Changing Perceptions of Wildlife: How Collaboration Can Protect Gopher Tortoises (*Gopherus polyphemus*) While Maintaining Industrial Progress

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Background

- In 2015, the University of Georgia (UGA) Andrews Coastal Ecology Lab and Southern Ionics Minerals (SIM), a part of Chemours, initiated a partnership to protect wildlife, focusing mainly on gopher tortoises (*Gopherus polyphemus*), at heavy mineral sand mines in South Georgia.
- SIM operates two heavy mineral sand mines in Folkston and Jesup in Georgia, where their primary products are extracted zircon, titanium, and ilmenite mineral deposits. Zircon is commonly used for aircraft engine parts, and titanium is employed in the manufacturing of aircraft, sports equipment, medical supplies, and even personal care products.
- In their commitment to environmental stewardship, SIM sought UGA to help meet their mitigation requirements and to develop new research questions about the ecology, reproduction, health and management needs of translocated gopher tortoises.
- During the past five years, this collaboration has protected over 400 gopher tortoises from mining activities, head-started an estimated 300 gopher tortoises from eggs, and additionally protected all commensal species encountered.



Perspectives *Based on individual interviews*

- Southern Ionics Minerals, LLC
  - Involving an academic institution assures stakeholders that wildlife concerns are being addressed by ***creditable scientists*** who can maintain independence and objectivity.
  - UGA's presence on the mine facilitates outreach with SIM employees to spread ***awareness*** of environmental concerns and engage staff in wildlife response.
  - "The flexibility this partnership allows ***balances*** SIM's conservation commitments with the needs of mining operations." Jim Renner (SIM)
- Georgia Department of Natural Resources
  - Involving an academic institution provides ***confidence*** that decisions are being made with species conservation and science-based answers as the major drivers.
  - UGA brings educated subject-matter experts to the conversation who ***propose solutions*** to address wildlife conflicts on the mines.
  - "Supporting the ***continued monitoring*** of relocated tortoises allows for more eyes and ears on Wildlife Management Areas (WMAs) to increase likelihood of encountering other protected species, such as eastern indigo snakes." John Jensen (retired GA DNR)
- University of Georgia Coastal Ecology Lab
  - SIM's ***support of research*** on gopher tortoise ecology and management in response to mining activities is a critical part of this collaboration.
  - "The partnership shows it can be productive for ecologists and industry to team up...it just takes planning, patience, and ***continual dialogue***. " Dr. Kimberly Andrews (UGA)
  - "An important aspect of our role is being prepared with proactive imperiled species surveys so we can be ***adaptable*** to rapidly changing mineral market prices, which cause changes in mining schedules." Lance Paden (UGA)

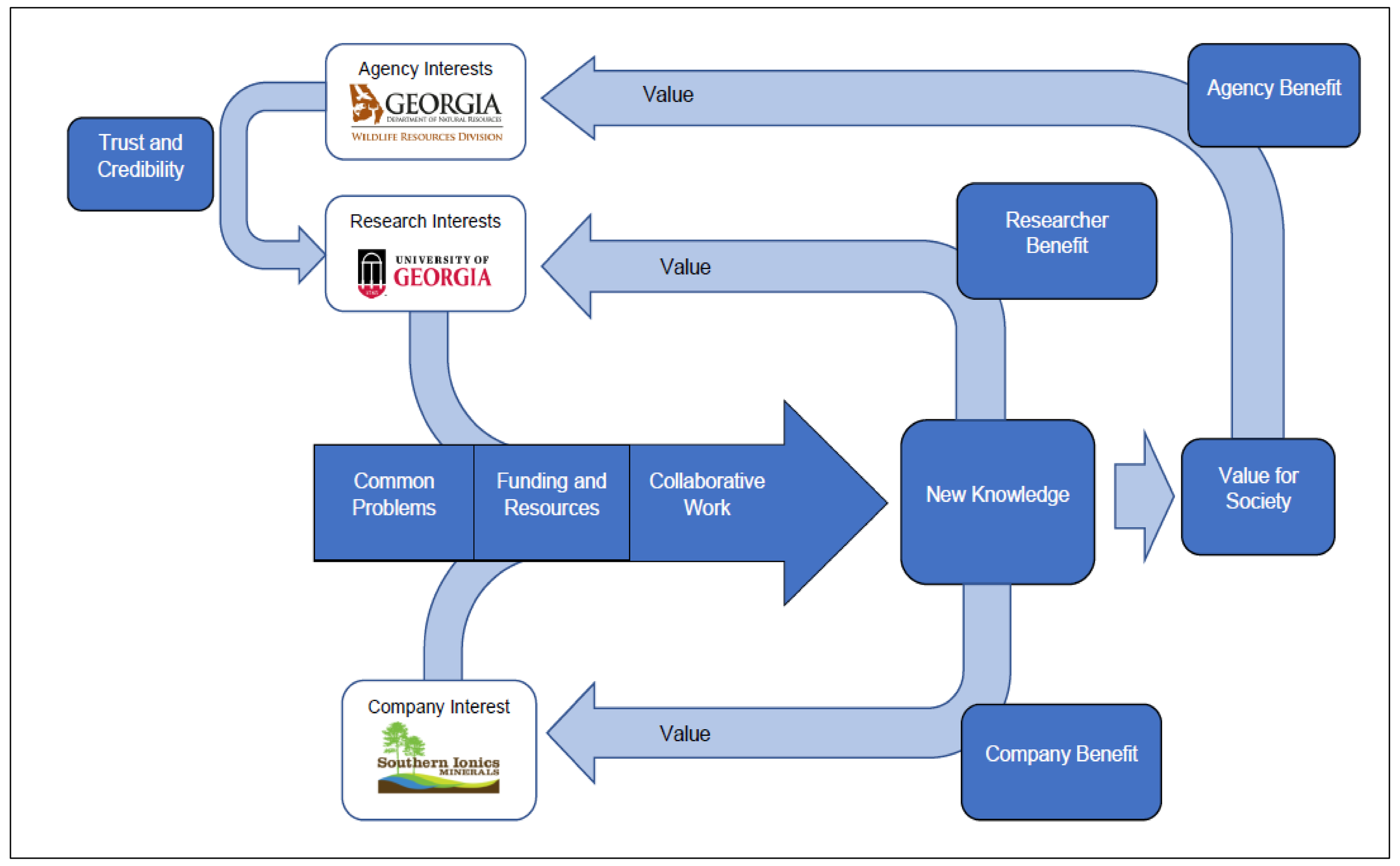

Figure 1. Co-production process based on the Knowledge Foundation co-production model (Sanno et al. 2019), with modifications.

Mitigation Actions

- Mine Site Mitigation Actions
  - On-site relocations
    - Temp pens and adjacent private landowners
  - Off-site translocation of gopher tortoises and commensal species
  - Exclusion fences to protect resident animals from impact areas
  - Southern Ionics Minerals employee education
    - Required MSHA safety trainings for every new employee where we present on wildlife
    - Wildlife crossing signs on roads
    - On-call wildlife response
  - Protection of gopher tortoise eggs through captive headstarting and release
- Recipient Site Mitigation Actions
  - Pens for over-wintering at recipient sites financially supported by SIM
  - Continual monitoring of relocated and translocated gopher tortoises by UGA
- Measures at mine and recipient sites to advance the mission of the Gopher Tortoise Conservation Initiative

Figure 2. UGA researchers outlined preferred location for exclusion fences to protect a large population of gopher tortoises from mining activities.

Figure 3. Wildlife crossing signs are present to warn all personnel about wildlife in the area.

Figure 4. Long-term research on the post-release performance of translocated and head-started gopher tortoises is conducted on WMAs using GPS loggers, VHF transmitters, temperature loggers, camera traps, and vocalization units. *(Left)*

Successes

- Gopher Tortoise Population Augmentation
  - Boosted gopher tortoise numbers to minimal viable population size on multiple WMAs in Georgia
  - Captive-reared (head-starting) gopher tortoises from eggs excavated from mine sites
  - Documented benefits of translocated tortoise burrows to commensal species, such as eastern indigo snakes, at recipient sites
- Ecological Field Research
  - On-site at mineral sand mines
    - Recolonization of vegetation and wildlife species on reclaimed mined habitats
    - Prescribed fire to increase detection of smaller age classes of gopher tortoises
  - Recipient sites on GA DNR WMAs
    - Home range/movements of translocated adults and head-starts
    - Social interactions and reproductive success between translocated and resident tortoises

Figure 5. Eggs are excavated and incubated from the mines and released at WMAs. Eggs/hatchlings at recipient sites also are sampled to study the integration of translocated and resident gopher tortoises via an on-going genetics study with Dr. Stephen Spear (The Wilds).

Figure 6. Eastern indigo snake caught on camera trap placed at a resident gopher tortoise's burrow at a WMA.

Figure 7. Partners from SIM, UGA, and GA DNR at the release of head-started gopher tortoises at a WMA (pre-pandemic image).

