

Research Article

Case study of a Rapid Response Removal Campaign for the invasive alien green iguana, *Iguana iguana*

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Abstract

The Invasive Alien Green Iguana (IAGI), *Iguana iguana*, has spread worldwide via the pet trade, as stowaways and via other means and has become a pest species of global concern. It also represents a major threat to the endemic Lesser Antillean Iguana, *Iguana delicatissima*, on St. Eustatius. Following the capture of an adult female IAGI on St. Eustatius in early 2016, we conducted a Rapid Response Removal Campaign (RC) from April 2016 to January 2017. Three sets of directed visual surveys totaling 409.5 observer hours and covering a combined trajectory of 114.2 km realized only a single detection of a hybrid that was later removed. During the remainder of the campaign period, an additional four IAGI hybrids were opportunistically detected and removed thanks to park staff or community involvement. Since the end of the campaign, eight additional detections and removals have been realized, three of which were IAGIs caught while offloading freight in the harbour and five of which were hybrids caught in surrounding suburban areas. We suggest that at least four distinct IAGI introductions to St. Eustatius occurred between 2013 and 2020. Our results show the value of motivating and mobilizing stakeholders and the public at an early stage of an invasion. Since the program's initiation, eight of the 13 iguanas detected for culling were thanks to public and key stakeholder support and involvement. Four years after our campaign, the number of IAGIs and their hybrids still appear to be limited and concentrated in and around inhabited areas. Additional removal campaigns should be initiated as soon as possible, firmly based in public outreach, motivation and engagement. New legislation is needed to prohibit the importation, possession and harbouring of IAGIs or hybrids and to provide a framework for long-term structural funding required for effective control and removal. Routine fumigation and rigorous inspection of arriving cargo to eliminate the risk of stowaway IAGIs are also recommended. Culling of IAGIs is recommended for the port of St. Maarten, which serves as a major point of dispersal of IAGIs to St. Eustatius and likely also other islands in the region.

Key words: community engagement, invasive species, invasive reptile, hybridization, island

Introduction

Biological invasions are a major global concern and have significant consequences for biodiversity, the environment, agriculture, livelihoods, health and culture in affected regions (Pyšek et al. 2020). These effects tend

to be much stronger on islands than on continents (Russell et al. 2017). Worldwide, the most impactful invasive animals are generally mammals such as feral livestock, cats and rats for which many eradication programs have been undertaken (e.g. Campbell and Donlan 2005; Howald et al. 2007; Campbell et al. 2011). In recent years, however, the Invasive Alien Green Iguana (IAGI) has become a species of high worldwide concern as an invasive species. From its origins in South America, it has spread extensively throughout the Caribbean (Falcón et al. 2012) and is now rapidly spreading elsewhere throughout tropical and subtropical regions of the world, including Asia (Falcón et al. 2013, Van den Burg et al. 2020).

The Lesser Antillean Iguana, *Iguana delicatissima*, is a highly endangered Lesser Antillean endemic species (Van den Burg et al. 2018a) native to the Dutch Caribbean island of St. Eustatius. The species is classified as Critically Endangered on the IUCN Red List and has already been lost from most Caribbean islands on which it naturally occurred (Van den Burg et al. 2018a). Today, the IAGI is a recognized principal cause for its endangerment throughout its remaining range due to displacement by and hybridization with the IAGI (Knapp et al. 2014). Since the extinction of the endemic rice rat, *Pennatomys nivalis*, during the European colonial era, either due to introduction of invasive rodents/mammals or habitat destruction (Brace et al. 2015), *I. delicatissima* has been and still is the largest surviving endemic land vertebrate of St. Eustatius.

Awareness that the IAGI is a serious threat to *I. delicatissima* developed only gradually. For decades the IAGI was regarded as a merely compatible coexisting species. For instance, Wijffels (1976) opined that *I. delicatissima* was “absolutely not being supplanted by the IAGI advancing from South America as has been assumed for many decades”. Three decades later, in their review on the conservation state of reptiles of the Lesser Antilles, Powell and Henderson (2005) only indicated the possibility of hybridization as among the many threats to the species but gave it no further priority or urgency. In the *Lesser Antillean Iguana Species Profile* by Pasachnik et al. (2006) hybridization was mentioned, however, only in passing and was not highlighted as a principal threat. Likewise, in his review paper on the ecology and conservation of the Lesser Antillean Iguana, Knapp (2007) highlighted the threat of hybridization with the IAGI to the genetic integrity of the species, but offered little to prioritize it as a principal conservation concern.

By the early 2010s, expert opinions shifted, as they began to view the IAGI as a threat to the conservation of *I. delicatissima*. For instance, in 2012, the IAGI was described as a “potentially disastrous” future threat to the Lesser Antillean Iguana on St. Eustatius by Van Buurt and Debrot (2012) and later by Vuillaume et al. (2015). In 2013, Debrot and Boman (2013) and Debrot et al. (2013) listed the introduction of the IAGI as one

of the top four threats to the native iguana population on St. Eustatius. Finally, today, the most recent Species Action Plan for *I. delicatissima* recognizes “displacement through competition and hybridization with *I. iguana*” as a key factor in the loss of the Lesser Antillean Iguana from many islands (Knapp et al. 2014).

In 1992, the *I. delicatissima* population on St. Eustatius was estimated at approximately 300 animals, in 1998 at less than 300 animals, and in 2004 at about 425 (275–650) individuals (Reichling 1999; Fogarty et al. 2004). The most recent population survey concluded that, notwithstanding protective measures, the status of the native iguana had not improved significantly in the eight years since the 2004 assessment (Debrot and Boman 2013). The long-term prospects for the species worsened dramatically when, on 22nd February 2016, St. Eustatius National Parks (STENAPA) reported the capture of a gravid adult female IAGI. Recognizing the magnitude of this threat to the native *I. delicatissima* population, we swiftly initiated a rapid response removal campaign (RC) in an attempt to rid the island of this emergent threat and by April 2016 we had initiated the first of three directed removal surveys. Here we report on the results of our RC, the objectives of which were to: a) provide an initial assessment of the state of the IAGI invasion; b) engage community support in addressing this threat; c) evaluate the effectiveness of directed removal surveys and; d) recommend further actions required to deal with this most vital risk to the critically endangered *I. delicatissima* population.

