FINAL REPORT

carteret county Shore protection office
protectthebeach.com

Bogue Banks Beach
and Nearshore Mapping Program

October 2018

moffatt & nichol

geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

Executive Summary

Comprehensive surveying of shorelines and beach volumes along Bogue Banks began in 1999 to develop the Bogue Banks Beach Restoration Project. In Spring 2004, the Bogue Banks Beach and Nearshore Mapping Program was codified to continue assessing beach conditions and form strategies for future beach nourishment projects. Bear Island was added to the program in October 2004 and Shackleford Banks was added in May 2005. Currently, surveys are performed annually during the spring/summer timeframe along all three islands. In addition, after large storm events surveying is performed along Bogue Banks to assess damages. The most recent annual survey was completed during spring 2018 by Geodynamics. For this evaluation, the spring 2018 survey was compared with the spring 2017 survey to assess the changes in the beach occurring over the past year. The survey data was used to compute shoreline change at Mean High Water (MHW), which is designated as +1.5 ft NAVD88 for Bogue Banks and Shackleford Banks and +1.7 ft NAVD88 for Bear Island, and volume change above MHW, -5 ft NAVD88 (wading depth), -12 ft NAVD88 (outer bar), -20 ft NAVD88 (approximate closure), and -30 ft NAVD88 (offshore). This allows a detailed review of the shoreline and active profile performance since the 2017 monitoring report.

Key statistics for individual reaches along Bogue Banks along with the entire oceanfront shoreline were as follows:

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (Transects 1-11)	11,488	17.2	4.8	54,775	9.4	107,982	9.7	111,015	1.0	11,111	-2.9	-33,285
Emerald Isle-West (Transects 12-25)	18,288	-1.7	1.5	28,131	3.2	58,041	10.1	184,840	5.4	99,547	-1.5	-26,579
Emerald Isle-Central (Transects 26-36)	15,802	-0.7	3.8	60,580	5.9	92,562	14.3	226,150	9.1	143,706	0.8	12,073
Emerald Isle-East (Transects 37-48)	13,220	-13.1	0.7	8,827	5.3	70,233	10.8	142,338	9.3	123,129	2.1	27,254
Indian Beach-Salter Path (Transects 49-58)	12,850	-3.6	2.5	31,890	5.8	73,935	8.9	113,963	5.9	76,006	-3.8	-48,504
Pine Knoll Shores (Transects 59-76)	23,878	-8.1	1.3	31,692	2.4	57,122	7.1	169,571	6.0	142,860	-5.7	-135,443
Atlantic Beach (Transects 77-102)	26,176	-22.9	-0.1	-1,979	-2.8	-73,190	-0.3	-6,993	-0.7	-19,485	-11.7	-306,958
Fort Macon State Park (Transects 103-112)	6,691	-4.0	4.0	26,602	0.7	4,697	-7.0	-46,689	-27.3	-182,394	-30.9	-206,691
Beaufort Inlet (Transects 112B-116)	2,000	41.7	5.8	11,511	10.0	20,091	14.0	28,041	8.3	16,583	6.4	12,857
Bogue Inlet-Channel (Transects 117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Reach Length	Weighted Avg	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total
FEMA Engineered Beach (Transects 1-76)	**95,527**	**-2.7**	**2.3**	**215,895**	**4.8**	**459,876**	**9.9**	**947,877**	**6.2**	**596,360**	**-2.1**	**-204,484**
Oceanfront (Transects 1-112)	**128,393**	**-6.9**	**1.9**	**240,517**	**3.0**	**391,383**	**7.0**	**894,195**	**3.1**	**394,481**	**-5.6**	**-718,133**

*Note: Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

The Bogue Banks oceanfront shoreline experienced an overall average landward recession at MHW of -6.9 ft over the past year. However, this is somewhat influenced by equilibration of the Atlantic Beach nourishment project. The remainder of the beach west of the nourishment project (FEMA engineered beach) experienced an overall landward recession of the shoreline at MHW of only -2.7 ft over the past year.

Despite shoreline recession, volumetrically, the Bogue Banks oceanfront experienced an overall volume gain above all elevations analyzed except above -30 ft NAVD88. Oceanfront volume gains increased moving down the profile from above MHW (+240,517 cy), to above -5 ft NAVD88 (+391,383 cy), to above -12 ft NAVD88 (+894,195 cy). This indicates a gain in material along each section of the profile out to the offshore bar. Volumes gains then decreased above -20 ft NAVDD88 (+394,481 cy) and turned into volume losses at -30 ft NADV88 (-718,133 cy). This indicates offshore losses that were limited to seaward of the offshore bar. Profile plots indicate several locations where there was a distinct decrease in elevation along the offshore portion of the profile. The same volume change pattern was experienced for just the FEMA engineered beach portion of Bogue Banks with increasing volume gains above MHW (+215,895 cy), -5 ft NAVD88 (+459,876 cy), and -12 ft NADV88 (+947,877 cy). Smaller gains were experienced above -20 ft NAVD88 (+596,360 cy) and losses experienced above -30 ft NAVD88 (-204,484 cy). The quiescent weather over the past year likely aided in beach recovery from storms which occurred during spring 2017 that caused some noticeable erosion of the beach. The only reach to experience losses at all elevations analyzed was Atlantic Beach. This was expected due to equilibration of the 2017 USACE project during the first year post-construction. However, losses from the project were considerably less than what often occurs immediately post-nourishment with only 131,500 cy of material being lost above -12 ft NAVD88 from Transects 91 to 100 out of 621,000 cy placed (approximately 21% loss).

The difference in position of the base of the dune was also analyzed. Results indicated overall erosion of the base of the dune. This appears to be inaccurate, given the results of the volume change analysis, and is likely the result of comparing dune base positions established from two different methods. A new method of locating the base of the dune was introduced in 2018. Previously, an ATV was driven along the base of the dune but it was highly subject to surveyor interpretation and accuracy was hard to achieve given the size of the ATV and obstacles inhibiting the vehicle from reaching the base of the dune. In 2018, a mobile laser scanner was used to achieve high density elevation data from the seaward face of the dune to the waterline. From this, the base of the dune where the slope breaks for the berm was extracted from a DEM surface created from the high density data. It appears that this method of locating the base of the dune is more precise and will provide more accurate results in future comparisons.

Key statistics calculated for Bear Island were as follows:

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.7 ft NAVD88	Average Volume Change Above +1.7 ft NAVD88	Cumulative Volume Change Above +1.7 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bear Island (Transects 1-18)	16,500	-23.6	-2.5	-40,795	-8.5	-140,969	-13.0	-214,546	-17.7	-292,108	-26.7	-441,223

Bear Island experienced significant landward recession of the shoreline at MHW over the past year of -23.6 ft. Volumetric calculations also indicate overall volume losses above all elevations analyzed, with losses above -12 ft NAVD88 totaling -214,546 cy (-13.0 cy/ft). The entire island experienced erosion with the western end of the island experiencing the largest losses. It should be noted that there were two significant storm events in April 2018 with offshore wave heights reaching 14 ft (April 16) and 18 ft (April 24). Bear Island was surveyed on May 1, 2018 so the

higher than average erosion experienced over the past year is likely due to the effects of the April 2018 storms.

Key statistics calculated for Shackleford Banks were as follows:

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Shackleford Banks (Transects 1-18)	35,331	-21.7	-1.4	-47,813	2.0	69,535	1.7	60,528	-0.04	-1,269	-11.2	-395,796
Shackleford Banks (Transects 19-22)	7,054	-140.7	-16.0	-113,132	-36.9	-260,599	-64.2	-452,937	-96.7	-682,036	-111.3	-784,870
Shackleford Banks (Transects 1-22)	42,385	-41.5	-3.8	-160,945	-4.5	-191,065	-9.3	-392,410	-16.1	-683,305	-27.9	-1,180,666

Transects 1 – 18, which comprise most of the island, experienced moderate landward recession of the shoreline at MHW of -21.7 ft. The remaining transects along Shackleford Banks (19-22) experienced extreme landward recession of the shoreline at MHW of -140.7 ft. Volumetrically, Transects 1-18 experienced minor accretion above -12 ft NAVD88 of +60,528 cy (+1.7 cy/ft). The remaining transects along Shackleford Banks (19-22) experienced significant losses in volume of approximately -452,937 cy (-64.2 cy/ft). Extreme erosion along the western end of the island, adjacent to Beaufort Inlet, has been a consistent trend since 2010. This behavior is not unexpected given the location of the deep draft channel being directly adjacent to this area of Shackleford Banks and the recent history of significant erosion. The combination of the deep draft channel hydraulics, episodic dredging and shoaling, as well as barrier island morphology make this a very dynamic area.

Carteret County has developed a programmatic Environmental Impact Statement (EIS) which essentially outlines the nourishment needs (quantity, location, and timeframe) and sediment resources for Bogue Banks for the next 50 years and is being used to obtain a permit to cover these activities. The annual monitoring efforts will decide the exact timing and extents of future nourishment projects by tracking the average profile volume in each management reach as compared to nourishment triggers that define the minimum profile volumes required to provide an equal level of protection along the Bogue Banks shoreline for a 25 yr storm event. Assessment of current conditions compared to the nourishment triggers defined in the Master Beach Nourishment Plan (engineering portion of the EIS) was completed as part of this report. The following table indicates that all management reaches currently contain average profile volumes above their individual nourishment triggers as well as the island wide average trigger of 233 cy/ft. However, Emerald Isle – East and Pine Knoll Shores are close to approaching the nourishment triggers and projects are in the process of being planned for winter 2018/2019 or winter 2019/2020. It is anticipated that the Master Beach Nourishment Plan – Project #1 will place material on Emerald Isle and Indian Beach/Salter Path, preferably during winter 2018/2019 if permitting can be finalized and feasible bid prices can be achieved, while Pine Knoll Shores is expected to collaborate with the USACE in winter 2019/2020 to do a delta project as an add on to the USACE project in Atlantic Beach. It is important to note that Hurricane Florence, which occurred in mid-September after completion of the annual analysis, is expected to have a large effect on the next expected nourishment project.

Reach (Profiles)	Management Reach Length (ft)	2018 Volume Above -12 ft NAVD88 (cy)	25 yr LoP Nourishment Trigger (cy)
Bogue Inlet (1-11)	11,488	318	235
Emerald Isle West (12-25)	18,288	321	266
Emerald Isle Central (26-36)	15,802	308	211
Emerald Isle East (37-48)	13,220	277	221
Indian Beach/Salter Path (49-58)	12,850	293	224
Pine Knoll Shores (59-76)	23,878	262	211
Atlantic Beach (77-102)	26,176	337	254
TOTAL	**121,702**		
AVERAGE		**303**	**233**
		weighted	weighted

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1.0 Objective

The Bogue Banks Beach and Nearshore Mapping Program (BBBNMP) is sponsored by Carteret County and formally began in June 2004 as a continuation of the 1999 monitoring program initiated for assessing beach conditions. The program's primary purpose centered on forming strategies for the Bogue Banks Beach Restoration Project or County Project (Phases I, II, and III). The monitoring program was initiated along Bogue Banks and expanded to include Bear Island in October 2004. The inclusion of Shackleford Banks occurred later in May 2005. Since May 2005, surveys along Bogue Banks, Bear Island, and Shackleford Banks have been performed annually during the spring/summer timeframe. In addition, surveys occur for Bogue Banks after large storm events to quantify storm related shoreline and volume changes and to augment the municipalities' FEMA reimbursement request for beach nourishment. The most recent annual survey occurred during the spring of 2018 and was performed by Geodynamics LLC (Geodynamics). This report documents the data sources, methods, and results of a survey evaluation performed to compare the spring 2018 survey with a previous survey performed in spring 2017.

2.0 Summary of Previous Work

Previous beach monitoring studies performed by Coastal Science & Engineering (CSE) between 2004 and 2007 were reviewed to gain an understanding of previous survey methods, associated coastal analysis, and observed trends (Note: University of North Carolina Institute of Marine Sciences completed the 2003 work). Each year, comparisons along Bogue Banks were made to an initial survey performed in 1999, providing for some long-term analysis. Bear Island and Shackleford Banks were added to the monitoring effort in 2004 and 2005, respectively. Each year, surveys for these regions were compared to the initial surveys in 2004 and 2005 to provide other long-term analysis results. In addition, at Bogue Banks, Bear Island, and Shackleford Banks, comparisons were made each year to the previous year's survey, providing insight into sand movement within a single year. **Table 2-1** and **Table 2-2** show the long-term and short-term volume changes over the various reaches of shoreline included in the BBBNMP.

Table 2-1. Long-term Volume Change (Previous Studies: 2004-2007)

	Dune to -4' NGVD				Dune to -11' NGVD				Dune to -15' NGVD			
	June 1999-June 2004	June 1999-May 2005	June 1999-May 2006	June 1999-May 2007	June 1999-June 2004	June 1999-May 2005	June 1999-May 2006	June 1999-May 2007	June 1999-June 2004	June 1999-May 2005	June 2004-May 2006	June 2004-May 2007
Reach	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy
Bogue Inlet-Channel	-	-	-	-	-	-	-	-	-	-	115,528	-
Bogue Inlet-Ocean	185,872	250,657	-25,335	33,023	-268,237	395,676	99,426	147,797	-	-	-	-
Emerald Isle-West	420,971	963,253	739,518	899,412	723,052	1,321,780	1,072,208	1,185,131	-	-	685,012	1,783,395
Emerald Isle-Central	604,558	675,135	586,251	661,490	874,031	1,002,184	742,535	781,223	-	-	-11,291	1,194,915
Emerald Isle-East	700,213	670,766	640,656	685,168	965,114	963,911	803,382	946,483	-	-	-20,827	1,335,655
Indian Beach/Salter Path	856,179	829,318	681,474	783,473	1,361,192	1,290,983	1,035,738	1,155,522	-	-	-178,053	1,744,153
Pine Knoll Shores-West	329,308	305,689	226,660	403,726	398,891	526,330	357,306	680,649	-	-	87,624	1,135,995
Pine Knoll Shores-East	500,958	392,759	315,186	781,720	650,158	576,150	399,946	1,072,778	-	-	-190,587	1,796,876
Atlantic Beach	-10,721	931,032	661,520	558,278	136,193	1,902,206	1,305,619	1,194,947	-	-	1,661,386	2,358,100
Fort Macon	-196,301	15,679	23,930	36,932	-184,943	287,847	179,302	221,169	-	-	695,424	558,157
Beaufort Inlet	-	-	-	-	-	-	-	-	-	-	-	-
County Project	3,412,182	3,836,920	3,189,745	4,214,989	4,972,437	5,681,337	4,411,116	5,821,785	-	-	371,879	8,990,990
Entire Oceanfront	3,390,495	5,034,288	3,849,860	4,843,223	4,655,450	8,267,067	5,995,463	7,385,699	-	-	2,728,689	11,907,247
Bear Island	-	-	-	-	-	-	-	-	-	-	-	-
Shackleford Banks	-	-	-	-	-	-	-	-	-	-	-	-

Table 2-2. Short-term Volume Change (Previous Studies: 2004-2007)

	Dune to -4' NGVD				Dune to -11' NGVD				Dune to -15' NGVD			
	Dec 2003-June 2004	June 2004-May 2005	May 2005-May 2006	May 2006-May 2007	Dec 2003-June 2004	June 2004-May 2005	May 2005-May 2006	May 2006-May 2007	Dec 2003-June 2004	June 2004-May 2005	May 2005-May 2006	May 2006-May 2007
Reach	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy
Bogue Inlet-Channel	-9,809	10,792	42,160	-26,182	-24,465	20,639	131,171	-7,147	-17,943	18,389	-	103,996
Bogue Inlet-Ocean	46,594	13,918	-204,216	58,358	-8,041	626,020	-299,980	48,372	-	-	-235,915	-52,942
Emerald Isle-West	54,586	542,282	-223,735	159,894	153,489	598,728	-249,571	112,922	147,494	807,600	-122,588	82,591
Emerald Isle-Central	11,253	70,577	-88,885	75,240	80,919	128,154	-259,649	38,688	70,888	238,146	-249,437	50,782
Emerald Isle-East	35,498	-29,447	-41,418	44,512	60,434	-1,204	-177,539	143,100	37,466	86,866	-127,967	130,604
Indian Beach/Salter Path	350,295	-43,495	-128,931	101,999	651,819	-85,523	-234,853	119,783	649,217	6,703	-184,756	103,996
Pine Knoll Shores-West	45,812	-8,333	-66,901	177,066	39,306	146,225	-149,924	323,343	26,129	233,908	-146,284	400,836
Pine Knoll Shores-East	45,904	-83,525	-97,553	466,534	67,286	-59,354	-197,027	672,831	11,741	-44,338	-146,248	563,500
Atlantic Beach	123,250	942,289	-269,512	-103,242	65,826	1,766,014	-596,587	-110,672	-63,325	2,189,434	-528,048	-274,554
Fort Macon	8,783	255,147	-13,739	17,087	-42,921	473,780	-84,893	33,818	-94,922	792,583	-14,647	151,211
Beaufort Inlet	41,514	85,619	-22,410	-11,428	85,574	448,098	-56,020	-4,905	103,219	1,035,861	-	-
County Project	543,349	448,059	-647,422	1,025,245	1,053,253	727,025	-1,268,564	1,410,668	942,935	1,328,884	-977,280	1,332,309
Entire Oceanfront	721,977	1,659,414	-1,134,889	997,448	1,068,117	3,592,840	-2,250,025	1,382,186	784,689	4,310,901	-1,755,890	1,156,024
Bear Island	-	-29,705	-162,365	-105,930	-	-135,310	-139,170	-343,295	-	11,980	-64,820	-471,975
Shackleford Banks	-	-	-450,401	-74,356	-	-	-686,685	55,122	-	-	-665,033	270,338

For analysis from 2008 – 2017, please refer to the annual and post-storm reports prepared by Moffatt & Nichol.

3.0 Survey Procedures and Data Processing

3.1 Survey Transects and Reaches

Most recently, Geodynamics conducted a survey of Bogue Banks, Shackleford Banks, and Bear Island in March through May 2018. The profile lines and origins used in previous studies were also used for the most recent survey for ease and consistency of comparison. **Figure 3-1** and **Figure 3-2** show the location of the profile lines and origins applied by Geodynamics for the surveying. Two transects were added near Beaufort Inlet (112B) and Bogue Inlet (117B) in 2008 to better track sand movement near the inlets. As shown, lines were stationed from west to east along Bogue Banks and east to west along Bear Island and Shackleford Banks. The figures further detail how Bogue Banks has been subdivided into smaller sub-reaches based upon town limits and similar profile characteristics (dune height, berm width, maintenance placement, etc.). As a reminder, annual monitoring is now being performed in accordance with the Master Beach Nourishment Plan which involves a slight adjustment of the shoreline reaches previously established for monitoring. **Table 3-1** shows the changes that were made in Bogue Inlet – Ocean, Emerald Isle – West, and Pine Knoll Shores. Bogue Inlet – Ocean has become slightly larger while Emerald Isle – West has lost a few transects. Pine Knoll Shores – West and Pine Knoll Shores – East are now combined into one management reach. These changes were first introduced in the 2016 monitoring report.

