Management response to the threat of Burmese pythons in Arthur R. Marshall Loxahatchee National Wildlife Refuge

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Authors: Rebekah Gibble[1], Marcie Kapsch[2], Mathieu Bonneau[3], Laura Brandt[4], Kristen Hart[5], Kelly Irik[6], Jenny Ketterlin-Eckles[7], Page Klug[8], Carol Mitchell[9], Rolf Olson[2], Christina Romagosa[10], Hardin Waddle[11], Amy Yackel Adams[8], Cindy Hauser[12], Fred Johnson[3], Donna Brewer[13], and Sarah Converse[14].

Structured Decision Making

The process of structured decision provides a framework for analyzing and resolving complex decisions by systematically addressing and linking the basic elements of any decision. Essential elements include identifying the decision maker, clearly and specifically defining the decision problem and objectives, developing alternatives, considering consequences, assessing uncertainties, and evaluating tradeoffs (Hammond et al. 1999). This approach provides a logical and consistent method for finding solutions to complex problems that promotes the introduction of novel and improved solutions, strengthens stakeholder participation and acceptance of resolutions, and is more readily defensible due to the inherent transparency of the process (Gregory and Keeney 2002). Using the process to develop multiple rapid prototypes of the decision framework is often recommended so issues that invariably arise during development of the first prototype can be addressed by refining problem statements and objectives. The development of quantitative models to aid in defining the problem and evaluate alternatives is often beneficial to the decision making process, and was used in this instance.

Decision Problem

Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge) wishes to determine the most efficient allocation of resources for surveillance (detection with intent to eliminate the threat), and control (removal) activities in and around Refuge lands in order to minimize ecological damage from Burmese pythons (*Python molurus*) in the Refuge.

[1] USFWS, A.R.M. Loxahatchee National Wildlife Refuge, Boynton Beach, FL, USA, rebekah_gibble@fws.gov
[2] USFWS, A.R.M. Loxahatchee National Wildlife Refuge, Boynton Beach, FL, USA
[3] USGS, Southeast Ecological Science Center, Gainesville, FL, USA
[4] USFWS, Davie, FL, USA
[5] USGS, Davie, FL, USA
[6] Florida Fish and Wildlife Conservation Commission, Tallahasse, FL, USA
[7] Florida Fish and Wildlife Conservation Commission, Davie, FL, USA
[8] USGS, Fort Collins Science Center, Fort Collins, CO, USA
[9] NPS, Everglades National Park, Homestead, FL, USA
[10] University of Florida, Davie, FL, USA
[11] USGS, National Wetlands Research Center, Lafayette, LA, USA
[12] University of Melbourne, Victoria, Australia
[13] USFWS National Conservation Training Center, Shepherdstown, WV, USA
[14] USGS Patuxent Wildlife Research Center, Laurel, MD, USA

The allocation of surveillance and control activities must be done over both space and time, and is subject to budgetary constraints. The spatial extent of the decision problem includes the Refuge, and bordering areas: Everglades & Francis S. Taylor Wildlife Management Area (EWMA), the Everglades Agricultural Area (EAA), storm water treatment areas (STAs), and the urban area east of the Refuge. The spatial grain (i.e., the scale at which actions are implemented) has not been determined, but will likely represent a compromise between the dynamics of the python invasion and the logistic capabilities of resource agencies. Likewise, the frequency and timing of decisions are yet to be determined, and will depend on the speed of the invasion front, logistics, budgets, and the transient effects of management actions. It is clear, however, that python surveillance and control is a sequential decision problem, in which decisions have to be made repeatedly over time because of temporal changes in python abundance and distribution as well as the ephemeral nature of management actions. Therefore, this is a state- and time-dependent problem that will require a three stage approach:

- Stage 1- current status (pythons not present or only a few individuals are present),
- Stage 2- when python populations in the Refuge are low-density and ecological impacts are minimal, and
- Stage 3- when there is an established python population in the Refuge and impacts are extensive.

These three stages reflect invasion progress within the Refuge through time in the absence of an effective control program. The most effective management strategy is likely to be different in each stage, and should prevent or slow progression through the stages. Each state also correlates with a different, and increasingly costly, phase of the Invasion Curve (Figure 1). Stage 1 corresponds with the early Prevention and Eradication phases of the Invasion Curve in which populations are absent or scattered, low-density populations exist and eradication is still possible. Stage 2 corresponds to progression from the Eradication phase to the Containment phase of the Invasion Curve, in which individuals exist at numerous locations within an area and eradication becomes increasingly unlikely. Stage 3 corresponds to the Resource Protection and Long-term Management Phase of the Invasion Curve when populations are at or near their biological potential and the greatest resources are required to control populations.

The greatest challenge confronting managers regarding python control is the inherently low detectability of Burmese pythons. As a result of cryptic coloration, behavior, and the nature of the Everglades landscape, only a very small percentage of the pythons present are ever detected or subsequently removed. Other key uncertainties in the decision process include poorly understood python population growth and distribution, and unknown total costs and effectiveness of various surveillance and control activities. However, there are numerous ongoing efforts in the Everglades to understand python ecology and to develop better detection and control strategies, such as stomach content analysis and development of techniques such as using DNA found in the environment to detect the presence of individual species. Results from studies such as these, need to be integrated into decisions using quantitative model(s) and an adaptive management approach, in which new information is incorporated into the decision process as it becomes available. Additionally, the contribution to increasing detection and control should be a consideration during selection of optimal management strategies.

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Ultimately, a two-part problem statement was developed by the group: 1) Where, when, and which actions should the conservation community take to minimize the ecological impacts of pythons in and around the Refuge, and 2) because the effectiveness of various detection and control methods is highly uncertain, how can management be undertaken in such a way that this uncertainty can be reduced over time?

Refuge management, specifically the Project Leader, is the ultimate decision maker in this case; however, input from land management and scientific communities is imperative to making the best decision possible, particularly because there is so much uncertainty associated with most available information regarding pythons. Interagency collaboration and coordination will also be a critical element of an effective strategy for local control of pythons, which is highly dependent upon regional control.

Background

Legal, regulatory, and political context

The Refuge has the authority to act against pythons within its boundaries, subject to the conditions of the license agreement between the US Fish and Wildlife Service (USFWS) and the state of Florida (specifically the South Florida Water Management District; SFWMD). Thus, coordination with the Florida Fish & Wildlife Conservation Commission (FWC) and SFWMD is essential. Coordination with these agencies will be necessary when considering python detection and control activities beyond Refuge borders. A joint federal-state control strategy is also likely the most effective and efficient approach because pythons are found on lands managed and controlled by a range of state and federal agencies. This makes interagency coordination and partnership crucial to effectively address python populations in the Everglades. Constraints on actions include applicable state and federal laws and agreements that govern management of the Refuge and adjoining areas, as well as, the need to acquire sufficient funding for surveillance and control activities.

Ecological context and ongoing control efforts

Burmese pythons have become widespread in southern areas of the Everglades and evidence suggests their presence is causing extensive ecological damage (Dorcas et al. 2012; Reed et al. 2009; McCleery and Sovie 2014). Pythons pose a risk to the native resources of the Everglades because they consume a wide variety of native prey species, including mammals, birds (including wading birds), and reptiles, including alligators (Dorcas et al. 2012; Dove et al. 2011; Reed et al. 2009). Based on confirmed sightings, pythons are known to be spreading northward from the point of origin in southern Everglades National Park (ENP), but are not yet believed to be established in the Refuge, which is the northern-most remnant of the remaining Everglades (Figure 2). In areas near the site of introduction (Flamingo, ENP; Figure 2), a 90 – 95% reduction in small and medium mammals has been documented (Dorcas et al., 2012; McCleery and Sovie 2014), further suggesting the potential for ecological damage to the Refuge is high. When considered at a local level, this situation provides a unique opportunity to address known invasive species at the point on the Invasion Curve (Figure 1) where actions are most effective and efficient (Prevention/Eradication phases).