Materials and methods

The IAGI can be readily distinguished from *I. delicatissima* based on several morphological characteristics such as the presence of a large subtympanic scale, nasal horns, large nuchal tubercles, a flat instead of bumpy top of the head, the presence of black rings around the tail and the absence of the thick sub-labial scales that typify *I. delicatissima* (Breuil 2013). F1 hybrids of the two species have a mix of these characteristics and are distinguished by a much smaller size and more forward placement of the subtympanic scale and dull-black rings around the tail (Figure 1). The most important signs for field detection of IAGIs and their hybrids at a distance are the black rings around the tail, a spiky dorsal crest and the presence of a large to very large subtympanic scale, most prominent on adult males.

Green iguanas are generally shy and successfully use camouflage to avoid detection. Therefore, due to this low detection probability, two well-experienced, iguana spotters (H. Madden and T. van Wagensveld) were assigned to conduct three sets of directed visual surveys spread out over the course of a year. The three sets of surveys were conducted in April 2016, August–September 2016 and January 2017, respectively. Our campaign period

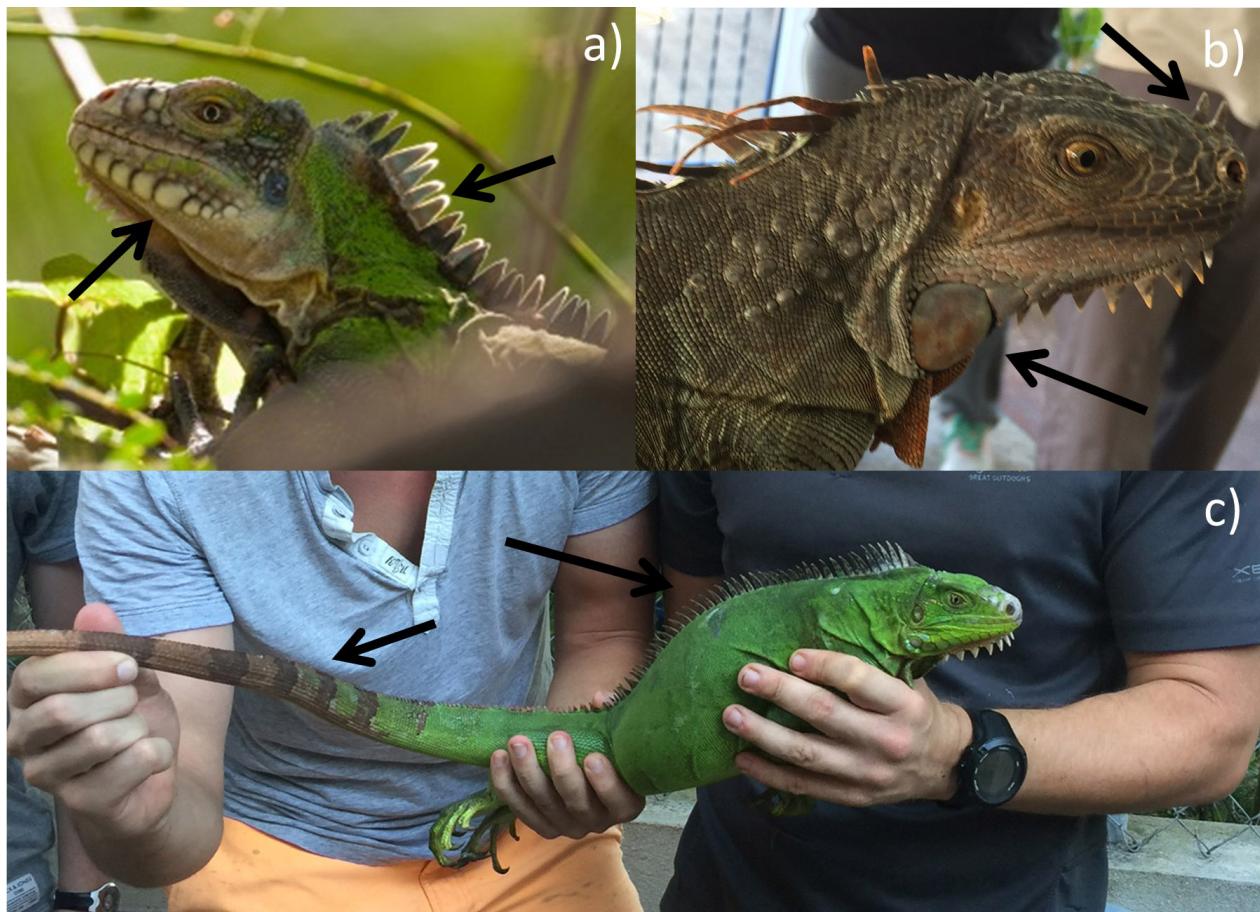


Figure 1. Key distinguishing phenotypic characteristics of a) *I. delicatissima* with arrows pointing to thick sub-labial scales and stout triangular dorsal spines, b) a specimen of Invasive Alien Green Iguana (specimen 2) caught prior to our Rapid Response Removal Campaign with arrows pointing at the large subtympanic scale and nasal spikes and c) a presumed F1 hybrid (specimen 7) with arrows pointing at the tempered-black tail rings and the spiky dorsal crest (all photos: STENAPA).

is defined as the whole period from April 2016 to January 2017. Opportunistic removals, however, continued after the campaign ended thanks to the continuing public awareness effort and broad community support. In this assessment we include information on IAGIs seen and culled both before and subsequent to our campaign, up through December 2020.

