

1 **Final report to the Gulf Coast Joint Venture: Black Skimmer and Gull-billed Tern.**

2 May 13, 2024

3 IN SUPPORT OF INTRA-AGENCY AGREEMENT #4500155651: “Enhancing the Black  
4 Skimmer and Gull-billed Tern Bayesian network model to achieve habitat objectives for the Gulf  
5 Coast Biological Planning Units.”

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31 **Summary.** Many bird species are of conservation concern across the Northern Gulf of Mexico  
32 from stressors such as human disturbance, predation, and habitat loss due to directional  
33 environmental change (e.g., increased sea-level rise and storm frequency and intensity, human  
34 infrastructure, changes in land use). Consequently, managers need decision-support tools that can  
35 help to answer important conservation questions for different species (e.g., which areas and how  
36 much area should be targeted by management actions to meet a particular species' needs). The  
37 Black Skimmer (*Rynchops niger*; hereafter Skimmer) and Gull-billed Tern (*Gelochelidon*  
38 *nilotica*; hereafter Tern) are designated as U.S. Fish and Wildlife Service (USFWS) Species of  
39 Conservation Concern and Gulf Coast Joint Venture (GCJV) Priority Species with nesting  
40 habitats in the USFWS Gulf Coast Biological Planning Units (BPU; Tirpak et al. 2017). They are  
41 also representative of a variety of other beach and barrier-island nesting birds whose Gulf Coast  
42 nesting habitats are threatened by directional environmental change. The Skimmer has breeding  
43 pair targets in six GCJV Initiative Areas (IA), and the Tern has breeding pair targets in five  
44 GCJV IAs. Our goal was to inform GCJV management scenarios that efficiently and  
45 simultaneously achieve both species' targets by prioritizing sites where management actions  
46 (e.g., maintain existing habitat or change habitat, geomorphology [landmass area, landmass  
47 elevation], predator management, human and dog restrictions) could be implemented.

#### 48 **Deliverables.**

- 49 1. Data and associated meta-data that contains (a) a .neta file of the Black Skimmer and  
50 Gull-billed Tern Bayesian network model, (b) a site-level shapefile that contains the  
51 model inputs (data used to develop the model; habitat characteristics) and model outputs  
52 (predicted nest counts), (c) an island-level shapefile that summarizes site-level model  
53 outputs at the island-level, and (d) a site-level .csv file that contains the observed bird  
54 survey data.
- 55 2. A .csv file contained in the site-level shapefile (see 1b) that includes the site rankings and  
56 management actions for achieving the GCJV population objectives.
- 57 3. A final report to the GCJV that documents the methods and results.

58 **Methods.** We used existing (2005–2015) nest count survey data (Table 1), geospatial habitat data  
59 (Table 1), and a Bayesian network model that predicts a site's mean nest count (Figure 1) to  
60 generate nest count probability distributions for each species at 163,013 BPU bare ground sites,  
61 of which 153,649 sites were in IAs (Cronin et al. 2024a, b). We used bootstrap analyses  
62 ( $n=1,000$ ) of the nest count survey data to judge if an IA's breeding pair target was most  
63 frequently achieved (i.e.,  $\geq 50\%$  samples) based on existing conditions. If the IA's target was  
64 achieved, we ranked known-colony sites using a Joint Proportional Contribution Index (JPCI),  
65 which is a certainty-weighted nest count index that simultaneously accounts for the site's  
66 contribution to both species' targets (Eqn 1). We defined the management scenario for  
67 maintaining existing conditions as the minimal set of highest JPCI ranked known-colony sites  
68 that achieved both species' targets. If either species target was met before the other species, its

69 contribution to the JPCI of additional sites was dropped to prevent it from influencing  
70 prioritization of the remaining sites required by the other species.

71 If an IA's target was not achieved for one or both species, then the IA's management scenario  
72 was a mixture of maintaining existing conditions on known-colony sites, interventions (i.e.,  
73 simulated management actions) on known-colony sites, or existing conditions on remaining (i.e.,  
74 surveyed non-colony or non-surveyed) sites. First, we modeled the effect of 71 sets of  
75 interventions on each known-colony site, where each set were comprised of  $\geq 1$  intervention  
76 variables that differed in effort (Table 2). An intervention variable's value at a site was  
77 determined via assertion (e.g., changing the site's Restrictions from "None" to  
78 "Caution/Protection") or backward inference (i.e., using the model to solve for the intervention's  
79 value) and the non-intervention variable values and a hypothesized best performance nest count.  
80 The hypothesized best performance nest count for a known Tern site was its greatest Tern nest  
81 count bin with an empirical probability  $> 0.01$ . For known non-Tern sites, the Skimmer's best  
82 performance nest count was used. We favored Terns at known Tern sites because they influence  
83 Skimmers (Fig. 1) and their objectives are harder to meet on average. Although Tern has a  
84 smaller target compared to Skimmer, it has an even smaller colony size. If the intervention  
85 increased one or more species' nest count, and did not decrease either, then the site's JPCI value  
86 was recalculated using its intervention nest count (i.e., the intervention was implemented at that  
87 site), where any island-level interventions (e.g., geomorphology) were cross-walked to all sites  
88 on that island. Otherwise, the empirical JPCI values were retained (i.e., existing conditions were  
89 maintained). We selected the intervention set that provided the greatest reduction of nest deficit  
90 for the least intervention effort and met additional GCJV considerations. A single intervention's  
91 effort (Table 1) was based on GCJV perceived levels of complexity, cost, and other factors  
92 required to conduct the intervention. An intervention set's total effort was the sum of its  
93 individual efforts.