Current efforts to control large invasive reptiles, including Burmese pythons, are largely being led by the FWC and SFWMD through partnerships with local partners such as the University of Florida and The Nature Conservancy. Efforts include a variety of control methods including operation of an Exotic Species hotline through which sightings can be reported, as well as, a 'Python Patrol' program, which is a training program for people that are likely to encounter pythons through their jobs or normal activities or are willing to respond to reports of sightings to the hotline. Road cruising and walking surveys are also regularly conducted as part of the Everglades Invasive Reptile and Amphibian Monitoring Program (EIRAMP). Additional details regarding these efforts are found in Appendix A.

Decision Structure

The scope of the problem was simplified for the purposes of the Refuge by focusing on the central and northern Everglades. However, the group acknowledged that future events in the Refuge are dependent upon actions taken (i.e. management and changes in populations) in the surrounding areas, including ENP (the accepted site of origin of the south Florida python invasion).

The decision structure was also greatly simplified by considering a single species and a subset of considered alternatives. However, the group also recognized that the Refuge faces threats from other invasive reptile species, such as Argentine black and white tegus and Nile monitors. Refuge management has specifically acknowledged the potential threat of these species and is committed to continued efforts to address these issues, as well as, to leverage efforts for different species whenever possible. Lessons learned, and hopefully the framework developed here, can be modified to address those threats. However, this decision focused specifically on Burmese pythons because of the specific behaviors, level of observed and anticipated impact, and survey techniques required for this particular species.

Because this problem is state- and time-dependent, it was necessary to frame the decision within a specific time period. As mentioned previously, the status or state of the python population in the Refuge currently corresponds with the first phase of the Invasion Curve, in which pythons have not been detected in the Refuge, the cost of treatment is at a minimum, and eradication is still a possibility. In this context, a 5-year time period corresponds to Stage 1 of the three-stage approach and was selected for the first prototype of this problem based on projected distribution patterns (see predictive model section) and assuming no new control actions are implemented. We anticipate considering longer time horizons in future prototypes. Following the development of Prototype 1, a second prototype was developed to address challenges encountered in Prototype 1. The following sections are divided into Prototype 1 (P1) and Prototype 2 (P2) subsections.

Objectives

Defining objectives is one of the most critical elements of structured decision making and can include both means objectives and fundamental objectives. Means objectives are objectives that help achieve the ultimate goal, while fundamental objectives describe the ultimate goal. Means objectives can be used to determine actions that can achieve the fundamental objective (i.e., ultimate goal). The ultimate goal of the Refuge can be expressed as: (1) minimize python-related ecological damage subject to a budget constraint; or (2) to minimize cost while not exceeding an

acceptable level of ecological damage. As the Refuge currently has no existing budget for python control, the second form may be more applicable. This form will also be useful in determining the level of funding necessary to maintain python damage below various critical levels and, thus, it can assist in the budgeting process. Coordination and collaboration with partners will be required to leverage knowledge and resources to meet Refuge and regional goals.

Prototype 1. Minimizing python impact on Refuge ecology, human impacts, and cost, while maximizing feasibility were the initial objectives outlined during development of Prototype 1. Measureable attributes for these objectives included maximizing marsh rabbit pellet counts, minimizing environmental DNA signals of pythons in the Refuge and surrounding area, and maximizing encounter rates of small mammals such as raccoons, marsh rabbits, and opossums.

The impacts of pythons on wading birds was also discussed as a particular concern because of their protected status and role as indicators of Everglades restoration. However, wading birds were not further included in measureable attributes of stated objectives due to a general lack of knowledge regarding the extent and dynamics of wading birds as prey items.

Operational costs for public outreach and responding to calls, as well as number of calls from the public, were discussed as metrics to monitor progress towards the objective of minimizing human impact.

Specific metrics for the feasibility objective were briefly discussed in terms of whether or not a particular method was immediately available for use, ranked on a scale from 0 – 5. However, this objective was not further considered at this step.

Ultimately, the objectives associated with these metrics were weighted by the group, with the decision maker having the final say in the weighting of each objective. The final weights were 50, 30, and 20%, for the objectives of minimizing python impacts on Refuge ecology, minimizing impacts to human welfare, and maximizing cost efficiency, respectively. The group anticipated using these weights to evaluate the consequences or outcomes of different actions.

Discussion regarding the metrics for monitoring python impacts on Refuge ecology continued following the weighting exercise. There were concerns among the group that measuring the ecological impacts of pythons via marsh rabbit pellet counts and encounter rates of small mammals would not be an effective indicator under current conditions due to uncertainty regarding the interactions/dynamics between pythons and their prey (including wading birds) as well as current densities of pythons in and around the Refuge. Python populations in the Refuge are believed to be currently very low density or absent, making ecological impacts insensitive over the five year time horizon specified for this exercise. By the time an ecological response was observed, pythons would most likely already be established. Thus, the group concluded that the proposed metrics in Prototype 1 lacked the sensitivity necessary to be useful for evaluating impacts at this stage.

Prototype 2. In order to address the issues encountered during P1, the primary metric selected for P2 was ‘python abundance’ rather than rabbit pellet and small mammal densities.

Operational costs and calls from the public continued to be included as metrics for cost and public impact.

Ultimately, the specific objectives selected for the decision were:

1) In order to minimize the ecological impact of pythons, minimize the abundance of pythons in the Refuge over time.
2) Minimize the cost of management, in terms of staff time, operational costs, and indirect costs to the management community.
3) Maximize human well-being, in terms of safety, public perceptions, and potential property damage.

Alternative actions

Prototype 1: A list of possible actions was developed through brainstorming done in small groups (4-5 people). A full list was developed by merging the group lists (Table 1). A subset of actions were selected from the full brainstormed list to represent a few contrasting approaches that were feasible in the Refuge (Table 2).

Prototype 2: This prototype was still under development at the time of this report and is dependent upon completion of predictive models discussed below. Ultimately, the landscape adjacent to the Refuge will be stratified by habitat type and actions (from the list of brainstormed actions) that are relevant within each habitat type, at each python density level, will be selected. Actions deemed appropriate for Refuge habitat will be selected based on relevance, feasibility, and anticipated impact.

Predictive models

In order to be useful for this decision, Predictive models must include a description of the distribution and density of pythons, as well as, the relative cost and effectiveness of alternative actions. Useful models will necessarily include the factors that influence the distribution of pythons both spatially and temporally (time, distance from site of introduction, python density, and rate of python removal). Other factors necessary to evaluate potential actions include rate of detection, level of control, and required resources.

Prototype 1: A reaction-diffusion (R-D) model (i.e., population expansion model) (Figure 3) (Hastings et al. 2005; Kaiser and Burnett 2010) was used to predict the abundance of pythons over space and time (expansion) in order to better understand and characterize the temporal and spatial components required of an effective management response. Python density is modeled as a function of time, distance, python density at the site of introduction, and python growth, dispersal, and removal rates. In the R-D model 'reaction' represents the growth of the population and 'diffusion' represents how the population spreads across the landscape (Hastings 1996). The model assumes:

- Random movements of pythons in two dimensions
- An asymptotic growth rate derived from an age-structured population model with no density dependence (i.e., exponential growth)
- A homogeneous environment (all of South Florida provides suitable habitat)

The results of the model indicated that the python invasion front (defined as python density ≥ 1/km^2) currently is approximately 90 km from the southern Refuge border and are likely to become established in the Refuge within 10 years in the absence of concerted control efforts. Model results are based on assumptions of 100 female pythons near Flamingo, Florida (introduction site) in 1995, an intrinsic rate of growth is 0.38 (based on clutch size and age-specific survival in the literature), and a dispersal coefficient of 19.3 km^2 (based on how the area encompassing python sightings has changed over time). Confirmed sightings from EDDMapS (http://www.eddmaps.org) place the invasion front approximately 60 km from the Refuge border, which is in close agreement with model predictions. The rate of spread predicted by the initial model is 5.4 km/year.

