Hawaiian hoary bat mitigation-supported research

U.S. Geological Survey – Pacific Island Ecosystems Research Center
University of Hawai‘i at Hilo – Hawai‘i Cooperative Studies Unit

Modeling foraging habitat suitability of the Hawaiian hoary bat

Hawaiian hoary bat conservation genetics

Hawaiian hoary bat conservation biology: movements, roosting behavior, and diet

Auwahi Wind Power bat research at Waihou Mitigation Area

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Hawaiian hoary bat

How many bats are there?

What are the trends?

- distribution, activity, population size

How to assess efforts to mitigate for bat fatalities?

- effects of habitat restoration

Hawaiian hoary bat

How many bats are there?

What are the trends?

- **distribution**, **activity**, population size

How to assess efforts to mitigate for bat fatalities?

- **effects of habitat restoration**

Hawaiian hoary bat

How to assess bat use of areas?

- baseline or pre-management action
- response to post-management action

What are the limiting factors?

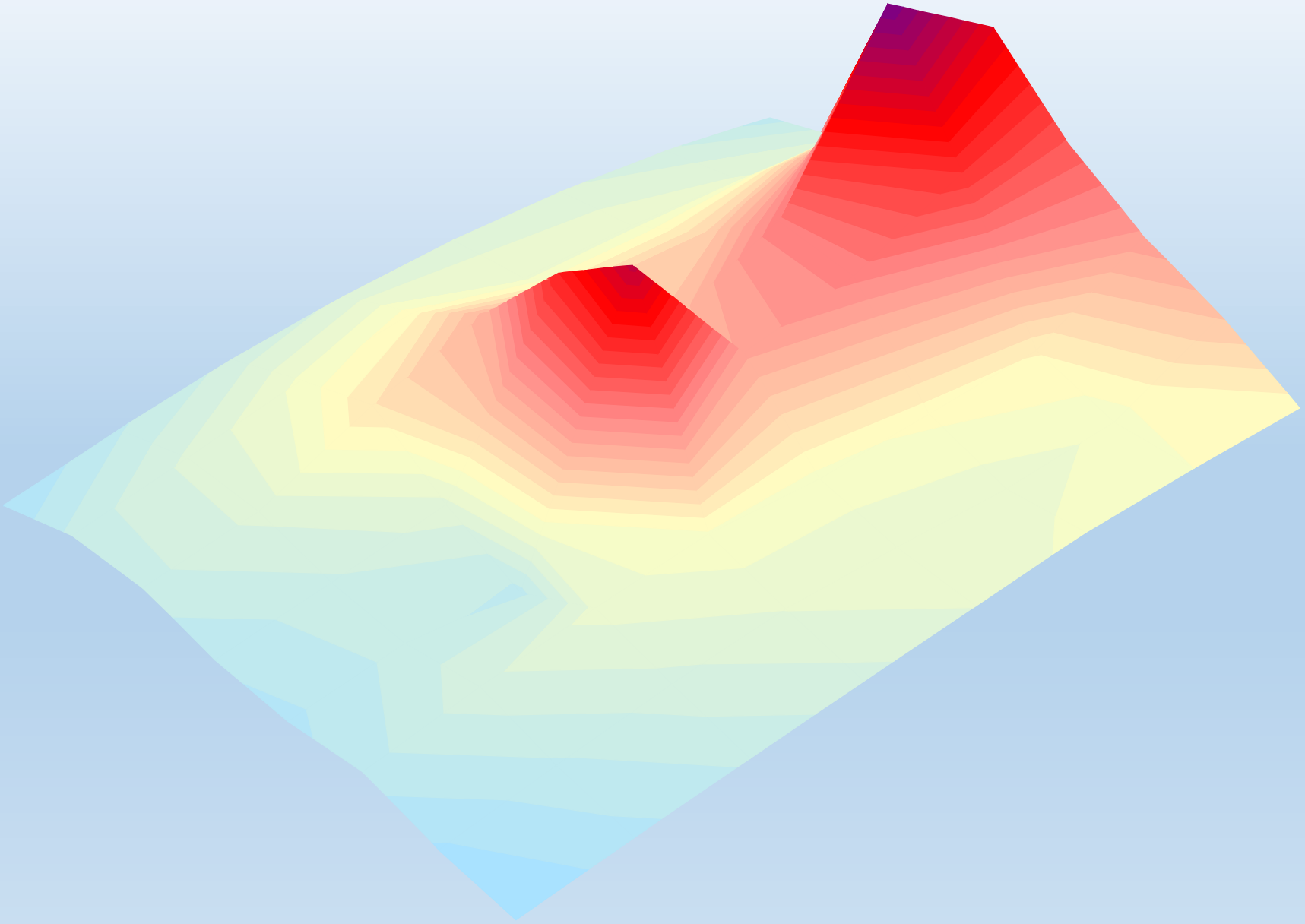
- food and shelter → insects and tree roosts
- how are limiting factors affected?

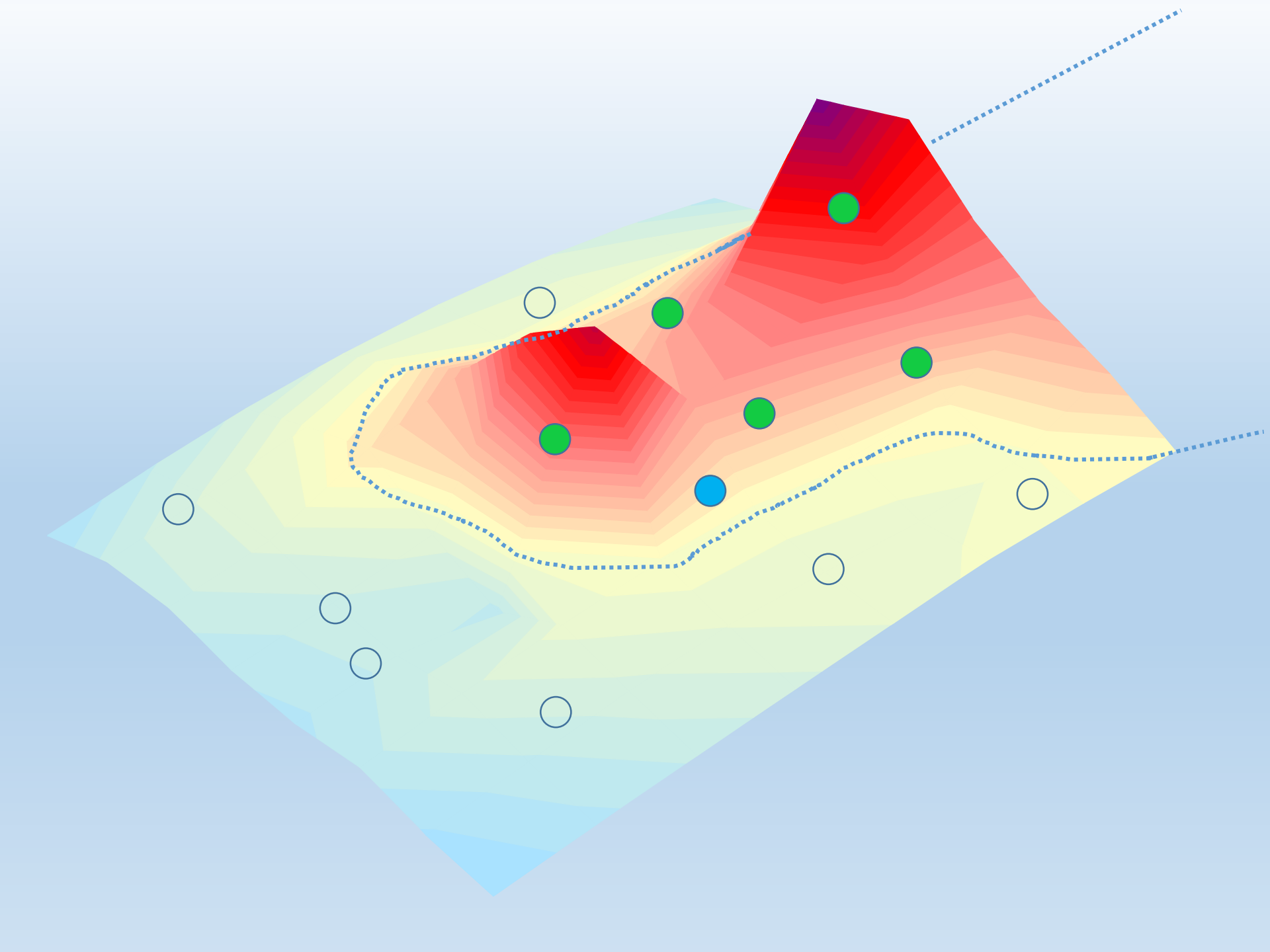
Modeling foraging habitat suitability of the Hawaiian hoary bat

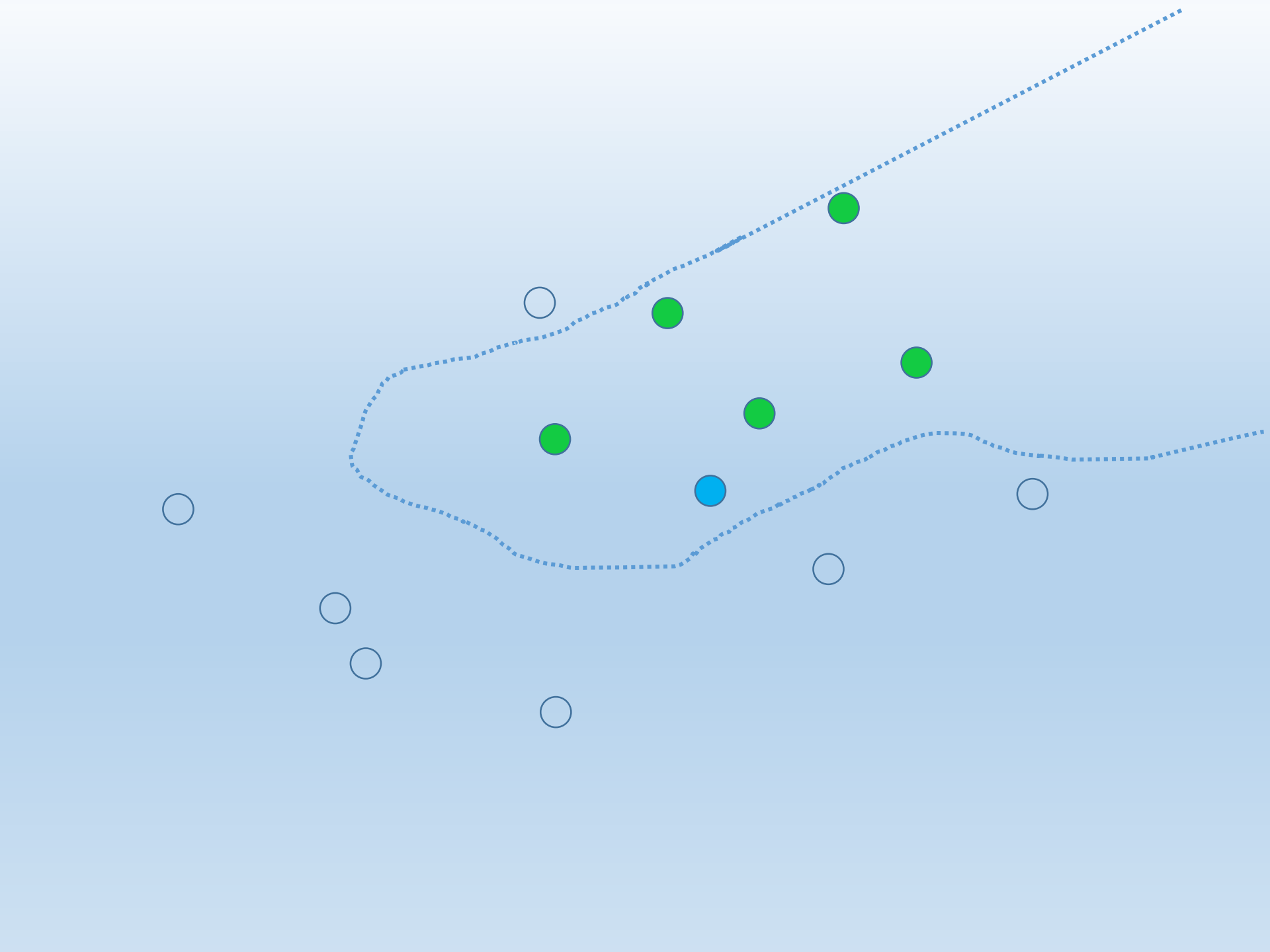
- Test and demonstrate a new analytical method:
  - Quantifies bat foraging habitat use
    - baseline or post-management response
  - Applies & compares multiple sampling methods
    - echolocation recordings
    - thermal videography
    - insect trapping

Occupancy analysis as a model for quantifying distribution and habitat associations

- probability of **site occupancy**, proportion of sampled **area occupied** and **detection probability**
- explicitly deals with **imperfect detection**
- important for **cryptic**, hard-to-detect species







Inference limited when using detection / non-detection ("presence/absence") data

"Occupancy" can be categorized into **multiple** states:

0 = none
1 = some
2 = lots

0 = not occupied
1 = non-breeders only
2 = breeders also present

0 = absent
1 = species A present
2 = both species A and B present

Kroll et al 2016 Multistate models reveal long-term trends of northern spotted owls in the absence of a novel competitor. PLoS ONE

Multi-state occupancy modeling of HHB foraging behavior

Activity level (number of detections)

0 = no bat detection
1 = present with **low** levels of activity
2 = present with **high** levels of activity

Feeding behavior

0 = no bat detection
1 = present but no indication of **prey targeting**
2 = present & **prey targeting**

Acoustic Feeding buzz >>> prey targeting

Video "Hot pursuit" flight >>> prey targeting

Multi-state occupancy modeling of HHB foraging behavior

Four models:

Activity level — acoustic

Activity level — video

Feeding — acoustic

Feeding — video

Search

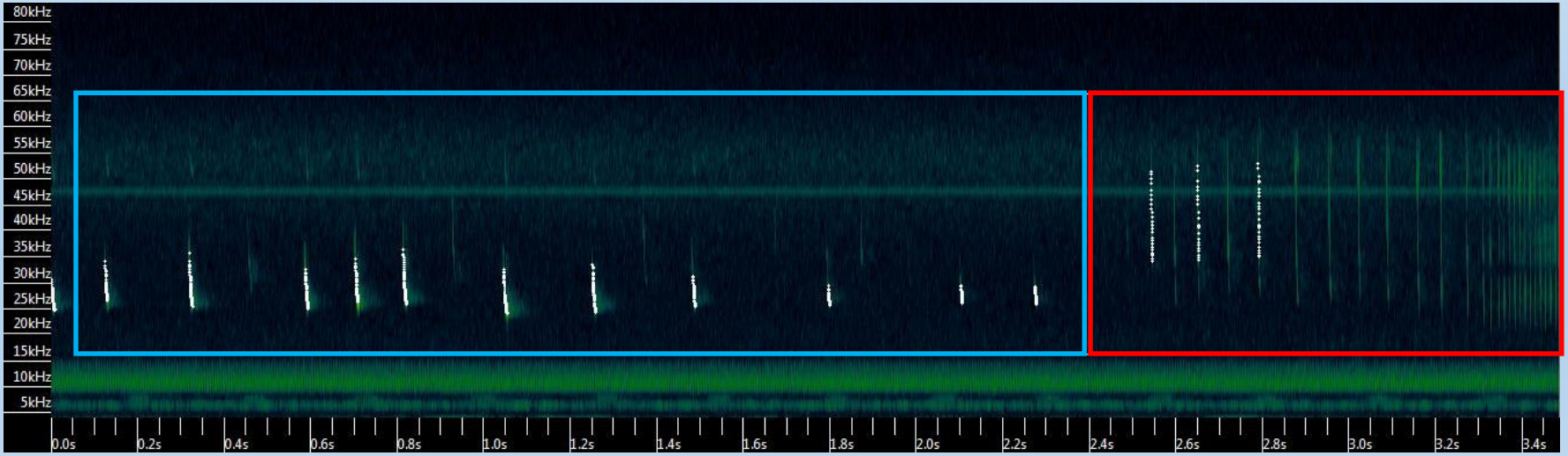
Search

Search

Search

Feeding buzz

unambiguous indicator of prey targeting but can be hard to detect



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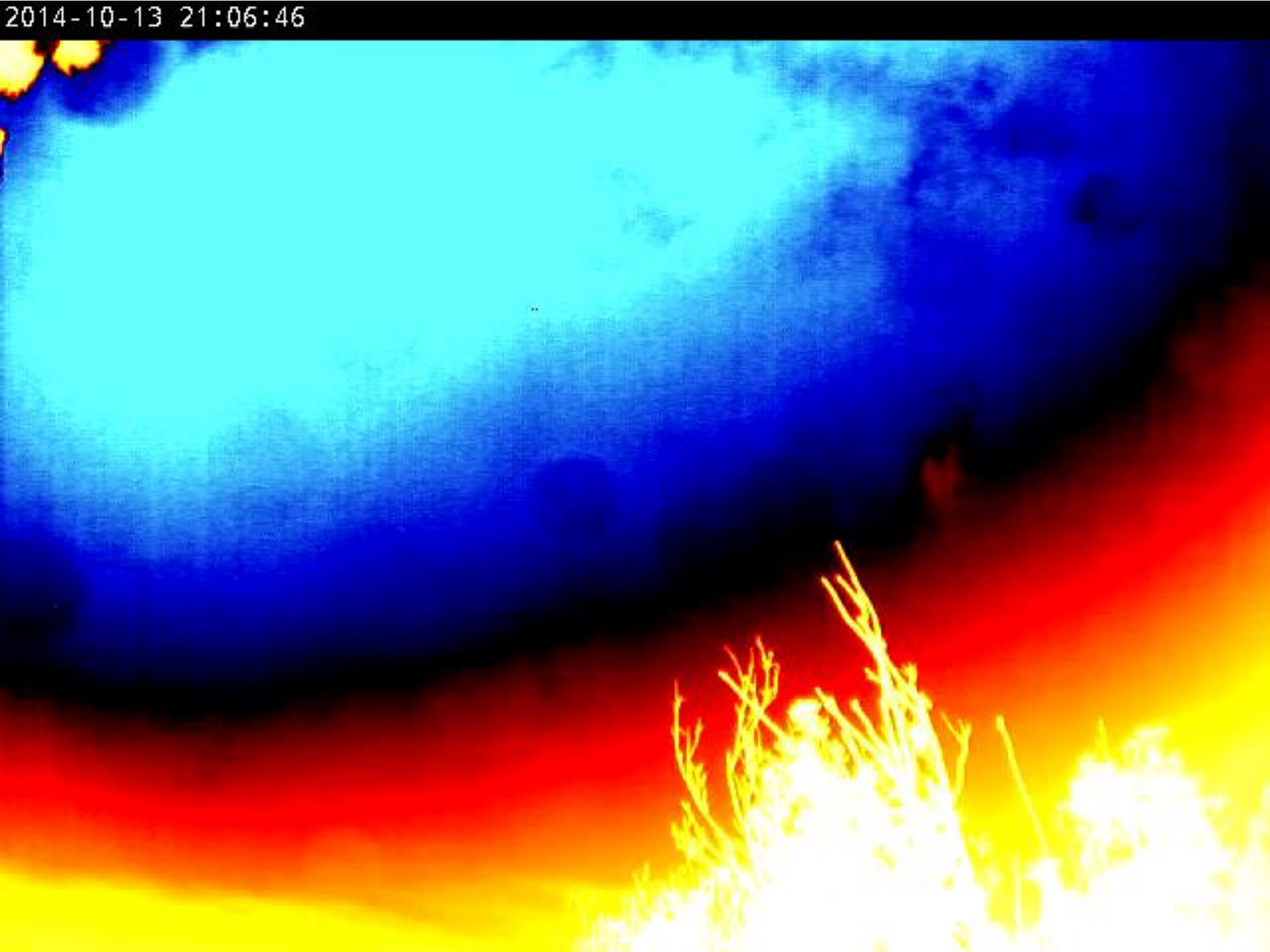
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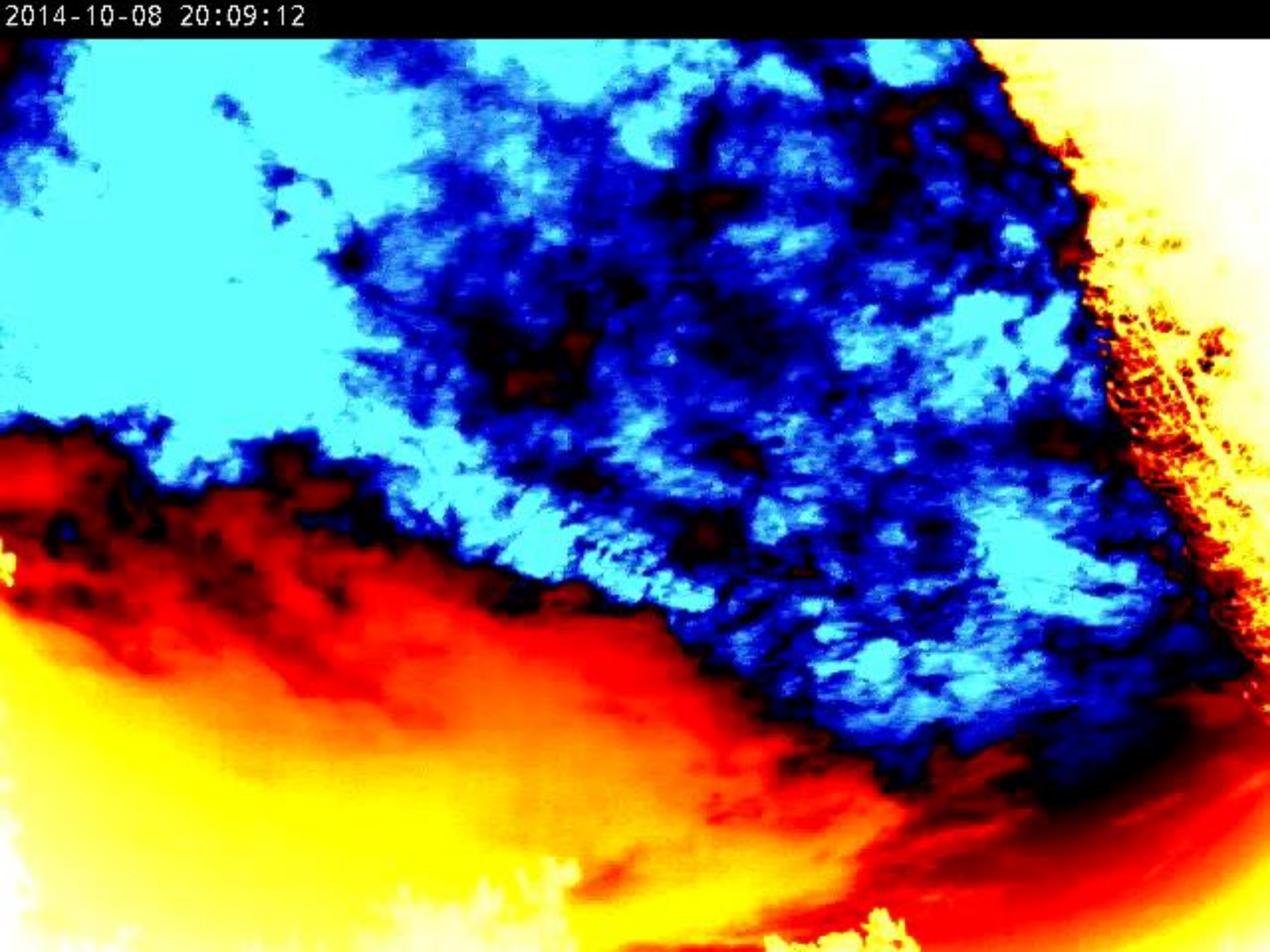
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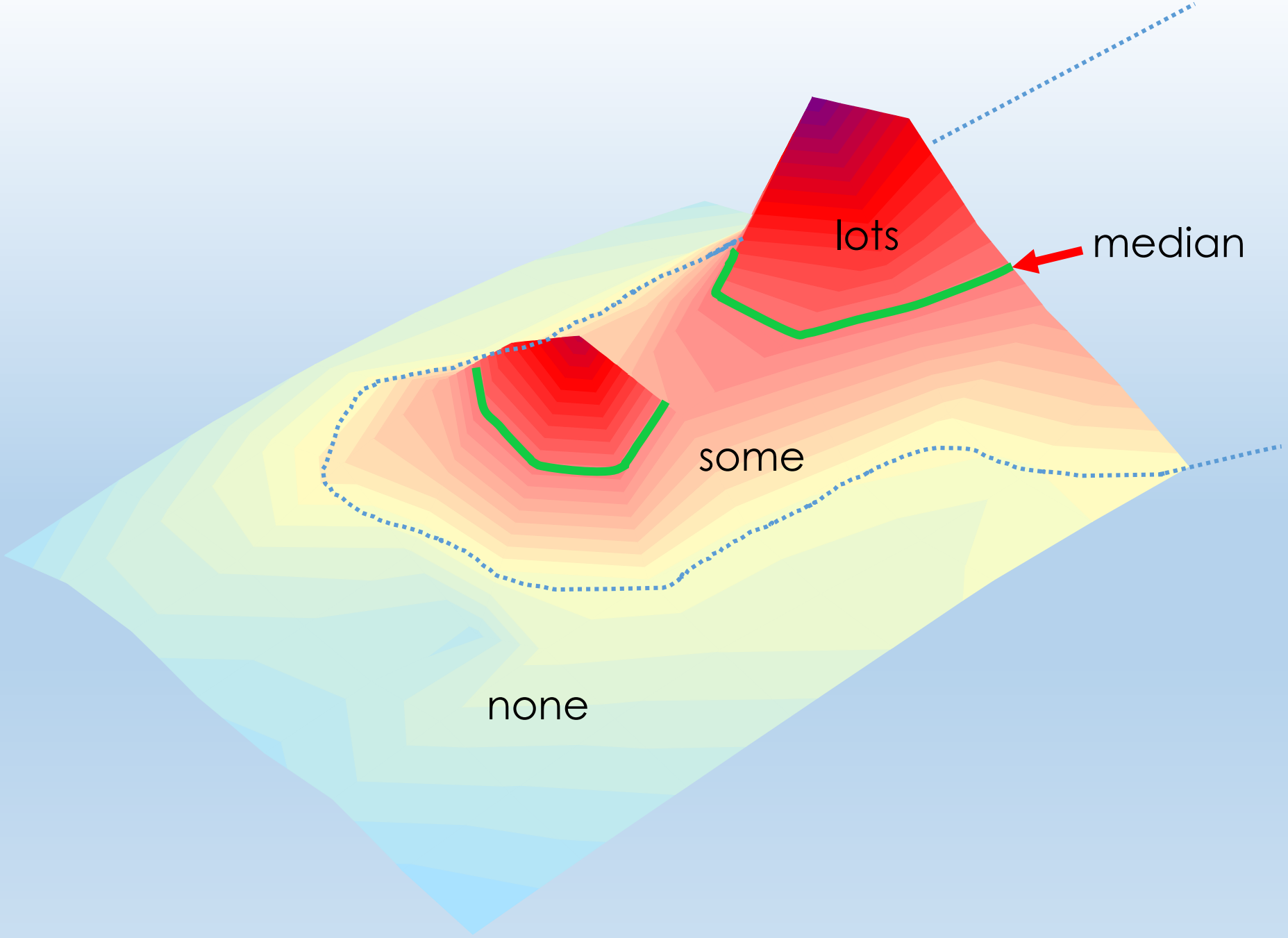
lots
median
some
none

Multi-state occupancy modeling

Predictors of bat occurrence and occupancy state:

- Sampling attributes:
  - wind speed (-), nightly mean, maximum
  - precipitation (-), nightly cumulative total

- Site attributes:
  - insect abundance, biomass (+), beetles and moths
  - elevation (~)
  - wind exposure (-)

Multi-state occupancy modeling

Predictors of bat occurrence and occupancy state:

