DIVING BEHAVIOR OF CUVIER'S BEAKED WHALES (*ZIPHIUS CAVIROSTRIS*) OFF CAPE HATTERAS, NORTH CAROLINA

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ROBIN BAIRD[2], DANIEL WEBSTER[2], NICOLA QUICK[1],

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CUVIER'S BEAKED WHALE

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FIVE CUVIER'S BEAKED WHALES STRAND DURING MILITARY EXERCISE OFF CRETE – HOW MANY MORE TIMES?

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Blue and beaked whales affected by simulated navy sonar

By Victoria Gill
Science reporter, BBC News

3 July 2013 Science & Environment

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Sound effect. The Navy admits that sonar caused this beaked whale to strand in the Bahamas.

Navy Admits Sonar Killed Whales

By David Malakoff | Jan. 7, 2002 , 12:00 AM

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U.S. Navy Implicated in New Mass Stranding of Whales

April 02, 2014 Michael Jasny

BEHAVIORAL RESPONSE STUDIES

biology letters

Conservation biology

First direct measurements of behavioural responses by Cuvier's beaked whales to mid-frequency active sonar

Stacy L. DeRuiter[1], Brandon L. Southall[3,4,5], John Calambok
M. X. Zimmer[7], Dinara Sadykova[1], Erin A. Falcone[6], Ari S. F
John E. Joseph[8], David Moretti[9,2], Gregory S. Schorr[6], Len T
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Most marine mammal strandings coincident with naval sona

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Beaked Whales Respond to Simulated and Actual Navy Sonar

Peter L. Tyack[1]*, Walter M. X. Zimmer[2], David Moretti[3], Brandon L. Southall[4,5], Diane E. Claridge[6], John W. Durban[7], Christopher W. Clark[8], Angela D'Amico[9], Nancy DiMarzio[3], Susan Jarvis[3], Elena McCarthy[3], Ronald Morrissey[3], Jessica Ward[3], Ian L. Boyd[10]

1 Biology Department, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, United States of America, 2 North Atlantic Treaty Organisation Undersea Research Centre, La Spezia, Italy, 3 Naval Undersea Warfare Center Division, Newport, Rhode Island, United States of America, 4 Southall Environmental Associates, Aptos, California, United States of America, 5 Long Marine Laboratory, University of California Santa Cruz, Santa Cruz, California, United States of America, 6 Bahamas Marine Mammal Research Organisation, Marsh Harbour, Abaco, Bahamas, 7 Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, California, United States of America, 8 Bioacoustics Research Program, Cornell Lab of Ornithology, Cornell University, Ithaca, New York, United States of America, 9 Space and Naval Warfare Systems Center Pacific, San Diego, California, United States of America, 10 Sea Mammal Research Unit, Scottish Oceans Institute, University of St. Andrews, Fife, Scotland, United Kingdom

Abstract

Beaked whales have mass stranded during some naval sonar exercises, but the cause is unknown. They are difficult to sight but can reliably be detected by listening for echolocation clicks produced during deep foraging dives. Listening for these clicks, we documented Blainville's beaked whales, *Mesoplodon densirostris*, in a naval underwater range where sonars are in regular use near Andros Island, Bahamas. An array of bottom-mounted hydrophones can detect beaked whales when they click anywhere within the range. We used two complementary methods to investigate behavioral responses of beaked

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A Risk Function for Behavioral Disruption of Blainville's Beaked Whales (*Mesoplodon densirostris*) from Mid-Frequency Active Sonar

David Moretti[1]*, Len Thomas[2], Tiago Marques[2], John Harwood[2], Ashley Dilley[1], Bert Neales[1], Jessica Shaffer[1], Elena McCarthy[1], Leslie New[3], Susan Jarvis[1], Ronald Morrissey[1]

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Abstract

There is increasing concern about the potential effects of noise pollution on marine life in the world's oceans. For marine mammals, anthropogenic sounds may cause behavioral disruption, and this can be quantified using a risk function that relates sound exposure to a measured behavioral response. Beaked whales are a taxon of deep diving whales that may be particularly susceptible to naval sonar as the species has been associated with sonar-related mass stranding events. Here we derive the first empirical risk function for Blainville's beaked whales (*Mesoplodon densirostris*) by combining *in situ* data from passive acoustic monitoring of animal vocalizations and navy sonar operations with precise ship tracks and sound field modeling. The hydrophone array at the Atlantic Undersea Test and Evaluation Center, Bahamas, was used to locate

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SUBJECT AREAS:
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Correspondence and requests for materials should be addressed to A.K.S. (astimpert@mlml.calstate.edu)

Acoustic and foraging behavior of a Baird's beaked whale, *Berardius bairdii*, exposed to simulated sonar

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[1]Department of Oceanography, Naval Postgraduate School, Monterey, CA, [2]Vertebrate Ecology Lab, Moss Landing Marine Laboratories, Moss Landing, CA, [3]Centre for Research into Ecological and Environmental Modeling, University of St. Andrews, St. Andrews, UK, [4]Southall Environmental Associates, Inc., Aptos, CA, [5]Naval Undersea Warfare Center, Newport, RI, [6]Cascadia Research Collective, Olympia, WA, [7]Department of Biology, Hopkins Marine Station, Stanford University, Pacific Grove, CA, [8]Sea and Marine Mammal Institute, Hatfield Marine Science Center, Oregon State University, Newport, OR.

Beaked whales are hypothesized to be particularly sensitive to anthropogenic noise, based on previous strandings and limited experimental and observational data. However, few species have been studied in detail. We describe the underwater behavior of a Baird's beaked whale (*Berardius bairdii*) from the first deployment of a multi-sensor acoustic tag on this species. The animal exhibited shallow (23 ± 15 m max depth), intermediate (324 ± 49 m), and deep (1138 ± 243 m) dives. Echolocation clicks were produced with a mean inter-click interval of approximately 300 ms and peak frequency of 25 kHz. Two deep dives included presumed foraging behavior, with echolocation pulsed sounds (presumed prey capture attempts) associated with increased maneuvering, and sustained inverted swimming during the bottom phase of the dive. A controlled exposure to simulated mid-frequency active sonar (3.5–4 kHz) was conducted 4 hours after tag deployment, and within 3 minutes of exposure onset, the tagged whale increased swim speed and body movement, and continued to show unusual dive behavior for each of its next three dives, one of each type. These are the first data on the acoustic foraging behavior in this largest beaked whale species, and the first experimental demonstration of a response to simulated sonar.

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ENDANGERED SPECIES RESEARCH
Endang Species Res

Published December 6

Contribution to the Theme Section '21st century paradigms for measuring and managing the effects of anthropogenic ocean noise'

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REVIEW

Experimental field studies to measure behavioral responses of cetaceans to sonar

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Accepted: 8 May 2015

Subject Category:
Biology (whole organism)

First indications that northern bottlenose whales are sensitive to behavioural disturbance from anthropogenic noise

P. J. O. Miller[1], P. H. Kvadsheim[2], F. P. A. Lam[3], P. L. Tyack[1], C. Curé[4], S. L. DeRuiter[5], L. Kleivane[2], L. D. Sivle[6], S. P. van IJsselmuide[3], F. Visser[7,8], P. J. Wensveen[1], A. M. von Benda-Beckmann[3], L. M. Martín López[1], T. Narazaki[1] and S. K. Hooker[1]

