Supplementary information for:

Historical depletion and future drought driven risks to Gulf of Mexico fisheries production

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Supplementary Tables

Table S1. Basic inputs and estimates for the 1980 Gulf-wide Ecopath model including biomass (*B*, t km^{-2}), biomass accumulation rate (*BA*, year^{-1}), production to biomass ratio (*P/B*, year^{-1}) or total mortality rate (*Z*, year^{-1}), consumption to biomass ratio (*Q/B*, year^{-1}), landings and discards (t km^{-2}), trophic level (TL), ectotrophic efficiency (EE), fishing mortality (*F*, year^{-1}, with the percent attributed to the menhaden purse seine bycatch (PS) given in parentheses), and predation mortality (M_2, year^{-1}). Note that a value of 0* indicates either landings or discards < 0.00005 or *F* < 0.005.

No	Functional group	B	BA	Z or P/B	Q/B	Landings	Discards	TL	EE	F (%PS)	M2
1	Coastal dolphins	0.021	0	0.16	15	0	0	3.44	0.82	0	0.131
2	Offshore dolphins	0.021	0	0.16	15	0	0	3.79	0.6	0	0.097
3	Baleen whales	0.021	0	0.16	15	0	0	3.47	0.07	0	0.011
4	Seabird	0.015	0	0.25	33	0	0	3.31	0.54	0	0.134
5	Sea turtle	0.013	0	0.12	3.5	0	0	3.42	0.83	0	0.1
6	Blacktip shark	0.095	0	0.32	3.2	0.0006	0.0004	3.37	0.21	0.01 (18.7)	0.06
7	Dusky shark	0.009	0	0.28	2.8	0.0002	0*	3.75	0.26	0.03 (65.6)	0.045
8	Sandbar shark	0.002	0	0.34	3.2	0.0001	0.0001	3.64	0.69	0.16 (11.6)	0.071
9	Large coastal sharks	0.038	0	0.3	3	0.0006	0.0006	3.64	0.4	0.03 (22.9)	0.091
10	Large oceanic sharks	0.028	0	0.29	2.7	0*	0	3.61	0.28	0	0.079
11	Atlantic sharpnose shark	0.020	0	0.58	5.8	0.0007	0.0067	3.39	0.94	0.38 (0.3)	0.17
12	Small coastal sharks	0.002	0	0.5	5	0.0001	0.0002	3.47	0.97	0.15 (4.5)	0.336
13	Yellowfin tuna	0.003	0	1.08	8.4	0.0022	0*	3.85	0.96	0.8	0.235
14	Bluefin tuna	0.001	0	0.43	4.3	0*	0*	3.71	0.8	0.11	0.234
15	Other tunas	0.006	0	0.89	8.9	0.0033	0*	3.62	0.83	0.56	0.179
16	Billfish	0.003	0	0.6	4.9	0.0014	0.0001	3.74	0.95	0.51	0.063
17	Swordfish	0.014	0	0.44	3.8	0.0055	0*	3.75	0.98	0.4	0.037
18	Pelagic coastal piscivores	0.062	0	0.76	6.3	0.0155	0.0010	3.33	0.84	0.27 (8.2)	0.369
19	Amberjack	0.029	0	0.44	3.9	0.0061	0.0001	3.57	0.85	0.21	0.158
20	Cobia	0.011	0	0.62	4.1	0.0017	0.0006	3.66	0.57	0.21	0.149
21	King mackerel (0-1yr)	0.001	0	1.46	14.3	0	0.0001	3.35	0.37	0.12	0.418
22	King mackerel (1+yr)	0.140	0	0.22	3.5	0.0093	0*	3.36	0.9	0.07 (1.8)	0.129
23	Spanish mackerel (0-1yr)	0.001	0	2	19.8	0.0001	0.0015	3.33	0.93	1.37	0.483
24	Spanish mackerel (1+yr)	0.063	0.0009	0.52	5.2	0.0060	0.0061	3.54	0.74	0.19 (11.2)	0.189
25	Skates-rays	0.034	0	0.48	4.8	0.0004	0.0001	2.88	0.93	0.02 (63.9)	0.433
26	Gag grouper (0-3yr)	0.003	0.0003	0.57	9.3	0.0006	0.0001	3.4	0.82	0.24	0.227
27	Gag grouper (3+yr)	0.018	0.0018	0.37	3.6	0.0044	0*	3.47	0.93	0.25	0.098
28	Red grouper (0-3yr)	0.003	0.0002	0.43	9.2	0	0*	3.38	0.79	0.01	0.332
29	Red grouper (3+yr)	0.027	0.0013	0.37	3.7	0.0069	0.0005	3.33	0.97	0.28	0.083
30	Yellowedge grouper (0-3yr)	0.000	0	0.32	18.1	0*	0	3.28	0.69	0	0.221
31	Yellowedge grouper (3+yr)	0.048	0.0005	0.1	3.7	0.0013	0	3.17	0.53	0.03	0.027
32	Goliath grouper	0.001	0	0.33	3.3	0.0003	0*	3.59	0.93	0.21	0.095
33	Deep-water grouper	0.007	0	0.4	4	0.0009	0	3.56	0.44	0.14	0.039
34	Shallow-water grouper	0.013	0	0.62	6.2	0.0041	0.0004	3.48	0.85	0.36	0.168
35	Red snapper (0yr)	0.003	0.0002	1	18.4	0*	0.0009	3.38	0.47	0.31	0.162
36	Red snapper (1-2yr)	0.020	0.0016	1.6	7.9	0.0021	0.0002	3.42	0.17	0.11	0.158
37	Red snapper (3+yr)	0.042	0.0034	0.33	3.3	0.0106	0.0002	3.32	0.84	0.26	0.024
38	Vermilion snapper	0.072	0	0.52	4.5	0.0006	0.0022	3.02	0.31	0.04	0.123
39	Mutton snapper	0.015	0	0.58	5.8	0.0009	0*	3.24	0.33	0.06	0.133
40	Other snapper	0.014	0	0.6	6	0.0022	0.0001	3.15	0.93	0.17	0.392

Table S1-Continued. Basic inputs and estimates for the 1980 Gulf-wide Ecopath model including biomass (B, t km^{-2}), biomass accumulation rate (BA, year^{-1}), production to biomass ratio (P/B, year^{-1}) or total mortality rate (Z, year^{-1}), consumption to biomass ratio (Q/B, year^{-1}), landings and discards (t km^{-2}), trophic level (TL), ectotrophic efficiency (EE), fishing mortality (F, year^{-1}, with the percent attributed to the menhaden purse seine bycatch (PS) given in parentheses), and predation mortality (M_2, year^{-1}). Note that a value of 0* indicates either landings or discards < 0.00005 or F < 0.005.