94 If including interventions on known-colony sites did not achieve both species targets, we added  
95 remaining sites until the target was achieved. These sites were low or medium connected sites  
96 whose JPCI values were calculated from their observed (surveyed non-colony) or modeled (non-  
97 surveyed) nest count given existing conditions. For completeness, we also prioritized the  
98 remaining high connected sites so that all sites in the study area had a priority ranking.

99 We visually inspected each IA's management scenario sites in Google Earth from dates 2000-  
100 2023 (accessed March 2024) and recorded if they appeared to have attributes that could limit  
101 their current management potential. These attributes were intermittent inundation (too frequently  
102 inundated), landcover (currently non-habitat e.g., forest, emergent marsh, or mud); land loss (no  
103 longer exists), misaligned (i.e., exists but migrated in space), or partial (appears to belong to a  
104 larger site). Partial was difficult to score as it was based on a subjective severity of fragmentation  
105 as indicated by diagonal adjacency and excluded linear sets of diagonally adjacent sites along  
106 narrow strips of shoreline. We re-ran the management scenario while excluding two Texas Mid-

107 Coast (TMC) sites that appeared to be jetties. We also summarized the results at the island level  
108 because this is the level at which the GCJV partners operate.

109 **Results.** The breeding pair targets are shown in Figure 2's top panel at the top of each bar. The  
110 only IA where existing conditions met both species targets was the Mississippi River Coastal  
111 Wetlands (MRCW; Fig. 2 top). This required maintaining existing conditions of roughly 150 bare  
112 ground ha for Skimmers (Fig. 2 bottom) distributed across roughly 10 sites (Fig. 3 top; Cronin et  
113 al. 2024a) on just as many islands (Fig. 3 bottom; Cronin et al. 2024a). For Terns, this required  
114 maintaining existing conditions of roughly 90 bare ground ha (Fig. 2 bottom) distributed across  
115 roughly 5 sites (Fig. 3 top) on just as many islands (Fig. 3 bottom). The Louisiana Chenier Plain  
116 (LACHEN) has a relatively small Black Skimmer target, no Gull-billed Tern target, and had no  
117 known-colony sites (Fig. 2 top). Meeting its Skimmer target required maintaining existing  
118 conditions of roughly 70 ha (Fig. 2 bottom) located on 1 non-surveyed site (Fig. 3 top).

119 The Laguna Madre (LAG), TMC, Texas Chenier Plain (TXCHEN), and Coastal Mississippi-  
120 Alabama (CMA) targets required a combination of maintaining existing conditions on some  
121 known-colony sites, interventions on some known-colony sites, and maintaining existing  
122 conditions on some remaining sites (Fig. 2 top). Most of this habitat was distributed on the non-  
123 remaining sites, except for the CMA, where it was distributed on mostly known-colony sites  
124 (Fig. 2 bottom; Fig. 3). The interventions that we selected for known-colony sites included  
125 altering shrub area, cat and wild predator removal, or restrictions on human and dog activity (see  
126 black points in Fig. 4; Cronin et al. 2024a). We acknowledge that the LAG, TMC, and TXCHEN  
127 joint nest count deficits could be made lower by including higher effort interventions on habitat  
128 and/or geomorphology (Fig. 4a–c). However, compared to the selected intervention, those  
129 interventions provided only small reductions in the joint deficit: The LAG's  
130 shrub.geo.predY.resP could decrease its joint deficit by an additional 42 nests for 17  
131 geomorphology interventions. The TMC's hab.geo.predY.restC could decrease its joint deficit by  
132 an additional 6 nests for 7 geomorphology interventions. The TXCHEN's hab.shrub.geo.predY,  
133 hab.shrub.geo.predY.restP, and hab.shrub.geo.predY.restC could reduce its joint deficit by up to  
134 an additional 28 nests for 3 geomorphology interventions, of which one required an island's area  
135 to be increased from 2.28 ha to 3,000 ha. The TXCHEN joint deficit could also be reduced, but  
136 only slightly, by constantly removing predators (predY.restP).

137 The visual inspection found that the LAG, TMC, and TXCHEN generally had more types of  
138 attributes, which were associated with 2% to 43% of the management scenario's sites (Fig. 5).  
139 Misalign was common in TXCHEN (43%) and TMC (15%). Otherwise, the most common  
140 attributes tended to be intermittent, landcover, and/or partial (Fig. 5; Cronin et al. 2024a). The  
141 LACHEN's one site appeared to be intermittent (Fig. 5). The MRCW and CMA most common  
142 attributes were land loss (14%) and misalign (17%) (Fig. 5).

143 **Discussion.** We developed tools for identifying efficient IA management scenarios that  
144 simultaneously meet Skimmer and Tern breeding pair targets. These include identifying and

145 quantifying key variables and their relationships (Fig. 1), an index for joint prioritization of sites  
146 (Eqn. 1), methods to rank intervention sets by nests per unit effort (Fig. 4), and a management  
147 scenario for each IA. The visual inspection results, however, suggest that the geospatial inputs  
148 may inadequately identify Skimmer and Tern nesting habitat. Although sites that are misaligned,  
149 lost, or currently forest or emergent marsh could be restoration targets, the intermittent and  
150 landcover attributes suggested many sites appeared to be frequently underwater or were mudflats  
151 that the GCJV partners would not target for restoration. Additionally, many sites were diagonally  
152 adjacent to other sites on what appeared to be contiguous habitat, suggesting that the landcover  
153 may be overly fragmented. We also observed a similar issue when we aggregated the results at  
154 the island level: The imagery suggested that the landcover fragmented many islands. We  
155 discussed updating the landcover because the sources do not reflect current conditions (Table 1).  
156 However, we are aware of other beach nesting bird projects that, facing the same challenges,  
157 resorted to teams that hand delineate nesting habitats. We concluded that effort is beyond our  
158 capacity due to the small spatial resolution required over such a large spatial extent.