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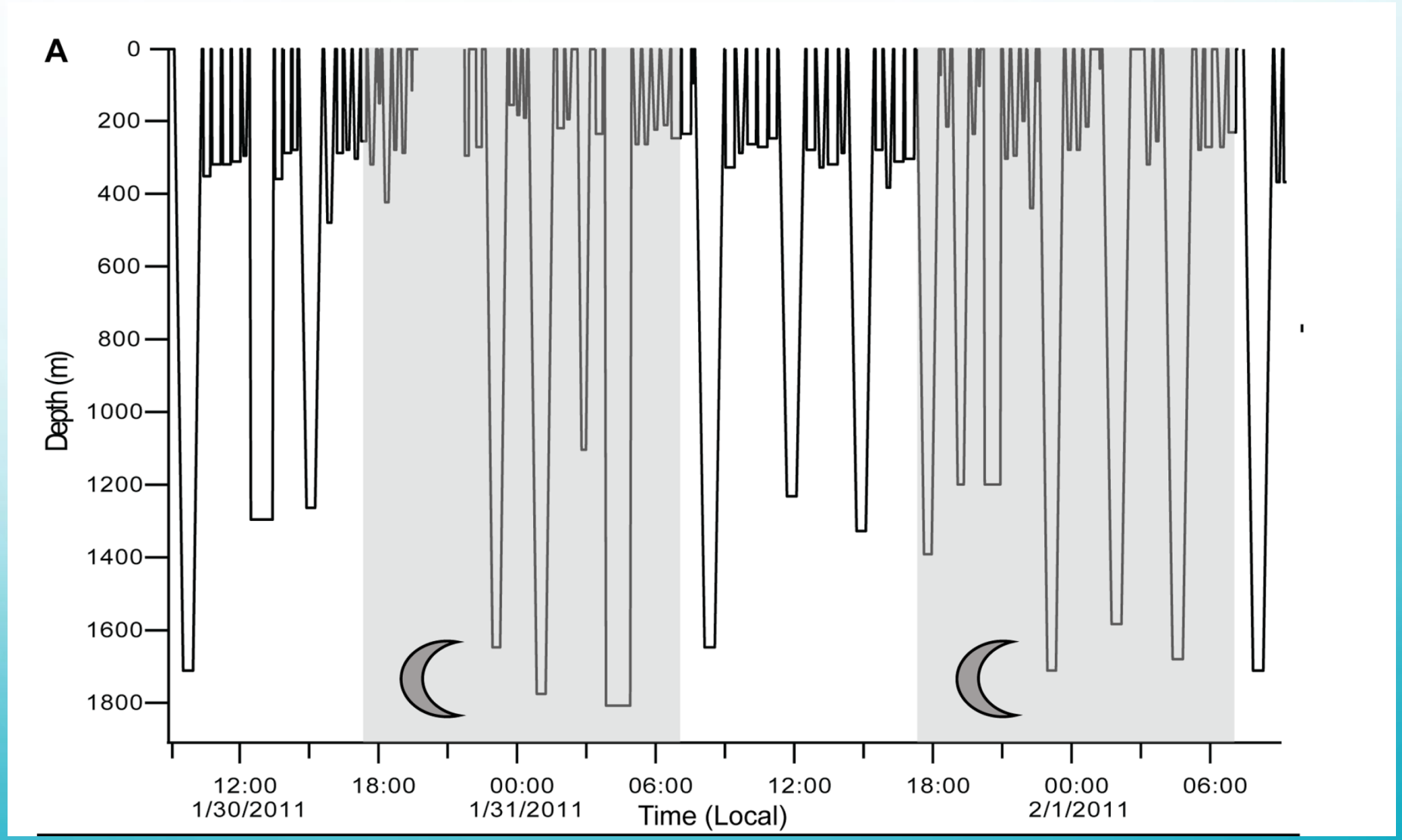
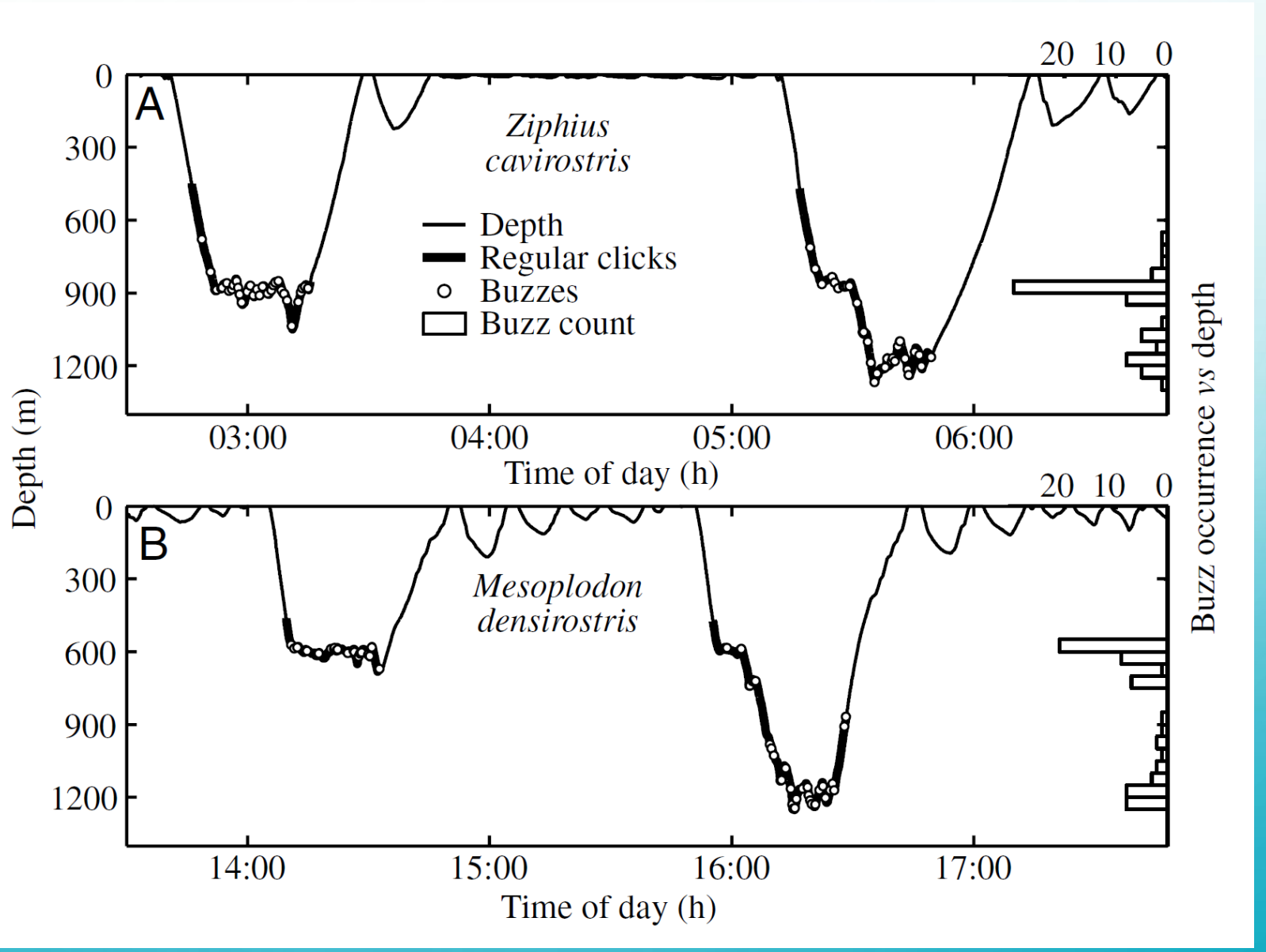
BEAKED WHALE BEHAVIOR



Schorr et al. 2014

BEAKED WHALE BEHAVIOR



Tyack et al. 2006

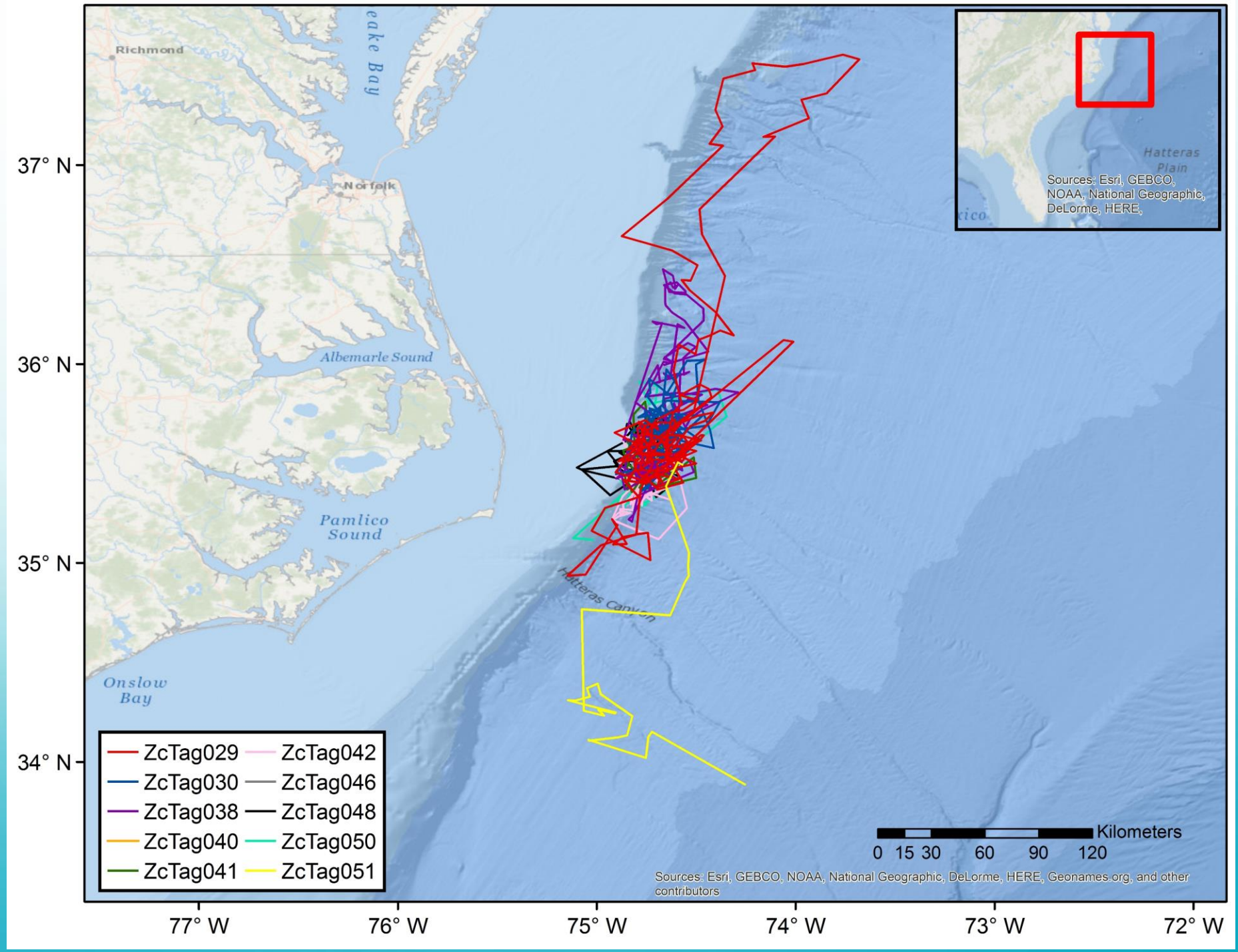

Richmond
Norfolk
Albemarle Sound
Pamlico Sound
Onslow Bay
Hatteras Canyon
Hatteras Plain
Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE,
37° N
36° N
35° N
34° N
77° W
76° W
75° W
74° W
73° W
72° W
ZcTag029
ZcTag030
ZcTag038
ZcTag040
ZcTag041
ZcTag042
ZcTag046
ZcTag048
ZcTag050
ZcTag051
Kilometers
0 15 30 60 90 120
Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Table 2. Summary of beaked whale detections in the continuous acoustic datasets analyzed. Mean number of detections per day was calculated across all *n* days with at least one detection. The number of detected events per day and the detection duration are reported as the mean ± standard deviation.

Site	Species	# of days detected (*n*)	% of days detected	Mean # of detections/day	Mean detection duration (min)
Cape Hatteras (*N = 289 days*)	*Z. cavirostris*	272	94	11.8 (±7.3)	7.3 (±7.5)
	M. europaeus	120	42	3.3 (±2.8)	5.5 (±5.5)
	M. densirostris	4	1	1.8 (±0.5)	3.2 (±3.0)
Norfolk Canyon (*N = 289 days*)	*Z. cavirostris*	59	20	2.0 (±1.5)	7.6 (±6.5)
	M. europaeus	43	15	1.9 (±1.1)	6.0 (±5.0)
	M. bidens	103	36	1.9 (±1.3)	4.7 (±3.8)
The Gully (*N = 8 days*)	*H. ampullatus*	6	75	7.0 (±2.3)	22.3 (±17.9)
	M. bidens	7	88	3.0 (±2.2)	6.6 (±3.7)