No	Functional group	B	BA	Z or P/B	Q/B	Landings	Discards	TL	EE	F (%PS)	M2
41	Coastal piscivores	0.085	0	0.67	6.5	0.0189	0.0004	3.13	0.96	0.23 (72.9)	0.42
42	Sea trout	0.108	0	0.73	7	0.0451	0.0049	3.03	0.98	0.47 (29.3)	0.25
43	Oceanic piscivores	0.036	0	1	8.5	0.0004	0*	3.36	0.99	0.01 (99.5)	0.98
44	Benthic piscivores	0.027	0	0.7	5	0.0020	0.0003	3.32	0.97	0.09 (0.01)	0.593
45	Reef piscivores	0.025	0	0.84	5.4	0.0050	0.0001	3.3	0.93	0.2	0.581
46	Reef invertebrate feeders	0.183	0	1.05	5.8	0.0128	0.0015	2.8	0.9	0.08 (1.4)	0.867
47	Demersal coastal invertebrate feeders	0.255	0	1	5.9	0.0566	0.0183	2.81	0.9	0.29 (21.3)	0.607
48	Red drum	0.115	0	0.5	5	0.0125	0.0003	3.18	0.35	0.11 (0.2)	0.065
49	Benthic coastal invertebrate feeders	0.170	0	1.25	5.8	0.0003	0.0002	2.8	0.97	0* (11.5)	1.203
50	Tilefish	0.007	0	0.35	3.5	0.0003	0*	3.27	0.27	0.04	0.051
51	Gray triggerfish	0.055	0	0.59	5.9	0.0017	0.0062	2.79	0.38	0.14	0.082
52	Coastal omnivores	0.165	0	0.88	8.8	0.0027	0.0002	2.73	0.99	0.02 (3.8)	0.851
53	Reef omnivores	0.020	0	1.4	8.4	0.0001	0*	2.68	0.95	0*	1.323
54	Surface pelagics	0.125	0	1.45	11.7	0.0003	0	2.86	0.91	0* (8.9)	1.322
55	Large oceanic planktivores	0.017	0	0.16	1.3	0	0	3.22	0.38	0	0.06
56	Oceanic planktivores	0.045	0	0.87	8.7	0	0	3.16	0.94	0	0.818
57	Sardine-herring-scad	0.630	0	1.05	10.5	0.0076	0*	2.77	0.91	0.01 (24.9)	0.946
58	Menhaden (0yr)	1.893	0.6246	1.67	42.9	0.0024	0	2.25	0.04	0* (55.2)	0.057
59	Menhaden (1yr)	4.414	1.4565	1.51	22	0.7595	0	2.25	0.15	0.17 (99.9)	0.059
60	Menhaden (2yr)	2.007	0.6623	1.73	15.4	1.2558	0	2.25	0.43	0.63 (99.9)	0.108
61	Menhaden (3yr)	0.496	0.1635	1.52	12.7	0.2159	0	2.25	0.45	0.44 (99.9)	0.246
62	Menhaden (4+yr)	0.143	0.0473	1.42	11.1	0.0317	0.0003	2.25	0.46	0.22 (99.1)	0.423
63	Anchovy-silverside-killifish	0.705	0	1.59	15.9	0*	0	2.62	0.84	0* (99.7)	1.342
64	Mullet	0.287	0	0.8	8	0.0449	0*	2.41	0.6	0.16 (2.8)	0.321
65	Butterfish	0.073	0	1.36	8.1	0.0012	0.0005	2.76	0.98	0.02 (68.8)	1.31
66	Cephalopod	1	0	2.8	13.7	0.0002	0	2.97	0.82	0* (45.7)	2.283
67	Pink shrimp	0.080	0	3.77	19.2	0.0269	0	2.43	0.41	0.34	1.198
68	Brown shrimp	0.061	0	5.22	19.2	0.1306	0	2.06	0.64	2.15 (0.02)	1.191
69	White shrimp	0.500	0	3.32	19.2	0.0652	0	2.05	0.18	0.13 (0.05)	0.473
70	Crab	0.250	0	1.6	10.5	0.0640	0	2.86	0.94	0.26 (0.2)	1.253
71	Sessile epifauna	12	0	1.6	9	0.0277	0	2.01	0.63	0*	0.998
72	Mobile epifauna	18	0	2.6	16	0.0341	0	2.13	0.35	0* (0.1)	0.92
73	Zooplankton	15	0	10	74	0.0020	0	2.05	0.72	0* (100)	7.246
74	Infauna	18.5	0	5.17	22	0*	0	2.04	0.49	0	2.528
75	Algae	29.8	0	27.5	0	0	0	1	0.07	0	2.049
76	Seagrass	150	0	25	0	0	0	1	0.01	0	0.162
77	Phytoplankton	25	0	160	0	0	0	1	0.3	0	48.079
78	Detritus	100	0			0	0	1	0.09	-	-

Table S2. Sources of time series for catch, biomass, and fishing mortality for each EwE functional group. NOAA refers to catches (landings in weight) from NOAA commercial and recreational sources, as described in the text. For Catch and Biomass, values in parentheses represent the weight assigned to each time series and the type (6 = catches, 61 = relative catches, 0 = relative biomass). Fishing mortality always input as a driver (type = 4).

No	Functional group	Catch (*C*)	Biomass (*B*)	Fishing mortality (*F*)
6	Blacktip shark	NOAA (0.5, 6)	SEDAR 29 Update (1, 0)	SEDAR 29 Update
7	Dusky shark	NOAA (0.5, 61 - catches deemed unreliable for use in assessment)	SEDAR 21 Update (1, 0)	SEDAR 21 Update
8	Sandbar shark	NOAA (0.5, 6)	SEDAR 54 (HMS) (1, 0)	SEDAR 54
9	Large coastal sharks	NOAA (0.5, 6)	SEDAR 11 (1, 0)	-
10	Large oceanic sharks	NOAA (0.5, 6)	ICCAT 2017a for shortfin mako (1, 0)	ICCAT 2017a for shortfin mako
11	Atlantic sharpnose shark	NOAA (0.5, 6)	SEDAR 34 (1, 0)	SEDAR 34
12	Small coastal sharks	NOAA (0.5, 6)	SEDAR 34 for bonnethead (1, 0)	-
13	Yellowfin tuna	NOAA (1, 6)	Pelagic longline index (1, 0)	ICCAT 2019a
14	Bluefin tuna	NOAA (1, 6)	Pelagic longline index (1, 0)	ICCAT 2017c
15	Other tuna	NOAA (1, 6)	Pelagic longline index (1, 0)	-
16	Billfish	ICCAT (1, 6)	Pelagic longline index (3.78, 0)	ICCAT 2018
17	Swordfish	NOAA (1, 61)	Pelagic longline index (9.04, 0)	ICCAT 2017b
18	Pelagic coastal piscivores	NOAA (1, 6)	SEAMAP Bottom trawl (0.55, 0)	-
19	Amberjacks	SEDAR 33 Update (7.85, 6)	SEDAR 33 Update (10.68, 0)	SEDAR 33 Update *C*/*B*
20	Cobia	SEDAR 28 (2.91, 6)	SEDAR 28 (7.88, 0)	SEDAR 28 *C*/*B*
21	King mackerel (0-1yr)	-	SEDAR 38 (12.29, 0)	-
22	King mackerel (1+yr)	SEDAR 38 (17.73, 6)	SEDAR 38 (15.03, 0)	SEDAR 38 *C*/*B*
23	Spanish mackerel (0-1yr)	-	SEDAR 28 (5.11, 0)	-
24	Spanish mackerel (1+yr)	SEDAR 28 (5.71, 6)	SEDAR 28 (10.78, 0)	SEDAR 28 *C*/*B*
25	Skates-rays	NOAA (1, 6)	SEAMAP Bottom trawl (2.61, 0)	-
26	Gag grouper (0-3yr)	-	SEDAR 33 Update (15.32, 0)	-

Table S2-Continued. Sources of time series for catch, biomass, and fishing mortality for each EwE functional group. NOAA refers to catches (landings in weight) from NOAA commercial and recreational sources, as described in the text. For Catch and Biomass, values in parentheses represent the weight assigned to each time series and the type (6 = catches, 61 = relative catches, 0 = relative biomass). Fishing mortality always input as a driver (type = 4).