Prototype 2: Additional necessary model development was determined to include building efficiency curves for each action using available and/or estimated data. Efficiency curves allow evaluation and comparison of different actions in terms of cost and number of pythons removed (Figure 4). Model optimization will include stratification of the Refuge and surrounding area in order to model the most efficient allocation of resources among the areas (EAA, Refuge, EWMA, STAs, urban), as well as, how much effort should be invested in the various control activities in each area.

As new information becomes available, it will be used to optimize allocation between available control actions for each unit. Ultimately, the goal is to be able to project python abundance at the unit level for various budget scenarios (i.e. how much resources have been used to delay invasion) and then use this information to dynamically allocate a given budget over the entire area of interest (Refuge and surrounding areas including the invasion front). As the time horizon extends beyond five years, investment in research programs for novel methods may be warranted, accommodating set-up costs and delayed, uncertain returns for management.

Decision Analysis

Pythons are a resource management challenge throughout south Florida; in order to make the problem more manageable, this decision focused on actions designed to minimize impacts of pythons on Refuge resources. Focusing on the Refuge permitted the decision to focus on a single state and point in time, rather than encompassing all time-dependent states of all python populations found within the boundary of southern Florida. The group concluded that the most effective immediate management actions to protect the Refuge would likely occur *outside of the Refuge* in the surrounding areas where there are currently low to moderate densities of populations, rather than put resources into excluding pythons directly at the Refuge boundary. As previously mentioned, the python issue is state and time dependent. Developing a quantitative decision model for use in making the current decisions with the hope of using the framework for other species and areas was an important component of the workshop. The group also concluded it would be important to incorporate an adaptive management component in order to utilize new information as it becomes available.

Prototype 1: Initially, the group focused the decision on what actions to take within or along Refuge boundaries to meet stated objectives. A consequence table as described in Hammond et

al. (1999) was developed using select actions from Table 2 (Table 3), with the exception of 'discing', which was added after further group discussion. Items included in the consequence table were selected based on their feasibility and expected effectiveness in the Refuge and assumed no further research within the 5-year time frame selected for this decision. Each item in the consequence table was ranked based on expected impact on each objective. Scores ranged from 0 – 3, with 0 indicating the lowest expected impact and 3 indicating the highest expected impact. The final consequence table suggested there were overall low expectations that any available action or group of actions would effectively address stated objectives. The expected impact on the metrics established for ecological effects was particularly low despite being weighted as one of highest priorities by Refuge managers (40%). The low expected effectiveness was attributed to the current state of python populations in the Refuge (low density or not present) and the inherently low sensitivity of the relevant metrics. These factors were identified as issues that would be addressed in a second prototype.

Prototype 2: Although there wasn't time to complete this prototype, the group determined the issue would be best addressed as a two-tier allocation problem. Therefore, P2 is split into Tier A and Tier B. In Tier A the question is 'for a given python density, detection probability, habitat type, and budget, what bundle of actions will best meet our objectives'? This optimization can be pursued once development of efficiency curves is complete. Assessment of efficiency curves can include basic visual comparisons, discussion regarding risk tolerance with respect to uncertainty, and/or a formal optimization using a computer algorithm.

Tier B was described as deriving the best allocation of a single budget, spatially and temporally, to the different habitats, with given python densities across all habitat types. The Tier B analysis will reveal when to apply effort outside the Refuge vs inside the Refuge. Our Tier A results will be important inputs for this Tier B optimization. Computer algorithms are strongly recommended for this optimization to take into account learning/research opportunities over time.

The final decision will use model optimization and simulation to form a landscape-scale solution that indicates how much budget and which actions to allocate to different areas, as well as, the ability to determine how much a desired result will cost with a set of defined parameters.

However, in the meantime the group concluded through discussion that the most effective course of action would be to work with partners to begin taking action in the priority areas previously mentioned. Many of these locations are off-Refuge, along what is believed to be the current python population invasion front. This conclusion was made based on the inherent difficulty detecting and removing pythons, as well as, the potential impacts of pythons on the Refuge.

Uncertainty

Uncertainty is a major constraint of this decision analysis. There is very little existing data regarding dynamics and relationships of python populations and their prey, or the effectiveness and cost of various detection and/or control techniques. One of the biggest challenges is the low detection rates of pythons, as well as, the lack of effective control or removal responses once individuals have been indirectly detected. Detection probabilities of Burmese pythons were

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estimated for a range of simulated scenarios consisting of two possible occupancy rates (0.1 and 0.5) combined with previously estimated detection probabilities (0.005 and 0.01) (H. Waddle, unpubl data; Appendix B) (Table 4). Although only estimates, the exercise demonstrated that even with the most optimistic detectability, there is a relatively high chance of not detecting present individuals and subsequently miscalculating the density and/or area occupied. See Appendix B for more information.

In order to address uncertainty and improve efficiency of control methods and modeling exercises, management strategies will be leveraged to collect information that will improve the current knowledge state regarding pythons in regards to their impact on Everglades ecology and the most effective and efficient control methods (i.e., adaptive management).

Discussion

Value of decision structuring

The decision structure used by the group had the advantage of a clearly defined problem statement and specific objectives that focused attention solely on addressing the stated problem. There is a high level of uncertainty for many aspects of this problem, and having an explicit problem statement and objectives allowed the group to focus on how to meet those specific objectives within the specific constraints of the problem. The decision structure was useful for identifying and characterizing biases and also constrained the spatial and temporal aspects of the problem, which simplified the issue in a way that allowed for critical analysis of actions and expected outcomes in a reasonable amount of time. Brainstorming was a useful part of the process to ensure that all options were given consideration. Refining the brainstormed list allowed evaluation of all options, including those actions which needed more development and those that could be immediately implemented (Table 1) due to minimal development needs, low cost, and expected impact.

Inherent in the structured decision making process is the participation and engagement of relevant managers, scientists, and experts, which allowed discussions with more diverse perspectives considered and represented. This was of great benefit to the decision process by enhancing cooperation and coordination through shared experiences, leveraging existing knowledge, and strategizing as a group.

Further development required

Efficiency models need to be developed for each individual action as a function of python density and resources invested. Participants in the workshop have committed to providing available data that will be used to develop the model and reduce uncertainty to the extent possible. Once model development is complete, optimization can be performed to identify cost-efficient bundles of actions for every possible scenario (state of invasion, resources available, geographical area affected). We will additionally be able to predict the plausible outcomes for each scenario in terms of our means objectives and metrics (e.g., staff time required, operational costs, python abundance, and public response).

What development does the reaction-diffusion (population expansion) model need?

Predictions of python population growth and spread, plus the action bundles derived in our Tier A optimization will be brought together in the Tier B optimization to recommend spatially and

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temporally explicit management strategies that account for future learning. The precise structure of this optimization problem is yet to be agreed upon, and a suitable optimization algorithm must be found.

Prototyping process

Our group ultimately developed two rapid decision prototypes. The rapid prototyping process was effective at allowing the group to quickly determine the information needed to make the decision, as well as, which of the necessary information was available and which was uncertain. The first prototype of the problem revealed major issues, in particular that the available metrics were not appropriate for evaluating actions given the current state of the Refuge and the nominated five-year time horizon. This realization allowed the group to rethink the strategy and come up with a more appropriate decision prototype for the problem and time frame. Therefore, the rapid prototyping process was beneficial to the overall decision framing process. The coaches were critical to keeping the process moving forward by providing feedback on the value of discussions and not allowing excessive focus on uncertainties.