Stanistreet et al. 2016

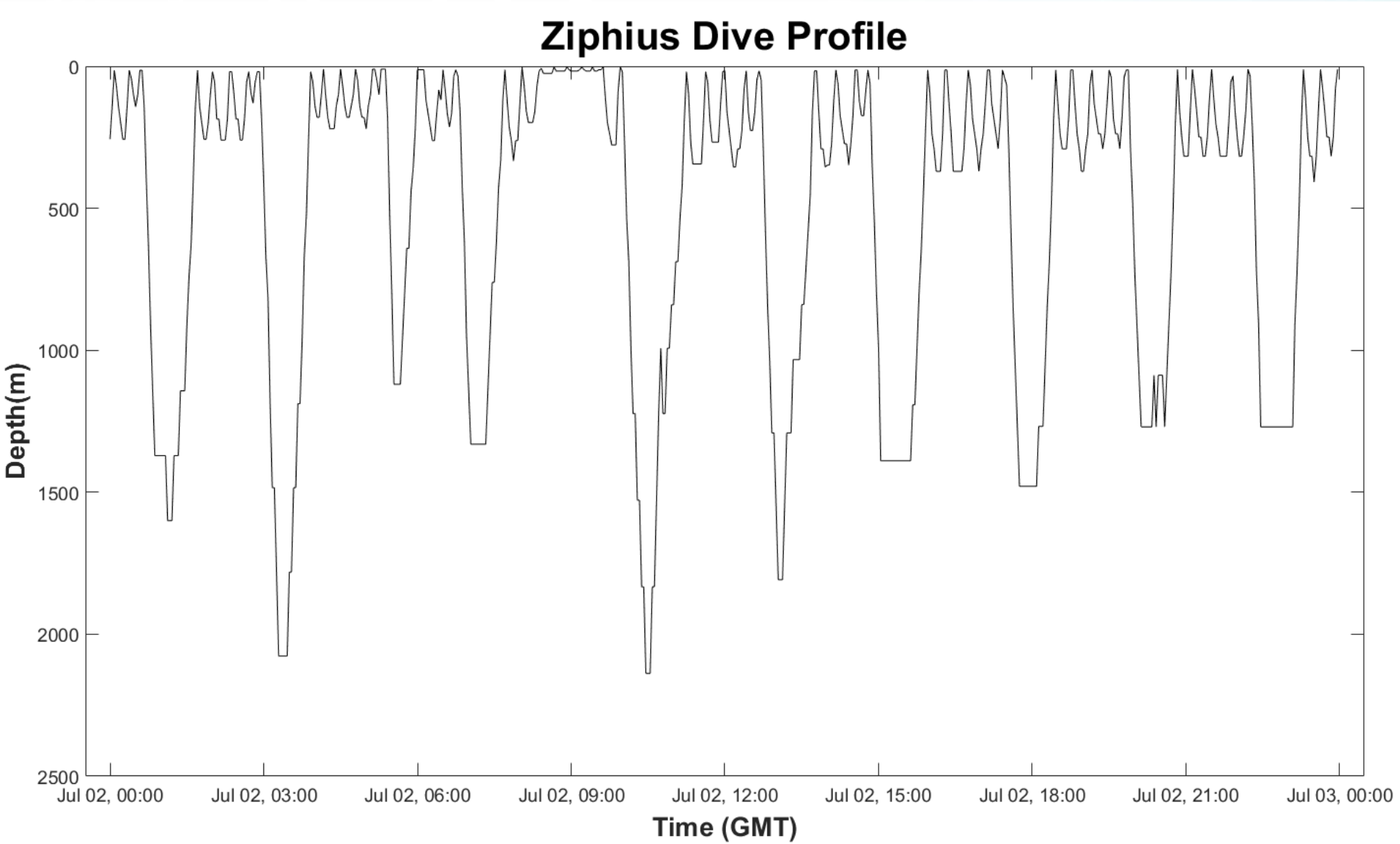
WILDLIFE COMPUTERS LIMPET TAGS

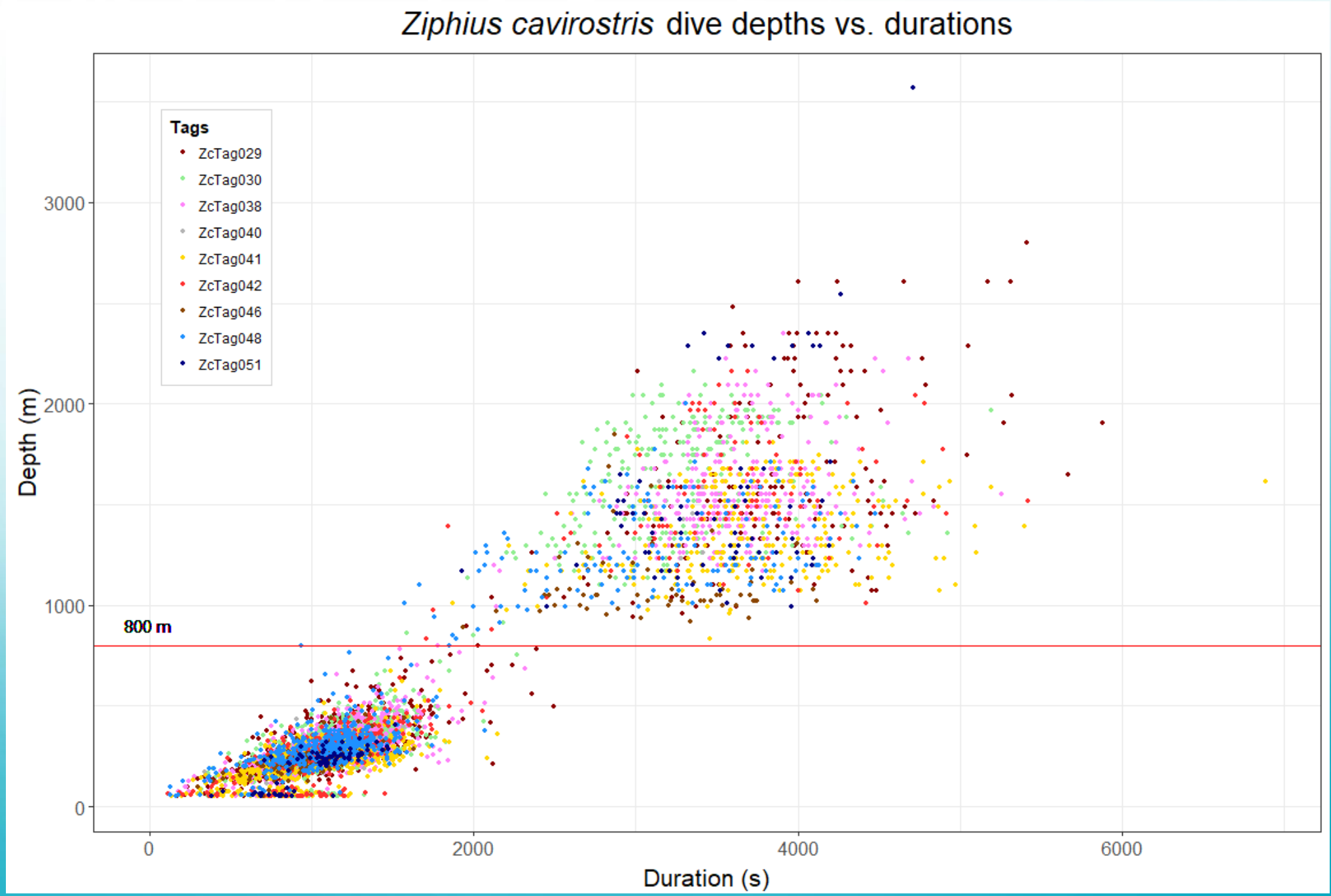
- Depth (1 Hz)
- Location

WILDLIFE COMPUTERS

DATA COLLECTION

Tag ID	Date Tagged	Data Duration (days)	Age/Sex	Number of Deep Dives
ZcTag029	05/13/2014	60	Unknown	157
ZcTag030	09/16/2014	39	Adult Male	260
ZcTag038	06/14/2015	57	Adult Male	324
ZcTga040	06/14/2015	1	Adult Male	9
ZcTag041	10/15/2015	33	Probable Adult Male	274
ZcTag042	10/21/2015	18	Adult Male	98
ZcTag046	05/25/2016	10	Adult Male	59
ZcTag048	05/27/2016	31	Unknown	144
ZcTag050	08/20/2016	25	Probable Adult Female	17
ZcTag051	08/21/2016	10	Adult Male	67

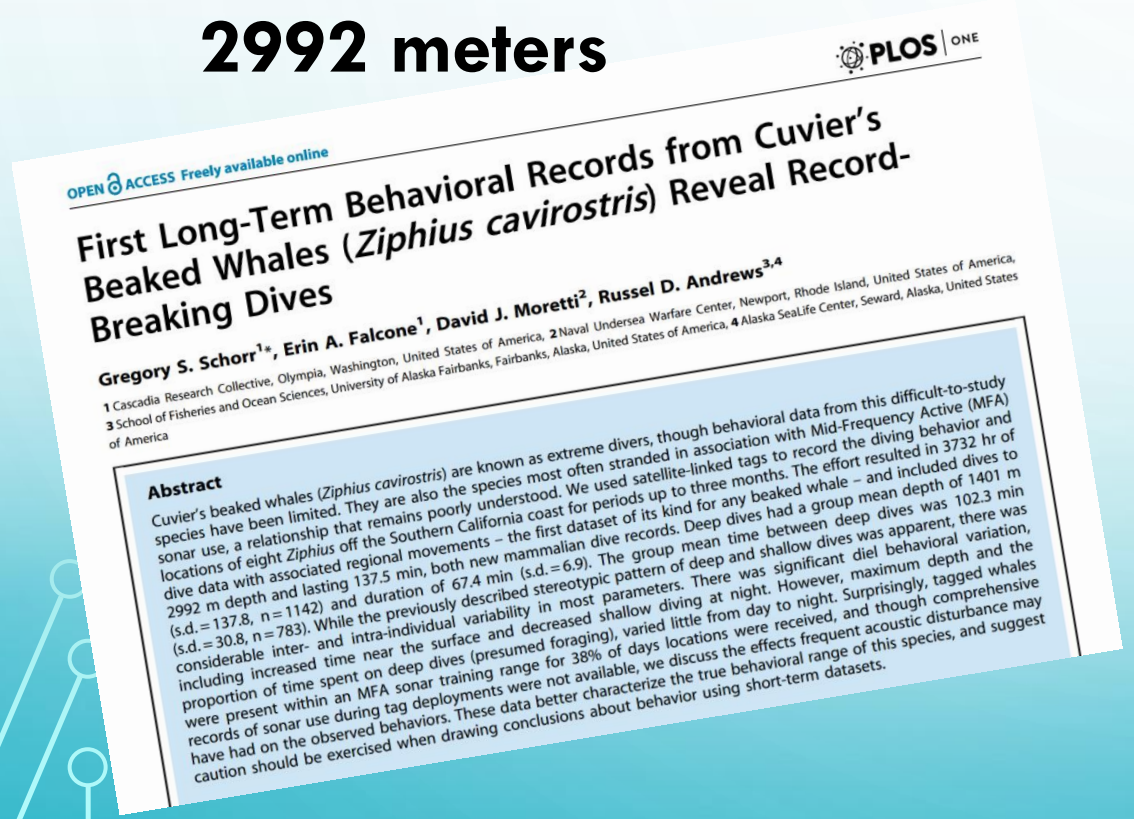

Ziphius Dive Profile
Depth(m)
0
500
1000
1500
2000
2500
Jul 02, 00:00
Jul 02, 03:00
Jul 02, 06:00
Jul 02, 09:00
Jul 02, 12:00
Jul 02, 15:00
Jul 02, 18:00
Jul 02, 21:00
Jul 03, 00:00
Time (GMT)


Ziphius cavirostris dive depths vs. durations
Tags
ZcTag029
ZcTag030
ZcTag038
ZcTag040
ZcTag041
ZcTag042
ZcTag046
ZcTag048
ZcTag051
800 m
Depth (m)
0
1000
2000
3000
Duration (s)
0
2000
4000
6000

RECORD DIVES!