No	Functional group	Catch (*C*)	Biomass (*B*)	Fishing mortality (*F*)
27	Gag grouper (3+yr)	SEDAR 33 Update (7.41, 6)	SEDAR 33 Update (22.12, 0)	SEDAR 33 Update *C*/*B*
28	Red grouper (0-3yr)	-	SEDAR 61 (4.54, 0)	-
29	Red grouper (3+yr)	SEDAR 61 (4.98, 6)	SEDAR 61 (7.23, 0)	SEDAR 61 Update *C*/*B*
30	Yellowedge grouper (0-3yr)	-	SEDAR 22 (7.79, 0)	-
31	Yellowedge grouper (3+yr)	SEDAR 22 (27.14, 6)	SEDAR 22 (20.71, 0)	SEDAR 22 *C*/*B*
32	Goliath grouper	NOAA (1, 6)	SEDAR 47 (13.17, 0)	SEDAR 47
33	Deep-water grouper	NOAA (1, -6)	-	-
34	Shallow-water grouper	NOAA (1, -6)	SEDAR 49 for yellowmouth grouper video index (1, 0)	-
35	Red snapper (0-1yr)	-	SEDAR 52 (15.87, 0)	-
36	Red snapper (1-2yr)	SEDAR 52 (20, 61)	SEDAR 52 (14.57, 0)	SEDAR 52 *C*/*B*
37	Red snapper (3+yr)	SEDAR 52 (20, 6)	SEDAR 52 (13.27, 0)	SEDAR 52 *C*/*B*
38	Vermilion snapper	SEDAR 67 (10.24, 6)	SEDAR 67 (21.17, 0)	SEDAR 67 *C*/*B*
39	Mutton snapper	SEDAR 15 Update (1, 6)	SEDAR 15 Update (13.17, 0)	SEDAR 15 Update *C*/*B*
40	Other snapper	NOAA (1, 6)	SEAMAP Bottom trawl (0.69, 0)	-
41	Coastal piscivores	NOAA (1, 6)	-	-
42	Seatrout	NOAA (1, 6)	SEAMAP Bottom trawl (5.57, 0)	-
43	Oceanic piscivores	NOAA (1, 6)	SEAMAP Bottom trawl (3.27, 0)	-
44	Benthic piscivores	NOAA (1, 6)	SEAMAP Bottom trawl (14.36, 0)	-
45	Reef piscivores	NOAA (1, 6)	SEAMAP Bottom trawl (3.05, 0)	-
46	Reef invertebrate feeders	NOAA (1, 6)	SEAMAP Bottom trawl (9.22, 0)	-
47	Demersal coastal invertebrate feeders	NOAA (1, 6)	SEAMAP Bottom trawl (5.06, 0)	-
48	Red drum	SEDAR 49 (1980-2013) and NOAA (2014+) (1, -6)	SEDAR 49 (Dauphin Island Sea Lab longline index) (1, 0)	-

Table S2-Continued. Sources of time series for catch, biomass, and fishing mortality for each EwE functional group. NOAA refers to catches (landings in weight) from NOAA commercial and recreational sources, as described in the text. For Catch and Biomass, values in parentheses represent the weight assigned to each time series and the type (6 = catches, 61 = relative catches, 0 = relative biomass). Fishing mortality always input as a driver (type = 4).

No	Functional group	Catch (*C*)	Biomass (*B*)	Fishing mortality (*F*)
49	Benthic coastal invertebrate feeders	NOAA (1, 6)	SEAMAP Bottom trawl (11.37, 0)	-
50	Tilefish	NOAA (3.21, 6)	SEDAR 22 (3.64, 0)	SEDAR 22 *C*/*B*
51	Gray triggerfish	SEDAR 43 (10.68, 6)	SEDAR 43 (5.74, 0)	SEDAR 43 *C*/*B*
52	Coastal omnivores	NOAA (1, 6)	SEAMAP Bottom trawl (10.39, 0)	-
53	Reef omnivores	NOAA (1, 6)	-	-
54	Surface pelagics	NOAA (1, 6)	-	-
55	Large oceanic planktivores	-	-	-
56	Oceanic planktivores	NOAA	-	-
57	Sardine-herring-scad	NOAA (1, 6)	SEAMAP Bottom trawl (3.03, 0)	-
58	Menhaden (0yr)	-	SEDAR 63 (1, 0)	-
59	Menhaden (1yr)	SEDAR 63 (5.5, 61)	SEDAR 63 (13.17, 0)	SEDAR 63 *C*/*B*
60	Menhaden (2yr)	SEDAR 63 (5.5, 6)	SEDAR 63 (13.17, 0)	SEDAR 63 *C*/*B*
61	Menhaden (3yr)	SEDAR 63 (5.5, 61)	SEDAR 63 (13.17, 0)	SEDAR 63 *C*/*B*
62	Menhaden (4+yr)	SEDAR 63 (5.5, 61)	SEDAR 63 (13.17, 0)	SEDAR 63 *C*/*B*
63	Anchovies-silversides-killifish	-	SEAMAP Bottom trawl (2.74, 0)	-
64	Mullet	NOAA (1, -6)	-	-
65	Butterfish	-	SEAMAP Bottom trawl (1.42, 0)	-
66	Cephalopods	-	SEAMAP Bottom trawl (4.99, 0)	-
67	Pink shrimp	2018 Update (0.97, 6)	2018 Update (13.17, 0)	2018 Update *C*/*B*
68	Brown shrimp	2018 Update (10.62, 6)	2018 Update (13.17, 0)	2018 Update *C*/*B*
69	White shrimp	2018 Update (7.98, 6)	2018 Update (13.17, 0)	2018 Update *C*/*B*
70	Crab	NOAA (1, 6)	SEAMAP Bottom trawl (0.55, 0)	GDAR 01
71	Sessile epifauna	NOAA	-	-
72	Mobile epifauna	NOAA (1, 6)	SEAMAP Bottom trawl (0.63, 0)	-

Table S3. Source of fishing effort time series for each fishing fleet from 1985-2016.

Fishing fleet	Effort source
Commercial Dredge/Dig	NMFS Vessel Operating Units, sum of gear number (number of dredges)
Commercial Handline	Number of commercial vertical line trips (SEDAR 49)
Commercial Longline (Fish)	Number of commercial bottom longline trips (SEDAR 49)
Commercial Longline (Pelagic)	Relative pelagic longline fishery effort (SEDAR 29 Update)
Commercial Longline (Shark)	Relative bottom longline fishery effort (SEDAR 29 Update)
Commercial Nets	NMFS Vessel Operating Units, sum of gear number (number of nets)
Commercial Other	NMFS Vessel Operating Units, sum of gear number
Commercial Pots and Traps	NMFS Vessel Operating Units, sum of gear number (number in use at one time)
Commercial Purse Seine (Menhaden)	Vessel-ton-weeks (SEDAR 63)
Commercial Purse Seine (Other)	NMFS Vessel Operating Units, sum of gear number (number of nets)
Commercial Bottom Trawl (Other)	NMFS Vessel Operating Units, sum of gear number (number of nets)
Commercial Bottom Trawl (Shrimp)	Days fished (SEDAR 52 effort)
Recreational Headboat	Number of trips (SRHS)
Recreational Shore	Number of trips (MRIP)
Recreational Charter	Number of trips (MRIP + TPWD)
Recreational Private	Number of trips (MRIP + TPWD)

Table S4: Coupled Model Intercomparison Project 5 (CMIP5) models which were used in Cook et al. (2014)[1] to compute spatially explicit gridded PDSI maps, based on which the time series and maps in Fig. 2a were computed. Note that CNRM_CM5 data of the Centre National de Recherches Me´te´orologiques / Centre Europe´en de Recherche et Formation Avance´e en Calcul Scientifique was not available for download.