Table 3-1. Master Beach Nourishment Plan Management Reaches

OLD MONITORING REACHES:		NEW MANAGEMENT REACHES:	
Reach (Profiles)	**Length (ft)**	**Reach (Profiles)**	**Length (ft)**
Bogue Inlet-Ocean (1-8)	7,432	Bogue Inlet (1-11)	11,488
Emerald Isle-West (9-25)	22,344	Emerald Isle West (12-25)	18,288
Emerald Isle-Central (26-36)	15,802	Emerald Isle Central (26-36)	15,802
Emerald Isle-East (37-48)	13,220	Emerald Isle East (37-48)	13,220
Indian Beach-Salter Path (49-58)	12,850	Indian Beach/Salter Path (49-58)	12,850
Pine Knoll Shores-West (59-65)	9,063	Pine Knoll Shores (59-76)	23,878
Pine Knoll Shores-East (66-76)	14,815		
Atlantic Beach (77-102)	26,176	Atlantic Beach (77-102)	26,176
Fort Macon (103-112)	6,691	Fort Macon (103-112)	6,691

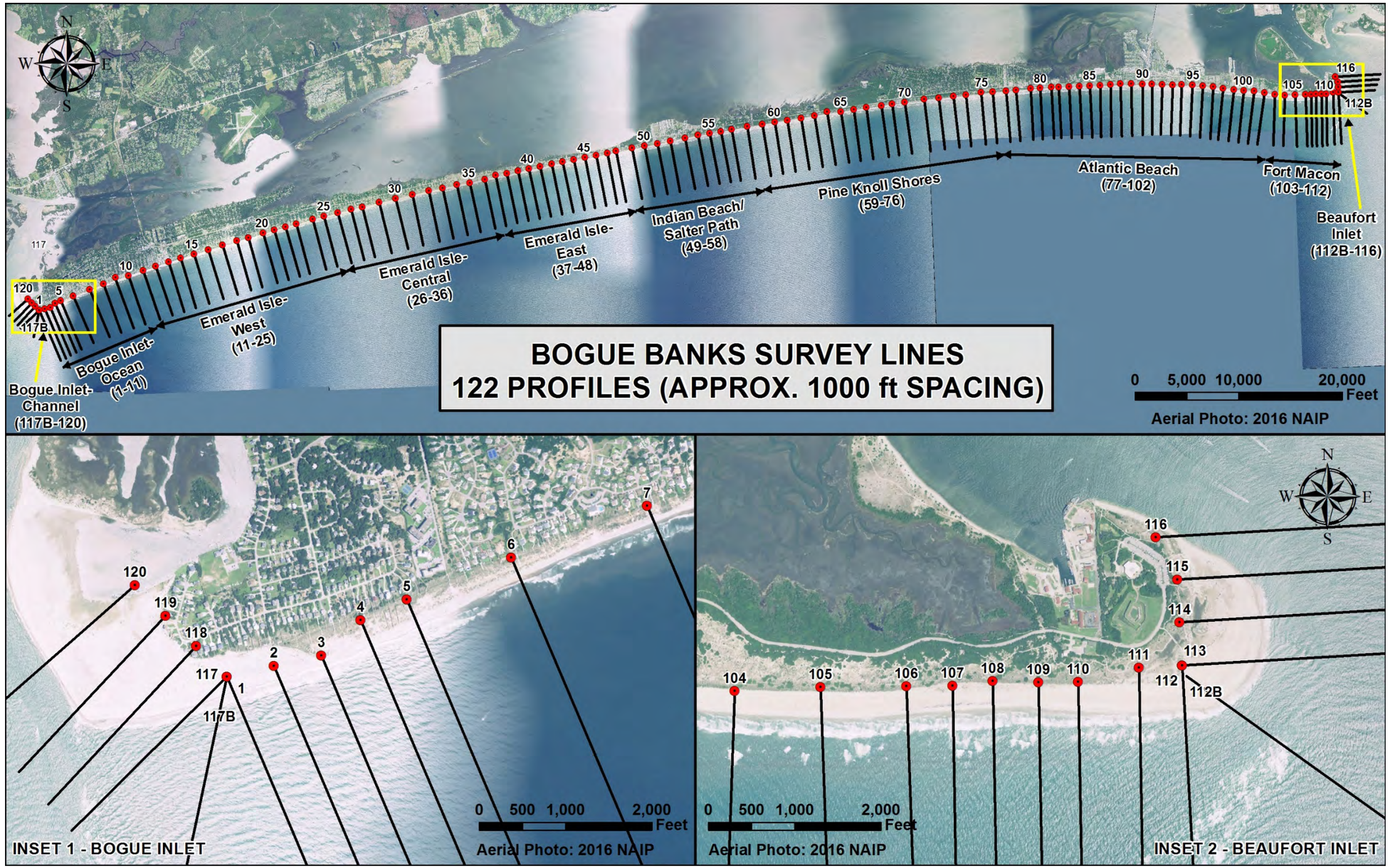


Figure 3-1. BBBNMP Profile Line Locations – Bogue Banks

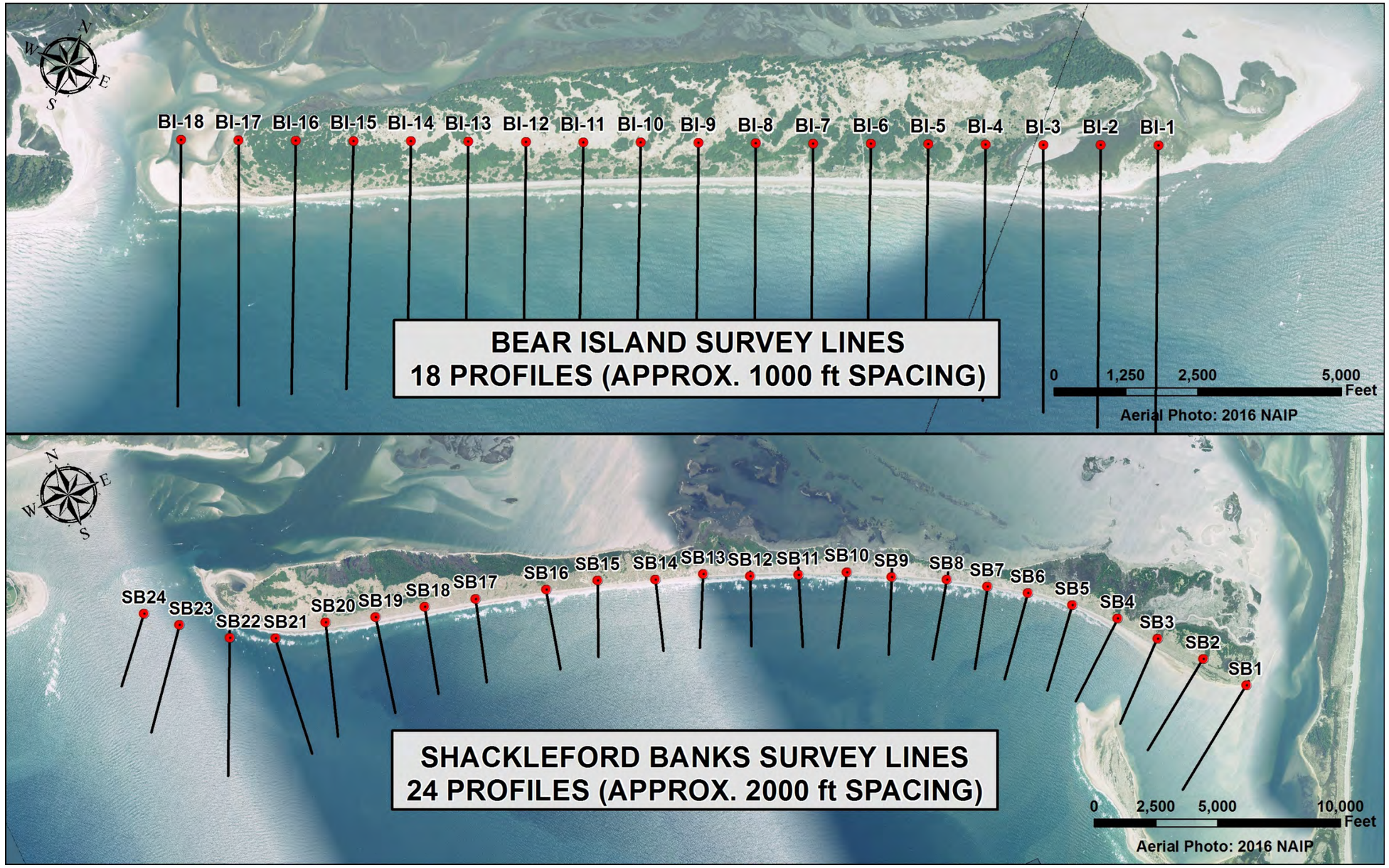


Figure 3-2. BBBNMP Profile Line Locations – Bear Island and Shackleford Banks

3.2 Survey Data Acquisition

Several steps were taken by Geodynamics to ensure the most accurate survey data. The spring 2018 survey represents the eleventh survey conducted by Geodynamics for the Carteret County Shore Protection Office using high-density singlebeam sonar to collect data for 122 profiles along Bogue Banks, 24 profiles along Shackleford Banks, and 18 profiles along Bear Island. In addition, topographic mobile laser scanning was introduced this year for a portion of Bogue Banks ranging from Transect 27 to Transect 82. **Figure 3-3** presents the survey equipment used by Geodynamics to collect the topographic, hydrographic, and mobile laser scanner data. All surveys conducted by Geodynamics meet the requirements specified in the National Ocean Service (NOS) Hydrographic Surveys Specifications and Deliverables (April, 2012), the Office of Coast Survey (OCS) Field Procedures Manual for Hydrographic Surveying (April 2012) and the criteria for Navigation and Dredging Support Hydrographic Surveys as outlined in the U.S. Army Corps of Engineers Hydrographic Surveying Manual, EM 1110-2-1003 (EM 1110-2-1003 January 2002).

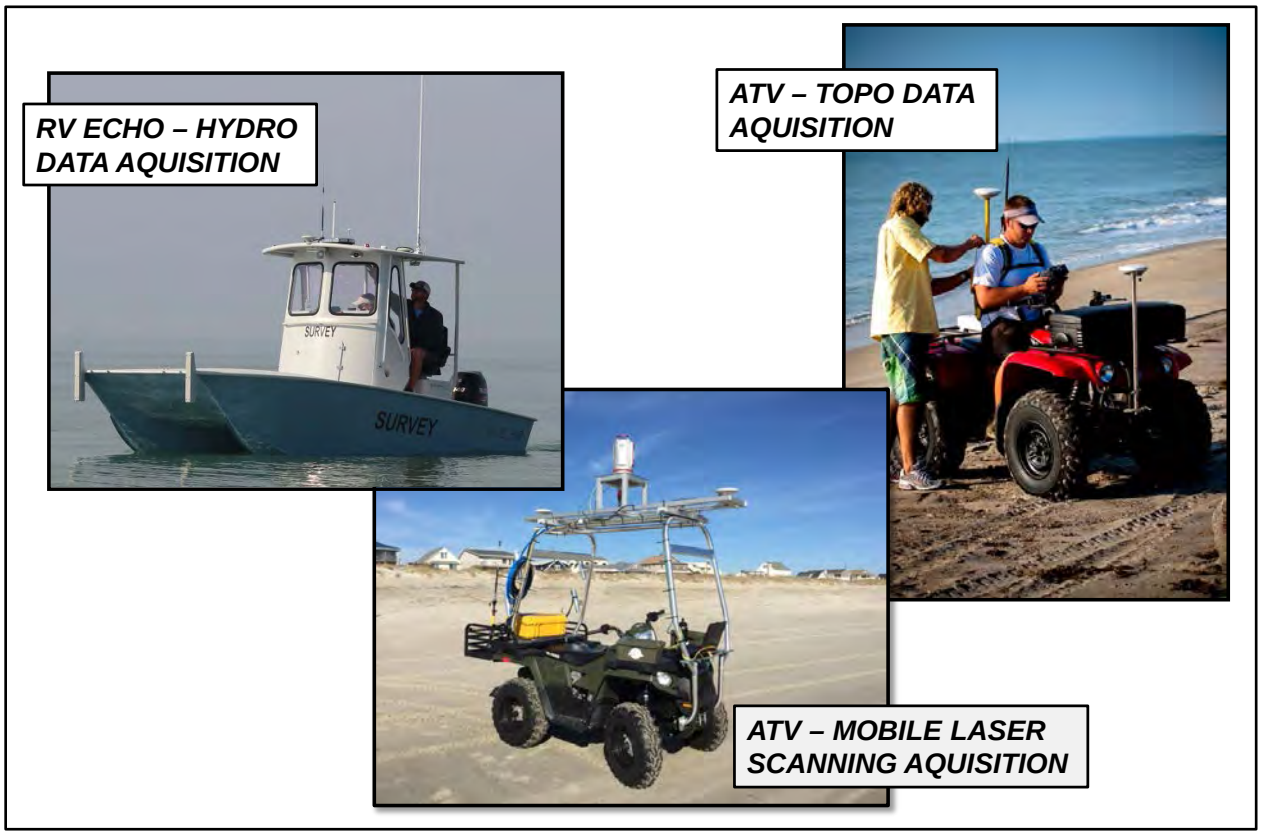


Figure 3-3. Geodynamics Survey Equipment

Appendix A contains the Geodynamics Field Report which discusses, in detail, the singlebeam (bathymetric) and topographic data acquisition as well as the mobile laser scanning. The field report also provides the associated equipment and quality control procedures (QA/QC) utilized in the data collection and processing tasks. Through the precise use of high quality data collection equipment and meticulous processing procedures, Geodynamics is able to provide seamless overlap of the topographic and hydrographic portions of the profile, guaranteeing reliable surfzone data.

The most recent set of annual survey data was collected by Geodynamics during March through May of 2018. The Shackleford Banks survey was completed on April 20-21, 2018. Bear Island was surveyed on May 1, 2018. The Bogue Banks survey, due to weather, was performed over a longer range of dates encompassing March 6-8, 2018 (dune topographic data) and March 19 – 23, 2018 (remaining topographic data, hydrographic data, and mobile laser scanning). The date used for the 2018 Bogue Banks profiles for this report is March 23, 2018, when surveying was completed.

The previous set of annual survey data was collected by Geodynamics during February through June of 2017. The Shackleford Banks survey was completed on March 6-7, 2017. Bear Island was surveyed on March 16-17, 2017. The Bogue Banks survey, due to weather and the USACE project, was performed over a longer range of dates from February 27, 2017 to June 9, 2017. Dune topography was collected on February 27-28, 2017. Remaining topography and hydrographic surveys for Transects 1-90 and 117-120 was performed on April 11-13, 2017. Remaining topography and hydrographic surveys for Transect 91-116 were performed post-nourishment on June 9, 2017. The date used for the 2017 Bogue Banks profiles for this report is June 9, 2017, when surveying was completed.

The processed survey data was provided to Moffatt & Nichol in ASCII (xyz), Excel (xyz), BMAP (free format), and GIS (shapefile, grid) formats allowing for compatibility with multiple programs. The data referenced the horizontal North American Datum 1983 (NAD83) State Plane North Carolina (feet) and the vertical datum used was the North American Vertical Datum of 1988 (NAVD88). A copy of the survey data files is included on the attached CD also containing an electronic copy of the report.

3.3 Revision of the MHW Contour Elevation

Recent advancements in tidal datum modeling, the addition of tidal datum stations, and improved datum relationships has allowed for a more accurate estimate of the MHW contour elevation than was previously calculated when monitoring began in 1999. Using Vdatum, a software tool that transform geospatial data among different datums, Geodynamics developed new values for MHW throughout the study area which were incorporated into the annual analysis beginning in 2017. Previously, MHW was established as +1.1 ft NAVD88 for all three islands within the study area. Based on the new and improved tidal datum analysis, MHW will be established as +1.5 ft NAVD88 for Bogue Banks and Shackelford Banks and +1.7 ft NAVD88 for Bear Island.

4.0 Survey Evaluation Methods

Survey comparisons and respective analysis were performed using Beach Morphology Analysis Package (BMAP). BMAP is a program developed by the USACE to analyze morphologic and dynamic properties of beach profiles.

All survey data sources were imported into ArcGIS, in xyz format, and displayed to compare the coverage of each set of data. Free format files containing the 2017 and 2018 beach profiles being used for comparison were imported into BMAP. Using BMAP, two indicators of change were calculated for each transect.

First, the change in shoreline position at mean high water (MHW), which was defined as +1.5 ft NAVD88 for Bogue Banks and Shackleford Banks and +1.7 ft NAVD88 for Bear Island, was calculated at each transect between the spring 2017 and spring 2018 profiles. The resulting value represents the shoreline change (ft) over the time period between surveys. The shoreline change rate (ft/yr) was then calculated by dividing by the amount of time (years) between survey dates. This allows an equivalent comparison of shoreline migration rates occurring between different time periods. For visual reference, a Digital Elevation Model (DEM) was created by Geodynamics using Surfer, a 3D surface mapping software package, for both the spring 2017 and spring 2018 profile data and mobile laser scanner data (2018 only). The MHW shoreline position contour was extracted from the spring 2017 and spring 2018 DEMs and plotted on aerials. In addition, the base of the dune was extracted from the 2018 surface and plotted as well. These figures are presented in **Appendix B**.

Next, representative volume changes were calculated at each transect between the spring 2017 and spring 2018 surveyed conditions. Volume changes were calculated for five different extents in order to better understand the processes occurring onshore and offshore of the Bogue Banks beach area. Calculations included volume change above MHW (+1.5 ft NAVD88 for Bogue Banks and Shackleford Banks and +1.7 ft NAVD88 for Bear Island), above -5 ft NAVD88 (wading depth/recreational beach), above -12 ft NAVD88 (outer bar), above -20 ft NAVD88, and above -30 ft NAVD88. Upon inspection of recent survey data, it appears the depth of closure occurs somewhere between -20 ft NAVD88 and -30 ft NAVD88 (likely closer to -20 ft NAVD88). For those profiles which did not extend to -30 ft NAVD88, volume calculations were performed above -30 ft out to the extent of the shortest survey. As with the shoreline change, the results represent volume change (cy/ft) over the period of time between surveys. The volume change rate (cy/ft/yr) was then calculated by dividing by the amount of time (years) between survey dates in order to better compare changes between different time periods. In addition, the volume changes were converted to cumulative changes over the entire shoreline. This was done by applying the average end area method to the unit volume changes (cy/ft) and unit volume change rates (cy/ft/yr) computed at each transect and summing the total volume changes over the entire shoreline. The resulting value indicated the total loss or gain of material between survey periods based on the applicable profile extents. It should be noted that the uncertainty in the hydrographic portion of the survey is approximately ±0.11 ft. If this uncertainty is applied along the portion of the profile between the seaward side of the outer bar (approximately 1300 ft offshore) and a depth of -30 ft NAVD88 (approximately 2850 ft offshore) along all 128,393 ft of oceanfront shoreline, this lends itself to an uncertainty of approximately ±811,000 cy.

