Commercial Launch Site

Construction-Phase Vegetation Monitoring Survey

Prepared for:

Space Exploration Technologies (SpaceX)

Prepared by:

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University of Texas Rio Grande Valley

Brownsville, Texas

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(2021 – 2022 reporting cycle)

1. Intensive vegetation monitoring (adjacent to vertical launch area at Boca Chica, TX):

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Description of Sampling Activities

In October 2022, University of Texas Rio Grande Valley researchers (PI Gabler, one M.S. students: Garrett, and two undergraduate students: Chavez and Lee) visited and surveyed vegetation plots previously established across a sampling grid within (a) the 8.66 acres of piping plover habitat that was originally anticipated to be impacted by water vapor ground clouds (**Figure 1.1**, orange circle), and (b) an additional 23.51 acres that may be subject to additional changes, but for which the USFWS had not issued take at the start of this monitoring effort (**Figure 1.1**, yellow circle). The original grid created by former PI Heather Alexander consisted of 107 points, each separated by 100 ft, plus 6 vegetation creep plots (113 plots total in 2015). Sampling areas encompassed low-lying, unvegetated mudflats, a transition zone comprised of halophytic vegetation, and short hind dunes (**Figure 1.2**). We established 6 additional study plots in 2016 and 2 more plots in 2022 to supplement the original grid where we felt there were gaps in coverage. In 2022, we surveyed a total of 121 intensive vegetation plots.

As discussed in prior reports, former PI Alexander marked each sampling point (except those on barren mudflats) with a steel pin flag and acquired horizontal coordinates (latitude and longitude) for each point via handheld GPS. The pin flags degraded quickly and their remains were not discoverable by PI Gabler and his team in 2016, so we placed new markers in 2016 using ca. 60 cm long PVC pipes buried 30 cm deep at sampling points as close as possible to the original points. Importantly, the placement of these new markers was guided solely by a handheld GPS unit with a real-time horizontal accuracy of 1-4 meters in optimal conditions. Therefore, our 2016 surveys were unlikely to cover the exact same 1-m^2 sample areas as were surveyed in 2015. Given that most individual species in the Boca Chica Beach area have patchy distributions, and the area has highly distinct zonation over short distances, the presence and abundance of different species can vary considerably over only a few meters. As a result, direct comparisons between the 2015 and 2016 surveys of the same plots were of limited meaning.

Since 2016, however, we have not had this problem with plot location continuity. The PVC marker pipes placed in 2016 have held up extremely well and have been easily discoverable during our subsequent surveys, except in cases where PVC pipes were presumably destroyed by off-road vehicles or heavy machinery or were removed by vandals or misguided beach cleanup crews. Only 2 marker pipes were undiscoverable in 2022 and presumed destroyed, buried, or removed. This was fewest missing markers we have experienced since 2016 and was comparable to 2019 and 2020, when 6 and 3 markers were missing, respectively. Other years have seen far more missing marker pipes: 22 markers were lost in 2018, when we think a beach cleanup crew started removing our markers before realizing their purpose; and 18 markers were lost in 2021, presumably when heavy machinery was used extensively in the area to clean up rocket debris following the SN10 prototype explosion in March 2021. Two of the sampling plots were overtaken by a southward expansion of the launch pad, as also happened in 2020 and 2021, but these plots were not restaked. Missing pipes on mudflats have little impact on our surveys

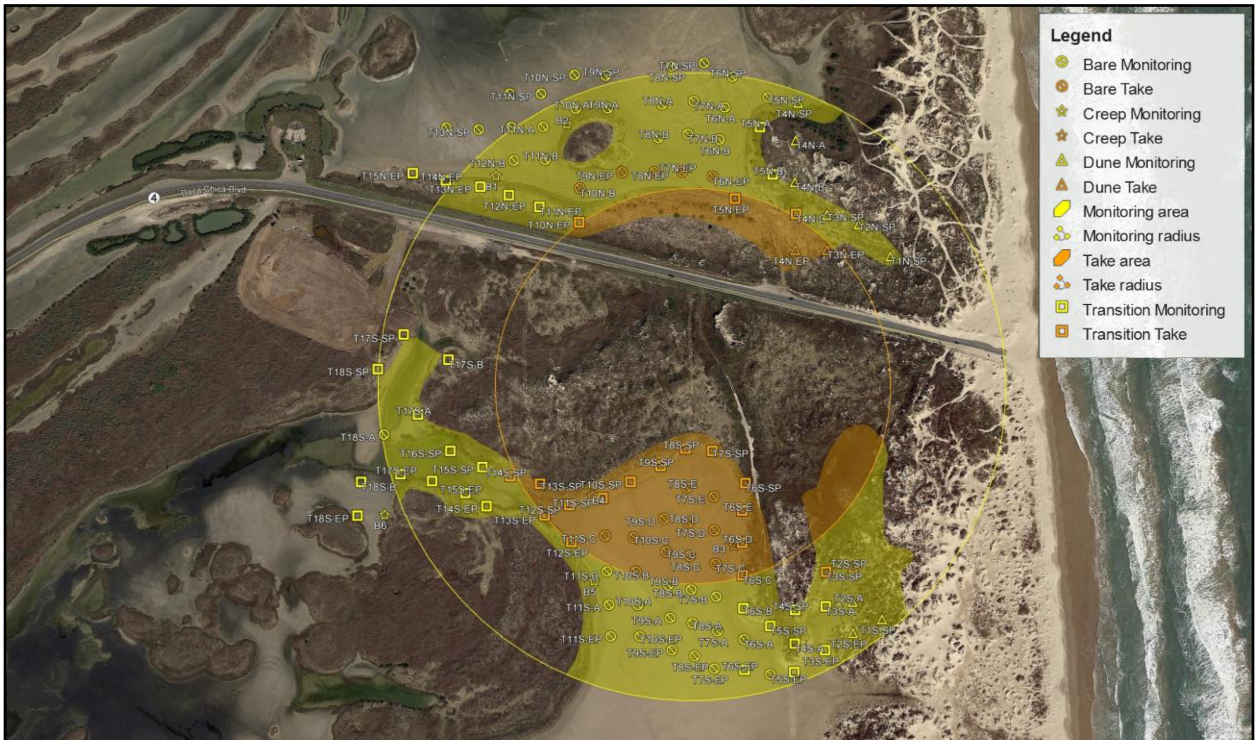


Figure 1.1. Vegetation sampling points near the launch pad site at Boca Chica Beach in south Texas. 'Take' denotes the 8.66-acre area for which USFWS has issued take, and those sampling plots considered to be in that zone. In some areas (e.g., the NNW region), we consider the sampling plots nearest the take zone to be within the zone for the sake of comparative analyses. 'Monitoring' denotes the additional 23.51-acre are designated for supplementary monitoring. Note that the precise locations for the Monitoring and Take zones are approximate, this map should be used for visualization purposes only. 'Bare', 'Transition', and 'Dune' refer to the three main types of habitats surveyed, which are described above and illustrated in **Figure 1.2**. 'Creep' refers to plots placed at the edge of a vegetation zone transition between mudflats and halophytic salt flats for the sake of tracking encroachment or "creep" of plants into mudflats.

because no change in vegetation cover should arise from inexact placement of a replacement pipe, but missing marker pipes in vegetated areas reduced our ability to use a standard repeated measures approach to make direct plant community comparisons between years. This has not, however, impeded our ability to make meaningful group-scale comparisons and draw important conclusions.

Plant cover by species and the percentage of bare ground at each sampling point were visually estimated within a 1-m^2 area. Plant species were identified to the lowest taxonomic level possible. The maximum height attained by the tallest species in each plot was also measured, and we estimated the average overall vegetation canopy height. Five photographs were taken at each sampling point (including bare mudflats), including four photographs taken in each cardinal direction (**Figure 1.3**) and one photograph of the 1-m^2 survey plot.

Figure 1.2. (A) Mudflats – relatively flat, muddy, low-lying zones with little or no vegetation. **(B)** Transition zones – areas characterized by scattered halophytic grasses and succulents with relatively high proportions of bare ground. These assemblages are also called salt flats and are a mid-elevation transitional zone between mudflats and dunes. Mangroves were infrequently observed in this zone at the study site, but no mangroves were within the sampling area. **(C)** Dunes – higher elevation areas dominated mainly by graminoids and short woody vegetation or creeping vines with relatively little bare ground. Dunes were predominantly found at the easternmost portions of the study site near the shoreline.

PI Gabler carefully reviewed the survey photographs and found important differences in the recent imagery, but substantive photographic analyses and comparisons are beyond the scope of our current contract and thus this report. It is the opinion of PI Gabler that analyses of our recent ground-based imagery are merited in the immediate future and should be considered in future contracts.

Our surveys also included consideration of any large shrubs or shrub layer vegetation >1.4 m tall (e.g., mangrove, huisache, etc.) that occurred within a 2-m radius of each sampling point; however, shrub layer vegetation only grew within range of one sampling point during the current sampling period. The observed shrub layer vegetation was comprised entirely of black mangrove trees (*Avicennia germinans*), which were also in the vicinity but not in sampling range of other plots (**Figure 1.4**). We were able to quantify vegetation creep into bare mudflats from 2016 to 2022 at two of the six designated points (B2 and B6); from 2016-2020 and 2021-2022 for 3 points (B1, B4, and B5) because the marker pipes for these points were among the 18 lost but replaced in 2021; and from 2018 to 2022 for creep plot B3, which was lost and replaced in 2018. We added a seventh vegetation creep plot in 2022. For these plots especially, replacement of lost

Figure 1.3. (top) Photographs were acquired at each sampling point facing each cardinal direction at Boca Chica Beach, TX. The compass denotes the directions in which each photograph was taken in the example provided. **(bottom row)** The same four photographs are arranged in a panoramic orientation to better demonstrate coverage.

marker pipes introduce an unknown amount of horizontal wander that limits the precision of certain interannual comparisons.

Figure 1.4. Black mangrove trees (*Avicennia germinans*), the taller, darker green vegetation in the red rectangle, were observed in the vicinity of sampling points at Boca Chica Beach, TX, but were only within 2 m of one sampling point.

Findings

We surveyed a total of 121 vegetation plots in 2022. Of these, 41 (33.1%) were within the take zone, and 80 (66.9%) were within the monitoring zone. Overall, 58 plots (47.9%) were categorized as bare/mudflat, 14 (11.5%) as dune, 42 (34.7%) as transition, and 7 (5.8%) as creep. Across all sampling areas, in 2022, we observed 36 distinct morphotypes (down from 40 in 2021), including 31 plants identifiable to species, 2 identifiable to genus, 2 identifiable to family, and 1 identifiable to functional group, altogether representing 17 families (**Table 1.1**). The unidentifiable morphotype could only be categorized based on its functional group because all individuals observed were small and immature and lacked distinguishing features.

A total of 61 identifiable species have been observed within the sampling area since 2015 and are listed in **Table 1.2**, as are all 25 unidentifiable morphotypes from prior years.

Table 1.3 summarizes cover by each observed species within each vegetative zone for the last four years (2018–2022). Within each zone, bare area was the dominant ground cover class, comprising 98% of cover in the mudflats, 83% in the transitional zones, 73% in the dunes, and 80% in the creep plots in 2022. Total live plant cover averaged across all habitat types was 9.4% in 2022, which was about 13% lower than was observed in 2021 (10.7%) and 2020 (10.9%) and roughly 25% less live plant cover than in 2018 (12.5%) but was similar to 2016 (9.7%).

Total plant cover within different habitat types was highly variable between 2021 and 2022: there was a 57% decrease in total live plant cover in mudflats (from 1.87% to 0.80%; **Table 1.4**) and a 20% decrease in transition plots (from 17.57% to 13.97%; **Table 1.5**); however, live plant cover changed little in dune plots (from 26.2% to 26.4%; **Table 1.6**), and there was a 20% increase in creep plots (from 15.7% to 18.8%; **Table 1.7**). These patterns differed considerably from the changes in total live plant cover observed in the prior year (from 2020 to 2021), when mudflats and transition plots changed little, and there was a modest 4% increase in dune plots, but cover decreased sharply by 24% decrease in creep plots (from 20.6% to 15.7%). This was the lowest plant cover observed by a large margin in mudflat and transition plots since 2018, and, for transition plots, this represents a continuing decline in plant cover that cannot be ignored. Conversely, this also represents additional evidence of a gradual (with variability) 5-year increase in plant cover in creep plots, which was one of the key concerns at the onset of this monitoring. This pattern in creep plots holds true even if we exclude the seventh creep plot established this year (B7), which would reduce total live plant cover in creep plots in 2022 to 16.9%; if so, this represents a less intense but still significant increase over time. Live plant cover was considerably higher within dune plots in 2018 than in 2022, but dune cover values have been consistent since 2019, so 2018 may have been unusually high.

This observed increase in plant cover in creep plots reflects a reversal of the temporary decrease seen in 2021 and reinforces a larger multi-year trend towards increasing plant cover at the mudflat margins. Given that vegetation cover also decreased considerably in 2022 in mudflats and especially transition plots, which are probably the plot type most sensitive to rainfall variation, the simultaneous increase in 2022 of plant cover in creep plots suggests that this pattern of increases in creep cover cannot be entirely explained by normal interannual variation. In 2019 and 2020, vegetation appeared to be creeping into the mudflats from

Table 1.1a. Species list of plants found within the Boca Chica Beach, TX intensive vegetation monitoring area in 2022, in alphabetical order by family, then genus and species. Species code is made up of the first three letters of the genus name and the first three letters of the species name. Not all plants possessed the structures necessary for definitive identification.

Family	Genus	Species	Common Name	Species Code
Acanthaceae	*Avicennia*	*germinans*	black mangrove	Avi-ger
Acanthaceae	*Chromolaena*	*odorata*	blue mistflower, crucita	Chr-odo
Aizoaceae	*Sesuvium*	*portulacastrum*	sea purslane, cenicilla	Ses-por
Amaranthaceae	*Blutaparon*	*vermiculare*	silverhead	Blu-ver
Amaranthaceae	*Tidestromia*	*lanuginosa*	woolly tidestromia	Tid-lan
Asteraceae	*Borrichia*	*frutescens*	sea ox-eye daisy	Bor-fru
Asteraceae	*Heterotheca*	*subaxillaris*	camphor weed	Het-sub
Asteraceae	*Iva*	*angustifolia*	narrowleaf marshelder	Iva-ang
Asteraceae	*Rayjacksonia*	*phyllocephala*	camphor daisy	Ray-phy
Asteraceae	*Solidago*	*sempervirens*	seaside goldenrod	Sol-sem
Bataceae	*Batis*	*maritima*	saltwort, vidrillos	Bat-mar
Chenopodiaceae	*Salicornia*	*bigelovii*	annual saltwort	Sal-big
Chenopodiaceae	*Salicornia*	*depressa*	glasswort	Sal-dep
Chenopodiaceae	*Suaeda*	*linearis*	annual seepweed	Sua-lin
Convolvulaceae	*Cressa*	*nudicaulis*	nakedstem alkaliweed	Cre-nud
Cyperaceae	*Carex*	*?*	true sedge	Car-sp.
Cyperaceae	*Fimbristylis*	*castanea*	coastal marsh fimbry	Fim-cas
Fabaceae	*Prosopis*	*reptans*	screwbean mesquite	Pro-rep
Juncaceae	*Juncus*	*effusus*	soft rush	Jun-eff
Leguminosae	*Chamaecrista*	*fasciculata*	partridge pea	Cha-fas
Linaceae	*Linum*	*alatum*	winged flax	Lin-ala
Plumbaginaceae	*Limonium*	*carolinianum*	sea lavender	Lim-car
Poaceae	*Distichlis*	*spicata*	seashore saltgrass	Dis-spi
Poaceae	*Monanthochloe*	*littoralis*	shoregrass	Mon-lit
Poaceae	*Panicum*	*amarum*	bitter panicum	Pan-ama
Poaceae	*Paspalum*	*?*	paspalum	Pas-sp.
Poaceae	*Schizachyrium*	*scoparium*	seacoast bluestem	Sch-sco
Poaceae	*Spartana*	*spartinae*	Gulf cordgrass	Spa-spa
Poaceae	*Sporobolus*	*airoides*	alkali Sacaton	Spo-air
Poaceae	*Uniola*	*paniculata*	sea oats	Uni-pan
Poaceae	*?*	*?*	unknown grass 1	Poaceae 1-2022
Poaceae	*?*	*?*	unknown grass 2	Poaceae 2-2022
Primulaceae	*Samolus*	*ebracteatus*	bractless brookweed	Sam-ebr
Scrophulariaceae	*Agalinis*	*maritima var. grandiflora*	seaside Agalinis	Aga-mar
Solanaceae	*Lycium*	*carolinianum*	Carolina wolfberry	Lyc-car
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2022

Table 1.1b. Species list of plants found within the Boca Chica Beach, TX intensive vegetation monitoring area in 2022, in alphabetical order by genus and species. Species code is made up of the first three letters of the genus name and the first three letters of the species name. Not all plants possessed the structures necessary for definitive identification.

Family	Genus	Species	Common Name	Species Code
Scrophulariaceae	*Agalinis*	*maritima var. grandiflora*	seaside Agalinis	Aga-mar
Acanthaceae	*Avicennia*	*germinans*	black mangrove	Avi-ger
Bataceae	*Batis*	*maritima*	saltwort, vidrillos	Bat-mar
Amaranthaceae	*Blutaparon*	*vermiculare*	silverhead	Blu-ver
Asteraceae	*Borrichia*	*frutescens*	sea ox-eye daisy	Bor-fru
Cyperaceae	*Carex*	*?*	true sedge	Car-sp.
Leguminosae	*Chamaecrista*	*fasciculata*	partridge pea	Cha-fas
Acanthaceae	*Chromolaena*	*odorata*	blue mistflower, crucita	Chr-odo
Convolvulaceae	*Cressa*	*nudicaulis*	nakedstem alkaliweed	Cre-nud
Poaceae	*Distichlis*	*spicata*	seashore saltgrass	Dis-spi
Cyperaceae	*Fimbristylis*	*castanea*	coastal marsh fimbry	Fim-cas
Asteraceae	*Heterotheca*	*subaxillaris*	camphor weed	Het-sub
Asteraceae	*Iva*	*angustifolia*	narrowleaf marshelder	Iva-ang
Juncaceae	*Juncus*	*effusus*	soft rush	Jun-eff
Plumbaginaceae	*Limonium*	*carolinianum*	sea lavender	Lim-car
Linaceae	*Linum*	*alatum*	winged flax	Lin-ala
Solanaceae	*Lycium*	*carolinianum*	Carolina wolfberry	Lyc-car
Poaceae	*Monanthochloe*	*littoralis*	shoregrass	Mon-lit
Poaceae	*Panicum*	*amarum*	bitter panicum	Pan-ama
Poaceae	*Paspalum*	*?*	paspalum	Pas-sp.
Fabaceae	*Prosopis*	*reptans*	screwbean mesquite	Pro-rep
Asteraceae	*Rayjacksonia*	*phyllocephala*	camphor daisy	Ray-phy
Chenopodiaceae	*Salicornia*	*bigelovii*	annual saltwort	Sal-big
Chenopodiaceae	*Salicornia*	*depressa*	glasswort	Sal-dep
Primulaceae	*Samolus*	*ebracteatus*	bractless brookweed	Sam-ebr
Poaceae	*Schizachyrium*	*scoparium*	seacoast bluestem	Sch-sco
Aizoaceae	*Sesuvium*	*portulacastrum*	sea purslane, cenicilla	Ses-por
Asteraceae	*Solidago*	*sempervirens*	seaside goldenrod	Sol-sem
Poaceae	*Spartana*	*spartinae*	Gulf cordgrass	Spa-spa
Poaceae	*Sporobolus*	*airoides*	alkali Sacaton	Spo-air
Chenopodiaceae	*Suaeda*	*linearis*	annual seepweed	Sua-lin
Amaranthaceae	*Tidestromia*	*lanuginosa*	woolly tidestromia	Tid-lan
Poaceae	*Uniola*	*paniculata*	sea oats	Uni-pan
Poaceae	*?*	*?*	unknown grass 1	Poaceae 1-2022
Poaceae	*?*	*?*	unknown grass 2	Poaceae 2-2022
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2022

Table 1.2a. Species list of plants found within the Boca Chica Beach, TX intensive vegetation monitoring area since 2015. Species code is made up of the first three letters of the genus name and the first three letters of the species name. Species are in alphabetical order by family, then genus and species. Not all plants possessed the structures necessary for definitive identification.

Family	Genus	Species	Common Name	Species Code
Acanthaceae	*Avicennia*	*germinans*	black mangrove	Avi-ger
Acanthaceae	*Chromolaena*	*odorata*	blue mistflower, crucita	Chr-odo
Aizoaceae	*Sesuvium*	*portulacastrum*	sea purslane, cenicilla	Ses-por
Aizoaceae	*Sesuvium*	*verrucosum*	winged sea purslane	Ses-ver
Amaranthaceae	*Amaranthus*	*greggii*	Gregg's amaranth	Ama-gre
Amaranthaceae	*Blutaparon*	*vermiculare*	silverhead	Blu-ver
Amaranthaceae	*Tidestromia*	*lanuginosa*	woolly tidestromia	Tid-lan
Asclepiadaceae	*Cynanchum*	*angustifolius*	Gulf Coast swallow-wort	Cyn-ang
Asteraceae	*Borrichia*	*frutescens*	sea ox-eye daisy	Bor-fru
Asteraceae	*Erigeron*	*procumbens*	prostrate fleabane	Eri-pro
Asteraceae	*Gaillardia*	*pulchella var. australis*	firewheel	Gai-pul
Asteraceae	*Heterotheca*	*subaxillaris*	camphor weed	Het-sub
Asteraceae	*Iva*	*angustifolia*	narrowleaf marshelder	Iva-ang
Asteraceae	*Rayjacksonia*	*phyllocephala*	camphor daisy	Ray-phy
Asteraceae	*Solidago*	*semperviens*	seaside goldenrod	Sol-sem
Asteraceae	*Thelesperma*	*ambiguum*	ambiguous green thread	The-amb
Asteraceae	*?*	*?*	unknown aster 1	Asteraceae 1-2016
Bataceae	*Batis*	*maritima*	saltwort, vidrillos	Bat-mar
Brassicaceae	*Cakile*	*lanceolatum*	coastal searocket	Cak-lan
Cactaceae	*Opuntia*	*engelmannii*	Texas prickly pear	Opu-eng
Chenopodiaceae	*Salicornia*	*bigelovii*	annual saltwort	Sal-big
Chenopodiaceae	*Salicornia*	*depressa*	glasswort	Sal-dep
Chenopodiaceae	*Suaeda*	*linearis*	annual seepweed	Sua-lin
Chenopodiaceae	*Suaeda*	*tampicensis*	coastal seepweed	Sua-tam
Convolvulaceae	*Cressa*	*nudicaulis*	nakedstem alkaliweed	Cre-nud
Cyperaceae	*Bolboschoenus*	*maritimus*	cosmopolitan bulrush	Bol-mar
Cyperaceae	*Carex*	*?*	true sedge	Car-sp.
Cyperaceae	*Fimbristylis*	*castanea*	coastal marsh fimbry	Fim-cas
Cyperaceae	*?*	*?*	unknown sedge 1	Cyperaceae 1-2020
Euphorbiaceae	*Chamaesyce*	*cordifolia*	heartleaf sandmat	Cha-cor
Euphorbiaceae	*Euphorbia*	*corollata*	Flowering spurge	Eup-cor
Fabaceae	*Galactica*	*canescens*	hoary milkpea	Gal-can
Fabaceae	*Pediomelum*	*rhombifolium*	round leaf scurf pea	Ped-rho
Fabaceae	*Prosopis*	*reptans*	screwbean mesquite	Pro-rep
Gentianaceae	*Eustoma*	*exaltatum*	catchfly prairie gentian	Eus-exa
Gentianaceae	*Sabatia*	*arenicola*	salt marsh pink	Sab-are
Juncaceae	*Juncus*	*effusus*	soft rush	Jun-eff
Juncaceae	*Juncus*	*?*	rush	Jun-sp.
Leguminosae	*Chamaecrista*	*fasciculata*	partridge pea	Cha-fas
Leguminosae	*Dalea*	*emarginata*	prairie clover	Dal-ema
Linaceae	*Linum*	*alatum*	winged flax	Lin-ala
Onagraceae	*Calylophus*	*australis*	square bud primrose	Cal-aus
Onagraceae	*Gaura*	*sinuata*	wavy leaved Gaura	Gau-sin

Family	Genus	Species	Common Name	Species Code
Onagraceae	*Oenothera*	*drummondii*	beach evening primrose	Oen-dru
Plumbaginaceae	*Limonium*	*carolinianum*	sea lavender	Lim-car
Poaceae	*Distichlis*	*spicata*	seashore saltgrass	Dis-spi
Poaceae	*Eragrostis*	*secundiflora*	red lovegrass	Era-sec
Poaceae	*Monanthochloe*	*littoralis*	shoregrass	Mon-lit
Poaceae	*Panicum*	*amarum*	bitter panicum	Pan-ama
Poaceae	*Panicum*	*virgatum*	switchgrass	Pan-vir
Poaceae	*Paspalum*	*notatum*	bahiagrass	Pas-not
Poaceae	*Paspalum*	*?*	paspalum	Pas-sp.
Poaceae	*Schizachyrium*	*scoparium*	seacoast bluestem	Sch-sco
Poaceae	*Spartana*	*spartinae*	Gulf cordgrass	Spa-spa
Poaceae	*Spartina*	*patens*	saltmeadow cordgrass	Spa-pat
Poaceae	*Sporobolus*	*airoides*	alkali Sacaton	Spo-air
Poaceae	*Sporobolus*	*virginicus*	seashore dropseed	Spo-vir
Poaceae	*Uniola*	*paniculata*	sea oats	Uni-pan
Poaceae	*?*	*?*	unknown grass 1	Poaceae 1-2016
Poaceae	*?*	*?*	unknown grass 1	Poaceae 1-2021
Poaceae	*?*	*?*	unknown grass 1	Poaceae 1-2022
Poaceae	*?*	*?*	unknown grass 2	Poaceae 2-2016
Poaceae	*?*	*?*	unknown grass 2	Poaceae 2-2022
Poaceae	*?*	*?*	unknown grass 3	Poaceae 3-2016
Primulaceae	*Samolus*	*ebracteatus*	bractless brookweed	Sam-ebr
Scrophulariaceae	*Agalinis*	*maritima var. grandiflora*	seaside Agalinis	Aga-mar
Scrophulariaceae	*Bacopa*	*monnieri*	coastal water hyssop	Bac-mon
Solanaceae	*Lycium*	*carolinianum*	Carolina wolfberry	Lyc-car
Vitaceae	*Cissus*	*trifoliata*	cow-itch vine	Cis-tri
?	*?*	*?*	unknown 1	Unk. 1-2015
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2016
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2018
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2020
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2021
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2022
?	*?*	*?*	unknown forb 2	Unk. Forb 2-2016
?	*?*	*?*	unknown forb 2	Unk. Forb 2-2018
?	*?*	*?*	unknown forb 2	Unk. Forb 2-2021
?	*?*	*?*	unknown forb 3	Unk. Forb 3-2016
?	*?*	*?*	unknown succulent 1	Unk. Succ 1-2018
?	*?*	*?*	unknown succulent 1	Unk. Succ 1-2019
?	*?*	*?*	unknown vine 1	Unk. Vine 1-2016
?	*?*	*?*	unknown vine 1	Unk. Vine 1-2018
?	*?*	*?*	unknown vine 1	Unk. Vine 1-2019
?	*?*	*?*	unknown vine 2	Unk. Vine 2-2016
?	*?*	*?*	unknown vine 2	Unk. Vine 2-2019

Table 1.2b. Species list of plants found within the Boca Chica Beach, TX intensive vegetation monitoring area since 2015. Species code is made up of the first three letters of the genus name and the first three letters of the species name. Species are in alphabetical order by genus and species. Not all plants possessed the structures necessary for definitive identification.