Model	Spatial resolution	Modeling center/Group	Country
CanESM2	2.8˚×2.8˚	Canadian Centre for Climate Modelling and Analysis (CAN)	Canada
CCSM4- r1i1p1	0.94˚×1.25˚	National Center for Atmospheric Research (USA)	USA
CCSM4- r2i1p1	0.94˚×1.25˚	National Center for Atmospheric Research (USA)	USA
CCSM4- r3i1p1	0.94˚×1.25˚	National Center for Atmospheric Research (USA)	USA
CCSM4- r4i1p1	0.94˚×1.25˚	National Center for Atmospheric Research (USA)	USA
CCSM4- r5i1p1	0.94˚×1.25˚	National Center for Atmospheric Research (USA)	USA
CCSM4- r6i1p1	0.94˚×1.25˚	National Center for Atmospheric Research (USA)	USA
CCSM-r1	0.94˚×1.25˚	National Center for Atmospheric Research (USA)	USA
CSIRO_Mk3_6_0	1.87˚×1.87˚	Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence (AUS)	Australia
GFDL_CM3	2.0˚×2.5˚	NOAA Geophysical Fluid Dynamics Laboratory	USA
GFDL_ESM2G	2.0˚×2.5˚	NOAA Geophysical Fluid Dynamics Laboratory	USA
GFDL_ESM2M	2.0˚×2.5˚	NOAA Geophysical Fluid Dynamics Laboratory	USA
GISS_E2_R	2.0˚×2.5˚	NASA Goddard Institute for Space Studies (USA)	USA
INMCM4.0	1.5˚×2.5˚	Institute for Numerical Mathematics (RUS)	Russia
IPSL-CM5A-LR	1.9˚×3.75˚	Institut Pierre-Simon Laplace	Japan
MIROC5	1.4˚×1.4˚	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (JAP)	
MIROC-ESM	2.8˚×2.8˚	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	Japan
MIROC-ESM-CHEM	2.8˚×2.8˚	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	Japan
MRI-CGCM3	1.1˚×1.1˚	Meteorological Research Institute	Japan
NorESM1-M	1.9˚×2.5˚	Norwegian Climate Centre	Norway

Table S5: List of modeling efficiency values for the Ecosim fitted biomass and catches Ecosim time series. MEF = 1 - $[\Sigma_i(\hat{Y}_i - Y_i)^2 / \Sigma_i(Y_i - \bar{Y})^2]$, where Y_i represents the ith observed value, $\hat{Y}_i$ represents the ith predicted value, and $\bar{Y}$ is the mean of the observed values. For reference, MEF values closer to 1 indicate good performance, while values approaching –1 indicate poor performance.

Time series	MEF catch	MEF biomass
Blacktip shark	0.70	-0.09
Dusky shark	0.18	0.58
Sandbar shark	-0.32	-0.10
Large coastal sharks	0.28	0.96
Large oceanic sharks	0.57	0.92
Atlantic sharpnose shark	-0.24	-0.38
Small coastal sharks	-0.44	0.78
Yellowfin tuna	-0.03	0.10
Bluefin tuna	0.34	-0.30
Other tunas	-0.30	0.01
Billfish	0.30	0.12
Swordfish	-0.14	-0.36
Pelagic coastal piscivores	-0.40	0.01
Amberjack	0.87	0.88
Cobia	0.33	0.18
King mackerel (1+yr)	0.81	0.79
Spanish mackerel (1+yr)	0.92	0.88
Skates-rays	-0.16	0.56
Gag grouper (3+yr)	0.71	0.60
Red grouper (3+yr)	0.71	0.57
Yellowedge grouper (3+yr)	1.00	0.99
Goliath grouper	0.40	0.98
Deep-water grouper	1.00	NA
Shallow-water grouper	1.00	0.19
Red snapper (1-2yr)	0.94	0.46
Red snapper (3+yr)	0.76	0.98
Vermilion snapper	0.82	0.87
Mutton snapper	0.92	0.92
Other snapper	0.02	0.27
Inshore coastal piscivores	-0.28	NA
Sea trout	-0.04	-0.05
Oceanic piscivores	0.13	0.43
Benthic piscivores	0.29	0.16
Reef piscivores	0.64	-0.06
Reef invertebrate feeders	0.42	0.27
Demersal invertebrate feeders	0.00	0.37
Red drum	1.00	-0.39
Benthic invertebrate feeders	-0.04	0.45

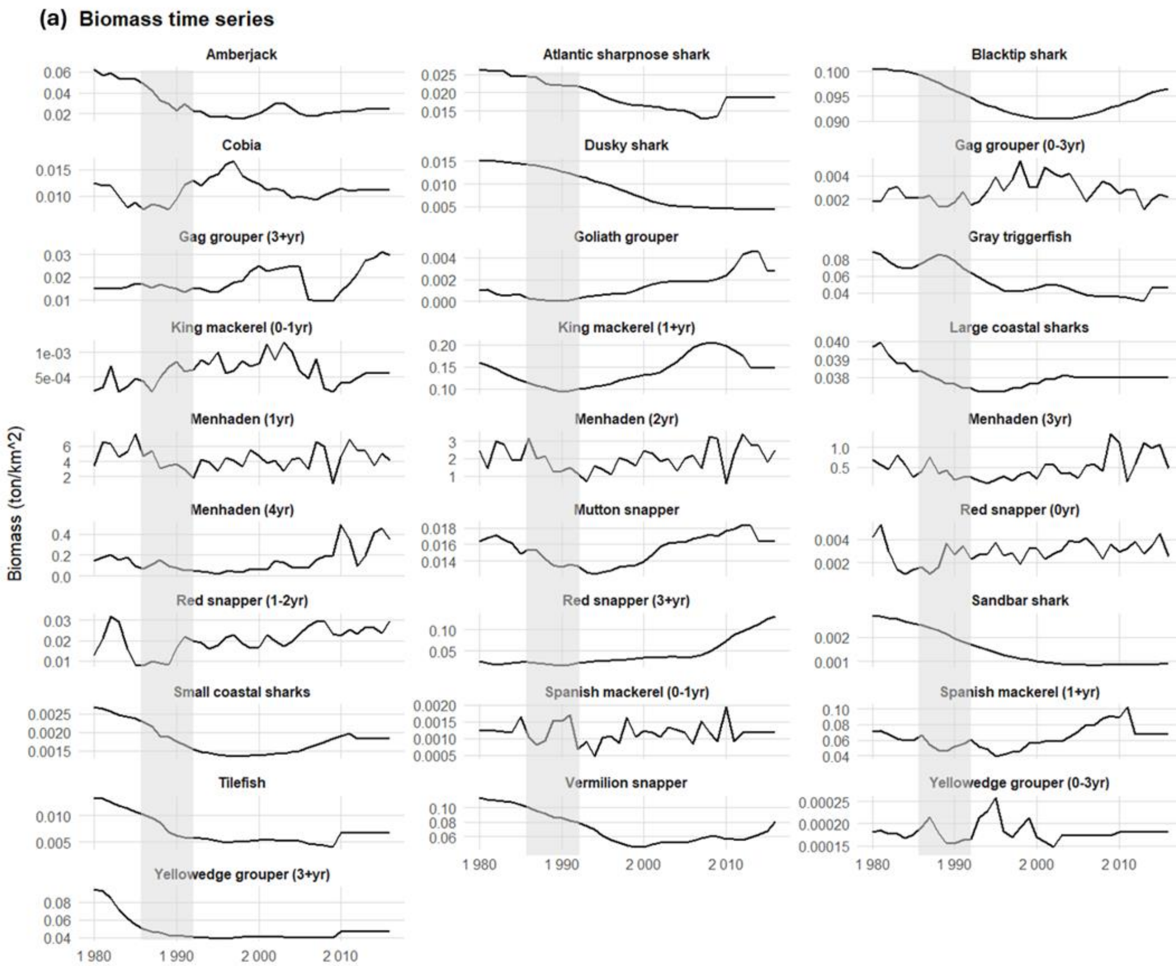
Table S5- continued: List of modeling efficiency values for the Ecosim fitted biomass and catches Ecosim time series. MEF = $1 - [\Sigma_i(\hat{Y}_i - Y_i)^2 / \Sigma_i(Y_i - \bar{Y})^2]$, where Y_i represents the *i*th observed value, $\hat{Y}_i$ represents the *i*th predicted value, and $\bar{Y}$ is the mean of the observed values.