Previous record:

2992 meters



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PLOS ONE

First Long-Term Behavioral Records from Cuvier's Beaked Whales (*Ziphius cavirostris*) Reveal Record-Breaking Dives

Gregory S. Schorr[1]*, Erin A. Falcone[1], David J. Moretti[2], Russel D. Andrews[3,4]

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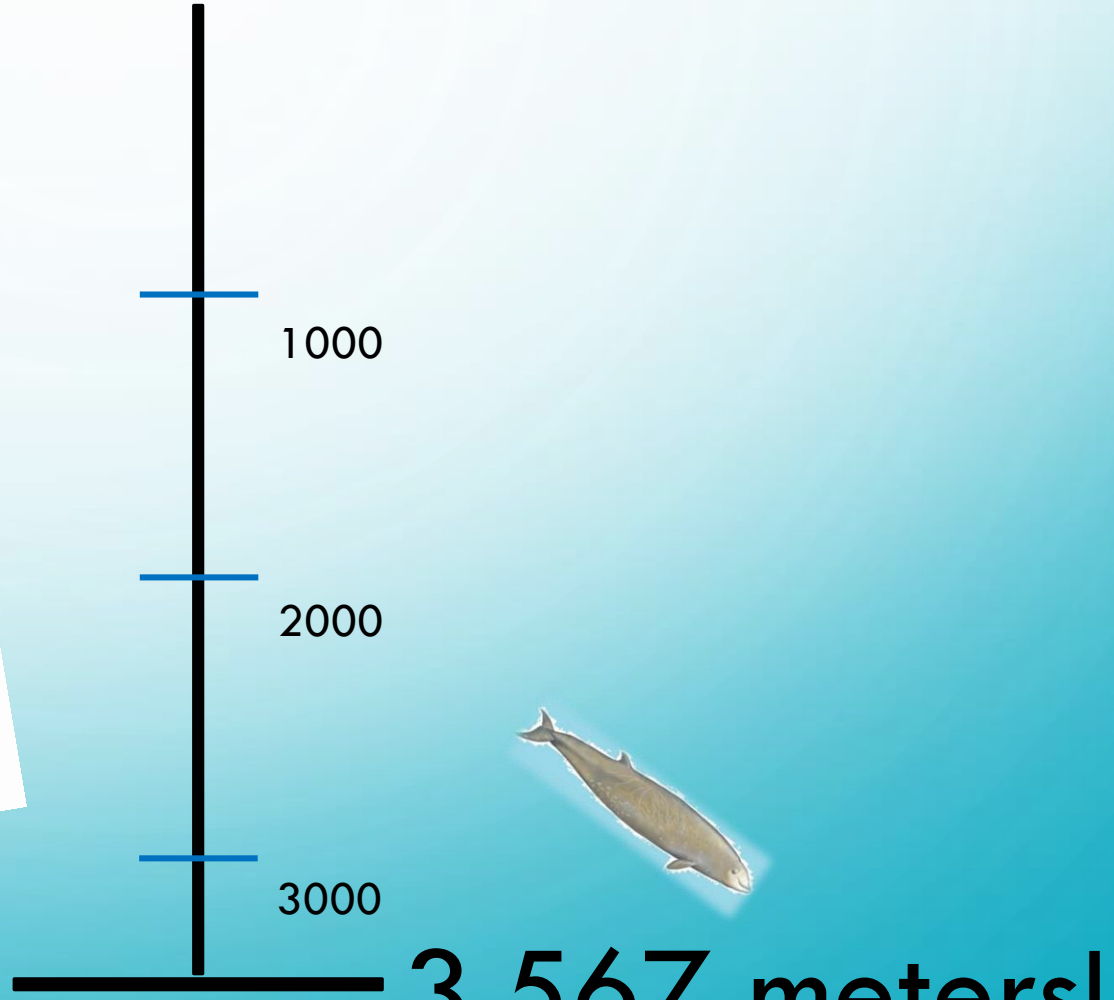
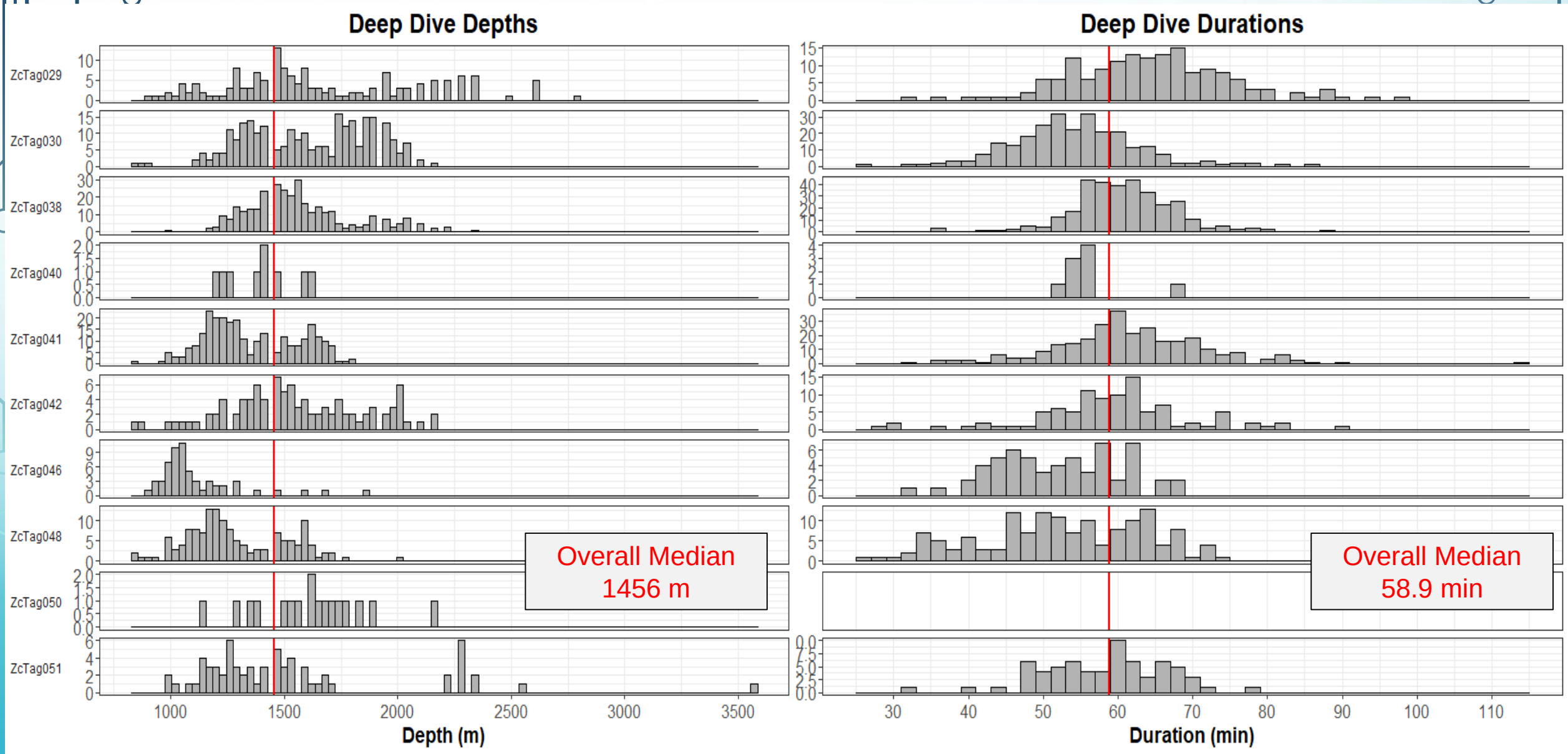
Abstract

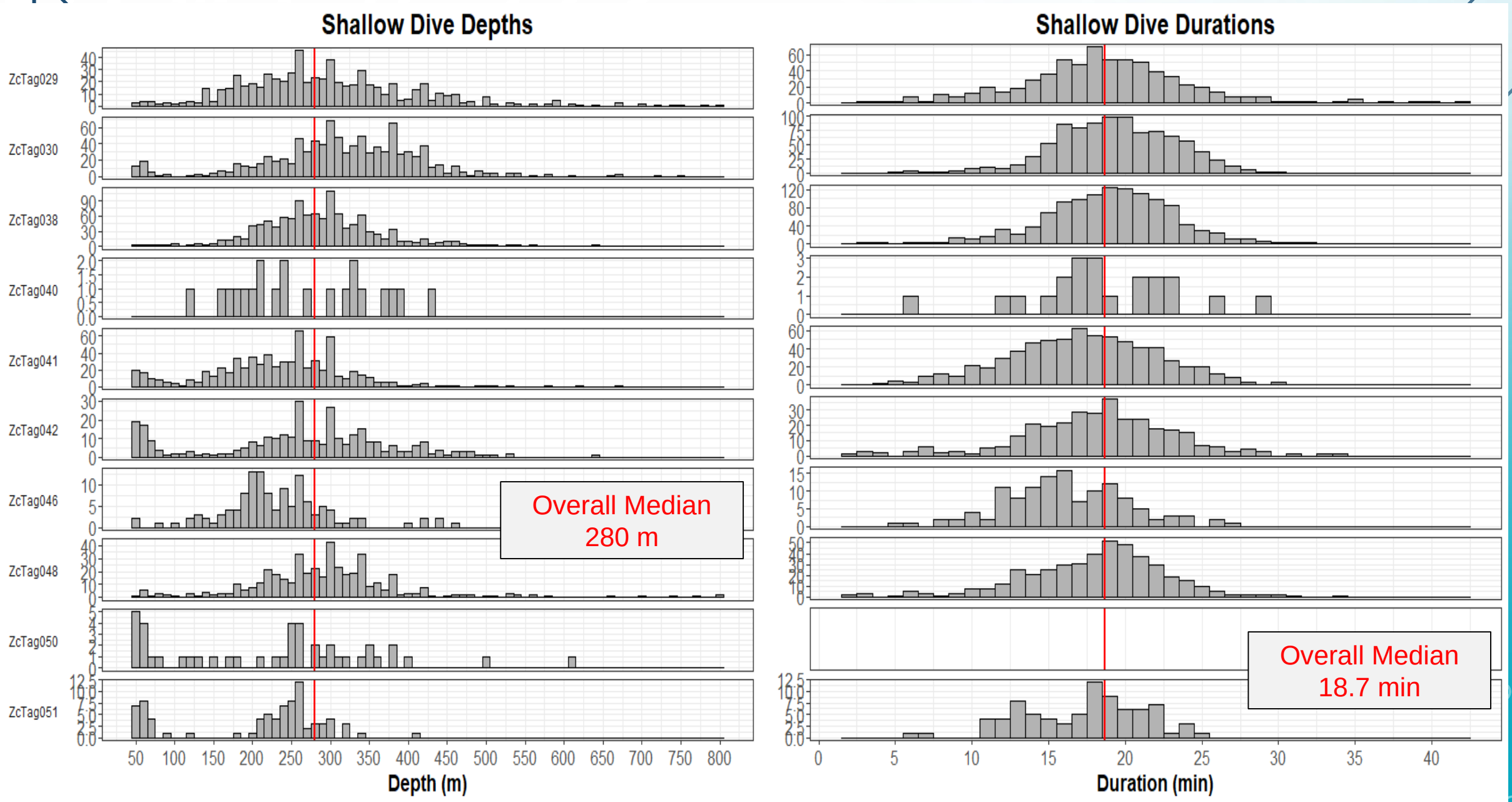
Cuvier's beaked whales (*Ziphius cavirostris*) are known as extreme divers, though behavioral data from this difficult-to-study species have been limited. They are also the species most often stranded in association with Mid-Frequency Active (MFA) sonar use, a relationship that remains poorly understood. We used satellite-linked tags to record the diving behavior and locations of eight *Ziphius* off the Southern California coast for periods up to three months. The effort resulted in 3732 hr of dive data with associated regional movements – the first dataset of its kind for any beaked whale – and included dives to 2992 m depth and lasting 137.5 min, both new mammalian dive records. Deep dives had a group mean depth of 1401 m (s.d. = 137.8, n = 1142) and duration of 67.4 min (s.d. = 6.9). The group mean time between deep dives was 102.3 min (s.d. = 30.8, n = 783). While the previously described stereotypic pattern of deep and shallow dives was apparent, there was considerable inter- and intra-individual variability in most parameters. There was significant diel behavioral variation, including increased time near the surface and decreased shallow diving at night. However, maximum depth and the proportion of time spent on deep dives (presumed foraging), varied little from day to night. Surprisingly, tagged whales were present within an MFA sonar training range for 38% of days locations were received, and though comprehensive records of sonar use during tag deployments were not available, we discuss the effects frequent acoustic disturbance may have had on the observed behaviors. These data better characterize the true behavioral range of this species, and suggest caution should be exercised when drawing conclusions about behavior using short-term datasets.