Family	Genus	Species	Common Name	Species Code
Scrophulariaceae	*Agalinis*	*maritima var. grandiflora*	seaside Agalinis	Aga-mar
Amaranthaceae	*Amaranthus*	*greggii*	Gregg's amaranth	Ama-gre
Acanthaceae	*Avicennia*	*germinans*	black mangrove	Avi-ger
Scrophulariaceae	*Bacopa*	*monnieri*	coastal water hyssop	Bac-mon
Bataceae	*Batis*	*maritima*	saltwort, vidrillos	Bat-mar
Amaranthaceae	*Blutaparon*	*vermiculare*	silverhead	Blu-ver
Cyperaceae	*Bolboschoenus*	*maritimus*	cosmopolitan bulrush	Bol-mar
Asteraceae	*Borrichia*	*frutescens*	sea ox-eye daisy	Bor-fru
Brassicaceae	*Cakile*	*lanceolatum*	coastal searocket	Cak-lan
Onagraceae	*Calylophus*	*australis*	square bud primrose	Cal-aus
Cyperaceae	*Carex*	*?*	true sedge	Car-sp.
Leguminosae	*Chamaecrista*	*fasciculata*	partridge pea	Cha-fas
Euphorbiaceae	*Chamaesyce*	*cordifolia*	heartleaf sandmat	Cha-cor
Acanthaceae	*Chromolaena*	*odorata*	blue mistflower, crucita	Chr-odo
Vitaceae	*Cissus*	*trifoliata*	cow-itch vine	Cis-tri
Convolvulaceae	*Cressa*	*nudicaulis*	nakedstem alkaliweed	Cre-nud
Asclepiadaceae	*Cynanchum*	*angustifolius*	Gulf Coast swallow-wort	Cyn-ang
Leguminosae	*Dalea*	*emarginata*	prairie clover	Dal-ema
Poaceae	*Distichlis*	*spicata*	seashore saltgrass	Dis-spi
Poaceae	*Eragrostis*	*secundiflora*	red lovegrass	Era-sec
Asteraceae	*Erigeron*	*procumbens*	prostrate fleabane	Eri-pro
Euphorbiaceae	*Euphorbia*	*corollata*	Flowering spurge	Eup-cor
Gentianaceae	*Eustoma*	*exaltatum*	catchfly prairie gentian	Eus-exa
Cyperaceae	*Fimbristylis*	*castanea*	coastal marsh fimbry	Fim-cas
Asteraceae	*Gaillardia*	*pulchella var. australis*	firewheel	Gai-pul
Fabaceae	*Galactica*	*canescens*	hoary milkpea	Gal-can
Onagraceae	*Gaura*	*sinuata*	wavy leaved Gaura	Gau-sin
Asteraceae	*Heterotheca*	*subaxillaris*	camphor weed	Het-sub
Asteraceae	*Iva*	*angustifolia*	narrowleaf marshelder	Iva-ang
Juncaceae	*Juncus*	*effusus*	soft rush	Jun-eff
Juncaceae	*Juncus*	*?*	rush	Jun-sp.
Plumbaginaceae	*Limonium*	*carolinianum*	sea lavender	Lim-car
Linaceae	*Linum*	*alatum*	winged flax	Lin-ala
Solanaceae	*Lycium*	*carolinianum*	Carolina wolfberry	Lyc-car
Poaceae	*Monanthochloe*	*littoralis*	shoregrass	Mon-lit
Onagraceae	*Oenothera*	*drummondii*	beach evening primrose	Oen-dru
Cactaceae	*Opuntia*	*engelmannii*	Texas prickly pear	Opu-eng
Poaceae	*Panicum*	*amarum*	bitter panicum	Pan-ama
Poaceae	*Panicum*	*virgatum*	switchgrass	Pan-vir
Poaceae	*Paspalum*	*notatum*	bahiagrass	Pas-not
Poaceae	*Paspalum*	*?*	paspalum	Pas-sp.
Fabaceae	*Pediomelum*	*rhombifolium*	round leaf scurf pea	Ped-rho
Fabaceae	*Prosopis*	*reptans*	screwbean mesquite	Pro-rep

Family	Genus	Species	Common Name	Species Code
Asteraceae	*Rayjacksonia*	*phyllocephala*	camphor daisy	Ray-phy
Gentianaceae	*Sabatia*	*arenicola*	salt marsh pink	Sab-are
Chenopodiaceae	*Salicornia*	*bigelovii*	annual saltwort	Sal-big
Chenopodiaceae	*Salicornia*	*depressa*	glasswort	Sal-dep
Primulaceae	*Samolus*	*ebracteatus*	bractless brookweed	Sam-ebr
Poaceae	*Schizachyrium*	*scoparium*	seacoast bluestem	Sch-sco
Aizoaceae	*Sesuvium*	*portulacastrum*	sea purslane, cenicilla	Ses-por
Aizoaceae	*Sesuvium*	*verrucosum*	winged sea purslane	Ses-ver
Asteraceae	*Solidago*	*sempervirens*	seaside goldenrod	Sol-sem
Poaceae	*Spartana*	*spartinae*	Gulf cordgrass	Spa-spa
Poaceae	*Spartina*	*patens*	saltmeadow cordgrass	Spa-pat
Poaceae	*Sporobolus*	*airoides*	alkali Sacaton	Spo-air
Poaceae	*Sporobolus*	*virginicus*	seashore dropseed	Spo-vir
Chenopodiaceae	*Suaeda*	*linearis*	annual seepweed	Sua-lin
Chenopodiaceae	*Suaeda*	*tampicensis*	coastal seepweed	Sua-tam
Asteraceae	*Thelesperma*	*ambiguum*	ambiguous green thread	The-amb
Amaranthaceae	*Tidestromia*	*lanuginosa*	woolly tidestromia	Tid-lan
Poaceae	*Uniola*	*paniculata*	sea oats	Uni-pan
Asteraceae	*?*	*?*	unknown aster 1	Asteraceae 1-2016
Cyperaceae	*?*	*?*	unknown sedge 1	Cyperaceae 1-2020
Poaceae	*?*	*?*	unknown grass 1	Poaceae 1-2016
Poaceae	*?*	*?*	unknown grass 1	Poaceae 1-2021
Poaceae	*?*	*?*	unknown grass 1	Poaceae 1-2022
Poaceae	*?*	*?*	unknown grass 2	Poaceae 2-2016
Poaceae	*?*	*?*	unknown grass 2	Poaceae 2-2022
Poaceae	*?*	*?*	unknown grass 3	Poaceae 3-2016
?	*?*	*?*	unknown 1	Unk. 1-2015
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2016
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2018
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2020
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2021
?	*?*	*?*	unknown forb 1	Unk. Forb 1-2022
?	*?*	*?*	unknown forb 2	Unk. Forb 2-2016
?	*?*	*?*	unknown forb 2	Unk. Forb 2-2018
?	*?*	*?*	unknown forb 2	Unk. Forb 2-2021
?	*?*	*?*	unknown forb 3	Unk. Forb 3-2016
?	*?*	*?*	unknown succulent 1	Unk. Succ 1-2018
?	*?*	*?*	unknown succulent 1	Unk. Succ 1-2019
?	*?*	*?*	unknown vine 1	Unk. Vine 1-2016
?	*?*	*?*	unknown vine 1	Unk. Vine 1-2018
?	*?*	*?*	unknown vine 1	Unk. Vine 1-2019
?	*?*	*?*	unknown vine 2	Unk. Vine 2-2016
?	*?*	*?*	unknown vine 2	Unk. Vine 2-2019

Table 1.3. Percent cover by species or category within each vegetation zone by year from 2018–2022. Unobserved species are blank. Species cover values in creep plots were first quantified by PI Gabler in 2016. Data from 2015 and 2016 are not shown. Colored cell shading reflects cell values and is included strictly as a visual aid to identify patterns and relatively higher or lower values.

Species / Category	**Mudflats**					**Transition**					**Dunes**					**Creep**				
	'18	**'19**	**'20**	**'21**	**'22**	**'18**	**'19**	**'20**	**'21**	**'22**	**'18**	**'19**	**'20**	**'21**	**'22**	**'18**	**'19**	**'20**	**'21**	**'22**
Bare ground	98.4	98.1	98.1	98.1	98.5	78.6	82.1	82.4	82.5	83.0	67.2	73.5	75.0	74.2	73.2	86.1	83.2	79.4	84.3	79.9
Aga-mar						0.4	0.2		0.1	0.1	1.4	1.4	0.4		0.8		0.3			
Ama-gre							0.1					0.2								
Avi-ger									0.0	0.1										
Bac-mon						0.1														
Bat-mar						1.9	1.7	2.3	2.0	1.4										
Blu-ver						0.5	0.4	0.7	0.8	0.9				0.5	0.3					
Bol-mar												0.2								
Bor-fru						0.5	0.2	0.2	0.3	0.2	0.2	0.1		0.0	0.1					
Cak-lan											0.2									
Cal-aus						0.5					1.1	0.1								
Car-sp.						0.1	0.1	0.3	0.1	0.1	0.1	0.2	0.3	2.6	5.4				0.3	
Cha-fas						1.2	1.1	0.9		0.0	10.9	8.9	2.2		0.5					
Chr-odo										0.3					0.4					
Cis-tri													0.2							
Cre-nud									0.1	0.0										0.3
Dal-ema														0.1						
Dis-spi	0.1	0.1	0.1	0.0	0.0	4.5	2.7	2.5	2.4	2.0	0.6	0.2	0.6	1.2	1.0	0.8	0.2	0.3	0.5	1.1
Era-sec											1.1					0.2				
Eus-exa									0.0											
Fim-cas						1.2	0.4	0.4	0.6	0.2	1.8	1.5	1.5	1.1	0.6		0.1			
Gai-pul						0.1			0.1				0.2	0.5						
Het-sub							0.2	0.1	0.1			1.0	1.0	0.2	1.8					
Iva-ang										0.0					1.8					
Jun-eff									0.0	0.6										
Jun-sp.									0.1					2.5						
Lim-car				0.0	0.0	0.3	0.4	0.5	0.6	0.3	0.2	0.1		0.2	0.1	0.1	0.3		0.2	0.1
Lin-ala									0.0	0.0		0.3	0.2	0.2	0.1					
Lyc-car						0.1	0.1	0.1	0.1	0.0										
Mon-lit	1.2	1.7	1.6	1.8	0.7	3.7	3.4	2.8	2.0	0.5						7.7	11.3	14.7	9.7	15.0

Species / Category	Mudflats					Transition					Dunes					Creep				
	'18	'19	'20	'21	'22	'18	'19	'20	'21	'22	'18	'19	'20	'21	'22	'18	'19	'20	'21	'22
Oen-dru								0.1	0.5				1.5	1.5				0.1	0.2	
Pan-ama							0.1			0.0		0.3	1.0	0.4	0.1					
Pan-vir									0.3										1.7	
Pan-sp.									0.3	1.2				0.2	0.4					
Pas-not						0.8		0.1			0.4									
Pro-rep						0.3	0.2	0.2	0.1	0.1				0.4		0.6	0.2	0.2	0.1	
Ray-phy						1.3	1.4	0.4	0.7	0.3	4.5	1.4	1.1	1.0	0.1	1.5	0.3	0.5	1.0	
Sab-are														0.1						
Sal-big					0.0				0.0							0.2	0.2	0.1		0.1
Sal-dep				0.1		1.3	0.8	1.4	2.9	1.7						0.8	0.8	0.5	0.6	0.4
Sam-ebr						0.1	0.1	0.2	0.1	0.0	2.6	2.0	1.8	1.2	0.3		0.8	2.0		
Sch-sco						1.0	0.6	1.6	1.0	2.2	5.7	5.4	7.5	7.4	8.0		0.3	1.2	0.3	
Ses-por	0.2	0.1	0.1			0.2	0.1		0.0							1.7	1.0	0.8	1.0	1.7
Sol-sem						0.4	0.8	1.2		0.6	1.8	1.9	4.1		1.5	0.3	0.3	0.3		
Spa-pat							0.1		1.4			0.9	0.3	3.6					0.2	
Spa-spa						0.1	0.7	0.2	0.2	0.2		0.4		0.3						
Spo-air										0.4					0.3					
Spo-vir							1.2	0.5	0.3			0.1	0.8	0.3						
Sua-lin						0.5	0.4	0.5	0.2	0.1			0.1			0.2	0.8		0.2	0.1
Tid-lan									0.1						0.5					
Uni-pan															0.3					
Poaceae 1-2021														0.2						
Poaceae 1-2022										0.1					1.0					
Poaceae 2-2016																				
Poaceae 2-2022															0.3					
Unk. Forb 1-2018						0.1														
Unk. Forb 1-2020													0.2							
Unk. Forb 1-2021									0.1					0.2						
Unk. Forb 1-2022															0.7					
Unk. Forb 2-2021									0.0											
Unk. Vine 1-2018											0.2									
Unk. Vine 1-2019							0.1													
Unk. Vine 2-2019												0.3								
Total Species	6	8	7	4	4	34	35	32	36	29	21	23	21	25	24	11	14	11	13	8

Table 1.4. The percent cover, changes in percent cover between consecutive sampling periods, and abundance ranks for all 11 species observed in bare type plots (mudflats) since 2018, ordered by their 2022 live plant cover values. Colored cell shading reflects cell values and is included strictly as a visual aid to identify patterns and relatively higher or lower values.

Bare plots (mudflats)														
Species / Category	**Cover (%)**					**Change in Cover (%)**				**Rank**				
	2018	**2019**	**2020**	**2021**	**2022**	**2018-19**	**2019-20**	**2020-21**	**2021-22**	**2018**	**2019**	**2020**	**2021**	**2022**
All plants	1.56	1.92	1.86	1.87	0.80	0.36	-0.06	0.01	-1.07	-	-	-	-	-
Mon-lit	1.24	1.72	1.64	1.78	0.73	0.48	-0.08	0.14	-1.04	1	1	1	1	1
Dis-spi	0.05	0.06	0.09	0.03	0.04	0.01	0.03	-0.06	0.01	3	3	2	3	2
Sal-big	0	0	0	0	0.02	0	0	0	0.02	.	.	.	.	3
Lim-car	0	0	0	0.01	0.01	0	0	0.01	0.00	.	.	.	4	4
Sal-dep	0.01	0.01	0.03	0.05	0	0	0.02	0.02	-0.05	6	7	4	2	.
Ses-por	0.21	0.07	0.05	0	0	-0.14	-0.02	-0.05	0	2	2	3	.	.
Blu-ver	0.02	0.01	0.03	0	0	-0.01	0.02	-0.03	0	5	7	5	.	.
Bor-fru	0.03	0.02	0.02	0	0	-0.01	0	-0.02	0	4	4	6	.	.
Sam-ebr	0	0	0.01	0	0	0	0.01	-0.01	0	.	.	7	.	.
Aga-mar	0	0.02	0	0	0	0.02	-0.02	0	0	.	4	.	.	.
Ray-phy	0	0.02	0	0	0	0.02	-0.02	0	0	.	4	.	.	.

Table 1.5. The percent cover, changes in percent cover between consecutive sampling periods, and abundance ranks for all 45 species observed in transition type plots since 2018, ordered by their 2022 live plant cover values. Colored cell shading reflects cell values and is included strictly as a visual aid to identify patterns and relatively higher or lower values.

Transition plots														
Species / Category	Cover (%)					Change in Cover (%)				Rank				
	2018	2019	2020	2021	2022	2018-19	2019-20	2020-21	2021-22	2018	2019	2020	2021	2022
All plants	21.38	17.86	17.63	17.57	13.97	-3.52	-0.23	-0.06	-3.60	-	-	-	-	-
Sch-sco	1.02	0.61	1.64	0.98	2.22	-0.41	1.03	-0.66	1.24	8	10	4	6	1
Dis-spi	4.49	2.65	2.48	2.35	2.05	-1.84	-0.17	-0.13	-0.30	1	2	2	2	2
Sal-dep	1.3	0.77	1.43	2.87	1.66	-0.53	0.66	1.44	-1.21	4	8	5	1	3
Bat-mar	1.89	1.68	2.25	1.95	1.44	-0.21	0.57	-0.30	-0.51	3	3	3	4	4
Pan-sp.	0	0	0	0.26	1.24	0	0	0.26	0.99	.	.	.	15	5
Blu-ver	0.46	0.43	0.7	0.78	0.88	-0.03	0.27	0.08	0.10	12	11	8	7	6
Jun-eff	0	0	0	0.05	0.61	0	0	0.05	0.56	.	.	.	30	7
Sol-sem	0.39	0.82	1.23	1.41	0.60	0.43	0.41	0.18	-0.82	14	7	6	5	8
Mon-lit	3.71	3.4	2.83	2.00	0.51	-0.31	-0.57	-0.83	-1.49	2	1	1	3	9
Spo-air	0	0	0	0	0.44	0	0	0.00	0.44	.	.	.	.	10
Lim-car	0.32	0.4	0.5	0.61	0.34	0.08	0.1	0.11	-0.27	15	12	10	9	11
Chr-odo	0	0	0	0	0.30	0	0	0	0.30	.	.	.	.	12
Ray-phy	1.26	1.37	0.44	0.68	0.29	0.11	-0.93	0.24	-0.39	5	4	12	8	13
Fim-cas	1.19	0.38	0.39	0.57	0.23	-0.81	0.01	0.18	-0.34	7	14	13	10	14
Bor-fru	0.52	0.23	0.18	0.28	0.21	-0.29	-0.05	0.10	-0.07	11	15	17	14	15
Spa-spa	0.12	0.74	0.17	0.24	0.20	0.62	-0.57	0.07	-0.05	19	9	18	16	16
Avi-ger	0	0	0	0.01	0.11	0	0	0.01	0.10	.	.	.	33	17
Pro-rep	0.29	0.15	0.23	0.12	0.11	-0.14	0.08	-0.11	-0.01	16	18	15	18	18
Aga-mar	0.44	0.18	0.04	0.10	0.09	-0.26	-0.14	0.06	-0.01	13	17	25	23	19
Sua-lin	0.52	0.39	0.54	0.20	0.09	-0.13	0.15	-0.34	-0.11	10	13	9	17	20
Car-sp.	0.07	0.13	0.32	0.11	0.07	0.06	0.19	-0.21	-0.04	20	20	14	21	21
Poaceae 1-2022	0	0	0	0	0.06	0	0	0	0.06	.	.	.	.	22
Lin-ala	0	0.02	0.01	0.02	0.05	0.02	-0.01	0.01	0.02	.	27	30	31	23
Iva-ang	0	0	0	0	0.05	0	0	0.00	0.05	.	.	.	.	23
Cre-nud	0	0	0	0.07	0.04	0	0	0.07	-0.04	.	.	.	26	25
Pan-ama	0	0.1	0.02	0	0.04	0.1	-0.08	-0.02	0.04	.	24	27	.	25
Lyc-car	0.06	0.1	0.08	0.11	0.02	0.04	-0.02	0.03	-0.09	21	22	21	22	27
Sam-ebr	0.14	0.14	0.21	0.12	0.02	0	0.07	-0.09	-0.10	18	19	16	19	28

Transition plots														
Species / Category	**Cover (%)**					**Change in Cover (%)**				**Rank**				
	2018	**2019**	**2020**	**2021**	**2022**	**2018-19**	**2019-20**	**2020-21**	**2021-22**	**2018**	**2019**	**2020**	**2021**	**2022**
Cha-fas	1.19	1.1	0.9	0	0.01	-0.09	-0.2	-0.9	0.01	6	6	7	.	29
Oen-dru	0	0	0.14	0.49	0	0	0.14	0.35	-0.49	.	.	20	11	.
Pan-vir	0	0	0	0.29	0	0	0	0.29	-0.29	.	.	.	12	.
Spo-vir	0	1.24	0.48	0.29	0	1.24	-0.76	-0.19	-0.29	.	5	11	13	.
Unk. Forb 1-2021	0	0	0	0.12	0	0	0	0.12	-0.12	.	.	.	20	.
Het-sub	0	0.21	0.14	0.10	0	0.21	-0.07	-0.04	-0.10	.	16	19	24	.
Jun-sp.	0	0	0	0.10	0	0	0	0.10	-0.10	.	.	.	25	.
Gai-pul	0	0	0	0.07	0	0	0	0.07	-0.07	.	.	.	27	.
Spa-pat	0	0.1	0.05	0.07	0	0.1	-0.05	0.02	-0.07	.	23	23	28	.
Tid-lan	0	0	0	0.07	0	0	0	0.07	-0.07	.	.	.	29	.
Eus-exa	0	0	0	0.02	0	0	0	0.02	-0.02	.	.	.	32	.
Sal-big	0.01	0.02	0.05	0.01	0	0.01	0.03	-0.04	-0.01	22	26	24	34	.
Ses-por	0.21	0.11	0.04	0.01	0	-0.1	-0.07	-0.03	-0.01	17	21	26	35	.
Unk. Forb 2-2021	0	0	0	0.01	0	0	0	0.01	-0.01	.	.	.	36	.
Pas-not	0.76	0.04	0.07	0	0	-0.72	0.03	-0.07	0	9	25	22	.	.
Cyperaceae 1-2020	0	0	0.02	0	0	0	0.02	-0.02	0	.	.	28	.	.
Unk. Forb 1-2020	0	0	0.02	0	0	0	0.02	-0.02	0	.	.	29	.	.

Table 1.6. The percent cover, changes in percent cover between consecutive sampling periods, and abundance ranks for all 45 species observed in dune type plots since 2018, ordered by their 2022 live plant cover values. Colored cell shading reflects cell values and is included strictly as a visual aid to identify patterns and relatively higher or lower values.