Time series	MEF catch	MEF biomass
Tilefish	0.95	0.98
Gray triggerfish	0.78	-0.24
Coastal omnivores	0.16	-0.40
Reef omnivores	-0.05	NA
Surface pelagics	0.14	NA
Sardine-herring-scad	0.21	-0.03
Menhaden (1yr)	0.68	0.25
Menhaden (2yr)	0.11	0.49
Menhaden (3yr)	0.60	0.75
Menhaden (4yr)	0.77	0.86
Mullet	1.00	NA
Pink shrimp	0.87	0.46
Brown shrimp	0.32	0.84
White shrimp	-0.04	0.43
Crab	0.42	0.61
Mobile epifauna	0.55	-0.20

Table S6: List of Ecosim simulations and their details. The 5th projection year (terminal year) was used for all comparative analyses.

Simulation name	Description	Fishing pressure multipliers	Nutrient input multipliers	Used in Figure	No. model runs
Biomass and catches comparison hindcast + projections: main runs	Simulating the late 1980s drought (hindcast), as well as simulations account for 5-year of status quo, and 2050 and 2100 conditions (forecast).	[0, 0.5,..,5] (*N*=11)	[0.45, 0.57,1] (*N*=3)	Fig. 2c, Fig. 3	33
Biomass and catches comparison projections: error bars	Simulating the simulations account for 5-year of status quo, and 2050 and 2100 conditions. The standard deviation are computed for the 5th confidence interval percentile of the CMIP5 PDSI projections. Based on the mean and SD, 43 values were randomly drawn, following ensuing normality of the 5th confidence interval percentile data. These were then implemented in the regression equation depicted in Fig. 2b to estimate the corresponding vector of nutrient input levels.	[0.5,1,2] (*N*=3)	$Y \sim N(\mu v, \sigma^2_v I_{50})$ (*N*=86) where v is the 5th CI percentile of the CMIP5 PDSI projections.	Fig. 2c, Fig. 3	258
Biomass and catches comparison: tradeoff analysis	Trade-off Analysis: simulating incremental changes in nutrient input and menhaden fishing pressure multipliers. The menhaden fishing pressure multiplier varies from 0 to 5 in increments of 0.5, while the nutrient input multiplier ranges from 0 to 2 in increments of 0.1. Based on this data, the trade-off plots presented in Fig. 2d-f are created.	[0, 0.5,..,5] (*N*=11)	[0, 0.1,..,2] (*N*=21)	Fig. 2d-f	231
Sensitivity analysis of number of drought years (1 yr and 3 yrs)	Drought Conditions under both 3-year and 1-year drought conditions projected for 2050 and 2100, highlighting the impacts of short-term drought scenarios on the ecosystem dynamics and functional group performance.	[0, 0.5,..,5] (*N*=11)	[0.45, 0.57,1] (*N*=3)	Fig. S5	66

Biomass and catch time series used for Fig. 1



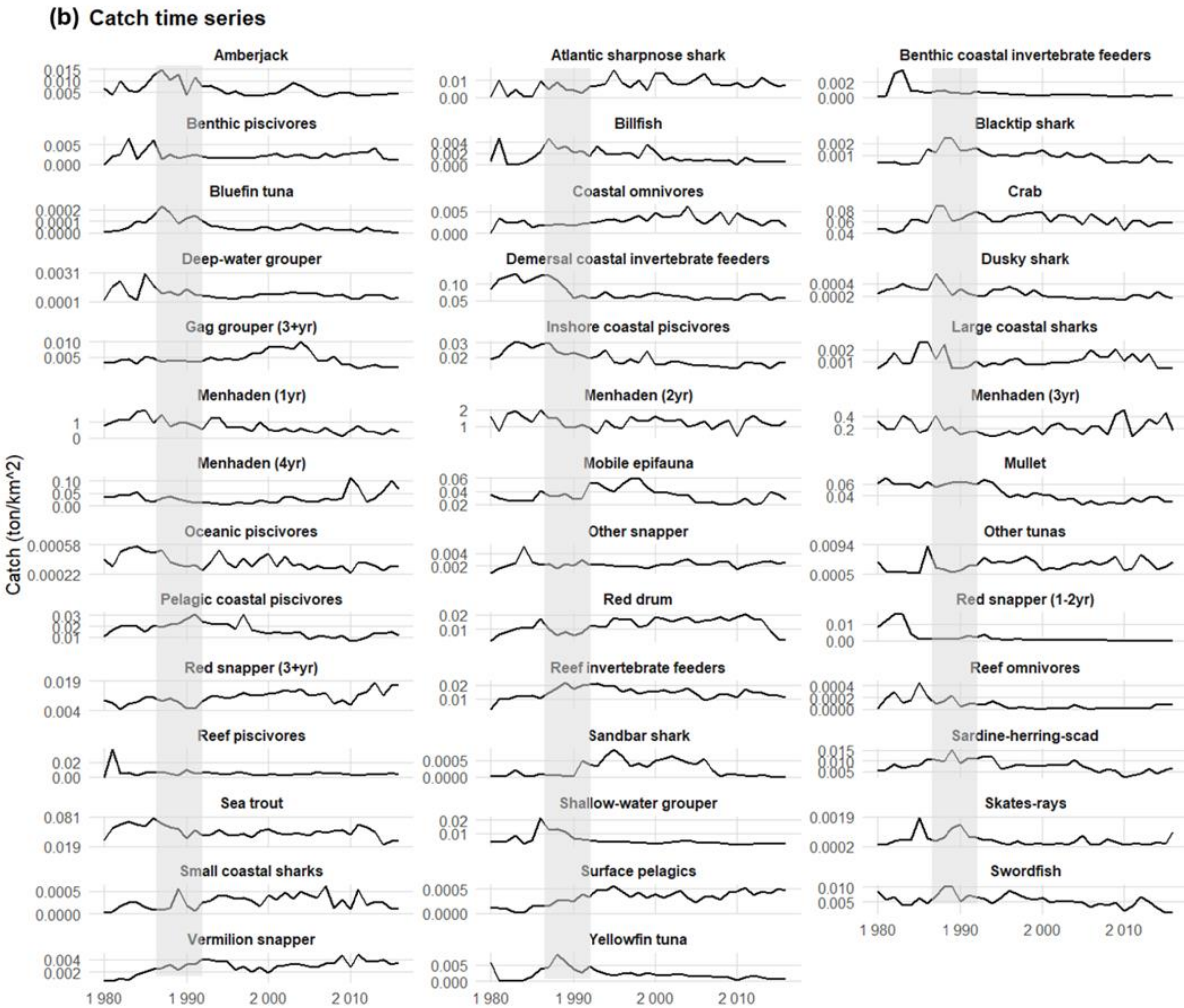


Figure S1. Biomass (a) and catch (b) time series (tons km^{-2}) of functional groups displayed as aggregated biomass in Fig. 1i and j, respectively. Shaded area represents the time period which was affected by the late 1980s prolonged drought.

