REPTILES & AMPHIBIANS

Potential Vertebrate Predators of the Non-native Green Iguana (*Iguana iguana*) in Hong Kong

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Introduced species are a global wildlife management issue with varied impacts on both biodiversity and human communities (Reaser et al. 2020; Cuthbert et al. 2021). To address environmental, social and/or economic impacts of introduced species, managers employ a range of control measures, which generally focus on reducing the numbers of individuals of introduced species (Rivera-Milán and Haakonsson 2020; Debrot et al. 2022) and, where possible, eradicating their populations (Green and Grosholz 2021). Controlling introduced species numbers may involve active culling, removal and rehoming, poison baiting, administering contraceptives, or modifying environments to influence population dynamics, among other techniques (Asa and Moresco 2019; Hanley and Roberts 2019; Clark et al. 2020).

Biological control is the management of introduced species through the use of natural enemies (Hajek and Eilenberg 2018; Stenberg et al. 2021). Biosecurity programs may exploit biological control in the form of disease agents such as viruses, including programs addressing invasive vertebrates (Mahar et al. 2018; Mehmet et al. 2018). Biosecurity policies have also harnessed biological control in the form of animal predators. In most cases, the use of animal predators has been used for addressing invasive fish (Bajer et al. 2019; Poole and Bajer 2019) or invertebrate pests (Garcia et al. 2020; Trdan et al. 2020; Lee et al. 2022). The establishment of an introduced species population is usually indicative of indigenous predators having limited impact on their numbers, or indigenous predators occurring at low population levels (Conti et al. 2021; Twinning et al. 2022); however, indigenous predators may provide enough predation pressure to prevent exotic species from successfully establishing by suppressing released or escaped individuals that would otherwise be founder individuals (Mori et al. 2020).

The Green Iguana (*Iguana iguana*; Fig. 1) is an example of a successful colonizer, having established extralimital populations in parts of the West Indies where it was previously not found (De Jesús Villanueva et al. 2021; Perry et al. 2021), Florida (Meshaka et al. 2004b; Krysko et al. 2007), Hawaii (Powell 2005), Fiji (Falcón et al. 2013), Taiwan (Lee et al. 2019), and Japan (Mito and Uesugi 2004). These populations have become established mainly through captive iguanas being distributed widely through the exotic pet trade (Mitchell and Shane 2000; Stephen et al. 2011) and some subsequently escaping or being released (Meshaka et al. 2004a). In other cases, Green Iguanas have arrived as stowaways in cargo, construction and horticultural materials (van den Burg et al. 2020a; Perry et al. 2021), and on rafts of floating debris across seas (Censky et al. 1998). Furthermore, in some Asian countries, captive animals are often released as part of a Buddhist act believed to build spiritual merit (Agoramoorthy and Hsu 2005; Ng and Lim 2010). There have now been increasing reports of free-living Green Iguanas in additional locations in Asia, such as Singapore, Thailand, and Hong Kong (van den Burg et al. 2020b; Mo and Mo 2022), which occur at notably higher frequencies than the spasmodic or isolated incur-

Figure 1. A large adult Green Iguana (*Iguana iguana*) observed at the Tsing Tam Reservoirs, Hong Kong, on 1 October 2019. Photographed by Chris Wu.

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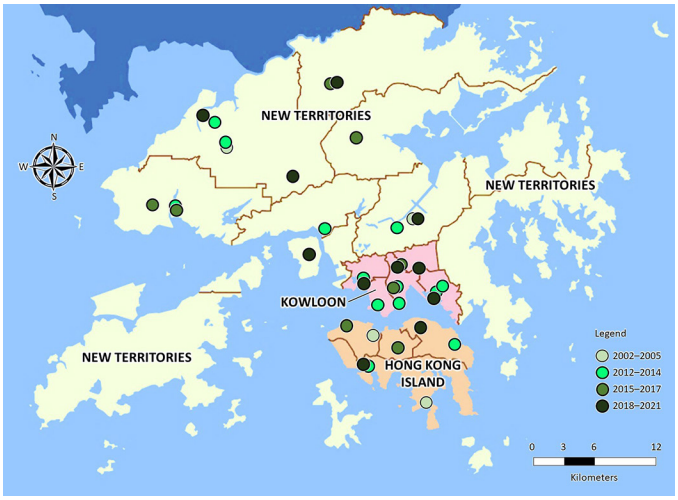

Figure 2. A map indicating reports of free-living Green Iguanas (*Iguana iguana*) in Hong Kong over four time periods since 2002.

sions reported in countries like Israel (Shacham and Nemtzov 2008) and Australia (Roznik et al. 2011).