Dune plots														
Species / Category	**Cover (%)**					**Change in Cover (%)**				**Rank**				
	2018	**2019**	**2020**	**2021**	**2022**	**2018-19**	**2019-20**	**2020-21**	**2021-22**	**2018**	**2019**	**2020**	**2021**	**2022**
All plants	32.77	26.54	25.04	26.19	26.39	-6.23	-1.5	1.15	0.20	-	-	-	-	-
Sch-sco	5.65	5.38	7.46	7.38	7.96	-0.27	2.08	-0.08	0.58	2	2	1	1	1
Car-sp.	0.08	0.19	0.31	2.62	5.39	0.11	0.12	2.31	2.78	16	15	14	3	2
Het-sub	0	1.04	1.04	0.23	1.82	1.04	0	-0.81	1.59	.	8	8	17	3
Iva-ang	0	0	0	0	1.79	0	0	0	1.79	.	.	.	.	4
Sol-sem	1.77	1.88	4.12	3.58	1.50	0.11	2.24	-0.54	-2.08	5	4	2	2	5
Poaceae 1-2022	0	0	0	0	1.04	0	0	0	1.04	.	.	.	.	6
Dis-spi	0.58	0.15	0.58	1.15	1.00	-0.43	0.43	0.57	-0.15	10	16	11	7	7
Aga-mar	1.42	1.42	0.38	0	0.75	0	-1.04	-0.38	0.75	7	6	12	.	8
Unk. Forb 1-2022	0	0	0	0	0.71	0	0	0	0.71	.	.	.	.	9
Fim-cas	1.77	1.46	1.46	1.12	0.57	-0.31	0	-0.34	-0.54	5	5	5	8	10
Cha-fas	10.92	8.92	2.23	0	0.5	-2	-6.69	-2.23	0.5	1	1	3	.	11
Tid-lan	0	0	0	0	0.5	0	0	0	0.5	.	.	.	.	12
Pan-sp.	0	0	0	0.19	0.43	0	0	0.19	0.24	.	.	.	19	13
Chr-odo	0	0	0	0	0.36	0	0	0	0.36	.	.	.	.	14
Blu-ver	0	0	0.04	0.54	0.29	0	0.04	0.50	-0.25	.	.	20	10	15
Poaceae 2-2022	0	0	0	0	0.29	0	0	0	0.29	.	.	.	.	16
Sam-ebr	2.58	2	1.85	1.19	0.29	-0.58	-0.15	-0.66	-0.91	4	3	4	6	17
Spo-air	0	0	0	0	0.29	0	0	0	0.29	.	.	.	.	18
Uni-pan	0	0	0	0	0.29	0	0	0	0.29	.	.	.	.	19
Bor-fru	0.23	0.08	0	0.04	0.14	-0.15	-0.08	0.04	0.10	12	18	.	25	20
Pan-ama	0.04	0.31	1	0.38	0.14	0.27	0.69	-0.62	-0.24	17	11	9	12	21
Ray-phy	4.46	1.42	1.08	0.96	0.14	-3.04	-0.34	-0.12	-0.82	3	6	7	9	22
Lim-car	0.23	0.08	0	0.15	0.11	-0.15	-0.08	0.15	-0.05	12	18	.	21	23
Lin-ala	0.04	0.27	0.15	0.23	0.11	0.23	-0.12	0.08	-0.12	17	13	17	18	24
Jun-sp.	0	0	0	2.54	0	0	0	2.54	-2.54	.	.	.	4	.
Oen-dru	0	0	1.46	1.50	0	0	1.46	0.04	-1.50	.	.	6	5	.
Gai-pul	0.04	0	0.23	0.50	0	-0.04	0.23	0.27	-0.50	17	.	15	11	.
Pro-rep	0	0	0	0.38	0	0	0	0.38	-0.38	.	.	.	13	.

Dune plots														
Species / Category	Cover (%)					Change in Cover (%)				Rank				
	2018	2019	2020	2021	2022	2018-19	2019-20	2020-21	2021-22	2018	2019	2020	2021	2022
Spa-pat	0	0.92	0.31	0.38	0	0.92	-0.61	0.07	-0.38	.	9	13	14	.
Spa-spa	0	0.38	0	0.31	0	0.38	-0.38	0.31	-0.31	.	10	.	15	.
Spo-vir	0	0.08	0.85	0.31	0	0.08	0.77	-0.54	-0.31	.	21	10	16	.
Poaceae 1-2021	0	0	0	0.19	0	0	0	0.19	-0.19	.	.	.	20	.
Unk. Forb 1-2021	0	0	0	0.15	0	0	0	0.15	-0.15	.	.	.	22	.
Dal-ema	0	0	0	0.08	0	0	0	0.08	-0.08	.	.	.	23	.
Sab-are	0	0	0	0.08	0	0	0	0.08	-0.08	.	.	.	24	.
Unk. Forb 1-2020	0	0	0.23	0	0	0	0.23	-0.23	0	.	.	16	.	.
Cis-tri	0	0	0.15	0	0	0	0.15	-0.15	0	.	.	18	.	.
Sua-lin	0	0	0.08	0	0	0	0.08	-0.08	0	.	.	19	.	.
Opu-eng	0	0	0.04	0	0	0	0.04	-0.04	0	.	.	21	.	.
Unk. Vine 2-2019	0	0.31	0	0	0	0.31	-0.31	0	0	.	11	.	.	.
Ama-gre	0	0.23	0	0	0	0.23	-0.23	0	0	.	14	.	.	.
Bol-mar	0	0.15	0	0	0	0.15	-0.15	0	0	.	16	.	.	.
Cal-aus	1.08	0.08	0	0	0	-1	-0.08	0	0	8	18	.	.	.
Unk. Succ 1-2019	0	0.04	0	0	0	0.04	-0.04	0	0	.	22	.	.	.
Unk. Vine 1-2019	0	0.04	0	0	0	0.04	-0.04	0	0	.	23	.	.	.

Table 1.7. The percent cover, changes in percent cover between consecutive sampling periods, and abundance ranks for all 19 species observed in creep type plots since 2018, ordered by their 2022 live plant cover values. Colored cell shading reflects cell values and is included strictly as a visual aid to identify patterns and relatively higher or lower values.

Creep plots														
Species / Category	Cover (%)					Change in Cover (%)				Rank				
	2018	2019	2020	2021	2022	2018-19	2019-20	2020-21	2021-22	2018	2019	2020	2021	2022
All plants	13.92	16.83	20.58	15.67	18.79	2.91	3.75	-4.91	3.12	-	-	-	-	-
Mon-lit	7.67	11.33	14.67	9.67	15.00	3.66	3.34	-5.00	5.33	1	1	1	1	1
Ses-por	1.67	1	0.83	1.00	1.71	-0.67	-0.17	0.17	0.71	2	2	4	4	2
Dis-spi	0.83	0.17	0.25	0.50	1.14	-0.66	0.08	0.25	0.64	4	11	8	6	3
Sal-dep	0.75	0.83	0.5	0.58	0.36	0.08	-0.33	0.08	-0.23	5	3	5	5	4
Cre-nud	0	0	0	0	0.29					.	.	.	.	5
Lim-car	0.08	0.25	0	0.17	0.14	0.17	-0.25	0.17	-0.02	11	9	.	9	6
Sua-lin	0.17	0.75	0	0.17	0.07	0.58	-0.75	0.17	-0.10	8	5	.	12	7
Sal-big	0.17	0.17	0.08	0	0.07	0	-0.09	-0.08	0.071429	8	11	10	.	7
Pan-vir	0	0	0	1.67	0	0	0	1.67	-1.67	.	.	.	2	.
Ray-phy	1.5	0.33	0.5	1.00	0	-1.17	0.17	0.50	-1.00	3	6	6	3	.
Car-sp.	0	0	0	0.25	0	0	0	0.25	-0.25	.	.	.	7	.
Sch-sco	0	0.33	1.17	0.25	0	0.33	0.84	-0.92	-0.25	.	6	3	8	.
Oen-dru	0	0	0.08	0.17	0	0	0.08	0.09	-0.17	.	.	11	10	.
Sol-sem	0.33	0.25	0.33	0.17	0	-0.08	0.08	-0.16	-0.17	7	9	7	11	.
Pro-pub	0.58	0.17	0.17	0.08	0	-0.41	0	-0.09	-0.08	6	11	9	13	.
Sam-ebr	0	0.83	2	0	0	0.83	1.17	-2	0	.	3	2	.	.
Aga-mar	0	0.33	0	0	0	0.33	-0.33	0	0	.	6	.	.	.
Fim-cas	0	0.08	0	0	0	0.08	-0.08	0	0	.	14	.	.	.
Era-sec	0.17	0	0	0	0	-0.17	0	0	0	8	.	.	.	.

surrounding transitional salt prairie habitats in some areas, but this pattern was influenced strongly by individual plots that showed large increases in 2019 and 2020 (e.g., B1) because there were only six creep plots. Last year, we suggested that the spike in ground disturbance by machinery and ATV traffic observed in 2021 may have been the key driver of the observed decrease in plant cover in creep plots in 2021, and this year's observed sharp increase in creep cover represents evidence in support of that hypothesis. These vegetation margins appear to be favored traffic lanes, likely because the ground is firmer than in the mudflats but less vegetated than farther upland. This merits further examination, including manipulative experimentation, to better understand these patterns and their drivers. We also suggest adding additional creep plots to better monitor these changes.

In all years, the most species observed in a given year were found in transitional salt flats (25–36 species) and dunes (16–25 species) (**Table 1.3** bottom row). Importantly, the average percent cover of any single species rarely exceeded 5% cover. The most abundant species within each zone differed between years. Changes in coverage of the observed species and changes in those species' rank order by abundance are presented in **Table 1.4** for bare plots (mudflats), in **Table 1.5** for transition plots, in **Table 1.6** for dune plots, and in **Table 1.7** for creep plots.

In bare plots (mudflats), all vegetation is rare and only 4 species were present. *Monanthochloe littoralis* has consistently been the most abundant species in mudflats but was always uncommon (1.2-1.8% cover from 2018–2021), and it decreased sharply in 2022 to 0.73% cover (**Table 1.3 and 2.4**). Next most common over time has been *Distichlis spicata*, but its cover in mudflat plots has remained below 0.1%. *Sesuvium portulacastrum* was second most abundant in 2018 and 2019 and third most abundant in 2020, but was not observed at all in mudflat plots in 2021 and 2022. *Salicornia bigelovii* appeared in mudflat plots for the first time in 2022 and was third most abundant with 0.02% cover.

In transition zones, the most abundant species used to be *Monanthochloe littoralis* and *Distichlis spicata*, but both have showed a clear and striking downward trend; *Monanthochloe* decreased from 3.7% in 2018 to 0.5% in 2022, while *Distichlis* decreased from 4.5% to 2.0% in the same period (**Table 1.3 and 2.5**). Even if cover values in 2018 were unusually high due to interannual variation, the trend has been consistently downward every year for the last 5 years. *Chamaecrista fasciculata* and *Rayjacksonia phyllocephala* also showed similar but less intense decreases in transition zones in the same period. *Salicornia depressa*, which has increased in abundance during the monitoring period, surpassed *Monanthochloe* and *Distichlis* as the most abundant species in 2021 with 2.9% cover, but it decreased to 1.7% cover in 2022. *Schizachyrium scoparium* and *Batis maritima* have also been consistently abundant but variable.

In the dunes, *Schizachyrium scoparium* was most abundant from 2020-2022 (7.4–8.0% cover) and second most abundant in 2018 and 2019 (5.4–5.7%) (**Table 1.3 and 2.6**). *Carex spp*. were second most common in 2022 (5.4%) and third most common in 2021 (2.6%) but were far less common in prior years. Similarly, *Heterotheca subaxillaris* was third most abundant in 2022 (1.82%) but rare previously, whereas *Iva angustifolia* was fourth most common in 2022 (1.79%) and not previously observed in dune plots. *Chamaecrista fasciculata* was the most abundant plant in dunes from 2016–2019 (8.9–10.9%), but its cover decreased significantly in 2020 (2.2%), it was not observed in any dune plots in 2021, and it was rare in 2022 (0.5%). *Samolus* *ebracteatus* also decreased substantially this year from relative prominence before 2022 (1.2-2.6%) to rarity in 2022 (0.3%). *Solidago sempervirens* had been very abundant in 2020 and 2021 (3.6–4.1%) but returned to pre-2020 levels in 2022 (1.5%).

In creep plots, *Monanthochloe littoralis* has consistently been the most abundant species by a very wide margin, ranging from 5.8%–15.0% cover from 2016-2022 (**Table 1.3 and 2.7**). This has included a consistent upward trend for *Monanthochloe* and overall, except for a notable decrease in 2021, that may suggest vegetation expansion into the mudflats (discussed above). *Sesuvium portulacastrum* and *Salicornia depressa* have also consistently been common in creep plots, with cover values of 0.8–1.7% and 0.4-0.8%, respectively. In 2020, we saw relatively high abundances and large single-year increases for *Samolus ebracteatus* (2.0%, up from 0.8%) and *Schizachyrium* (1.2%, up from 0.3%), but, by 2021, *Samolus* was absent (0% cover) and *Schizachyrium* was uncommon (0.3%), and both were absent from creep plots in 2022. The fifth most common creep species in 2022 (0.3%) was *Cressa nudicaulis*, which was not previously observed in any creep plots. In 2021, the second-most common species was tentatively identified as *Panicum virgatum*, which is a weedy native grass not normally associated with dunes that was not previously observed in the area; however, it was not detected in creep plots in 2022.

Table 1.8a and **2.8b** list percent cover by plant species within the monitoring and take zones from 2016–2021. Both tables present the same data but group the data differently to illustrate two key factors. First, **Table 1.8a** groups cover data by year to directly compare plant communities between the monitoring and take zones for each sampling period. If proximity to the launch pad site is influencing plant community structure, we would expect to see significant differences between these zones and for these differences to increase over time. However, the observed differences between zones were largely modest for most species and more subtle than the differences observed between habitat types. Species composition and even the abundance of individual species are largely consistent for most species, and much of the variability that does exist between monitoring and take zones, such as differences in abundance of *Batis maritima*, *Blutaparon vermiculare*, and *Suaeda linearis* are related to and cannot be fully disentangled from the differences in each zone's relative proportions of bare, transition, and dune plot types, which differ noticeably in terms of plant community structure. However, our statistical analyses below do a good job of separating and assessing the effects of individual factors, e.g., habitat type vs. monitoring zone effects, especially because we use full factorial ANOVAs with Type III sums of squares. Other differences, especially those that change over time, are less explainable by differences in the proportions of plots representing different habitat types. The abundance of *Distichlis spicata* remains relatively consistent over time in monitoring plots (0.5-1.2%), but there is a considerable downward trend in take plots only, going from 2.9% cover in 2016 to 1.9% in 2019 and finally to 1.1% in 2022. The previously described changes observed for *Monanthochloe littoralis* went largely back to normal in 2022 after a reversal in abundances in 2021, though its abundance was lower than usual and there was a clear trend for increase in take plots before 2022. *Salicornia depressa* went from being comparably uncommon (ca. 0.2–0.5% cover) in both zones to being rare in monitoring plots (0.1%) but one of the most common species (2.9%) in take plots in 2021. The abundance of *S. depressa* in take plots went down nearly 50% in 2022, but it remains dramatically overrepresented in take plots compared to monitoring plots.

Table 1.8a. Percent cover by species or category within the monitoring and take zones from 2016–2022. Data are grouped by year to juxtapose the monitoring and take zones for a given sampling period. Colored cell shading reflects cell values and is included strictly as a visual aid to identify patterns and relatively higher or lower values.

Species / Category	2016		2018		2019		2020		2021		2022	
	Monitor	Take	Monitor	Take	Monitor	Take	Monitor	Take	Monitor	Take	Monitor	Take
Bare ground	89.7	88.5	87.6	87	89.2	88.5	90.4	86.6	90.9	86.2	89.1	89.5
Dead vegetation	-	-	-	-	-	-	-	-	-	-	0.9	2.6
Aga-mar	0.1		0.4	0.1	0.3	0.2	0.1		0.0	0.0	0.1	0.2
Ama-gre						0.2						
Avi-ger										0.0	0.0	0.0
Bac-mon			0.1									
Bat-mar	0.7		1		0.9		1.2	0.1	1.0	0.0	0.7	0.0
Blu-ver	0.1	0.3		0.5		0.4	0.1	0.6	0.2	0.7	0.1	0.8
Bor-fru	0.1	0.1	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Cal-aus			0.2	0.6								
Car-sp.			0.1		0.1		0.2		0.5	0.1	0.9	0.1
Cha-fas	1.2	1.3	1.6	1.6	1.5	1	0.4	0.8			0.1	0.0
Cis-tri											0.2	
Cre-nud									0.0		0.0	
Dal-ema									0.0			
Dis-spi	0.8	2.9	1.2	2.8	0.5	1.9	0.5	2	0.5	1.9	0.8	1.1
Era-sec			0.1	0.2								
Eus-exa										0.0		
Fim-cas	0.4	0.6	0.7	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.2	0.1
Gai-pul	0.3								0.1			
Het-sub	0.2	0.1			0.1	0.4	0.2	0.1	0.1	0.1	0.3	0.0
Iva-ang											0.2	0.3
Jun-eff									0.0		0.3	
Jun-sp.									0.5			
Lim-car	0.2	0.1	0.1	0.3	0.1	0.3	0.1	0.4	0.1	0.5	0.1	0.2
Lin-ala									0.1		0.0	0.0
Lyc-car	0.1	0.2			0.1				0.1	0.0	0.0	
Mon-lit	2.3	1.2	2.8	1.4	2.9	2	2.8	2	1.6	3.0	1.6	0.9
Oen-dru							0.2	0.3	0.3	0.5		
Pan-ama					0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0

Species / Category	2016		2018		2019		2020		2021		2022	
	Monitor	Take	Monitor	Take	Monitor	Take	Monitor	Take	Monitor	Take	Monitor	Take
Pan-vir									0.1	0.4		
Pas-sp.									0.2		0.7	
Pas-not	0.1		0.5									
Pro-rep		0.1		0.4		0.2		0.3	0.1	0.2	0.0	0.1
Ray-phy	0.5	0.5	1.1	0.8	0.4	1.1	0.3	0.4	0.3	0.5	0.1	0.1
Sab-are									0.0			
Sal-big								0.1		0.0	0.0	
Sal-dep	0.3	0.4	0.2	1	0.2	0.5	0.1	1.4	0.1	2.9	0.1	1.5
Sam-ebr	0.2	0.1	0.3	0.3	0.2	0.5	0.2	0.8	0.2	0.2	0.1	
Sch-sco	0.9	0.8	0.8	1.3	0.7	1.1	1.1	2.1	1.1	1.2	1.7	1.5
Ses-por			0.2	0.4	0.1	0.2	0.1	0.1	0.1		0.2	
Ses-ver		0.2										
Sol-sem	0.4	0.3	0.4	0.3	0.7	0.2	1	0.8	1.0	0.8	0.4	0.2
Spa-pat					0.2		0.1		0.1			
Spa-spa			0.1		0.5		0.1		0.2		0.1	
Spo-vir					0.7		0.4		0.2	0.1		
Spo-air											0.2	0.1
Sua-lin		0.6	0.1	0.3	0.1	0.3		0.5	0.0	0.1	0.0	0.0
Tid-lan									0.0		0.0	0.1
Uni-pan												0.1
Poaceae 1-2016	0.1											
Poaceae 1-2021									0.0	0.0		
Poaceae 1-2022											0.2	0.1
Poaceae 2-2022											0.1	
Poaceae 3-2016	0.2	0.1										
Unk. Forb 1-2021									0.1	0.0		
Unk. Forb 1-2022											0.2	
Unk. Forb 2-2021									0.0			
Unk. Forb 3-2016	0.1	0.7										
Unk. Vine 1-2018			0.1									
Unk. Vine 2-2016		0.1										

Table 1.8b. Percent cover by species or category within the monitoring and take zones from 2016–2022. Data are grouped by zone type to juxtapose individual sampling years and to illustrate observed interannual variability and multi-year trends. Colored cell shading reflects cell values and is included as a visual aid to identify patterns and relatively higher or lower values.

Species / Category	Monitor						Take					
	'16	'18	'19	'20	'21	'22	'16	'18	'19	'20	'21	'22
Bare ground	89.7	87.6	89.2	90.4	90.9	89.1	88.5	87	88.5	86.6	86.2	89.5
Dead vegetation	-	-	-	-	-	0.9	-	-	-	-	-	2.6
Aga-mar	0.1	0.4	0.3	0.1	0.0	0.1		0.1	0.2		0.0	0.2
Ama-gre									0.2			
Avi-ger						0.0					0.0	0.0
Bac-mon		0.1										
Bat-mar	0.7	1	0.9	1.2	1.0	0.7				0.1	0.0	0.0
Blu-ver	0.1			0.1	0.2	0.1	0.3	0.5	0.4	0.6	0.7	0.8
Bor-fru	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1
Cal-aus		0.2						0.6				
Car-sp.		0.1	0.1	0.2	0.5	0.9					0.1	0.1
Cha-fas	1.2	1.6	1.5	0.4		0.1	1.3	1.6	1	0.8		0.0
Chr-odo						0.2						
Cre-nud					0.0	0.0						
Dal-ema					0.0							
Dis-spi	0.8	1.2	0.5	0.5	0.5	0.8	2.9	2.8	1.9	2	1.9	1.1
Era-sec		0.1						0.2				
Eus-exa											0.0	
Fim-cas	0.4	0.7	0.2	0.2	0.2	0.2	0.6	0.5	0.5	0.5	0.5	0.1
Gai-pul	0.3				0.1							
Het-sub	0.2		0.1	0.2	0.1	0.3	0.1		0.4	0.1	0.1	0.0
Iva-ang						0.2						0.3
Jun-eff					0.0	0.3						
Jun-sp.					0.5							
Lim-car	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.4	0.5	0.2
Lin-ala					0.1	0.0						0.0
Lyc-car	0.1		0.1		0.1	0.0	0.2				0.0	
Mon-lit	2.3	2.8	2.9	2.8	1.6	1.6	1.2	1.4	2	2	3.0	0.9
Oen-dru				0.2	0.3					0.3	0.5	
Pan-ama			0.1	0.1	0.1	0.0			0.1	0.1	0.0	0.0
Pan-vir					0.1						0.4	
Pas-sp.					0.2	0.7						
Pas-not	0.1	0.5										
Pro-rep					0.1	0.0	0.1	0.4	0.2	0.3	0.2	0.1
Ray-phy	0.5	1.1	0.4	0.3	0.3	0.1	0.5	0.8	1.1	0.4	0.5	0.1
Sab-are					0.0							
Sal-big						0.0				0.1	0.0	
Sal-dep	0.3	0.2	0.2	0.1	0.1	0.1	0.4	1	0.5	1.4	2.9	1.5
Sam-ebr	0.2	0.3	0.2	0.2	0.2	0.1	0.1	0.3	0.5	0.8	0.2	
Sch-sco	0.9	0.8	0.7	1.1	1.1	1.7	0.8	1.3	1.1	2.1	1.2	1.5
Ses-por		0.2	0.1	0.1	0.1	0.2		0.4	0.2	0.1		
Ses-ver							0.2					
Sol-sem	0.4	0.4	0.7	1	1.0	0.4	0.3	0.3	0.2	0.8	0.8	0.2

Species / Category	Monitor						Take					
	'16	'18	'19	'20	'21	'22	'16	'18	'19	'20	'21	'22
Spa-pat			0.2	0.1	0.1							
Spa-spa		0.1	0.5	0.1	0.2	0.1						
Spo-vir			0.7	0.4	0.2						0.1	
Spo-air						0.2						0.1
Sua-lin		0.1	0.1		0.0	0.0	0.6	0.3	0.3	0.5	0.1	0.0
Tid-lan					0.0	0.0						0.1
Uni-pan												0.1
Poaceae 1-2016	0.1											
Poaceae 1-2021					0.0						0.0	
Poaceae 1-2022						0.2						0.1
Poaceae 2-2022						0.1						
Poaceae 3-2016	0.2						0.1					
Unk. Forb 1-2021					0.1						0.0	
Unk. Forb 1-2022						0.2						
Unk. Forb 2-2021					0.0							
Unk. Forb 3-2016	0.1						0.7					
Unk. Vine 1-2018		0.1										
Unk. Vine 2-2016							0.1					

Table 1.8b groups plant cover data by zone type to more directly compare individual sampling periods (years). These comparisons illustrate observed interannual variability (differences between years, which may be driven by anything that normally varies from year to year, such as rainfall amounts or timing and tidal influence). The observed differences between years are also mostly modest and within the expected range for south Texas coastal ecosystems, with the exceptions already discuss above, which are significant. For example, the observed changes in abundances of *Distichlis spicata*, *Monanthochloe littoralis*, and *Salicornia depressa* are even more pronounced when grouped by zone designation instead of year.