Recommendations

The purpose of this effort was to construct a framework that will allow Refuge managers to make decisions regarding the best way to delay and minimize the negative impact of pythons in the Refuge. That framework is still under development, as all the information required to construct it is not yet available. Even so, several recommendations can be made to move the Refuge toward its objectives of minimizing the negative impacts of pythons while the quantitative model central to the framework is in development. Specific actions the Refuge can take with minimal resources required include, training staff on capturing and monitoring pythons (training is currently available through the FWC), integrating Refuge staff with the south Florida team that responds to credible python sightings, using Refuge staff to conduct driving and walking surveys on adjacent levees that supplement and support EIRAMP, and increasing signage at the Refuge warning people of the presence of pythons and the number for the reporting hotline. These actions require few resources, but are expected to have significant impacts.

It is also highly recommended that staff continue to participate in interagency coordination and collaboration, as well as seek funding not only for detection and control efforts (implementation and development), but also for collecting baseline data on proposed metrics, such as small mammal abundance. Actions should be leveraged to collect additional information regarding python populations (dynamics, ecological interactions, impacts) and the effectiveness of detection and control strategies that support an adaptive management approach.

NOTE: As of February 2015, a manuscript outlining further model development was submitted for review and will be publicly available at a later date. Citation: Bonneau M, Johnson F, Romagosa C. (*in review)* Spatially explicit control of invasive species using Reaction-Diffusion model. Methods in Ecology and Evolution

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Tables

Table 1. Complete list of brainstormed actions developed during Prototype 1. Actions recommended by the group that could be immediately implemented, with little resources or further development, are indicated with an asterisk.

Agricultural community outreach and monitoring
Boat clubs (airboat users allowed in Refuge to do python surveys)
Broader effort coordination (includes R&D)
Camera trap (i.e., cameras outside of park, wading bird rookeries)
*Capture and monitor training (SFWMD, contractors, staff)
Communicating funding needs
Crows
*Discing (for observations and body count)
Dogs (rapid response)
Dogs on levees (for surveys)
Drift fence
eDNA
Exclusion method (barriers)
*Increase targeted visual surveys (road cruising) temporally and spatially
*Increase targeted visual surveys (walking) temporally and spatially
Exotic scavenger hunt
Expanding responder base (network) for sightings and speed
Helicopter surveys and response
Hunter reporting
Hunter take
Infra-red (from aerial perspective)
Judas snakes
Marsh rabbit sentinels (bait)
Pellet counts
Pet trade regulations
Reducing python drop off
Secretive marsh bird monitoring
*Signage and brochures in Refuge
Small mammal monitoring
Thermal refugia on levees
Updating policy for take (published regulation books)

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Table 2. Potential actions for incorporation into an overall management strategy for the Refuge to address expanding python populations in the Everglades. Actions are a subset of a larger group of actions and were selected based on expected efficiency, required effort and resources needed for implementation in order to simply development of a prototype model.

Action	Expected level of detection	Provides control (yes or no)	R&D needed? (yes or no)
Road cruising	Medium	Yes	Yes
Walking surveys	Medium	Yes	Yes
Dogs	Medium	Yes	Yes
Capture/monitoring training (staff)	Medium	Yes	
Judas snakes	Medium	Yes	
Thermal refugia on levees	Uncertain	Yes	Yes
Drift fence	Uncertain	Yes	Yes
Marsh rabbit sentinels	High	Yes	Yes
Camera traps	Uncertain		Yes
Helicopter surveys	Uncertain	Yes	Yes
Aerial infrared	Uncertain	Yes	Yes
Signs and brochures (public awareness and reporting)	Uncertain		
Electrofishing	Uncertain	Yes	Yes
Crows	Uncertain	Yes	Yes

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Table 3. Consequences table developed during Protoype 1 of the decision analysis. The expected impacts of actions on select metrics for each objective, based on existing data and professional opinion. Manager-assigned weights are indicated as percentages in parentheses. Impact of '0' indicates no effect, an impact classified as '1' indicates low effect, '2' indicates medium effect, and '3' indicates the highest level of impact.

	Ecological Effects (40%)		**Cost (40%)**		**Human Welfare (20%)**	
Action	**Rabbits**	**Other mammals**	**FTE**	**$**	**Calls**	**Incidents**
Search and detect animals (levees)	1	1	3	3	2	1
Judas snakes (WCA)	1	1	3	3	2	1
Thermal refugia (levee)	1	1	2	1	2	1
Refuge signs (public)	1	1	1	1	3	0
Staff training	1	1	1	1	2	1
Discing	1	1	1	1	3	1
Marsh rabbit sentinels	1	1	2	2	2	1
Visual surveys (road and walking)	1	1	2	1	2	1

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Table 4. Simulated detection scenarios of Burmese pythons at a range of occupancy rates and detection probabilities. See Appendix B for more information.

Proportion of sites occupied: 0.1; Detection Probability: 0.005		
No. Samples	Mean Number of Python Detections	Prob. of Detecting No Pythons
6	0.164	85.6%
12	0.262	77.3%
24	0.586	55.9%
48	1.169	35.4%
Proportion of sites occupied: 0.5; Detection Probability: 0.005		
No. Samples	Mean Number of Python Detections	Prob. of Detecting No Pythons
6	0.771	46.3%
12	1.519	23.1%
24	3.009	5.7%
48	6.003	0.3%
Proportion of sites occupied: 0.1; Detection Probability: 0.01		
No. Samples	Mean Number of Python Detections	Prob. of Detecting No Pythons
6	0.272	76.3%
12	0.616	55.4%
24	1.214	32.5%
48	2.436	12.8%
Proportion of sites occupied: 0.5; Detection Probability: 0.01		
No. Samples	Mean Number of Python Detections	Prob. of Detecting No Pythons
6	1.51	20.5%
12	3.026	7.1%
24	5.812	0.3%
48	12.14	0.0%