Reports of free-living Green Iguanas in Hong Kong were first published in the scientific literature by van den Burg et al. (2020b). Though no established populations have been confirmed to date, a recent study found 44 reported sightings of free-living Green Iguanas in Hong Kong (Mo and Mo 2022), which showed an increasing pattern of sightings since 2012 (Fig. 2). In anticipation of this pattern potentially continuing into the future, we compared known vertebrate predators of the Green Iguana with the fauna of Hong Kong for an indication of taxa that may provide a form of biotic resistance against escaped or released Green Iguanas (Table 1).

Mammals (Class Mammalia)

Order Carnivora.—A number of carnivorans are known predators of Green Iguanas in North and South America. There are nine extant members of this order in Hong Kong, which are the Leopard Cat (*Prionailurus bengalensis*), Small Indian Civet (*Viverricula indica*), Masked Palm Civet (*Paguma larvata taivana*), Javan Mongoose (*Urva javanica*), Crab-eating Mongoose (*Urva urva*), Yellow-bellied Weasel (*Mustela kathiah*), Yellow-throated Marten (*Martens flavigula*), Eurasian Otter (*Lutra lutra*), and Chinese Ferret Badger (*Melogale moschata*). We consider all these species to be possible predators of Green Iguanas. Free-roaming and stray domestic dogs and cats, which also have been documented to prey upon iguanas (Rivas et al. 1998; Meshaka et al. 2004a), occur in Hong Kong as well (Dahmer 2002; Chemonges-Nielsen 2003; Woo et al. 2012).

Order Primates.—A number of primates are omnivorous and one species, the Wedge-capped Capuchin Monkey (*Cebus olivaceus*) has been documented to prey upon Green Iguanas (Rivas et al. 1998). Wild primates in Hong Kong are limited to Rhesus Macaques (*Macaca mulatta*), Crab-eating Macaques (*M. fascicularis*) and hybrids of these species

Table 1. Summary of documented predators of the Green Iguana, indicating whether those taxa prey on hatchlings and juveniles only or all life stages.

Order	Taxa
Carnivora	*All life stages* – wild cats (Chinchilla 1997; Loc-Barragán 2017), otters (Pereira et al. 2020), Tayras (Galef et al. 1976; Barrio-Amorós and Ojeda 2015), raccoons (Smith et al. 2006), coatimundis (Greene et al. 1978)
Primates	*All life stages* – capuchin monkeys (Rivas et al. 1998)
Cuculiformes	*Hatchlings and juveniles only* – cuckoos (Rivas et al. 1998; Savage 2002; Coutinho et al. 2014)
Pelecaniformes	*Hatchlings and juveniles only* – herons (Rivas et al. 1998; Engeman et al. 2005)
Accipitriformes	*All life stages* – hawks (Greene et al. 1978; Rivas et al. 1998)
Cathartiformes*	*All life stages* – vultures (Greene et al. 1978)
Falconiformes	*Hatchlings and juveniles only* – falcons (Rivas et al. 1998), caracaras (Rivas et al. 1998)
Strigiformes	*All life stages* – owls (Rivas et al. 1998; McKie et al. 2005; Filipiak et al. 2012)
Piciformes	*Hatchlings and juveniles only* – toucans (Savage 2002)
Passeriformes	*Hatchlings and juveniles only* – flycatchers (Rivas et al. 1998), icterids (Rivas et al. 1998)
Squamata	*All life stages* – boas (Quick et al. 2005; Rivas et al. 2007; Oliveira et al. 2015; Ribeiro Sanches et al. 2018), pythons (Kimmel and Edwards 2019), monitor lizards (Mazzotti et al. 2020) *Hatchlings and juveniles only* – colubrids (Rivas et al. 1998; Savage 2002; Perry et al. 2021), basilisk lizards (Burghardt et al. 1977), racerunners (Rivas et al. 1998), tegus (Rivas et al. 1998)
Crocodylia*	*All life stages* – crocodiles (Platt et al. 2006; Balaguera-Reina et al. 2018), caimans (Rivas et al. 1998)

*Orders not represented in Hong Kong.

(Southwick and Southwick 1983; Wong 1994). We know of one publication reporting small lizards in the diet of one macaque species (Schülke et al. 2011), so macaques preying on juvenile iguanas may be plausible.

Order Artiodactyla.—In addition to the orders represented in Table 1, we considered one species of odd-toed ungulate native to Hong Kong as a potential predator; Wild Boar (*Sus scrofa*) are omnivorous and documented to prey upon reptiles (Jolley et al. 2010) and their eggs (Campos and Mourão 2015). Thus, we consider them likely to also prey upon Green Iguanas and their eggs.