<u>Statistical Analyses</u>

We first fit a series of permutational linear models and performed a series of univariate ANOVAs (analyses of variance) using the lmp() function in R version 4.2.2 to examine the effects of year, habitat type, monitoring zone, and their interactions on total plant cover and cover of the five most common plant species in 2022 (*Schizachyrium scoparium*, *Monanthochloe littoralis*, *Distichlis spicata*, *Carex* spp., and *Salicornia depressa*). Full ANOVA results for each response variable may be found in **Table 1.9a-f**. Visualizations of all significant results from these analyses are shown in **Figures 1.5-2.11**. When our permutational ANOVAs detected significant differences, we then also performed least square mean post-hoc tests to identify differences between individual treatment levels. Post-hoc test results are reported as capital letters in the associated figures; groups that share the same letter are not significantly different from each other.

We utilized the lmp() function, which uses a permutational approach to calculate P values (a type of bootstrapping, also known as PerANOVA), because of the unbalanced design inherent to the spatial arrangement of habitats within the monitoring and take zones, as well as the zero-heavy nature of this dataset. Permutational linear models like these are not affected by unbalanced designs, non-normality of residuals, heteroscedasticity, or overdispersion, as are classical linear models.

The main effect of year significantly influenced *Schizachyrium*, and it had a marginal effect on *Carex* spp. (**Table 1.9**, **Figure 1.5**). Habitat type significantly affected all six plant cover response variables and explained the largest portion of variance overall (**Table 1.9**, **Figure 1.6**). Monitoring class designation (zones based on distance from the launch pad) significantly impacted *Distichlis* and *Salicornia depressa* cover (**Table 1.9**, **Figure 1.7**).

The year × habitat type interaction had a significant effect on *Schizachyrium* and *Carex* spp. cover, which suggests that their coverage varied over time, but only in certain habitat types (**Table 1.9**, **Figure 1.8**). *Schizachyrium* was abundant and increased gradually in dunes from 2016–2022, except for a low year in 2019; it remained consistent in bare (mudflat) and creep plots; and, although not as abundant as in dune plots, it was significantly more abundant in transition plots in 2020 and 2022 compared to some earlier years. *Carex* spp. were consistently rare in bare, creep, and transition plots in all years and until 2020 in dune plots, but then became significantly more abundant in dunes in 2021 and significantly increased again (doubling) in dunes in 2022.

The habitat type × monitoring class interaction significantly influenced total live plant cover and cover values of *Monanthochloe*, *Distichlis*, and *Salicornia depressa* (**Table 1.9**, **Figure 1.9**). A significant habitat × monitor class interaction suggests that there were detectable differences in coverage between the monitor and take zones, but only for certain habitat types. Total live plant cover was higher in the more distant monitoring zone but only in creep and dune habitats. *Monanthochloe* cover was higher in the take zone (nearer the launch pad) in bare (mudflat) habitats, but higher in the monitoring zone in transition and creep habitats. *Distichlis* was higher in the take zone in creep and transition habitats. *Salicornia* was higher in the monitoring zone in creep plots and higher in the take zone in transition plots.

The year × monitoring class interaction significantly impacted *Salicornia depressa* cover only (**Table 1.9**, **Figure 1.10**). A significant year × monitor class interaction suggests that temporal patterns or year effects depended on (differed by) the monitoring zone designation. *Salicornia* cover increased significantly and relatively gradually from 2016 to 2022 in the take zone (closer to the launch pad), but its cover remained consistently low (perhaps with a very subtle decrease) in same time period within the monitoring zone (farther from the launch pad).

Lastly, the three-way year × habitat type × monitoring class interaction was marginally significant for *Salicornia depressa* only and suggests that there were significant changes over time, but only within certain habitat and monitoring class combinations (**Table 1.9**, **Figure 1.11**). Specifically, *Salicornia* significantly increased in cover from 2016–2022, but only in transition habitats within the take zone, whereas *Salicornia* cover remained statistically consistent (and relatively rare) in all other habitat types and in the transition habitats within the monitoring zone. In many ways, this represents a refinement of the significant year × monitoring class patterns observed and described for *Salicornia* above (**Figure 1.10**). This additionally shows most *Salicornia* cover observed in the creep plots was within the monitoring zone, where there was a notable but statistically insignificant gradual decrease over time (**Figure 1.11**).

Table 1.9. Permutational ANOVA results examining the effects of survey year, habitat type, monitoring class, and their interactions on total plant coverage and coverage of the five most common plant species. Habitat type includes bare, transition, dune, or creep categories. Monitoring class includes monitoring or take categories originally designated by USFWS. Legend – SS: sums of squares (Type III or marginal); d.f.: degrees of freedom; $F_{47,664}$: F statistic with 47 model degrees of freedom and 664 denominator degrees of freedom; *P*: *p*-value, with stars denoting statistical significance (., *P* < 0.1; *, *P* < 0.05; **, *P* < 0.01; ***, *P* < 0.001). *P*-values here are calculated using a permutational approach and are based on simulated F values derived from 10,000 simulations using random resampling with replacement.

(a) Total plant cover					
Factor	**SS**	**d.f.**	**$F_{47,664}$**	**P**	
Year (Y)	712	5	0.55	0.4237	
Habitat type (H)	64775	3	121.15	**<0.0001**	***
Monitor class (M)	0	1	3.58	1.0000	
Y*H	1223	15	0.44	0.8455	
Y*M	839	5	0.61	0.3233	
H*M	1300	3	3.12	**0.0488**	*
Y*H*M	889	15	0.43	0.9265	
Residuals	91809	664			
Model		47	10.73	**<0.0001**	***

(b) *Schizachyrium scoparium* cover					
Factor	**SS**	**d.f.**	**$F_{47,664}$**	***P***	
Year (Y)	145.2	5	3.13	**0.0132**	*
Habitat type (H)	2235.9	3	65.77	**<0.0001**	***
Monitor class (M)	6.2	1	1.88	1.0000	
Y*H	359	15	2.16	**<0.0001**	***
Y*M	23.5	5	0.99	0.8502	
H*M	15	3	0.52	0.6400	
Y*H*M	164.3	15	1.10	0.2157	
Residuals	6617.8	664			
Model		47	6.30	**<0.0001**	***

(c) *Monanthochloe littoralis* cover					
Factor	**SS**	**d.f.**	**$F_{47,664}$**	***P***	
Year (Y)	117.5	5	0.53	0.7378	
Habitat type (H)	3542.8	3	12.67	**<0.0001**	***
Monitor class (M)	123	1	21.28	0.2287	
Y*H	776.9	15	1.06	0.3458	
Y*M	163.7	5	0.41	0.6339	
H*M	2048.7	3	14.77	**<0.0001**	***
Y*H*M	514.3	15	0.73	0.7401	
Residuals	31220.8	664			
Model		47	3.297	**<0.0001**	***

(d) *Distichlis spicata* cover					
Factor	**SS**	**d.f.**	**$F_{47,664}$**	***P***	
Year (Y)	70.4	5	0.75	0.4799	
Habitat type (H)	1272.7	3	33.23	**<0.0001**	***
Monitor class (M)	180.6	1	8.33	**<0.0001**	***
Y*H	138.2	15	0.75	0.6766	
Y*M	36.2	5	0.37	0.7792	
H*M	159.3	3	4.05	**0.0143**	*
Y*H*M	71	15	0.37	0.9456	
Residuals	8595.3	664			
Model		47	3.17	**<0.0001**	***

(e) *Carex* spp. cover					
Factor	**SS**	**d.f.**	**$F_{47,664}$**	***P***	
Year (Y)	37.82	5	2.11	**0.0709**	.
Habitat type (H)	144.96	3	4.86	**<0.0001**	***
Monitor class (M)	9.13	1	2.90	0.2637	
Y*H	290.69	15	2.05	**0.0222**	*
Y*M	8.9	5	1.05	0.8464	
H*M	37.97	3	2.66	**0.1107**	
Y*H*M	77.31	15	1.12	0.1942	
Residuals	3066.96	664			
Model		47	2.80	**<0.0001**	***

(f) *Salicornia depressa* cover					
Factor	**SS**	**d.f.**	**$F_{47,664}$**	***P***	
Year (Y)	43	5	0.42	0.1391	
Habitat type (H)	331	3	23.01	**<0.0001**	***
Monitor class (M)	147.7	1	2.19	**<0.0001**	***
Y*H	83.8	15	1.31	0.3164	
Y*M	106.7	5	0.90	**0.0114**	*
H*M	271.6	3	15.64	**<0.0001**	***
Y*H*M	151.7	15	1.74	**0.0531**	.
Residuals	3858.9	664			
Model		47	4.16	**<0.0001**	***

Figure 1.5. Means ± standard error of total live plant coverage and coverage of the five most common plant species broken down by year. Stars denote statistical significance of factors (., $P < 0.1$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$). Capital letters denote results of post-hoc tests; groups that share a letter are not significantly different.

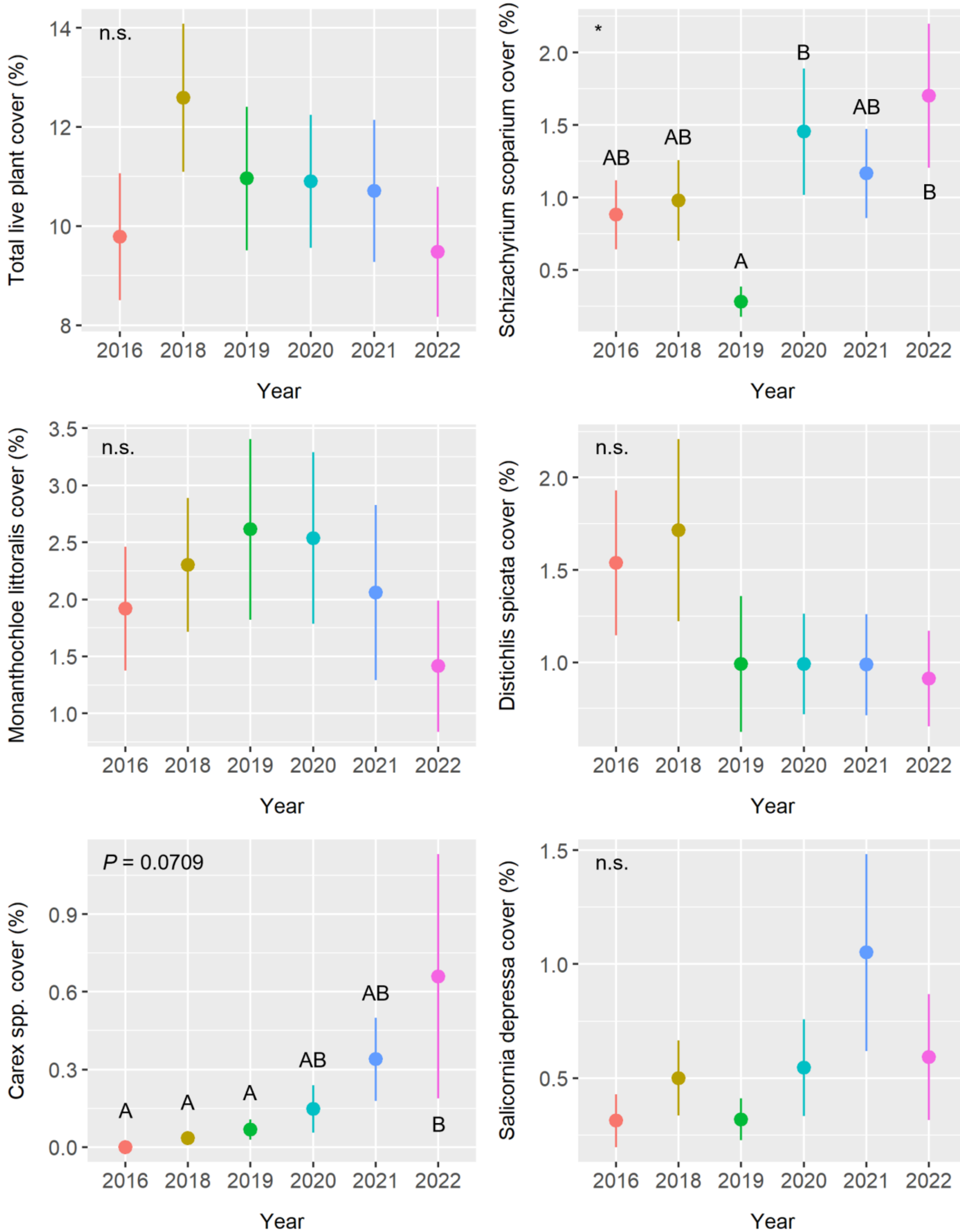


Figure 1.6. Means ± standard error of total live plant coverage and coverage of the five most common plant species broken down by habitat type. Stars denote statistical significance of factors (., $P < 0.1$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$). Capital letters denote results of post-hoc tests; groups that share a letter are not significantly different.

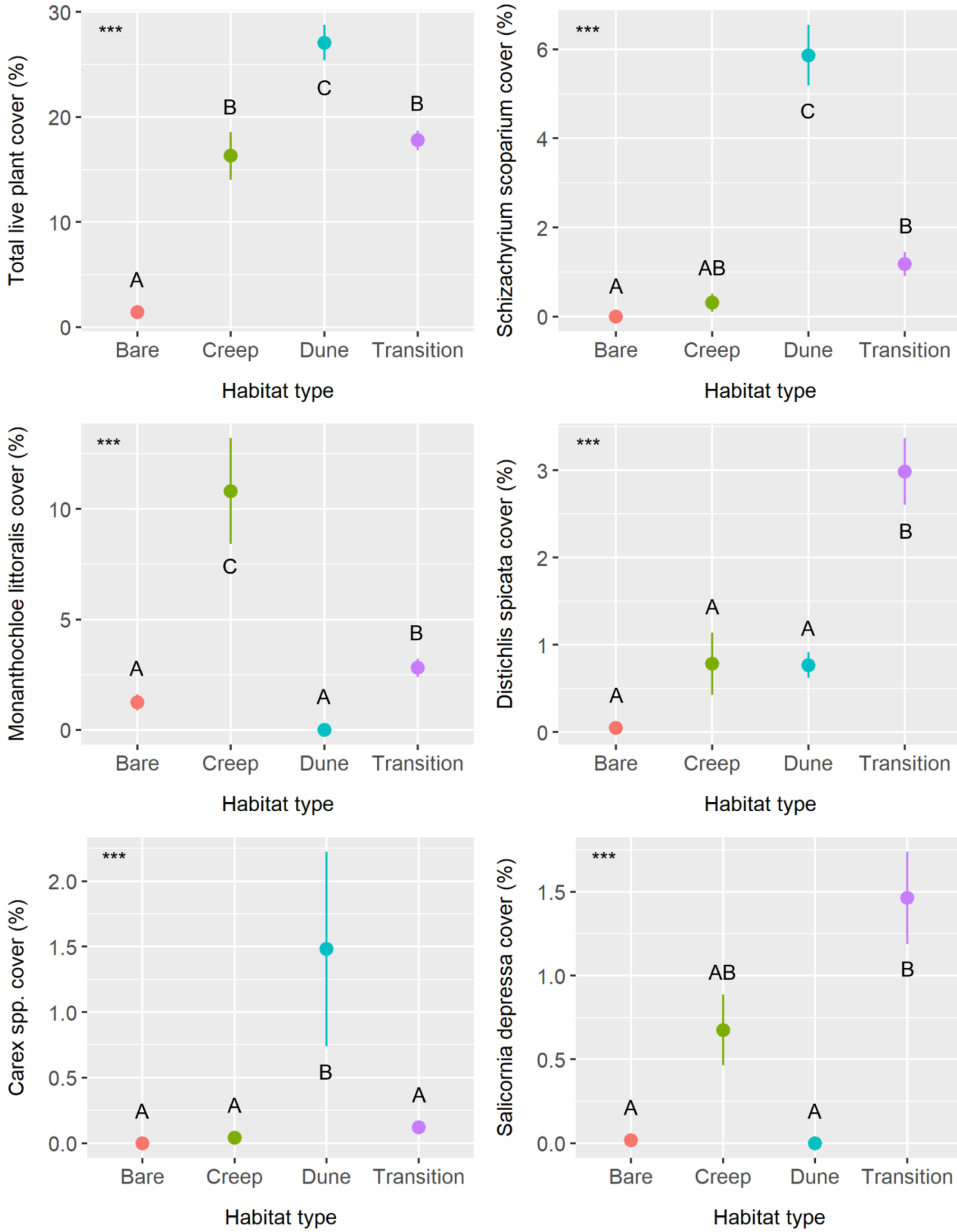


Figure 1.7. Means ± standard error of total plant coverage and coverage of the five most common plant species broken down by monitoring class. Stars denote statistical significance of factors (., $P < 0.1$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$). Capital letters denote results of post-hoc tests; groups that share a letter are not significantly different.

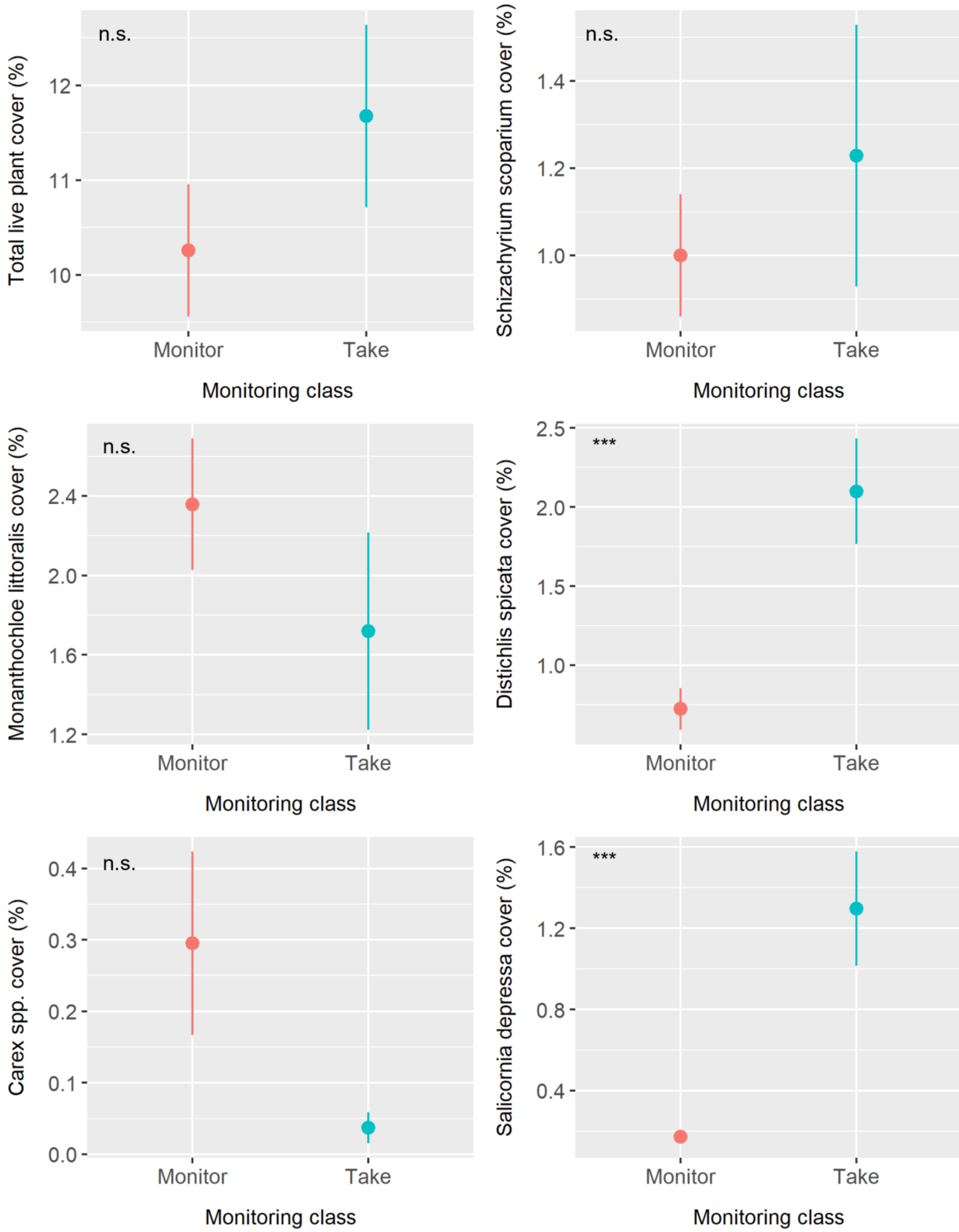


Figure 1.8. Means ± standard error of *Schizachyrium scoparium* and *Carex* species coverage broken down by year and habitat type. Stars denote statistical significance of the year × habitat interaction (., $P < 0.1$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$). Capital letters denote results of post-hoc tests; groups that share a letter are not significantly different.

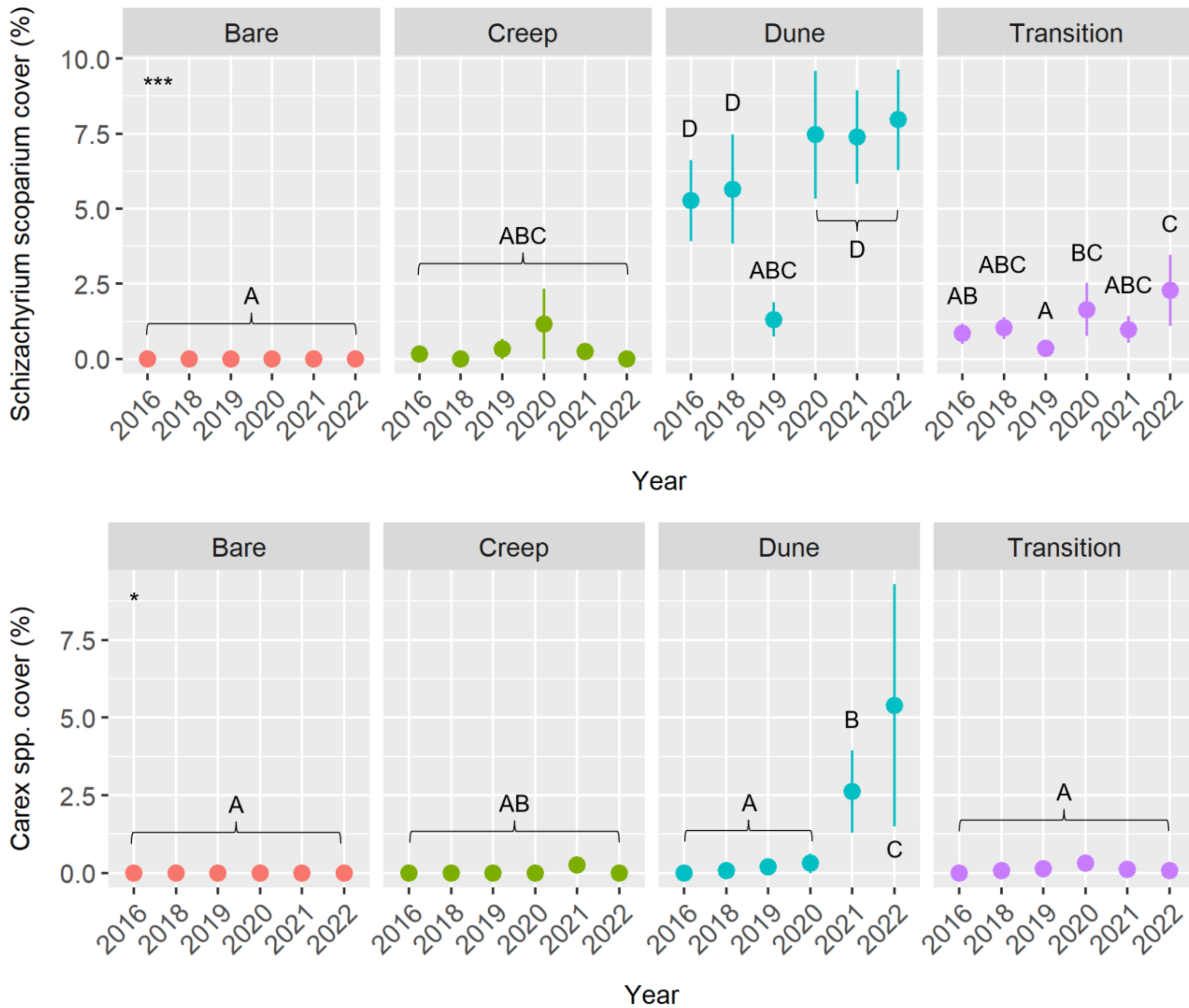


Figure 1.9. Means ± standard error of total live plant coverage and coverage of *Monanthochloe littoralis*, *Distichlis spicata*, and *Salicornia depressa* broken down by habitat type and monitoring class. Stars denote statistical significance of the habitat × monitor class interaction (., *P* < 0.1; *, *P* < 0.05; **, *P* < 0.01; ***, *P* < 0.001). Capital letters denote results of post-hoc tests; groups that share a letter are not significantly different.