159 **Recommendations.** Future efforts could focus on updating the geospatial inputs to better  
160 characterize nesting habitat. The model can be easily updated as these new data become  
161 available. However, we recommend two changes to the modeling approach. First, the GCJV's  
162 conservation partners approach their habitat management decisions at the scale of islands, not  
163 sites. Thus, we suggest that future efforts focus on predicting the number of nests per island,  
164 rather than nests per site. While increase in spatial resolution could greatly simplify the modeling  
165 and decision space, and address the partial attribute, it would still be faced with the geospatial  
166 challenge of delineating islands that are relevant to management.

167 Second, we only modeled interventions on known-colony sites by hypothesizing the site's  
168 empirically known best performance nest count. We did not model interventions on known non-  
169 colony and non-surveyed sites. The best performance nest count on these sites is 0 or not  
170 empirically known. It is the counterfactual, "What would a non-surveyed site's maximum nest  
171 count be if it were a known-colony or a surveyed site?" Obtaining that value requires building  
172 additional models that predict a site's maximum nest count. Building these models and analyzing  
173 their outputs was beyond the scope of the project.

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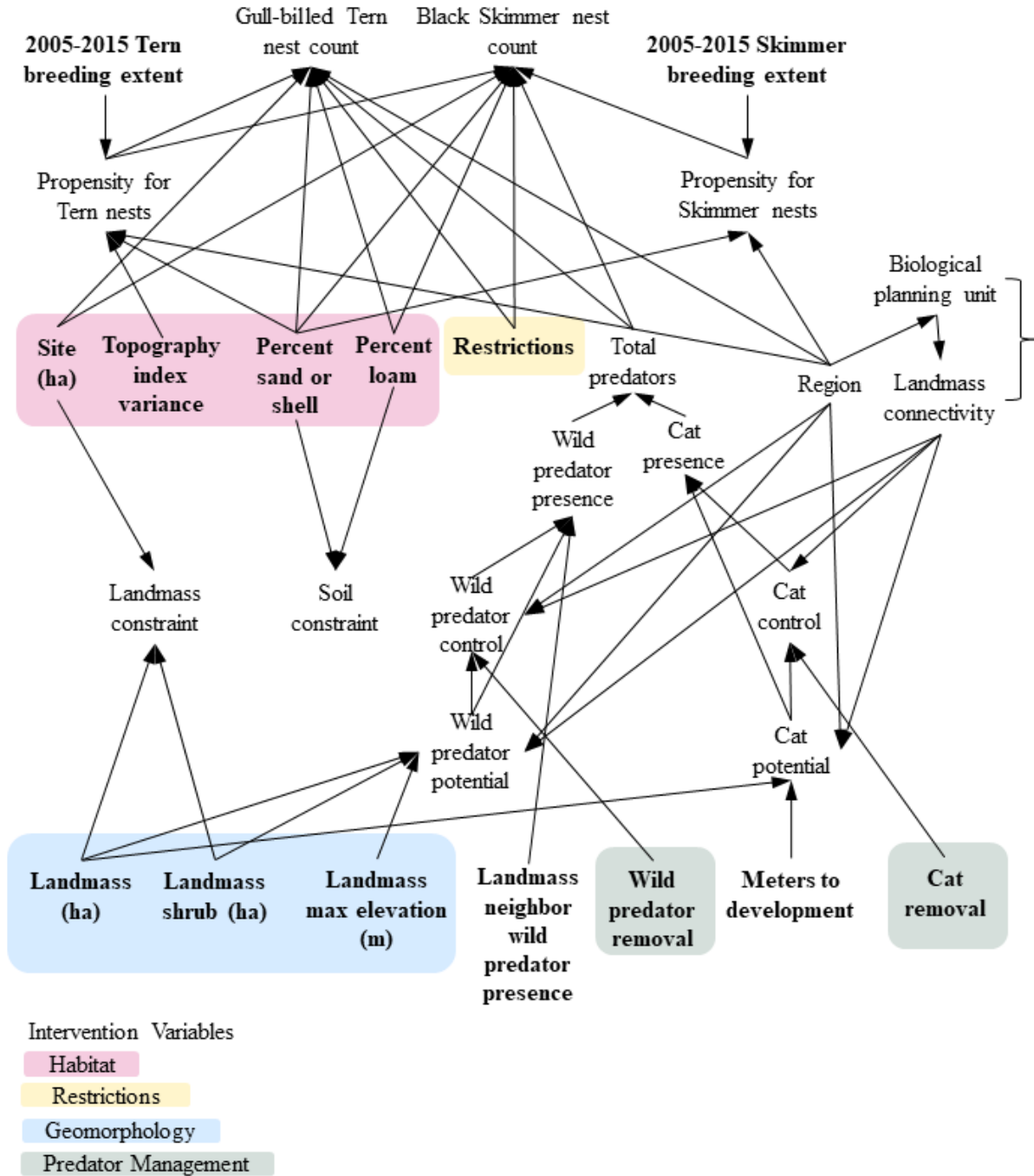
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180 **Table 1.** A summary of data concepts and sources.