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Figures

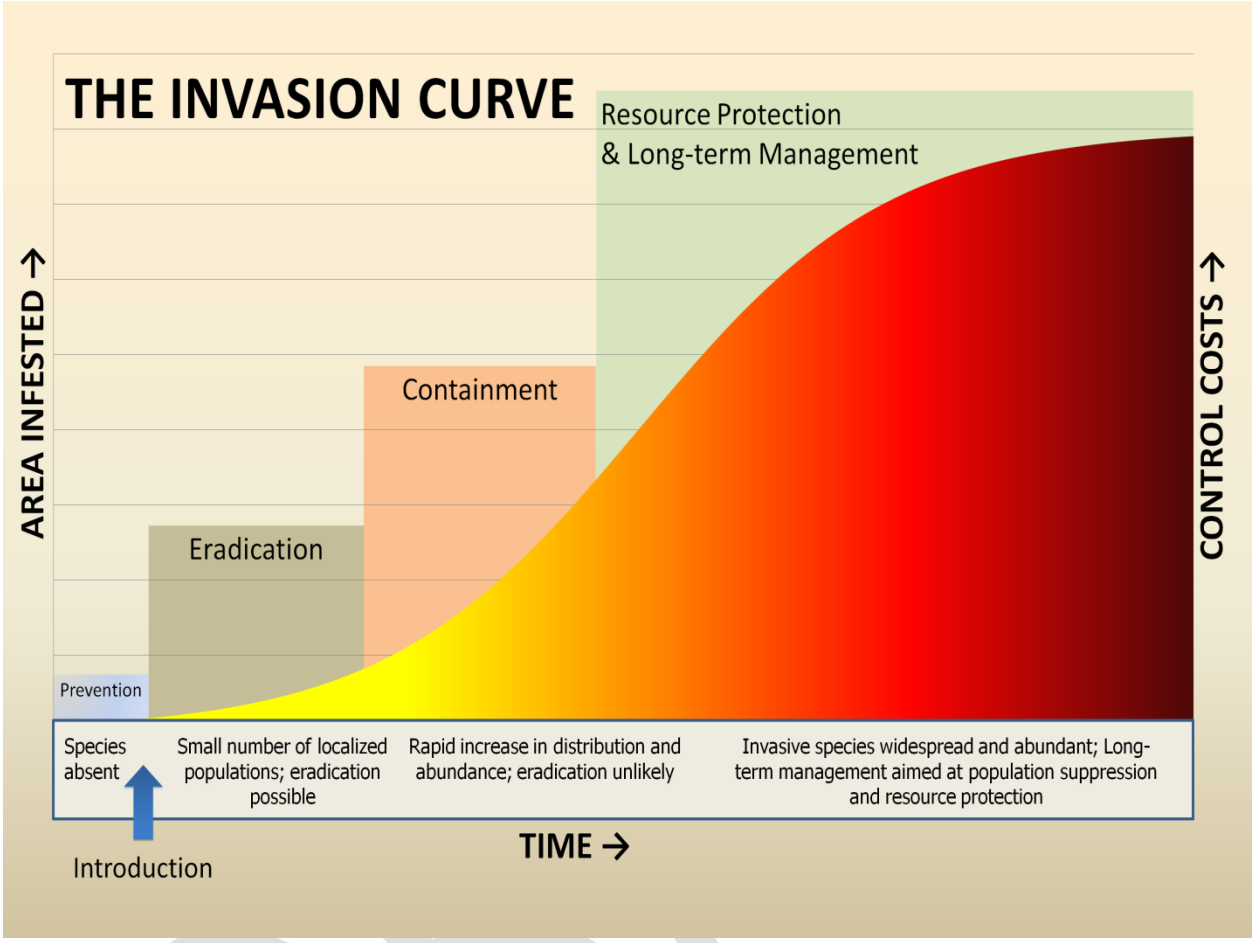

Figure 1. Invasive exotic species Invasion Curve showing relative abundance and control costs for each phase in a typical invasion of an exotic species to a new area. Source: LeRoy Rodgers, South Florida Water Management District (http://www.naisn.org/generalinformation.html)

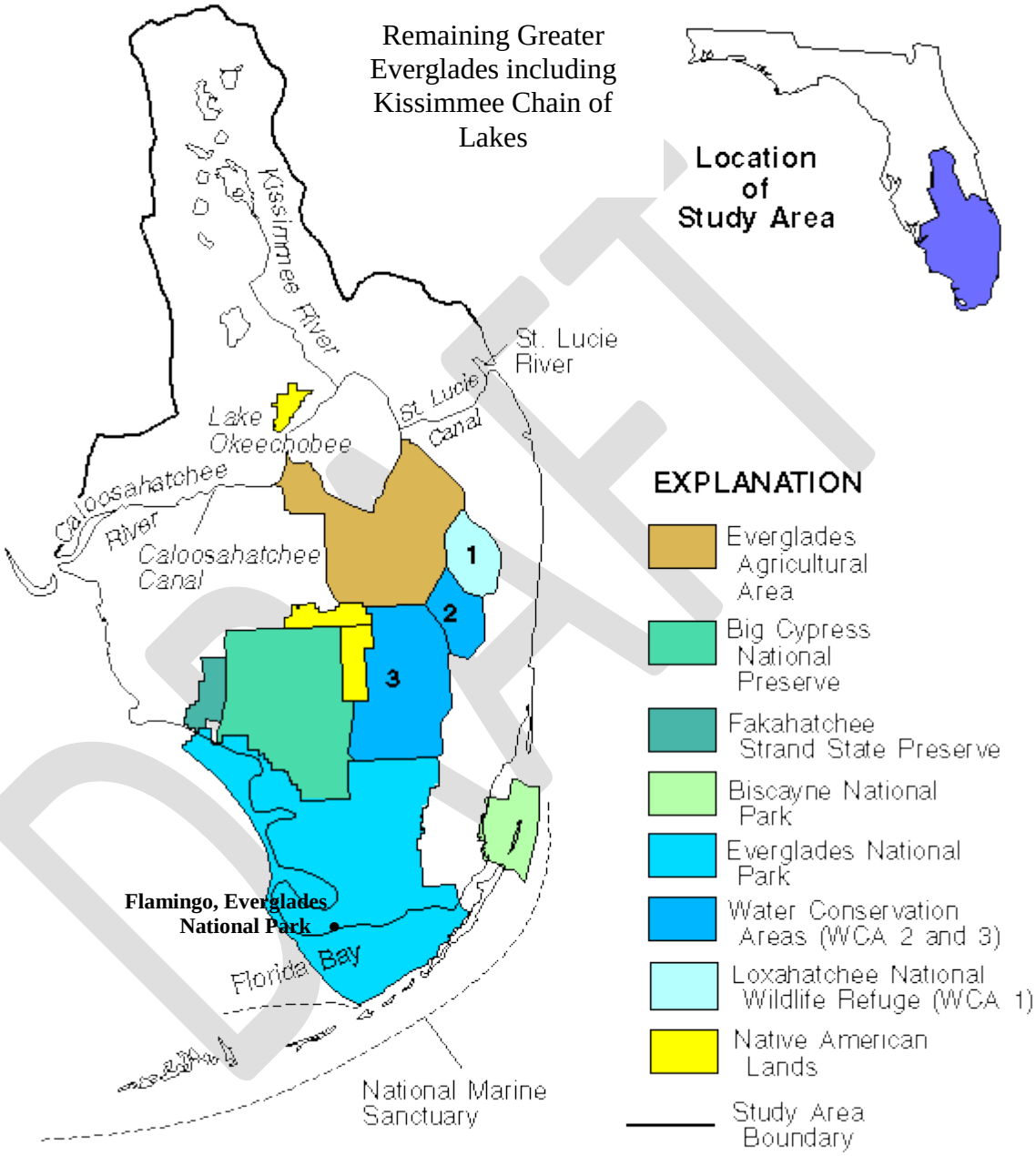

Figure 2. Location of A.R.M. Loxahatchee National Wildlife Refuge (WCA 1). The Refuge is the northern-most remnant of the remaining Everglades. Photo source: http://kanat.jsc.vsc.edu/student/pollockj/main_page.htm