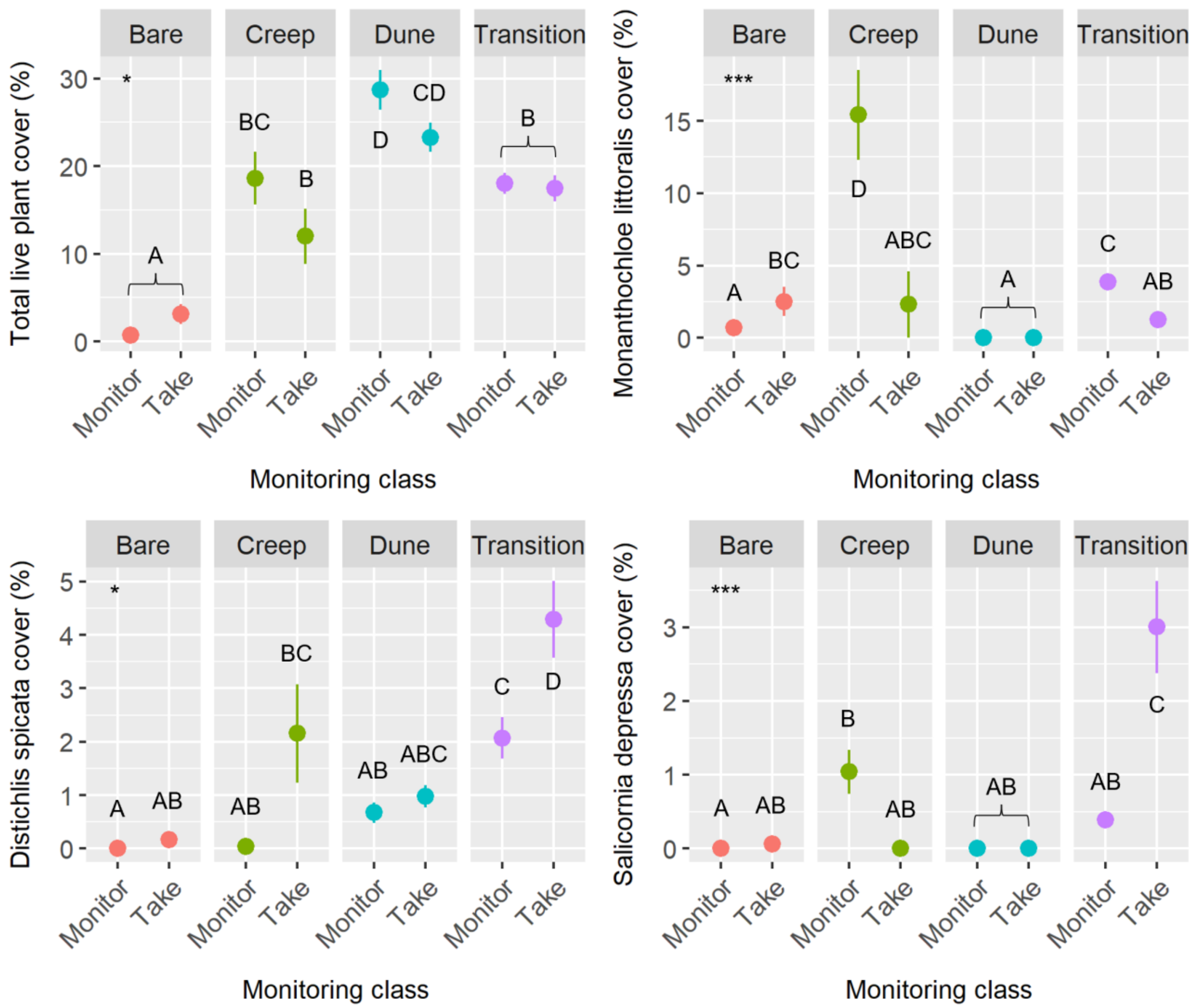


Figure 1.10. Means ± standard error of *Salicornia depressa* cover broken down by year and monitoring class. The star denotes the statistical significance of the year × monitoring class interaction (*, $P < 0.05$). Capital letters denote results of post-hoc tests; groups that share a letter are not significantly different.

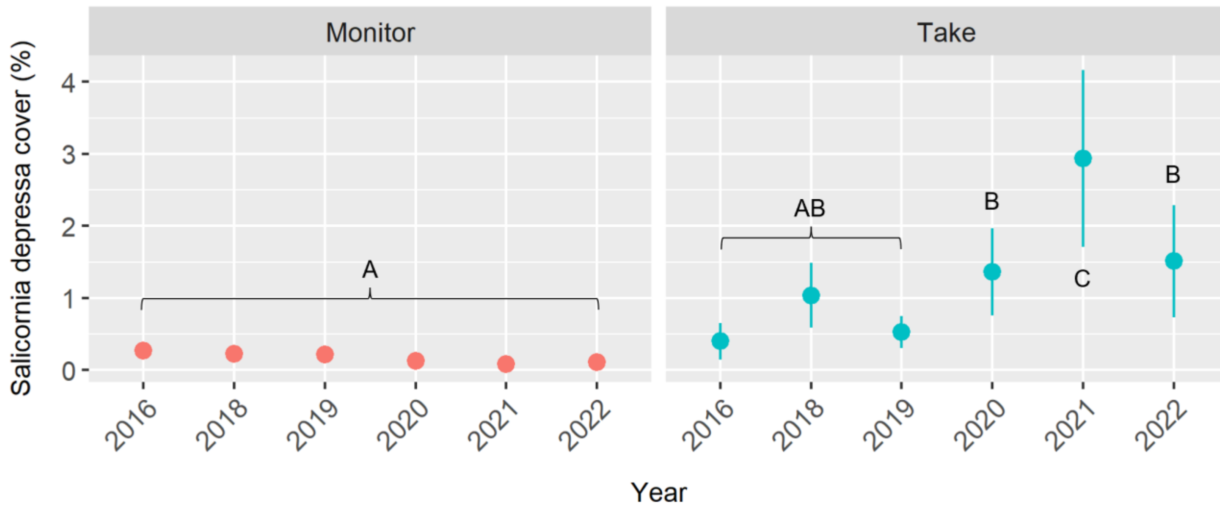
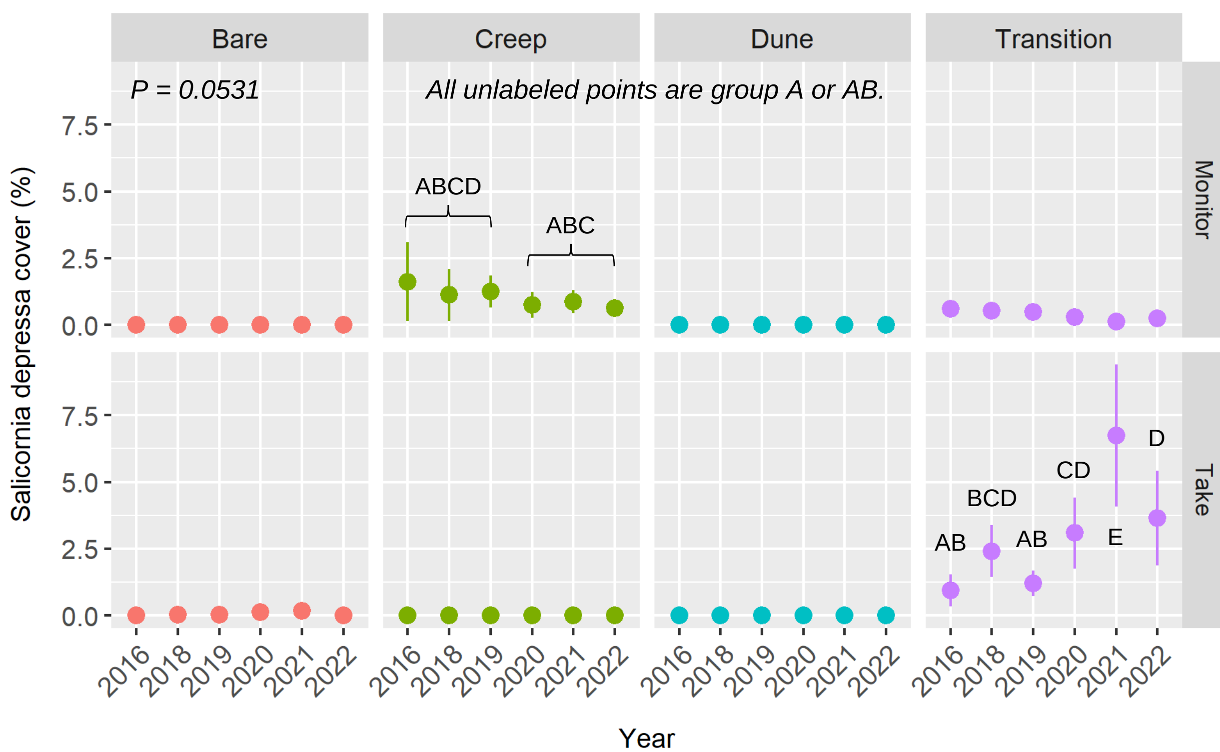


Figure 1.11. Means ± standard error of *Salicornia depressa* cover broken down by year, habitat type, and monitoring class. The three-way year × habitat type × monitoring class interaction was marginally significant but is shown to illustrate a notable pattern and trends over time. Capital letters denote results of post-hoc tests; groups that share a letter are not significantly different.



Discussion

Variation among habitat types and some variation among years is normal and expected. Observed variation in plant communities is often within the ranges expected for natural variability, but, as we gain additional years of data, we become more able to distinguish natural variation (expected differences among years and habitat types or areas) from variation that is explainable based on land use changes at the Boca Chica launch site. Cases where observed variability is noteworthy and/or exceeds the expected range and there is statistical evidence that changes have taken place are described above.

Significant differences between monitoring designation zones suggest that proximity to the launch pad site has influenced plant community structure or composition. Such variation is detectable and significant as a main effect for some dominant plant species, such as *Distichlis* and *Salicornia depressa*, and within certain habitat types for other species like *Monanthochloe* and for overall live plant cover, as described above. Plant community structure is expected to differ between monitor and take designations to some degree because the proportions of plots representing different habitat types varies between monitoring zone designations. Importantly, however, our statistical analyses accounted for these differences by including habitat type and all possible interactions that include habitat type as terms in our models, and we used marginal (Type III) approaches to calculate our model sums of squares. In other words, we have statistically controlled for any artefacts of our monitoring design to ensure that our comparisons between monitoring zones are meaningful and reliable. Please note that patterns for individual species are important but only part of our considerations; in many ways, a superior but less intuitive consideration is the whole plant community and the variation and patterns observed therein, which we quantify and examine below using multivariate analyses.

The differences in total plant cover and cover by individual species between monitoring zones were sometimes large (**Figure 1.7**) but were mostly not significant (**Table 1.9**). Variation over time is also important, especially because, if activities at the launch pad are having an effect, we might expect to see patterns of increases or decreases over time, or changes occurring after a certain date when a specific action was taken or threshold was reached. We do see some trends over time, such as for *Schizachyrium*, *Carex*, and *Salicornia* (**Figure 1.5**), but these do not always represent an enduring change and are sometimes better explained by other factors.

The observed differences merit careful consideration, as do two possible alternative explanations: First, it is possible that some of the observed differences between plant communities in the monitoring and take zones could be explained by additional factors that we have not quantified or analyzed, such as proximity to the road or differences in elevation. Second, it is possible that proximity to the launch pad is having more and/or stronger effects on plant communities than we have been able to detect because the operational distance for this proximity effect is greater than the cutoff between our monitoring zone categories. That is, the split between monitoring and take plots is located ca. 200 m from a central point located a short distance east-south-east of the eastern edge of the launch pad (see **Figure 1.1**). Plots within ca. 200 m of radial distance from this central point are in the 'take' zone, and plots located between ca. 200 m and ca. 340 m from the central point are in the 'monitor' zone. If any of the factors associated with launch pad proximity that are hypothesized to affect plant communities are having an effect more than 200 m away from this central point, then plots in both of our monitoring class categories would be influenced by these factors, and we may not be able to detect differences in this proximity effect, unless we also surveyed points farther away and outside the range of the influences of these factors.

This second alternative scenario is particularly important to consider because current observations suggest at least some of the factors related to launch pad proximity are having impacts well beyond 200 m. We have documented ground disturbance and vehicle tracks caused by heavy machinery and ATVs since 2015 and found that ground cover by vehicle tracks in 2021 was actually more abundant in the monitoring zone (7.0% cover) located ca. 200–340 m from the launch pad than in the ‘take’ zone plots (6.1% cover) located within ca. 200 m of the launch pad. This difference was not statistically significant (PerANOVA, $F_{1,688} = 0.001$, $p = 0.9806$) nor was the year × monitoring class interaction (PerANOVA, $F_{5,688} = 0.20$, $p = 0.9616$), but these results substantiate the second impact scenario described above by suggesting that vehicular impacts are comparable in both distance-based monitoring zones. Notably, while cover by vehicle tracks did not differ among monitoring zones, tracks cover did differ significantly among years (PerANOVA, $F_{5,588} = 9.78$, $p < 0.0001$). It is essential to emphasize that overall cover by vehicle tracks in 2021 (6.7%) was over three times higher than the overall cover by the most abundance plant species (Monanthochloe) in the same period (2.1%). Conceptually, some impacts are expected to be more localized than others. For example, impacts of rocket explosions and subsequent cleanups can obviously reach beyond 200 m from the launch pad, whereas other point source impacts could theoretically be more localized. Differences in plant communities between monitor and take zone plots merit special attention, and further monitoring and investigation are recommended.

Multivariate analyses and findings

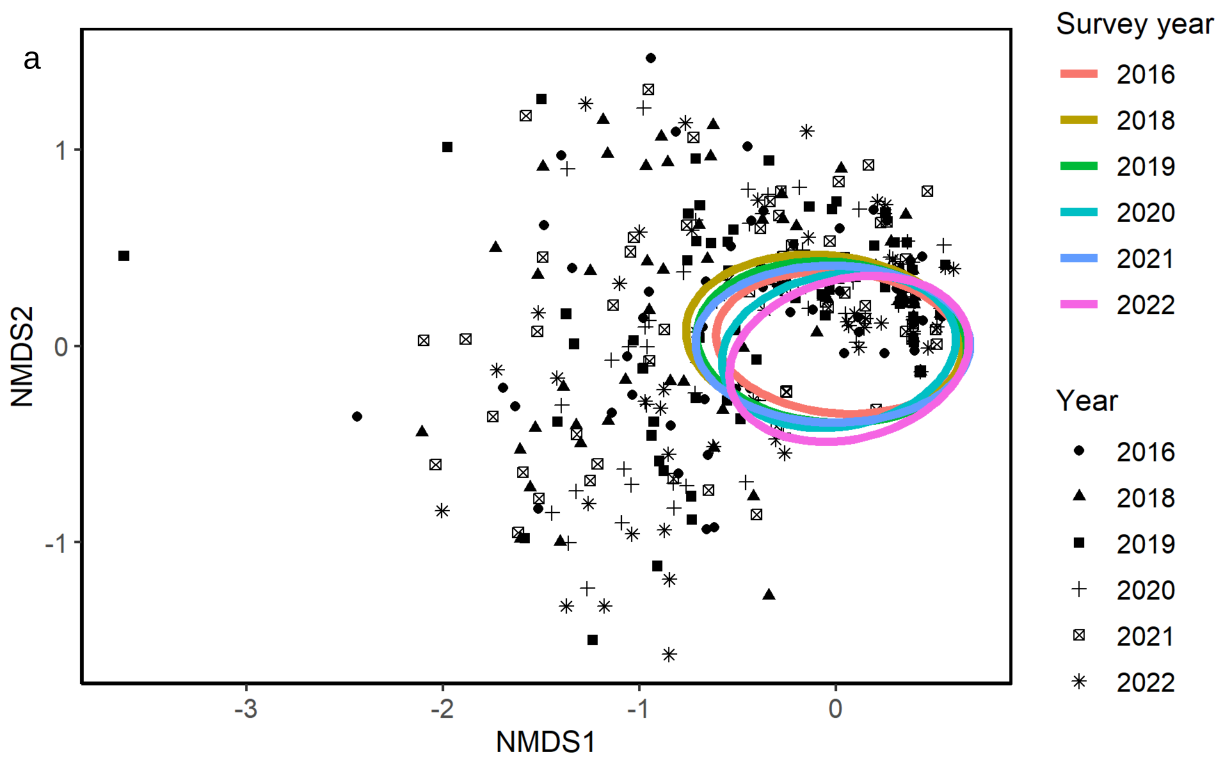
We performed multivariate analyses of plant communities observed from 2016–2022 using the full set of species abundances as our response variables and habitat type, monitoring zone class, and year as categorical predictor variables. We fit a nonmetric multidimensional scaling (NMDS) ordination using all plots and calculated group means (centroids; the theoretical “average community”) and 95% confidence ellipses (confidence intervals across the two NMS dimensions) for each grouping factor. Each point in the ordinations represents one observed plant community (cover values for all species) and corresponds to a single study plot in a single year. In all NMDS ordinations, similarity among communities is represented as spatial proximity along the NMDS axes, so the closer together points are, the more similar the communities are that they represent; conversely, the farther points are apart, the less similar are the communities they represent. Plots showing the centroids and confidence intervals for the main effects of each group are show in **Figures 1.12a-c**.

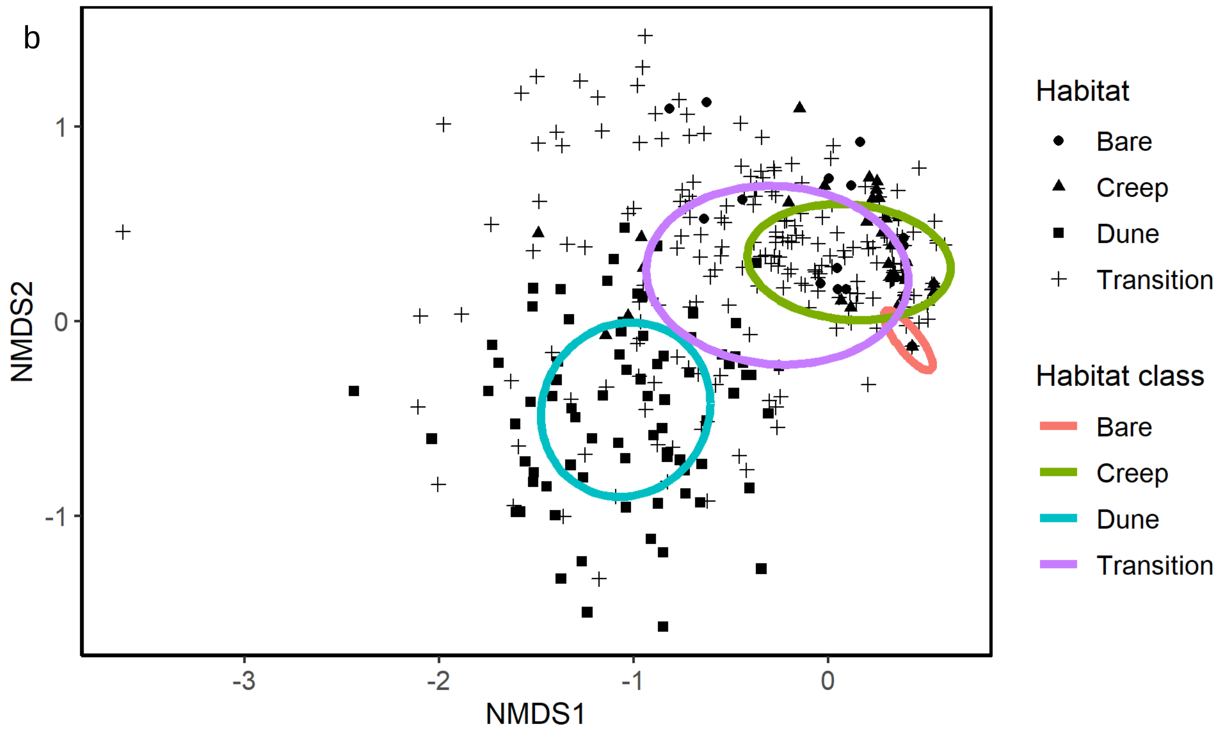
We also performed permutational multiple analysis of variance (PerMANOVA) to examine the effects of habitat type, monitoring zone class, year, and their interactions on plant community composition. Our PerMANOVA results are shown in **Table 1.10** and indicate that habitat type, monitoring class, and the interactions of habitat × year and habitat × monitoring class significantly influenced plant community composition. The main effect of year also had a marginal effect; however, for these analyses, it is reasonable to consider this a significant effect because these analyses concern “messy” natural systems and large multivariate ecological dataset inherently include greater variability and noise. Such an interpretation is consistent with many comparable multivariate analyses found in the literature. Differences between habitat types are expected and indeed were most strongly associated with separation among survey plots (**Figure 1.12b**). The dissimilarity between monitoring zone classes was more subtle (**Figure 1.12c**), but a significant overall difference between these groups across all years is a major finding (the main effect of monitor class in **Table 1.10**) and suggests that the plant communities in the monitor and take zones are significantly different, even when we account for the variability attributable to different habitat types and differences in the proportion of plots from different habitats in the different monitoring zones. This further substantiates the conclusion that proximity to the launch pad is indeed having detectable impacts on plant communities.

Dissimilarities between years were even more subtle; the variation in community composition within years was large and confident ellipses were wide and overlapped to a large extent (**Figure 1.12a**). Nevertheless, our analyses identified year as an important factor in shaping the observed plant communities, but no obvious patterns were apparently over time when we considered our full dataset. Additionally, the significant year × habitat interaction (**Table 1.10**) indicates that there was significant variation between years, but the nature and extent of this variation depended on the habitat type (which is illustrated somewhat better in **Figures 1.13b-d**). Specifically, bare plots (mudflats) consistently remained unvegetated and did not vary significantly over time. Dune plots varied the most, with the greatest differences between 2016 and 2019, between 2016 and 2020, and between 2019 and 2021. We generally saw substantial separation in plant communities within the dunes in the vicinity of the launch pad (**Figure 1.13b**). Transition plots varied much less between years (**Figure 1.13c**), and, although there is still notable variability, it is within expected ranges of natural interannual variation in these diverse habitats. Differences between years in creep plots were more pronounced than in transition habitats but weaker than in dune habitats, yet we still see an interesting narrowing of the centroid’s confidence ellipse for 2022, which suggests creep plots in the last year were much more uniform and less variable than in prior years (**Figure 1.13d**). Importantly, we have substantially fewer observations for creep plots, and they have often exhibited higher than average variability within years, which both lead to wide confidence intervals.

Lastly, the significant habitat × monitoring class interaction indicates that the differences between monitoring zone classes also depended on habitat type. This is similar to what was observed for the habitat × year interaction and follows a similar pattern for particular habitats. In this case, bare plots (mudflats) and dune plots did not differ between monitoring and take zones, but creep and transition plots did differ between monitoring and take zones (**Figure 1.13a**). This phenomenon and its drivers are discussed in the results above. This is also a major finding.

Figure 1.12. NMDS ordinations representing plant community compositions observed from 2016-2022 broken down by (a) survey year, (b) habitat type, and (c) monitoring zone class. Points represent observed communities and correspond to individual study plots in a given year; their position reflects community composition, and the spatial proximity between points reflects similarities among observed communities. The shape of symbols denotes the factor specified in the inset legends. Colored ellipses represent the 95% confidence intervals around the theoretical average communities found in each group. See Table 1.10 (PerMANOVA results) for additional information related to these ordinations.