Row	Concepts	Sources
1	Site	Contiguous bare ground within 200 meters of mainland and island shoreline that shares the same values for human and dog restrictions and cat removal.
2	Shoreline	Mean higher high water (Office for Coastal Management 2016).
3	Landcover	Texas EMS (Elliot et al. 2010); NWI (USFWS 2017); 2010 C-CAP ( National Oceanic and Atmospheric Administration 2013); CLC ( Florida Fish and Wildlife Conservation Commission [FWC] 2014, 2015a); Armitage et al. 2015.
4	Elevation	NED (U.S. Geological Survey [USGS] 2009, 2013a, 2013b) and LiDAR (Office of Coastal Management Partners 2006, 2007, 2009, 2010a, 2010b).
5	Soil Texture	Soil Survey Staff (2016); Cronin et al. (2024b).
6	Predators, Restrictions	Expert knowledge; ordinance and regulation information (U.S. Census Bureau [USCB] 2016; CivicPlus 2024; USGS 2024); Maslo et al. (2016).
7	Connectivity	Roads (USCB 2015).
8	Nests	Bird monitoring data (Dinsmore (2005); Fontenot et al. (2012); FWC (2015b, 2015c); Texas Colonial Waterbird Society (2015); Deepwater Horizon Regionwide Trustee Implementation Group (2023).

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182



184 **Figure 1.** Black Skimmer and Gull-billed Tern Bayesian network model’s variables and  
 185 influences. Intervention variables are color coded. Bolded nodes are directly influenced  
 186 Biological Planning Unit and Landmass connectivity nodes; Those influences are represented by  
 187 a bracket for illustrative purposes.

189 **Equation 1.** Joint Probability Contribution Index:

190 
$$JPCI_j = \frac{N_{j1} \times C_{j1}}{T_1} + \frac{N_{j2} \times C_{j2}}{T_2} \quad (1)$$

191 where  $j$  indexes the site;  $N_{ji}$  is the nest count for species  $i$  at site  $j$ ;  $C_{ji}$  is the nest count certainty  
192 for species  $i$  at site  $j$ , and  $T_i$  is the IA breeding pair target for species  $i$ . The certainty,  $C_{ji}$ , ranges  
193 [0,1] with higher values denoting greater certainty (i.e., greater loading of outcome probabilities  
194 into fewer outcome states; Marcot 2012), where its value is 1 for empirical nest counts or, for  
195 modeled nest counts, is calculated from the nest count posterior probability distribution.

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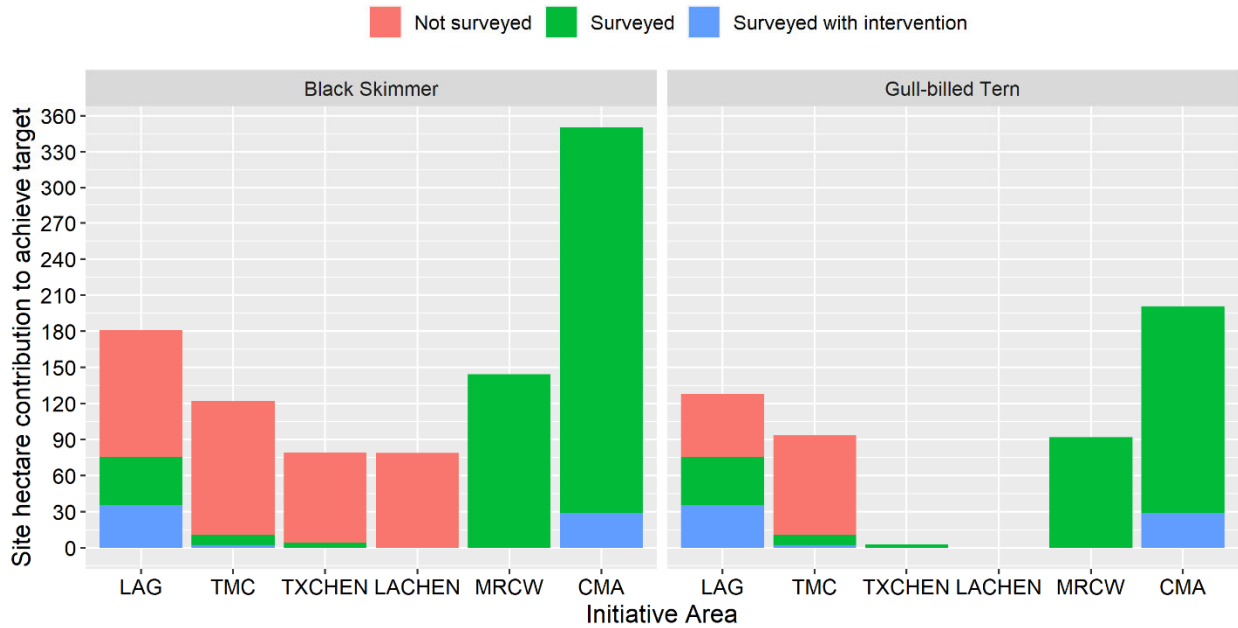
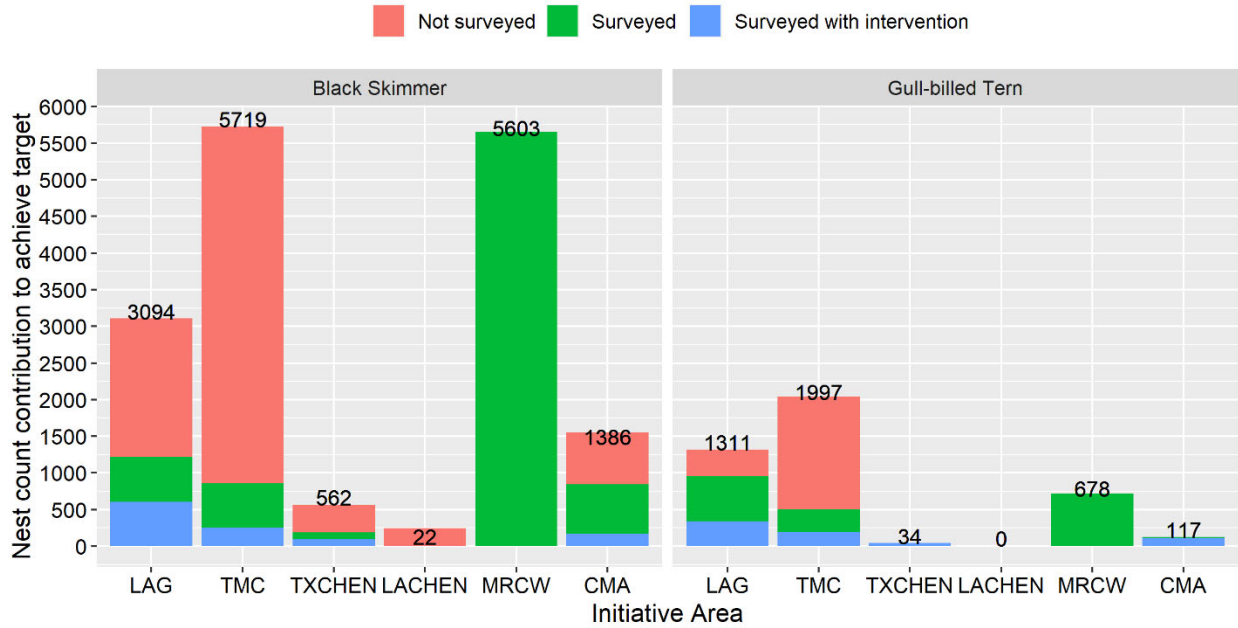
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198 **Table 2.** Interventions and effort. The 71 intervention sets included these single interventions and  
199 all sets of combinations, excluding impossible sets (i.e., Row 1 & 4; Rows 2 & 5).