Extensive genetic sampling in 2015 showed that, until that time, there was no evidence of hybridization of IAGI into the *I. delicatissima* population (Van den Burg et al. 2018b). Making use of the most up-to-date leads, all directed search effort using line transects was concentrated in an area of up to about 200 m around locations at which IAGIs had been caught, or suspected IAGIs or hybrids had been reported. This was done to maximize actual chances of detection and was based on the presumed early stage of the IAGI invasion in 2016, during which animals should not have yet spread extensively. Searches included the harbour area as a main suspected point of entry to the island for all three sets of directed surveys. This also meant that the exact search areas covered greatly overlapped but were adjusted each time depending on the most recent actual or likely sightings of IAGIs or their hybrids (Figure 2). The distances covered during these line transect surveys were recorded and mapped, as was the time and number

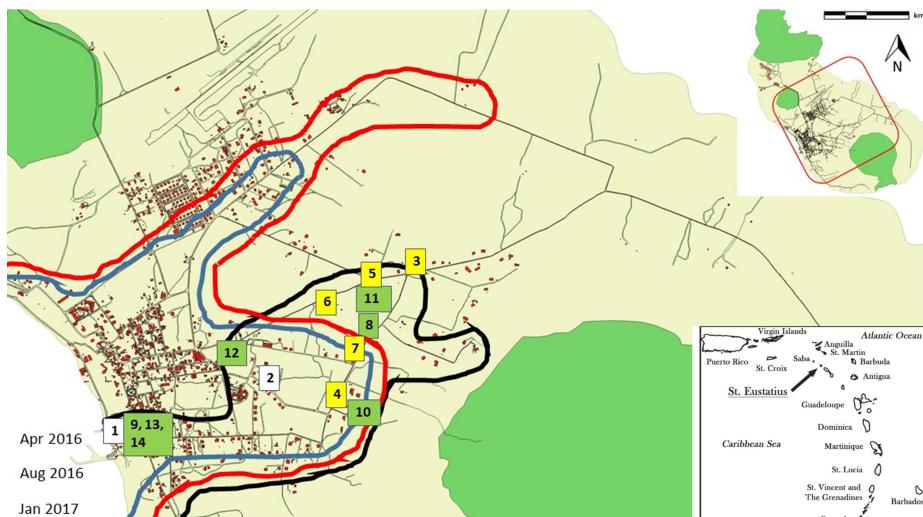


Figure 2. Map outlining the outer borders of the area envelope in which three sets of Rapid Response directed removal surveys (colored lines) were conducted; April 2016, August 2016 and January 2017. The known locations of Invasive Alien Green Iguanas and hybrids captured and culled, shown as white rectangles (before April 2016), yellow rectangles (April 2016 to January 2017) and green rectangles (January 2017 to December 2020), where numbers shown correspond to the specimen numbers in Table 2. Location of capture of specimen 15 is unknown and therefore not included on the map.

Table 1. Effort and results of the three directed surveys executed during 2016 and 2017 in an effort to find, capture and cull Invasive Alien Green Iguanas (IAGI) and hybrids on St. Eustatius.

Survey #	Time period	Days with search activity (n)	Average search team group size (n)	Person-hours spent (hr)	Distance covered (km)	Surface surveyed (ha)	IAGI or hybrids detected (n)
1	Apr 2016	7	2.2	72.0	23.8	47.6	0
2	Aug–Sept 2016	21	2.4	154.5	40.0	80.0	0
3	Jan 2017	12	4.3	183.0	50.4	100.8	1
Totals:		40	3.2	409.5	114.2	228.4	1

of persons searching. The effective total visual widths of the transects varied greatly depending on vegetation density or visual obstruction by buildings and differed from roughly 10 to 50 m. With more intensive searching than applied by us in earlier work (Debrot et al. 2013) and with the generally more open suburban terrain and greater range of sight, this time our searches averaged about 10 m in width to either side of the line transects. Transect surveys were (practically) always performed by two experienced iguana spotters walking side by side, each focusing on a separate side of the transect. The only exception was for eight search hours (out of the total of 154.5 August 2016 search hours) that involved an expert observer working alone. The core group of two expert spotters was often accompanied by additional volunteers (once as many as nine) of mixed experience, tagging along to learn, help detect and help catch. Table 1 shows that the average search team size for the two first directed survey periods was only slightly above the core team size of two but that during the third period on average two or more volunteers additionally joined in the search. In total, 409.5 observer hours were spent during the three sets of directed surveys in and around areas where IAGIs or hybrids had been captured, seen or reported by the public. Searches were spread out over a

total of 40 days and covered a total trajectory of 114.2 km and an (overlapping) searched surface area of 228.4 ha (Table 1).

Iguana activity differs during the course of the day. Individuals seek out customary vantage points for basking as early as a half hour after sunrise (Van Marken Lichtenbelt et al. 1993). After initial basking they disperse more widely during mid to late-morning feeding and then generally retreat to shade during the midday heat. Line transect surveys were conducted from 7:30 am to 1:00 pm and our search strategy was adjusted according to iguana activity. Table 1 provides information on the total time spent, the distance and surface areas covered, as well as the average number of participants during each of the three directed transect surveys. Total transect distances covered differed per day, varying between two and 3.4 km for a mean length of 2.6 km per survey day. Vegetation height was highly variable in the largely suburban habitat surveyed. The vegetation was maximally 8–10 m high and generally consisted of a mix of grassy fields, scattered bushes, fruit trees or fence-line trees. Iguanas were often detected in the first half of the morning basking in the sun on rooftops, wall tops, or the top branches of higher trees. During the periods between which the three sets of directed surveys were held, as well as in the four years since, all additional IAGI captures were based on opportunistic detections from park staff and personnel and from the public and stakeholders.