- Sampling attributes:
  - wind speed (-), nightly mean, maximum
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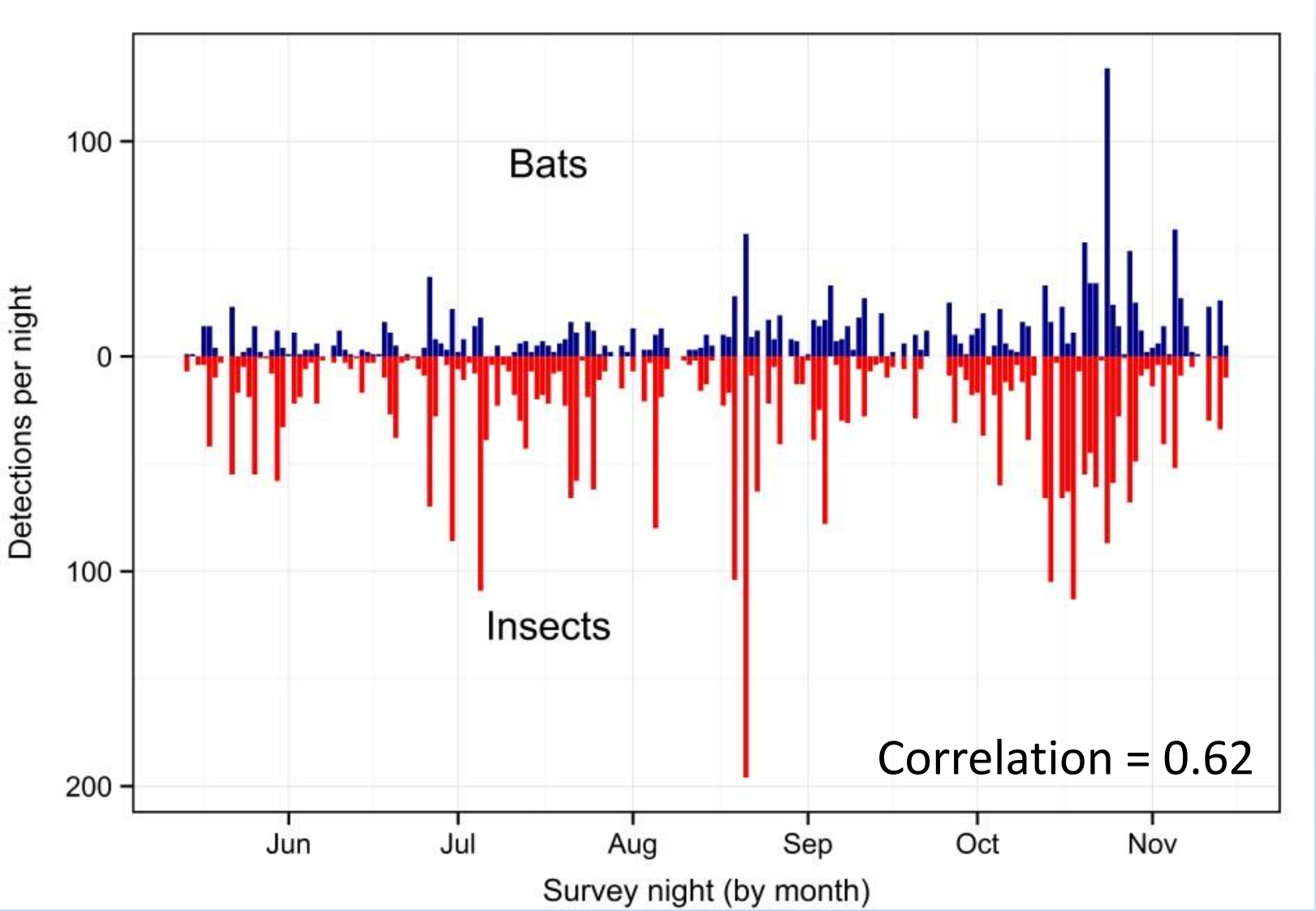
  - **insect abundance, biomass (+), beetles and moths**
  - elevation (~)
  - wind exposure (-)

Correlation with insect detections

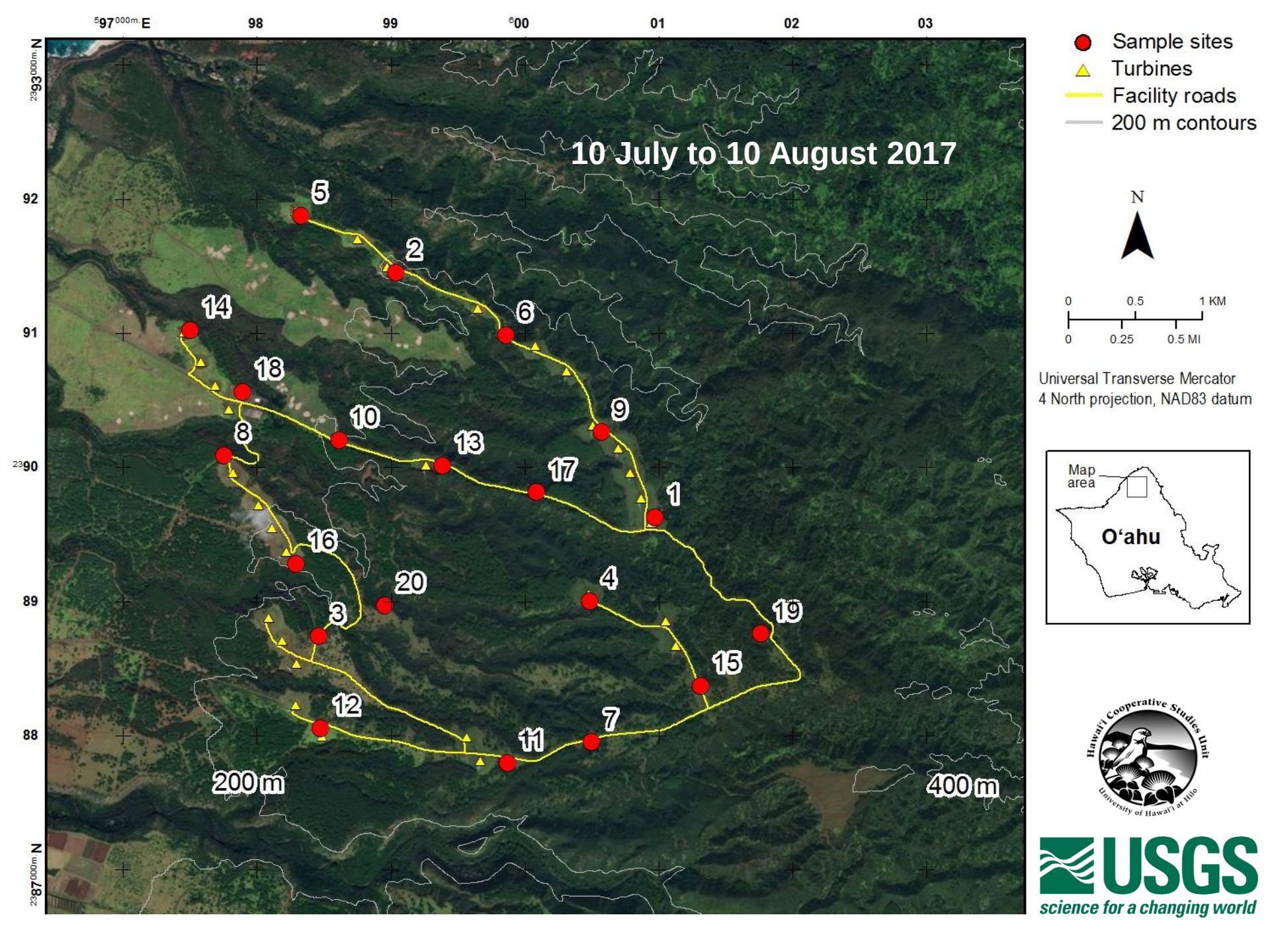
Photo: M. Tuttle

Correlation with insect detections



Gorresen et al 2015 Behavior of the Hawaiian hoary bat (*Lasiurus cinereus semotus*) at wind turbines and its distribution across the North Koʻolau mountains, Oʻahu. Hawaiʻi Cooperative Studies Unit Tech. Rep. HCSU-064