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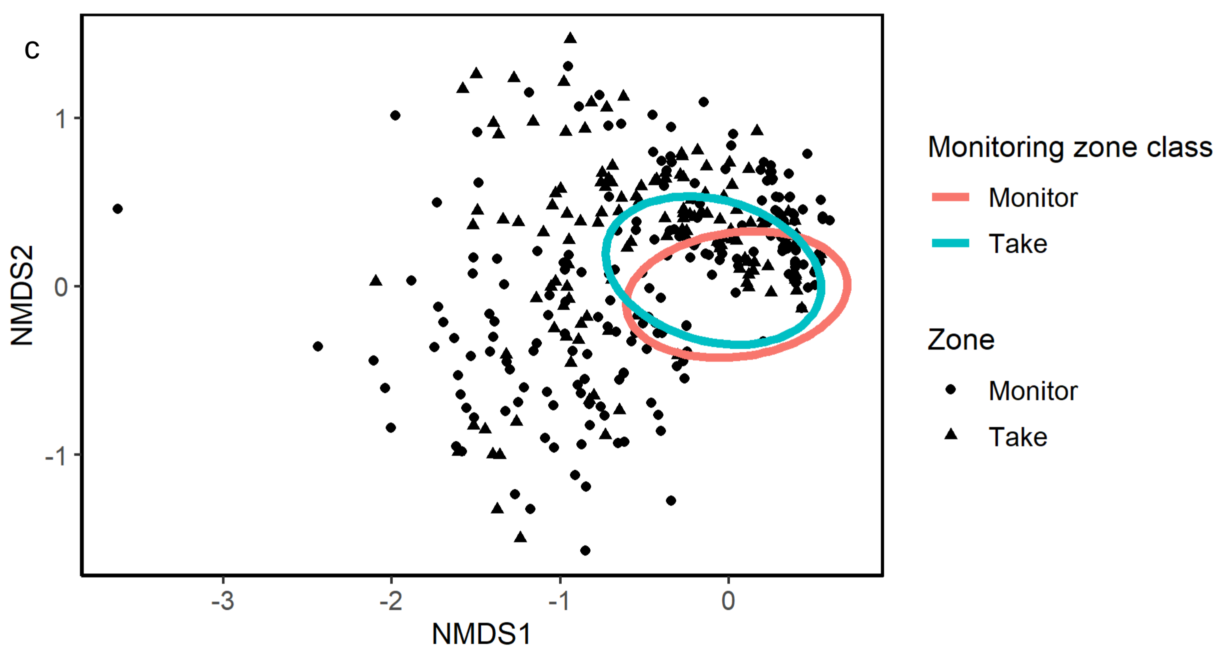
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Monitoring zone class
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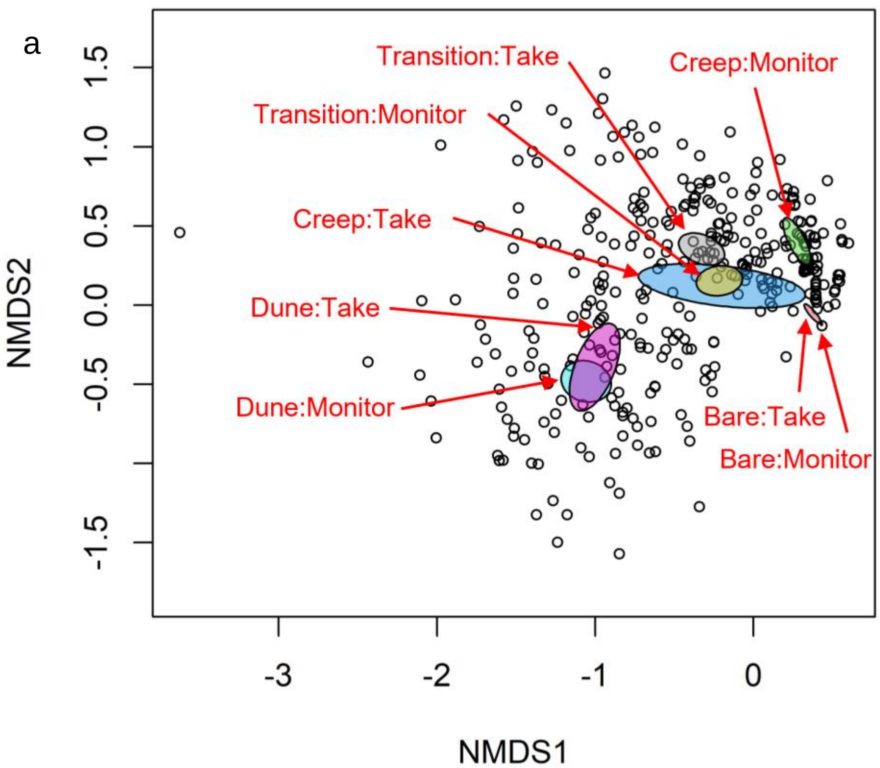
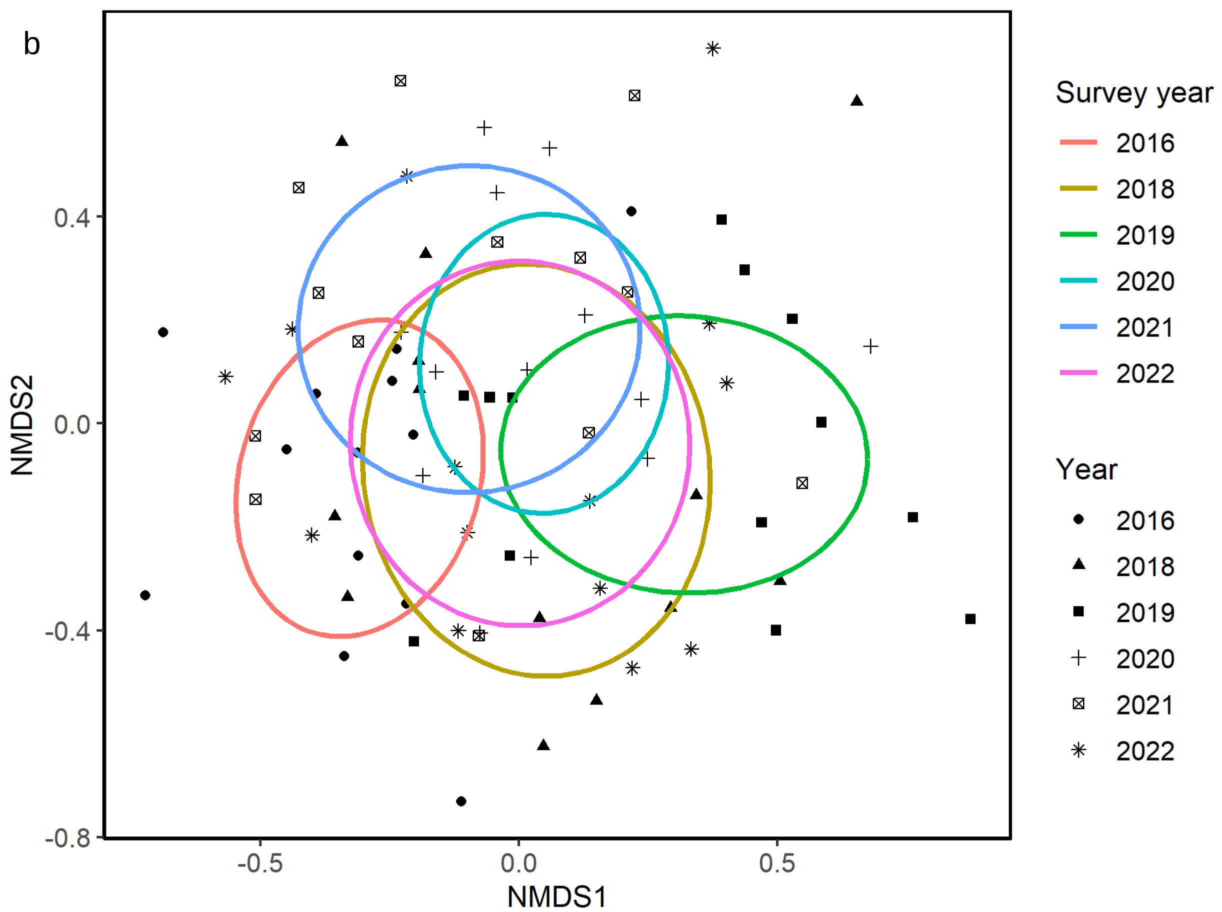
Zone
Monitor
Take

Table 1.10. Permutational multiple analysis of variance (PerMANOVA) results examining the effects of year, habitat type, monitoring zone class, and their interactions on plant community composition. Legend: ., $0.05 < p < 0.1$; *, $0.01 < p < 0.05$; **, $0.001 < p < 0.01$; ***, $p < 0.001$.

Factor	SS	d.f.	$F_{47,664}$	*P*	
Year (Y)	0.167	5	1.39	**0.074**	.
Habitat type (H)	3.912	3	54.13	**<0.001**	***
Monitor class (M)	0.109	1	4.54	**0.002**	**
Y*H	0.516	15	1.43	**0.028**	*
Y*M	0.071	5	0.59	0.967	
H*M	0.433	3	5.99	**<0.001**	***
Y*H*M	0.242	15	0.67	0.959	
Residuals	15.995	664			

Figure 1.13. NMDS ordinations representing plant community compositions observed from 2016-2022 broken down by (a) habitat type and monitoring zone class, and (b-d) habitat type and survey year. To better distinguish differences between years for individual habitat types, separate ordinations were fit and are shown for dunes (b), transition (c), and creep (d) habitat types. Bare (mudflat) habitats are not shown because they were effectively unvegetated in all years, so there was negligible variation to illustrate. Points represent observed communities and correspond to individual study plots in a given year; their position reflects community composition, and the spatial proximity between points reflects similarities among observed communities. Colored ellipses represent the 95% confidence intervals around the theoretical average communities found in each group. See Table 1.10 (PerMANOVA results) for additional information related to these ordinations.





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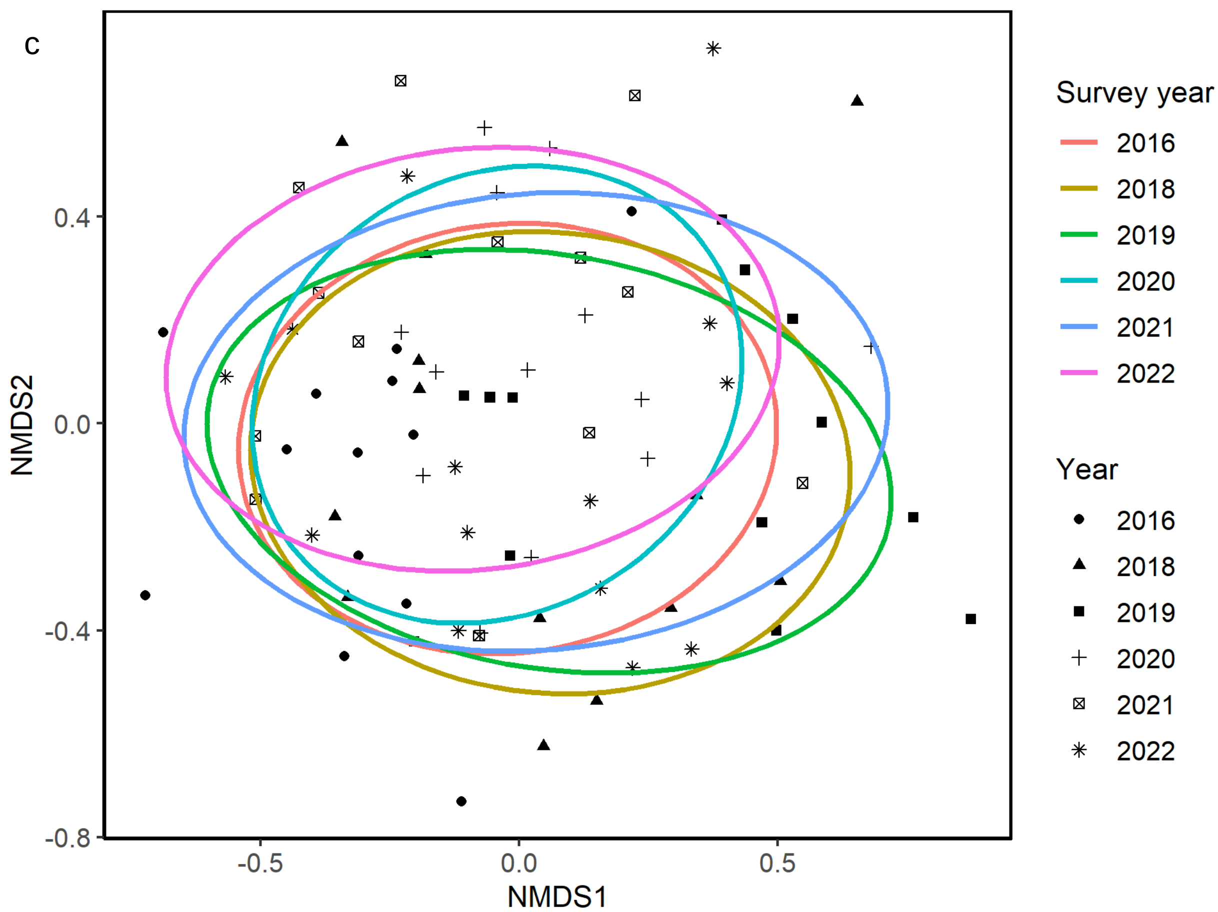
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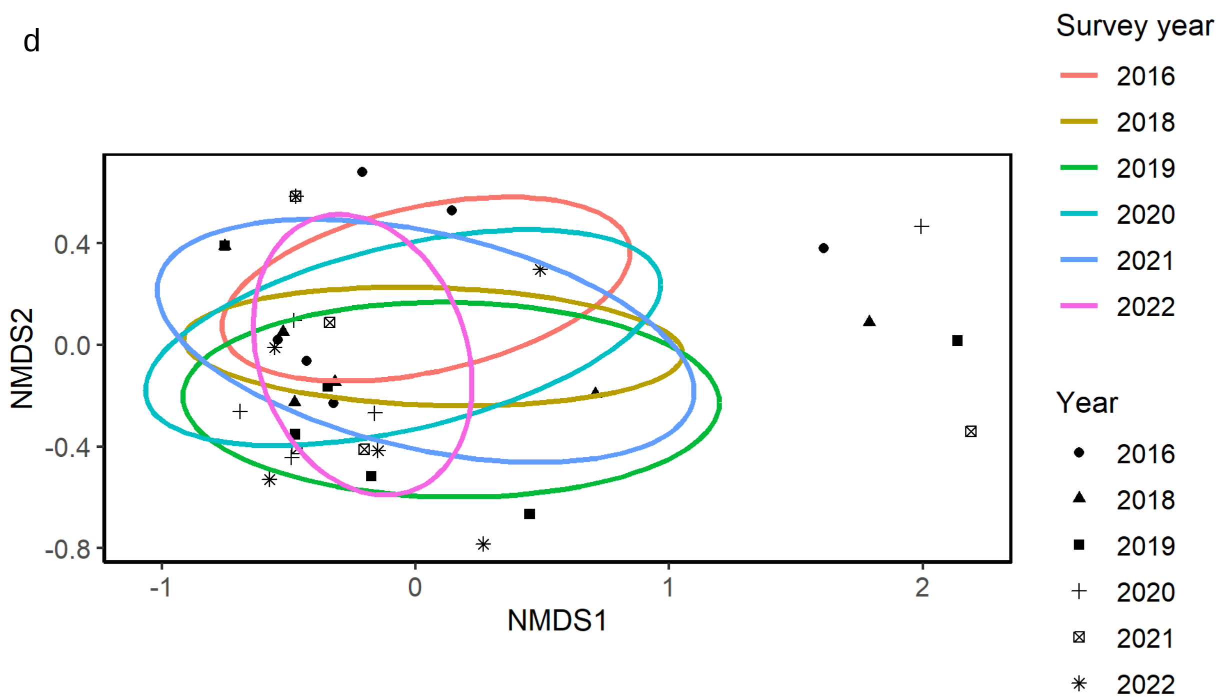
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2021
2022
NMDS2
NMDS1
0.4
0.0
-0.4
-0.8
-1
0
1
2

Conclusions

Much of the variation observed over the past 7 years has been within the range of natural variability, but some large changes statistically attributable to land use change at the Boca Chica launch pad have also been observed. This has been true for the two most recent sampling periods, where most change in species composition and abundance were relatively small, and some changes reversed changes observed in prior sampling periods (e.g., the increase in plant cover in creep plots in 2022 following a sharp decrease in 2021). However, some of the largest changes observed to date occurred in the most recent sampling period or represent continuations of changes observed in 2021, which have been the most active years to date by far for launch pad construction and operations. Some of the large changes observed are directly attributable to this activity, such as the over 20-fold increase in cover by vehicle tracks in our survey plots in 2021 compared to prior years. The present evidence suggests the following:

1) Proximity to the launch site has influenced total plant cover and the overall cover of some dominant plant species, such as *Distichlis spicata* and *Salicornia depressa* (**Figure 1.7**), as well as the abundance of a larger set of species in certain habitat types (**Figure 1.9**); however, we cannot say with absolute certainty whether these changes are due to SpaceX activities, other drivers, or unquantified variation in environmental conditions.

2) Some observed changes are clearly the result of increased activity in the area, such as the 20-fold increase in vehicle tracks in 2021 from 0.3% to 6.7% ground cover, which was over 3 times greater than the cover of the most abundant plant species. Notably, groups other than SpaceX, primarily Border Patrol and the public, also use vehicles (especially ATVs) in the area. These changes may be associated with other observed changes in ways that could not be substantiated or tested with the current design, such as whether increased vehicle traffic in 2021 contributed to the reduction in total plant cover in creep plots in 2021 and its rebound in 2022.

3) Plant community composition, according to our multivariate analyses, differed significantly between the monitoring and take proximity zones (**Table 1.10** and **Figure 1.12c**). Please note that the results shown in Table 1.10 reflect residual analyses and are not readily visible in Figure 1.12c because the ordination does not display residual values. The effect of monitoring zone is much more visible in **Figure 1.13a**, and this effect was mainly seen in dune and transition habitats, but it did have a significant overall effect. Dune habitats exhibited significantly greater changes in community composition over time than other habitat types (habitat × year interaction), indicating that plant communities in the vegetated areas in the vicinity of the launch pad have changed in significant ways since 2016.

Further monitoring and investigation are merited to identify (a) whether observed impacts are temporary, or if recent changes will persist or progress further; and (b) whether these impacts are better explained by natural confounding factors not yet quantified, or if they are genuine impacts of launch pad construction and/or operation. Such investigations would also provide information critical to the success of potential future mitigation efforts.

III. Extensive vegetation monitoring (within a three-mile launch site radius at Boca Chica Beach, TX):

David W. Hicks, Ph.D., and Leticia Contreras, M.S.

Description of Sampling Activities

SpaceX currently operates from two sites within the Boca Chica area. The westernmost area which includes processing, production, manufacturing, and launch control operations extends ~0.33 mi (0.6 km) west of Remedios Ave to ~0.08 mi (0.1 km) northeast of LBJ Blvd. Launch control operations were relocated to the UTRGV-STARGATE facility in 2018. The Vertical Launch Area is to the east <0.5 miles from the beach. The first launch from the SpaceX Boca Chica facility occurred on April 5, 2019.

Extensive vegetation monitoring makes use of multispectral satellite imagery to detect large-scale changes within a circular study area with a 3 mi (4.8 km) radius centered at the SpaceX Vertical Launch Area at Boca Chica, Texas. The study area is approximately 19.6 sq. mi (50.8 sq. km.) excluding the Gulf of Mexico to the East, and the Rio Grande River and Mexico to the South, and is largely contained within the Lower Rio Grande National Wildlife Refuge. Major habitats include dune, marsh, coastal prairie, tidal flats, and coastal lagoon habitat. Of particular concern are designated piping plover critical habitat (Unit TX-1) and proposed red knot critical habitat Unit (TX-11) which extend into the 3 mi radius study area (Figure 2.1).

The imagery representing the 2021-2022 reporting cycle was collected on March 18, 2022, from the WorldView-3 (WV3) satellite and exhibited high quality with minimal cloud cover. The WV3 satellite collects 8 multispectral bands, visible and near-infrared (400 nm - 1040 nm), at 1.24 m resolution.

The March 18, 2022, image was compared to WV3 imagery from December 17, 2020 (prior reporting cycle) and to WV3 imagery from November 9, 2014 (initial reporting cycle) for extensive-scale vegetation variation based on the Normalized Difference Vegetation Index (NDVI). The NDVI transforms multispectral data into a single image band with values ranging from -1 to +1 where values < 0 represent surfaces that contain no chlorophyll while values > 0 contain chlorophyll. NDVI values varies by plant community and condition. In comparing changes in NDVI, increases could be greener vegetation (with the same extent) or an increase of extent (with the same greenness). Therefore, NDVI may serve as a proxy for determining relative density (~biomass) of vegetation.

Images were compared using the Image Change workflow in ENVI (Exelis Visual Information Solutions, ver. 5.5.3). The Image Change workflow compares two images of the same geographic extent, taken at different times, and identifies differences between them based on a specified input band or feature index (e.g., NDVI). Prior to image analyses, all imagery was atmospherically corrected using the ENVI QUAAC atmospheric correction module. Large subtidal and intertidal areas were masked so only habitats dominated primarily by vascular plants were considered. Smaller areas subject to inundation, primarily from precipitation (e.g., prairie potholes, swales), and scattered throughout the study area were not masked. Following an initial change detection analysis, thresholds for detecting increases and decreases in NDVI were set manually to focus only on a range of data values that relate to major decreases and increases in NDVI. For example, the threshold for major decreases in NDVI were set based upon values in areas known to have been cleared and graded between time intervals (i.e., anthropogenic impacts). Minor temporal variation of spectral responses that can influence NDVI between two time periods can be due to a variety of reasons, particularly variation in the physical environment, climate (variation in precipitation), and disturbance. For example, when water limits vegetation growth, it has a lower relative NDVI. As part of the interpretation and accuracy assessment processes reported herein, areas of detected change were examined in detail to determine the nature of change (e.g., changes in vegetation coverage and/or changes in greenness).

Findings

Image Change Analyses: 2022 vs. 2020

Developed Areas: Anthropogenically-induced land use changes occurring between December 2020 and March 2022 were primarily associated with further infrastructure expansion at the 1) SpaceX processing, production, manufacturing, and launch control areas and 2) SpaceX Vertical Launch Area (Figure 2.2 C and E). SpaceX processing, production, manufacturing, and launch control operations occur on the western extent of a former barrier island feature that extends in a northeastern direction to the coast (Figure 2.2C). The westernmost extent of this area, south of Remedios Ave, is the site of the SpaceX Processing, Production, and Manufacturing Area (Processing Area, Figure 2.3, Area 1). Between December 2020 and March 2022, Processing Area expansion decreased vegetation cover by 2.1 hectares (5.3 acres). An additional 1.4 hectares (3.5 acres) of vegetation was impacted due to increased parking and road widening and maintenance adjacent to this area (Figure 2.3, Area 1). The SpaceX Launch and Landing Control Center and Production and Manufacturing Area extend between Remedios Ave and San Martin Blvd (Figure 2.3, Area 2). Continued development in this area decreased vegetation cover by 3.9 hectares (9.6 acres) at the southwestern end of San Martin Blvd due to operations expansion and 1.1 hectares (2.8 acres) at southeastern end of San Martin Blvd due to parking expansion and road widening adjacent to the area (Figure 2.3, Area 2). The area between San Martin Blvd and LBJ Blvd is the site of the SpaceX Solar Farm, Ground Tracking Station, restaurant, and residential areas including Boca Chica Village (Figure 2.3, Area 3). Vegetation cover has been reduced in this area for expansion of residential areas (1.4 hectares [3.4 acres]), operations expansion (0.9 hectares [2.2 acres]) and by additional vehicle paths (1.1 hectares [2.8 acres]) (Figure 2.3, Area 3). SpaceX operations have continued to expand east of LBJ Blvd decreasing vegetation cover by approximately 1.7 hectares (4.3 acres) (Figure 2.3, Area 4). Total vegetation cover reductions at the SpaceX processing, production, manufacturing, launch control areas were estimated at 13.6 hectares (33.9 acres) since the December 2020 imagery.

To the east, further development of the SpaceX Vertical Launch Area, and associated parking and access areas (cleared lot and roadside parking on northside of State Highway 4) resulted in NDVI decreases across approximately 0.4 hectares (1.1 acres) (Figures 2.2E and 2.4). Immediately to the west of the Vertical Launch Area, a decline in black mangroves, *Avicennia germinans*, (0.05 hectares [0.1 acres]) was observed around the perimeter of ponded water (Figure 2.4). The reason for the decline of black mangroves at this location is unclear as surrounding areas supporting black mangroves appear unaffected.

General decreases in NDVI between December 2020 and March 2022 along State Highway 4 as a result of continued widening and maintenance of the roadway and off highway parking beginning west of processing, production, manufacturing, and launch control operation areas and extending to the Vertical Launch Area totaled 6.4 hectares [16 acres] (Figures 2.3, 2.4, 2.5, and 2.6).

Undeveloped Natural Areas: Decreases in NDVI within the study site were also observed away from developed areas between December 2020 and March 2022. A majority of these reductions are believed to be associated with the varying spectral signals of microflora (non-vascular plants) in unvegetated areas (e.g., unmasked flats, swales, and intertidal areas) which are expected to increase/decrease with variations in soil dampness and standing water due to rainfall and/or tidal amplitude. Damp and inundated sediments provide habitat for microflora, which when exposed also reflect radiation in the near infrared and absorb in the red portion, therefore produce a NDVI value > 0 indicating the presence of photosynthetic organisms. For example, the current analyses also showed decreases in NDVI along the eastern and southern shores of South Bay and in dune swales (Figures 2.2A and 2.7). Detailed examination of these areas indicate that the difference is largely related to the varying level of shoreline inundation wherein lower water levels in 2020 exposed unmasked algal flats nearshore and in depressions increasing NDVI compared to 2022 when these areas were inundated. Thus, these analyses-identified reductions in NDVI were not related to losses of vegetation cover in these areas (Figures 2.2A and 2.7).