Opportunities

- "When to Move and When not to Move"
  - In some cases, mine boundaries may be adjusted to avoid moving tortoises. In others, we minimize relocation numbers while not leaving behind inviable numbers of adults.
- Understanding Mining Methods and Terminology
  - To better address wildlife conflicts on the mines, we must understand the mining process and be able to communicate potential conflicts in the right language.
- Data Management and Accessibility
  - Maintaining detailed survey and capture data in a format that can be used for multiple applications and by multiple partners maximizes the conservation value of our efforts.
- Overcoming the "Tree-Hugger" Stereotype
  - Changing the miners' view of environmentalists so they realize we are not there to make their job more complicated, but we are there to help resolve wildlife conflicts.

Acknowledgments

- Funding was received from Southern Ionics Minerals, LLC/Chemours.
- Lab members and other staff at UGA MAREX – Brunswick for support and patience with lots of tortoises all the time.
- Dr. Terry Norton, Jekyll Island Authority Georgia Sea Turtle Center, for veterinary support on wildlife health research.
- Robert Horan and Greg Nelms with GADNR for support at recipient sites.

Observations of Gopher Tortoise (*Gopherus polyphemus*) Recruitment Following Prescribed Fires on a Private, Working Forest Landscape in Louisiana

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Introduction

The gopher tortoise, a keystone species in southern pine (*Pinus* spp.) ecosystems, is threatened under the Endangered Species Act in the western portion of its range (Figure 1). Approximately 70% of potential tortoise habitat occurs on privately owned lands often managed primarily for timber production. Tortoise ecology on private, working forest landscapes is understudied. Therefore, we examined tortoise response to active forest management within a private, working forest in Washington Parish, Louisiana.

Study Site and Methods

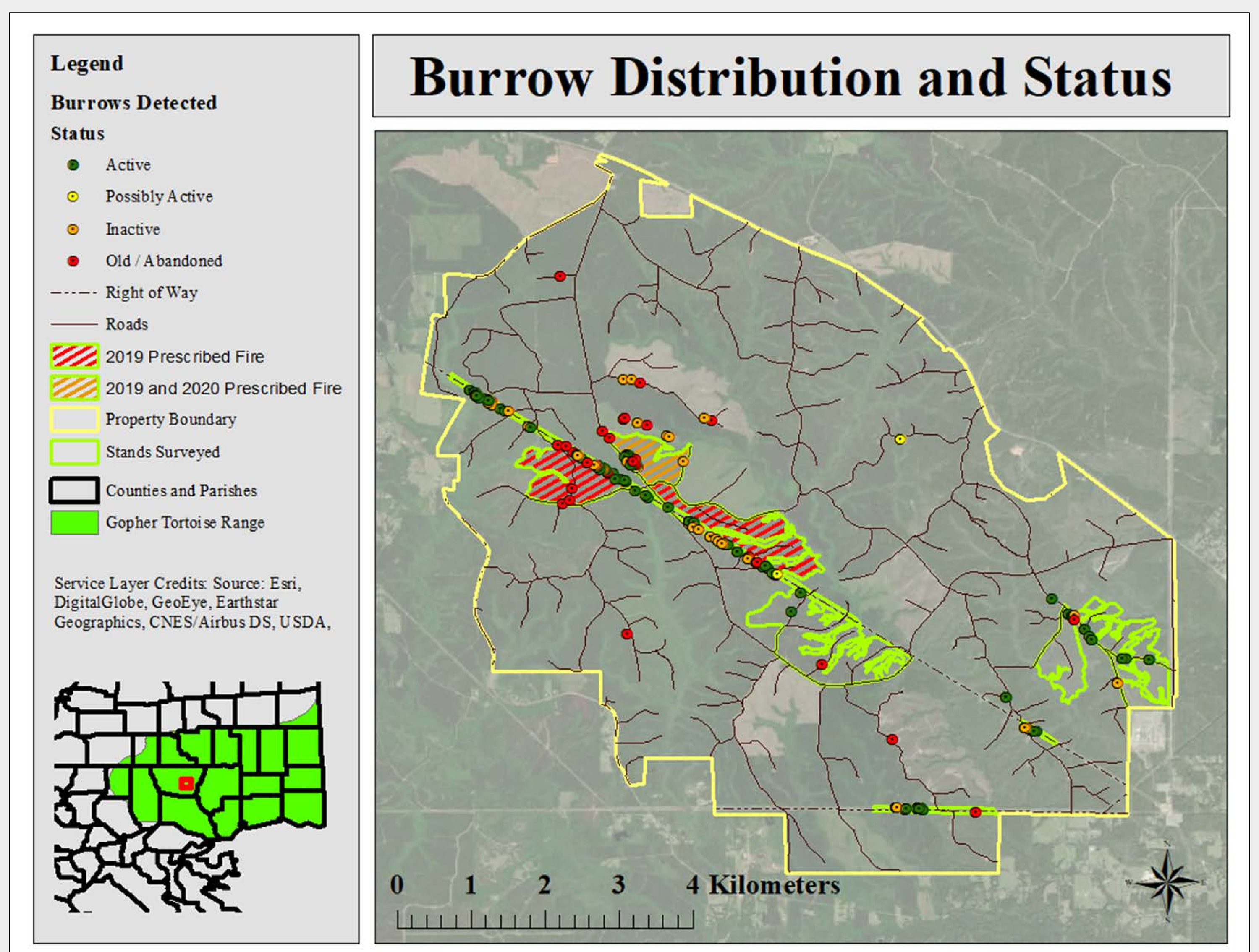

Figure 1: Adult and juvenile tortoise burrow distribution and status at Ben's Creek in Washington Parish, LA. Forest stands and rights-of-way surveyed in 2017 – 2020 are outlined in green.

- Burrow surveys conducted in 2017 – 2020 including line transect distance sampling burrow surveys in 2018 (Figure 1).
- Mark-recapture surveys: 2017, 2018 and 2020.
- Two loblolly pine (*P. taeda*) stands and adjoining rights-of-way burned in January and February 2019 (134 ha; stands with red hash marks in Figure 1 and Figure 2).
- One longleaf pine (*P. palustris*) stand burned during same period in 2019 and in March 2020 (42 ha; stand with orange hash marks in Figure 1 and Figure 2).
- Management prior to this study included prescribed fires (March 2009), herbicide treatments (October 2015), and timber harvest.

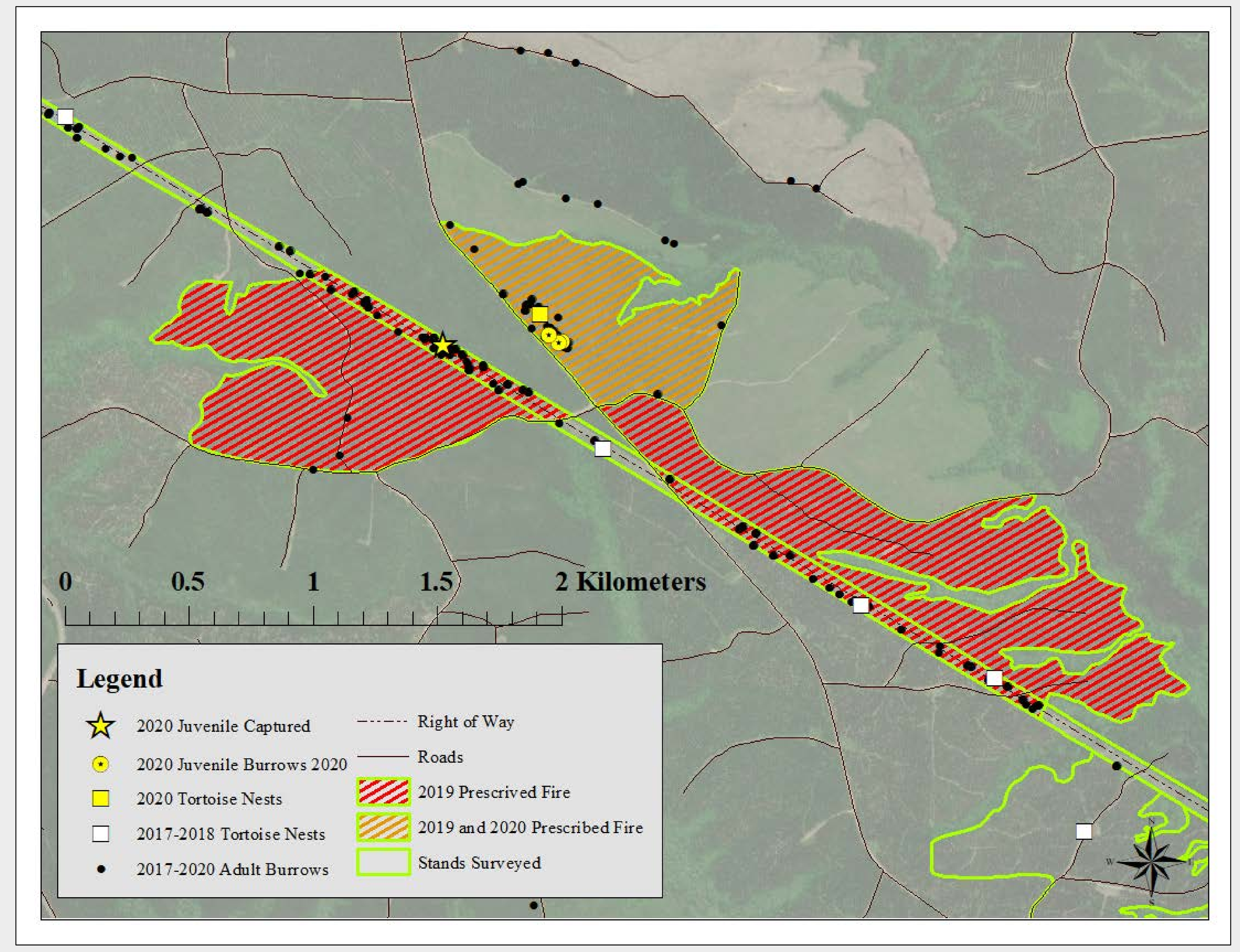

Figure 2: Detections of juvenile recruitment around burned forest stands and ROW before (2017-2018) and after prescribed fires (2020).