The total number of inhabitants on St. Eustatius is less than 3,500, mainly concentrated in the capital Oranjestad. Public support for the RC was deemed essential (Vane and Runhaar 2016). In this small, tight-knit community, the nature conservation and agricultural sectors carry a high public profile and visibility, and thanks to extensive close personal contacts, the locals leading our effort were well-known. Also, all agencies involved in the nature and agriculture sectors are strongly embedded in the island community. Focused involvement of key institutional and community leading figures (who were well-connected, willing to communicate and whom the public respect and are willing to cooperate with) greatly facilitated broad support for the initiative. Hence, prior to starting the campaign, the agricultural, veterinary, customs services and general public were informed of the need for the RC. This was done using a combination of folders distributed to home-owners and the general public, a broadcasted radio interview, newspaper articles and social media presenting explanatory images for distinction of the two species and their hybrids, as well as a bumper sticker initiative (Figure 3). Bumper stickers and ‘how to spot the IAGI/hybrid Iguana’ handbooks were distributed to community members of all ages. Many vehicles sported the bumper sticker. The handbook (Powers 2016) and folders contained illustrations of both the native *I. delicatissima* and the IAGI, illustrating the key diagnostic phenotypic characteristics of the species. Numerous local radio shows, social media articles and in-school lessons were produced by STENAPA during the campaign

More aggressive steps taken to protect St. Eustatius's native Lesser Antillean iguanas



This is van den Burg and RAVON's Tim van Wagenveld.

ST. EUSTATIUS—A crowdfunding campaign to save St. Eustatius's native Lesser Antillean Iguanas from the invasive Green Iguana was recently launched by Hannah Madden, terrestrial ecologist and founder of Ecological Professionals EcoPro.

Madden initiated the campaign after a second hybrid iguana was spotted on St. Eustatius in August. After further best efforts collaboration between local stakeholders EcoPro, STENAPA and RAVON failed to locate that hybrid.

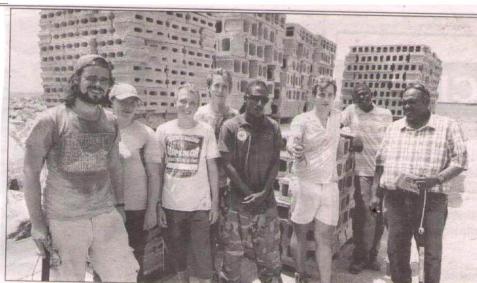
A fifth month of searching the less and Big Stone areas were unable to find the animal and it remains at large.

Photo credit: Hannah Madden, EcoPro

Iguanas pose a major threat to the Lesser Antillean Iguana which is listed as endangered by the International Union for the Conservation of Nature. Following the introduction of the Green Iguana, as has happened on St. Maarten, the ecosystem will make a domino effect and ultimately be impacted by the more aggressive species.

The funds raised will be used to cover costs and expenses of our campaign. This is our first step, therefore immediate action is required once it is discovered on a new island before it gets a foothold. Hence the need for urgent funding.

More information of crowd funding effort



Stenapa's team involved in the search for the invasive green iguana, with RAVON biologist Tim Wagenveld (third right) holding the "stowaway."

Stenapa search team captures invasive green iguana on Statia

ST. EUSTATIUS—An invasive green iguana was caught by Stenapa's National Parks ranger Rupnor Redan last week at the L

Personnel informed the team that four green iguanas were seen escaping from a shipment. "Unintended imports are

area of vulnerability for invasive species can become a huge threat to the native species. Stenapa prevent invasive species entering the country working with harbour offices," said Stenapa Director Clarisse Buma.

The organisation asks public to notify the National Parks Office of as with black bands on the tail, especially in the area of the sur by calling at tel. 884. Stenapa is to

population-assess operations for the Antillean iguana side patrolling, for green iguanas. Stenapa will involve county of Statia's lo

cal iguana across 30 fixed areas.

The last accurate transect was carried out in 2004 concluding that there were approximately 425 Lesser Antillean iguanas left on the island, which is considered insufficient for a stable breeding population.

National Park Ranger Redan recently completed a ten-day international iguana conservation workshop in Roatan, Honduras, in order to better protect Statia's endangered iguana.

Stenapa thanks harbour officials, the Department of Agriculture, Animal Husbandry and Fishery LVV, RAVON, Caribbean Netherlands Science Institute (CNSI) and all other stakeholders for their continued cooperation in conservation efforts for the Lesser Antillean iguana.

(STENAPA, Ecological Professionals, and RAVON) has led to the discovery and capture of eight hybrid individuals to date in addition to two Green Iguanas. The Green Iguanas arrived by boat from St. Maarten, which is home to large numbers of these non-native reptiles. The size variation of the hybrids indicates that a minimum of two hybrid nests have successfully hatched on St. Eustatius. It is therefore extremely likely that more hybrid Iguanas are present.

Based on the identification of hybridization and remaining presence of non-native iguanas, conservation management action is crucial to ensure the genetic integrity and longer-term survival of the St. Eustatius's Lesser Antillean Iguana. Fortunately, a successful grant application with the Mohamed bin Zayed Species Conservation Fund will boost conservation work by providing accommodation to two experienced researchers on St. Eustatius. These scientists will perform a systematic survey of the distribution and abundance of the current invasion.

Stenapa's Ecological professionals, and RAVON have been working on the identification of the current invasion is

the progress of biological potential for eradication an invasion curve (Figure 3). The spread of the invasive species controlling the invasion, lack of hybrids in our number of discovered hybrids to the current invasion is

0

ST. EUSTATIUS—This week, St. Eustatius National Parks was involved in the "beating" of the special and unique St. Eustatius Lesser Antillean Iguana.

Stenapa ranger Rupe "Jobo" Redan worked with iguana expert Tim van Wagenveld from Dutch Institute for the Research on Reptiles, Amphibians and Fishes RAVON and with local territorial manager Ambrosius van Zanten.