Volume changes calculated for portions of the profiles above MHW represent changes in the amount of material in the dune system and on the subaerial beach. These areas are highly influenced by storm activity. Volume comparisons for portions of the profiles above -5 ft NAVD88, an approximate wading depth, represent changes in the recreational beach area. Volume comparisons above -12 ft NAVD88 help to track sand movement to and from the outer sand bar and are ultimately used in decision making for future beach nourishment projects. Volume comparisons above -20 ft NAVD88 allow for the tracking of sand movement offshore while reducing the amount of uncertainty associated with the survey data by eliminating changes beyond this depth related to the vertical margin of uncertainty in the hydrographic survey data. Finally, volume comparisons above -30 ft NAVD88 allow the complete tracking of sand

movement offshore. However, hydrographic survey measurement accuracy may impact these calculations. This is a comprehensive way to assess the impact of storm activity on the subaerial beach and dune system as well as track the movement of sand offshore and quantify total gains and losses in the entire system. **Figure 4-1** presents a graphic showing the various calculation lenses.

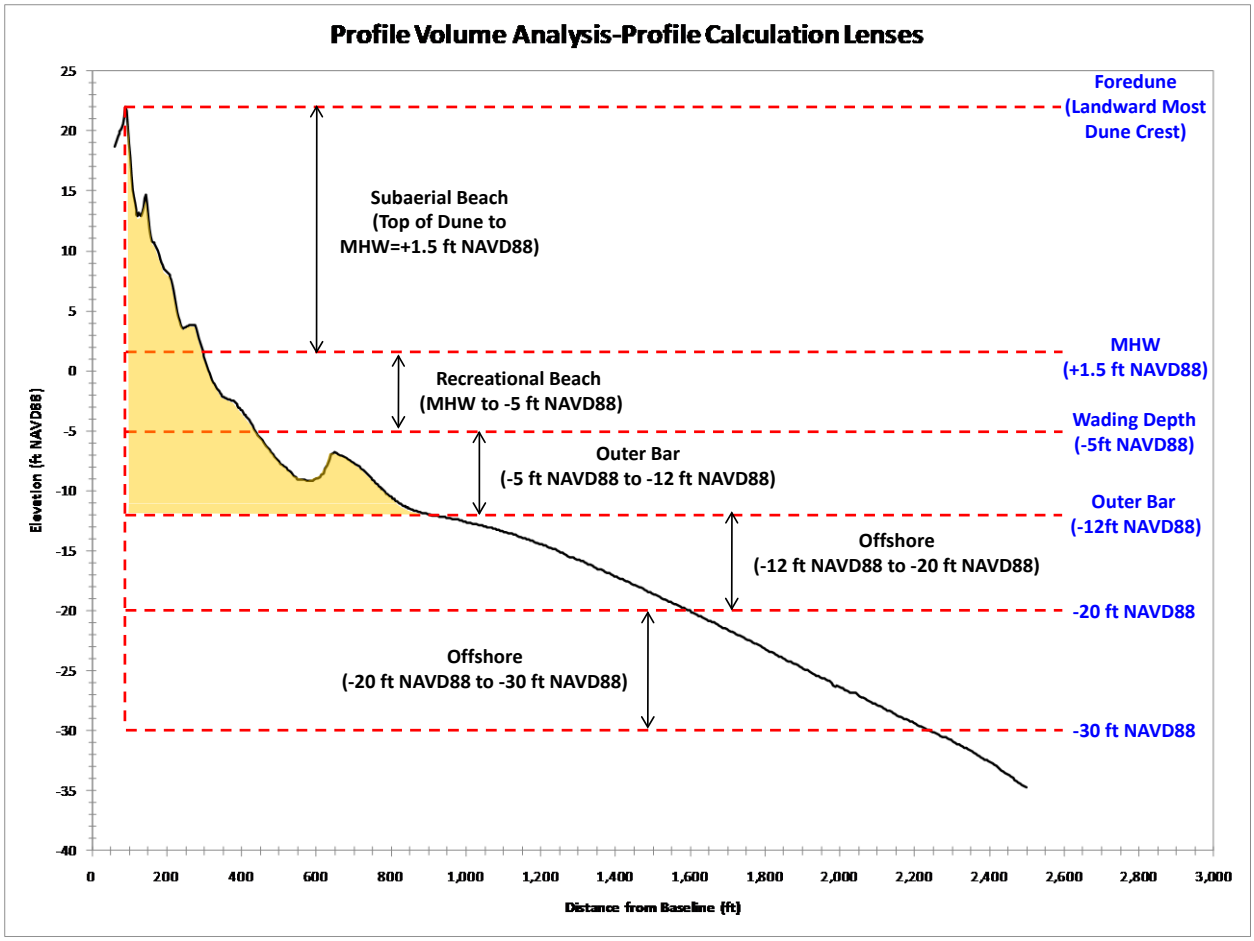


Figure 4-1. Profile Volume Calculation Lenses

Furthermore, an assessment of the mobile laser scanning data will be performed once multiple data sets are available for comparison. It is expected that mobile laser scanning will be performed twice a year (spring and fall/winter), allowing for several comparisons during the annual survey analysis. For 2018, data comparison is not possible but the data set will be assessed for morphological features not captured with the survey transects. For reference, figures showing the DEM are presented in **Appendix B**.

Additionally, an assessment of the change in position of the base of the dune along Bogue Banks from 2017 to 2018 was performed. It should be noted that the 2017 dune base position is based on the previous method of using shore parallel survey lines collected by driving the survey ATV along the base of the dune. The 2018 dune base position was obtained from the detailed surface created using a combination of profile data and mobile laser scanner data. Therefore, this years comparison involves two different methods of data collection, possibly effecting the accuracy. It

is believed that future comparisons using surfaces enhanced by the mobile laser scanner data will be decidedly more accurate as the dune base extracted from the mobile laser scanning data appears to be more precise than what is possible to drive using an ATV. The difference in position calculated at each transect will be plotted to determine any trends in seaward growth or landward erosion of the dune along the oceanfront shoreline.

Finally, in accordance with the Master Beach Nourishment Plan, a preliminary assessment of current conditions of the beach compared to the new nourishment triggers was completed as part of this report.

5.0 Discussion of Annual Surveying Evaluation

This section discusses key events in the past year which influence the results of the annual analysis (i.e. nourishment projects, storms, etc.), development of updated background erosion rates to include the 2018 survey, annual shoreline and volume change trends (2017 – 2018), statistical analysis of long-term trends (2008 - 2018), and the current status of the beach as it relates to the Master Beach Nourishment Plan nourishment triggers.

5.1 Key Events During the Reporting Period

Beach changes are greatly influenced by natural and engineered processes. This section describes key events that occurred during the reporting period that likely had an impact on shoreline change as well as profile volume gains and losses.

5.1.1 Storm Events

Wave data from the NDBC Onslow Bay – Station 41159 was downloaded for March 2017 through May 2018 to cover the period of time between the 2017 and 2018 surveys. The wave data was then plotted in order to analyze storm activity which may have impacted the study area. **Figure 5-1** shows the location of the buoy while **Figure 5-2** presents a plot of the wave heights during the reporting period. The 2017 Atlantic hurricane season (June 2017 – November 2017) was relatively quiet with no named storms impacting the North Carolina coast. The winter storm season (December 2017 – May 2018) was more active. Multiple winter storms events in which wave heights approached 12 ft occurred on four occasions during the season. In addition, there were two events in April 2018 in which wave heights reached 14 ft and 18 ft.

Figure 5-1. Onslow Bay (Sta 41159) Buoy Location

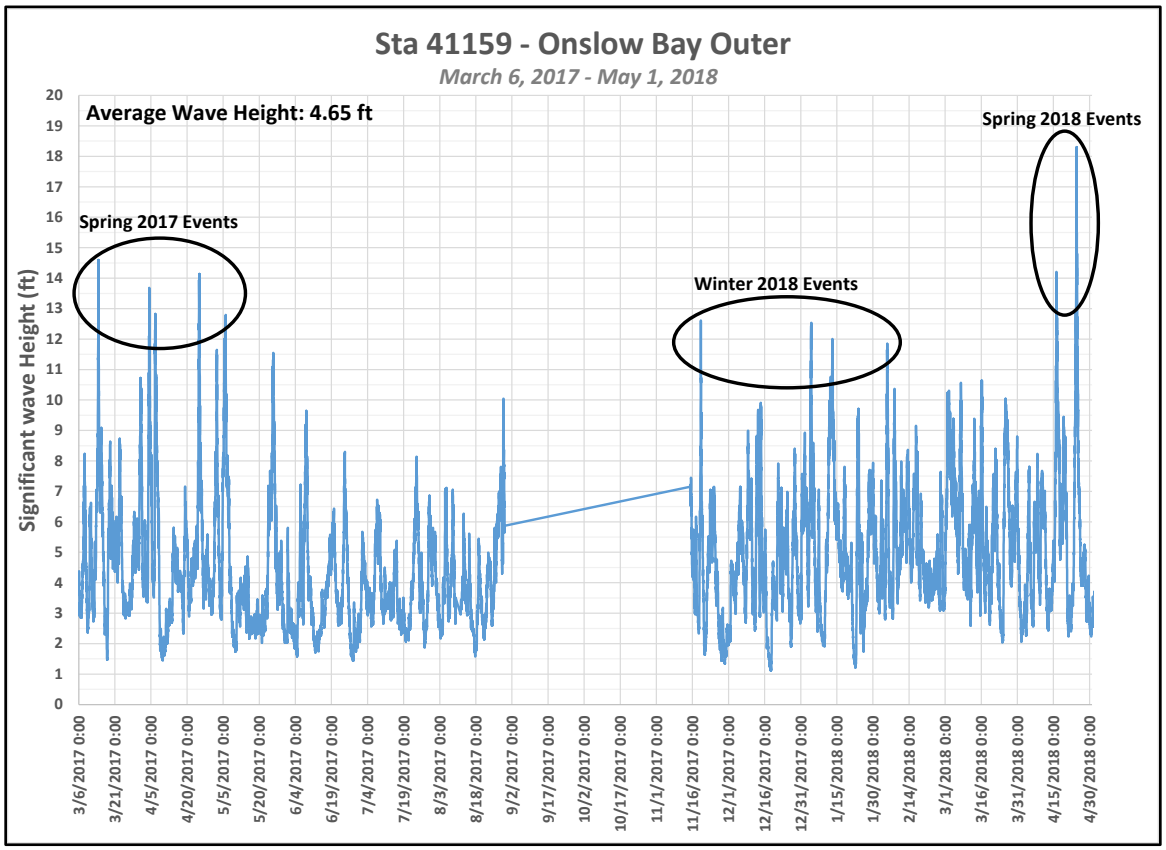


Figure 5-2. Onslow Bay Outer-Station 41159 Wave Height

5.1.2 Nourishment Events

There was no nourishment activity during the time period between the 2017 and 2018 surveys. As a reminder, as part of the Interim Operation Plan effort for the Morehead City Harbor DMMP, the USACE placed approximately 621,000 cy of material dredged from Morehead City Harbor on Atlantic Beach from Transects 91 through 100 during March 26 to May 17, 2017. **Figure 5-3** presents the approximate placement locations and quantities along two reaches of shoreline on either side of the Oceanana Pier. The 2017 survey data in this area was collected immediately post-nourishment. Therefore, the performance of the project during the first year after placement will be inherent in the shoreline and volume change numbers calculated for Atlantic Beach.

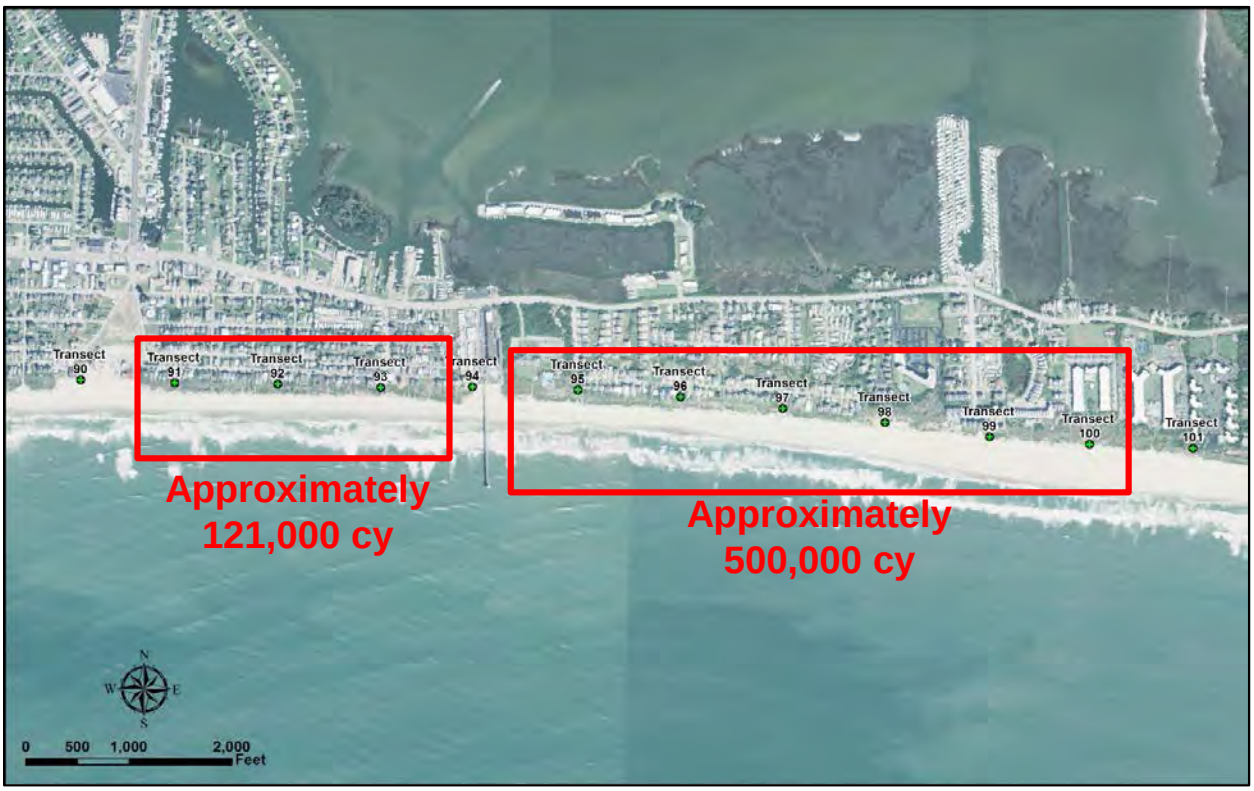


Figure 5-3. 2017 Atlantic Beach Nourishment Placement Locations

5.2 Determination of Background Erosion Rates for Bogue Banks (1999 – 2018)

Due to the numerous nourishment projects which have taken place along Bogue Banks since the monitoring program was initiated in 1999, it is important to determine a background erosion rate without nourishment from which to compare the performance of the various projects and to develop long-term trends in volume losses/gains. This report updates the background erosion rates previously calculated to include the newest spring 2018 survey. First, the beach nourishment volumes were documented for the period of time from the initial Bogue Banks Restoration Project in 2002 through 2018. The Bogue Banks area has undergone extensive beach nourishment throughout the duration of the monitoring effort as part of the County Project, the USACE Section 933 Project, USACE Dredge Disposal Projects, and post-storm FEMA work. **Table 5-1** and **Table 5-2** summarize the nourishment projects in the study area since initiation of the monitoring program.

Table 5-1. Nourishment Volumes by Project & Management Reach

Year	Project	Management Reach	Nourishment Volume (cy)
2002	County Phase 1	Pine Knoll Shores	1,276,586
2002	County Phase 1	Indian Beach/Salter Path	456,994
2002	USACE Disposal	Fort Macon	209,348
2003	County Phase 2	Emerald Isle - Central	1,016,946
2003	County Phase 2	Emerald Isle - East	850,780
2004	USACE Section 933	Indian Beach/Salter Path	582,735
2004	USACE Section 933	Pine Knoll Shores	116,547
2004	FEMA Post Isabel	Emerald Isle - Central	57,408
2004	FEMA Post Isabel	Emerald Isle - East	98,592
2005	Brandt Island Pump Out	Atlantic Beach	2,390,000
2005	USACE Disposal	Fort Macon	530,729
2005	County Phase 3	Bogue Inlet - Ocean	173,919
2005	County Phase 3	Emerald Isle - West	516,949
2007	USACE Section 933	Pine Knoll Shores	507,939
2007	FEMA Post Ophelia	Emerald Isle - West	304,037
2007	FEMA Post Ophelia	Emerald Isle - Central	114,942
2007	FEMA Post Ophelia	Emerald Isle - East	229,468
2007	FEMA Post Ophelia	Indian Beach/Salter Path	319,113
2007	FEMA Post Ophelia	Pine Knoll Shores	262,276
2007	USACE Disposal	Fort Macon	184,828
2008	AIWW Tangent B Disposal	Pine Knoll Shores East	148,393
2011	USACE Disposal	Atlantic Beach	799,504
2011	USACE Disposal	Fort Macon	547,196
2013	FEMA Post Irene	Emerald Isle - West	198,190
2013	FEMA Post Irene	Emerald Isle - Central	83,635
2013	FEMA Post Irene	Emerald Isle - East	367,965
2013	FEMA Post Irene	Pine Knoll Shores	315,221
2014	USACE Disposal	Atlantic Beach	522,518
2014	USACE Disposal	Fort Macon	585,067
2015	USACE Disposal	Fort Macon	150,000
2017	USACE Disposal	Atlantic Beach	621,000
TOTAL			***14,538,825***

Table 5-2. Total Nourishment Volumes by Management Reach

Management Reach (Transects)	Nourishment Volume (cy)
Bogue Inlet - Ocean (1-11)	173,919
Emerald Isle West (12-25)	1,019,176
Emerald Isle Central (26-36)	1,272,931
Emerald Isle East (37-48)	1,546,805
Indian Beach/Salter Path (49-58)	1,358,842
Pine Knoll Shores (59-76)	2,626,962
Atlantic Beach (77-102)	4,333,022
Fort Macon (103-112)	2,207,168
TOTAL	***14,538,825***

Second, historical volume changes above -12 ft NAVD88 (typical vertical extent of nourishment placement) were documented from 1999 through 2018. The volume changes were established by adding the annual volume changes calculated by M&N since 2008 to the volume changes from 1999-2007 calculated in the 2007 monitoring report (CSE 2007). **Table 5-3** shows the computed volume change (including nourishments) above -12 ft NAVD88 from 1999-2018 for the defined management reaches.

