

Severe mammal declines coincide with proliferation of invasive Burmese pythons in Everglades National Park

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Invasive species represent a significant threat to global biodiversity and a substantial economic burden. Burmese pythons, giant constricting snakes native to Asia, now are found throughout much of southern Florida, including all of Everglades National Park (ENP). Pythons have increased dramatically in both abundance and geographic range since 2000 and consume a wide variety of mammals and birds. Here we report severe apparent declines in mammal populations that coincide temporally and spatially with the proliferation of pythons in ENP. Before 2000, mammals were encountered frequently during nocturnal road surveys within ENP. In contrast, road surveys totaling 56,971 km from 2003–2011 documented a 99.3% decrease in the frequency of raccoon observations, decreases of 98.9% and 87.5% for opossum and bobcat observations, respectively, and failed to detect rabbits. Road surveys also revealed that these species are more common in areas where pythons have been discovered only recently and are most abundant outside the python's current introduced range. These findings suggest that predation by pythons has resulted in dramatic declines in mammals within ENP and that introduced apex predators, such as giant constrictors, can exert significant top-down pressure on prey populations. Severe declines in easily observed and/or common mammals, such as raccoons and bobcats, bode poorly for species of conservation concern, which often are more difficult to sample and occur at lower densities.

invasion biology | population declines | top-down regulation | reptiles

Invasive species represent one of the most significant threats to global biodiversity and ecosystem function (1). In the United States the cost of invasive species management exceeds \$120 billion annually (2). Invasive species affect native ecosystems via alteration of habitat structure (3), competition (4), reduction of native predator populations (5), and alteration of trophic structure (6). Invasive predators can reduce or even extirpate native prey populations (7, 8).

Nonnative reptiles are increasingly recognized as problematic invaders (9). Most reptiles are predators that, as ectotherms, can direct large proportions of assimilated energy to growth, storage, and reproduction (9), often allowing them to persist at high densities and pose major risks to native wildlife (10). For example, Brown treesnakes (*Boiga irregularis*) introduced to Guam before 1950 devastated populations of native vertebrates (11), greatly altering natural ecosystems (12). However, treesnakes were not implicated in the decline of native vertebrates for more than 30 y (13). Unfortunately, the time from the establishment of an invasive reptile species to the recognition of impacts often is decades, and for many invasions, the historical data necessary to evaluate impacts are unavailable (10).

Burmese pythons (*Python molurus bivittatus*), large (up to 5.5 m) constrictors native to Southeast Asia (14), now are established across thousands of square kilometers in southern Florida, including all of Everglades National Park (ENP) (Fig. 1) (15). Pythons were sighted intermittently in ENP for about 20 y before

2000, when they first were recognized as being established (16); subsequently, the number of pythons removed annually from ENP has increased dramatically (Fig. 2). Pythons in Florida consume a wide range of mammals and birds, including species classified as threatened or endangered under the US Endangered Species Act, such as the Key Largo woodrat (*Neotoma floridana smalli*) and wood stork (*Mycteria americana*) (14–15, 17–18). Pythons also occasionally prey on American alligators (*Alligator mississippiensis*) (14, 18). Although hundreds of prey items and more than 40 prey species for pythons in Florida have been documented, the impacts of python predation on native prey populations are essentially unknown. We used systematic road surveys to sample mammals in ENP before and after the proliferation of pythons. Road surveys also were conducted in areas where pythons have been documented only recently. Here, we present spatial and temporal data supporting the hypothesis that Burmese pythons have severely reduced populations of several species of formerly common mammals in ENP within 11 y of being recognized as an established invasive species.

Results

From 1993–1999, raccoons (*Procyon lotor*), Virginia opossums (*Didelphis virginiana*), and rabbits (*Sylvilagus* spp.) were the most common mammals found during roadkill surveys in ENP (Fig. 3). Encounter rates of live and dead mammals during systematic nocturnal road surveys in 1996–1997 corroborated this pattern, with raccoons (2.8 observations/100 km) and opossums (0.9/100 km) being the most frequently encountered species. Substantial decreases in the encounter rates of several species of mammals were apparent from 2003–2011 (Fig. 4A). Despite consistency of survey methods, we observed no rabbits or foxes (*Urocyon cinereoargenteus* and *Vulpes vulpes*) between 2003 and 2011, found a 99.3% decrease in raccoon observations and decreases of 98.9%, 94.1%, and 87.5% for opossums, white-tailed deer (*Odocoileus virginianus*), and bobcats (*Lynx rufus*), respectively. Observations of other mammals, including rodents, coyotes (*Canis latrans*), and Florida panthers (*Puma concolor coryi*) increased slightly (<0.02/100 km), but the overall numbers of observations for these groups were low.

We also found considerable spatial variation in mammal observations. At peripheral locations, where pythons have been documented only recently and python densities presumably are

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