When iguanas are caught they are weighed, measured, photographed and banded. Beading the iguanas involves threading a thin wire through their loose neck skin and securing on coloured beads so to identify them. Every colour or colour combination is an indication of the animal's sex and age.

With this Stenapa can monitor their migratory behaviour over the years and see how the total population of iguanas evolves.

At the same time the team surveyed the island for hybrids. A hybrid iguana was photographed in Princess. A hybrid iguana is a offspring of an invasive iguana and a local iguana. Stenapa fears a takeover of the local population by the invasive and hybrid iguana's recognizable by the black bands on tail.

"We need to protect these local iguanas. There are

with the native species to create hybrids.

It is feared that if the green iguana is not controlled it will eventually replace the native St. Eustatius iguana will lose its genetic purity and become extinct.

While it is very difficult to eradicate invasive reptiles once they become established on islands, if the species is caught early enough it should be possible to prevent its spread on St.

St. Maarten, Madden said.

Stenapa is one of the last remaining islands in the Lesser Antilles that still supports a healthy population of the Iguana delicatissima and extensive DNA field-work was conducted last year.

The iguana was put in a se

STENAPA surveys for invasive and hybrid iguanas on Statia

ST. EUSTATIUS—St. Eustatius National Parks (STENAPA) has teamed up with the St. Eustatius Society (SES) to conduct surveys for invasive and hybrid iguanas on the island.

"When you see an iguana with black bands, call the office immediately, and STENAPA will come and catch the animal," Buma said.

"With that, Stenapa would be able to get its main address of where the iguana is located because St. Eustatius is well known for its iguanas, and that is something we are very proud of."

STENAPA calls on the community to keep an eye on the iguanas, and inform the office by email or telephone when they spot a possible invasive or hybrid iguana.

The local iguana is slate grey, but when young, it is bright green. It is important to be mistaken for a hybrid or a native green iguana, which is bright green with black bands on its tail and is larger in size than the local

iguana.

"Where the invasive green iguana (Iguana Iguana) in

is bright green with black bands on its tail and is larger in size than the local

iguana.

STENAPA is trying to catch as many hybrid iguanas as possible in order to prevent them from breeding.

Organized, Statia: Between January 21 and January 25, 2017, intensive field surveys have been conducted by Stenapa to search for invasive Green Iguanas and their hybrid offspring on Statia.

These efforts formed part of a "Search and Destroy" mission funded by the Ministry of Economic Affairs and facilitated by Wageningen University following the discovery of an adult female Green Iguana on the island in February 2017. Local stakeholders Ecological Professionals Foundation (EcoPro) and St. Eustatius National Parks (STENAPA) joined forces with Dutch biologists Tim van Wagenveld (RAVON) and Tim van den Burg (University of Amsterdam) to search four main "hotspots" where invasive iguanas have already been captured: Big St. Eustatius, Princess Garden, Lodi Lampoon, and Galloper Bay Harbor.

The team invested hundreds of man-hours searching the hotspots, from early morning until late every night. Both day and night surveys brought them into contact with over 80 native Lesser Antillean Iguanas, however no invasive green iguanas or hybrids were seen until the final day of fieldwork. During a final search last Tuesday at a private yard in Princess, where a hybrid had been photographed in August 2016, team member van den Burg spotted a large iguana with a striped tail in a tree. The team jumped into action and caught the animal. It was confirmed that it was a hybrid.

The iguana in question was the offspring of the native Lesser Antillean Iguana mixed with the invasive Green Iguana. The genes of the non-native Green Iguana are changing so that the species outcompetes the native species and eventually causes a decline. Key features to look for when identifying hybrids include: black bands on tail, small bumps behind the neck, flattened elongated head, longer spine, and shape of scales along the jaw, and lighter colored patterns on the body.

Stenapa St Eustatius
May 6, 2020

Be on the lookout for STENAPA's Most Wanted 'Hybrid Iguanas'. This one was spotted in the Princess/Chopstick area.

These offspring of the invasive green iguana (Iguana iguana) and our critically endangered local Lesser Antillean Iguana (Iguana delicatissima) still has the striped tail of its green iguana parent. There is also a larger-than-most scale on its cheek. Our iguana has no stripes on its tail and the scales on its cheek are of similar size.

Contact us at 318-2884 if you see any iguana that is not beaded (small colours by its neck). This will help us monitor the population numbers of our local iguana and help us confirm its type. It is important not to harm any iguana even if it has a striped tail. Call us to retrieve the animal and confirm it.

Support conservation of our local iguana by donating to our foundation

<http://www.statapark.org>

Large round scale on chin.

How to distinguish the invasive Green iguana from the Native St. Eustatius iguana

Photo: St. Eustatius National Parks

Photo:

August 6 and September 15. Because the problem with IAGIs and hybrids had clearly not been eliminated after the campaign ended in January 2017, STENAPA continued providing attention to the issue and additional newspaper articles appeared on March 27 and May 2, 2018 and December 21, 2020. Other media attention for the IAGI removal campaign was given on March 23, 2016 (BioNews Newsletter 23), October 17, 2016 (radio), February 2, 2017 (BES Reporter), April 17, 2017 (CaribischNetwerk), May 2018 (BioNews 13), and October 11, 2018 (Twitter). A local “iguana hotline” and website link were established and publicized through STENAPA’s social media accounts to alert STENAPA to suspicious sightings and even encourage volunteers for “iguana patrols” (outreach@statiapark.org). Via these channels, the public was urged to help by calling the park and/or the coordinating staff member on her mobile phone to report any likely sightings of IAGIs. An invasive species workshop was hosted by the local Caribbean Netherlands Science Institute in November 2017. One of the goals of the workshop, attended by representatives of STENAPA, Public Health, the St. Eustatius Agriculture, Livestock and Fisheries Service (LVV) and the port authorities, was to educate associated border staff how to recognize the IAGI and hybrids.