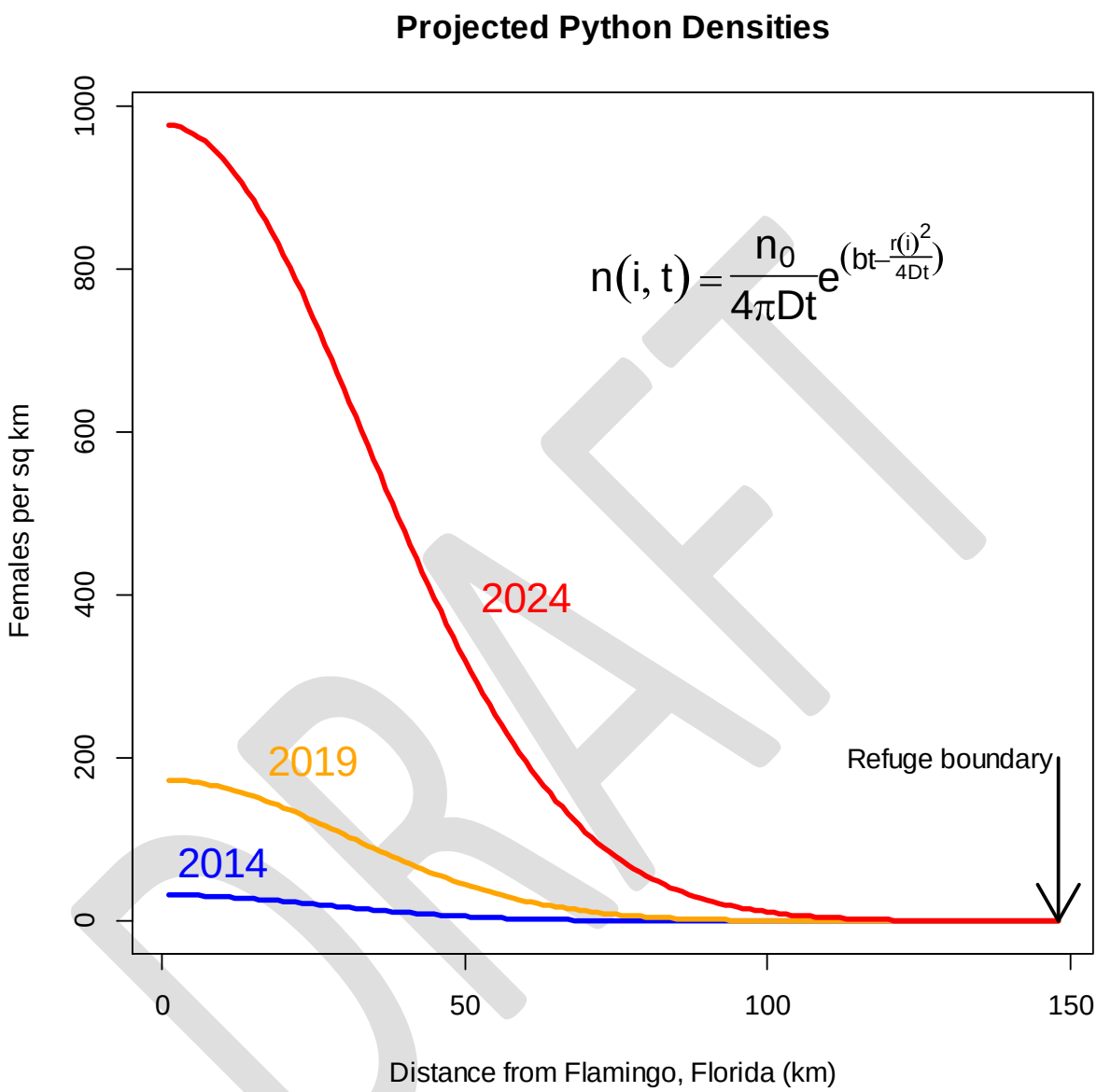

Figure 3. Reaction-diffusion model used to estimate python population densities at various points in space (*i*) and time (*t*). Parameters are 'n_0 = 100 is the assumed population size at the introduction site in Flamingo, Florida in 1994, D = 19.3 km^2 is the diffusion coefficient, b = 0.38 is the intrinsic rate of population growth, and r = the radial distance from Flamingo, Florida. This model assumes there are no effective control actions implemented over the entire time frame.

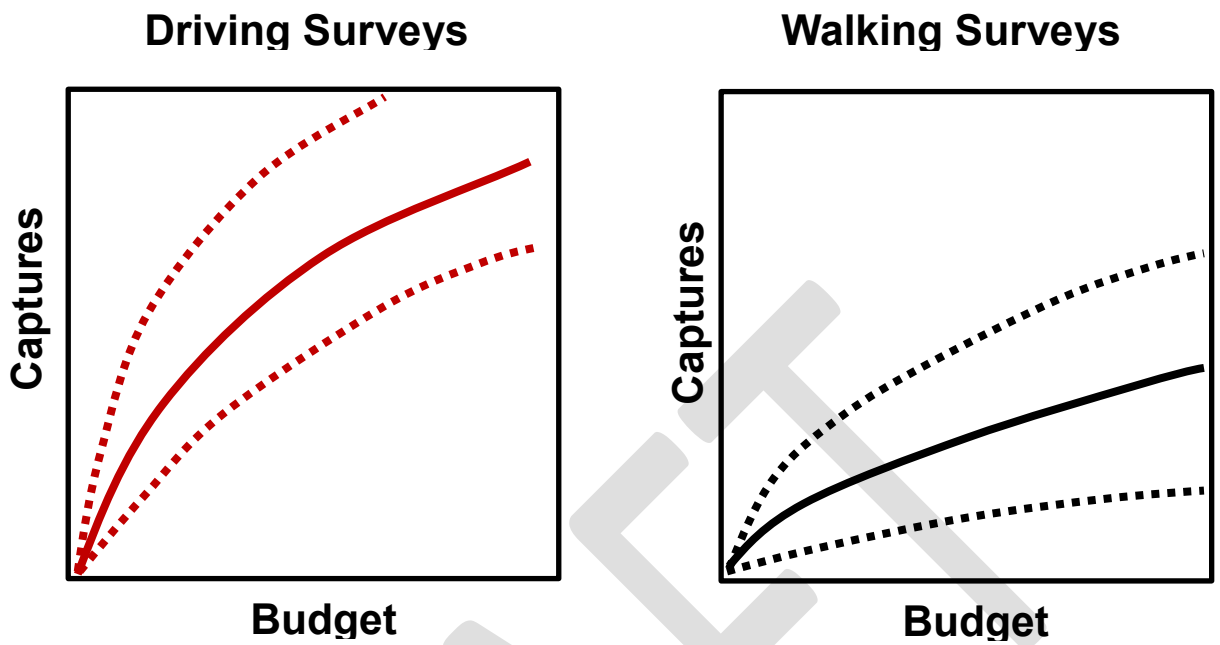

Figure 4. Theoretical efficiency curves comparing the efficiency of two survey methods (driving surveys and walking surveys) in terms of budget and number of captures. Solid lines are means and dotted lines are confidence limits.

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Appendix A

(*The following was taken from an email sent to the group by Jennifer Ketterlin-Eckles on May 22, 2014)*

Description of ongoing FWC/SFWMD invasive reptile (including python) control efforts.

Author: Jennifer Eckles
Date: May 22, 2014

Hello all. Kelly Irick and I thought it might be helpful to send a follow-up email regarding activities conducted by the Florida Fish and Wildlife Conservation Commission (FWC) and South Florida Water Management District (SFWMD) as part of a python management strategy, as well as information on our Palm Beach county Nile monitor management activities.

I will first point out that with the exception of one District employee, FWC and SFWMD staff do not spend a lot of time surveying for Burmese pythons ourselves. We will take advantage of cold weather events to do opportunistic surveys in high-priority areas with whatever staff and partner volunteers are available but surveys for Northern African pythons will take priority in these cases.

Instead, FWC and SFWMD have contracted the University of Florida to perform surveys for pythons and other nonnative herps via the Everglades Invasive Reptile and Amphibian Monitoring Program (EIRAMP). Our contracts cover a variety of control, body management, and data synthesizing activities but detecting Burmese pythons, as well as native herps and mammals, is the primary focus of their monthly nighttime surveys of around 15 routes on roads and levees throughout the greater Everglades. They also will perform opportunistic surveys based on weather events and recent sightings and some routes are conducted weekly.

FWC created a python permittee program in 2009 to allow permitted individuals with experience in finding and capturing large constrictors to remove pythons live from FWC-managed lands. We partnered with SFWMD to allow these individuals on District managed lands in 2011. FWC also began allowing hunters on WMAs to take these animals during regular hunting seasons in 2009 and created a Conditional Reptiles season to cover prime daytime hunting times of the year. Hunters must dispatch animals in the field and permittees are allowed to transport them live. We have found the permittees to be much more effective in removing pythons.