Figure 3: Example of understory vegetation in longleaf pine stand after prescribed fires in 2019 and 2020 (June 2020).

Acknowledgements

Financial and logistical support for this project came from Weyerhaeuser Company, Louisiana Department of Wildlife and Fisheries, National Council for Air and Stream Improvement, Inc., and Mississippi State University College of Forest Resources. We thank technicians, Weyerhaeuser and LDWF personnel, and volunteers who assisted with these surveys. This work was conducted under USFWS permit: TE41910B-3, LDWF permits: LNHP-18- 087 and WDP-20-081, and MSU IACUC protocols: IACUC-17-213 and IACUC-20-216.

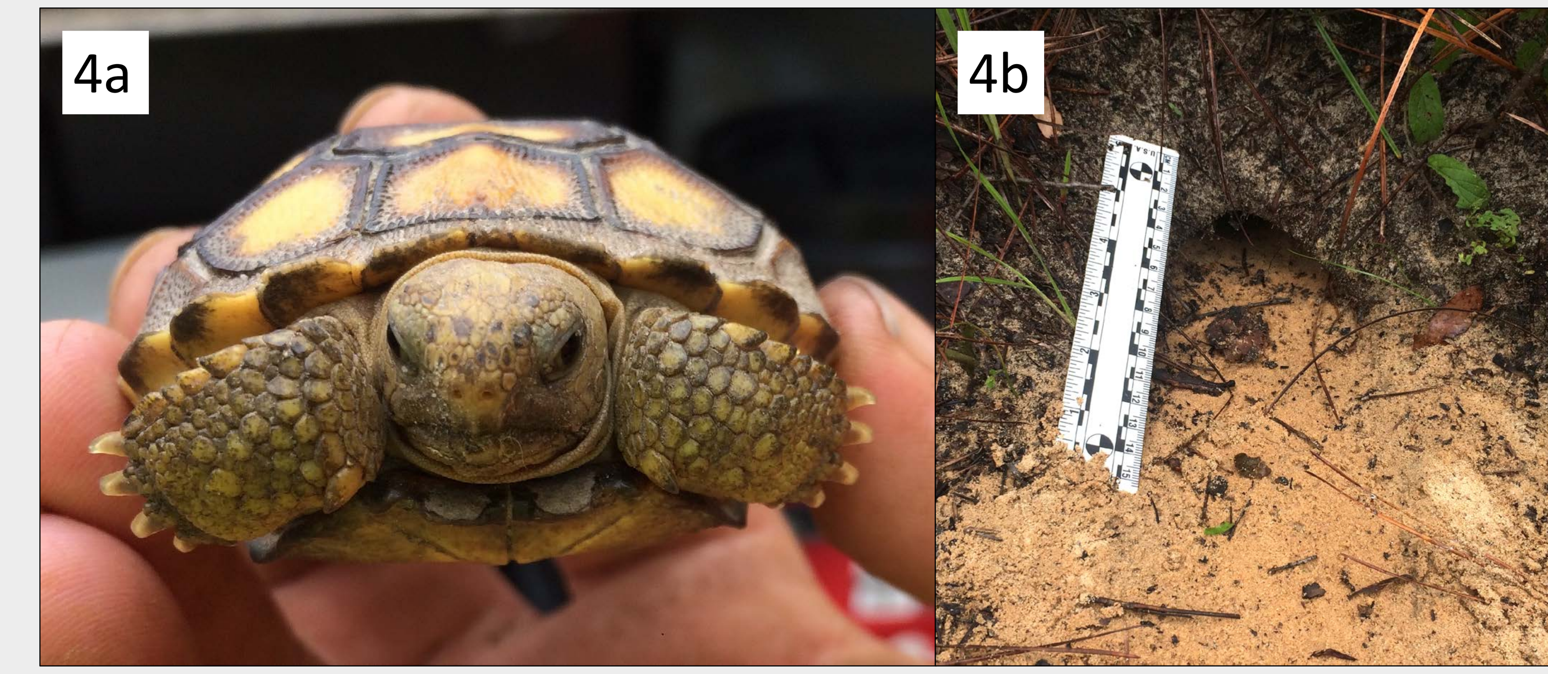

Figure 4: Observations of juvenile recruitment in 2020 following prescribed fires included one juvenile tortoise captured (Figure 4a) and three juvenile burrows (Figure 4b).

Table 1: Number of individual gopher tortoises captured by age group during previous studies and the current study. The unknown category includes data for adult tortoises that could not be identified to sex and studies where data for sex were not available.

Study	Years	n	Female	Male	Unknown	Immature
Hurley 1993	1991-1993	88	41	46	0	1
Diaz-Figueroa 2005	2002-2003	16	0	0	16	0
Clostio 2010	2006-2008	21	10	7	4	0
Gaillard 2014	2011	17	9	6	2	0
Current Study	2017-2020	40	16	23	0	1

Results and Discussion

- 180 burrows detected (Figure 1).
  - 176 adult burrows.
  - 4 juvenile burrows (burrow width of 5.5 – 7.0 cm; one occupied; Figure 2).
  - 9 nests (eggshells on burrow aprons assumed to be depredated).
- 40 individual tortoises captured (Table 1).
  - 2017 – 7 females and 7 males.
  - 2018 – 13 females and 18 males.
  - 2020 – 11 females, 10 males, and 1 juvenile (straight-line carapace length = 6.0 cm; Figure 2 and Figure 4).

Observations of juvenile recruitment have been sparse since the 1990's at this site. While juveniles may have been present but not detected prior to prescribed fires, we estimate that juveniles detected in 2020 were hatched in 2019. Prescribed fire, combined with other forest management practices, may have improved conditions for gopher tortoise recruitment on this site.

Annual and Lifetime Home Ranges Reveal Movement Patterns of Gopher Tortoises

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INTRODUCTION

- Telemetry data are important in delimiting local populations
- Telemetry typically is performed from a single season of activity (May-October for tortoises)
- Examination of long-term movements is needed
- Study Goals
  - Compare annual and lifetime home range size of the same individuals

STUDY SITE

- Site 4, Conecuh National Forest, Alabama
- 54 ha; dominated by Troup soils
- Composed of 2 adjacent sand hills (Fig. 1)
- "Main" and "Annex"
- Abundance monitored during 1992–2020
  - Population increased from ca. 30 individuals to ca. 60 in 1992–2002
  - Remained at ca. 60 individuals in 2002–2020

METHODS

- Annual Home Range: Telemetry
  - All adults monitored during 2000 (Fig. 2)
  - Relocated 3–5 times/wk for a field season
  - 100% minimum convex polygon (MCP) estimates annual home range area
- Lifetime Home Range: Trapping
  - All active or occupied burrows trapped from 1993–2020 (Fig. 3)
  - Trap location for each tortoise recorded
  - 100% MCP estimates lifetime home range area
- Combined telemetry and trapping to define behavioral phenotypes
- Repeated-measures ANOVA used to test for differences in home range area by sex and home range type (annual vs. lifetime)