All leads obtained for possible IAGIs, were followed up with a visit to each indicated location to conduct a search, generally within a day of the suspected sighting or more quickly if the animal happened to be in sight at the moment the lead came in. When an invasive iguana was not found, the site was revisited in the days thereafter to determine whether any IAGI or hybrids could be detected. All animals that could be captured by hand were humanely euthanized by the local vet; those that were out of reach were shot with an air rifle by a staff member of LVV. The specimens culled were stored in a freezer for further study. All subsequent directed surveys included these areas, as well as additional areas when new suspected sightings were reported by the public or actual captures were made. In general, the search areas were clustered around the inhabited portion of the island, starting from the harbour of Oranjestad, the suspected main point of entry of the IAGIs. Several locally-active, affiliated organizations (STENAPA, Wageningen University and Research, Caribbean Netherlands Science Institute and LVV) extensively conduct research and nature and livestock management activities in remote areas of the island and never noted anything to suggest IAGIs or their hybrids have (even up to our date of manuscript submission) spread outside Oranjestad or its immediate surroundings. Therefore, all RC directed survey effort was focused in areas most likely assumed to harbour the IAGA or its hybrids.

Results

At the start of our campaign, R. Hensen, former head of LVV, provided us photographs and information on a juvenile IAGI he had caught and euthanized



Figure 4. Juvenile Invasive Alien Green Iguana caught at the St. Eustatius harbour and euthanized by R. Hensen in 2013, exact date unknown. Photo taken at the office of the St. Eustatius Agriculture, Livestock and Fisheries Service by R. Hensen.

from the harbour area in 2013, thus documenting the first known introduction event (Figure 4). This specimen was not a direct result of our campaign but is still important to report as it provides a considerably earlier date for a first documentation of the IAGI on the island. Based on inquiries prior to our campaign, local accounts indicated that the IAGI we caught in 2016 (specimen 2) and based on which our campaign was coordinated, had been introduced as a pet but later escaped (Jesse et al. 2016). However, curiously, the specimen showed no common external signs of damage due to captivity (e.g., deformed snout and/or broken toes or nails).

During the campaign period, five hybrid iguanas were caught and culled. However, our three directed surveys yielded only a single detection of a hybrid (Table 1). The animal could initially not be retrieved despite several attempts to resight it. Nevertheless, it is believed to correspond to hybrid specimen 7 (Table 2) because of its similar size and identical capture location three months later, as based on a follow-up tip by the resident home owner. In contrast to the directed surveys, incidental detections by the public and park management staff and personnel, yielded four captures during the campaign. After the campaign ended and directed surveys were discontinued, eight more iguanas were opportunistically caught and culled, three of which were juvenile to young adult IAGIs intercepted in the harbour and five of which were hybrids caught in and around Oranjestad. Of these, six had been detected by the public and stakeholders while two had been detected by park staff and personnel. With two of the specimens documented in this study culled before our campaign, we here report on a total of 15 culled iguanas (Table 2). Most of these were young-adult hybrids, two of which were found gravid with eggs upon capture. During the whole study period, no IAGIs or hybrids were detected or reported from outside

Table 2. Overview of culled Invasive Alien Green Iguanas (IAGI) and hybrid iguanas in St. Eustatius. NA: not available; SVL: snout to vent length; VT: length of vent to tail-tip; TL: total length; U: unintentional; I: intentional; IS: incidental detection by park personnel or staff; IP: incidental detection by stakeholder or public.

Specimen number	Specimen type and order of capture	Date of capture	Year of likely separate introduction events	Period in relation to removal campaign	Type of detection	Maturity stage/sex	SVL (cm)	VT (cm)	Weight (kg)
1	IAGI 1	??/2013	2013 (U)	before	IP	Juvenile/NA	NA	NA	NA
2	IAGI 2	2/17/2016	2016 (I)	before	IP	Gravid/female	40.7	79.9	2.18
3	Hybrid 1	7/27/2016		during	IP	Subadult/male	19.3	15.6*	0.33
4	Hybrid 2	8/30/2016		during	IS	Adult/female	26.5	63.7	0.63
5	Hybrid 3	10/10/2016		during	IS	Adult/female	NA	NA	NA
6	Hybrid 4	10/19/2016		during	IP	Adult/male	26.9	67.0	1.40
7	Hybrid 5	1/24/2017		during	DS	Adult/female	32.5	79.6**	1.89
8	Hybrid 6	3/23/2017		after	IP	Adult/male	33.1	68.8**	2.30
9	IAGI 3	3/30/2017	2017 (U)	after	IP	Juvenile/NA	NA	NA	NA
10	Hybrid 7	4/21/2017		after	IP	Adult/female	27.3	62.2	2.30
11	Hybrid 8	4/18/2018		after	IP	Gravid/female	33.0	99.1	1.92
12	Hybrid 9	3/31/2020		after	IS	Gravid/female	26.0	29.9*	NA
13	IAGI 4	10/28/2020	2020 (U)	after	IP	Juvenile/male	17.0	40.5	NA
14	IAGI 5	12/12/2020		after	IP	Adult/female	31.0	49.0	NA
15	Hybrid 10	NA		after	IS	Subadult/NA	24.4	33.7	NA

* half of tail missing

** tip of tail missing

Oranjestad or its immediate surroundings, despite our intensive field research activities in those areas.