A dunal area at the intersection of South Bay and Boca Chica Bay (Figure 2.2B) also exhibited decreases in NDVI. Examination of this area indicates a loss of vegetation and replacement by sand for unknown reasons (Figure 2.8). Two large mangals on the northern banks of the Rio Grande River exhibited decreases in greenness (with similar extent) (Figure 2.2F, 2.9, and 2.10). These particular mangals on the banks of the Rio Grande River are a mix of black and red mangroves, *Rhizophora mangle*. Red mangroves are less tolerant of freezing conditions and potential freeze impacts, due to the freeze event on February 2021 wherein temperatures dropped to -4.5˚C (23.8˚F), could be responsible for observed decreases in NDVI.

Image Change Analyses: 2014 vs. 2022

Developed Areas:

The March 2022 WV3 imagery was compared to pre-construction November 2014 WV3 imagery based on change in NDVI using ENVI's Image Change workflow. From this analysis, decreases in NDVI due to aeronautical industry and associated developments were estimated across approximately 60 hectares (148 acres) between November 2014 and March 2022 (Figures 2.11B and D, 2.12, and 2.13); 52.4 hectares (129.5 acres) in the processing, production, manufacturing, and launch control areas and 7.5 hectares (18.4 acres) in the Vertical Launch Area. On the northwestern edge of the tidal flats within the Production and Manufacturing Area (between Remedios Ave and San Martin Blvd, Figure 2.3, Area 2), a small parcel (0.41 hectares [1.0 acre]) that, in the opinion of the surveyors would be classified as a wetland has been filled and paved (Figure 2.14). At this same location are three drainage ditches that empty into the adjacent tidal flats (Figure 2.15). Two of the three drainages, southernmost and northernmost, appear first in imagery in 2020. The middle drainage was constructed prior to 2014 (Figure 2.15).

Undeveloped Natural Areas: Decreases of NDVI in undeveloped areas across the study site since 2014 were also observed. The most notable of these include NDVI reductions adjacent to State Highway 4 and the site of the July 24, 2019-test launch wildfire (Figure 2.16). Decreases in NDVI adjacent to State Highway 4 are due to vegetation removal associated with widening and maintaining the roadway as well as general decreases in surrounding vegetation greenness (with similar extent) (Figure 2.16). Decreases in NDVI at the location of July 24, 2019-test launch wildfire are due to general decreases in vegetation greenness (with similar extent) and most likely due to a shift in the plant community as a result of loss/reduction of shrubs (e.g., black mangrove and yellow necklacepod [*Sophora tomentosa*]) (Figure 2.16) (Hicks and Contreras 2019). The analyses also showed vegetation losses along the eastern shores of South Bay (primarily black mangrove) and general decreases in vegetation greenness along the eastern edges of Boca Chica Bay (Figure 2.17). Similar to that observed between March 2022 and December 2020, the two large mangals on the northern banks of the Rio Grande River and a distributary channel appear to have losses in greenness (with similar extent) most likely due to the freeze event in occurring in February 2021 (Figure 2.18).

Conclusions

Much of the extensive scale vegetation changes observed within the Boca Chica 3 mi. radius study area since 2014 are directly related to land use change (clear and grub) for aeronautical industry and associated developments (road widening and maintenance). Other minor extensive scale vegetation changes in undeveloped areas appear to be in range of natural variation and largely associated with variation in rainfall and other episodic climatic events (e.g., freezes). An exception to this is the July 24, 2019-test launch wildfire which burned approximately 30 hectares (74 acres) of coastal prairie habitat. The first extensive scale vegetation analyses following the July 2019 wildfire (post-burn analysis) occurred in December 2020 (17 months post-wildfire, Hicks and Contreras 2021). At that time, NDVI remained reduced compared to pre-fire conditions across approximately 9 hectares (22 acres) or ~67% of the originally burned area. In the current, March 2022 analyses, reductions in NDVI are still apparent over pre-fire conditions (Figure 2.16). More intensive investigation would be required to determine the source of lower NDVI values in 2022, but could indicate a shift in plant community composition. Based upon the information collected herein, the investigators recommend the following:

1) Review current permitting for development plans as related to wetlands and drainages leading to tidal flats.

2) Monitor the tidal flats adjacent to recently constructed drainages (both intensive and extensive analyses). The monitoring plan specifically identifies the mudflats surrounding the Launch and Landing Control Center to be evaluated for changes (SpaceX 2022).

3) Monitor recovery and plant community redevelopment following wildfires, particularly for the presence and spread of invasive species.

4) Investigate loss of black mangroves adjacent to the Vertical Launch Area.

Figures

Figure 2.1. Location of SpaceX properties and facilities adjacent to the eastern terminus of State Highway 4, South Bay, and the Gulf of Mexico in Cameron County, Texas. Locations of the SpaceX operations (Launch and Control Center and Vertical Launch Area), radius of the circular study area (blue polygon): 4.8 km (3 mi), piping plover critical habitat (Unit TX-1, yellow polygon), and proposed red knot critical habitat (Unit TX-11, red polygon).

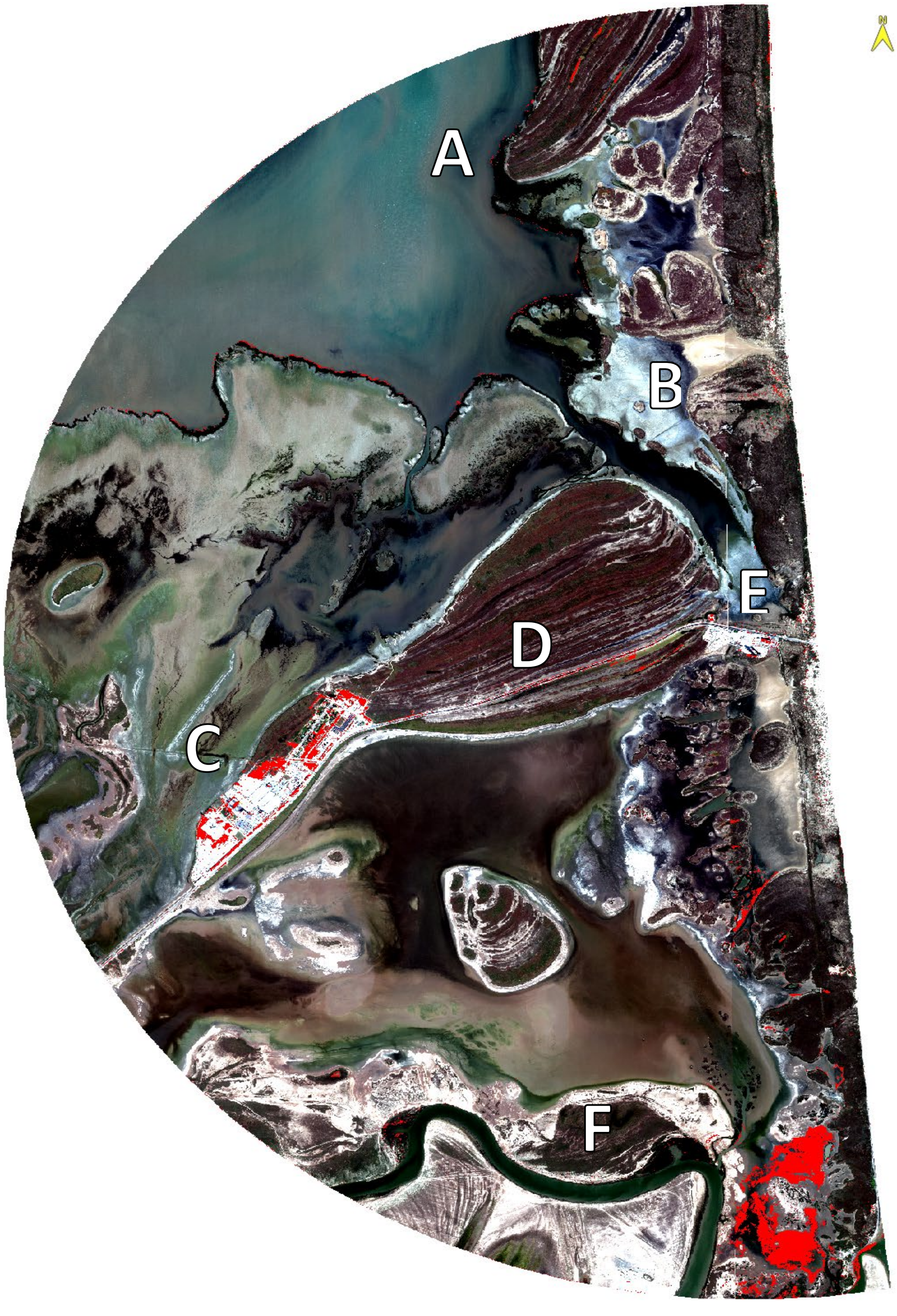

Figure 2.2. Change detection analysis on WorldView-3 satellite imagery between December 2020 and March 2022 by the Normalized Difference Vegetation Index (NDVI). Vegetation decrease (red); radius of the circular region: 4.8 km (3 mi). A) South Bay shoreline, B) Intersection of South Bay and Boca Chica Bay, C) SpaceX Processing and Manufacturing areas, D) relic barrier island swales and ridges, E) Vertical Launch Area, and F) Rio Grande River.

Figure 2.3. Change detection analysis on WorldView-3 satellite imagery of the SpaceX processing, production, manufacturing, and launch control areas depicting decreases (red areas) in the Normalized Difference Vegetation Index (NDVI) (upper panel) between December 2020 (bottom left) and March 2022 (bottom right). Area 1: southwest of Remedios Ave. Area 2: between Remedios Ave and San Martin Blvd; Area 3 between San Martine Blvd and LBJ Blvd; Area 3 northeast of LBJ Blvd. White lines represent roads Remedios Ave, San Martin Blvd, and LBJ Blvd from west to east respectively. Blue polygons identify land-use changes for SpaceX operations, green polygons represent clear and grub areas, yellow polygons represent parking and road widening, and pink polygons represent residential development.

Figure 2.4. Change detection analysis on WorldView-3 satellite imagery of the SpaceX Vertical Launch Area (VLA) depicting decreases (red areas) in Normalized Difference Vegetation Index (NDVI) (upper panel) between December 2020 (middle) and March 2022 (bottom). See Figure 2.2E for specific location within the study area. 1) yellow polygons represent parking areas and road expansion, 2) green polygons represent Mangrove losses, and 3) blue polygons represent VLA operations expansion.

Figure 2.5. Change detection analysis of WorldView-3 satellite imagery depicting a decrease (upper panel red areas) in Normalized Difference Vegetation Index (NDVI) along State Highway 4 between December 2020 (bottom left) and March 2022 (bottom right) immediately west of the Launch and Landing Control Center.

Figure 2.6. Change detection analysis of WorldView-3 satellite imagery depicting a decrease (upper panel red areas) in the Normalized Difference Vegetation Index (NDVI) along State Highway 4 between December 2020 (middle) and March 2022 (bottom) immediately east of the SpaceX Launch and Landing Control Center extending towards the SpaceX Vertical Launch Area. See Figure 2.2D for specific location within the study area.

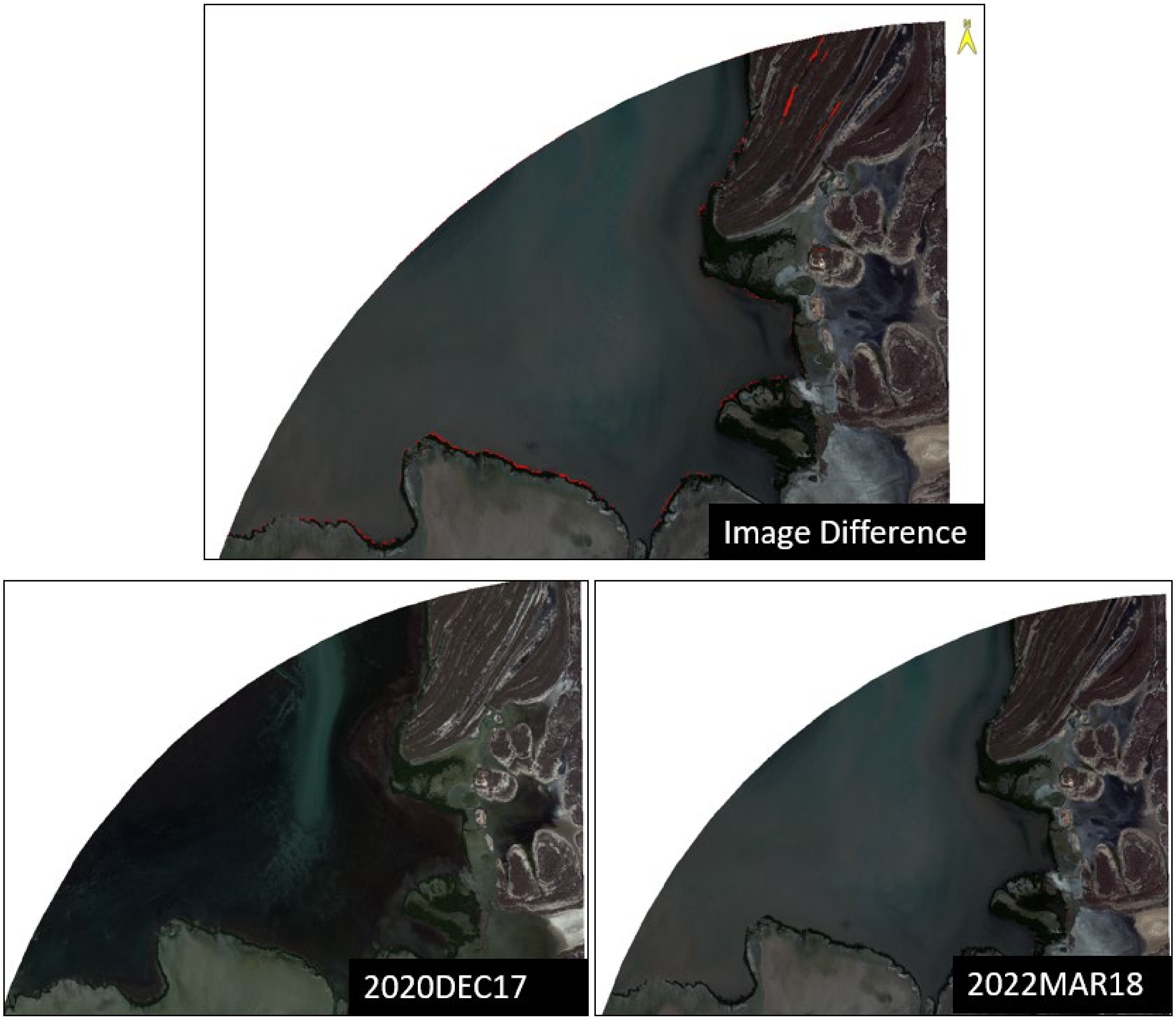

Figure 2.7. Change detection analysis of WorldView-3 satellite imagery depicting a decrease (upper panel red areas) in the Normalized Difference Vegetation Index (NDVI) between December 2020 (lower left) and March 2022 (lower right) along eastern and southern shorelines of South Bay and adjacent dune and swale areas. See Figure 2.2A for specific location within the study area.

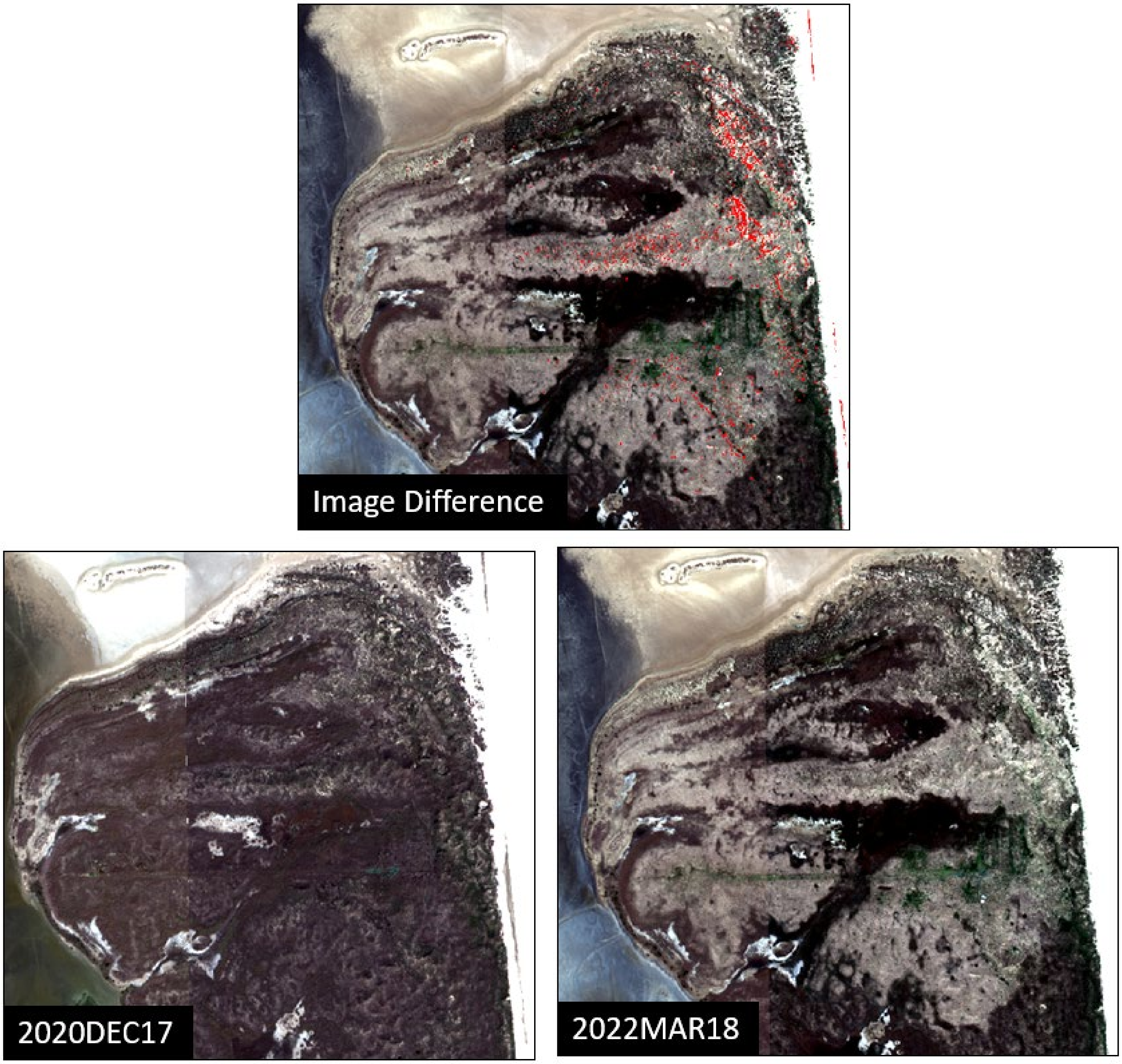

Figure 2.8. Change detection analysis of WorldView-3 satellite imagery depicting a decrease (upper panel red areas) in the Normalized Difference Vegetation Index (NDVI) between December 2020 (lower left) and March 2022 (lower right) in a dunal area at the intersection of South Bay and Boca Chica Bay. See Figure 2.2 for specific location within the study area.

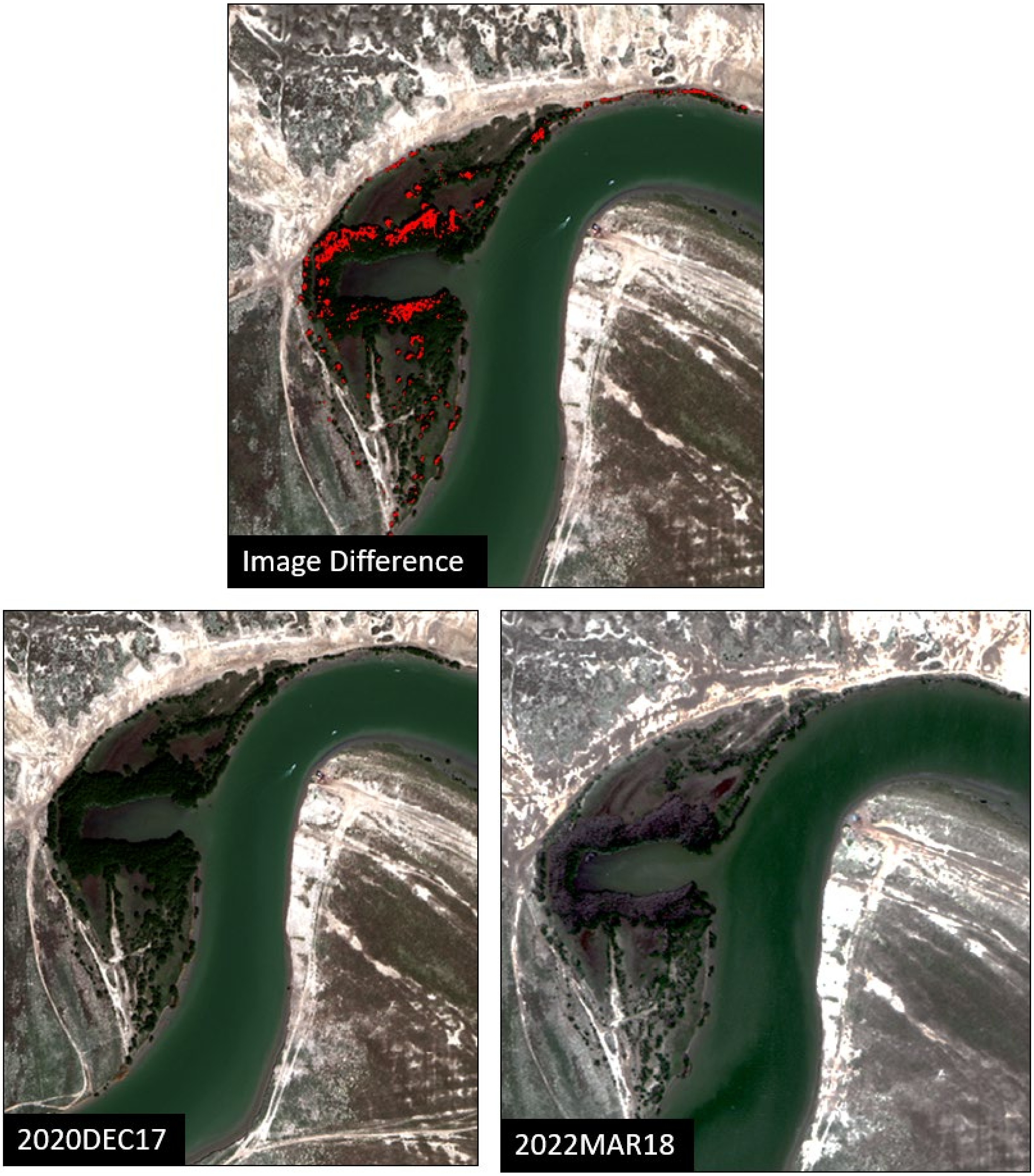

Figure 2.9. Change detection analysis of WorldView-3 satellite imagery depicting a decrease (upper panel red areas) in the Normalized Difference Vegetation Index (NDVI) in a mangrove area on the northern banks of the Rio Grande River between December 2020 (bottom left) and March 2022 (bottom right). See Figure 2.2F for specific location within the study area.