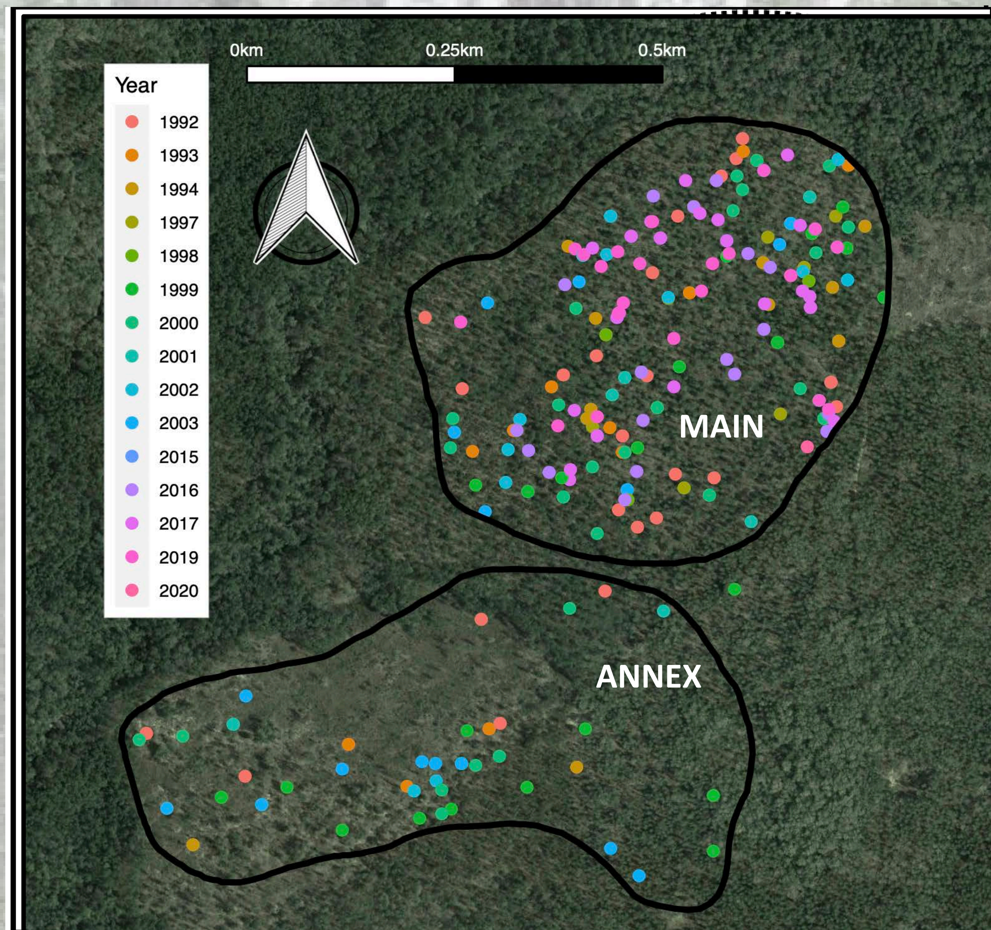

Fig. 1. Geographic distribution of Gopher Tortoise burrows at the study site. Burrow locations aggregate observations from 1993–2020

Fig. 2. Two Gopher Tortoises with telemetry radios monitored during 2000

Fig. 3. Live traps used to capture tortoises from 1993–2020

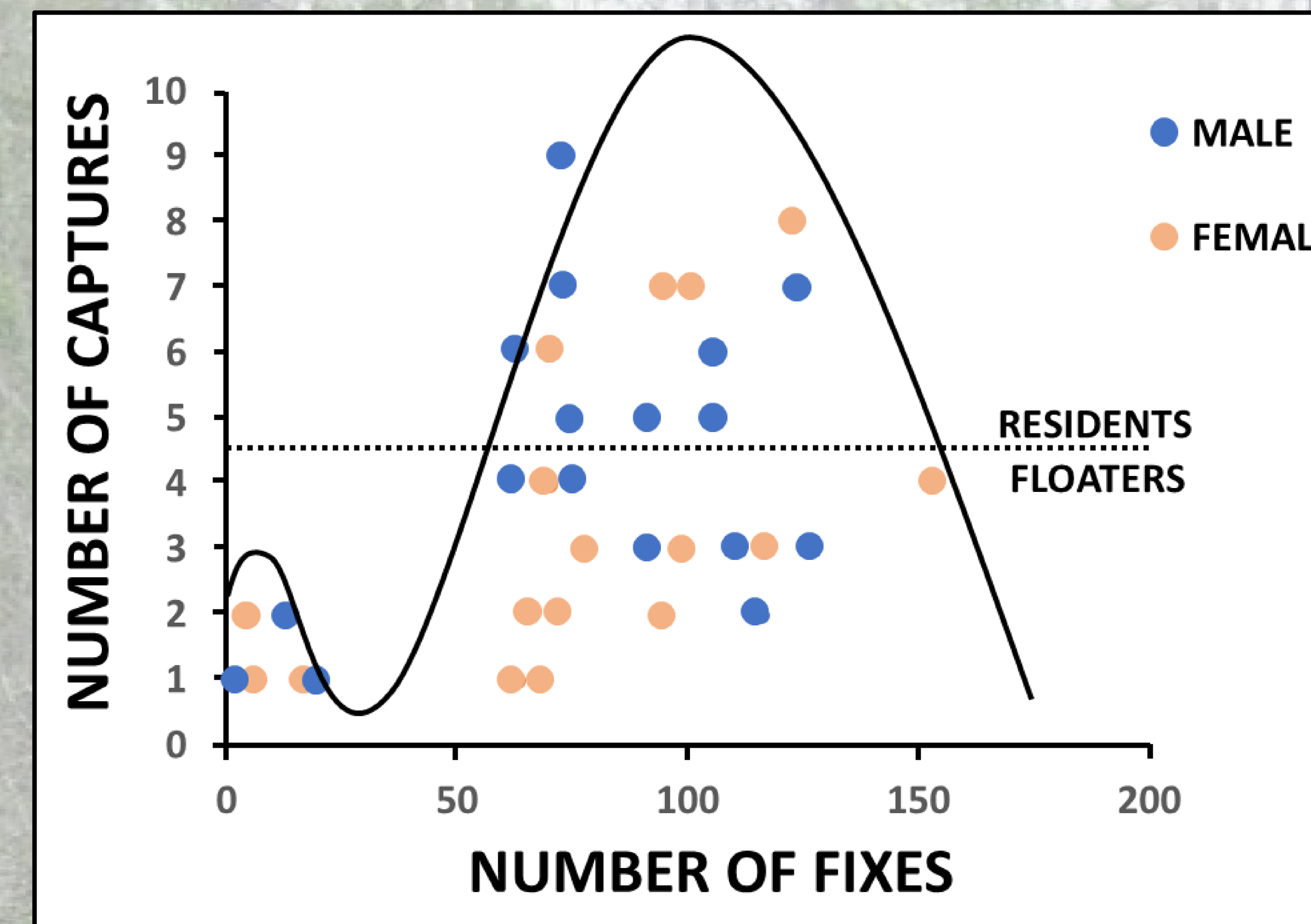

Fig. 4. Bivariate plot of telemetry fixes (x-axis) on number of captures (y-axis)

- Telemetry fixes are bimodal (Fig.4; p = .03); animals with few fixes also have few recaptures
- Distribution suggests 18% of tortoises emigrated (Table 1) in 2000
- Distribution used to define floaters (<5 captures) and residents (≥5 captures)

Table 1. Frequency of males and females categorized as emigrants, floaters, and residents in 2000 telemetry study

	MALE	FEMALE
EMIGRANTS	3	3
FLOATERS	6	10
RESIDENTS	8	4

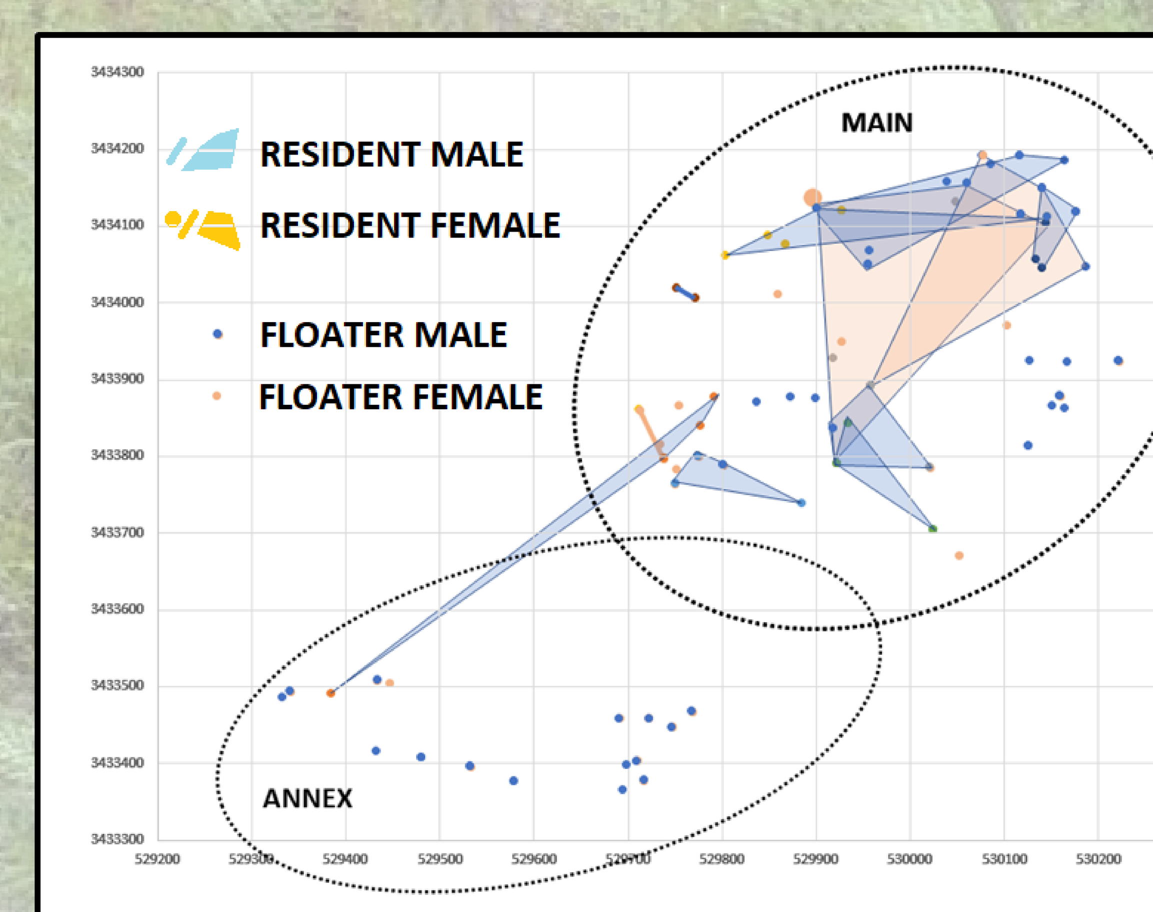

Fig. 5. Annual home ranges of telemetered Gopher Tortoises.