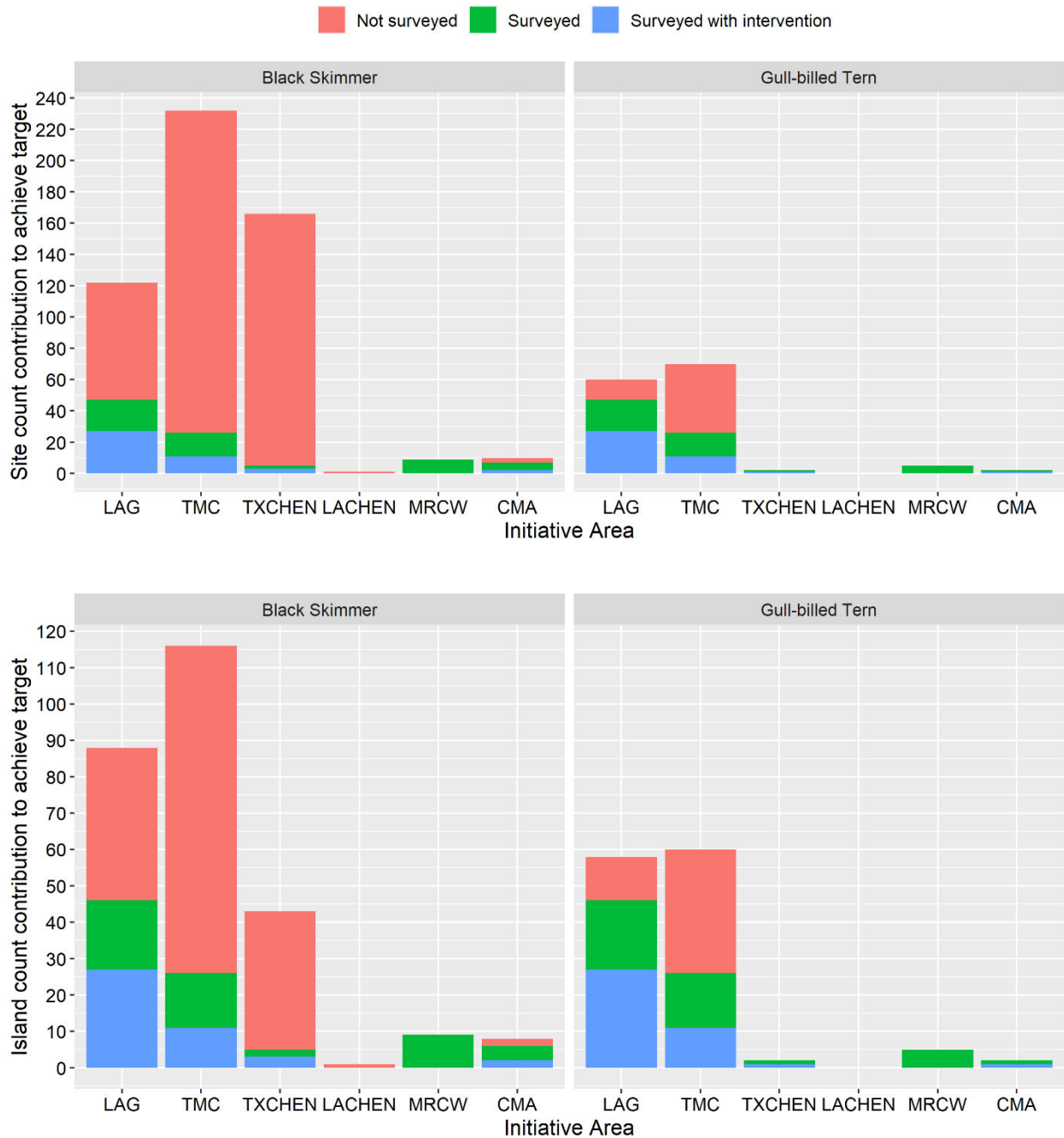
Row	Intervention	Intervention variables	Effort	Value	Level
1	Restrictions P	Restrictions “Caution/Protection”	0.1	Assertion	Site
2	Predators N	Wild predator and Cat removal “As needed”	0.2	Assertion	Island
3	Shrub	Landmass shrub (ha)	0.4	Inference	Island
4	Restrictions C	Restrictions “Closed”	0.5	Assertion	Site
5	Predators Y	Wild predator removal; Cat removal “Constant”	0.6	Assertion	Island
6	Habitat	Site (ha), Topographic index variance, Percent sand or shell; Percent loam	0.7	Inference	Site
7	Geomorphology	Landmass (ha), Landmass max. elevation	1	Inference	Island