In 2012, FWC contracted The Nature Conservancy to operate the Python Patrol program and create a plan to transition the program to FWC in 2013. The Python Patrol program is intended to train people who work and/or recreate in areas where they might see pythons on identification and reporting. There is also a more ‘advanced’ class that teaches the safe and humane live capture of pythons in the field. In the future, we plan to offer this class to all permittees, especially those with access to District lands. Many of those who take the Python Patrol live capture training have signed up as responders to python sightings and we have created the attached Google Earth layer of those individuals so that you can quickly see who your closest responders are when you type in the address of a python report [Figure A-1].

We receive the majority of python reports through our Exotic Species hotline (888-IVE-GOT1) and through the EDDMapS online reporting sight (ivegot1.org) which is also where you can look up distribution maps of sightings. EDDMapS is managed by the University of Georgia.

FWC was made aware of a breeding population of Nile monitors in 2010 and in 2011 we began trapping and surveying in cooperation with SFWMD. We had a very low success rate using live traps for this population even though we were using the same methods that have been employed very effectively on a population in Cape Coral.

We instead began conducting surveys by boat and dispatching animals that could be taken safely with a shotgun. We began doing the surveys monthly using protocol similar to what is used for EIRAMP. These surveys were confined to the C-51 canal east of Hwy 441 as this was where the population seemed to be centered and access to the west side of the C-51 is from a different boat ramp, making surveying the entire canal in one day too time consuming. Once we had UF under contract, they began conducting the surveys east of 441 and FWC conducted surveys west of 441. Our combined efforts have resulted in the removal of 25 Nile monitors but not all that have been seen have been removed. Daytime surveys are conducted year-round but we do seem to see more monitors on sunny, warmer days. Attached is a map of sightings and the two survey routes [Figure A-2].

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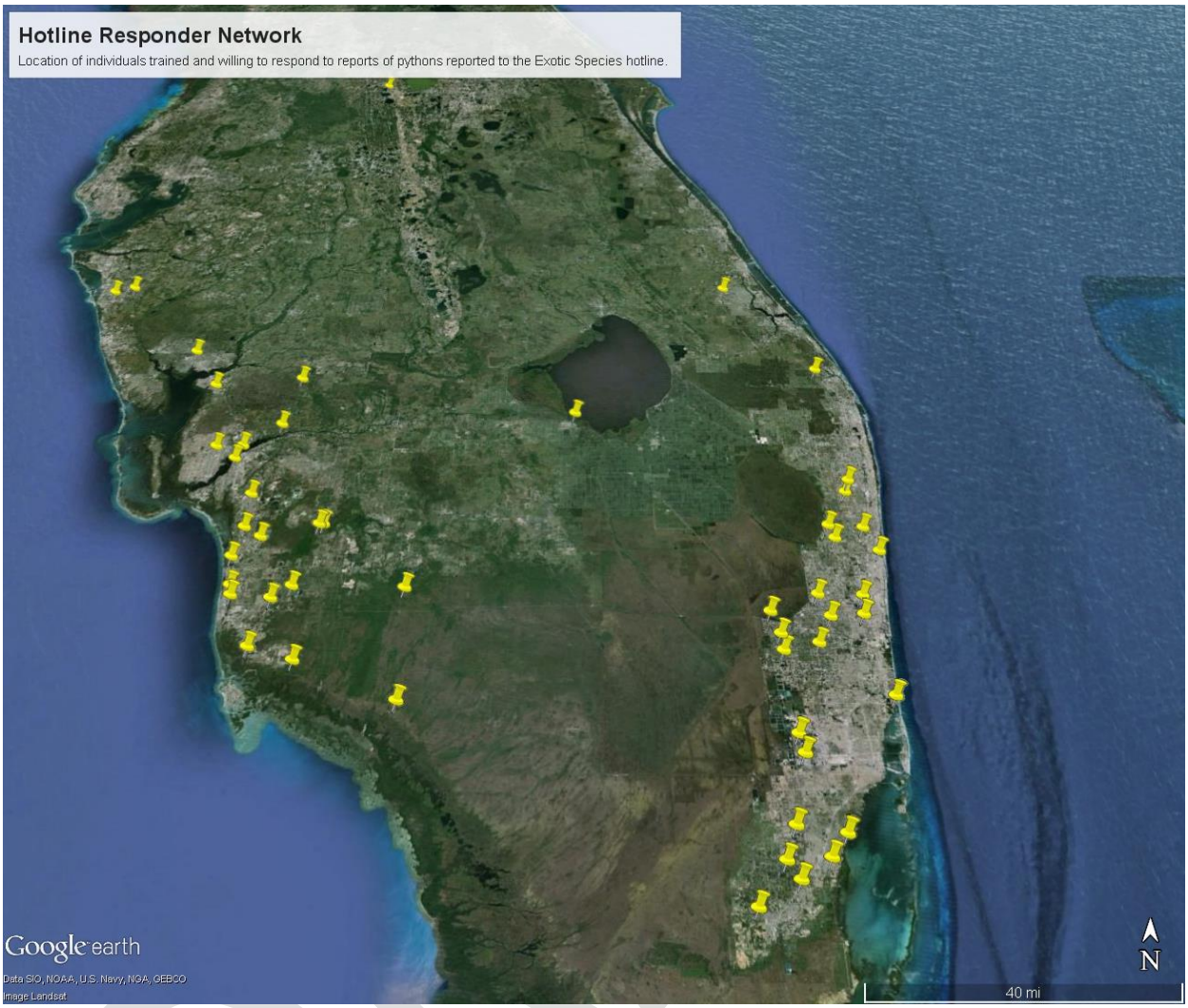

Figure A-1. Location of people trained and willing to respond to reports of python sightings to the Exotic Species hotline.