Supplementary note S1: extended time series

The late 1980s drought in the Mississippi River basin profoundly impacted GoM environmental conditions and consequently, as presented in this study, the Gulf menhaden populations (Figs. S2, S3). The severe drought, indicated by a sharp negative PDSI (Fig. S2a), caused reduced Mississippi River flow (Fig. S2b) and a marked decline in nutrient input to the GoM (Fig. S2c). While SST anomalies showed less dramatic change (Fig. S2d), hypoxia, primarily driven by nutrient input, exhibited a relationship with drought severity (Fig. S2e), such that years with more severe droughts (e.g., 1988, 2000, 2012) show smaller hypoxic areas (dead zones). Hurricane frequency showed no clear correlation with drought dynamics (Fig. S2f).

This drought coincided with a sharp decline in menhaden biomass (Fig. S3a) and catches (Fig. S3b) from 1987 into the early 1990s. Increased fishing mortality (F) (Fig. S3c) coupled with purse menhaden decreased fishing effort (Fig. S3d) suggests factors beyond direct environmental effects, such as economic or regulatory influences. The apparent persistence of high *F* despite declining effort likely reflects two processes: (i) the age-structured nature of the assessment outputs, where older cohorts remain selectively targeted even under reduced effort; and (ii) drought-driven reductions in biomass, which amplify the ratio of catch to biomass ($F = C/B$), thereby inflating estimated mortality rates. Reduced reproductive success is supported by lower recruitment of age 0 fish (Fig. S3e), reduced spawning stock biomass (Fig. S3f), and reduced juvenile abundance in Louisiana estuaries (Fig. S3g). This strongly links the drought to the significant decline in menhaden populations and subsequent impacts on fishery.

Following the 1980s drought period (1990–2016), the overall fishing pressure on menhaden was reduced, and prolonged and severe drought events did not occur. During this time the gradual decrease in fishing pressure led to a gradual increase in estimated menhaden biomass, with fluctuations affecting the Mississippi river input, for example the episodic decreases in menhaden populations following the 2006 and 2012 droughts and the abrupt increase in menhaden population following the extremely wet year of 2010 (Fig. S2,2). Although subsequent years experienced droughts of varying severity (Fig. S2a), menhaden populations did not exhibit similarly severe declines compared to those exhibited following the 1980s drought. This suggests resilience or compensatory mechanisms may have buffered the impacts of shorter or less intense droughts compared to the prolonged 1980s event when fishing effort was high. There was no evident correspondence between other environmental factors of SST, hypoxic area, and number of hurricanes, with menhaden population dynamics.

Extended time series: environmental variables

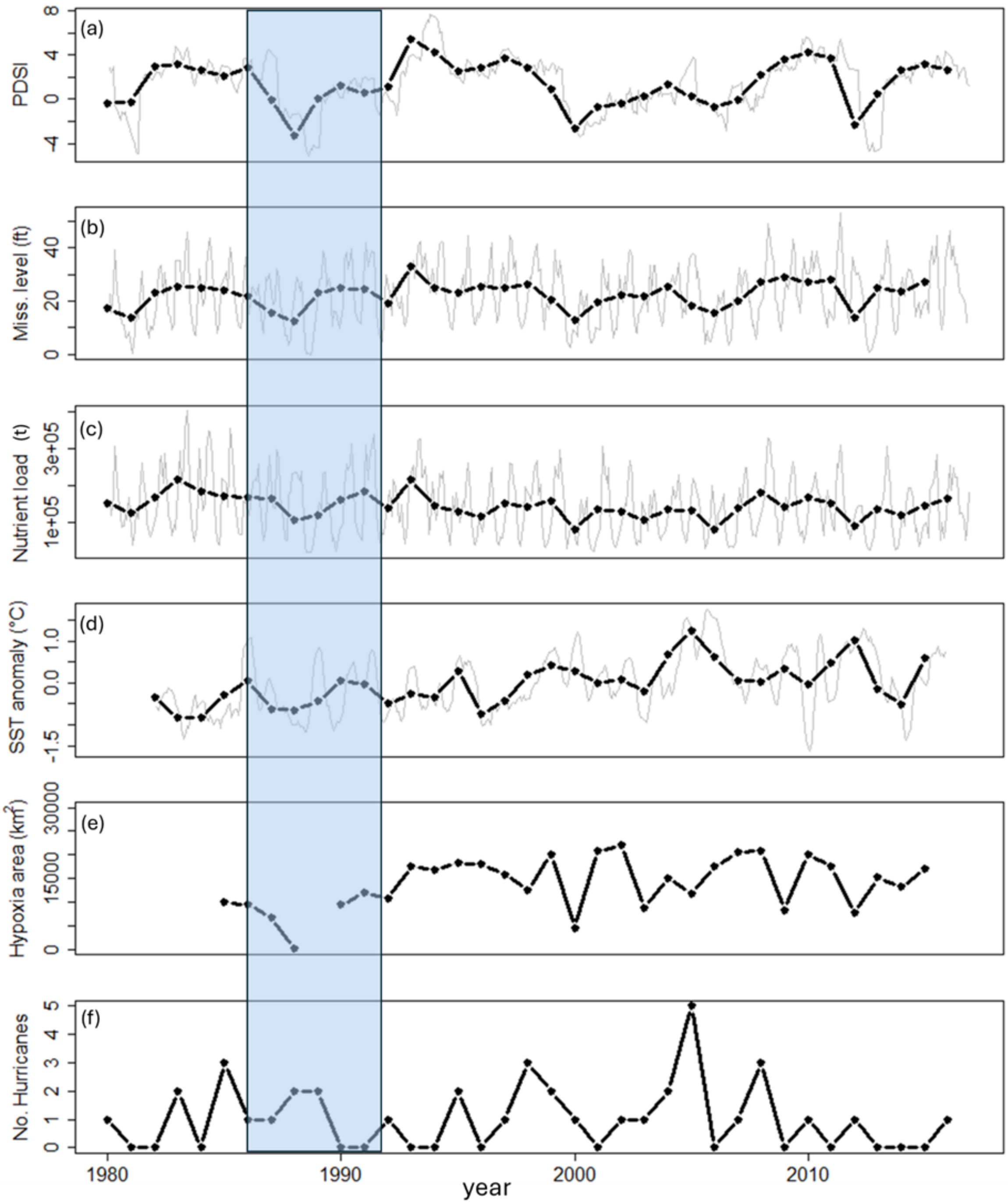


Figure S2. Extended time series – environmental variables: (a) Palmer's Drought Severity Index (PDSI) [2], (b) Mississippi river level (ft) [3], (c) Nutrient load (t/year) [4], (d) SST anomaly (ºC) [5], (e) Hypoxic area (km²)[6], (f) number of named hurricanes in the GoM[7]. Shaded area represents the time period which was affected by the late 1980s prolonged drought. Data are provided at doi: 10.24433/CO.3658239.v2.