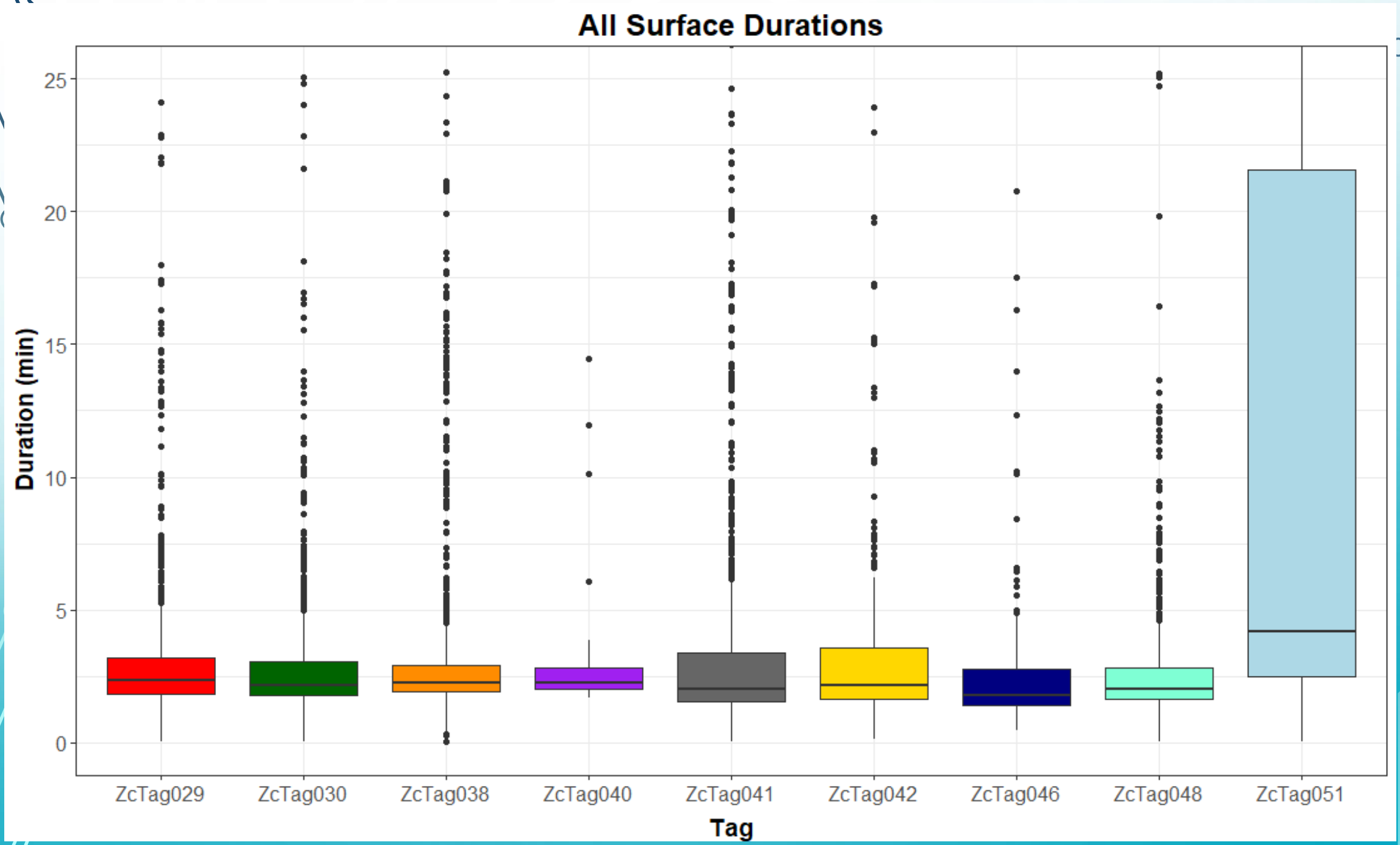


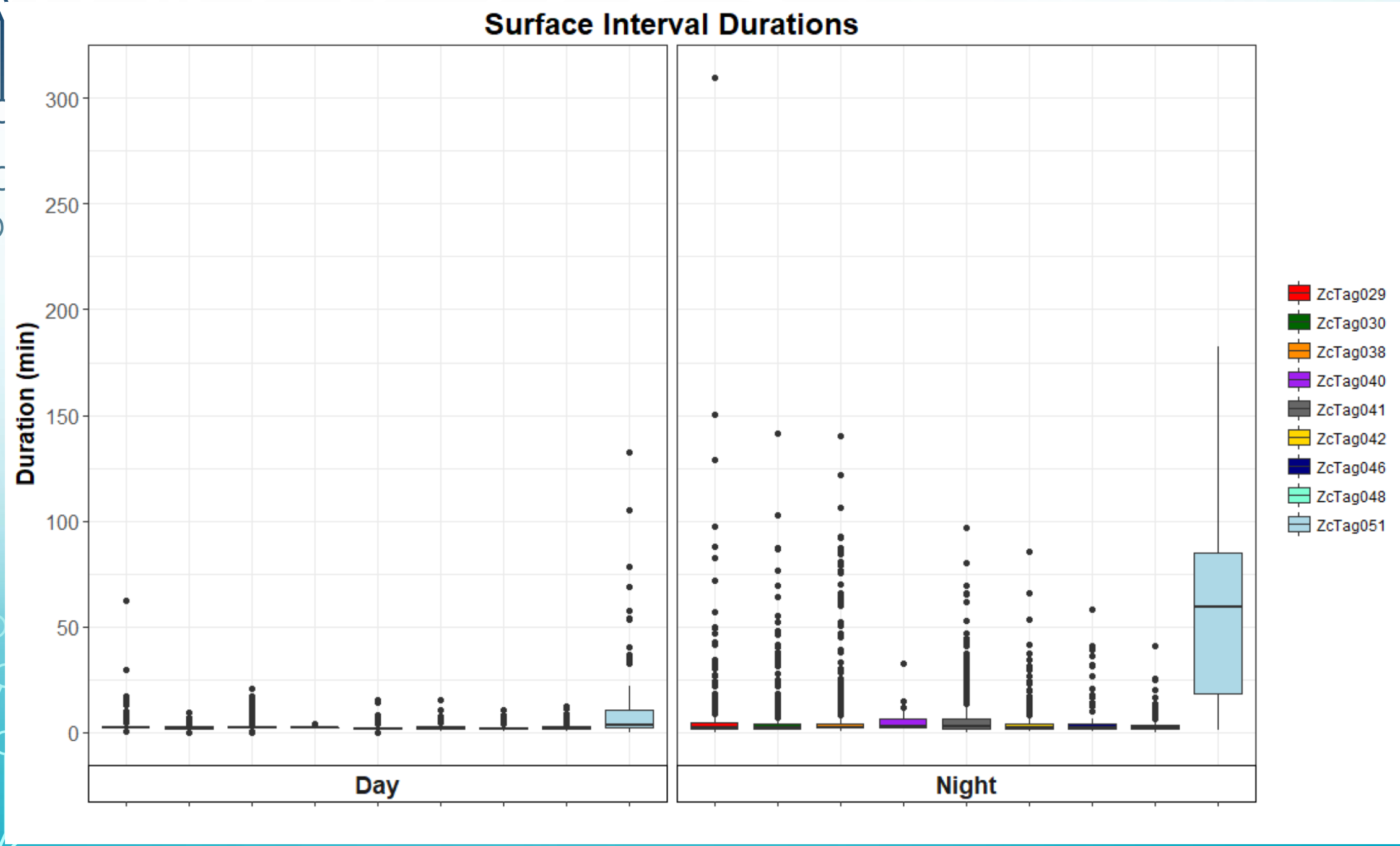
3,567 meters!