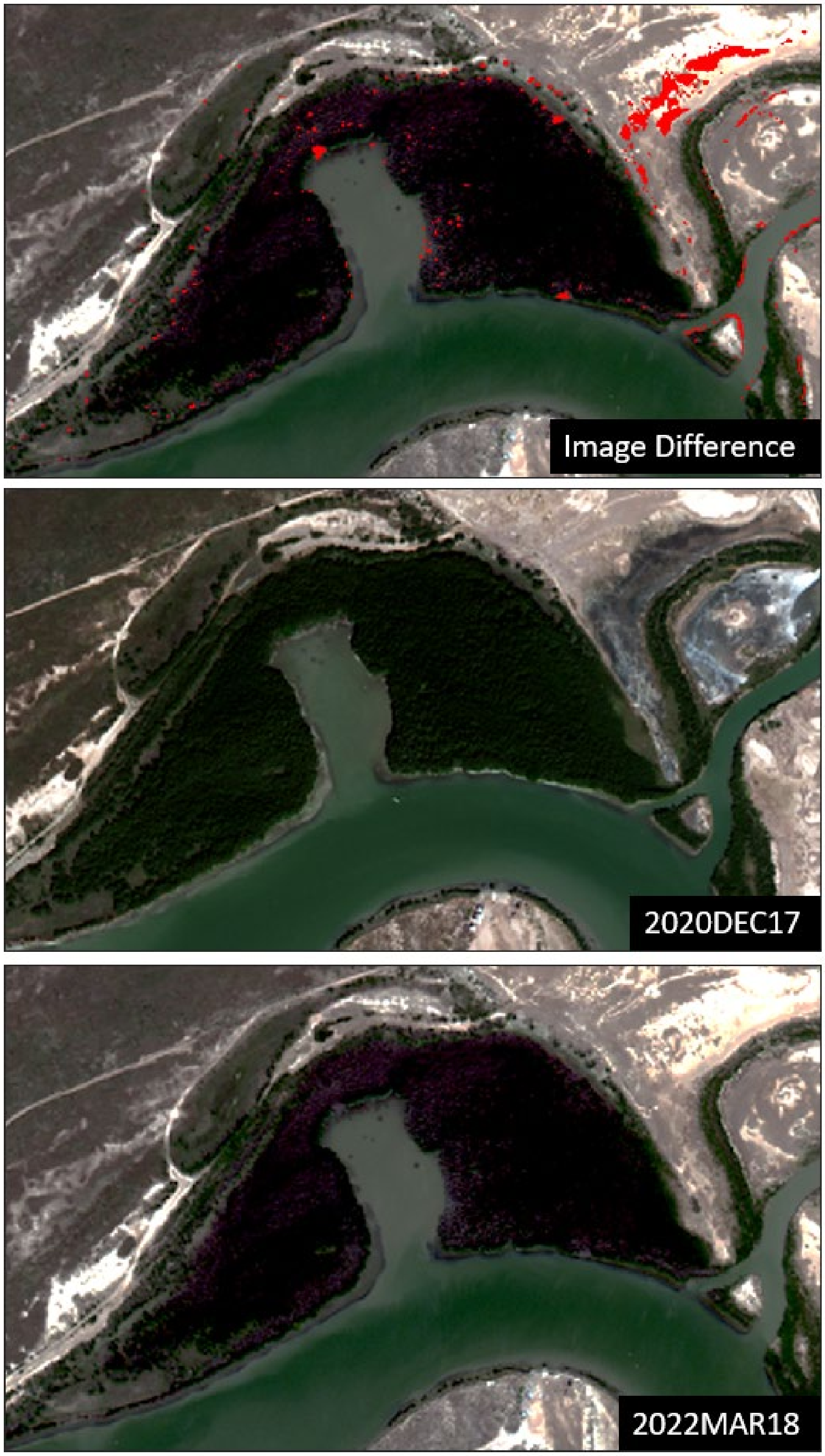

Figure 2.10. Change detection analysis of WorldView-3 satellite imagery depicting a decrease (upper panel red areas) in the Normalized Difference Vegetation Index (NDVI) in a mangrove area on the northern banks of the Rio Grande River between December 2020 (middle) and March 2022 (bottom). See Figure 2.2F for specific location within the study area.

Figure 2.11. Vegetation change analysis of WorldView-3 satellite imagery between November 2014 and March 2022 by the Normalized Difference Vegetation Index (NDVI). Vegetation decrease (red); radius of the circular region: 4.8 km (3 mi). A) South Bay shoreline and dune and swale areas, B) SpaceX processing and manufacturing areas, C) relic barrier island swale and dune feature, and D) SpaceX Vertical Launch Area, and E) Rio Grande River.

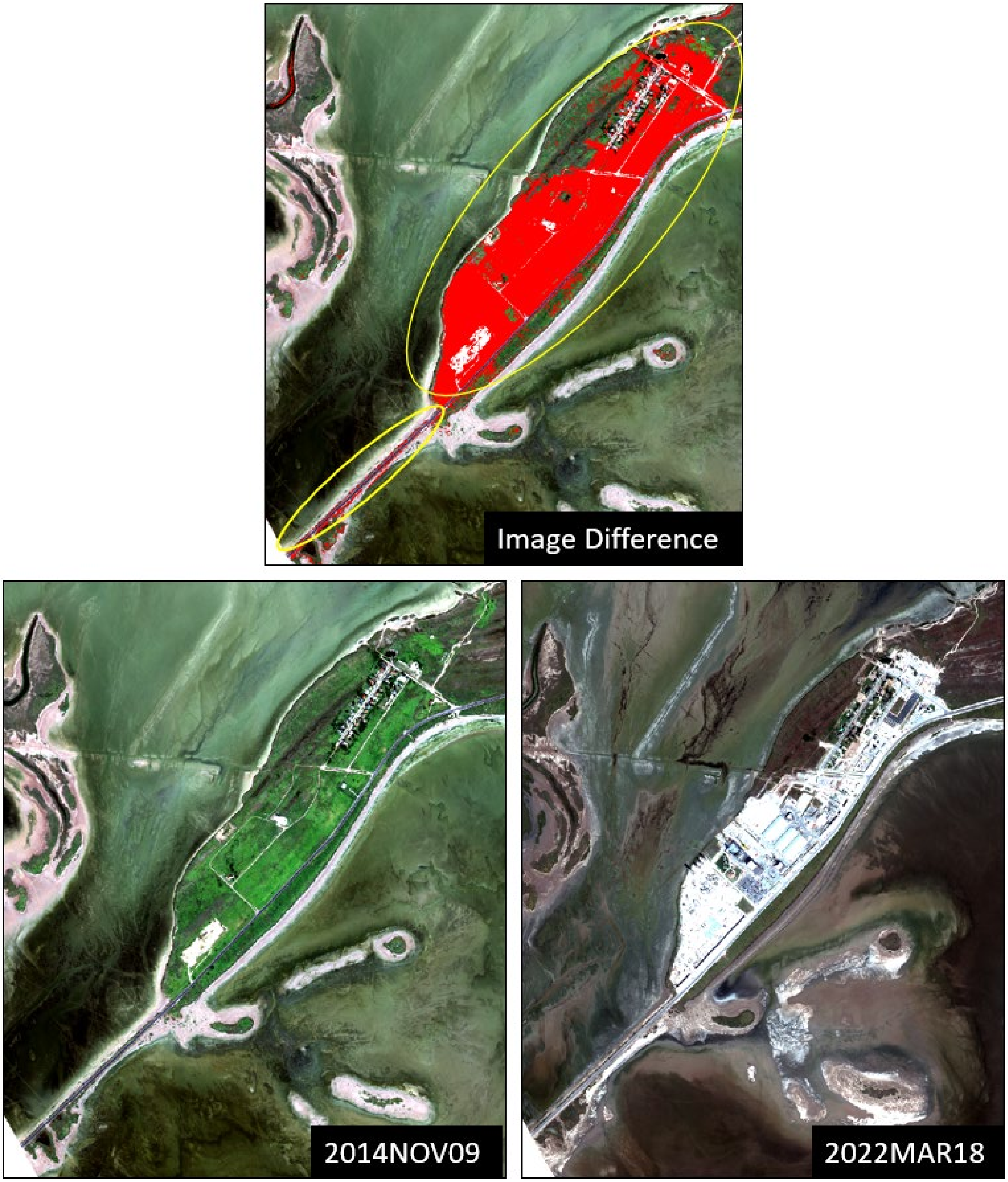

Figure 2.12. Change detection analysis of WorldView-3 satellite imagery of the SpaceX processing, production, manufacturing, and launch control areas depicting decreases (red areas, upper panel) in the Normalized Difference Vegetation Index (NDVI) between November 2014 (bottom left) and March 2022 (bottom right). See Figure 2.11B for specific location within the study area.

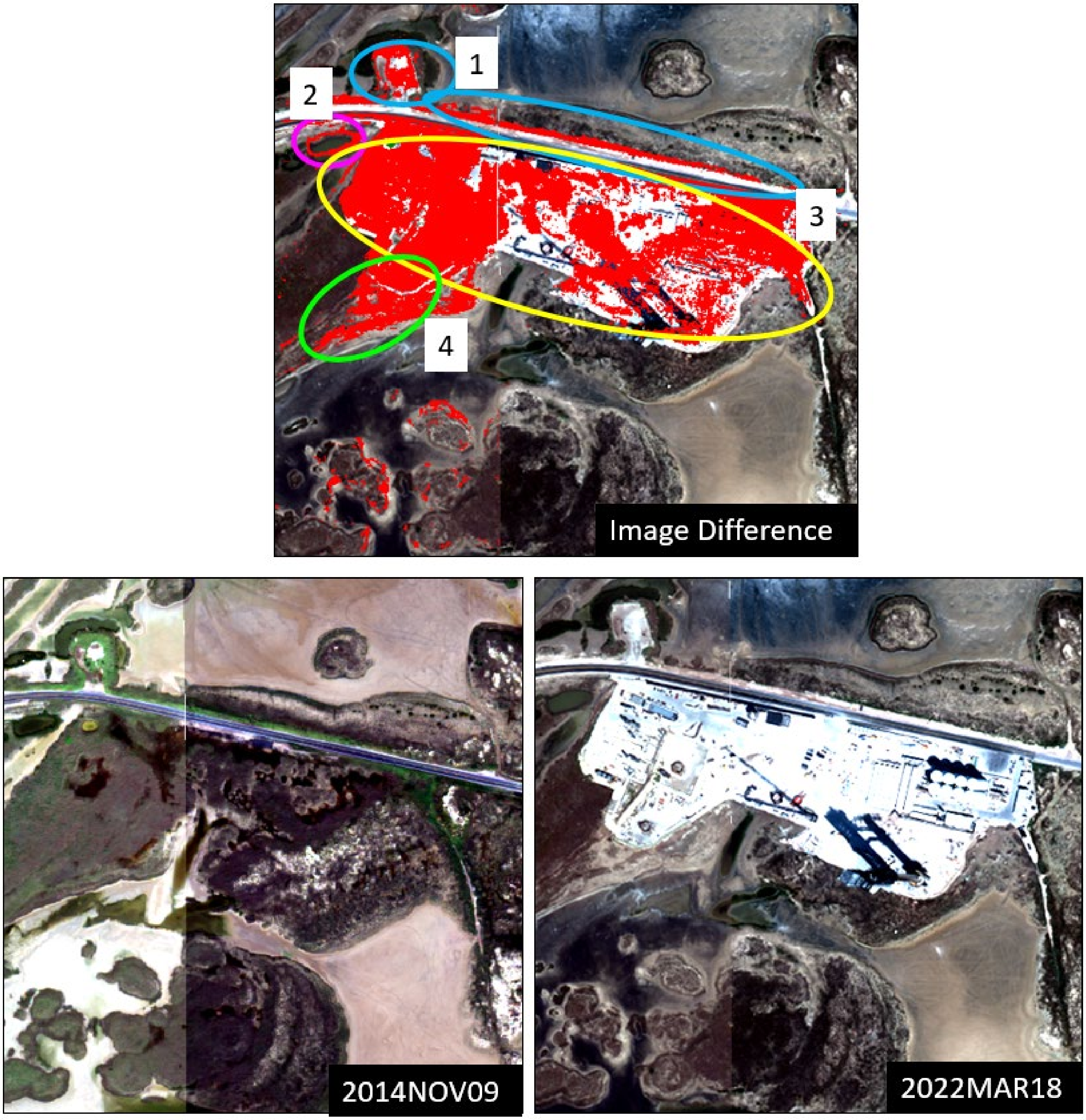

Figure 2.13. Change detection analysis of WorldView-3 satellite imagery of the SpaceX Vertical Launch Area (VLA) depicting decreases (red areas, upper panel) in the Normalized Difference Vegetation Index (NDVI) between November 2014 (bottom left) and March 2022 (bottom right). See Figure 2.11D for specific location within the study area. 1) blue polygons represent parking expansion and road widening, 2) pink polygons, mangrove losses, 3) VLA operations expansion, and 4) green polygons, clear and grub.

Figure 2.14. WorldView-3 (WV3) satellite imagery from November 2014 (upper), December 2020 (middle), and March 2022 (lower) of the Production and Manufacturing Area (between Remedios Ave and San Martin Blvd). Red polygon indicates a potential wetland developed area (0.41 hectares [1.0 acre]). See Figure 2.3, Area 2 for specific location within the study area.

Figure 2.15. WorldView-3 (WV3) satellite imagery from November 2014 (upper), December 2020 (middle), and March 2022 (lower) of the Production and Manufacturing Area that extends between Remedios Ave and San Martin Blvd depicting drainage canals (yellow circles) emptying into the adjacent tidal flats. The middle drainage existed prior to 2014. The remaining two drainages appeared in 2020. See Figure 2.3, Area 2 for specific location within the study area.

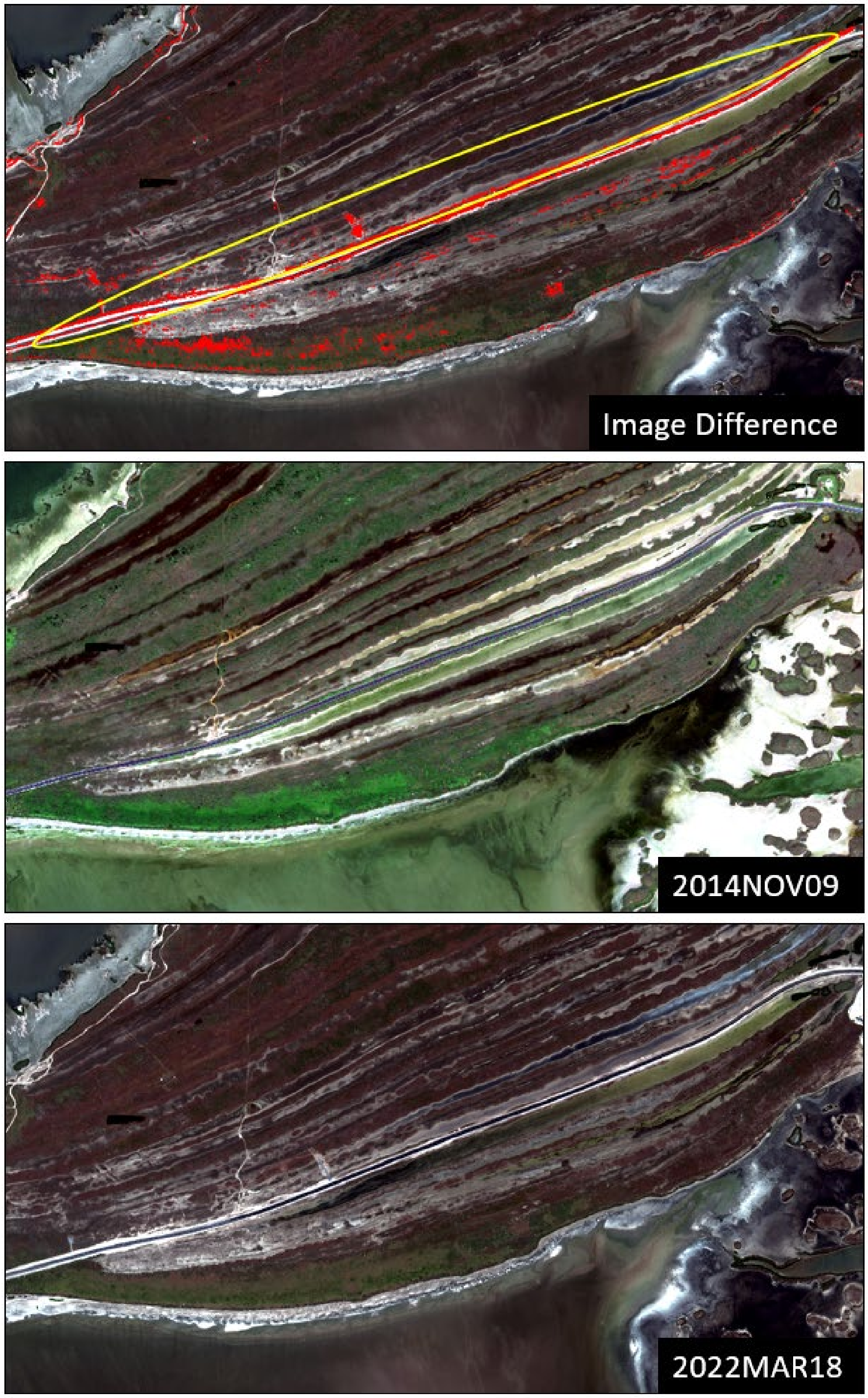

Figure 2.16. Change detection analysis of WorldView-3 satellite imagery depicting decreases (red areas, upper panel) in the Normalized Difference Vegetation Index (NDVI) along State Highway 4 between November 2014 (middle) and March 2022 (bottom) immediately east of the SpaceX Launch and Landing Control Center extending towards the SpaceX Vertical Launch Area. NDVI reductions on the southside of State Highway 4 are at the site of the July 24, 2019-test launch wildfire. See Figure 2.11C for the specific location within the study area.

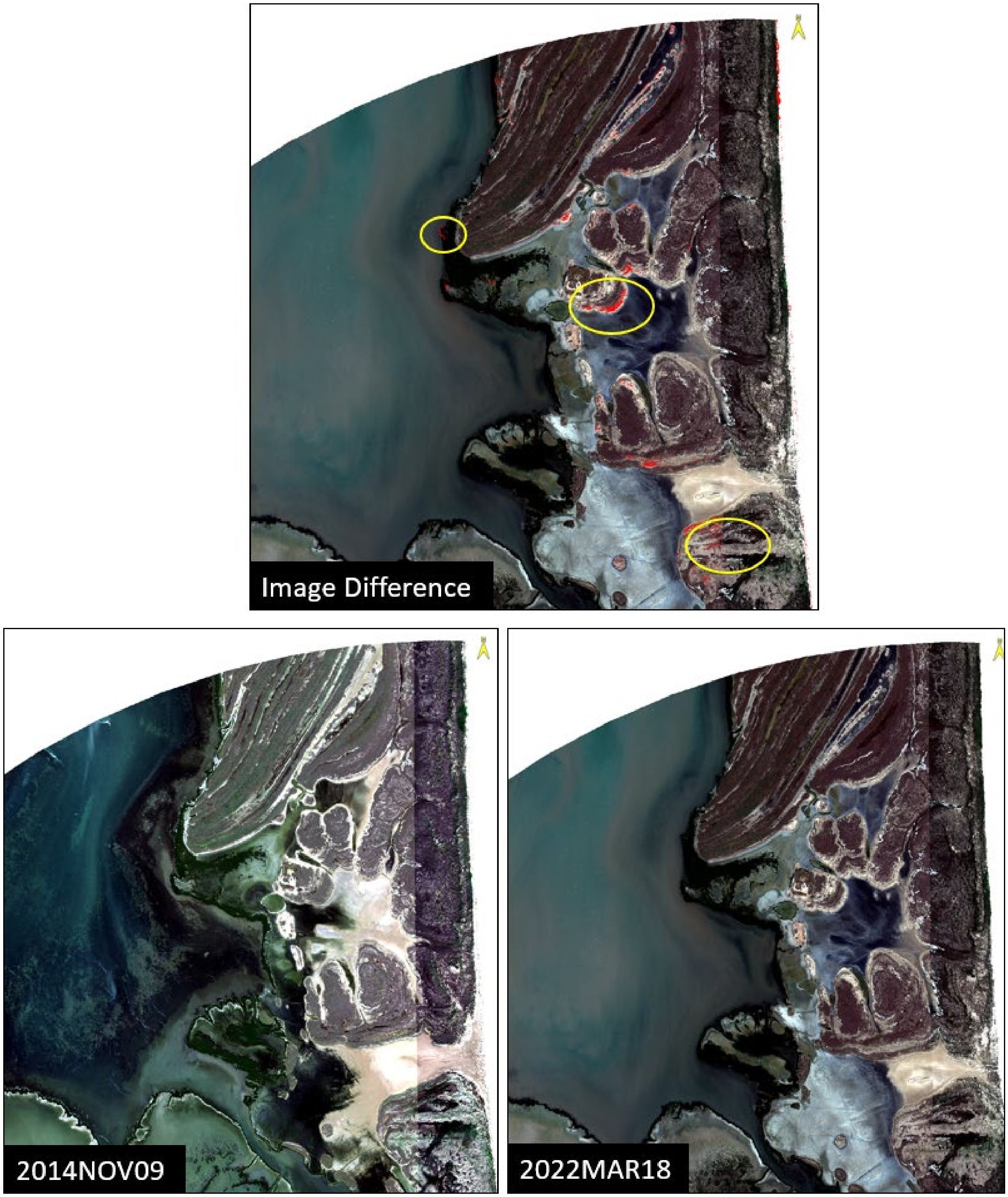

Figure 2.17. Change detection analysis of WorldView-3 satellite imagery depicting decreases (red areas, upper panel) in the Normalized Difference Vegetation Index (NDVI) between November 2014 (bottom left) and March 2022 (bottom right) along eastern margins of South Bay and adjacent dune and swale areas. See Figure 2.11A for specific location within the study area.

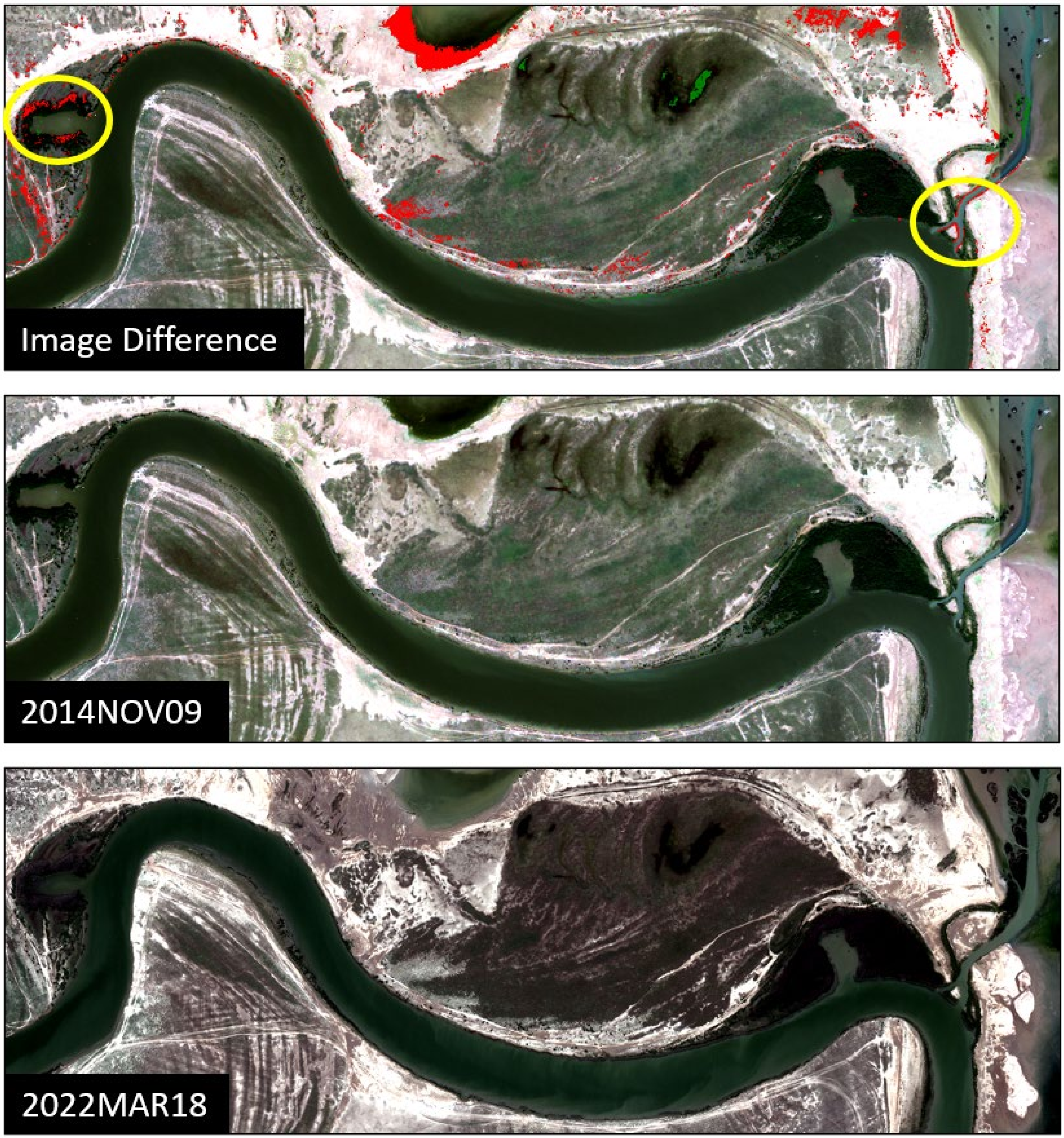

Figure 2.18. Change detection analysis of WorldView-3 satellite imagery depicting decreases (upper panel red areas) in the Normalized Difference Vegetation Index (NDVI) in mangrove areas on the northern banks of the Rio Grande River between November 2014 (middle) and March 2022 (bottom). Circled areas depict mangrove losses. See Figure 2.11E for specific location within the study area.

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