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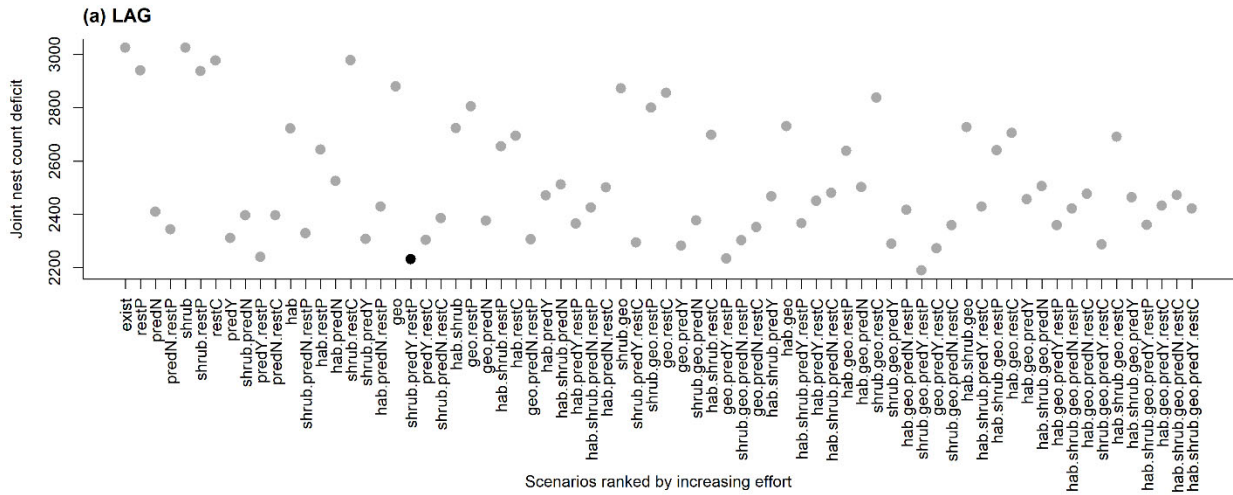
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 203 **Figure 2.** Nest counts (top) and site areas (bottom) required to meet the Gulf Coast Joint Venture  
 204 Initiative Areas Black Skimmer and Gull-billed Tern breeding pair targets. Targets are the values  
 205 at the top of each bar in the top panel. The Black Skimmer’s CMA site area (bottom left panel)  
 206 includes <1 (ha) non-surveyed area. The Initiative Areas are Laguna Madre (LAG), Texas Mid-  
 207 Coast (TMC), Texas Chenier Plains (TXCHEN), The Louisiana Chenier Plain (LACHEN),  
 208 Mississippi River Coastal Wetlands (MRCW), and Coastal Mississippi-Alabama (CMA).



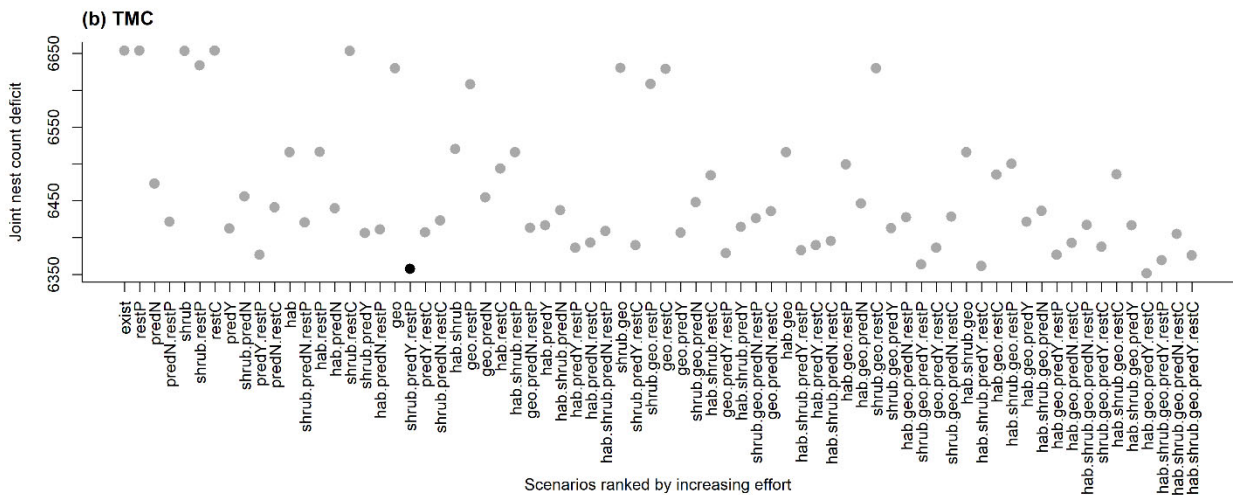
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210 **Figure 3.** The number of sites (top) and islands (bottom) required to meet Black Skimmer and  
 211 Gull-billed Tern breeding pair targets in Gulf Coast Joint Venture Initiative Areas. The Initiative  
 212 Areas are Laguna Madre (LAG), Texas Mid-Coast (TMC), Texas Chenier Plains (TXCHEN),  
 213 The Louisiana Chenier Plain (LACHEN), Mississippi River Coastal Wetlands (MRCW), and  
 214 Coastal Mississippi-Alabama (CMA).