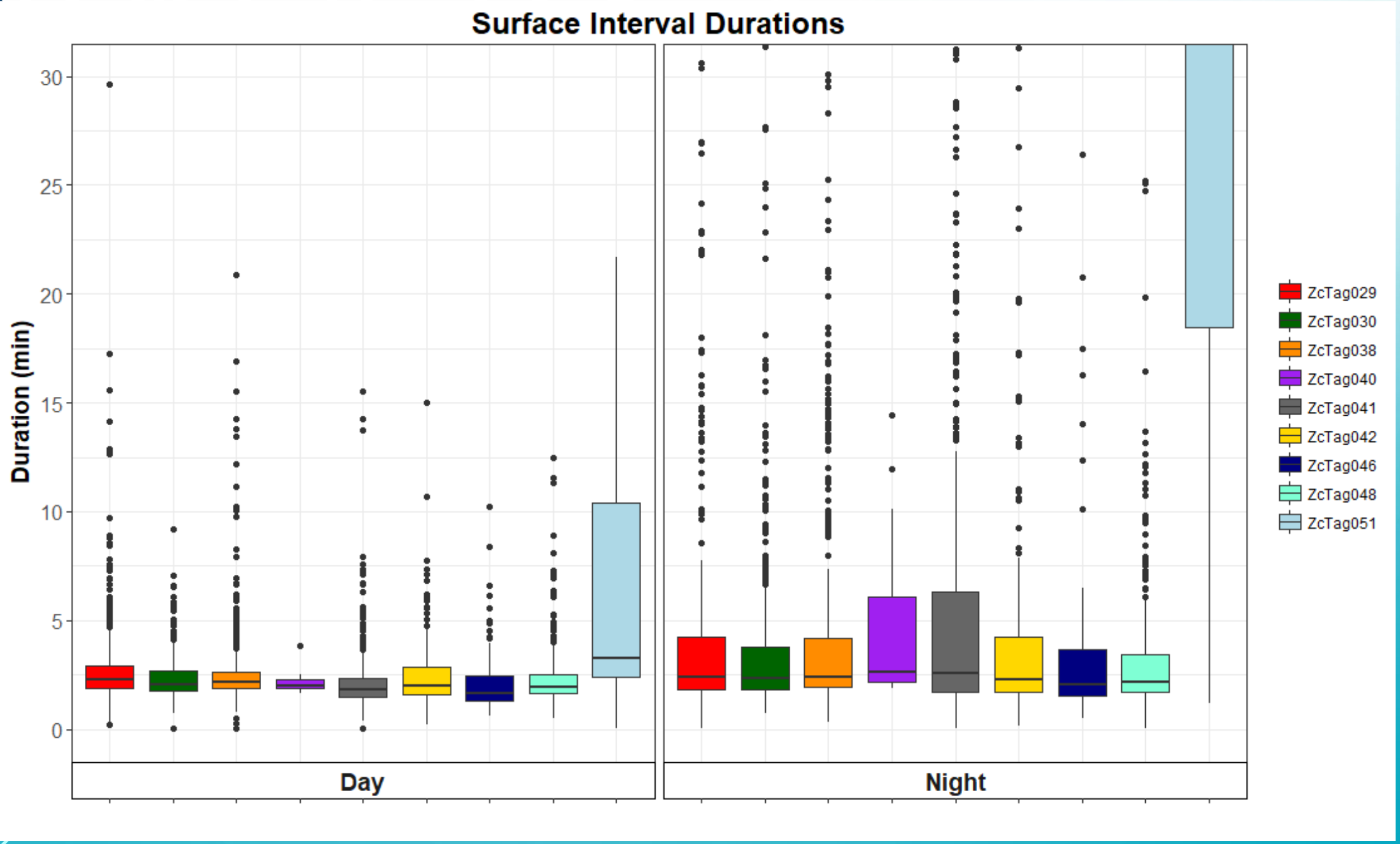
Cuvier's image from Hebridean Whale and Dolphin Trust


Deep Dive Depths
Deep Dive Durations
ZcTag029
ZcTag030
ZcTag038
ZcTag040
ZcTag041
ZcTag042
ZcTag046
ZcTag048
ZcTag050
ZcTag051
Overall Median
1456 m
Overall Median
58.9 min
Depth (m)
Duration (min)


Shallow Dive Depths
ZcTag029
ZcTag030
ZcTag038
ZcTag040
ZcTag041
ZcTag042
ZcTag046
ZcTag048
ZcTag050
ZcTag051
Overall Median
280 m
50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800
Depth (m)
Shallow Dive Durations
Overall Median
18.7 min
0 5 10 15 20 25 30 35 40
Duration (min)


All Surface Durations
Duration (min)
25
20
15
10
5
0
ZcTag029
ZcTag030
ZcTag038
ZcTag040
ZcTag041
ZcTag042
ZcTag046
ZcTag048
ZcTag051
Tag


Surface Interval Durations
Duration (min)
300
250
200
150
100
50
0
Day
Night
ZcTag029
ZcTag030
ZcTag038
ZcTag040
ZcTag041
ZcTag042
ZcTag046
ZcTag048
ZcTag051