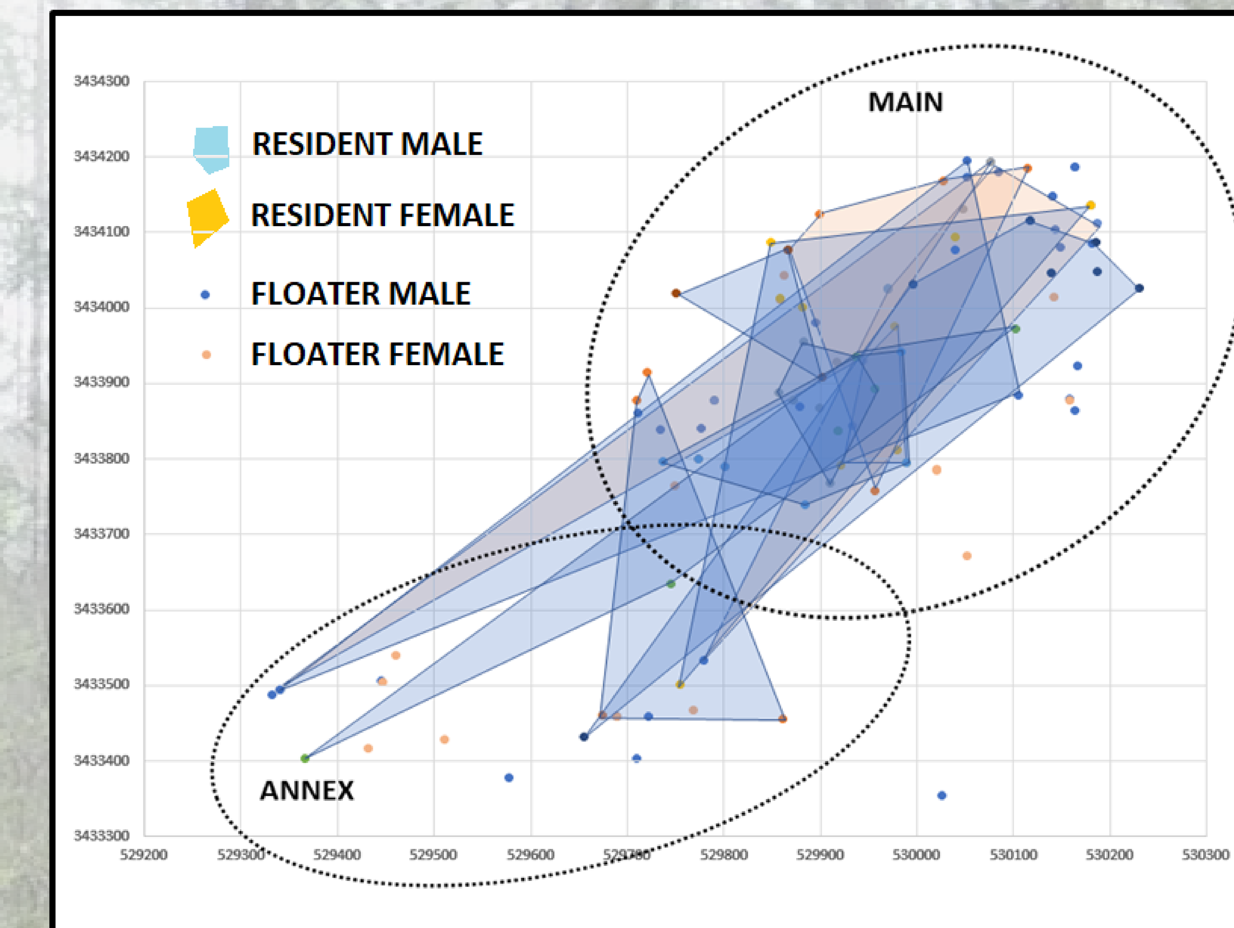

Fig. 6. Lifetime home ranges of marked Gopher Tortoises

- Telemetry Data
  - Resident tortoises had home ranges centered on main area (Fig. 5)
  - Floaters occupied both areas
  - 1 of 12 residents occupied both areas
- Trapping Data
  - Lifetime home ranges averaged 2.4–4.9 times greater area than annual home ranges (Fig. 6; Table 2)
  - 7 of 12 residents occupied both areas

Table 2. Summary statistics of effect of sex (male or female) and type (annual or lifetime) on home range area

	MALE	FEMALE
MEAN ANNUAL	1.2ha	1.4ha
MEAN LIFETIME	5.9ha	3.3ha
SEX	$X^2 = 0.74$, df = 1, p = 0.39	
TYPE	$X^2 = 9.59$, df = 1, p = .002	
SEX x TYPE	$X^2 = 1.24$, df = 1, p = 0.27	

CONCLUSIONS

- Annual estimate of emigration is 18% of adults per year for local populations
- Lifetime home ranges were 2.5–5 times larger than annual home ranges
- Data provide input for improved metapopulation and movement-based models

Investigating vertebrate relationships of the south Florida gopher tortoise: a study of vertebrate species within scrub, pine rockland, coastal hammock and grassland habitats

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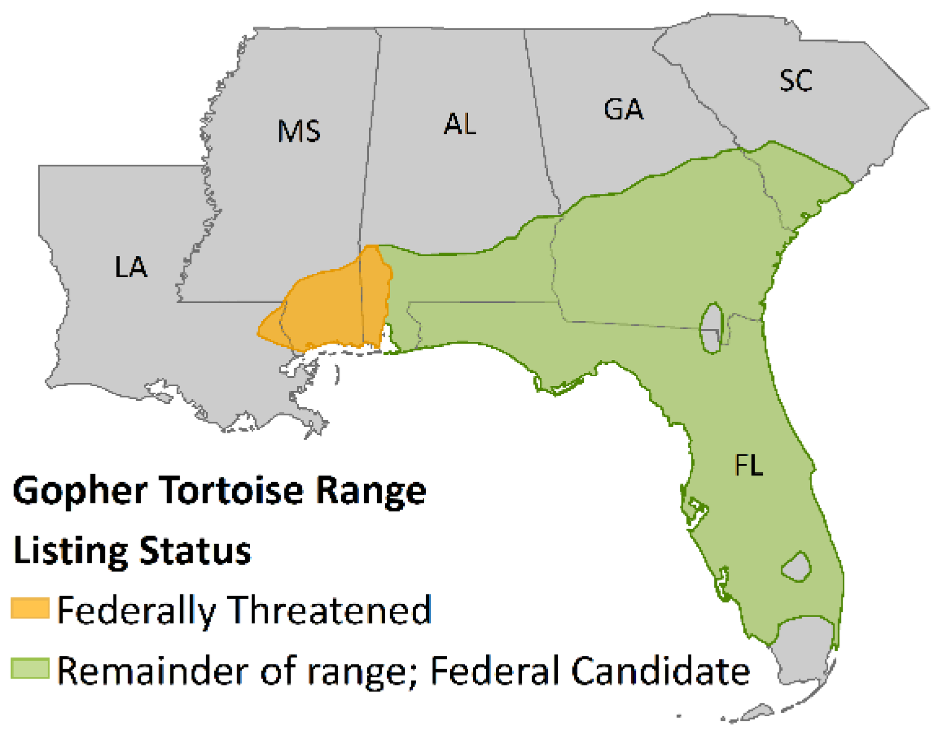
Background