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217 **Figure 4.** Intervention results for (a) Laguna Madre, (b) Texas Mid-Coast, (c) Texas Chenier  
 218 Plain, and (d) Coastal Mississippi-Alabama. The black points identify the selected intervention,  
 219 where the x-axis labels are: exist = existing conditions; restP = restrictions ‘No’ changed to  
 220 ‘Caution/Protection’; predN = wild predator and cat removal ‘No’ changed to ‘As needed’;  
 221 shrub; restC = restrictions ‘No’ changed to ‘Closed’; predY = wild predator and cat removal ‘No’  
 222 changed to ‘Constant’; hab = habitat; geo = geomorphology.

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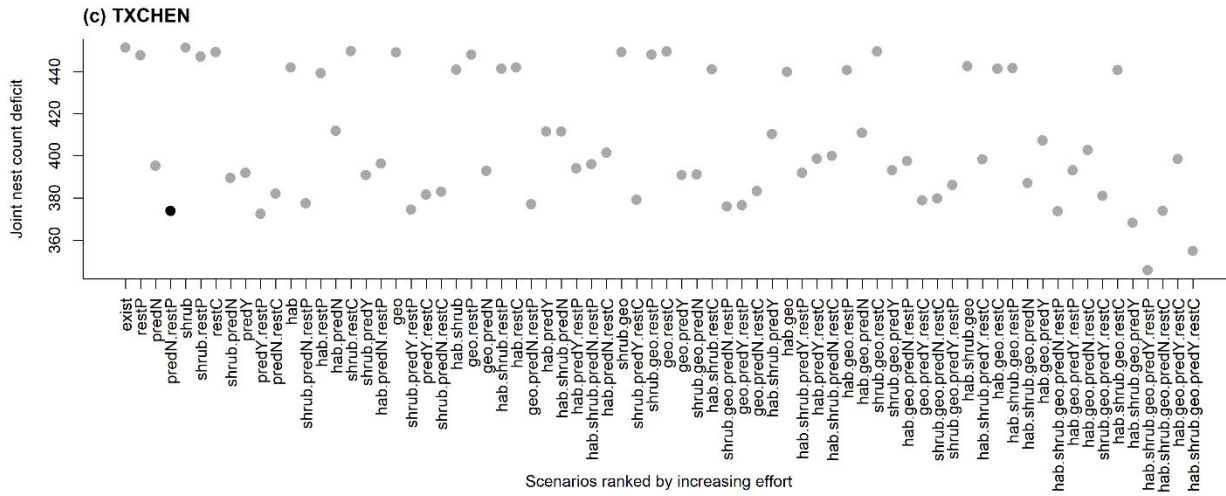
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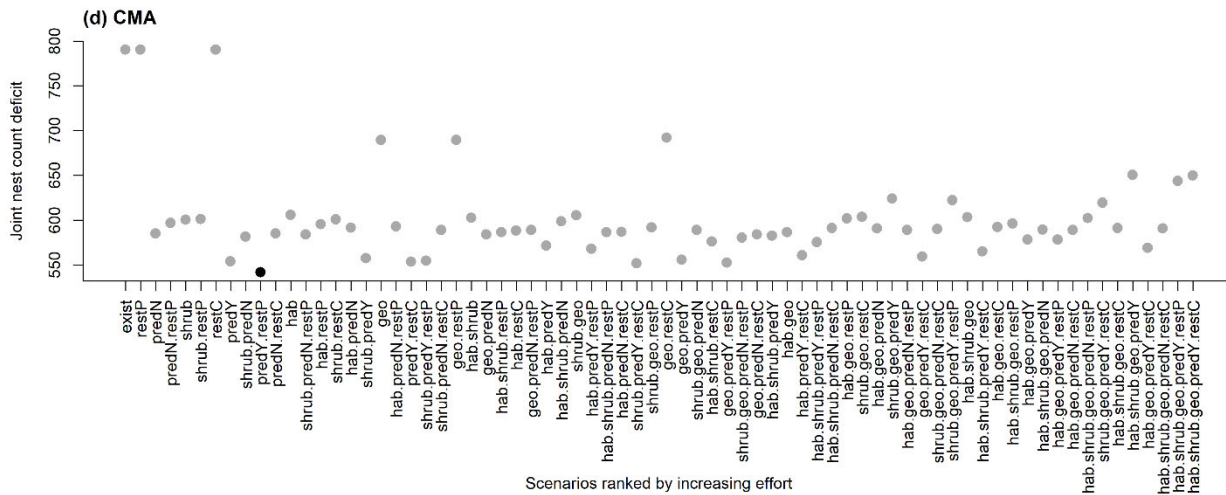
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228 Figure 4 (continued)