After our initial capture of an adult IAGI in 2016, all other incidents involving non-hybrid IAGIs concerned juveniles or young adults intercepted in the St. Eustatius harbour. In March 2017, one subadult IAGI was caught while attempting to escape from cargo being unpacked in the harbour. In October 2020, a juvenile IAGI jumped onto a forklift during the unloading of cargo and was caught. Another young adult IAGI was caught in the harbour area in December 2020 and, based on similarity in size and proximity in time of detection, is believed most likely to be associated with the October 2020 specimen (Table 2). In summary, our results indicate a total of one likely intentional and three almost certainly unintentional introductions spanning the eight-year period 2013–2020. Neither the local ‘iguana hotline’ nor the website link for reporting suspected iguanas yielded any positive identifications of IAGIs. Most local residents and stakeholders contacted STENAPA rangers directly when they saw a potentially invasive iguana. Despite a disappointing attendance of customs officials to the invasive alien species workshop, some harbour staff were able to recognize IAGI and through this three (specimens 9, 13 and 14) were captured shortly after their presumed arrival in St. Eustatius. Since campaign initiation and up to the present, eight of the 13 iguanas detected for culling can be primarily ascribed to public and key stakeholder support and involvement. The fact that most IAGIs and hybrids were reported to STENAPA by the public and stakeholders and caught long after completion of the RC attests to the achievement of lasting community support.

Discussion and conclusions

Rapid response campaigns can greatly lower the cost of invasive species removal (Alvarez and Solís 2018), and not surprisingly there is much recent literature available on decision models and governance frameworks for implementing such systems for early detection and rapid response (e.g. Kraus and Duffy 2010; Martinez et al. 2018; Burgos-Rodríguez and Burgiel 2020; Reaser et al. 2020). Even so, while often called for (e.g. Rocha et al. 2020), actual case studies of implemented RCs with which to inform future campaigns are relatively few (e.g. Genovesi 2005; Hodgkins et al. 2012; Caffrey et al. 2018). According to Genovesi (2005) and Caffrey et al. (2018), this is most likely because of the often limited ability to detect early invasions and rapidly react due to inadequate legal frameworks and scarcity of resources. Also for the IAGI, Knapp et al. (2020) recently emphasized the need for action, but pointed out that this has typically come very late, in which case all that remains feasible is culling and control. Examples of very late action include the case of Florida, where the IAGI was introduced around 1966 but the first legal measures were only (unsuccessfully) attempted in 2020 (Knapp et al. 2020) and Puerto Rico, where the species was introduced in the 1970s, but a management plan was only recommended in 2012 (Lopez-Torres et al. 2012). In the Dominican Republic, where the species was likely introduced in the early 1990s importation was only prohibited 20 years later, after the species had already invaded the whole island (Pasachnik et al. 2012). Finally, in the Cayman Islands where the species was likely introduced in the 1990s, the first island-wide culling only took place in 2018 (Rivera-Milán and Haakonsson 2020). In the case of the IAGI on St. Eustatius, a fortuitous early detection presented us with a unique opportunity for a potentially successful eradication/containment campaign.

Based on our findings, and contrary to several recent reports and publications (Van Wagensveld and Van den Burg 2018; Van den Burg et al. 2018b), the first documented record of the IAGI on St. Eustatius dates from 2013, not 2016. The animal caught in the harbour and euthanized in 2013 was evidently a juvenile. At the time of its capture, LVV was of the opinion that it was an isolated introduction event and that euthanizing it would eliminate the threat of invasion. Therefore, aside from a brief search in the harbour area, no further attention was given to the incident. The first IAGI caught in 2016, and around which our response was coordinated, was a large, gravid adult female IAGI with 29 eggs, caught approximately one km from the harbour on the outskirts of Oranjestad. Based on local inquiries, it was determined that the animal in question had likely been introduced as a pet (Jesse et al. 2016). According to Van den Burg et al. (2018a), the 2017 introduction event involved four IAGI, of which three managed to escape. Based on what is known about growth and maturation

in the IAGI (e.g., Van Marken Lichtenbelt and Albers 1993), none of our detections or removals could reasonably correspond to any of these escaped animals and their actual fate remains unknown. Three lines of evidence suggest that the IAGI invasion in St. Eustatius is still at a relatively early stage. Firstly, only a single adult IAGI (that had been purposefully introduced as a pet) has so far been found on the island (located close to its point of escape), secondly, all juvenile IAGIs have been recorded at their point of entry in the Oranjestad harbour and thirdly, a 2015 genetic assessment found no indication of hybridization in 289 *I. delicatissima* blood samples collected from the wild (Van den Burg et al. 2018b). This means that containment and/or eradication of the IAGI and hybrid iguanas on St. Eustatius should still be feasible. A factor likely to help limit the spread of IAGI out of Oranjestad towards the north is the grassy to barren central section of the island with largely unsuitable habitat (Debrot et al. 2013) and the airport runway which practically cuts the island into two isolated halves.

Pluess et al. (2012a, b) examined the effect of various factors typically considered critical to eradication success in 136 eradication campaigns and 75 species. They found that factors such as reaction time, the level of knowledge and insularity were all unrelated to eradication success. Only the spatial extent of the infestation was significantly related to the eradication outcome (Pluess et al. 2012a, b). In the case of the St. Eustatius IAGI, our work suggests that the spatial extent of IAGI and hybrids distribution (if still present) is still quite limited. Even four years after the campaign, numbers of the IAGI and its hybrids were all found in and around inhabited areas, and their likely main point of entry is the island's harbour. Therefore, we conclude that it may not be too late to fully quell the invasion. Preferably, additional RCs should be initiated as soon as possible as the F1 hybrids are fertile and can reproduce (e.g. Breuil 2013). When egg-laying is successful, F2 hybrids should also soon appear. This is a tremendous challenge to eradication, as F2 hybrids resulting from back-crossing with *I. delicatissima* show a much wider range of intermediate and often less-pronounced distinguishing characteristics, making them much harder to distinguish from pure *I. delicatissima* (Breuil 2013). Once hybridization progresses beyond the F1 level, much more laborious and costly genetic testing of individual animals is required to reliably distinguish hybridized animals for culling. Therefore, immediate action must be taken to prevent any surviving F1 hybrids from successfully reproducing.

