Singapore's reservoirs, Ng and Tan (2010) estimated that 90% of the fish fauna documented were also encountered in the ornamental trade, of which 80% were likely to have been releases of unwanted fish. Many of these like *O. mossambicus*, are now well established (Ng and Tan 2010). Similarly, *T. s. elegans* and Chinese soft-shelled turtles (*Pelodiscus sinensis* [Wiegmann, 1835]), both of which were documented here, are readily available at pet shops

and often readily discarded when they mature and lose their attractive juvenile coloration (Goh and O'Riordan 2007), providing regular propagule pressure for establishment in Singapore ecosystems. American bullfrogs (*Lithobates catesbaiena* [Shaw, 1802]) are also readily sold as food for predatory aquarium fish or for human consumption (Tan et al. 2010), and some inevitably escape or are released into local aquatic environments.

While alien invasive species are generally recognized to impact native biodiversity negatively, the dominance of many of Singapore's artificial aquatic ecosystems (i.e. reservoirs, mining pools, canals, open country streams) by many alien fish and some reptiles, some which are known invasive species, may have provided an unexpected benefit for native predators, particularly facultatively (e.g. grey-headed fish eagle) or opportunistically piscivorous (e.g. water monitor) species. Alternatively, it is likely that these predators would not have become as widespread in Singapore if this alien prey base was limited or absent. We document for the first time multiple examples of predator-alien prey interactions in Singapore's ecosystems. Massive human modification of natural habitats, combined with accidental or deliberate introduction of alien species (Tan et al. 2010), has led to the establishment of novel ecosystems in many of Singapore's aquatic habitats which however remain poorly studied. Similar situations can be expected across Southeast Asia.

Although our data are limited, the ecological context is likely to mirror that of similar studies examining native predation on invasive prey, such as predation by native turbot (*Lota lota*) on the invasive round goby (*Neogobius melanostomus*) (Madenjian et al. 2011) in North America. Two of our examples (i.e. grey-headed fish eagle, smooth-coated otter) have shown marked increases in occurrence in recent years (Theng 2009; Yong 2011), suggesting that they have potentially benefitted from the abundance of alien fish as prey items. The high frequency of cichlids in the diet of the smooth-coated otter (Theng 2009) suggests that the species may be dependent on these alien species as a regular component of the diet, at least where the otter's habitats overlaps with the occurrence of these cichlids. Furthermore, records of smooth-coated otter in areas of alien-dominated artificial aquatic habitats have increased recently, including heavily-used parkland (e.g. Ee 2014). Similarly, given that the two reptiles (Malayan water monitor, dog-faced water snake) in our review are abundant in estuarine habitats in Singapore, it is possible that alien fish, especially cichlids, form a significant part of the diet of both given the habitat overlap with *C. urophthalmus*, *O. mossambicus*, *E. suratensis* and *Poecilia sphenops*. Further research is required to determine the underlying ecological dynamics of these interactions, especially the impacts of predation on the demographics of these alien species, and net contribution of these aliens to the survival of the predators.

Our observations are suggestive of a scenario where alien fish, in the absence of native equivalents, constitute a possibly increasing component in diets of native predators. While there is some evidence for this, at least in the context of the alien *P. sphenops* which now forms a large component of the diet of the dog-faced water snake, at least on biomass terms (Chim 2009), judicious data collection over short to medium timescales will be needed to determine the significance of these alien species to native predators, and changes in dietary composition. There is also a need to sample freshwater fish communities to quantify the composition of alien species. Overall, there is virtually no data in Singapore and the wider Southeast Asian region to estimate the net impact of predation on the population structure and growth of abundant invasive species like *O. mossambicus* and *T. s. elegans* in the region's water bodies. In the wider research arena investigating negative impacts of invasions on native biodiversity worldwide, further research should also attempt to determine the trophic significance of established and invasive alien species in their host ecosystems, particularly in terms of their ecological importance to specific consumers.

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References

Abdur Rashid, SM (2004) Population ecology and management of water monitors, *Varanus salvator* (Laurenti, 1768) at Sungei Buloh Wetland Reserve, Singapore. Unpublished PhD thesis, Nanyang Technological University, Singapore, 508 pp

Baker N, Lim K (2008) Wild Animals of Singapore: A Photographic Guide to Mammals, Reptiles, Amphibians and Freshwater Fishes. Vertebrate Study Group, Nature Society (Singapore), Singapore, 180 pp

Carlsson NO, Sarnelle O, Strayer DL (2009) Native predators and exotic prey—an acquired taste? *Frontiers in Ecology and Environment* 7: 525–532, http://dx.doi.org/10.1890/080093

Chim CK (2009) Population ecology of the dog-faced water snake (*Cerberus rynchops*) at Sungei Buloh Wetland Reserve, Singapore. Unpublished Master's thesis, Nanyang Technology University, Singapore, 350 pp

Davison GWH, Ng PKL, Ho HC (2008) The Singapore Red Data Book: threatened plants and animals of Singapore. 2nd Edition. National Parks Board and Nature Society (Singapore), Singapore, 285 pp

Ee D (2014) An otter delight at Gardens by the Bay. The Straits Times (3 March)

Ehrlich PR (1989) Attributes of invaders and the invading process: Vertebrates. In: Drake JA, Mooney HA, DiCastri F, Groves RH, Kruger FJ, Rejmanek M, Williamson M (eds), Biological Invasions: A Global Perspective. John Wiley & Sons Ltd, New York, pp 315–328

Goh TY, O'Riordan RM (2007) Are tortoises and turtles still illegally traded as pets in Singapore? *Oryx* 41: 97–100, http://dx.doi.org/10.1017/S003060530700155X