Surface Interval Durations
Duration (min)
30
25
20
15
10
5
0
Day
Night
ZcTag029
ZcTag030
ZcTag038
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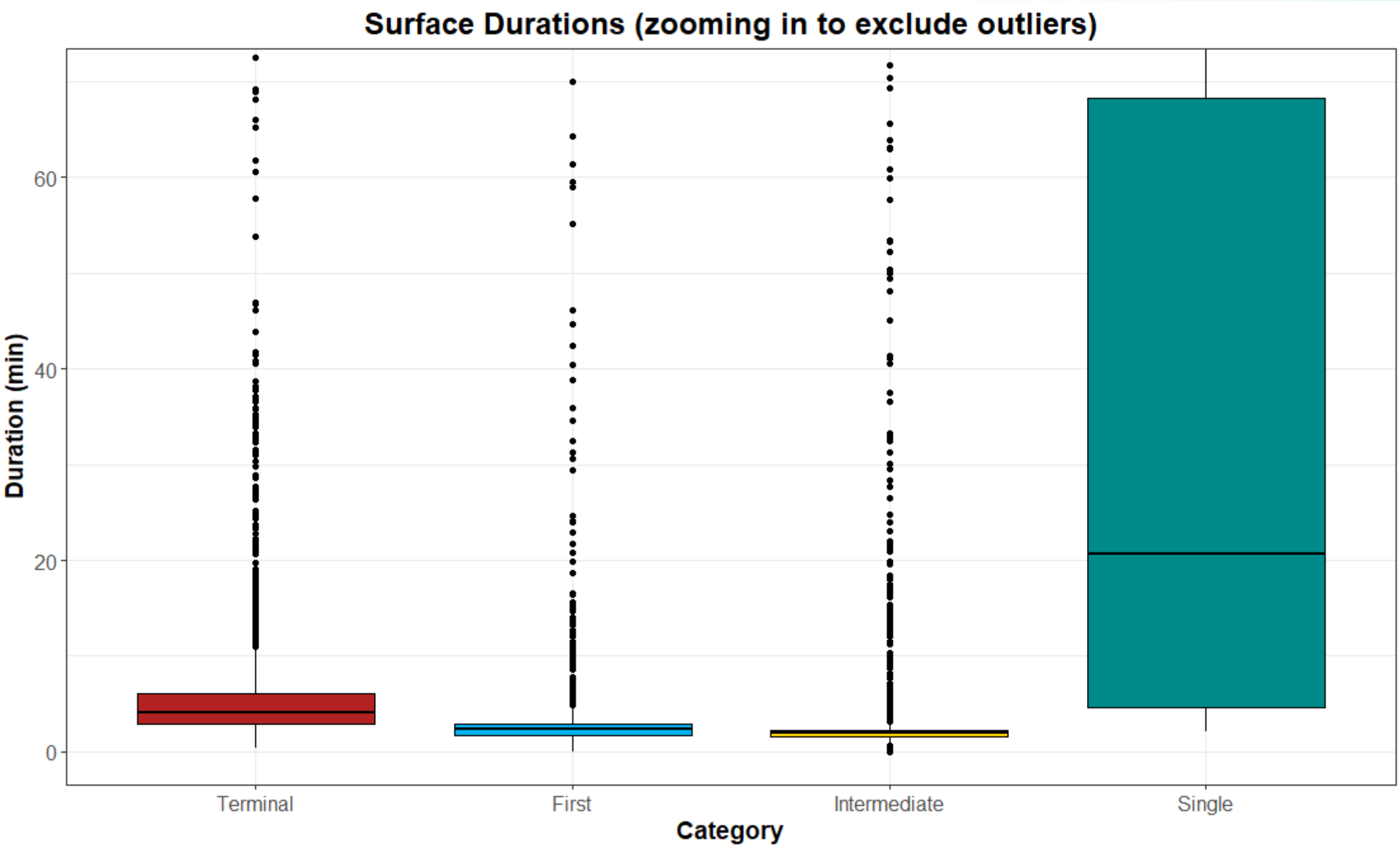
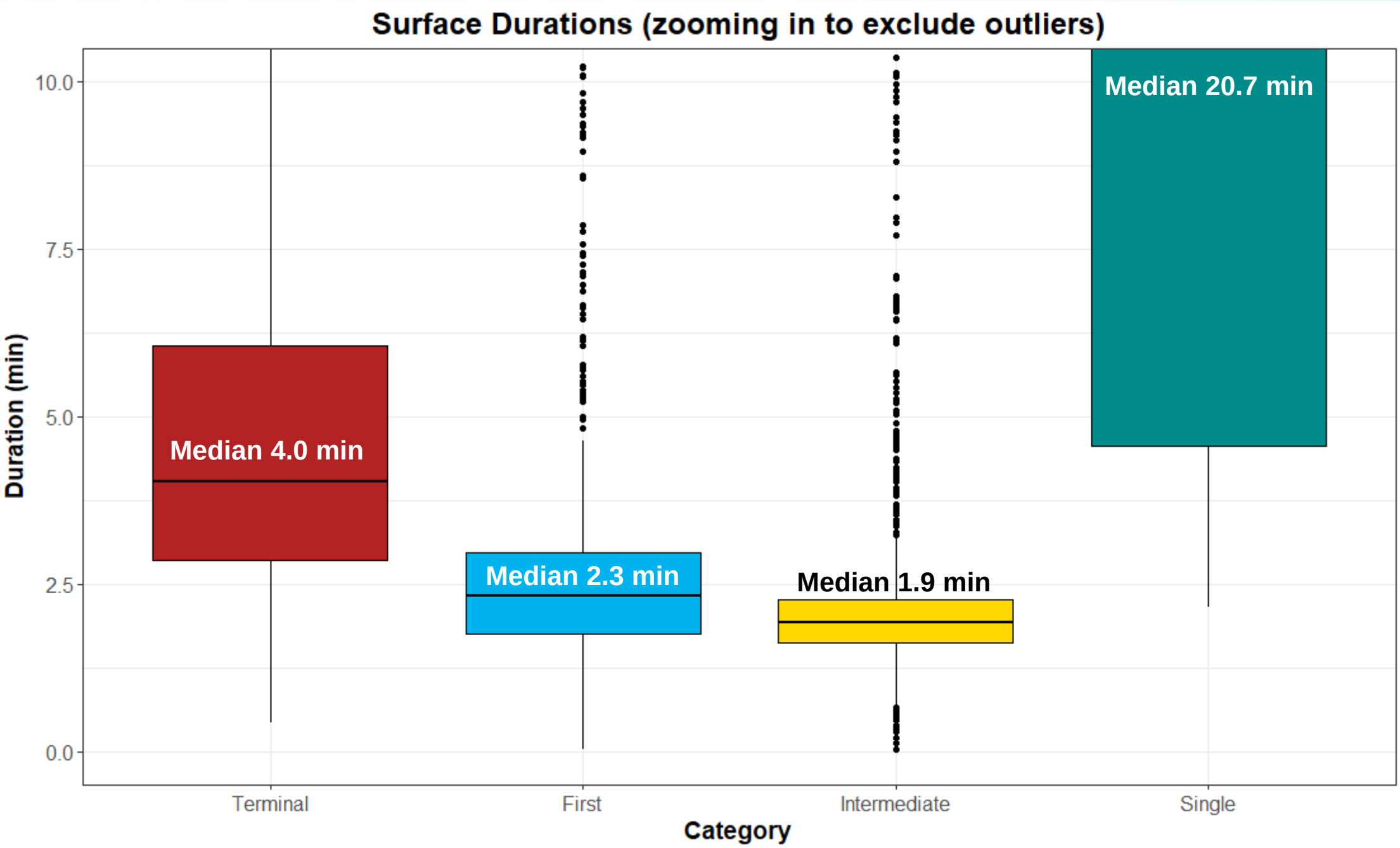
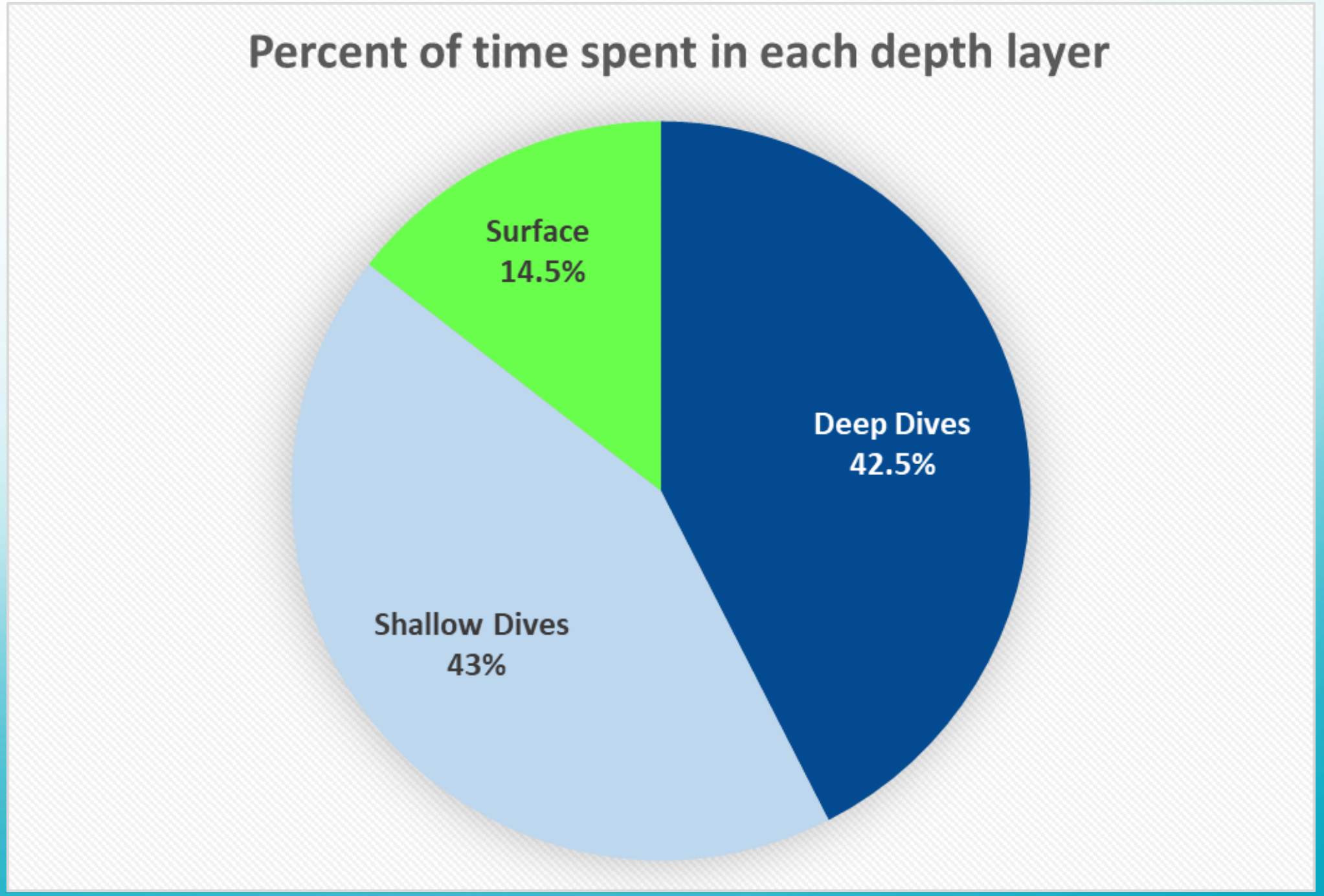
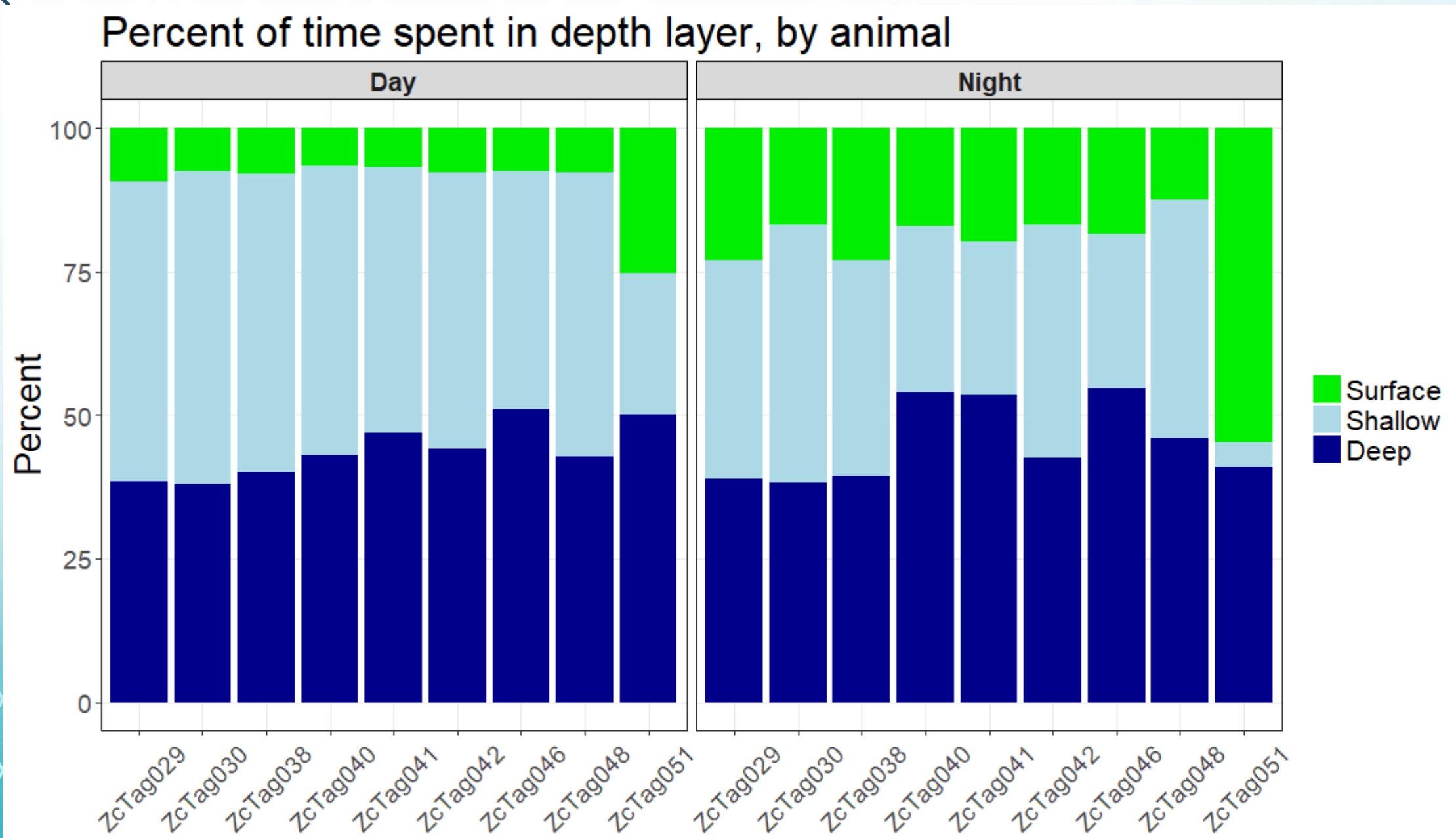
ZcTag041
ZcTag042
ZcTag046
ZcTag048
ZcTag051


Surface Durations (zooming in to exclude outliers)
Duration (min)
0
20
40
60
Terminal
First
Intermediate
Single
Category


Surface Durations (zooming in to exclude outliers)
Duration (min)
10.0
7.5
5.0
2.5
0.0
Median 4.0 min
Median 2.3 min
Median 1.9 min
Median 20.7 min
Terminal
First
Intermediate
Single
Category


Percent of time spent in each depth layer
Surface
14.5%
Deep Dives
42.5%
Shallow Dives
43%


Percent of time spent in depth layer, by animal
Day
Night
Percent
100
75
50
25
0
Surface
Shallow
Deep
ZcTag029
ZcTag030
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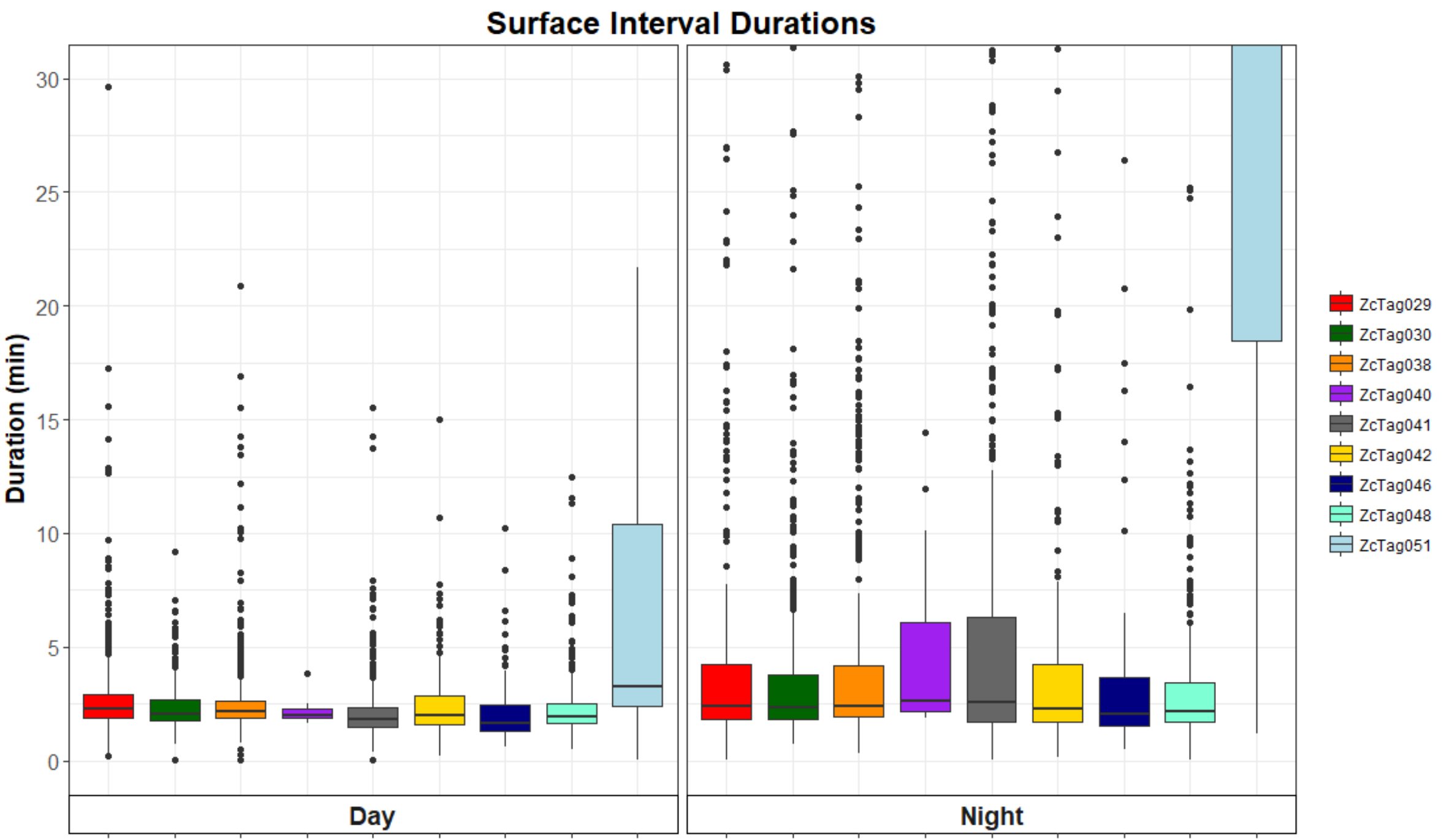
ZcTag041
ZcTag042
ZcTag046
ZcTag048
ZcTag051