Table 5-3. Volume Change by Reach Above -12 ft NAVD88

Reach (Transects)	Volume Change (cy) (1999-2007)	Volume Change (cy) (2007-2008)	Volume Change (cy) (2008-2009)	Volume Change (cy) (2009-2010)	Volume Change (cy) (2010-2011)	Volume Change (cy) (2011-2012)	Volume Change (cy) (2012-2013)	Volume Change (cy) (2013-2014)	Volume Change (cy) (2014-2015)	Volume Change (cy) (2015-2016)	Volume Change (cy) (2016-2017)	Volume Change (cy) (2017-2018)	Volume Change (cy) (1999-2018)
Bogue Inlet-Ocean (Transects 1-11)	362,928	-300,153	210,104	-110,684	-2,766	-270,969	190,178	51,969	-28,850	11,368	-76,021	111,015	148,119
Emerald Isle-West (Transects 12-25)	970,000	-25,922	34,719	-79,827	4,583	-193,402	310,178	111,906	120,098	-62,725	25,276	184,840	1,399,724
Emerald Isle-Central (Transects 26-36)	940,707	136,125	38,910	-161,290	1,206	-139,918	238,243	-1,999	102,953	-45,006	-4,375	226,150	1,331,706
Emerald Isle-East (Transects 37-48)	786,998	-18,603	-134,995	-120,185	56,038	-153,682	446,124	26,034	15,048	-96,674	-8,897	142,338	939,545
Indian Beach/Salter Path (Transects 49-58)	1,155,522	-116,245	-118,761	-118,078	55,234	-163,958	-44,355	58,729	115,676	-42,345	82,239	113,963	977,621
Pine Knoll Shores (Transects 59-76)	1,753,427	-57,452	-53,514	-162,946	-81,597	-313,077	385,385	-66,012	81,633	-37,740	77,923	169,571	1,695,601
Atlantic Beach (Transects 77-102)	1,194,947	27,172	-106,720	-11,803	750,462	-530,856	59,686	573,232	-64,358	-241,055	754,976	-6,993	2,398,690
Fort Macon State Park (Transects 103-112)	221,169	-137,402	-151,048	-46,357	595,792	-167,964	-79,760	436,823	-361	189,340	-70,543	-46,689	743,001
Total	**7,385,698**	**-492,480**	**-281,305**	**-811,170**	**1,378,951**	**-1,933,825**	**1,505,678**	**1,190,683**	**341,840**	**-324,837**	**780,577**	**894,195**	**9,634,006**

To calculate the background erosion rate, the documented nourishment volumes were subtracted from total volume changes above -12 ft NAVD88 between 1999 and 2018 and annualized over the 19 year time period. **Table 5-4** shows the average annual background erosion rates for each management reach of the Bogue Banks oceanfront. The average background erosion rate for the entire Bogue Banks shoreline is approximately -2.0 cy/ft/yr. This result is slightly lower than the rate calculated for the 2017 monitoring report, indicating some accretion has occurred during the 2017 - 2018 monitoring period. It is important to note that Atlantic Beach, Fort Macon and Emerald Isle – East continue to have the highest erosion rates.

Table 5-4. Average Annual Background Erosion Rates (1999 - 2018)

Reach (Transects)	Length (ft)	Volume Change Above -12 ft NAVD88 (cy) (1999-2018)	Nourishment Volume (cy) (1999-2018)	Background Erosion (cy) (1999-2018)	Average Annual Background Erosion Rates (cy/ft/yr)
Bogue Inlet-Ocean (Transects 1-11)	11,488	148,119	173,919	-25,800	-0.12
Emerald Isle-West (Transects 12-25)	18,288	1,399,724	1,019,176	380,548	1.10
Emerald Isle-Central (Transects 26-36)	15,802	1,331,706	1,272,931	58,775	0.20
Emerald Isle-East (Transects 37-48)	13,220	939,545	1,546,805	-607,260	-2.42
Indian Beach/Salter Path (Transects 49-58)	12,850	977,621	1,358,842	-381,221	-1.56
Pine Knoll Shores (Transects 59-76)	23,878	1,695,601	2,626,962	-931,361	-2.05
Atlantic Beach (Transects 77-102)	26,176	2,398,690	4,333,022	-1,934,332	-3.89
Fort Macon State Park (Transects 103-112)	6,691	743,001	2,207,168	-1,464,167	-11.52
Total	**128,393**	**9,634,006**	**14,538,825**	**-4,904,819**	**-2.01**

5.3 Bogue Banks Shoreline and Volume Change Analysis (2017 – 2018)

This section discusses the results of the shoreline and volume change analysis for the defined management reaches along Bogue Banks (see **Figure 3-1**). Key statistics were calculated to quantify average shoreline and volume changes for individual management reaches as well as the entire oceanfront shoreline for Bogue Banks. The computed statistics include average shoreline change, average volume change, and cumulative volume change (e.g. total volume of material lost or gained along a section of shoreline). Evaluation of the computed statistics will take into account volume changes computed for portions of the profile above MHW (+1.5 ft NAVD88), above -5 ft NAVD 88, above -12 ft NAVD88, above -20 ft NAVD88, and above -30 ft NAVD88 in order to better understand onshore and offshore processes.

For reference, **Appendix C** contains plots of the shoreline and volume changes from the spring 2017 and the spring 2018 surveys at each transect along Bogue Banks. **Appendix D** presents profile comparison plots for individual transects for the spring 2017 and the spring 2018 surveys. Lastly, **Appendix E** provides the computed shoreline changes and volume changes measured at each individual transect in tabular format.

5.3.1 Bogue Inlet (2017-2018)

The Bogue Inlet region is comprised of an oceanfront area along the western terminus of Bogue Banks which covers Transects 1 through 11 (Bogue Inlet – Ocean) and an area along the eastern side of Bogue Inlet covering Transects 117 through 120 (Bogue Inlet – Channel) (see **Figure 3-1**). **Table 5-5** presents a summary of average shoreline and volume changes occurring between 2017 and 2018 for the Bogue Inlet region.

Table 5-5. Average Shoreline and Volume Change for Bogue Inlet (2017 - 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (Transects 1-11)	11,488	17.2	4.8	54,775	9.4	107,982	9.7	111,015	1.0	11,111	-2.9	-33,285
Bogue Inlet-Channel (Transects 117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

*Note: Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

As shown in **Table 5-5**, the Bogue Inlet-Ocean region shoreline experienced seaward advancement at MHW and volume gains above all elevations except -30 ft NAVD88. **Figure 5-4** displays the unit volume change at each transect for the Bogue Inlet-Ocean region. As can be seen, a majority of the accretion was confined to Transects 1 – 3, adjacent to Bogue Inlet. Profile plots in **Appendix D** show large gains in material from the berm to the offshore bar at these transects. The remainder of the transects were fairly stable and actually experienced some minor erosion, especially offshore at the lower elevations of the profile. Shorelines adjacent to an inlet are typically very active due to more complex hydrodynamics and often greater sediment transport rates, leading to more extreme profile changes from year to year.

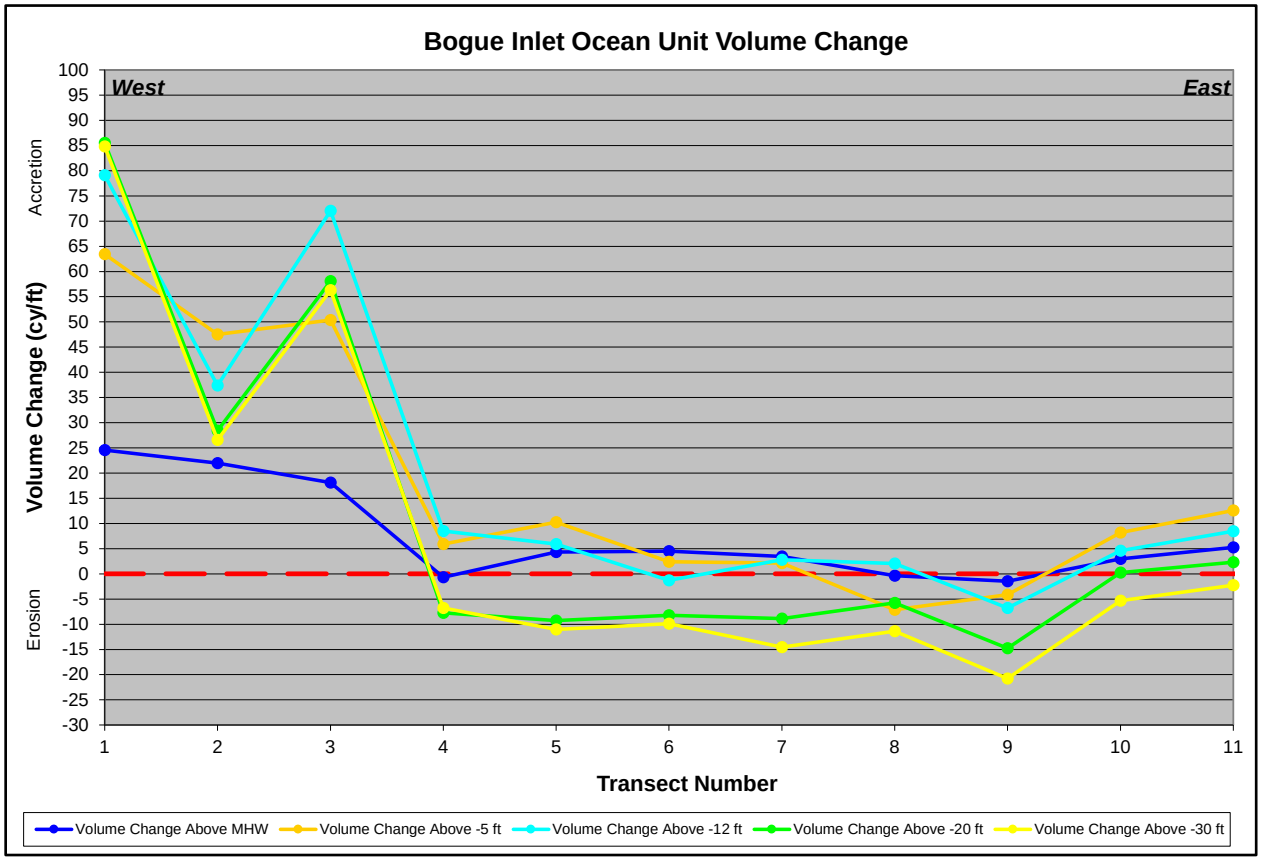


Figure 5-4. Bogue Inlet Ocean Unit Volume Change (2017 - 2018)

The Bogue Inlet-Channel region is highly dynamic due to the inlet. The location of dry land changes so frequently that profiles along Bogue Inlet often do not line up properly from year to year. Therefore, analytical calculations were not performed at Transect 117 through 120.

However, upon investigation of the profile plots in **Appendix D**, it appears that the accretion from the berm out to the offshore bar continues just around the corner into the throat of Bogue Inlet at Transects 117B and 117. Conversely, moving further into the inlet, Transects 118 and 119 experienced some erosion of the inlet channel bank. Transect 120, located closer to the middle of the inlet, experienced the least fluctuation in the channel bank position. In May 2018, the USACE conducted a condition survey to assess Bogue Inlet Channel. Based on this survey, it appears that approximately 315 ft exist between the edge of the current channel location and the boundary of the "safe box" which was determined as part of the Master Beach Nourishment Plan (see **Figure 5-5**). Based on recent trends, it would appear that the channel may reach the edge of the "safe box" in 5-8 years.

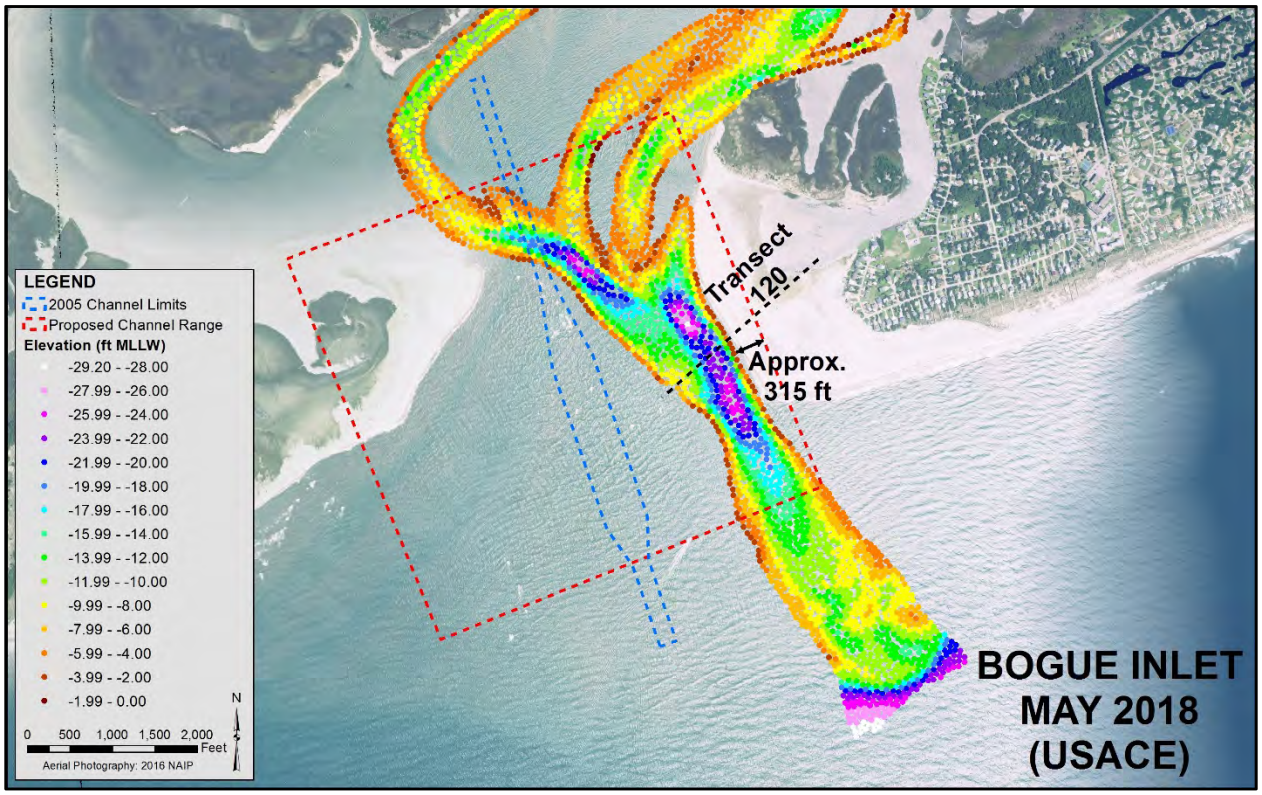


Figure 5-5. Bogue Inlet Channel Survey – May 2018 (USACE)

When compared with a similar survey taken in June 2017, the channel bank at MHW appears to have remained stable while the channel bank at lower elevations moved approximately 40 ft to the west and the channel centerline shallowed slightly. **Figure 5-6** shows an example profile (Transect 120) from Bogue Inlet which displays the stable channel bank at MHW and westward migration of the lower portion of the channel bank away from The Point between 2017 and 2018.

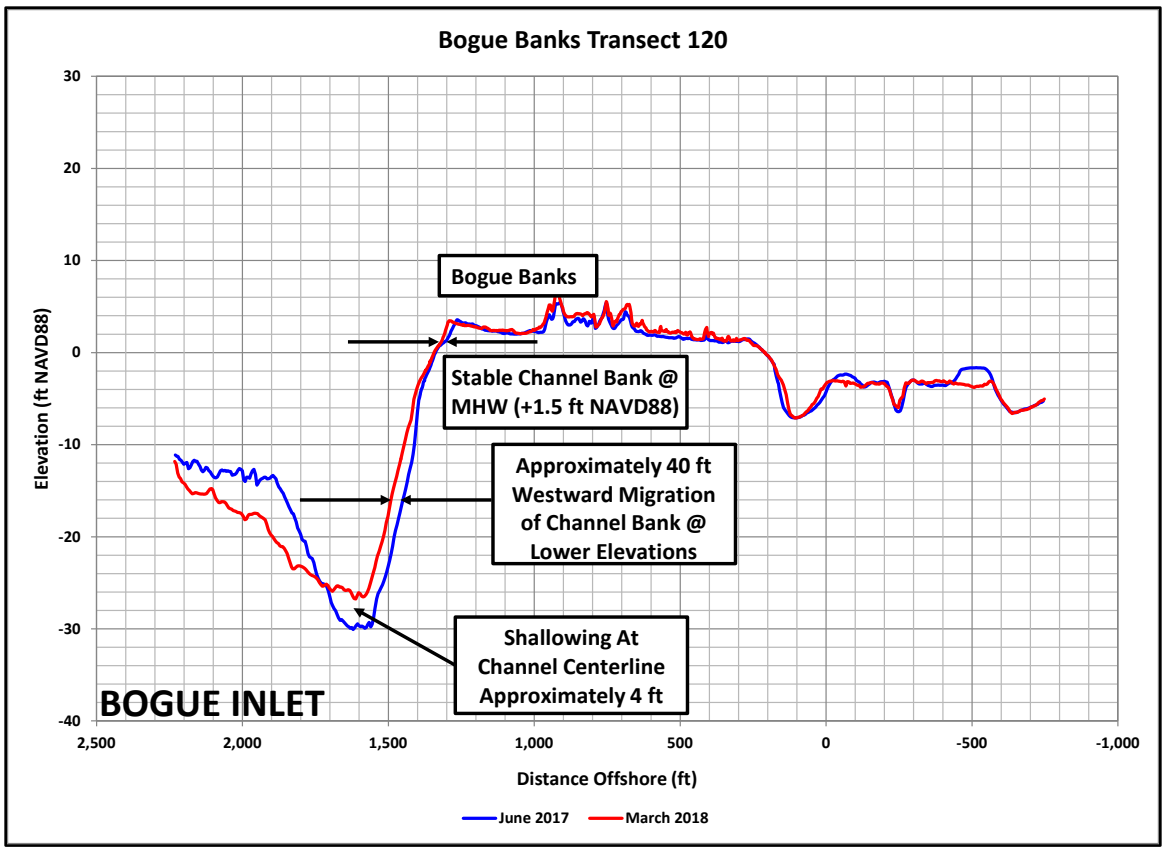


Figure 5-6. Example Bogue Inlet Transect

5.3.2 Emerald Isle (2017-2018)

The Emerald Isle region covers Transects 12 through 48 of the Bogue Banks shoreline and is divided into three management reaches (see **Figure 3-1**): 1) Emerald Isle – West (Transects 12-25), 2) Emerald Isle – Central (Transects 26-36), and 3) Emerald Isle – East (Transects 37-48). Since monitoring began in 1999, this area has received a total of 3.84 million cy of nourishment material as a result of the County Project and FEMA post-storm work (Isabel, Ophelia, and Irene). **Table 5-6** presents a summary of average shoreline and volume changes occurring between 2017 and 2018 for the Emerald Isle management reaches.