USGS
BATS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Turbines
Facility roads
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Universal Transverse Mercator
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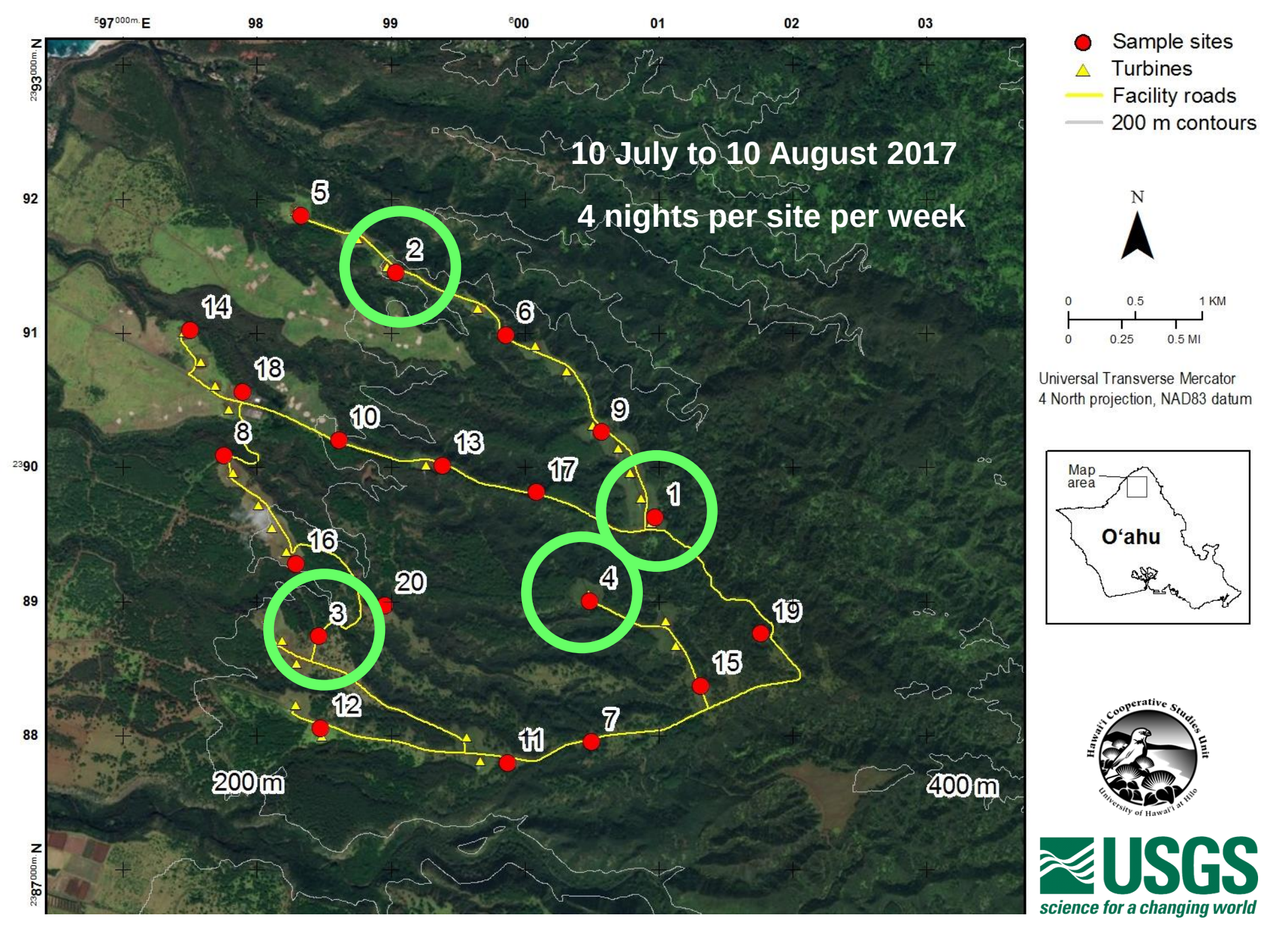
Map area
O‘ahu
Hawai‘i Cooperative Studies Unit
University of Hawai‘i at Hilo
USGS
science for a changing world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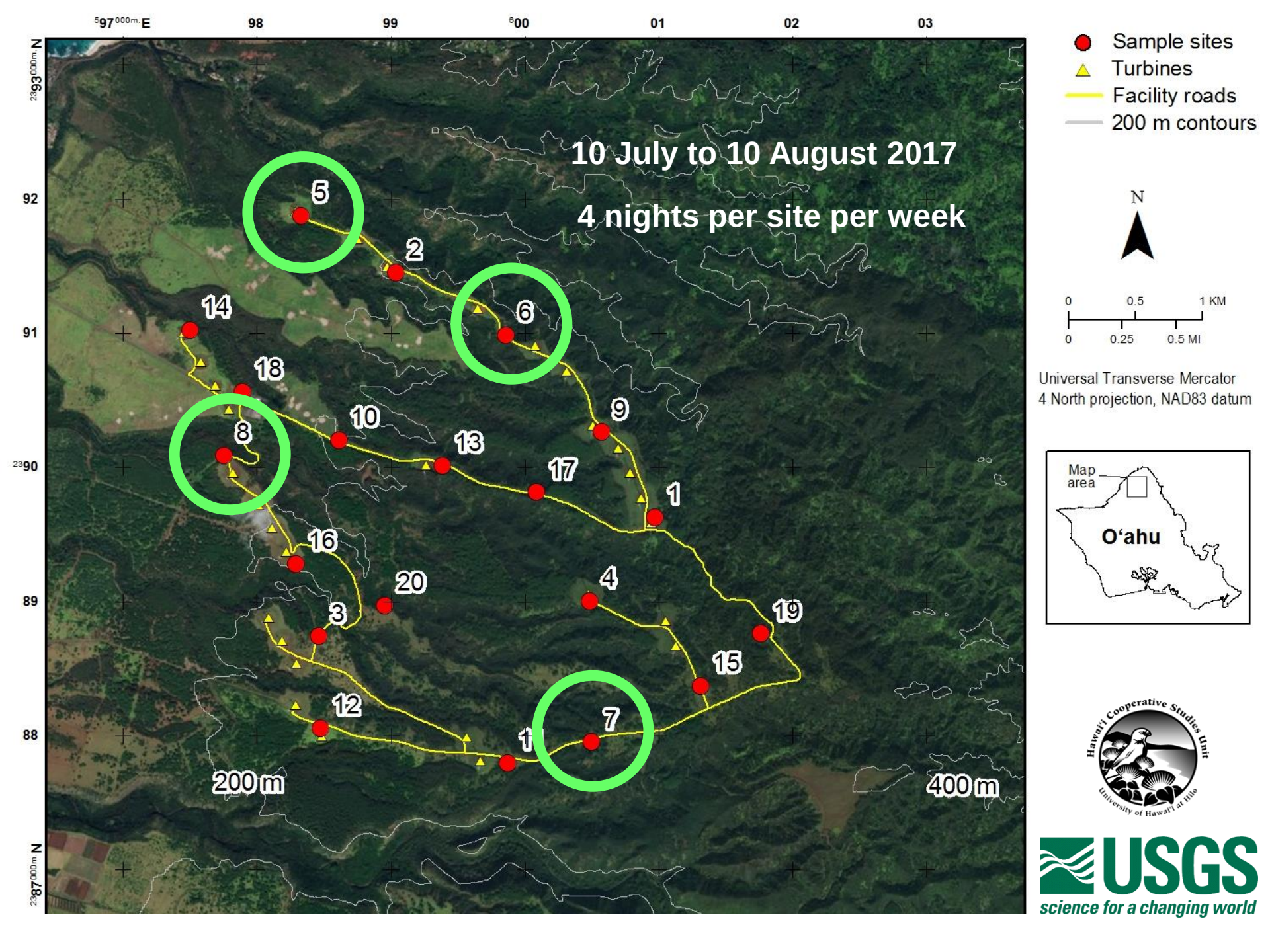
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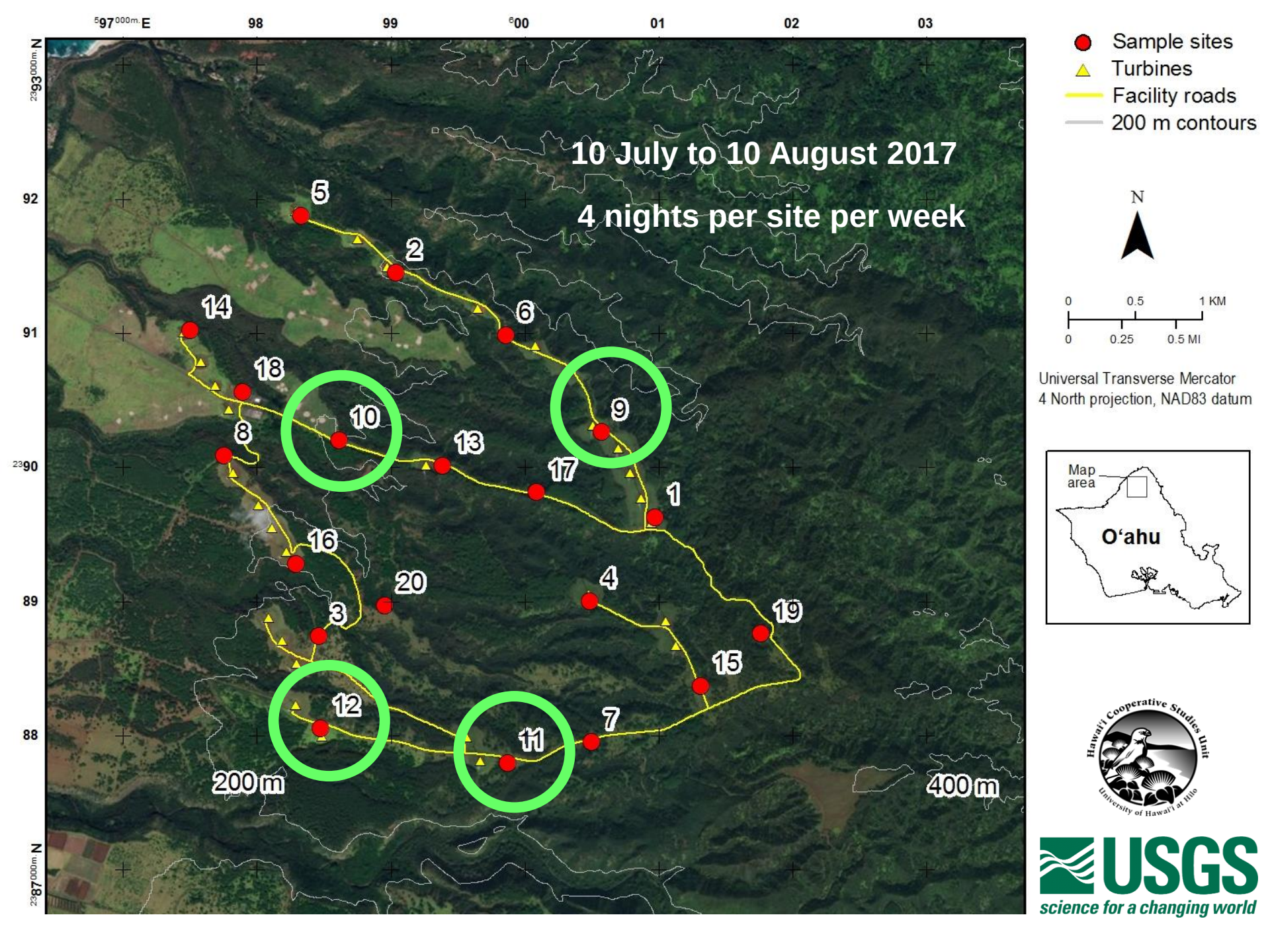
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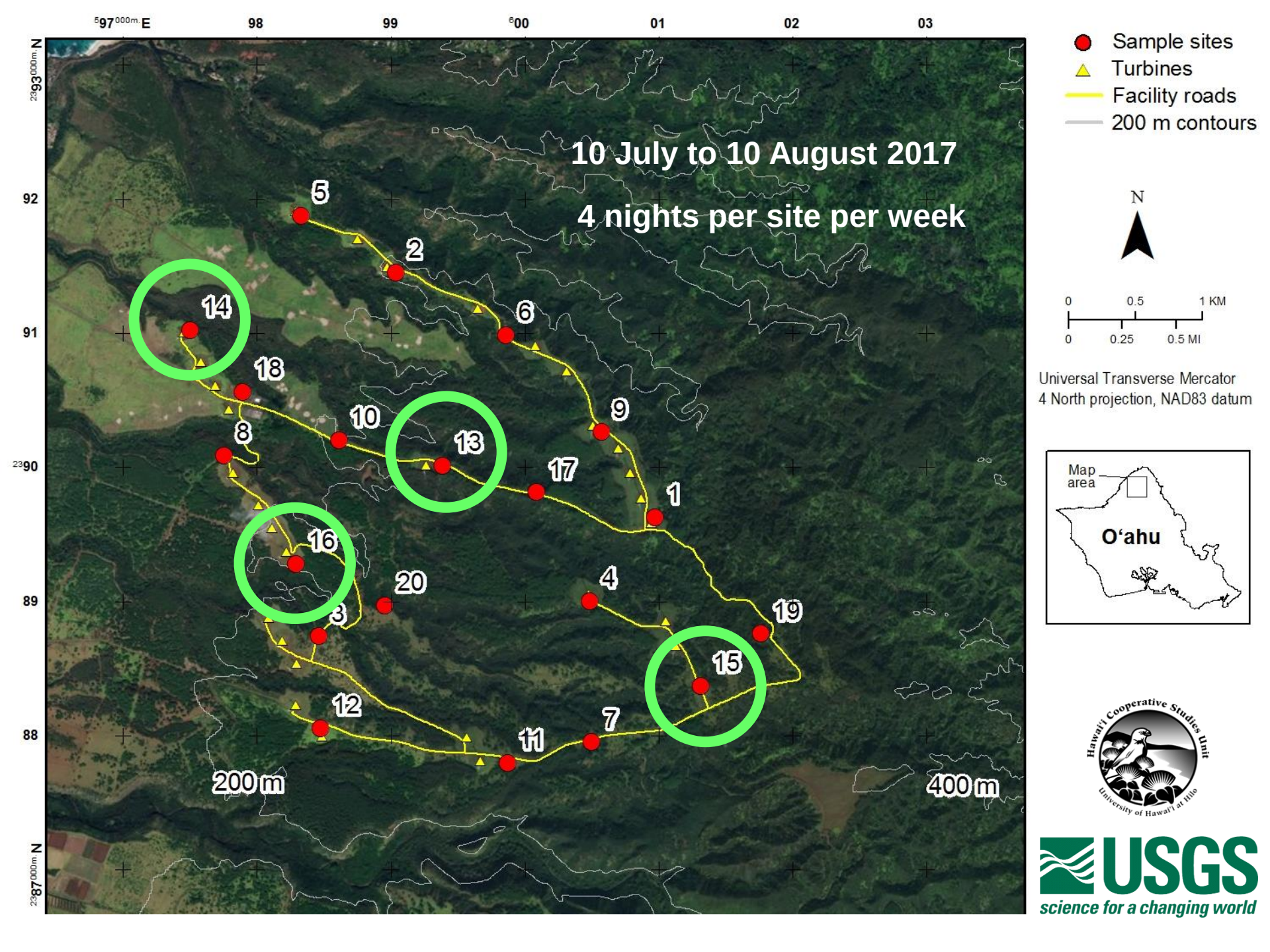
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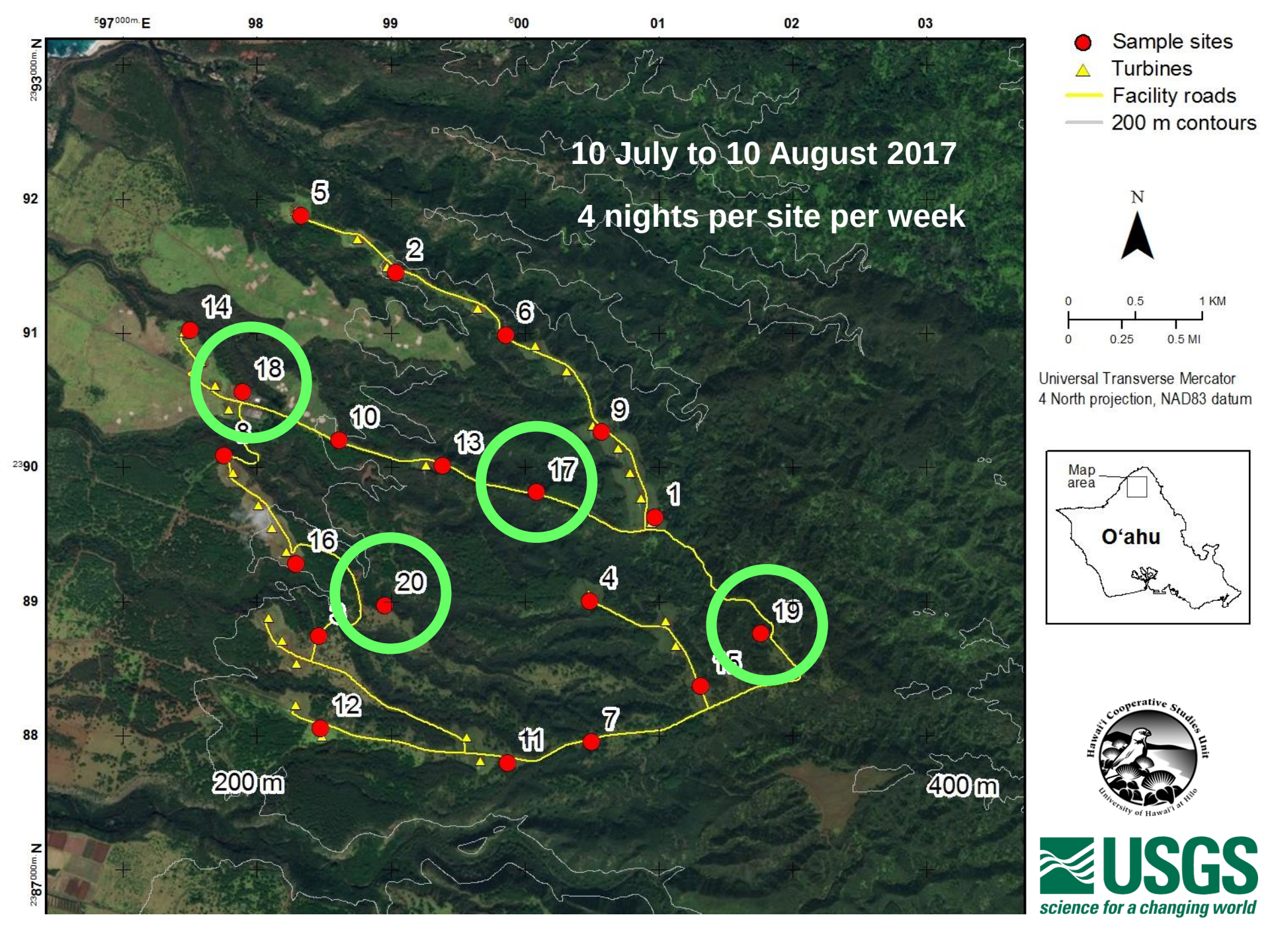
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Detection history of counts

	Acoustic–activity				Acoustic–feeding				Video–activity				Video–feeding			
	Night				Night				Night				Night			
Site	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	-	-	0	0	-	-	0	0	6	14	4	3	1	3	1	0
2	-	-	-	-	-	-	-	-	14	17	5	8	2	1	3	1
3	-	-	0	2	-	-	0	0	20	10	19	12	1	1	1	0
4	-	-	0	0	-	-	0	0	15	7	9	11	2	3	1	1
5	0	0	0	1	0	0	0	0	7	12	4	10	0	1	2	0
6	0	0	0	0	0	0	0	0	10	35	18	16	3	0	0	2
7	1	3	0	0	0	0	0	0	9	12	-	1	2	2	-	0
8	0	2	-	0	0	0	-	0	17	-	11	2	3	-	1	1
9	1	0	0	0	0	0	0	0	1	1	5	5	0	0	0	0
10	1	4	3	3	0	0	0	2	6	8	1	5	0	0	0	1
11	0	1	0	0	0	0	0	0	1	4	1	10	0	0	0	0
12	0	0	0	0	0	0	0	0	8	2	1	12	0	0	1	0
13	0	1	0	-	0	1	0	-	9	5	5	0	1	0	1	0
14	1	1	0	-	0	0	1	-	3	1	0	1	0	1	0	0
15	1	0	0	0	1	0	0	0	1	0	-	-	0	0	-	-
16	2	0	4	2	0	2	0	0	2	3	6	1	0	0	1	0
17	1	0	2	3	0	0	0	2	13	6	3	1	2	0	0	0
18	0	0	-	-	0	0	-	-	2	1	3	0	0	0	0	0
19	0	-	-	-	0	-	-	-	2	3	5	6	0	1	0	0
20	0	0	3	0	0	0	0	0	3	1	1	1	1	0	0	0