Surface Interval Durations
Duration (min)
30
25
20
15
10
5
0
Day
Night
ZcTag029
ZcTag030
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ZcTag040
ZcTag041
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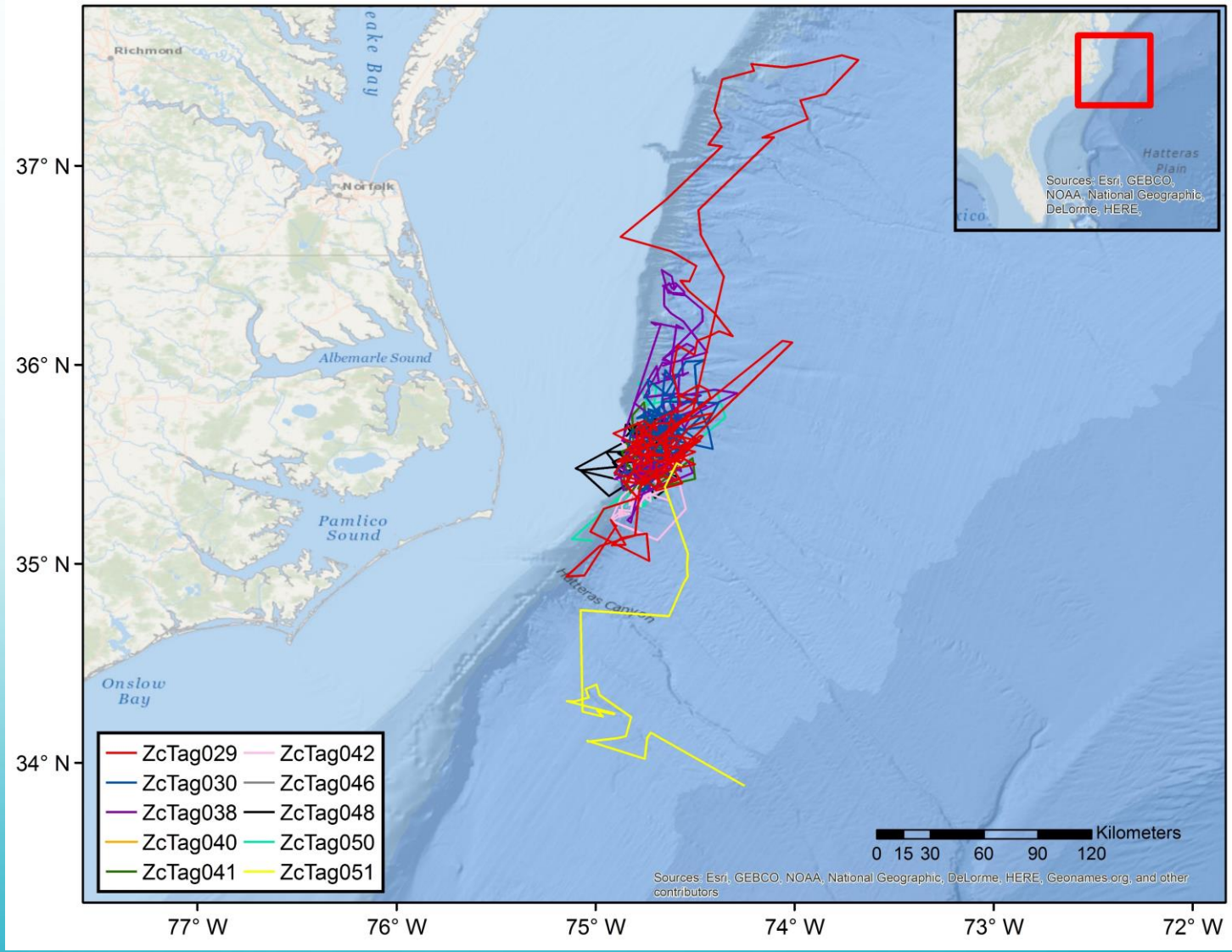
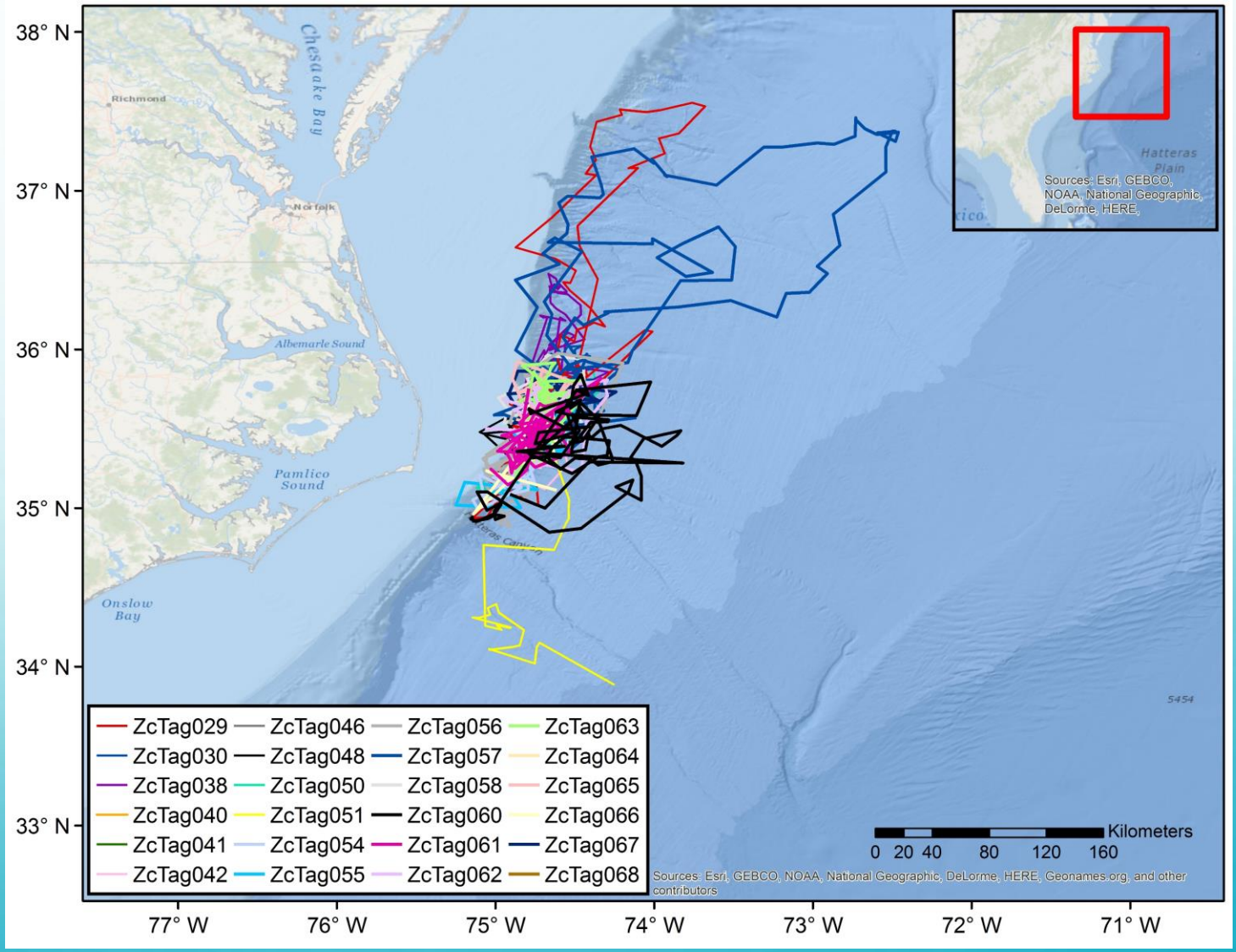
ZcTag046
ZcTag048
ZcTag051

DISCUSSION – INDIVIDUAL VARIATION

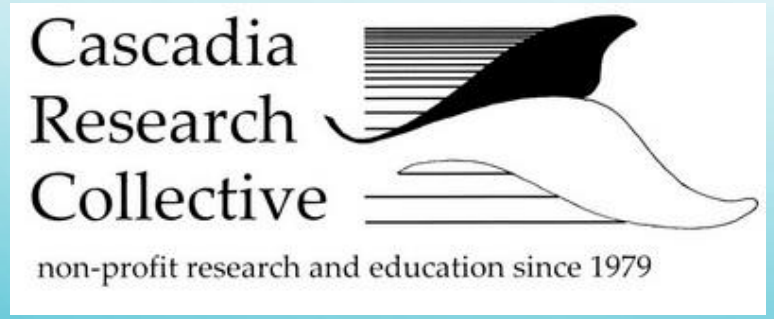



38° N
37° N
36° N
35° N
34° N
33° N
77° W
76° W
75° W
74° W
73° W
72° W
71° W
Chesapeake Bay
Richmond
Norfolk
Albemarle Sound
Pamlico Sound
Onslow Bay
Hatteras Plain
Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE,
ZcTag029
ZcTag030
ZcTag038
ZcTag040
ZcTag041
ZcTag042
ZcTag046
ZcTag048
ZcTag050
ZcTag051
ZcTag054
ZcTag055
ZcTag056
ZcTag057
ZcTag058
ZcTag060
ZcTag061
ZcTag062
ZcTag063
ZcTag064
ZcTag065
ZcTag066
ZcTag067
ZcTag068
Kilometers
0 20 40 80 120 160
Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

DISCUSSION – TAG FAILURES

CONCLUSIONS

ACKNOWLEDGEMENTS



QUESTIONS?