Birds (Class Aves)

Order Cuculiformes.—Savage (2002) and Coutinho et al. (2014) refer to anis (*Crotophaga* spp.) and the Guira Cuckoo (*Guira guira*) as predators of juvenile Green Iguanas respectively. There are at least 14 species of cuckoos of varying sizes native to Hong Kong, and one of the larger species, the Greater Coucal (*Centropus sinensis*), is known to take small lizards (Ali 2002).

Order Pelecaniformes.—Engeman et al. (2005) reported a Yellow-crowned Night Heron (*Nyctunussa violaceri*) preying on a Green Iguana hatchling. Similar predation would probably also occur in herons and egrets found in Hong Kong. A number of representatives of this order are known to prey upon lizards, including the Great Egret (*Ardea alba*; Nemeth and Schuster 2005; Pommer-Barbosa et al. 2021), Grey Heron (*Ardea cinerea*; Rodríguez et al. 2007), and Black-crowned Night-heron (*Nycticorax nycticorax*; Martín and López 1990).

Order Ciconiiformes.—In addition to the orders represented in Table 1, we considered storks to also represent potential predators of Green Iguanas. Similar to representatives of the order Pelecaniformes, storks sometimes prey upon lizards, including the two species that occur in Hong Kong, the Black Stork (*Ciconia nigra*; Martín and López 1996) and the Oriental Stork (*C. boyciana*; Tryjanowski et al. 2018), though they primarily feed on fish, amphibians, and invertebrates (Hampl et al. 2005; Tawa et al. 2021).

Order Accipitriformes.—Multiple hawk species have been documented as predators of Green Iguanas (Greene et al. 1978; Rivas et al. 1998). Accordingly, there are a number of sparrowhawks and goshawks (*Accipter* spp.) found in Hong Kong that would possibly prey upon hatchling and juvenile iguanas. Hong Kong also has a range of large to medium-sized raptors that may possibly take iguanas of any life stages; these include eagles of the genera *Aquila*, *Clanga*, *Haliaeetus*, and *Spilornis*, buzzards of the genera *Butastur* and *Buteo*, harriers (*Circus* spp.), the Black Kite (*Milvus migrans*), and the Osprey (*Pandion haliaetus*). In addition, a small raptor, the Black Baza (*Aviceda leuphotes*), which feeds on invertebrates and small lizards (Zacharias and Gaston 2016), also occurs in Hong Kong

Order Falconiformes.—Rivas et al. (1998) reported falcons and caracaras as predators of juvenile and hatchling Green Iguanas. The Eurasian Kestrel (*Falco tinnunculus*) is a representative of this order in Hong Kong that regularly feeds on small lizards (Steen et al. 2011), and is therefore likely to prey upon juvenile and hatchling Green Iguanas. A second falcon in Hong Kong, the Peregrine Falcon (*F. peregrinus*) has been known to prey upon small lizards but is primarily an avian specialist (Ellis et al. 2002). Two other species of falcon also occur in Hong Kong, the Amur Falcon (*F. amurensis*) and the Eurasian Hobby (*F. subbuteo*); however, the former is primarily insectivorous (Pietersen and Symes 2010), and the latter feeds primarily on mammals, birds and invertebrates (Zawadzka and Zawadzki 2001). These species are therefore less likely to take a Green Iguana.

Order Strigiformes.—We are only aware of three reports of owls preying on Green Iguanas, which were hatchlings and juveniles taken by a Barn Owl (*Tyto alba*; Rivas et al. 1998) and Burrowing Owls (*Athene cunicularia*; McKie et al. 2005), and a subadult being dispatched by a Spectacled Owl (*Pulsatrix perspicillata*; Filipiak et al. 2012). A range of owl species are found in Hong Kong, including at least eight species known to take small lizards, which could potentially prey upon hatchling or juvenile Green Iguanas. These include scops-owls (*Otus* spp.; Leadprathom et al. 2009; Aswari and Priyambodo 2020), the Eurasian Eagle-owl (*Bubo bubo*; Shehab 2004), Brown Fish-owl (*Ketupa zeylonensis*; Samad 2019), Asian Barred Owlet (*Glaucidium cuculoides*; del Hoyo et al. 1999), boobook owls (*Ninox* spp.; Taniguchi 1983; Konig et al. 1999), and the Eastern Grass Owl (*Tyto longimembris*; del Hoyo et al. 1999), though small lizards are not the primary food source of many of these species.

Order Piciformes.—To date, the only documented predators of Green Iguanas from this order are toucans (family Ramphastidae; Savage 2002), which do not occur in Hong Kong. There are other representatives of this order in Hong Kong, the Asian barbets (*Psilopogon* spp.) and woodpeckers (family Picidae); however, it is not clear whether any of these would prey upon iguanas.