Table 5-6. Average Shoreline and Volume Change for Emerald Isle (2017 - 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Emerald Isle-West (Transects 12-25)	18,288	-1.7	1.5	28,131	3.2	58,041	10.1	184,840	5.4	99,547	-1.5	-26,579
Emerald Isle-Central (Transects 26-36)	15,802	-0.7	3.8	60,580	5.9	92,562	14.3	226,150	9.1	143,706	0.8	12,073
Emerald Isle-East (Transects 37-48)	13,220	-13.1	0.7	8,827	5.3	70,233	10.8	142,338	9.3	123,129	2.1	27,254
Emerald Ise - Total (Transects 12-48)	47,310	-4.6	2.1	97,538	4.7	220,837	11.7	553,327	7.7	366,382	0.3	12,748

Shoreline change at MHW showed landward recession in all reaches of Emerald Isle with an average of -4.6 ft across the reach. However, **Table 5-6** indicates that the most significant

landward recession occurred in Emerald Isle – East. The shoreline change plot in **Appendix C** indicates fluctuation of the shoreline between landward recession and seaward advancement across the Emerald Isle sub-reaches, with a majority of transects experiencing landward recession.

Volumetrically, **Table 5-6** indicates that Emerald Isle experienced overall volume gains above all elevations analyzed with gains of +97,538 cy (+2.1 cy/ft) above MHW, +220,837 cy (+4.7 cy/ft) above -5 ft NAVD88, and +553,327 cy (11.7 cy/ft) above -12 ft NAVD88. Volume gains then start to decrease above -20 ft NAVD88 and -30 ft NAVD88 with gains of +366,382 cy (+7.7 cy/ft) and +12,748 cy (0.3 cy/ft), respectively, indicating offshore losses that were limited to seaward of the offshore bar. **Figure 5-7** displays the unit volume change at each transect above the five elevations analyzed. As can be seen, a majority of transects experienced volume gains, especially along the upper portion of the profile. A majority of losses were contained to above -30 ft NAVD88. Transects 42 and 43, located within the historical Emerald Isle hotspot, experienced the largest losses.

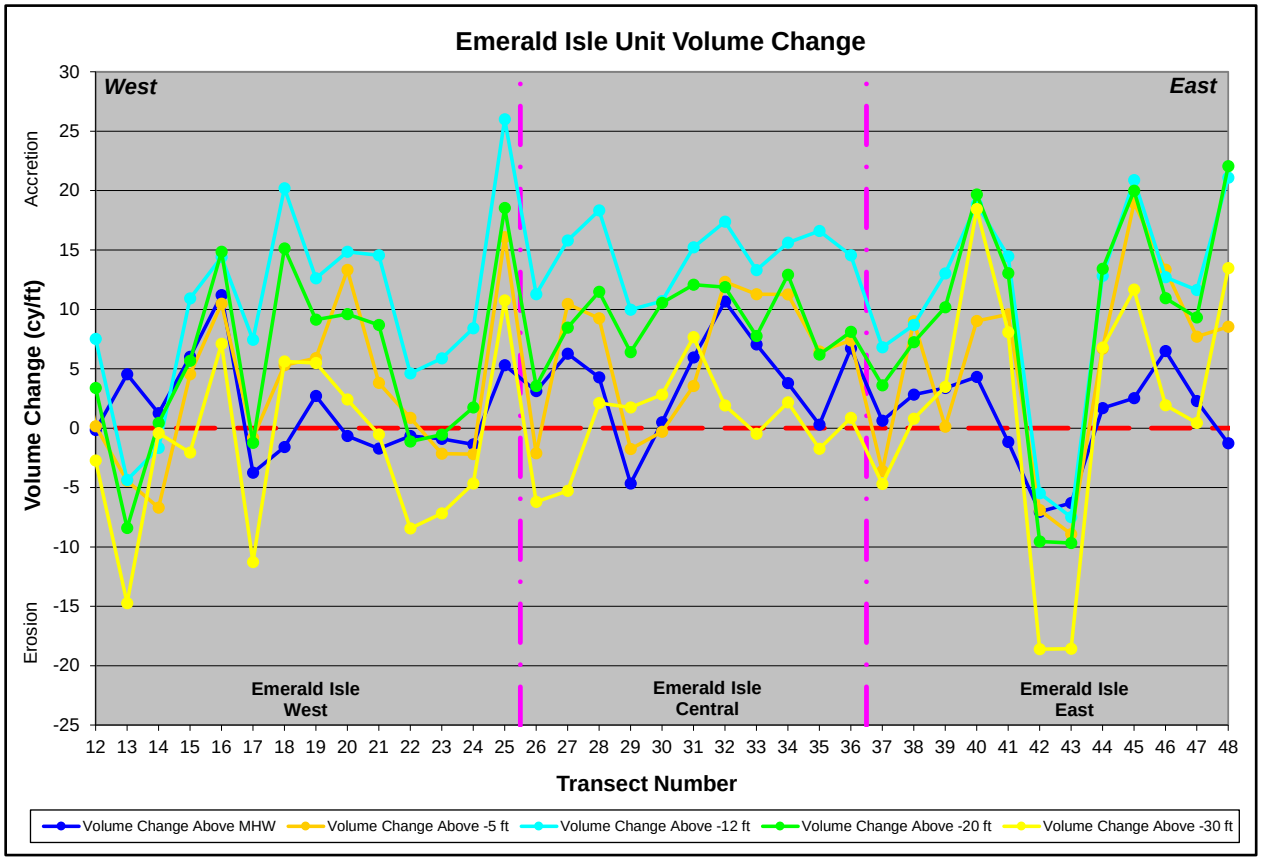


Figure 5-7. Emerald Isle Unit Volume Change (2017 - 2018)

Figure 5-8 presents an example profile from Emerald Isle. Apparent in this figure are the landward recession of the shoreline at MHW, the volume gains experienced in the upper portion of the profile, and a steady decrease in profile elevation offshore. Profile plots in **Appendix D** indicate that material at MHW has in many instances been pushed either onshore or offshore, remaining landward of the offshore bar. Thus, while Emerald Isle experienced shoreline recession, it did not correlate to a loss in volume but rather volume gains.

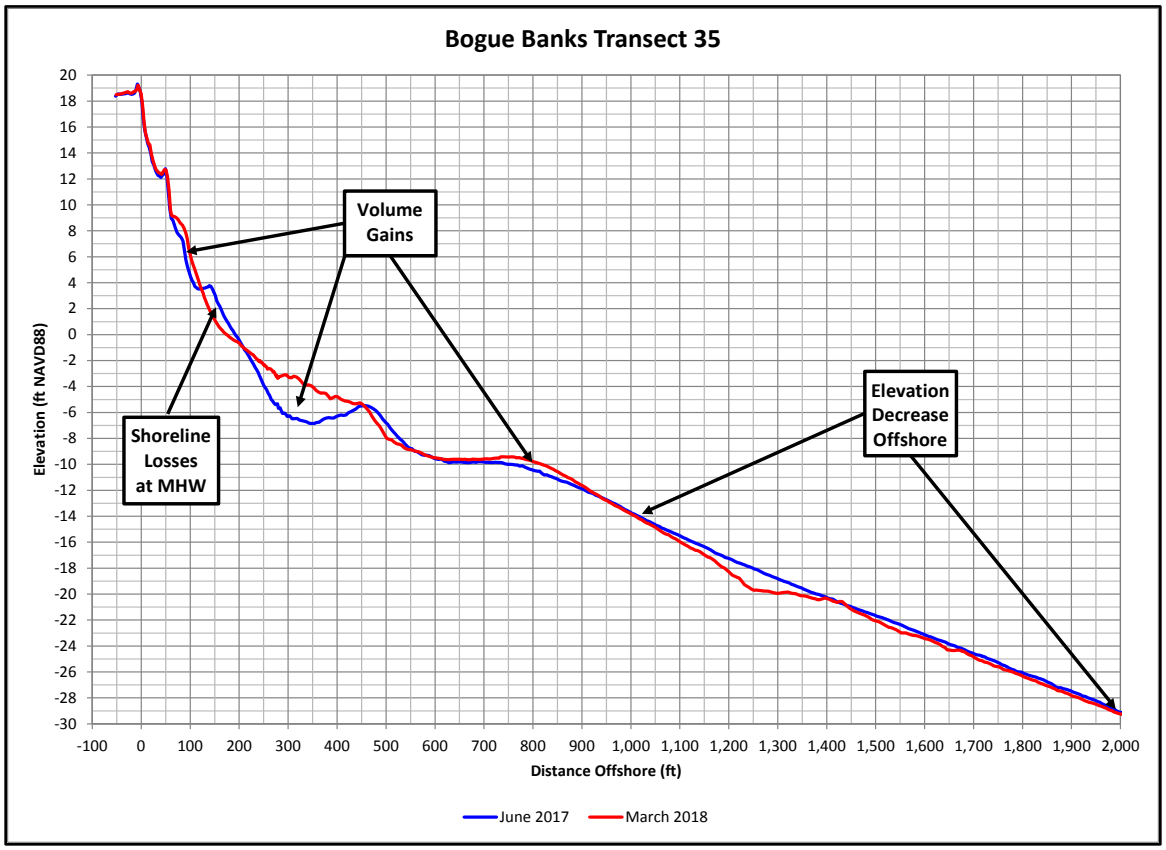


Figure 5-8. Example Profile – Emerald Isle

5.3.3 Indian Beach/Salter Path (2017-2018)

The Indian Beach/Salter Path region covers Transects 49 through 58 of the Bogue Banks shoreline and is defined as a single management reach (see **Figure 3-1**). Since monitoring efforts began in 1999, this area has received 1.36 million cy of nourishment material from the County Project, USACE Section 933, and FEMA post-storm work (Ophelia). **Table 5-7** presents a summary of average shoreline and volume changes occurring between 2017 and 2018 for the Indian Beach/Salter Path region.

Table 5-7. Average Shoreline and Volume Change for Indian Beach/Salter Path (2017 - 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Indian Beach-Salter Path (Transects 49-58)	12,850	-3.6	2.5	31,890	5.8	73,935	8.9	113,963	5.9	76,006	-3.8	-48,504

Shoreline change at MHW showed an overall average landward recession in Indian Beach/Salter Path of -3.6 ft. However, the shoreline change plot in **Appendix C** indicates that there was actually a fluctuation between landward recession and seaward advancement along the entire reach.

Table 5-7 indicates that Indian Beach/Salter Path experienced volume gains above all elevations analyzed except -30 ft NAVD88. Increasing volume gains of +31,890 cy (+2.5 cy/ft) above MHW,

+73,935 cy (+5.8 cy/ft) above -5 ft NAVD88, and +113,963 cy (+8.9 cy/ft) above -12 ft NAVD88 were experienced throughout the reach. Volume gains then start to decrease above -20 ft NAVD88 with gains of only +76,006 cy (+5.9 cy/ft) and turn into losses of -48,504 cy (-3.8 cy/ft) above -30 ft NAVD88, indicating offshore losses that were limited to seaward of the offshore bar. **Figure 5-9** displays the unit volume change at each transect for the Indian Beach/Salter Path region. As can be seen, volume gains are evident at every transect in Indian Beach/Salter Path with the exception of the offshore losses experienced above – 30 ft NAVD88.

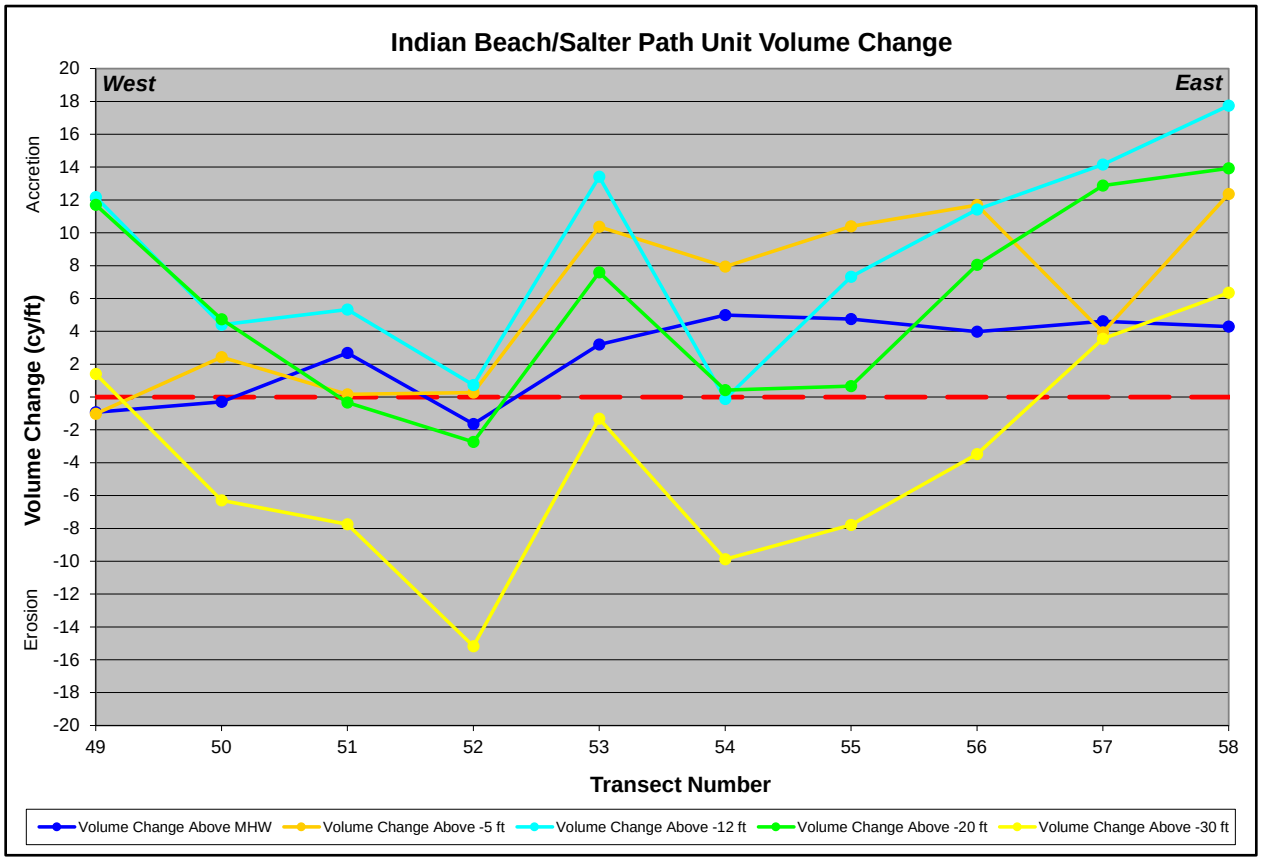


Figure 5-9. Indian Beach/Salter Path Unit Volume Change (2017 - 2018)

Figure 5-10 presents an example profile from Indian Beach/Salter Path. Apparent in this figure are the landward recession of the shoreline at MHW, the volume gains experienced in the upper portion of the profile, and a steady decrease in profile elevation offshore. Profile plots in **Appendix D** indicate that material at MHW has in many instances been pushed either onshore or offshore, remaining landward of the offshore bar. Thus, while Indian Beach/Salter Path experienced shoreline recession, this did not correlate to a loss in volume but rather volume gains.

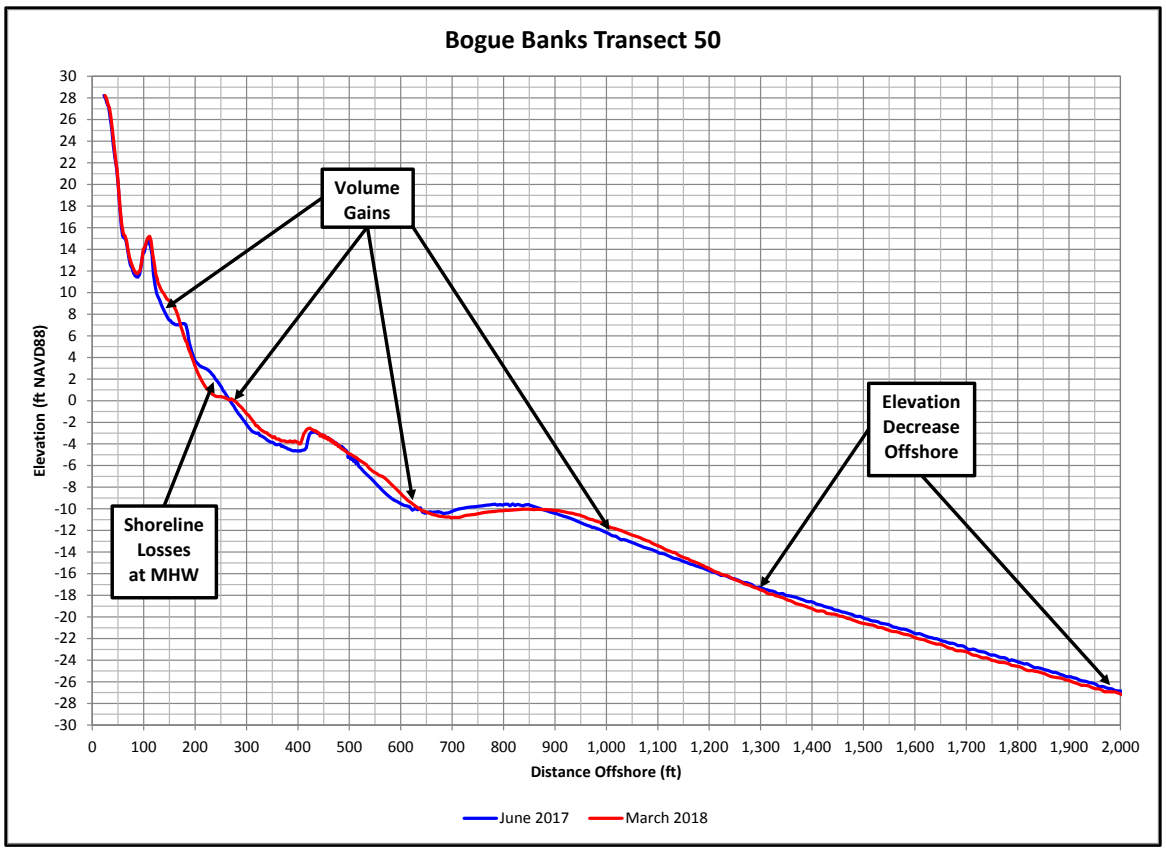


Figure 5-10. Example Profile – Indian Beach/Salter Path

5.3.4 Pine Knoll Shores (2017-2018)

The Pine Knoll Shores region covers Transects 59 through 76 of the Bogue Banks shoreline and is defined as a single management reach (see **Figure 3-1**). Since monitoring efforts began in 1999, the Pine Knoll Shores area has received 2.63 million cy of nourishment material as a result of the County Project, USACE Section 933, and FEMA post-storm work (Ophelia and Irene). **Table 5-8** presents a summary of average shoreline and volume changes occurring between 2017 and 2018 for the Pine Knoll Shores region.