low high (>1) present , no buzz present, buzz

Detection history of counts

	Acoustic–activity				Acoustic–feeding				Video–activity				Video–feeding			
	Night				Night				Night				Night			
Site	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	-	-	0	0	-	-	0	0	6	14	4	3	1	3	1	0
2	-	-	-	-	-	-	-	-	14	17	5	8	2	1	3	1
3	-	-	0	2	-	-	0	0	20	10	19	12	1	1	1	0
4	-	-	0	0	-	-	0	0	15	7	9	11	2	3	1	1
5	0	0	0	1	0	0	0	0	7	12	4	10	0	1	2	0
6	0	0	0	0	0	0	0	0	10	35	18	16	3	0	0	2
7	1	3	0	0	0	0	0	0	9	12	-	1	2	2	-	0
8	0	2	-	0	0	0	-	0	17	-	11	2	3	-	1	1
9	1	0	0	0	0	0	0	0	1	1	5	5	0	0	0	0
10	1	4	3	3	0	0	0	2	6	8	1	5	0	0	0	1
11	0	1	0	0	0	0	0	0	1	4	1	10	0	0	0	0
12	0	0	0	0	0	0	0	0	8	2	1	12	0	0	1	0
13	0	1	0	-	0	1	0	-	9	5	5	0	1	0	1	0
14	1	1	0	-	0	0	1	-	3	1	0	1	0	1	0	0
15	1	0	0	0	1	0	0	0	1	0	-	-	0	0	-	-
16	2	0	4	2	0	2	0	0	2	3	6	1	0	0	1	0
17	1	0	2	3	0	0	0	2	13	6	3	1	2	0	0	0
18	0	0	-	-	0	0	-	-	2	1	3	0	0	0	0	0
19	0	-	-	-	0	-	-	-	2	3	5	6	0	1	0	0
20	0	0	3	0	0	0	0	0	3	1	1	1	1	0	0	0

low high (>5) present, no feed present, feeding

Detection history of counts

	Acoustic–activity				Acoustic–feeding				Video–activity				Video–feeding			
	Night				Night				Night				Night			
Site	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	-	-	0	0	-	-	0	0	6	14	4	3	1	3	1	0
2	-	-	-	-	-	-	-	-	14	17	5	8	2	1	3	1
3	-	-	0	2	-	-	0	0	20	10	19	12	1	1	1	0
4	-	-	0	0	-	-	0	0	15	7	9	11	2	3	1	1
5	0	0	0	1	0	0	0	0	7	12	4	10	0	1	2	0
6	0	0	0	0	0	0	0	0	10	35	18	16	3	0	0	2
7	1	3	0	0	0	0	0	0	9	12	-	1	2	2	-	0
8	0	2	-	0	0	0	-	0	17	-	11	2	3	-	1	1
9	1	0	0	0	0	0	0	0	1	1	5	5	0	0	0	0
10	1	4	3	3	0	0	0	2	6	8	1	5	0	0	0	1
11	0	1	0	0	0	0	0	0	1	4	1	10	0	0	0	0
12	0	0	0	0	0	0	0	0	8	2	1	12	0	0	1	0
13	0	1	0	-	0	1	0	-	9	5	5	0	1	0	1	0
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15	1	0	0	0	1	0	0	0	1	0	-	-	0	0	-	-
16	2	0	4	2	0	2	0	0	2	3	6	1	0	0	1	0
17	1	0	2	3	0	0	0	2	13	6	3	1	2	0	0	0
18	0	0	-	-	0	0	-	-	2	1	3	0	0	0	0	0
19	0	-	-	-	0	-	-	-	2	3	5	6	0	1	0	0
20	0	0	3	0	0	0	0	0	3	1	1	1	1	0	0	0

"absence"

Detection history of counts

	Acoustic–activity				Acoustic–feeding				Video–activity				Video–feeding			
	Night				Night				Night				Night			
Site	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	-	-	0	0	-	-	0	0	6	14	4	3	1	3	1	0
2	-	-	-	-	-	-	-	-	14	17	5	8	2	1	3	1
3	-	-	0	2	-	-	0	0	20	10	19	12	1	1	1	0
4	-	-	0	0	-	-	0	0	15	7	9	11	2	3	1	1
5	0	0	0	1	0	0	0	0	7	12	4	10	0	1	2	0
6	0	0	0	0	0	0	0	0	10	35	18	16	3	0	0	2
7	1	3	0	0	0	0	0	0	9	12	-	1	2	2	-	0
8	0	2	-	0	0	0	-	0	17	-	11	2	3	-	1	1
9	1	0	0	0	0	0	0	0	1	1	5	5	0	0	0	0
10	1	4	3	3	0	0	0	2	6	8	1	5	0	0	0	1
11	0	1	0	0	0	0	0	0	1	4	1	10	0	0	0	0
12	0	0	0	0	0	0	0	0	8	2	1	12	0	0	1	0
13	0	1	0	-	0	1	0	-	9	5	5	0	1	0	1	0
14	1	1	0	-	0	0	1	-	3	1	0	1	0	1	0	0
15	1	0	0	0	1	0	0	0	1	0	-	-	0	0	-	-
16	2	0	4	2	0	2	0	0	2	3	6	1	0	0	1	0
17	1	0	2	3	0	0	0	2	13	6	3	1	2	0	0	0
18	0	0	-	-	0	0	-	-	2	1	3	0	0	0	0	0
19	0	-	-	-	0	-	-	-	2	3	5	6	0	1	0	0
20	0	0	3	0	0	0	0	0	3	1	1	1	1	0	0	0

few feeding buzz detections

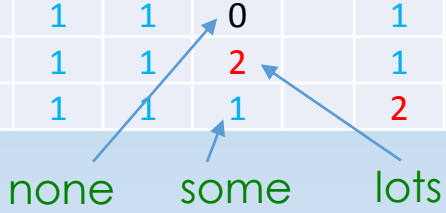
Detection history of counts

	Acoustic–activity				Acoustic–feeding				Video–activity				Video–feeding			
	Night				Night				Night				Night			
Site	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	-	-	0	0	-	-	0	0	6	14	4	3	1	3	1	0
2	-	-	-	-	-	-	-	-	14	17	5	8	2	1	3	1
3	-	-	0	2	-	-	0	0	20	10	19	12	1	1	1	0
4	-	-	0	0	-	-	0	0	15	7	9	11	2	3	1	1
5	0	0	0	1	0	0	0	0	7	12	4	10	0	1	2	0
6	0	0	0	0	0	0	0	0	10	35	18	16	3	0	0	2
7	1	3	0	0	0	0	0	0	9	12	-	1	2	2	-	0
8	0	2	-	0	0	0	-	0	17	-	11	2	3	-	1	1
9	1	0	0	0	0	0	0	0	1	1	5	5	0	0	0	0
10	1	4	3	3	0	0	0	2	6	8	1	5	0	0	0	1
11	0	1	0	0	0	0	0	0	1	4	1	10	0	0	0	0
12	0	0	0	0	0	0	0	0	8	2	1	12	0	0	1	0
13	0	1	0	-	0	1	0	-	9	5	5	0	1	0	1	0
14	1	1	0	-	0	0	1	-	3	1	0	1	0	1	0	0
15	1	0	0	0	1	0	0	0	1	0	-	-	0	0	-	-
16	2	0	4	2	0	2	0	0	2	3	6	1	0	0	1	0
17	1	0	2	3	0	0	0	2	13	6	3	1	2	0	0	0
18	0	0	-	-	0	0	-	-	2	1	3	0	0	0	0	0
19	0	-	-	-	0	-	-	-	2	3	5	6	0	1	0	0
20	0	0	3	0	0	0	0	0	3	1	1	1	1	0	0	0

"over-saturates" models?

States

	Acoustic–activity				Acoustic–feeding				Video–activity				Video–feeding			
	Night				Night				Night				Night			
Site	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	-	-	0	0	-	-	0	0	2	2	1	1	2	2	2	1
2	-	-	-	-	-	-	-	-	2	2	1	2	2	2	2	2
3	-	-	0	2	-	-	0	1	2	2	2	2	2	2	2	1
4	-	-	0	0	-	-	0	0	2	2	2	2	2	2	2	2
5	0	0	0	1	0	0	0	1	2	2	1	2	1	2	2	1
6	0	0	0	0	0	0	0	0	2	2	2	2	2	1	1	2
7	1	2	0	0	1	1	0	0	2	2	-	1	2	2	-	1
8	0	2	-	0	0	1	-	0	2	-	2	1	2	-	2	2
9	1	0	0	0	1	0	0	0	1	1	1	1	1	1	1	1
10	1	2	2	2	1	1	1	2	2	2	1	1	1	1	1	2
11	0	1	0	0	0	1	0	0	1	1	1	2	1	1	1	1
12	0	0	0	0	0	0	0	0	2	1	1	2	1	1	2	1
13	0	1	0	-	0	2	0	-	2	1	1	0	2	1	2	0
14	1	1	1	-	1	1	2	-	1	1	0	1	1	2	0	1
15	1	0	0	0	2	0	0	0	1	0	-	-	1	0	-	-
16	2	1	2	2	1	2	1	1	1	1	2	1	1	1	2	1
17	1	0	2	2	1	0	1	2	2	2	1	1	2	1	1	1
18	0	0	-	-	0	0	-	-	1	1	1	0	1	1	1	0
19	0	-	-	-	0	-	-	-	1	1	1	2	1	2	1	1
20	0	0	2	0	0	0	1	0	1	1	1	1	2	1	1	1



Null models

models without covariates

	Acoustic–activity		Acoustic–feeding		Video–activity		Video–feeding	
Parameter	Mean	SE	Mean	SE	Mean	SE	Mean	SE
$\hat{\psi}^1$	1.00	†	1.00	†	1.00	†	1.00	†
$\hat{\psi}^2$	0.48	0.161	0.48	0.205	0.78	0.103	0.89	0.108
$\hat{p}^1$	0.19	0.076	0.17	0.078	0.83	0.101	0.86	0.156
$\hat{p}^2$	0.52	0.116	0.70	0.273	0.98	0.021	0.96	0.028
$\hat{\delta}$	0.75	0.131	0.32	0.118	0.74	0.101	0.49	0.073

ψ^1 probability that bats were present at a site regardless of state

ψ^2 conditional probability that state 2 actually occurred given bat presence

p^1 probability of detecting the species in state 1 given its true state was 1

p^2 probability of detecting the species in state 2 given its true state was 2

δ probability of correctly identifying state 2 versus state 1 given detection of bat presence

Null models

full occupancy — bats detected at all sites

	Acoustic–activity		Acoustic–feeding		Video–activity		Video–feeding	
Parameter	Mean	SE	Mean	SE	Mean	SE	Mean	SE
$\hat{\psi}^1$	1.00	†	1.00	†	1.00	†	1.00	†
$\hat{\psi}^2$	0.48	0.161	0.48	0.205	0.78	0.103	0.89	0.108
$\hat{p}^1$	0.19	0.076	0.17	0.078	0.83	0.101	0.86	0.156
$\hat{p}^2$	0.52	0.116	0.70	0.273	0.98	0.021	0.96	0.028
$\hat{\delta}$	0.75	0.131	0.32	0.118	0.74	0.101	0.49	0.073

"oversatured"

ψ^1 probability that bats were present at a site regardless of state

ψ^2 conditional probability that state 2 actually occurred given bat presence

p^1 probability of detecting the species in state 1 given its true state was 1

p^2 probability of detecting the species in state 2 given its true state was 2

δ probability of correctly identifying state 2 versus state 1 given detection of bat presence

Null models

video samples → higher activity and feeding

	Acoustic–activity		Acoustic–feeding		Video–activity		Video–feeding	
Parameter	Mean	SE	Mean	SE	Mean	SE	Mean	SE
$\hat{\psi}^1$	1.00	†	1.00	†	1.00	†	1.00	†
$\hat{\psi}^2$	0.48	0.161	0.48	0.205	0.78	0.103	0.89	0.108
$\hat{p}^1$	0.19	0.076	0.17	0.078	0.83	0.101	0.86	0.156
$\hat{p}^2$	0.52	0.116	0.70	0.273	0.98	0.021	0.96	0.028
$\hat{\delta}$	0.75	0.131	0.32	0.118	0.74	0.101	0.49	0.073

based on median threshold

ψ^1 probability that bats were present at a site regardless of state

ψ^2 conditional probability that state 2 actually occurred given bat presence

p^1 probability of detecting the species in state 1 given its true state was 1

p^2 probability of detecting the species in state 2 given its true state was 2

δ probability of correctly identifying state 2 versus state 1 given detection of bat presence

Null models

video samples → higher detection probabilities

	Acoustic–activity		Acoustic–feeding		Video–activity		Video–feeding	
Parameter	Mean	SE	Mean	SE	Mean	SE	Mean	SE
$\hat{\psi}^1$	1.00	†	1.00	†	1.00	†	1.00	†
$\hat{\psi}^2$	0.48	0.161	0.48	0.205	0.78	0.103	0.89	0.108
$\hat{p}^1$	0.19	0.076	0.17	0.078	0.83	0.101	0.86	0.156
$\hat{p}^2$	0.52	0.116	0.70	0.273	0.98	0.021	0.96	0.028
$\hat{\delta}$	0.75	0.131	0.32	0.118	0.74	0.101	0.49	0.073

increase temporal spacing of samples?