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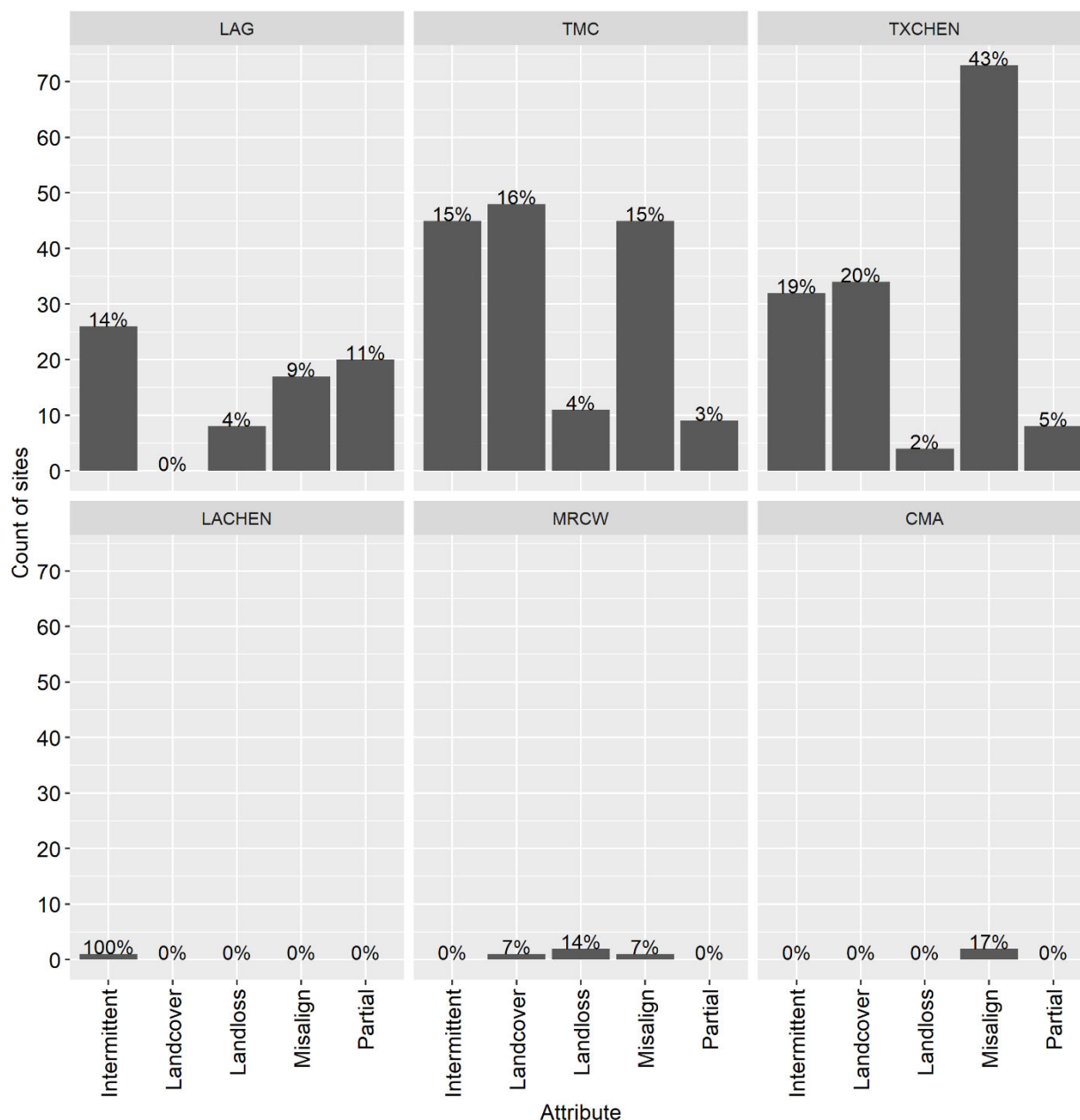


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234 **Figure 5.** Visual assessment results for each Initiative Area's (IA's) management scenario. See  
 235 main text for x-axis definitions. A single site might have multiple attributes. Percentages are the  
 236 IA's count of sites / IA's total sites. The IAs are Laguna Madre (LAG), Texas Mid-Coast (TMC),  
 237 Texas Chenier Plain (TXCHEN), The Louisiana Chenier Plain (LACHEN), Mississippi River  
 238 Coastal Wetlands (MRCW), and Coastal Mississippi-Alabama (CMA).

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241 **Acknowledgements**

242 Any use of trade, firm, or product names is for descriptive purposes only and does not imply  
243 endorsement by the U.S. Government.

244

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### 333 **Glossary of Acronyms.**

- 334 BPU. Biological Planning Units.
- 335 GCJV. Gulf Coast Joint Venture.
- 336 IA. Initiative Area.
- 337 JPCI. Joint Proportional Contribution Index.
- 338 CMA. Coastal Mississippi-Alabama.
- 339 LAG. Laguna Madre.
- 340 LACHEN. Louisiana Chenier Plain.
- 341 MRCW. Mississippi River Coastal Wetlands.
- 342 TMC. Texas Mid-Coast.
- 343 TXCHEN. Texas Chenier Plain.