Extended time series: Gulf menhaden variables

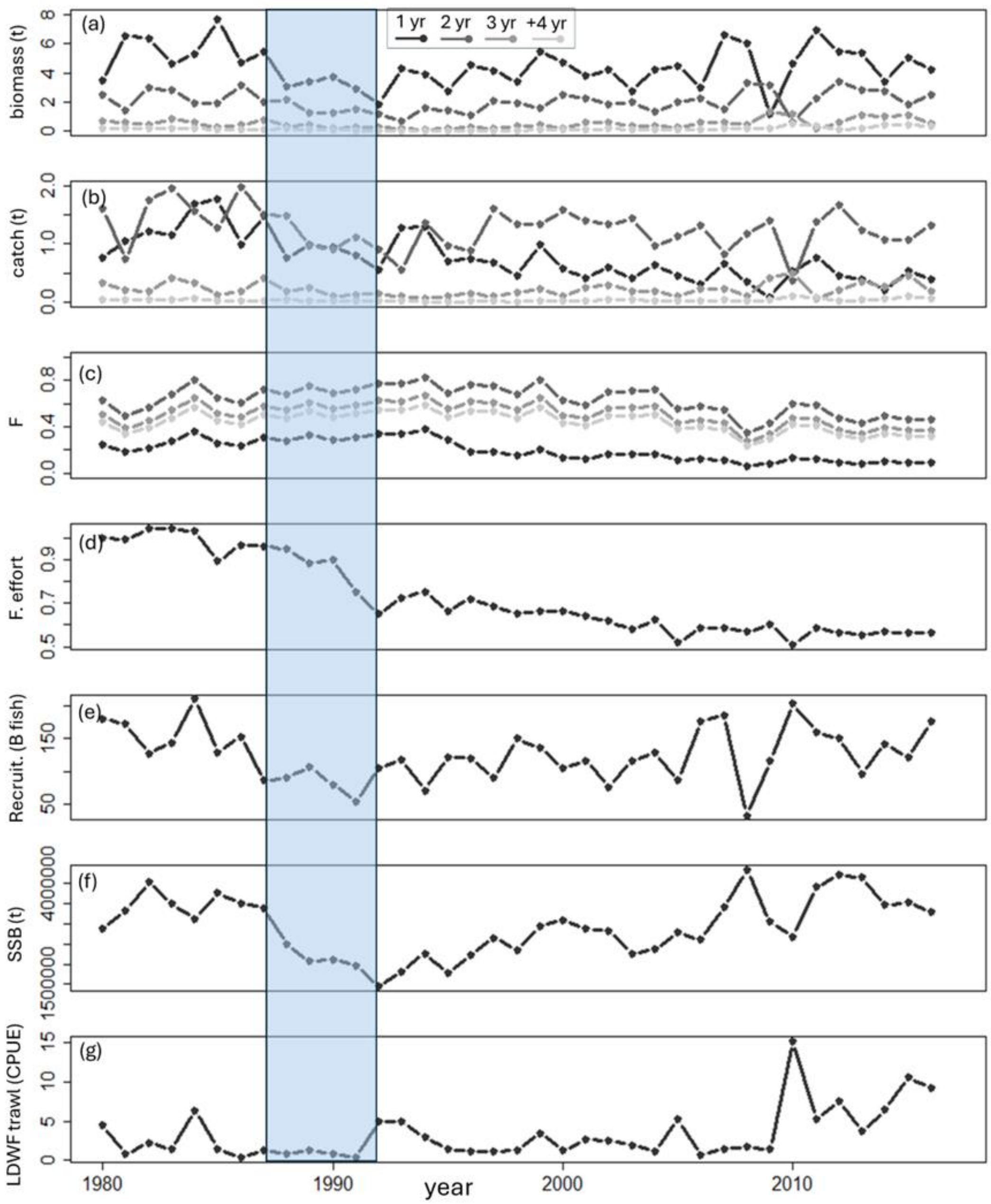


Figure S3. Extended time series – Gulf menhaden variables. Gulf menhaden EwE (a) biomass (t/km^2) [8], (b) catches (t /km^2) [8], (c) fishing mortality,(d) fishing relative effort, (e) recruitment of age 0 fish (Billions of fish), (f) Spawning stock biomass. Data for (a-e) are from SEDAR 63 Gulf Menhaden Assessment Report (2018)[8]. (g) Juvenile Gulf menhaden abundance in Louisiana estuaries. The catch per unit effort (CPUE) shows the abundance per trawl in Louisiana estuaries (the most significant nursery area for Gulf menhaden) from survey data routinely collected by the Louisiana Department of Wildlife and Fisheries (LDWF). Shaded area represents the time period which was affected by the late 1980s prolonged drought. Data are provided at doi: 10.24433/CO.3658239.v2.

Supplementary note S2: correspondence between Gulf menhaden (+3 yr) biomass and fishing effort

The relationship between Gulf menhaden (+3 yr) biomass and menhaden purse seine fishing effort over the years shows notable trends, particularly when comparing the 1980s to the subsequent years (1990-2016), as depicted in Fig. S4 where fishing effort was significantly higher in the 1980s. During this period, a positive correlation was observed between biomass and fishing effort (p-value = 0.022, df = 9, correlation coefficient = 0.68), indicating a statistically significant relationship. In contrast, from 1990 to 2016, the relationship shifted to a negative correlation (p-value = 0.0018, df = 24, correlation coefficient = -0.58), suggesting that increased fishing effort during these years was associated with a decline in biomass levels. While the dynamics of the post-1990 years align with the expectation that as biomass increases, fishing effort should decrease, and vice versa, the dynamics during the 1980s appear counterintuitive, as biomass decreased in parallel with a decrease in fishing effort, supporting the dominance of an external environmental force such as nutrient input deficiency. This pattern may also reflect a lagged management or economic response, where effort initially remained high, then dropped in reaction to declining biomass, and continued to decrease into the subsequent period as stocks rebuilt.

Gulf menhaden (+3 yr) biomass vs. effort

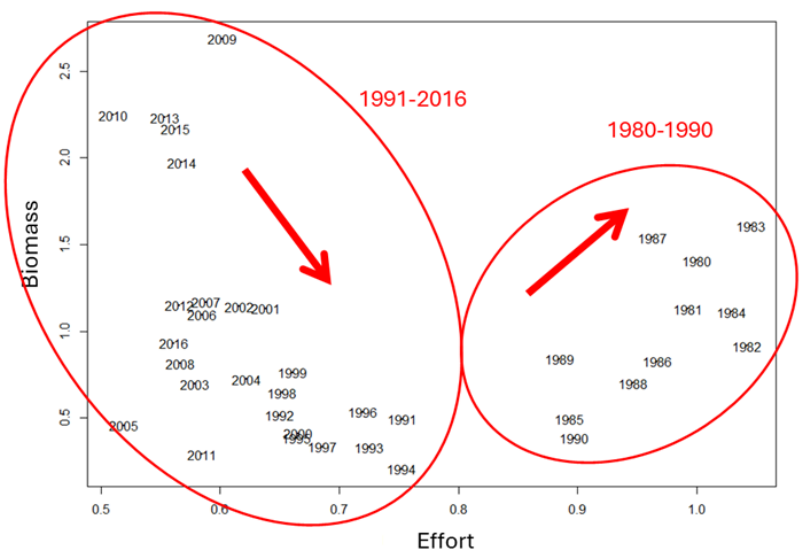


Figure S4. Gulf menhaden (+3 yr) estimated biomass versus the Purse menhaden fleet fishing effort, based on the model input time series data (data sources are listed in Tables S2 and S4).