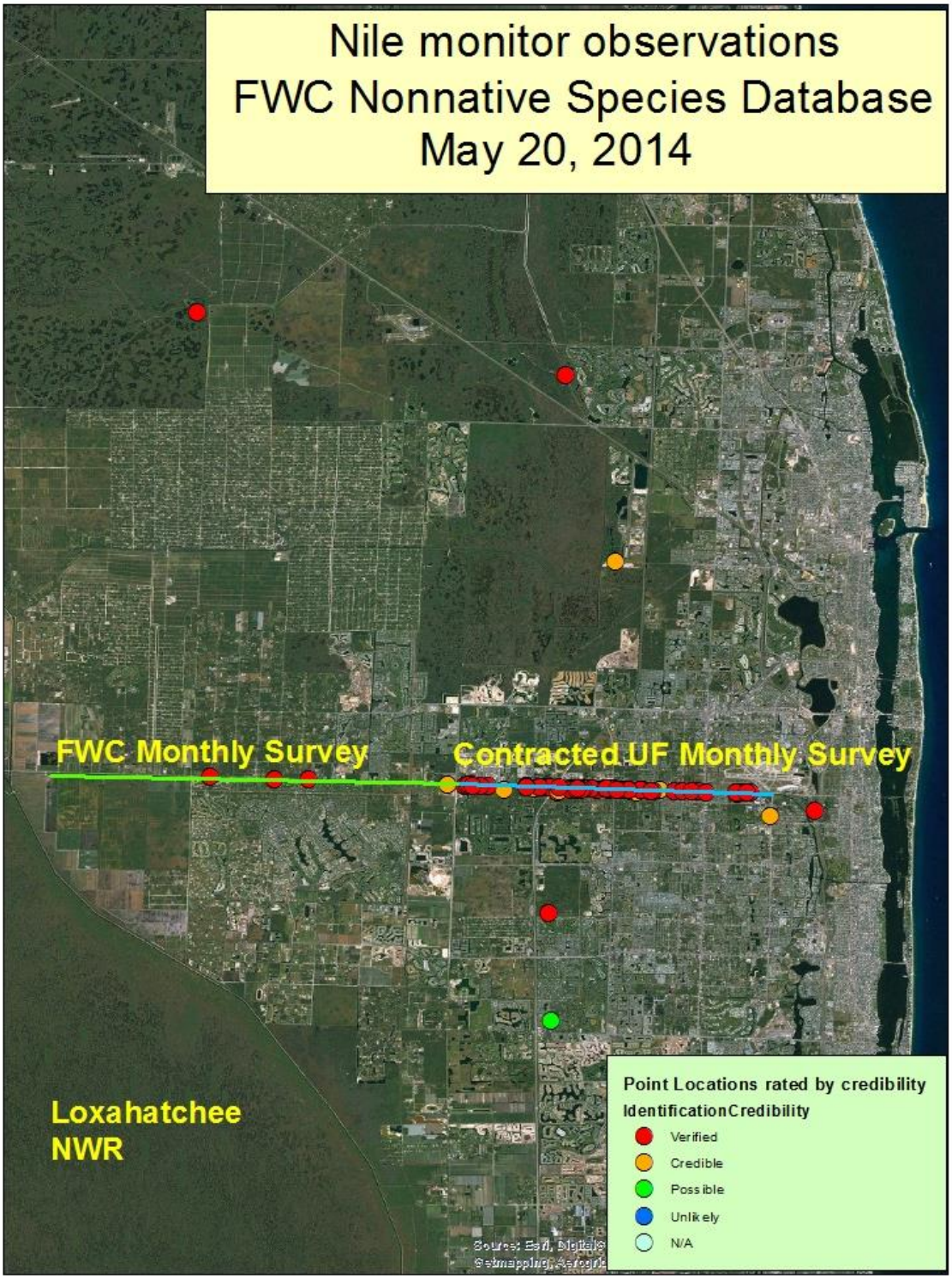

Figure A-2. Nile monitor survey routes and observations.

Appendix B

Some thoughts on python detectability for the LNWR Python workshop

Hardin Waddle, USGS, National Wetlands Research Center, June 2014

The following is very preliminary, but may be useful for people to look at prior to the SDM workshop at NCTC. Please do not consider this as a final product. It is intended to be a jumping off point where we can discuss what may or may not be possible given our ability to sample and model populations of pythons in the Everglades.

First off, I was given the EIRAMP data on pythons from Everglades National Park that Jenny and Kelly mentioned in their Email to the group. I won't go into too many details about the data, but here's a quick summary:

Over the four years from 2008-2011 a total of 34 pythons were observed on the road cruise surveys. I took the routes of the surveys in the park and broke them up into 30 segments to use as spatial replicates. We took each of the samples from those years and treated them like repeat visits during a closed period within each year. Thus we had 38, 47, 57, and 47 repeat visits during the four years. I then ran a simple dynamic occupancy model to estimate the probability of detecting a python, given that it is there, and the probability of a python occurring at a site.

Estimating Detection Probability

With the scarcity of actual python observations, detection probability was estimated to be very low. It came out to around 0.0054 (95% CI 0.0030–0.0096). In other words, if a python occurs along a segment of the main park road you have a 0.5% chance of detecting it. That is so low, that we would expect significant bias in any occupancy estimates (MacKenzie et al. 2002). For what it's worth, with a probability of detecting the species (given that it is there) so low, the model estimates that all of the sites are occupied by pythons. Realistically, though, this model is going to have a very hard time distinguishing between the case where pythons are everywhere but really hard to see, and the case where pythons are really rare.

So, we have an estimate of the detection probability of pythons from road cruising, but it is so low to be useless for occupancy modeling, and may or may not be reliable.

It is probably worth noting, however, that this is not actually much lower than the estimate of "about 1%" from the experiment by Dorcas and Wilson (2013) where they had observers search for a number of snakes in an enclosure.

Translating Detection into a Sampling Design

So now that we have a number for detection there are a couple of things we can do with that. The first is start to think about how many times we would need to sample in order to find a python, given that it is there. Obviously, if they aren't there you can't detect them.

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A paper by MacKenzie and Royle (2005) gives an equation to find the probability of detecting a species at least once with a given detection probability and number of samples:

$P^* = 1-(1-p)^K$

When we try various values of p and K (the number of samples at a site) we get a table like this:

detection	samples			
	6	12	24	48
0.005	0.030	0.058	0.113	0.21
0.01	0.059	0.114	0.214	0.38
0.05	0.265	0.460	0.708	0.91

Thus, even if we increase detection probability to 0.05 from 0.005, we still need 48 samples (almost weekly sampling) to get close to a 100% chance of seeing a python if it is there. If our estimate (0.005) of p is accurate, then with 48 surveys at a site, we only have about a 20% chance of actually seeing a python when it is there.

Based on a paper by Kery (2002) we can also calculate the reverse, and determine the minimum number of samples we would need to conduct in order to infer absence with a 95% confidence level. This value only depends on detection probability.

Detection Detection	Samples to infer absence (95% confidence level)
0.1	28
0.05	58
0.01	298
0.005	598

So, if the actual detection probability is between 0.005 and 0.01 we would need over 300 visits with no observations before we could say that we are 95% confident that pythons are not occurring at a site!

Simulating actual sampling

I wanted to determine how likely we would be to see no pythons in some simulated surveys while varying the true occupancy, the detection probability, and the number of samples we will conduct. There may be an analytical solution for this, but I don't know how to do it. Instead, I have developed a "brute force" simulation way to determine how many pythons we might expect to see under various conditions.

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In this simulated survey, we have a constant 50 sites. These could be thought of as discrete locations or as segments along a road cruise route. I simulated scenarios where 10% and 50% of the sites were actually occupied and then sampled those with a 0.005 and 0.01 probability of detecting pythons. All combinations were run 1000 times. The results are shown below:

Proportion of sites occupied: 0.1; Detection Probability: 0.005

No. Samples	Mean Number of Python Detections	Prob. of Detecting No Pythons
6	0.164	85.6%
12	0.262	77.3%
24	0.586	55.9%
48	1.169	35.4%

Proportion of sites occupied: 0.5; Detection Probability: 0.005

No. Samples	Mean Number of Python Detections	Prob. of Detecting No Pythons
6	0.771	46.3%
12	1.519	23.1%
24	3.009	5.7%
48	6.003	0.3%

Proportion of sites occupied: 0.1; Detection Probability: 0.01

No. Samples	Mean Number of Python Detections	Prob. of Detecting No Pythons
6	0.272	76.3%
12	0.616	55.4%
24	1.214	32.5%
48	2.436	12.8%

Proportion of sites occupied: 0.5; Detection Probability: 0.01

No. Samples	Mean Number of Python Detections	Prob. of Detecting No Pythons
6	1.51	20.5%
12	3.026	7.1%
24	5.812	0.3%
48	12.14	0.0%

As you can see above, if only 10% of the sites are occupied by pythons (i.e. early in the invasion) we have a high chance of not finding any pythons. If 50% of the sites are occupied, our chances of finding at least one python are pretty good if we do at least 24 surveys.

Conclusion

Clearly these numbers indicate that there are big challenges with regard to sampling pythons. Our best way to boost sampling efficiency would be to increase our probability of detecting pythons when

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they are present. That may be difficult to improve, so the next best thing we can do is increase the intensity of sampling effort. The simulation illustrates that even if half of the sites are occupied and we sample them monthly, we would only expect to see 1–3 pythons total and we would have a 7–23% chance of getting no pythons at our current detection probability of between 0.005 and 0.01.

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