Table 5-8. Average Shoreline and Volume Change for Pine Knoll Shores (2017 - 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Pine Knoll Shores (Transects 59-76)	23,878	-8.1	1.3	31,692	2.4	57,122	7.1	169,571	6.0	142,860	-5.7	-135,443

Shoreline change at MHW showed overall average landward recession of the shoreline at MHW in Pine Knoll Shores of -8.1 ft. The shoreline change plot in **Appendix C** indicates that while there were some transects that experienced seaward advancement of the shoreline at MHW, a majority experienced landward recession.

Table 5-8 indicates that, like Indian Beach/Salter Path, Pine Knoll Shores experienced volume gains above all elevations analyzed except -30 ft NAVD88. Increasing volume gains of +31,692

cy (+1.3 cy/ft) above MHW, +57,122 cy (+2.4 cy/ft) above -5 ft NAVD88, and +169,571 cy (+7.1 cy/ft) above -12 ft NAVD88 were experienced throughout the reach. Volume gains then start to decrease above -20 ft NAVD88 with gains of only +142,860 cy (+6.0 cy/ft) and turn into losses of -135,443 cy (-5.7 cy/ft) above -30 ft NAVD88, indicating offshore losses that were limited to seaward of the offshore bar. **Figure 5-11** displays the unit volume change at each transect for the Pine Knoll Shores region. As can be seen, volume gains are evident at a majority of transects in Pine Knoll Shores with the exception some losses experienced at Transects 60, 61, and 67, which are within the historical Pine Knoll Shores hotspot, as well as the offshore losses experienced above – 30 ft NAVD88. Volume gains along the western end of Pine Knoll Shores appear to be slightly higher than along the eastern end of Pine Knoll Shores.

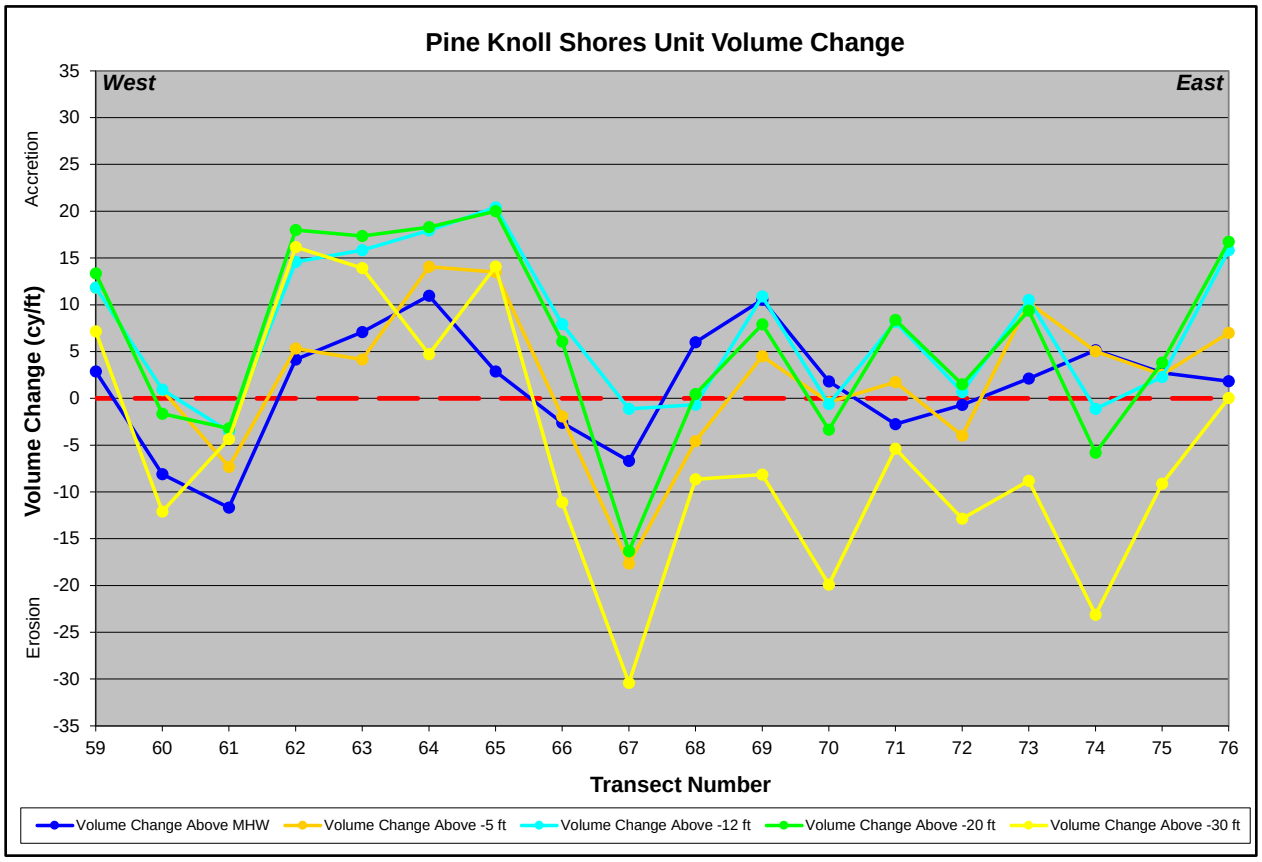


Figure 5-11. Pine Knoll Shores Unit Volume Change (2017 - 2018)

Figure 5-12 presents an example profile from Pine Knoll Shores. Apparent in this figure are the landward recession of the shoreline at MHW, the volume gains experienced in the upper portion of the profile, and a steady decrease in profile elevation offshore. Profile plots in **Appendix D** indicate that material at MHW has in many instances been pushed either onshore or offshore, remaining landward of the offshore bar. Thus, while Pine Knoll Shores experienced shoreline recession, this did not correlate to a loss in volume but rather volume gains.

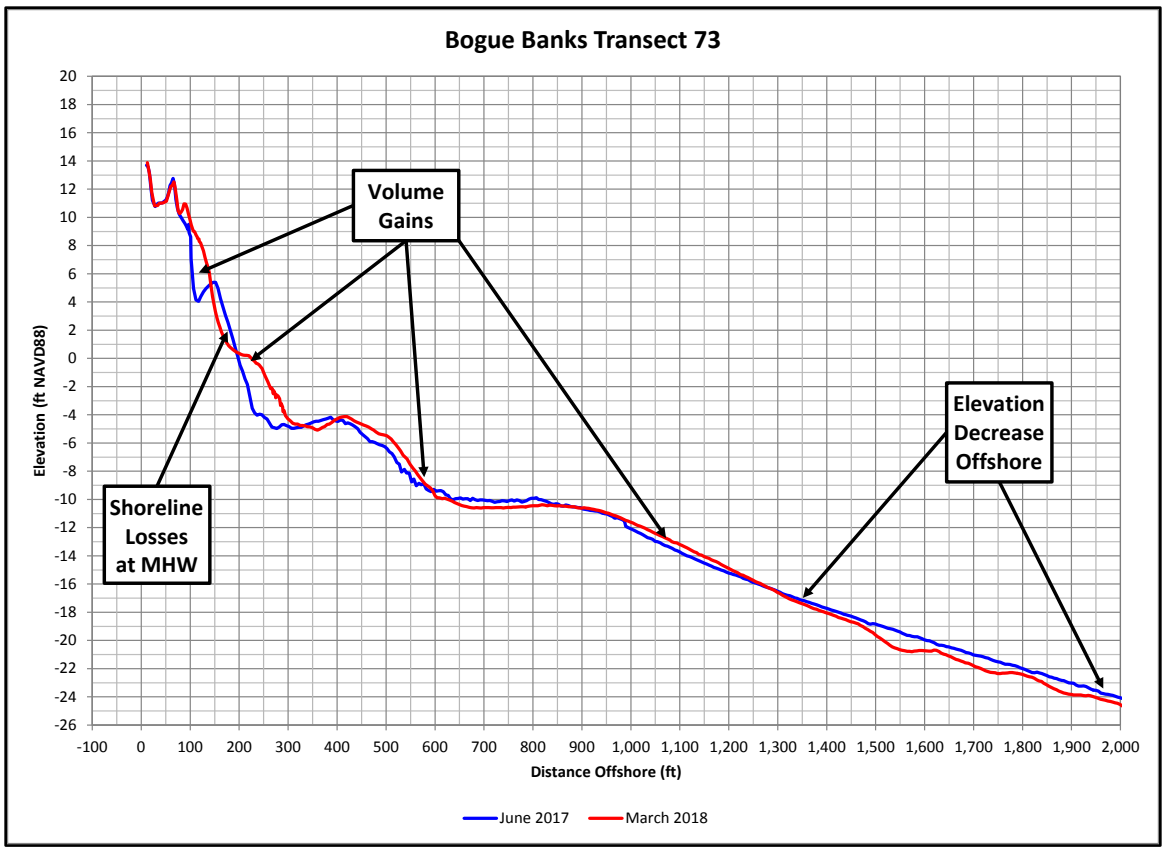


Figure 5-12. Example Profile – Pine Knoll Shores

5.3.5 Atlantic Beach (2017-2018)

The Atlantic Beach region covers Transects 77 through 102 of the Bogue Banks shoreline and is defined as a single management reach (see **Figure 3-1)**. Since monitoring began in 1999, the area has received 4.33 million cy of nourishment material from the Brandt Island Pump Out and USACE dredge disposal. Most recently, approximately 621,000 cy of material from Morehead City Harbor was placed from Transect 91 to Transect 100 as part of the USACE Interim Operation Plan in March – May 2017. **Table 5-9** presents a summary of average shoreline and volume changes occurring between 2017 and 2018 for the Atlantic Beach region. It should be noted that the 2017 monitoring survey was taken immediately post-nourishment. Therefore, the performance of the project in the first year post-nourishment is evident in the calculations.

Table 5-9. Average Shoreline and Volume Change for Atlantic Beach (2017 - 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Atlantic Beach (Transects 77-102)	26,176	-22.9	-0.1	-1,979	-2.8	-73,190	-0.3	-6,993	-0.7	-19,485	-11.7	-306,958

Atlantic Beach experienced significant overall landward recession of the shoreline at MHW on the order of -22.9 ft over the past year due to equilibration of the 2017 USACE project. Accelerated loses in the first year post-nourishment are typical as the construction template equilibrates to a more natural beach profile.

Volumetrically, Atlantic Beach experienced volume losses above all elevations analyzed which is expected in the first year post-nourishment. However, it should be noted that the losses experienced are slightly smaller than typical equilibration losses. Overall, Atlantic Beach only lost approximately -6,993 cy (-0.3 cy/ft) above -12 ft NAVD88. Taking into account only the transects that were nourished (Transects 91 – 100), losses above -12 ft NAVD88 totaled approximately -131,500 cy in those transects. This is approximately 21% of the material that was placed in that area. With a 3 year nourishment cycle at Atlantic Beach, losses during the first year would be expected to be more on the order of 30% - 40%. Therefore, the project performed very well in the first year post-nourishment. Profile plots in **Appendix D** indicate that the toe of the fill hit slightly more landward of the offshore bar than in some of the past projects, likely allowing more of the material to stay in place rather than be transported easily into the offshore. **Figure 5-13** displays the unit volume change for each transect in the Atlantic Beach region. As can be seen, while there were some large losses in the project area, the were some volume gains in the western portion of Atlantic Beach, possibly due to longshore transport of material form the project area. It should be noted that Transect 94 (Oceanana Pier) did not receive any nourishment, but material from the adjacent transects has likely been transported into this area as the beach equilibrated.

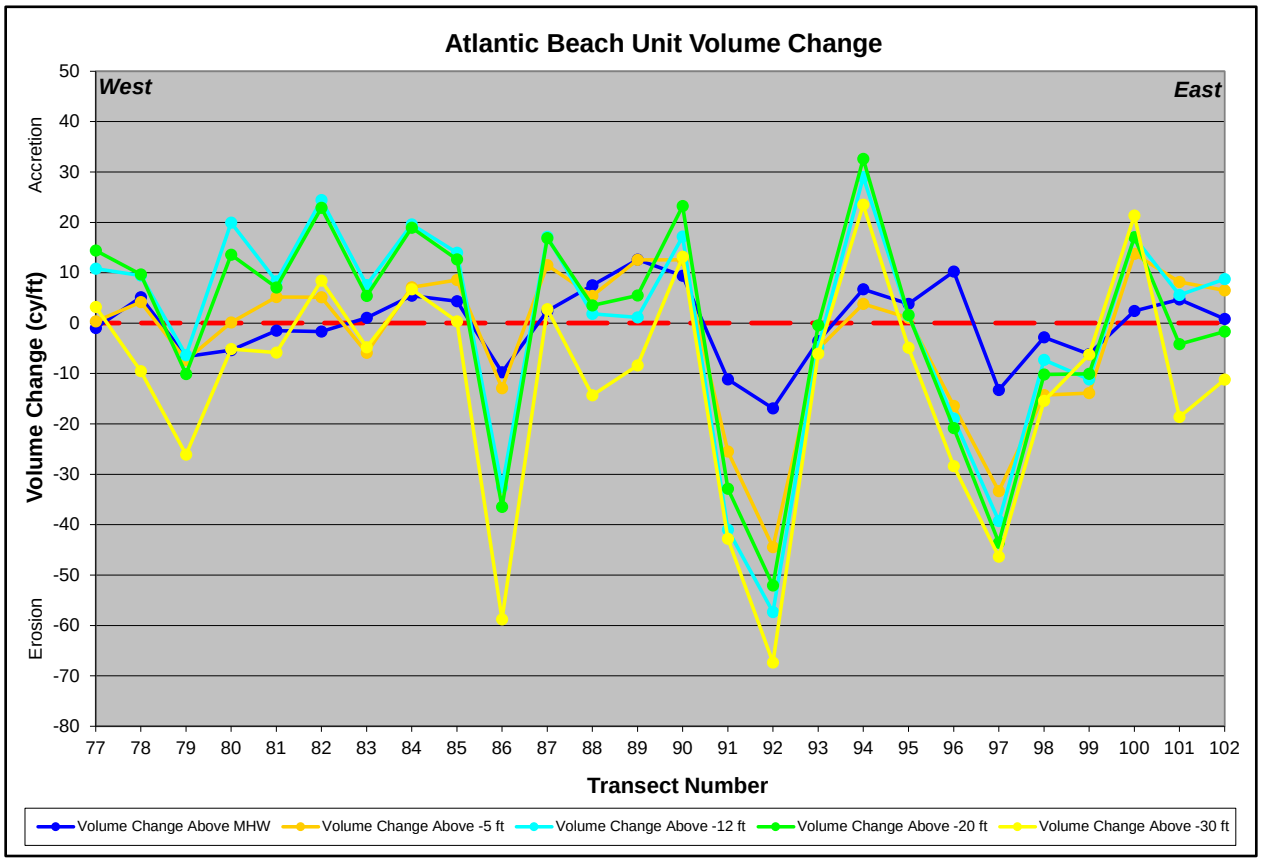


Figure 5-13. Atlantic Beach Unit Volume Change (2017 - 2018)

Figure 5-14 presents an example profile from the USACE nourishment project, showing the equilibration losses from the berm down to the offshore bar.

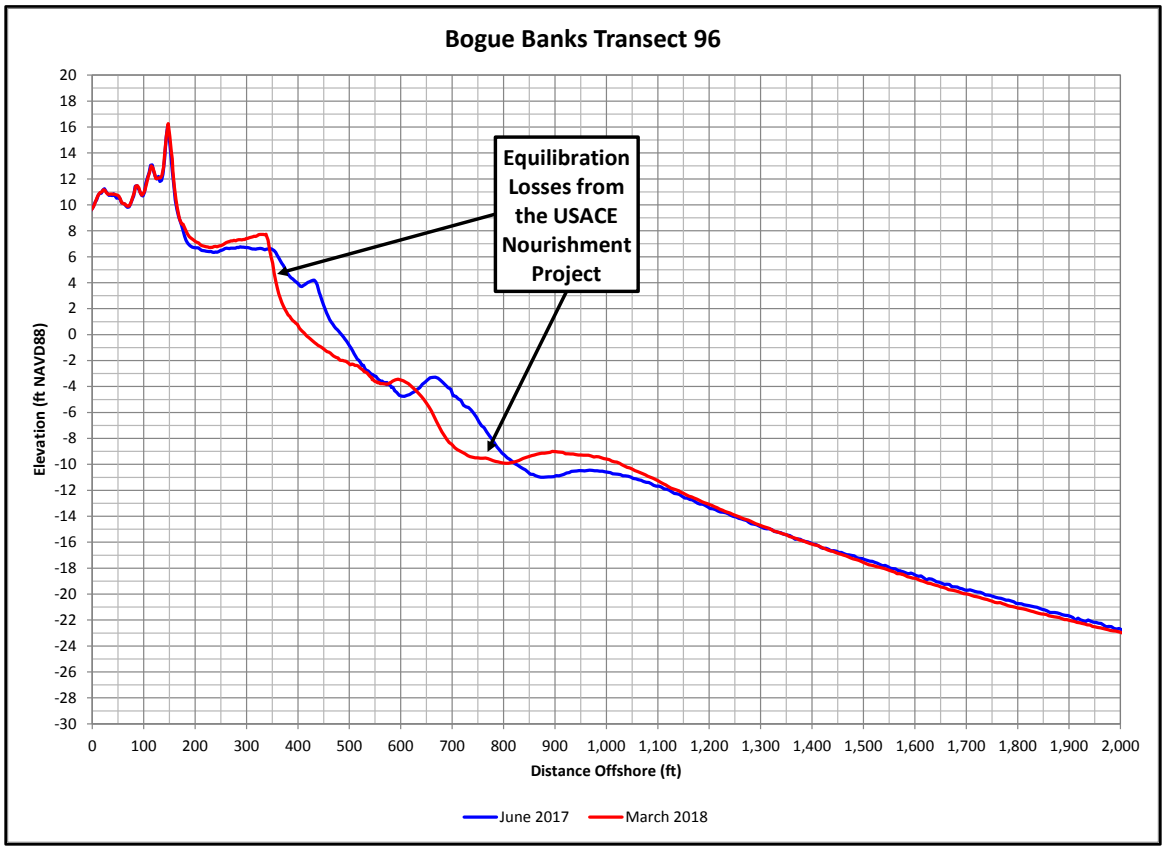


Figure 5-14. Atlantic Beach Example Profile

5.3.6 Fort Macon State Park (2017-2018)

The Fort Macon State Park region covers Transects 103 through 112 of the Bogue Banks shoreline and is defined as a single management reach (see **Figure 3-1**). Since monitoring began in 1999, this region has received 2.21 million cy of nourishment material from USACE Inner Harbor Dredging Disposal. **Table 5-10** presents a summary of average shoreline and volume changes occurring between 2017 and 2018 for the Fort Macon State Park region.

Table 5-10. Average Shoreline and Volume Change for Fort Macon State Park (2017 - 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Fort Macon State Park (Transects 103-112)	6,691	-4.0	4.0	26,602	0.7	4,697	-7.0	-46,689	-27.3	-182,394	-30.9	-206,691

Fort Macon experienced an overall landward recession of the shoreline at MHW over the past year of -4.0 ft. The shoreline change plot in **Appendix C** and profile plots in **Appendix D** indicate that the recession occurred primarily on the western portion of Fort Macon where erosion occurred from the berm down to the offshore bar. Meanwhile the eastern portion of Fort Macon actually experienced seaward advancement of the shoreline at MHW, likely due to the influence of the terminal groin.