ψ^1 probability that bats were present at a site regardless of state

ψ^2 conditional probability that state 2 actually occurred given bat presence

p^1 probability of detecting the species in state 1 given its true state was 1

p^2 probability of detecting the species in state 2 given its true state was 2

δ probability of correctly identifying state 2 versus state 1 given detection of bat presence

Null models

activity metrics → higher prob correct identification

	Acoustic–activity		Acoustic–feeding		Video–activity		Video–feeding	
Parameter	Mean	SE	Mean	SE	Mean	SE	Mean	SE
$\hat{\psi}^1$	1.00	†	1.00	†	1.00	†	1.00	†
$\hat{\psi}^2$	0.48	0.161	0.48	0.205	0.78	0.103	0.89	0.108
$\hat{p}^1$	0.19	0.076	0.17	0.078	0.83	0.101	0.86	0.156
$\hat{p}^2$	0.52	0.116	0.70	0.273	0.98	0.021	0.96	0.028
$\hat{\delta}$	0.75	0.131	0.32	0.118	0.74	0.101	0.49	0.073

reflects low counts

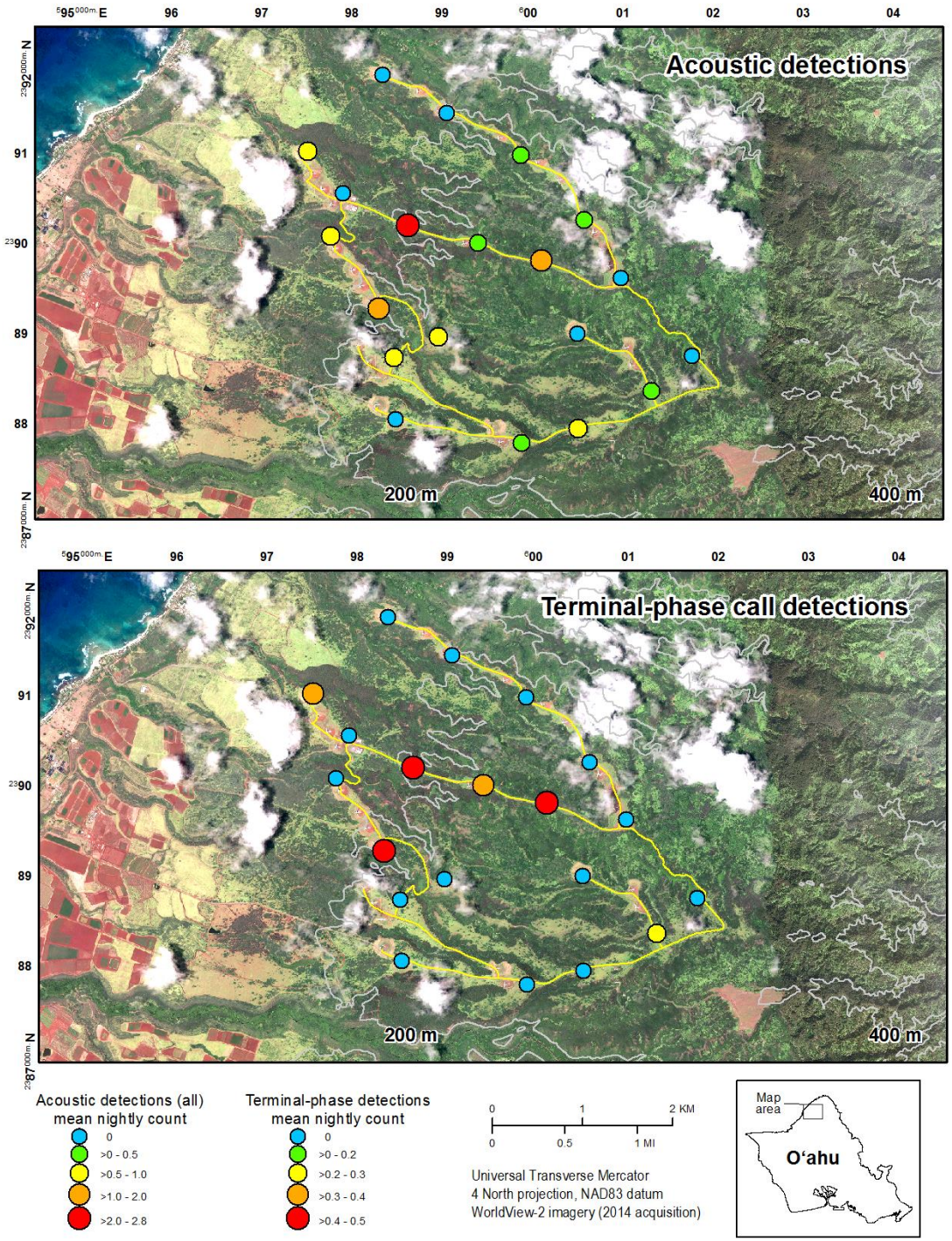
ψ^1 probability that bats were present at a site regardless of state

ψ^2 conditional probability that state 2 actually occurred given bat presence

p^1 probability of detecting the species in state 1 given its true state was 1

p^2 probability of detecting the species in state 2 given its true state was 2

δ probability of correctly identifying state 2 versus state 1 given detection of bat presence


595000m E
96
97
98
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2392000m N
91
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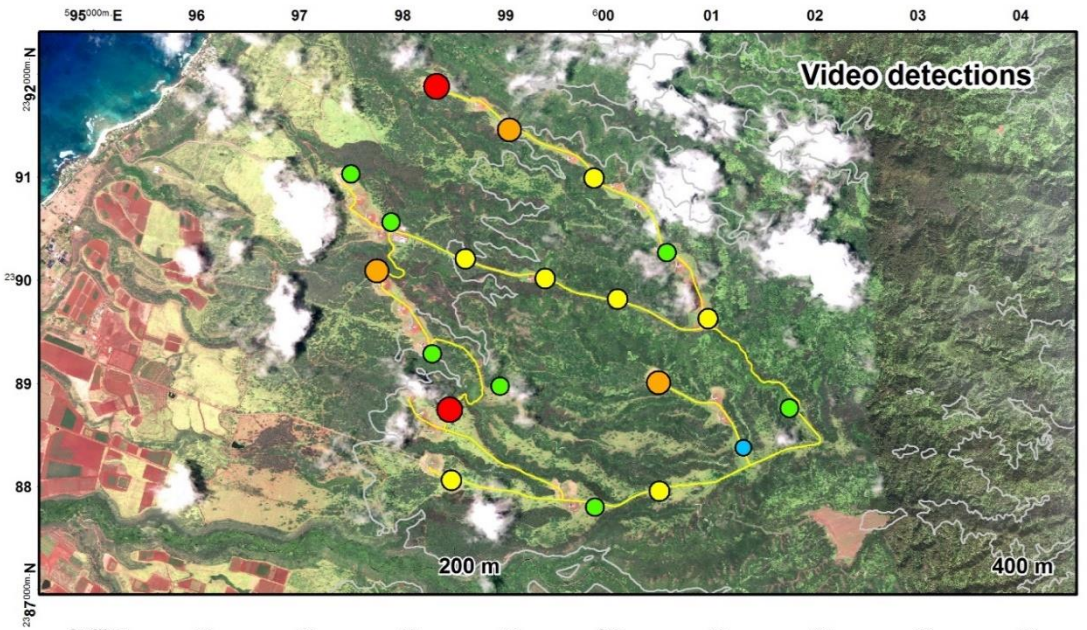
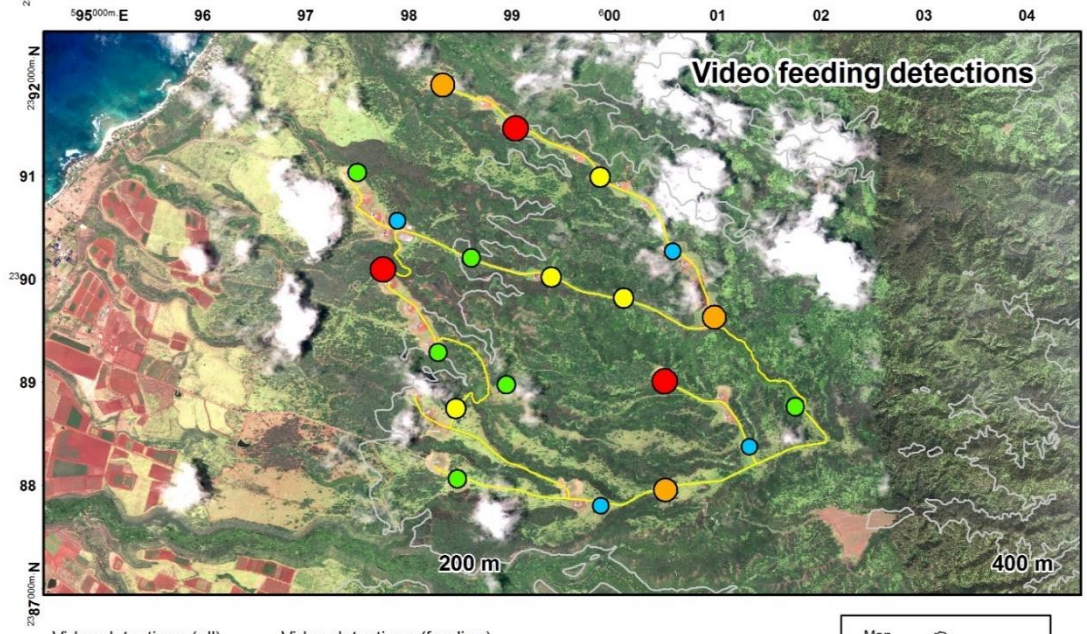
88
2387000m N
Acoustic detections
200 m
400 m
595000m E
96
97
98
99
600
01
02
03
04
2392000m N
91
2390
89
88
2387000m N
Terminal-phase call detections
200 m
400 m
Acoustic detections (all)
mean nightly count
0
>0 - 0.5
>0.5 - 1.0
>1.0 - 2.0
>2.0 - 2.8
Terminal-phase detections
mean nightly count
0
>0 - 0.2
>0.2 - 0.3
>0.3 - 0.4
>0.4 - 0.5
0
1
2 KM
0
0.5
1 MI
Universal Transverse Mercator
4 North projection, NAD83 datum
WorldView-2 imagery (2014 acquisition)
Map area
O‘ahu



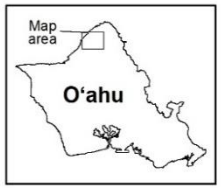


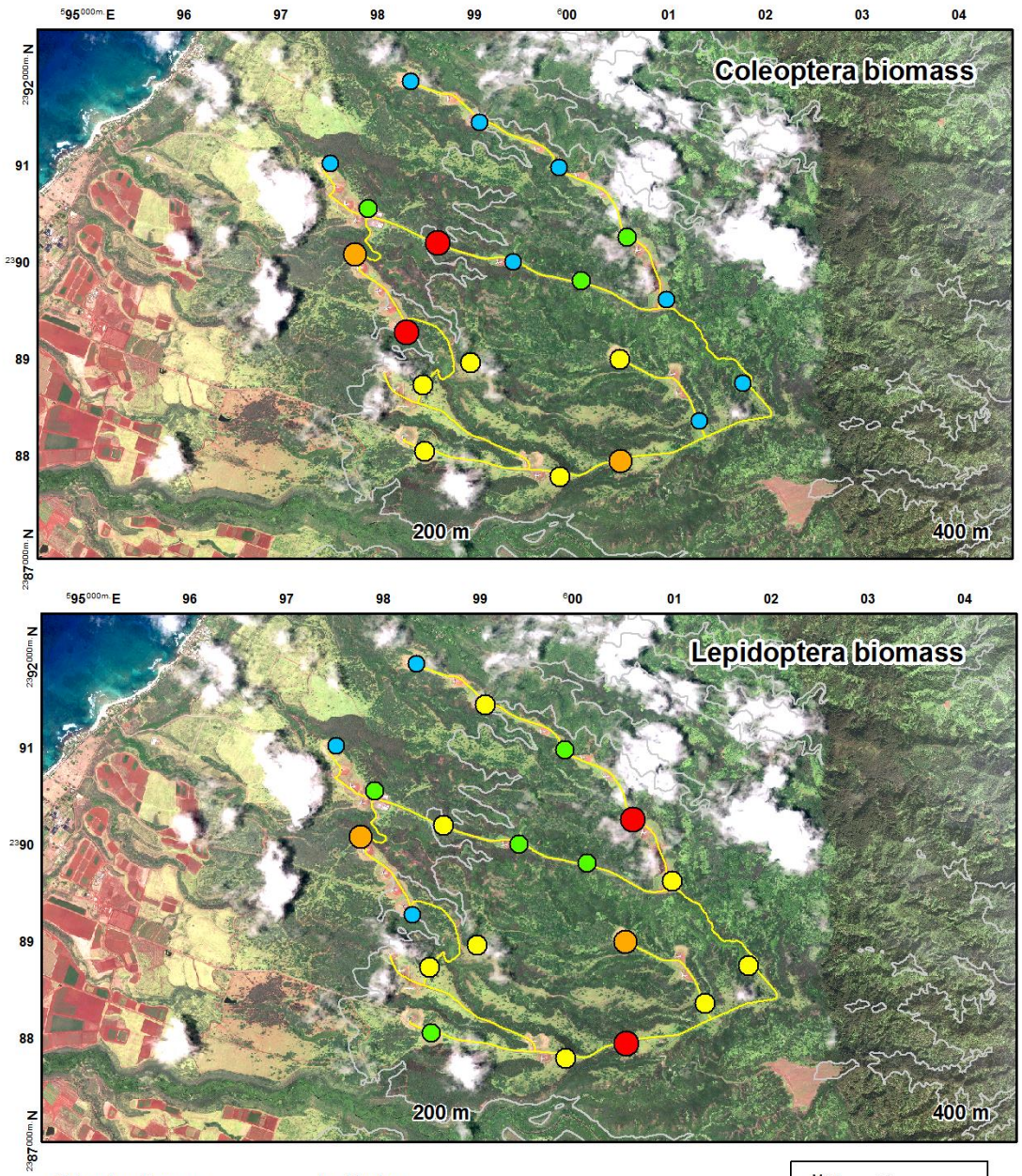
Video detections (all)
mean nightly count
- 0
- >0.5 - 5
- >5 - 10
- >10 - 15
- >15 - 21

Video detections (feeding)
mean nightly count
- 0
- >0 - 0.25
- >0.25 - 0.75
- >0.75 - 1.50
- >1.50 - 1.75

0 1 2 KM
0 0.5 1 MI

Universal Transverse Mercator
4 North projection, NAD83 datum
WorldView-2 imagery (2014 acquisition)