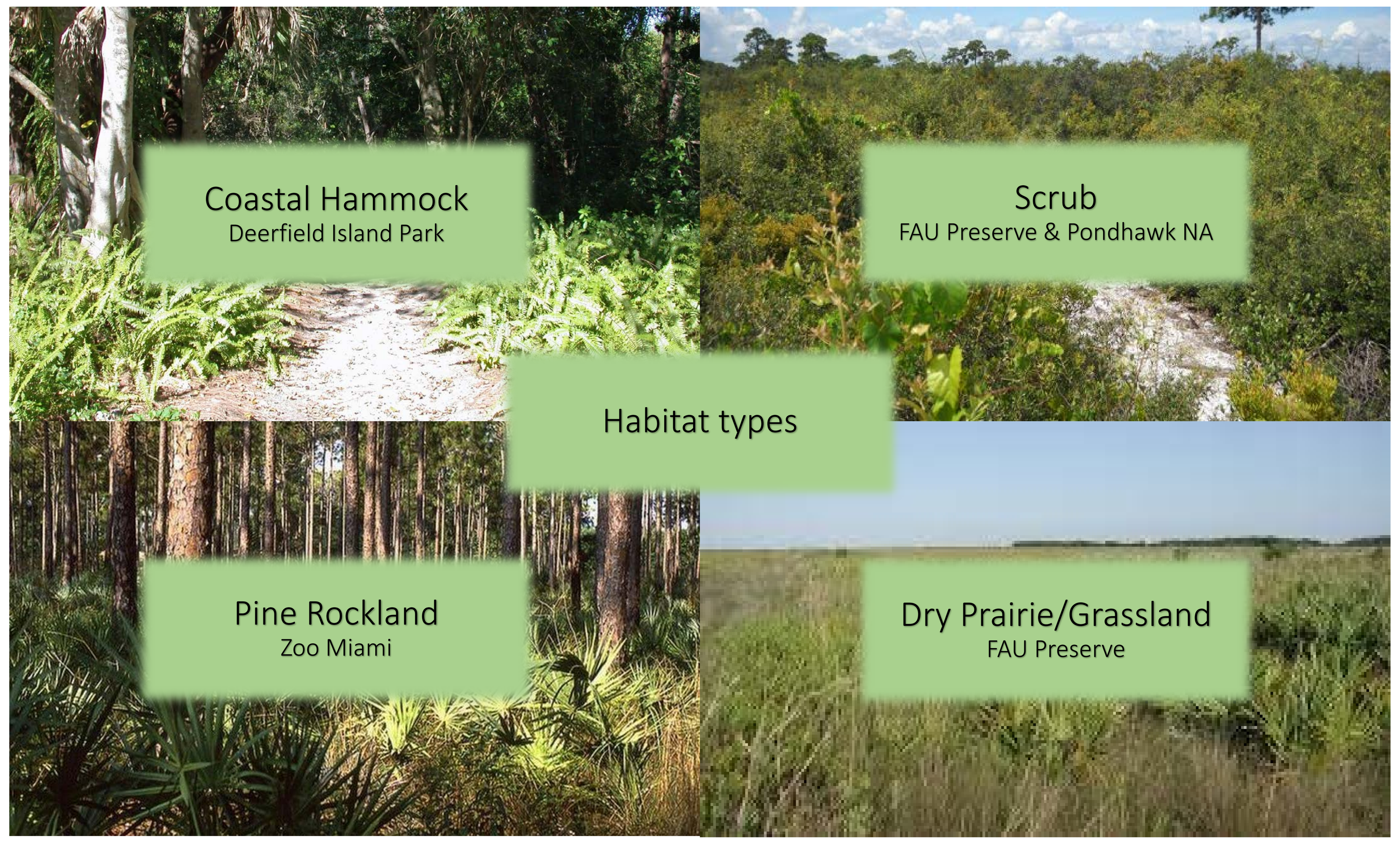


- *Gopherus polyphemus*, commonly known as the gopher tortoise
- Chelonian keystone species that is endemic to the southeastern United States
- Keystone species that plays pivotal role in ecosystem form and function
- Burrows home to over 350 species
  - 60 vertebrates and 290 invertebrates
- Vertebrate species present differ between habitat types
- Little information is available regarding the south Florida gopher tortoise populations

Objectives

- Species inventory of vertebrates
- Seasonality influencing vertebrate presence
- Environmental variables influencing vertebrate presence
- Territorial behavior in response to vertebrate presence

Study Sites



Preliminary Results

Observed vertebrate species seen at *Gopherus polyphemus* burrows in four south Florida sites

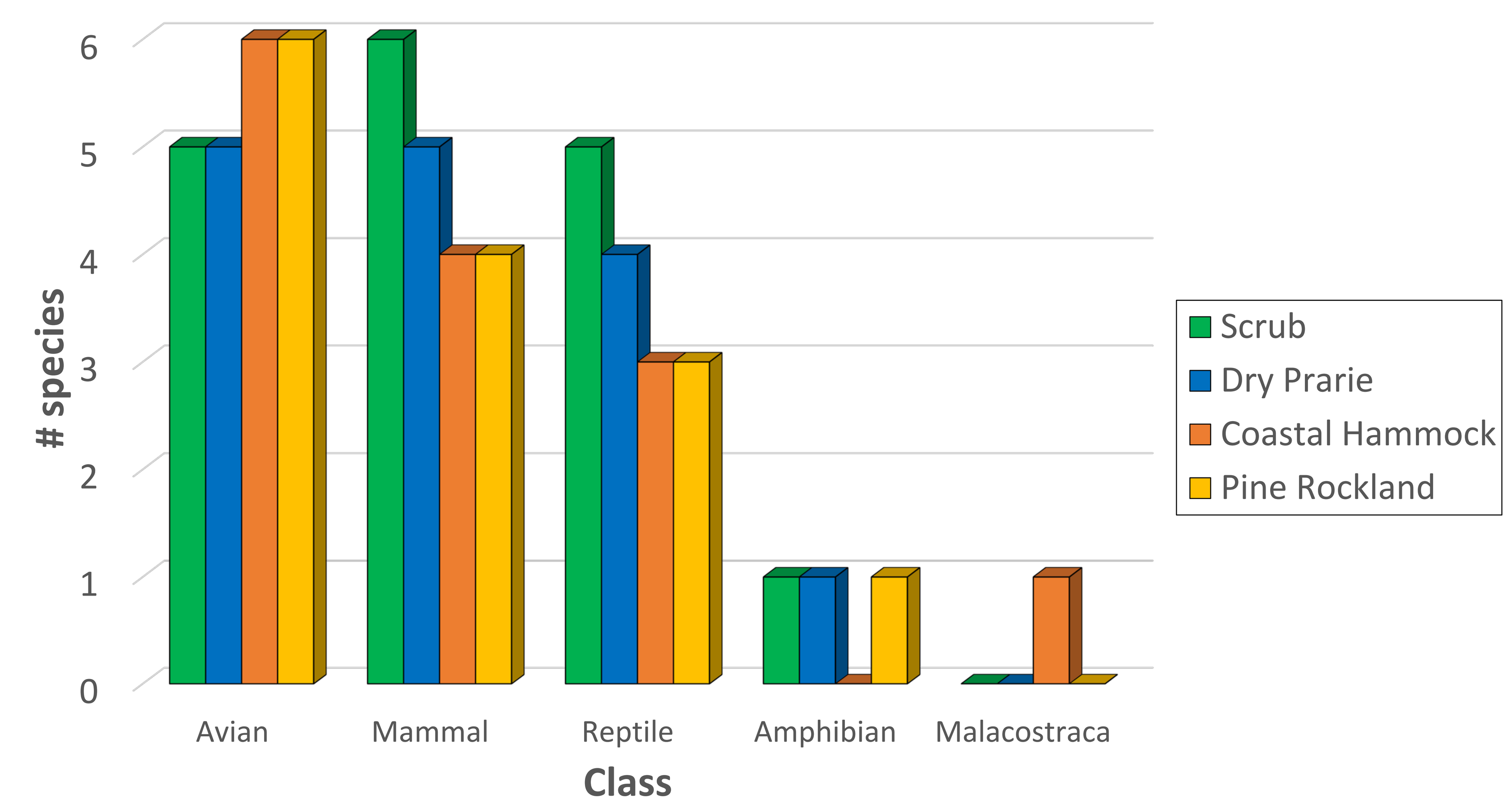


Figure 1: Observed vertebrate species in four habitat types in south Florida collected from 2019 to 2020.

Table 1: Observed vertebrate species in four habitat types in south Florida collected from 2019 to 2020.

Class	Species Name	Common Name
Aves	*Athene cunicularia*	Burrowing Owl
	Cardinalis cardinalis	Northern Cardinal
	Cyanicitta cristana	Blue Jay
	Lanius ludovivianus	Loggerhead Shrike
	Zenaida macroura	Mourning Dove
	Quiscalus major	Boat-tailed grackle
Mammalia	*Canis latrans*	Coyote
	Didelphis virginiana	Opossum
	Sylvilagus floridanus	Eastern Cottontail Rabbit
	Procyon lotor	Raccoon
	Sciurus carlinensis	Squirrel
	Podomys floridanus	Florida Mouse
Reptilia	*Masticophia flagellum*	Coachwhip
	Coluber constrictor priapus	Black racer
	Iguana iguana	Green iguana
	Leiocephalus	Curly tailed lizard
	Anolis sagrei	Brown anole
Amphibia	*Rana capito*	Gopher frog
Malacostraca	*Uca pugilator*	Fiddler crab

Materials and Methods

General

- 7 Moultrie A-25i game cameras at:
  - Pondhawk, Zoo Miami and Deerfield Island
- 14 Moultrie A-25i game cameras at:
  - Florida Atlantic University
- Set ~1 meter from burrow opening
- Takes 3 trigger shots with 15 second interval
- Date time and camera name is recorded

Territorial Behavior

Blocking

Charging

Significance

- Populations on the decline in south Florida
- South Florida's tortoise's behave differently than the remainder of their north western populations
  - Important to study to figure out why this may be
- "Action 1.7.15: Determine habitat use and movements of tortoises in relatively poorly drained soils, especially in south Florida." –Gopher tortoise habitat management plan FWC

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Vertebrate and invertebrate commensals in gopher tortoise burrows in southeastern Florida

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Background

- Few commensal studies have been conducted in southeastern Florida where the pressure to relocate is especially high to accommodate increased development. More information is needed for management plans pertaining to burrow commensals.
- Thirteen known invertebrate species are obligate because they are found exclusively within gopher tortoise burrows. Some of the obligate invertebrate commensals (OIC) may have mutualistic relationships with gopher tortoises by feeding on dung, organic matter, and other arthropod species, ultimately providing sanitation and pest control services. Population statuses of OIC's are unknown, yet it is likely that they are experiencing a similar decline to the gopher tortoise. Little is understood regarding their population status, habitat requirements, distributions and the impact they have on gopher tortoises.
- The subtropical climate of south Florida provides ideal habitat for many invasive species to flourish, and gopher tortoise burrows may allow some populations of invasive species to persist and expand.