Volumetrically, the reach experienced a gain volume above MHW and -5 ft NAVD88 but losses in volume above -12 ft NAVD88, -20 ft NAVD88, and -30 ft NAVD88. The total loss in material above -12 ft NAVD88 was approximately -46,689 cy (-7.0 cy/ft). **Figure 5-15** displays the unit volume change for each transect in the Fort Macon region. As can be seen losses in the western part of Fort Macon are more consistent while the volume changes in the eastern portion of the reach change drastically between transects. Volume gains in the upper portion of the profile at the transects closest to the terminal groin are evident.

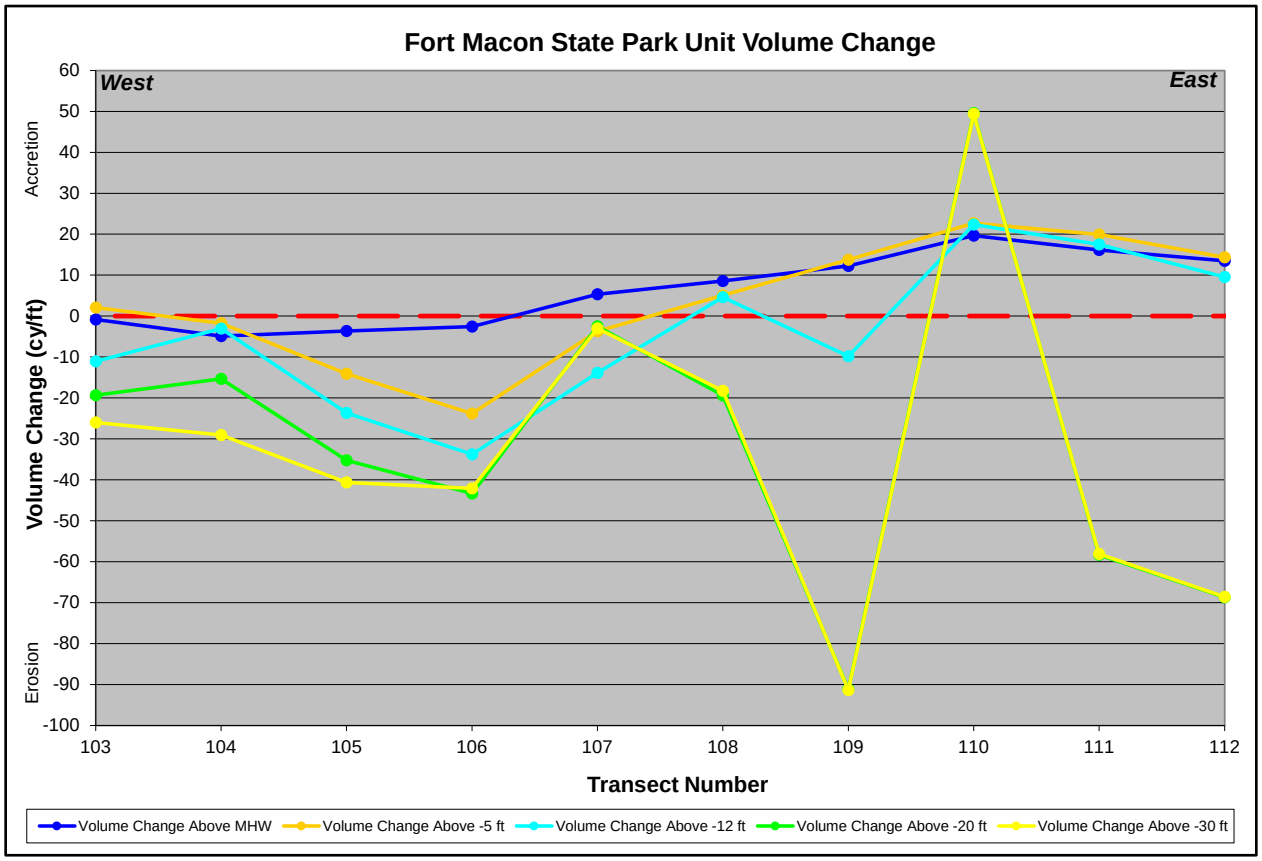
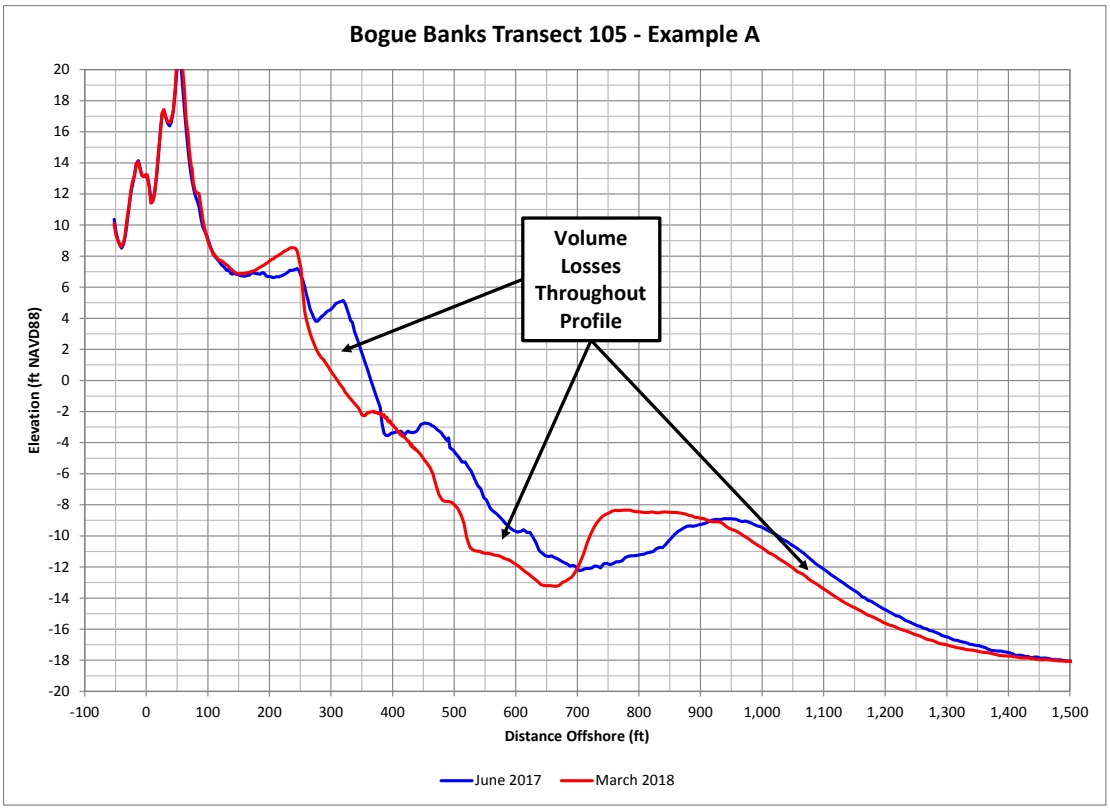


Figure 5-15. Fort Macon State Park Unit Volume Change (2017 - 2018)

Figure 5-16 presents example profiles from the western portion of the reach (Example A) which experienced consistent volumetric losses and the eastern portion of the reach (Example B) which experienced some overall volume gains.



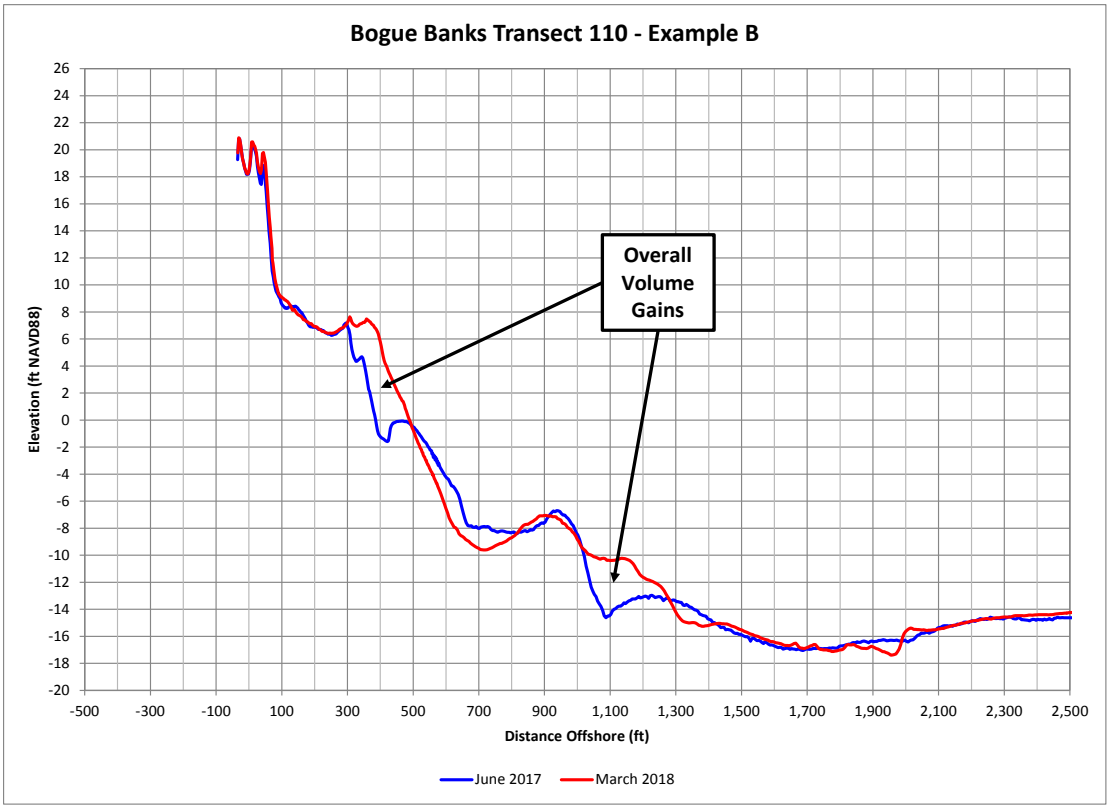


Figure 5-16. Fort Macon Example Profiles

5.3.7 Beaufort Inlet (2017-2018)

The Beaufort Inlet region is comprised of an area along the western side of Beaufort Inlet which covers Transects 112B through 116. **Table 5-11** presents a summary of average shoreline and volume changes occurring between 2017 and 2018 for the Beaufort Inlet region.

Table 5-11. Average Shoreline and Volume Change for Beaufort Inlet (2017 - 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Beaufort Inlet (Transects 112B-116)	2,000	41.7	5.8	11,511	10.0	20,091	14.0	28,041	8.3	16,583	6.4	12,857

Table 5-11 shows a significant seaward advancement of the shoreline at MHW in the Beaufort Inlet region. However, upon inspection of the profile plots in **Appendix D**, it appears that there was a large amount of seaward advancement at Transect 114 while the other transect were significantly more stable at MHW.

Volume changes at Beaufort Inlet show gains in material above all elevations. **Figure 5-17** displays the unit volume change at each transect in the Beaufort Inlet region. As can be seen, the interior portion of the inlet actually experienced some volume losses while the seaward portions of the inlet experienced volume gains.

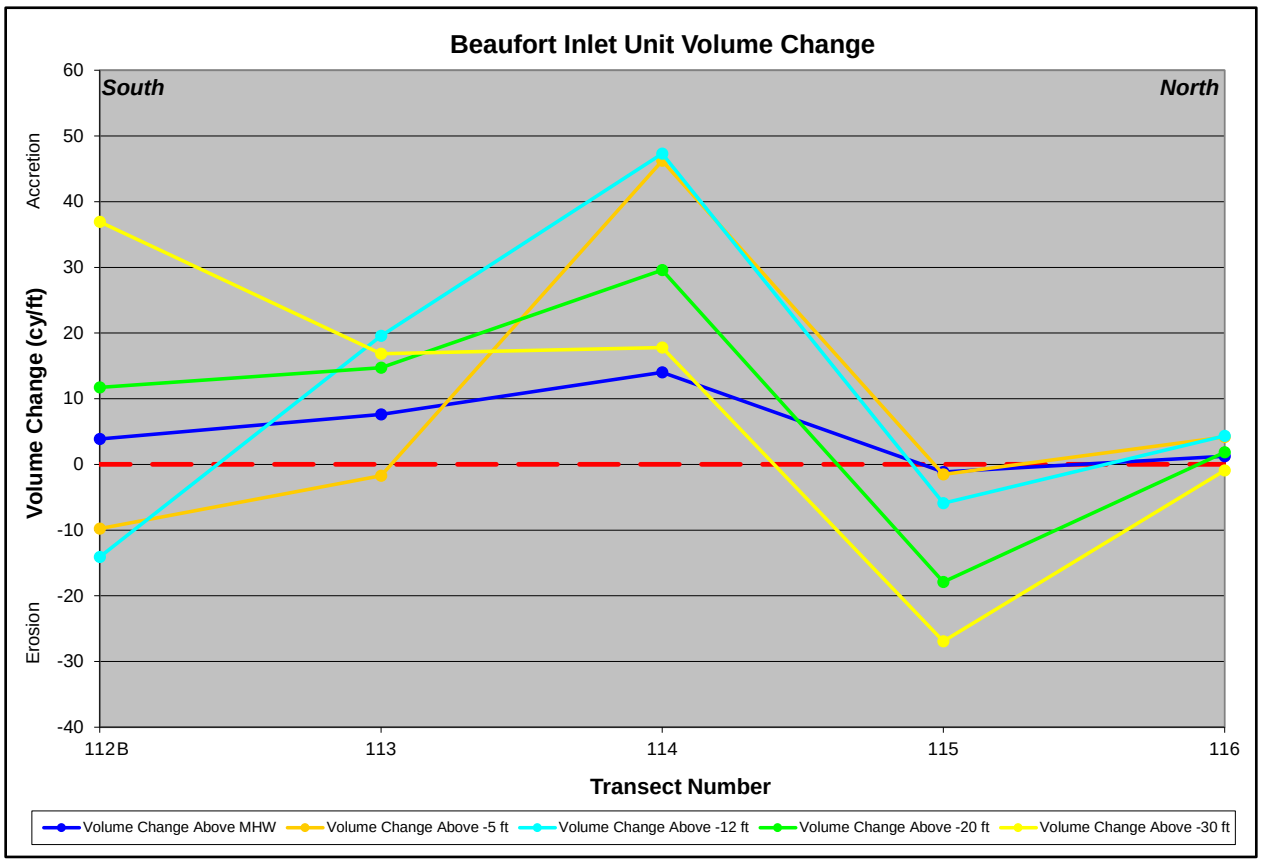


Figure 5-17. Beaufort Inlet Unit Volume Change (2017 - 2018)

In June 2018, the USACE performed a condition survey of the Morehead City Harbor navigation channel. **Figure 5-18** presents the results of the survey. Apparent from this figure is the submerged "toe" of Shackleford Banks along the eastern side of the channel. For the 2017 USACE project, the eastern side of the channel and channel bank were dredged in this area. The channel has naturally started to shoal back in as can be seen in the profile plot of Transect 112B (see **Figure 5-19**, Example A). The channel alignment inside the inlet appears to have been fairly stable over the last year as shown in Transect 114 (see **Figure 5-19**, Example B).

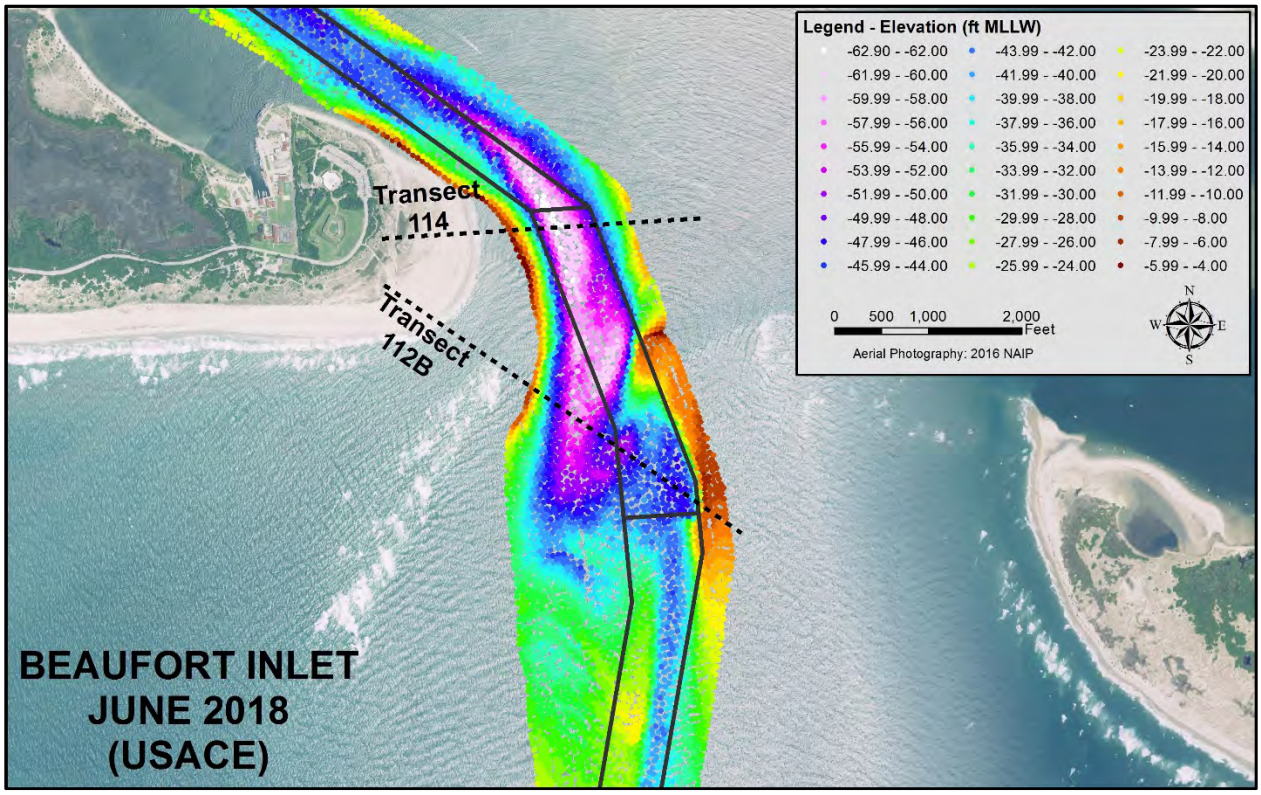
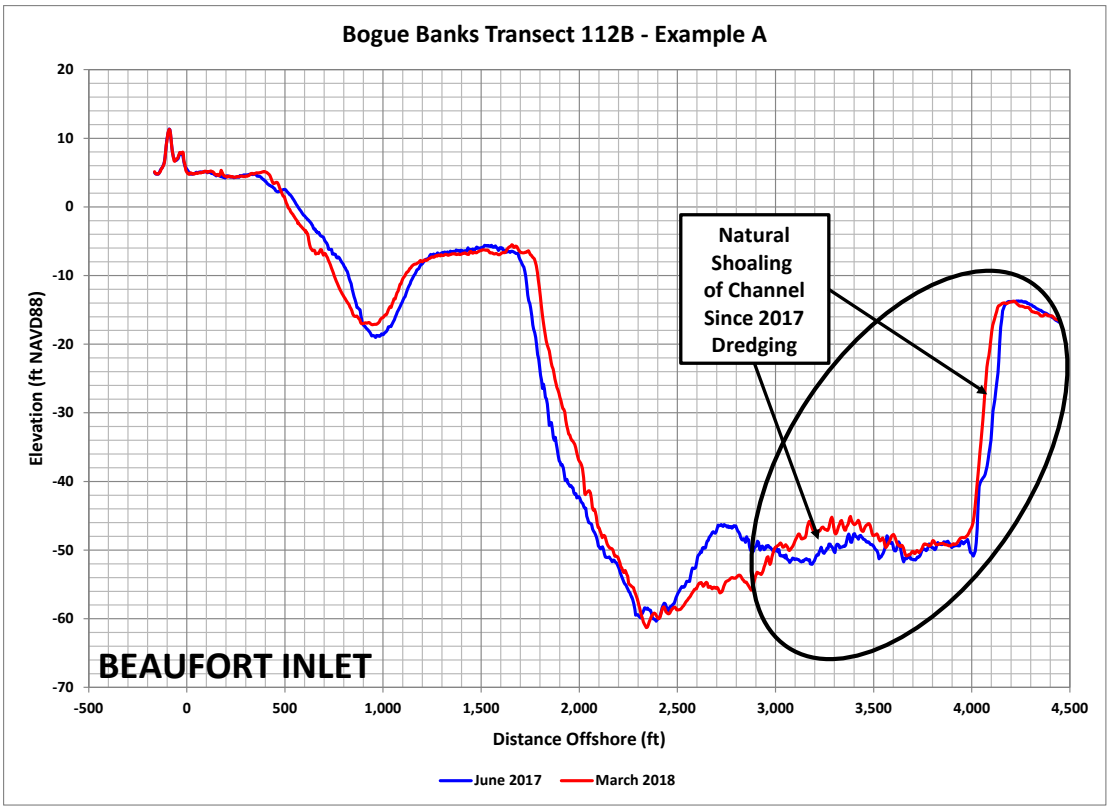