595000m E
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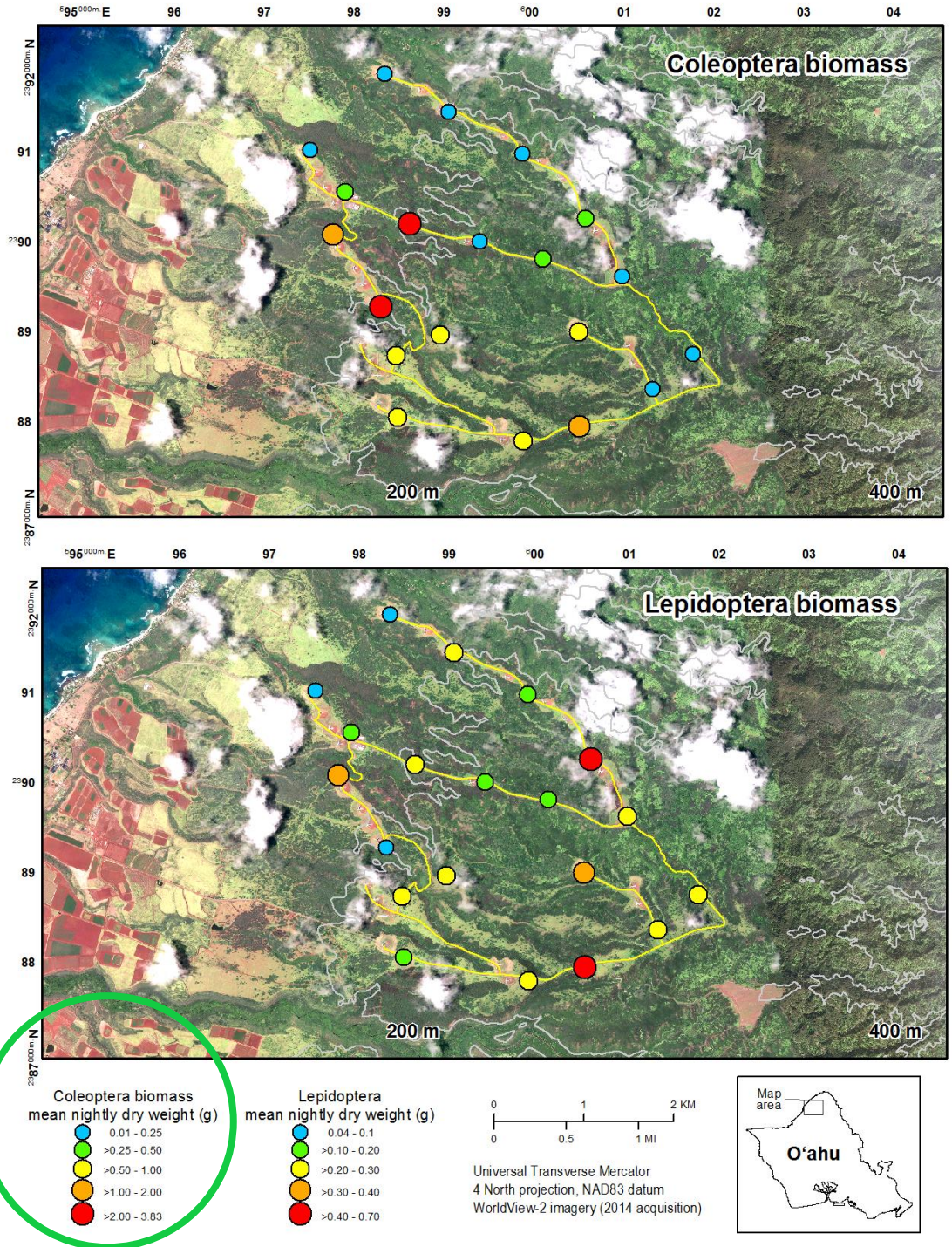
04
2392000m N
91
2390
89
88
2387000m N
Coleoptera biomass
200 m
400 m
595000m E
96
97
98
99
600
01
02
03
04
2392000m N
91
2390
89
88
2387000m N
Lepidoptera biomass
200 m
400 m
Coleoptera biomass
mean nightly dry weight (g)
0.01 - 0.25
>0.25 - 0.50
>0.50 - 1.00
>1.00 - 2.00
>2.00 - 3.83
Lepidoptera
mean nightly dry weight (g)
0.04 - 0.1
>0.10 - 0.20
>0.20 - 0.30
>0.30 - 0.40
>0.40 - 0.70
0
1
2 KM
0
0.5
1 MI
Universal Transverse Mercator
4 North projection, NAD83 datum
WorldView-2 imagery (2014 acquisition)
Map
area
O‘ahu


595000m E
96
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99
600
01
02
03
04
2392000m N
91
2390
89
88
2387000m N
Coleoptera biomass
200 m
400 m
Lepidoptera biomass
200 m
400 m
Coleoptera biomass
mean nightly dry weight (g)
0.01 - 0.25
>0.25 - 0.50
>0.50 - 1.00
>1.00 - 2.00
>2.00 - 3.83
Lepidoptera
mean nightly dry weight (g)
0.04 - 0.1
>0.10 - 0.20
>0.20 - 0.30
>0.30 - 0.40
>0.40 - 0.70
0
1
2 KM
0
0.5
1 MI
Universal Transverse Mercator
4 North projection, NAD83 datum
WorldView-2 imagery (2014 acquisition)
Map area
O‘ahu

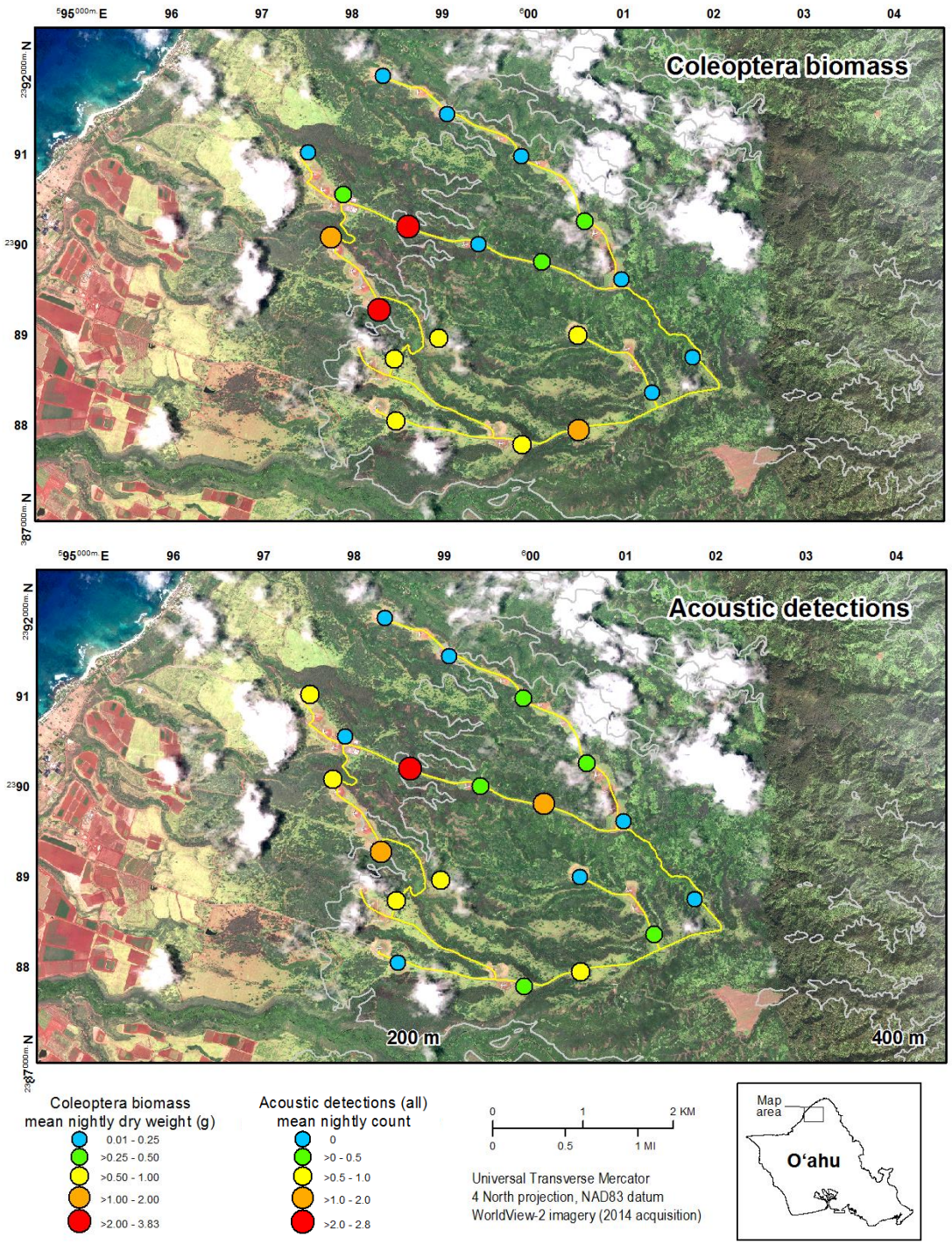
Prey base models

	$\psi^1(\cdot)\psi^2$(beetle)$p^1(\cdot)p^2(\cdot)\delta(\cdot)$		$\psi^1(\cdot)\psi^2$(insect)$p^1(\cdot)p^2(\cdot)\delta(\cdot)$		ψ^1(insect)ψ^2(beetle)$p^1(\cdot)p^2(\cdot)\delta(\cdot)$	
Parameter	Mean	SE	Mean	SE	Mean	SE
$\hat{\psi}^1$	1.00	†	1.00	†	1.00	†
$\hat{\psi}^2$	0.39	0.123	0.39	0.126	0.40	0.130
$\hat{p}^1$	0.20	0.069	0.20	0.068	0.22	0.078
$\hat{p}^2$	0.56	0.111	0.56	0.109	0.56	0.113
$\hat{\delta}$	0.79	0.107	0.79	0.107	0.79	0.107

top-ranked models → acoustic activity

beetles significantly associated with high acoustic activity

overall insect biomass also significant (beetle dominated)


595000m E
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3892000m N
91
3890
89
88
3887000m N
Coleoptera biomass
595000m E
96
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600
01
02
03
04
3892000m N
91
3890
89
88
3887000m N
Acoustic detections
200 m
400 m
Coleoptera biomass
mean nightly dry weight (g)
0.01 - 0.25
>0.25 - 0.50
>0.50 - 1.00
>1.00 - 2.00
>2.00 - 3.83
Acoustic detections (all)
mean nightly count
0
>0 - 0.5
>0.5 - 1.0
>1.0 - 2.0
>2.0 - 2.8
0
1
2 KM
0
0.5
1 MI
Universal Transverse Mercator
4 North projection, NAD83 datum
WorldView-2 imagery (2014 acquisition)
Map area
O'ahu

r = 0.78
p < 0.01

PLOS ONE

RESEARCH ARTICLE

Multi-state occupancy models of foraging habitat use by the Hawaiian hoary bat (*Lasiurus cinereus semotus*)

P. Marcos Gorresen[1]*, Kevin W. Brinck[1], Megan A. DeLisle[1], Kristina Montoya-Aiona[2], Corinna A. Pinzari[1], Frank J. Bonaccorso[2]

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OPEN ACCESS

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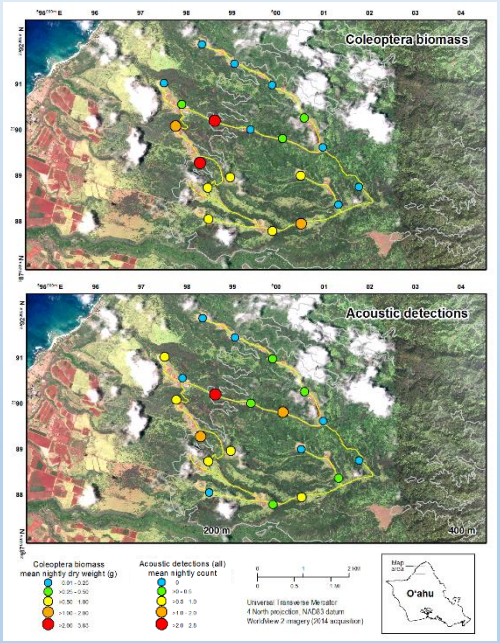
Abstract

Multi-state occupancy modeling can often improve assessments of habitat use and site quality when animal activity or behavior data are available. We examine the use of the approach for evaluating foraging habitat suitability of the endangered Hawaiian hoary bat (*Lasiurus cinereus semotus*) from classifications of site occupancy based on flight activity levels and feeding behavior. In addition, we used data from separate visual and auditory sources, namely thermal videography and acoustic (echolocation) detectors, jointly deployed at sample sites to compare the effectiveness of each method in the context of occupancy modeling. Video-derived observations demonstrated higher and more accurate estimates of the prevalence of high bat flight activity and feeding events than acoustic sampling methods. Elevated levels of acoustic activity by Hawaiian hoary bats were found to be related primarily to beetle biomass in this study. The approach may have a variety of applications in bat research, including inference about species-resource relationships, habitat quality and the extent to which species intensively use areas for activities such as foraging.

Multi-state occupancy modeling

- bat distribution
- activity & behavior → habitat use
- associations with habitat attributes

  and resources (prey availability)



- large-scale (landscape) applications
- baseline or post-management bat response
- mobile sampling equipment

Acknowledgements

Kawailoa Wind, LLC, for funding and access.

Tetra-tech for logistical support.

Ruth-Marie Stecker for many hours of insect sorting.

Modeling foraging habitat suitability of the Hawaiian hoary bat

Hawaiian hoary bat conservation genetics

Hawaiian hoary bat conservation biology: movements, roosting behavior, and diet

Auwahi Wind Power bat research at Waihou Mitigation Area

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Hawaiian hoary bat conservation genetics

Bat tissue sampling for sex genotyping, genomic analyses

- Ongoing
  - 260 samples (2005 – present) including representatives from Hawaii, Maui, Oahu, and Kauai
    - 72 samples from wind facilities statewide

- Increase geographic coverage (planned)
  - Kauai – mist netting trip fall 2019
  - Maui – augmented samples from Auwahi Tier 2 bat research project (11) with samples from HT Harvey Maui bat research (20)
  - Molokai/Lanai – historic museum sampling late 2019, using DNA from teeth

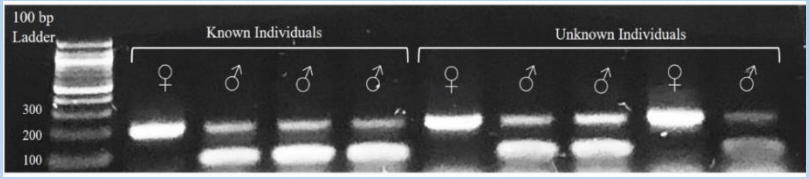
- Mitochondrial DNA sequencing of pop structure
  - 140 bats completed, ~45 in progress

Hawaiian hoary bat conservation genetics

Sex Genotyping

- "A test of sex specific genetic markers in the Hawaiian hoary bat and relevance to population studies" Pinzari & Bonaccorso, 2018 Technical Report HCSU-TR085
- USGS Data Release

  https://doi.org/10.5066/P9R7L1NS



Hawaiian hoary bat conservation genetics

Genomic analysis - single nucleotide polymorphisms (SNPs)

- Genomic diversity, population structure, effective population size, colonization timing, gene signatures of selection
  - 23 bats
  - draft ms
- Next: 24 additional Hawaiian + 10 North American hoary bats
  - Species level genetic differences, bottlenecks, divergence, inter-island migration
  - Reference genome
- SNPs will generate suite of HHB specific microsatellite markers
  - Subpopulation structure, effective population estimates on larger number of samples