Order Passeriformes.—Rivas et al. (1998) reported flycatchers (family Tyrannidae) and icterids (family Icteridae) as predators of Green Iguanas. Hong Kong has 45 families of passerines, of which we anticipate predation to come from corvids such as the Large-billed Crow (*Corvus macrorhynchos*; Karunarathna and Amarasinghe 2008) and House Crow (*C. splendens*; Wilson et al. 2015) and starlings such as the Common Myna (*Acridotheres tristis*; Kutt and Kemp 1997; Mohalik et al. 2020) based on literature records of these taxa preying on lizards. There are also other passerines that primarily feed on other foodstuffs that may opportunistically feed on small lizards, such as pittas (*Pitta* spp.; Peddie 1961).

Reptiles (Class Reptilia)

Order Squamata.—Growing numbers of studies have reported large-bodied constrictors as predators of Green Iguanas of all life stages (Quick et al. 2005; Rivas et al. 2007; Oliveira et al. 2015; Ribeiro Sanches et al. 2018), including the Burmese Python (*Python bivittatus*; Kimmel and Edwards 2019), which is the sole representative of the family Pythonidae in Hong Kong. Colubrids (family Colubridae), observed preying on smaller iguanas and which are represented in Hong Kong by more than 30 species, form the remainder of reports in the scientific literature concerning snake predation (Rivas et al. 1998; Savage 2002; Perry et al. 2021),. Although we are not aware of any literature reports of elapids (family Elapidae) preying on Green Iguanas, recent studies have reported lizards being taken by the King Cobra (*Ophiophagus hannah*; Kurniawan et al. 2018; Jones et al. 2020), a large elapid native to Hong Kong.

Monitor lizards (family Varanidae) are the only other squamate documented to prey upon adult Green Iguanas (Mazzotti et al. 2020). The Asian Water Monitor (*Varanus salvator*) is the sole representative of this family in Hong Kong. Once extirpated in the region (Dudgeon 1996), it is now occasionally recorded, probably from escapees of captive individuals (Agriculture, Fisheries and Conservation Department 2018). Other lizards documented to prey upon hatchlings and juveniles are the basilisk lizards (*Basiliscus* spp.; Burghardt et al. 1977) and racerunners and tegus (family Teiidae; Rivas et al. 1998), which are not represented in Hong Kong.

Discussion

The broad range of issues associated with introduced populations of Green Iguanas provide rationale for jurisdictions outside of the species' native range to address the risks of the species establishing populations (Knapp et al. 2020), for which developing an understanding of local taxa that may provide predation pressure is an important consideration. In other countries, introduced populations of Green Iguanas are thought to impact local biodiversity by processes such as overgrazing native vegetation (Carlo and García-Quijano 2008), dispersal of exotic seeds (Meshaka et al. 2007), and competition with native fauna for foraging resources and retreat sites (McKie et al. 2005). Green Iguanas in captive collections have also been reported with bacterial skin infections, which may represent a risk to native reptiles (Hellebuyck et al. 2018). Introduced populations of Green Iguanas also have social and economic impacts, such as problems for gardeners and horticulturalists from iguanas consuming vegetation (Krysko et al. 2007; Falcón et al. 2013), their burrowing behavior causing soil erosion, bank destabilization, and damage to infrastructure (López-Torres et al. 2012), and iguanas representing runway strike hazards at airport sites (Engeman et al. 2005). Mitigating the risk of Green Iguanas establishing populations in Hong Kong would therefore have triple-bottom line benefits.

The scientific literature on predator species of the Green Iguana is extensive and covers a broad range of taxa, specifically two mammalian orders, eight avian orders, and two reptilian orders. All but two of these orders are represented by species occurring in Hong Kong, while two additional orders represented in Hong Kong contain species that are documented to prey upon lizards in general. Thus, species present in Hong Kong that are considered likely to provide predation pressure on escaped or released iguanas comprise at least 12 taxonomic orders.

Numerous locations where free-living Green Iguanas have been reported in Hong Kong to date have been heavily developed areas, which is indicative of a high proportion of individuals originating from escaped or released pets (Mo and Mo 2022). In such environments, the impacts on wildlife from free-roaming and stray dogs (Young et al. 2011; Hughes and Macdonald 2013; Home et al. 2018) and cats (Loss et al. 2013; Rowan et al. 2019) are well-documented. Both are plentiful in Hong Kong (Dahmer 2002; Chemonges-Nielsen 2003; Woo et al. 2012) and are likely to provide an important source of predation. Amongst native species, the avian species generally have a greater representation in settled areas than mammals and reptiles, which are mostly confined to natural areas. Thus, we expect the avian species, along with free-roaming and stray dogs and cats, to be the potential predators most likely to take iguanas in settled areas. Once Green Iguanas venture into more natural surroundings, they are then exposed to potential predators from all three taxonomic classes.

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