Figure 1. *Bufo terrestris* (southern toad) and *Coluber flagellum* (eastern coachwhip).

Objectives

- Gain a better understanding of gopher tortoise commensal distribution, life history, status, population dynamics, and habitat requirements in southeastern Florida.
- Compile an account of vertebrate and invertebrate species utilizing gopher tortoise burrows in southeastern Florida.
- Evaluate a variety of noninvasive methods for surveying invertebrates associated with gopher tortoise burrows.

Methods

Figure 2. Some of the invertebrate survey methods tested.

- Six sites in southeastern Florida consisting of pine flatwoods and scrub habitats were selected. These sites include Harbor Branch Oceanographic Institute (scrub), Abacoa Greenway (flatwoods), and two sites each in Savannas Preserve State Park (scrub and flatwoods) and Jonathan Dickinson State Park (scrub and flatwoods). Twenty active burrows were surveyed at each site for a total of 120 burrows.
- Species utilizing the burrows and burrow aprons were recorded.
- Vertebrate commensal species were identified using a burrow camera scope and trail cameras.
- Several methods were tested to collect invertebrate commensal species: burrow façade traps (Fig. 2A), sifting through soil samples collected using two-meter-long dipper (Fig. 2B), insect pitfall traps, dissecting tortoise feces, baiting burrows with tortoise feces using pantyhose, blacklight traps using UV lights and white sheets for surveying moths (Fig. 2C), active searching at burrow entrances (Fig 2D), and baiting index cards with honey and tuna for ant surveys.
- **See QR code for more details and photos of survey methods.**

Highlights

- Eighty-nine species were recorded. This number is an underestimate because some invertebrates collected have not yet been identified to species. **See QR code for the full commensal list.**
  - Thirty-four vertebrate species were documented.
    - First recordings of *Seiurus aurocapillus* (ovenbird) foraging on burrow aprons (Fig. 3A).
    - Three nonnative vertebrate species were recorded: *Leiocephalus carinatus armouri* (Little Bahama curly-tailed lizard) (Fig. 3B), *Anolis sagrei* (brown anole), *Eleutherodactylus planirostris* (greenhouse frog).

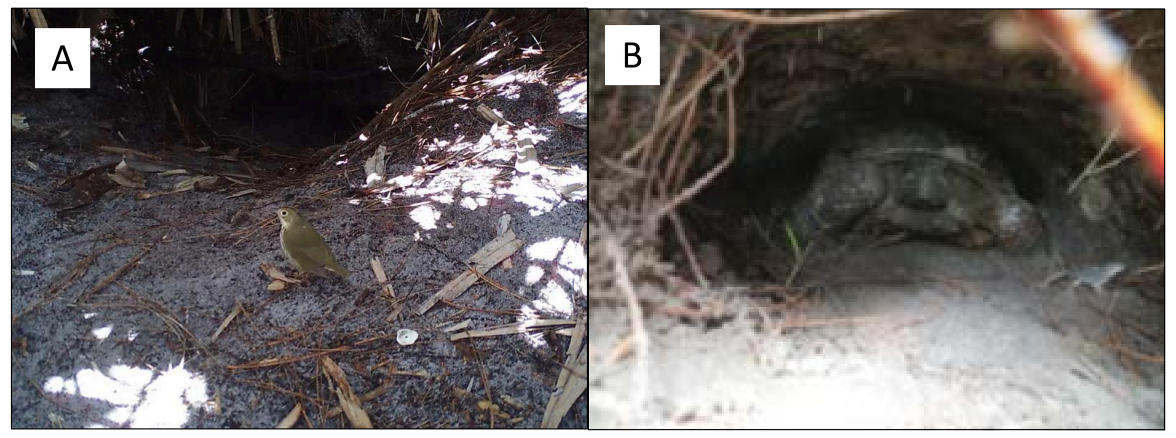

Figure 3. Vertebrate commensals. (A) *Seiurus aurocapillus* (ovenbird) foraging on burrow apron. (B) *Leiocephalus carinatus armouri* (curlytail lizard) inside of burrow.

- Fifty-five invertebrate species were recorded. Five species are obligate invertebrate commensals:
  - *Copris gopheri* (gopher tortoise copris beetle) (Fig. 4A)
  - *Eutrichota gopheri* (gopher tortoise burrow fly) (Fig. 4B)
  - *Alloblackburneus troglodytes* (little gopher tortoise scarab beetle)
  - *Chelyoxenus xerobatis* (gopher tortoise hister beetle)
  - *Acrolophus pholeter* (gopher tortoise acrolophus moth) (Fig. 4C)
- Eighteen species of ants were recorded.

Figure 4. Obligate invertebrate commensals. (A) *Copris gopheri* (gopher tortoise copris beetle). (B) *Eutrichota gopheri* (gopher tortoise burrow fly). (C) *Acrolophus pholeter* (gopher tortoise acrolophus moth).

Discussion

- Given that we detected nearly one-quarter of the number of all known species to use gopher tortoise burrows in only 120 burrows and added to the commensal list, our research suggests the list of commensal species is much larger than previously recorded.
- This study is new understanding of the distributional information on obligate invertebrate commensal (OIC) species, compiling an account of species dependent on gopher tortoise burrows in southeast Florida, and accumulating information on rare or invasive species.

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Archbold Biological Station (ABS), located at the southern end of the Lake Wales Ridge in south-central Florida, is the site of a 53-year demographic study of Gopher Tortoises (*Gopherus polyphemus*) initiated in 1967. The Gopher Tortoise is a focal species for our efforts to restore a rare southern ridge sandhill ("high scrubby pine") community on a part of the Station known as **Red Hill**.

Fire was excluded from Red Hill for > 50 years, allowing invasion by Sand Pines (*Pinus clausa*). Gopher Tortoises responded to closed canopy by moving to roadsides and other habitat edges, or crowding into an open, ruderal field maintained by mowing and burning (**Hill Garden**). Reintroduction of fire began in the late 1980s but was greatly hindered by logistical and safety challenges.

Based on capture-mark-recapture analyses, the population currently numbers ~113 adult tortoises. Our initial burrow survey in 2013 indicated the population was highly skewed toward older age classes. Despite its history of fire suppression, Red Hill retains an intact herpetofaunal community, including Eastern Indigo Snakes, Eastern Diamond-backed Rattlesnakes, Florida Pine Snakes, Gopher Frogs, Six-Lined Racerunners, Florida Scrub Lizards, and Florida Sand Skinks.

Restoration/management goals:

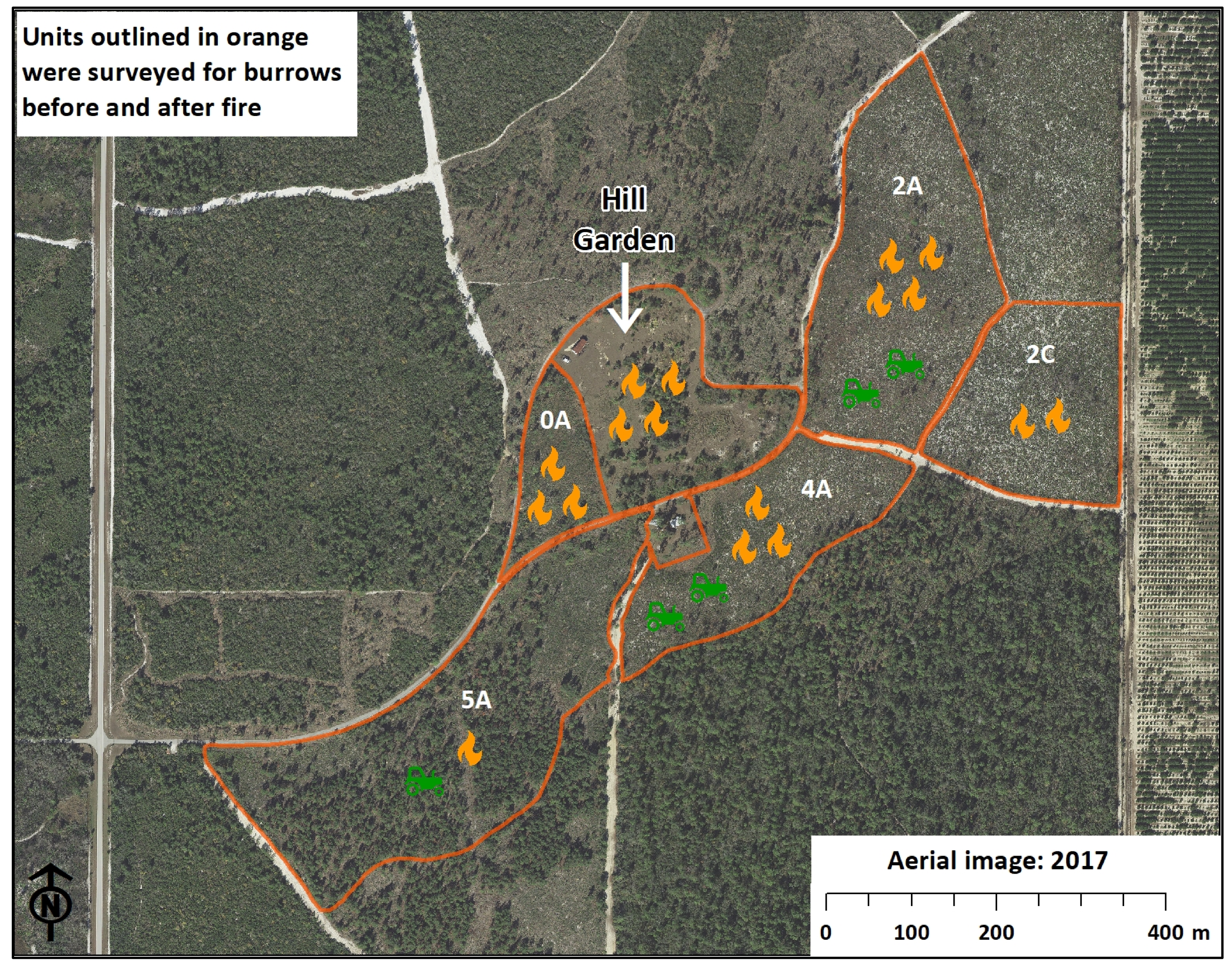
- Within 10 years, re-establish desired fire regime in interval of 2-5 yrs)
- Optimize management of ruderal habitat where currently reside

Restoration and management activities since 2013:

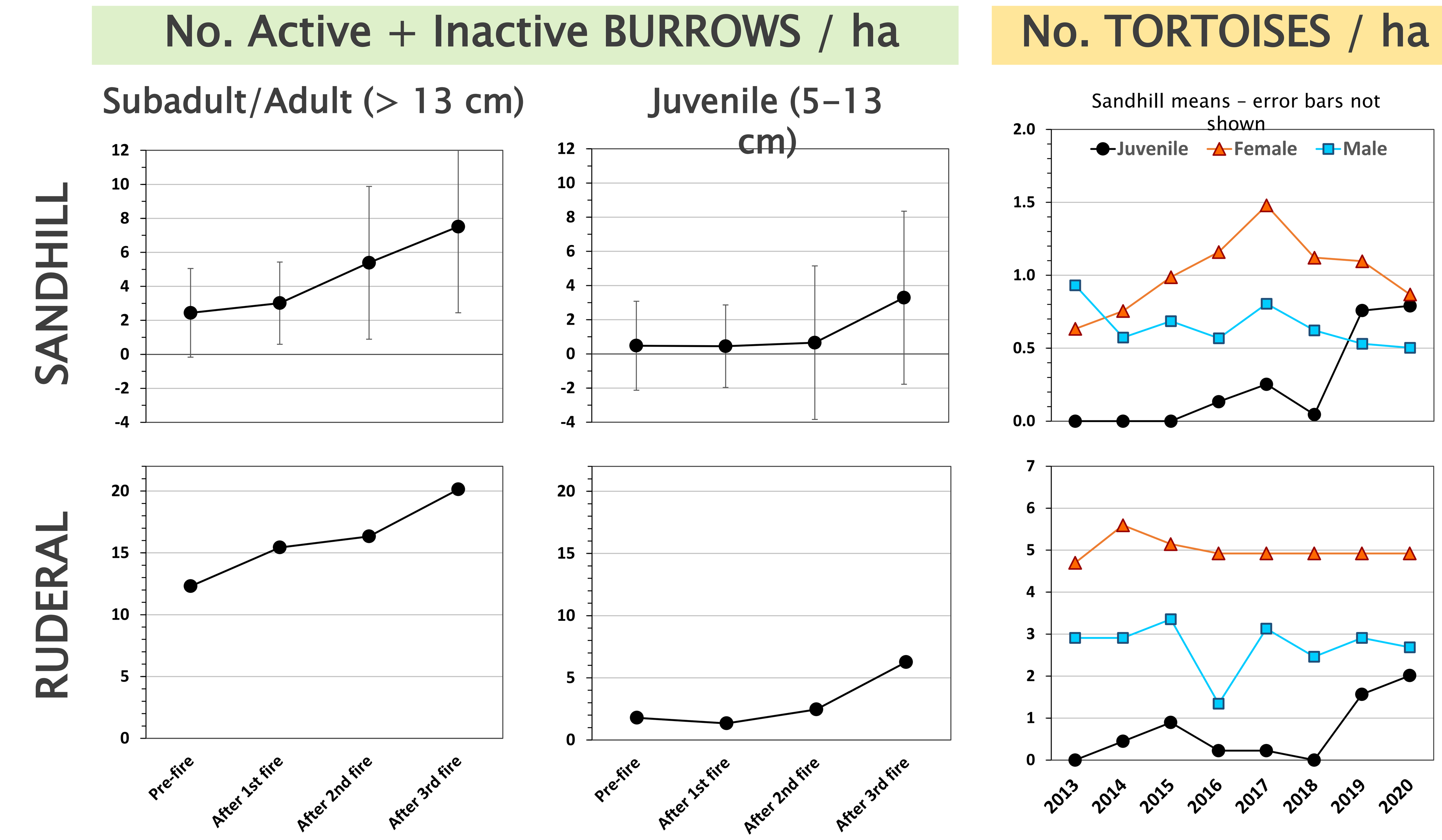
- Phased in mechanical clearing (gyrotracking) and prescribed burning in 5 sandhill units totaling ~37 ha
- Mapped extent of exotic plants and implemented control measures (hand removal, herbiciding) in targeted areas

Annual tortoise censuses and burrow surveys:

- 3-5 observers
- Transects spaced 3-5 m apart depending on veg density
- Mapped burrows of all sizes using Trimble GPS
- Measured burrow widths at a depth of 50 cm using calipers
- Compiled capture histories of individually marked tortoises to estimate minimum number using/residing in each unit



Sandhill units were mowed 0-2X and burned 1-4X since 2013
Hill Garden was mowed 1-3X per year and burned 4X since 2013



Immediate, ongoing increase in adult densities likely due to more immigration and less emigration

Uptick in juvenile densities after 2-3 fires suggests enhanced recruitment due to reintroduction of fire and other management changes

Fire alone won't cut it…

- Initial mechanical clearing may be needed to safely reintroduce fire to long-unburned areas
  - Once dry, mowed material provides ground-level fuel to carry fire; less risky fire behavior
- Although fire controls woody species, canopy removal and disturbance also creates opportunities for invasive exotic grasses, forbs, and vines
  - Even if absent from the seedbank, there are likely exotic species waiting in the wings along firelanes/roads
  - Proactive weed management is required

Timing is everything

- Aim for early detection and rapid response (EDRR) to exotics
- Treat weeds on edges before burning
- Survey and remove invading weeds soon after a burn, when it is easier to halt their spread
- Time burns to allow regrowth of ground cover by late summer when tortoise hatchlings emerge
- Follow common-sense precautions for mowing roadsides and ruderal habitats:
  - Only mow early in the morning, before tortoises become active aboveground
  - Don't mow when hatchlings are emerging in late summer

Expect some surprises

- Seedbank composition and responses of native and non-native species to disturbance are typically unknown and hard to predict
- Welcome surprises:
  - Huge Lupine response in 5A after 1st burn
  - Gopher Apple and Narrowleaf Silkgrass recovering on their own in some places
- Unwelcome surprises:
  - Resurgence of exotic woody species in Hill Garden (Strophanthus, Bael Fruit)
  - Colonization by fire ants
- Unexpected ally:
  - In Hill Garden, Bahiagrass (*Paspalum notatum*) holds the ground and provides abundant forage

Critical next steps to ensure positive outcomes:

- Develop **better strategies to control emerging exotics**, particularly invasive grasses like Natalgrass (*Melinis repens*) and Guineagrass (*Urochloa maxima*)
- Develop unit-specific, **integrated management plans** that consider the timing and sequencing of different management practices

Open questions:

- Given lack of data on **toxicity of herbicides**, which can we assume are relatively safe to use in tortoise habitats?
- As tortoise densities increase, mechanical treatments become less feasible - will there be enough **ground-level fuel to carry fire** without additional mowing?
- Given **limited resources** (staff, funding), how should we prioritize exotics control efforts?

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