IAGI encounter rates during our directed surveys were clearly extremely low, even though we carefully targeted these surveys to those areas of highest likelihood of detection. On the contrary, most detections were incidental and primarily based on tips received from the public and other community stakeholders. In addition, more animals were actually culled after than during the campaign period. Thus, a key message from our

assessment is that for species with low detection probability, a longer, broad-based community effort might be more (cost) effective than shorter intensive survey efforts. In their draft *Joint Invasive Alien Species Strategy*, Smith et al. (2014) stress the need to involve the public in Invasive Alien Species (IAS) campaigns at an early stage. As also discussed by Vane and Runhaar (2016), lack of support for IAS removal and eradication is typically the principal obstacle to success. Our RC, which was extensively publicized in various ways and through a variety of media, was successful in achieving broad and lasting community support and engagement. Our results further corroborate that motivating and mobilizing community support and engagement can clearly make a critical contribution towards a RC. This may especially be the case for species with low detection probability combined with low densities, which make directed surveys relatively costly and ineffective. We suggest that under such situations it may be wise not to spend limited resources on extensive surveying but instead on intensive public outreach and education campaigns. The small island setting, close-knit community, high public profile and leading-figure roles of the local campaign initiators also likely played an important role in achieving such broad community support and stakeholder engagement.

IAGIs caught escaping from cargo or from the cargo platform in the harbour are assumed to have been accidental introductions and indicative of an introduction event taking place. Therefore, from 2013 to 2020, we believe to have documented four separate IAGI introduction events, three of which were accidental and due to stowaway animals in cargo arriving in port (2013, 2017, 2020) and one of which was likely intentional (2016). In order to safeguard the existence of *I. delicatissima* on St. Eustatius for posterity under such high and continuing threat levels, additional preventative and control measures will be required. Of utmost priority will be to implement (and enforce) local legislation, combined with training of border officials to prevent repeated entry of the IAGI from neighboring islands (Debrot and Boman 2013; Debrot et al. 2013; Debrot et al. 2018). However, institutions on St. Eustatius have been found to be grossly in need of additional financing, staffing and general capacity in order to be able to effectively address not only nature management in general (Van Beek et al. 2015) but also the IAS issue (Smith et al. 2014). Only a combination of legally mandated measures, structural funding and effective implementation can ultimately help keep St. Eustatius free of the IAGI.

Unfortunately, according to the most recent national review of progress made towards biodiversity conservation goals, the authors concluded that since the Dutch Caribbean IAS action plan was drafted, “no action has been taken on any of the islands” (Sanders et al. 2019). Establishing a legal framework to prevent introduction and make it illegal to possess live IAGI or its hybrids is an urgent policy priority. Only then is a legal foundation for structural funding and intervention provided. The current draft St. Eustatius

Nature Ordinance being considered for ratification states (in Art. 1.9) that it should be “prohibited to release and/or import specimens of non-indigenous or genetically modified species of flora and fauna into the wild.” However, as the IAGI is notoriously prone to escape, difficult to retrieve, highly fecund and will readily hybridize with the native *I. delicatissima*, possession of live IAGI (including eggs), even in captivity, should also be fully prohibited. Supplementary ordinances will, therefore, clearly be needed.

As soon as possible, follow-up RCs should be conducted to reengage local nature, agricultural and border agencies and the public by means of personal contacts, involvement of community leading figures and public outreach in this small island community. A key practical recommendation is to implement decontamination treatment of shipments using biocide applications (Wittenberg and Cock 2005) and provide periodic inspection training to border staff, especially since officials rotate between the different Caribbean Netherlands islands on a regular basis. The border staff need to be able to recognize the IAGI and its hybrids (as well as other invasive alien species as listed by Smith et al. 2014) followed by immediately reporting of sightings to STENAPA, and preferably euthanizing animals themselves to exclude any chances of later escape. All cases of escape prior to euthanization should be reported immediately STENAPA to allow prompt follow-up action and all euthanized iguanas should be provided to STENAPA for documentation and specimen-storage purposes.

Not only do IAGI introductions pose a major danger to *I. delicatissima* on St. Eustatius and other islands of the Lesser Antilles, but also to other regional endemic iguana species and/or subspecies, three of which have only recently been described, namely *Iguana melanoderma*, from the nearby Caribbean Netherlands island of Saba, *I. i. sanctaluciae* from St. Lucia and *I. i. insularis* from St. Vincent and Grenada (Breuil et al. 2019, 2020). In order to give these last few large endemic island vertebrates a chance of survival, it will be essential to keep their island refuges free of the IAGI. The largest and most persistent source of IAGI in the Lesser Antilles is likely to be the port of St. Maarten that, for decades has been the largest Lesser-Antillean tourism and container shipping hub (Kester 2002; Pérez-Salas 2012; Ito et al. 2020). To reduce the threat of accidental stowaway or hitchhiking iguanas from the shipping hub of St. Maarten to nearby Anguilla and St. Barthélemy where *I. delicatissima* have small populations surviving on the IAGI-free satellite islands of, respectively, Prickly Pear East and Île Fourchue (Van der Burg et al. 2018a), we recommend the port of St. Maarten carry out regular iguana culling within their grounds in order to reduce the risk of further spreading IAGI to the surrounding islands. IAGIs are being successfully culled on Grand Cayman island by the Cayman Islands Department of the Environment using a bounty system as incentive to hunters (Rivera-Milán and Haakonsson 2020 and J.F. Burton *pers communication*). As the iguana is an appreciated culinary delicacy

throughout the Caribbean, allowing harvest for consumption purposes, as is also being promoted regionwide in the case of the invasive Lionfish, *Pterois volitans* (e.g. Chapman et al. 2016; Blakeway et al. 2019), might also be a more sustainable incentive for the culling of this invasive species on St. Maarten.

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Authors' contribution

Debrot: funding acquisition, study design, coordination and writing, selection of journal and potential reviewers; Boman: data collection and review; Madden: design, field data collection, writing and review.

Ethics and permits

All work was carried out in accordance with St. Eustatius rules and regulations and took place under auspices of the local park management authority, STENAPA.

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