Supplementary note S3: comparison of CMIP6 to CMIP5 simulations based on Cook et al. 2020[9]

The transition from CMIP5 to CMIP6 represents an advancement in understanding drought and hydroclimatic responses. CMIP6 models demonstrate improved performance relative to observations, especially concerning hydrological processes and ecosystem dynamics. This enhances confidence in projections, though uncertainties remain due to ongoing challenges in robust model validation.

Both CMIP5 and CMIP6 project drying trends across the continental U.S., but CMIP6 indicates more pronounced drying, particularly regarding soil moisture and runoff. Some regions previously projected to experience wetting in CMIP5 now show robust drying in CMIP6, especially concerning total column soil moisture and hydrological responses.

CMIP6's improved implementation of precipitation dynamics reveals that increased total annual precipitation does not always translate to higher soil moisture and runoff. Furthermore, CMIP6 projects a substantial increase in the frequency and intensity of extreme drought events, even under lower emission scenarios (SSP1-2.6 and SSP2-4.5), indicating persistent risk across warming trajectories. Given that CMIP6 projects more severe drought conditions than CMIP5, our results, based on CMIP5, may represent a relatively conservative estimate of future impacts.

Supplementary note S4: assessment of Ecosim model fits

The calibration of the Ecosim model to time series data from 1980 to 2016 involved fitting the model to an extensive set of reference time series ($N = 109$), including functional group biomasses and landings[10,11]. These observed values were primarily derived from stock assessments and monitoring surveys (Tables S1-S3). The model generally showed strong fits to historical biomass and catch data for economically significant species, particularly those supported by robust data sources like SEDAR stock assessments.

For instance, greater amberjack and Spanish mackerel exhibited good alignment between modeled and observed values. However, accuracy diminished for certain groups, particularly sharks and highly migratory species (HMS) like yellowfin tuna. This discrepancy largely results from the lower weights assigned during model fitting, reflecting uncertainties regarding data representativeness for the Gulf of Mexico (GoM) and the complex movements of these species.

The assignment of lower weights acknowledges that trends for these species may not fully capture their actual dynamics.

Model quality was demonstrated in good agreement between model predicted biomass with many reference time seriesand between model predicted estimates of the fishing mortality rate corresponding to the maximum sustainable yield (F_{MSY}) and F_{MSY} estimates from stock assessments. Ecosim-derived F_{msy} values was estimated within Ecosim using the built-in equilibrium MSY (compensatory) search routine, which iteratively adjusts fishing mortality to identify the rate that maximizes long-term equilibrium yield (see Berenshtein et al., 2021; 2023) [10,11]. For detailed plots comparing observed vs. model-predicted biomass for key functional groups, see Berenshtein et al. (2021, 2023)[10,11], where calibration and validation are presented extensively. These figures visually illustrate the quality of model fit and support the MEF values reported here. Note that our simulations applied both fishing mortality (*F*) and purse-seine fleet effort, such that catches varied proportionally with biomass and productivity. While this approach captures the relative impact of fishing under drought forcing, it does not account for possible synergistic effects if reductions in F lag behind biomass declines. In reality, such delays could intensify stock depletion, particularly under extreme drought conditions. Likewise, sustained high F in the years preceding drought events could produce stronger cumulative impacts once drought occurs. These potential interactions were not explicitly represented here and should be explored in future model extensions. In addition, the model fits exhibited largely positive modeling efficiency (MEF) values (see Table S5), with high values for commercially important groups such as groupers, snappers, and mackerels. Despite this, high-frequency fluctuations in biomass for species like billfish and bluefin tuna were not well captured, due to the closed nature of the Ecosim model, limiting its ability to represent large-scale migrations.

Additionally, significant population trends, such as the decline in red grouper and gag grouper biomass in 2005 linked to environmental stressors like red tide, were not adequately modeled. The Ecosim model also struggled with younger age classes of species such as juvenile yellowedge grouper, red grouper, and gag grouper, likely due to the absence of interannual recruitment variability estimates.

Supplementary note S5: EwE drought duration sensitivity analysis

In this section, we conduct a sensitivity analysis to assess the impact of drought duration on EwE-modeled biomass. We fixed the fishing mortality multiplier at several levels (×0.5, ×1, ×2), similar to the methodology used in Fig. 2c, and simulated both a 3-year drought and a 1-year drought, comparing these results with those from the 5-year drought presented in the main text. The findings reveal a clear correlation between drought duration and the decline in ecosystem biomass. As noted in the main text, the relative impact of fishing mortality diminishes as drought-related effects on biomass intensify.

Modeled cumulative biomass under variable drought duration periods

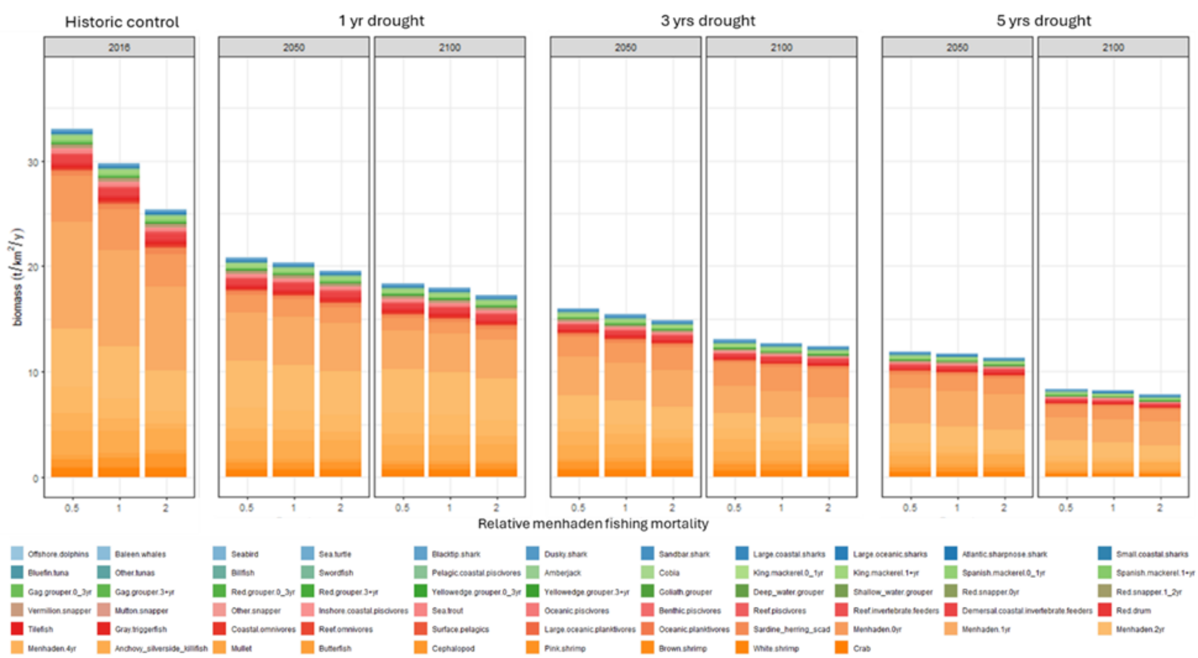


Figure S5. Modeled cumulative biomass of functional groups for the terminal year of the model (2016) (historic control) and projected for 2050 and 2100 following 1-, 3-, and 5-year drought conditions. X-axis represents the relative change in menhaden fishing mortality.

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