Hobbs RJ, Arico S, Aronson J, Baron JS, Bridgewater P, Cramer VA, Epstein PR, Ewel JJ, Klink CA, Lugo AE, Norton D, Ojima D, Richardson DM, Sanderson EW, Valladares F, Vila M, Zamora R, Zobel M (2006) Novel ecosystems: theoretical and management aspects of the ecological world order. *Global Ecology and Biogeography* 15: 1–7, http://dx.doi.org/10.1111/j.1466-822X.2006.00212.x

Hussain SA, de Silva PK, Mostafa Feeroz M (2008) *Lutrogale perspicillata*. In: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2. Accessed from www.iucnredlist.org

Jaafar Z, Yeo DCJ, Tan HH, O'Riordan RM (2012) Status of estuarine and marine non-indigenous species in Singapore. *The Raffles Bulletin of Zoology Supplement* 25: 79 – 92

Liew JH, Tan HH, Yeo DCJ (2012) Some cichlid fishes recorded in Singapore. *Nature in Singapore* 5: 229–236

Liew JH, Tan HH, Yi Y, Yeo DCJ (2013) Ecology and origin of the introduced cichlid *Acarichthys heckelii* in Singapore's fresh waters—first instance of establishment. *Environmental Biology of Fishes*: 1–10, http://dx.doi.org/10.1007/s10641-013-0201-z

Lowe S, Browne M, Boudjelas S, De Poorter M (2000) 100 of the World's worst invasive alien species: A selection from the Global Invasive Species Database. Invasive Species Specialist Group, IUCN Species Survival Commission. (Available online at www.issg.org/booklet.pdf)

Madenjian CP, Stapanian MA, Witzel LD, Einhouse DW, Pothoven SA, Whitford HL (2011) Evidence for predatory control of the invasive round goby. *Biological Invasions* 13: 987–1002, http://dx.doi.org/10.1007/s10530-010-9884-7

Naylor RL, Goldburg RJ, Primavera JH, Kautsky N, Beveridge, MCM, Clay J, Folke C, Lubchenko J, Mooney H, Troell M (2000) Effect of aquaculture on world fish supplies. *Nature* 405: 1017–1024, http://dx.doi.org/10.1038/35016500

Ng PKL, Chou LM, Lam TJ (1993) The status and impact of freshwater animals in Singapore. *Biological Conservation* 64: 19–24, http://dx.doi.org/10.1016/0006-3207(93)90379-F

Ng HH, Tan HH (2010) An annotated checklist of the non-native freshwater fish species in the reservoirs of Singapore. *Cosmos* 6: 95–116, http://dx.doi.org/10.1142/S0219607710000504

Padilla DK, Williams SL (2004) Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems. *Frontiers in Ecology and Environment* 2: 131–138, http://dx.doi.org/10.1890/1540-9295(2004)002[0131:BBWAAO]2.0.CO;2

Pallewatta N, Reaser JK, Gutierrez AT (eds) (2003) Invasive Alien Species in South – Southeast Asia: National Reports and Directory of Resources. Global Invasive Species Programme, Cape Town, 111 pp

Pysek P, Richardson DM, Pergl J, Jarosik V, Sixtova Z, Weber E (2008) Geographical and taxonomic biases in invasion ecology. *Trends in Ecology & Evolution* 23: 237–244, http://dx.doi.org/10.1016/j.tree.2008.02.002

Ramsay NF, Ng APK, O'Riordan RM, Chou LM (2007) The red-eared slider (*Trachemys scripta elegans*) in Asia: a review. Biological invaders in inland waters: profiles, distribution and threats – Springer Series in Invasion Biology 2, pp 161–174

Semmens BX, Buhle ER, Salomon AK, Pattengill-Semmens CV (2004) A hotspot of non-native marine fishes: Evidence for the aquarium trade as an invasion pathway. *Marine Ecology Progress Series* 266: 239–244, http://dx.doi.org/10.3354/meps266239

Sodhi NS, Sharp I (2006) Winged invaders: pest birds of the Asia Pacific. Singapore National Publishers, Singapore, 184 pp

Tan J (2004) Think again before freeing those animals. The Straits Times (25 May 2004)

Tan HTW, Chou LM, Yeo DCJ, Ng PKL (2010) The natural heritage of Singapore. Third edition. Prentice Hall, Singapore, 336 pp

Theng TY (2011) Status, Distribution and Diet of the Smooth-coated Otter *Lutrogale perspicillata* (Geoffroy, 1826) in Singapore. Unpublished undergraduate research opportunity in science report, National University of Singapore, Singapore, 72 pp

Wanger TC, Wielgoss AC, Motzke I, Clough Y, Brook BW, Sodhi NS, Tscharntke T (2011) Endemic predators, invasive prey and native diversity. *Proceedings of the Royal Society B* 278: 690–694, http://dx.doi.org/10.1098/rspb.2010.1512

Ward-Fear G, Brown GP, Shine R (2010) Using a native predator (the meat ant, *Iridomyrmex reburrus*) to reduce the abundance of an invasive species (the cane toad, *Bufo marinus*) in tropical Australia. *Journal of Applied Ecology* 47: 273–280, http://dx.doi.org/10.1111/j.1365-2664.2010.01773.x

Yeo DCJ, Ahyong ST, Lodge DM, Ng PKL, Naruse T, Lane DJW (2009) Semisubmersible oil platforms: understudied and potentially major vectors of biofouling-mediated invasions. *Biofouling* 26: 179–186, http://dx.doi.org/10.1080/08927010903402438

Yong DL (2011) Eating aliens: diet of the Grey-headed Fish-eagle *Ichthyophaga ichthyaetus* in Singapore. *Forktail* 27: 102–104