Modeling foraging habitat suitability of the Hawaiian hoary bat

Hawaiian hoary bat conservation genetics

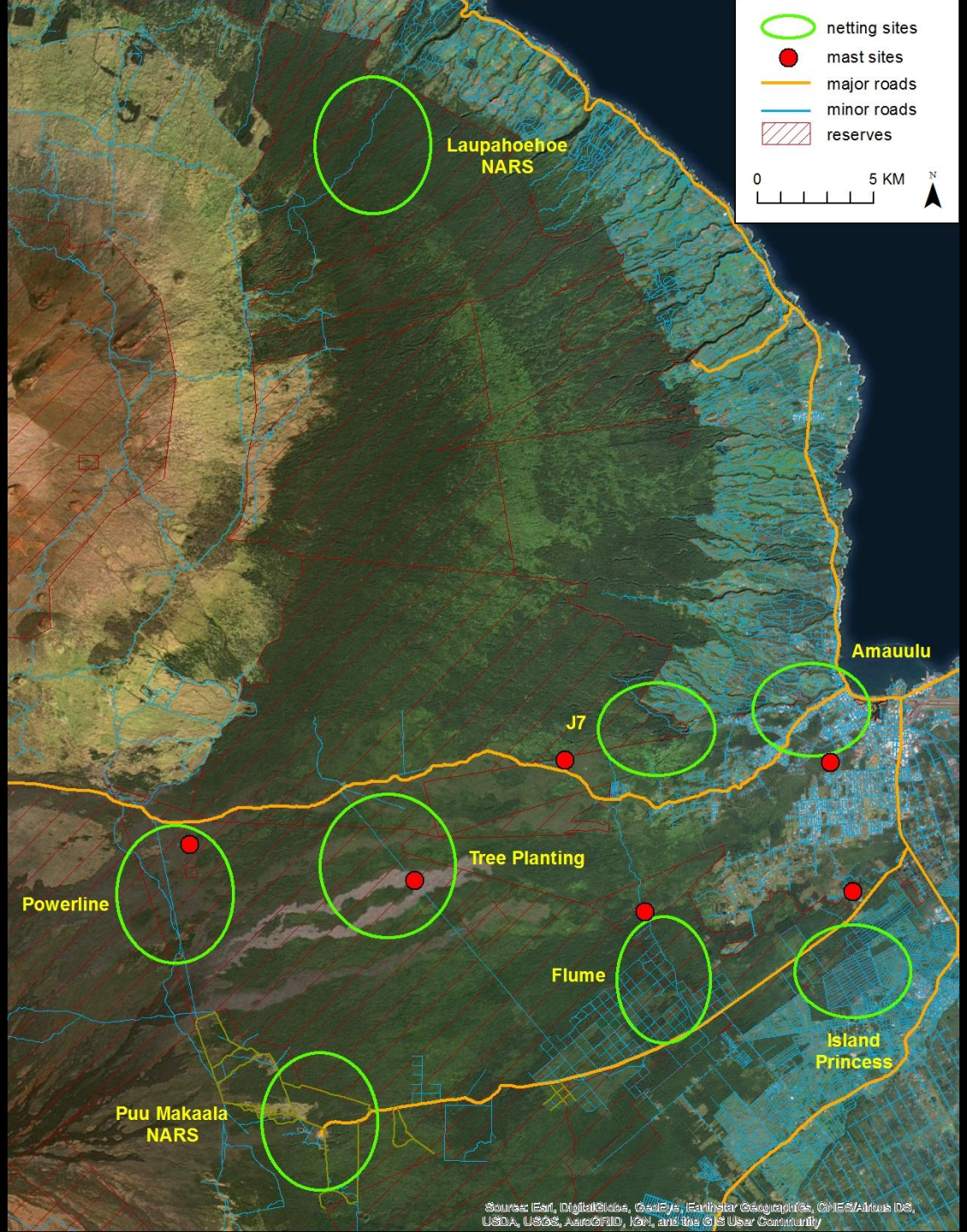
Hawaiian hoary bat conservation biology: movements, roosting behavior, and diet

Auwahi Wind Power bat research at Waihou Mitigation Area

Hawaiian hoary bat conservation biology: movements, roosting behavior, and diet

Objectives

- Home range – scale of movement
- Habitat use – foraging, roosting, and breeding
- Roost fidelity and roost tree characteristics
- Mother-pup behavior at roosts
- Movement patterns and food availability
- Insect prey-host plant associations
- Diet analysis – insect prey selection and availability using molecular bar-coding techniques
- Tissue collection – genetic, diet and pesticide studies


netting sites
mast sites
major roads
minor roads
reserves
0
5 KM
N
Laupahoehoe NARS
Amauulu
J7
Tree Planting
Powerline
Flume
Island Princess
Puu Makaala NARS
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Hawaiian hoary bat conservation biology: movements, roosting behavior, and diet

17 bat captures (May 2018 to present)

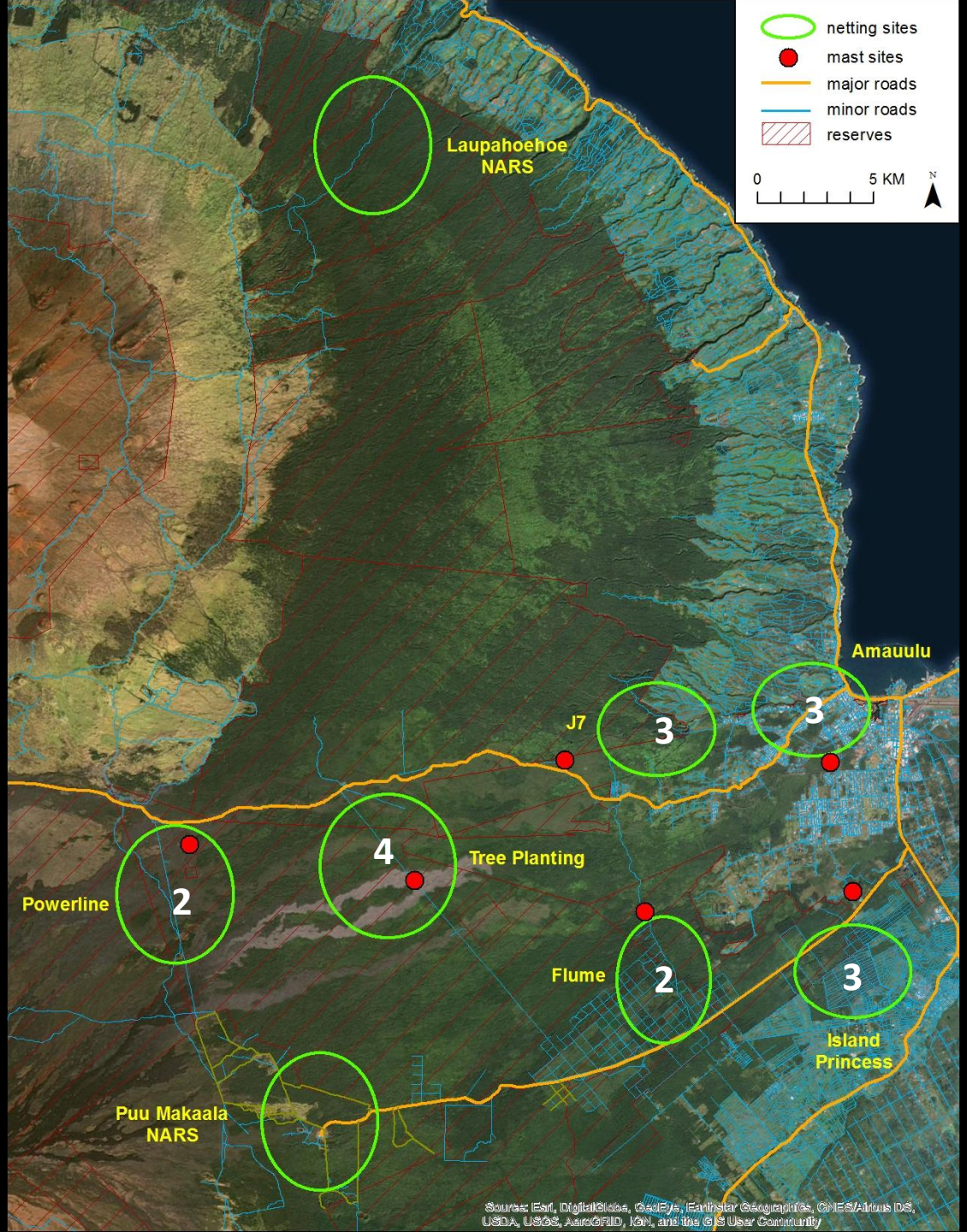
- 4 adult females, post-lactating or not visibly pregnant
- 13 adult males, testes not enlarged

Roosts located to

- individual trees for 5 bats
- stand-level only for 5 bats

Fecal pellets collected for diet study

- 11 bats
- other samples – hair, wing biopsy


netting sites
mast sites
major roads
minor roads
reserves
0
5 KM
N
Laupahoehoe NARS
Amauulu
J7
3
3
4
Tree Planting
Powerline
2
Flume
2
3
Island Princess
Puu Makaala NARS
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Hawaiian hoary bat conservation biology: movements, roosting behavior, and diet

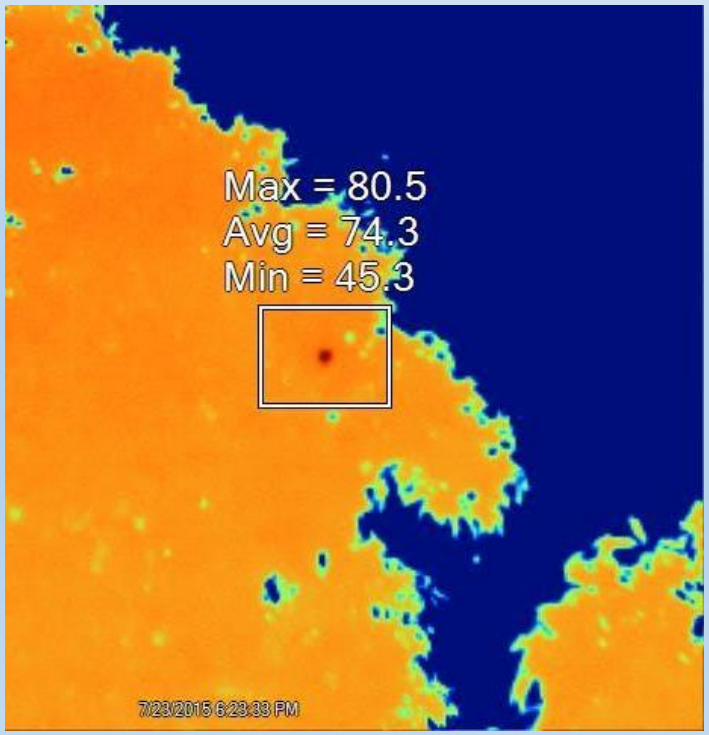
Insect reference library

- diversity, relative abundance of prey available to bats
- subset of samples preserved for barcoding and matching to DNA sequenced from bat fecal samples
- collect insects from plants

Hawaiian hoary bat conservation biology: movements, roosting behavior, and diet

Roost attributes ⟶ tree and stand-level

- tree species
- tree and roost height
- tree diameter
- canopy cover
- canopy volume
- basal area
- stand age
- density
- aspect



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Auwahi Wind Power bat research at Waihou Mitigation Area

Auwahi Wind Power bat research at Waihou Mitigation Area

Objectives

- Determine bat core area size and composition on Maui using radio telemetry
- Evaluate bat seasonal use and activity patterns over time in the vicinity of the Waihou mitigation area using acoustic monitoring and radio telemetry.
- Assess insect prey base in the vicinity of the Waihou mitigation area during the season of peak bat activity.
- Determine prey ingestion by bats in the Waihou mitigation area while activity patterns are tracked.

Auwahi Wind Power bat research at Waihou Mitigation Area

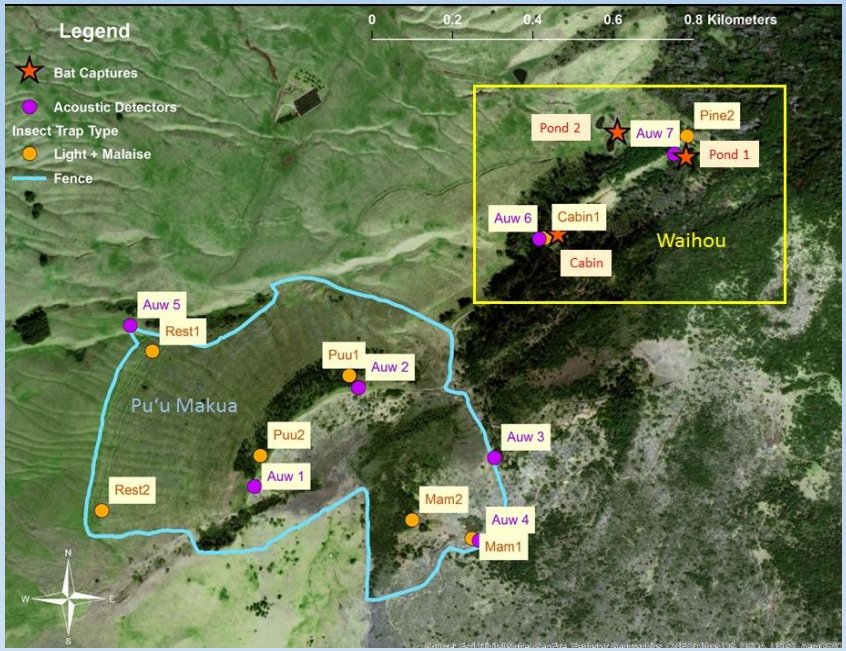
Objectives

- Determine bat core area size and composition on Maui using radio telemetry
- Evaluate bat seasonal use and activity patterns over time in the vicinity of the Waihou mitigation area using acoustic monitoring and radio telemetry.
- Assess insect prey base in the vicinity of the Waihou mitigation area during the season of peak bat activity.
- Determine prey ingestion by bats in the Waihou mitigation area while activity patterns are tracked.
- Increase bat capture effort for genetic and fecal sampling.
- Add 2nd season insect sampling; include Duck Pond area.
- Increase number insect prey species to be bar-coded.

Auwahi Wind Power bat research at Waihou Mitigation Area

Technical Report in progress

- Acoustic data (2015-2018)
  - 7 stations Waihou, 3 stations Auwahi wind farm area
- Bat captures in Waihou
  - November 2016 – 3 bats (males)
  - June 2017 – 8 bats (5 males, 3 females; 2 pregnant, 1 lactating)



Auwahi Wind Power bat research at Waihou Mitigation Area

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  - November 2016 – 3 bats (males)
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- Diet composition (insect order, family, some genus- and species-level identifications made) ~ 39 taxa identified
  - 7 guano samples from Waihou area
  - 1 guano sample from carcass found at Auwahi turbine 2 on August 2016 (female)
- Prey availability – two seasons of insect collection
- Waihou barcode reference library
  - ~ 57 unique taxa