Figure 5-18. USACE Morehead City Harbor Navigation Channel Survey – June 2018 (USACE)



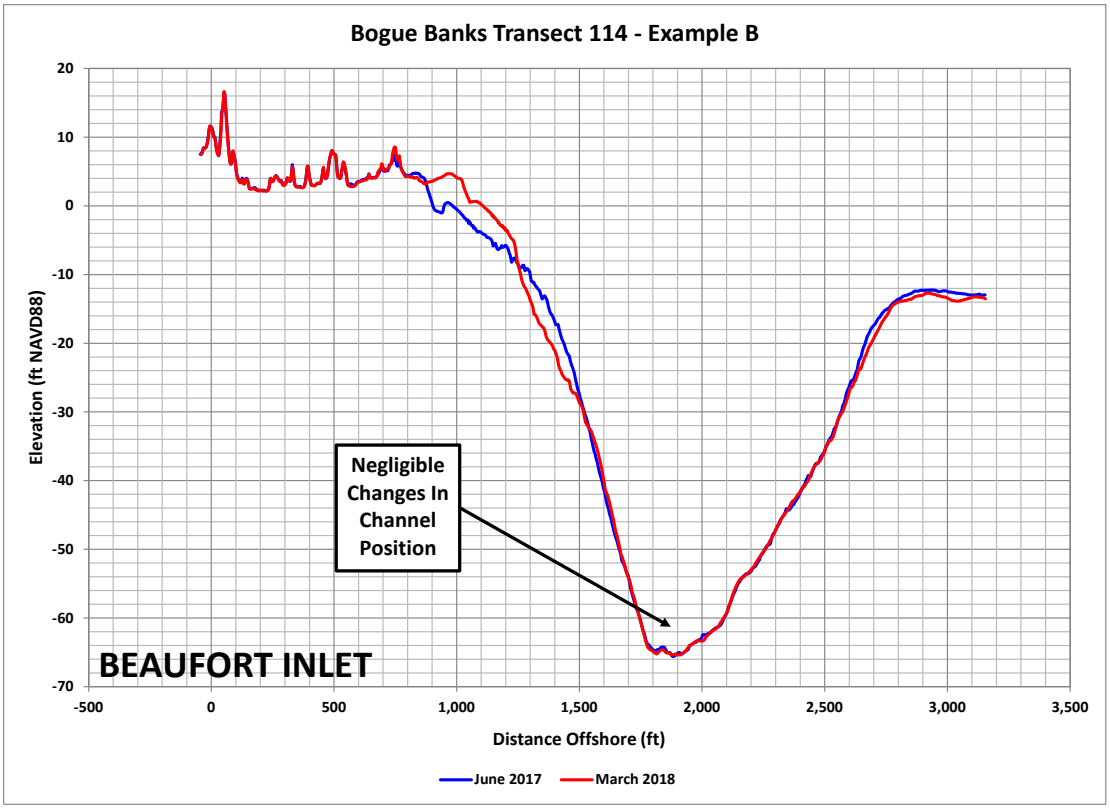


Figure 5-19. Example Beaufort Inlet Transects

5.3.8 Bogue Banks Summary (2017-2018)

Table 5-12 provides a summary of the shoreline and volume changes along Bogue Banks as presented in the previous sections along with average and total oceanfront values. For Bogue Banks, since each reach consists of a different length of shoreline, the calculations provide a weighted average for unit shoreline change (ft) and unit volume change (cy/ft) along the Bogue Banks oceanfront. The weighted average also accounts for differences in the shoreline length between each transect.

Table 5-12. Bogue Banks Shoreline and Volume Change Statistics (2017 – 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (Transects 1-11)	11,488	17.2	4.8	54,775	9.4	107,982	9.7	111,015	1.0	11,111	-2.9	-33,285
Emerald Isle-West (Transects 12-25)	18,288	-1.7	1.5	28,131	3.2	58,041	10.1	184,840	5.4	99,547	-1.5	-26,579
Emerald Isle-Central (Transects 26-36)	15,802	-0.7	3.8	60,580	5.9	92,562	14.3	226,150	9.1	143,706	0.8	12,073
Emerald Isle-East (Transects 37-48)	13,220	-13.1	0.7	8,827	5.3	70,233	10.8	142,338	9.3	123,129	2.1	27,254
Indian Beach-Salter Path (Transects 49-58)	12,850	-3.6	2.5	31,890	5.8	73,935	8.9	113,963	5.9	76,006	-3.8	-48,504
Pine Knoll Shores (Transects 59-76)	23,878	-8.1	1.3	31,692	2.4	57,122	7.1	169,571	6.0	142,860	-5.7	-135,443
Atlantic Beach (Transects 77-102)	26,176	-22.9	-0.1	-1,979	-2.8	-73,190	-0.3	-6,993	-0.7	-19,485	-11.7	-306,958
Fort Macon State Park (Transects 103-112)	6,691	-4.0	4.0	26,602	0.7	4,697	-7.0	-46,689	-27.3	-182,394	-30.9	-206,691
Beaufort Inlet (Transects 112B-116)	2,000	41.7	5.8	11,511	10.0	20,091	14.0	28,041	8.3	16,583	6.4	12,857
Bogue Inlet-Channel (Transects 117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Reach Length	Weighted Avg	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total
FEMA Engineered Beach (Transects 1-76)	**95,527**	**-2.7**	**2.3**	**215,895**	**4.8**	**459,876**	**9.9**	**947,877**	**6.2**	**596,360**	**-2.1**	**-204,484**
Oceanfront (Transects 1-112)	**128,393**	**-6.9**	**1.9**	**240,517**	**3.0**	**391,383**	**7.0**	**894,195**	**3.1**	**394,481**	**-5.6**	**-718,133**

Table 5-12 indicates that the Bogue Banks oceanfront shoreline experienced an overall average landward recession at MHW of -6.9 ft over the past year. However, this is somewhat influenced by equilibration of the Atlantic Beach nourishment project. The remainder of the beach west of the nourishment project (FEMA engineered beach) experienced an overall landward recession of the shoreline at MHW of only -2.7 ft over the past year. The shoreline change plot in **Appendix C** indicates that shoreline change actually fluctuated between landward recession and seaward advancement throughout Bogue Banks, with slightly more transects experiencing landward recession. Profile plots in **Appendix D** indicate that in many instances where shoreline recession occurred, the material was either pushed onshore or just slightly offshore, remaining landward of the offshore bar.

Volumetrically, the Bogue Banks oceanfront experienced an overall volume gain above all elevations analyzed except above -30 ft NAVD88. Oceanfront volume gains increased moving down the profile from above MHW (+240,517 cy), to above -5 ft NAVD88 (+391,383 cy), to above -12 ft NAVD88 (+894,195 cy). This indicates a gain in material along each section of the profile out to the offshore bar. Volumes gains then decreased above -20 ft NAVDD88 (+394,481 cy) and turned into volume losses at -30 ft NADV88 (-718,133 cy). This indicates offshore losses that were limited to seaward of the offshore bar. Profile plots indicate several locations where there was a distinct decrease in elevation along the offshore portion of the profile. The same

volume change pattern was experienced for just the FEMA engineered beach portion of Bogue Banks with increasing volume gains above MHW (+215,895 cy), -5 ft NAVD88 (+459,876 cy), and -12 ft NADV88 (+947,877 cy). Smaller gains were experienced above -20 ft NAVD88 (+596,360 cy) and losses experienced above -30 ft NAVD88 (-204,484 cy). The quiescent weather over the past year likely aided in beach recovery from storms which occurred during spring 2017 that caused some noticeable erosion of the beach. The only reach to experience losses at all elevations analyzed was Atlantic Beach. This was expected due to equilibration of the 2017 USACE project during the first year post-construction. However, losses from the project were considerably less than what often occurs immediately post-nourishment with only 131,500 cy of material being lost above -12 ft NAVD88 from Transects 91 to 100 out of 621,000 cy placed (approximately 21% loss).

Figure 5-20 and **Figure 5-21** display the trends seen in **Table 5-12** with bar plots of the average unit volume changes and cumulative volume changes at each management reach for Bogue Banks. Apparent from these figures are the volume gains along a majority of Bogue Banks. Several of the reaches that experienced volume gains did have losses above -30 ft NAVD88. In addition, volume losses in Atlantic Beach and Fort Macon are evident.

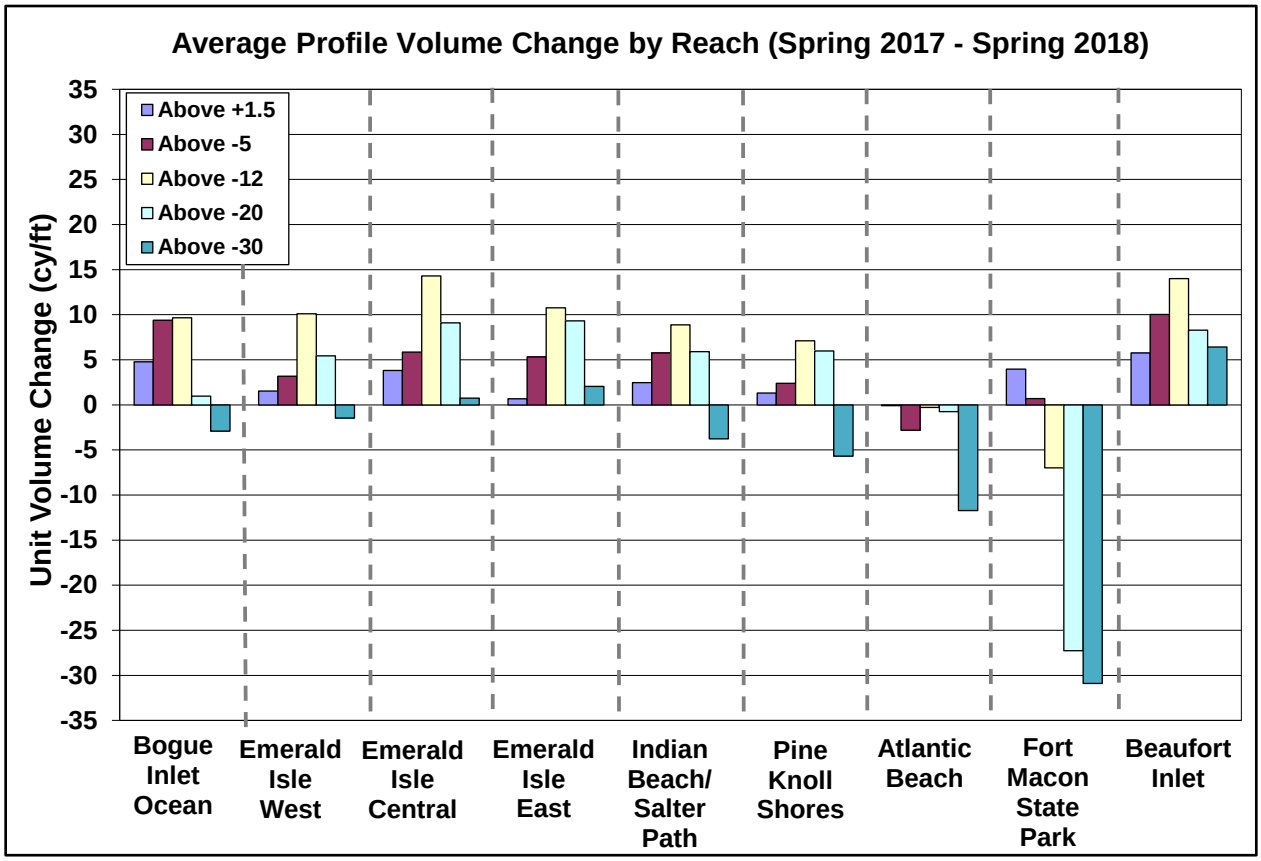


Figure 5-20. Average Unit Volume Change By Reach (2017 – 2018)

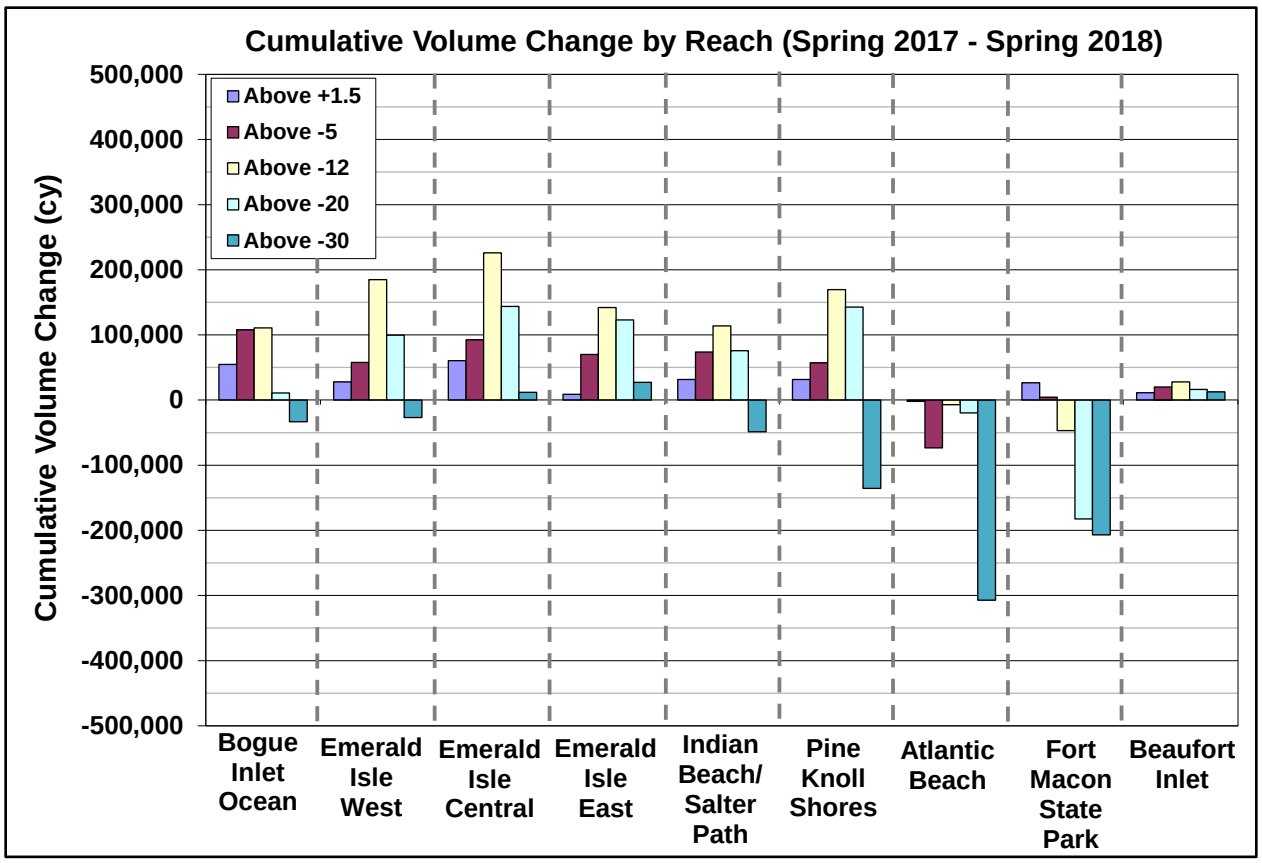


Figure 5-21. Cumulative Volume Change By Reach (2017 – 2018)

5.3.9 Dune Base Analysis (2017 – 2018)

In recent years, it has been noted that sand fencing and vegetation have managed to capture wind blown sand and cause some growth at the base of the dune, pushing it seaward in many locations. In an attempt to track the position of the base of the dune, a shore parallel survey line was collected by driving an ATV along the base of the dune in 2017. It has been noted that this method was highly subject to surveyor interpretation and has limits to the accuracy due to the size of the ATV and objects on the beach which prevented it from being able to drive along the exact base of the dune. In 2018, Geodynamics introduced new mobile laser scanning data which provides a high density dataset along the dry beach. From this dataset, a surface was created and the base of the dune extracted from a DEM which more clearly indicates the break in slope from the dune to the berm. The difference in position of the base of the dune at each transect from 2017 to 2018 was calculated and plotted to determine any trends in movement along the oceanfront shoreline. **Figure 5-22** presents the results of this analysis, indicating overall erosion at the base of the dune. However, since this years comparison was based on two different methods of establishing the position of the base of the dune, it is likely that the results are inaccurate. Given the results of the volume change analysis showed accretion above MHW in most cases, it is more likely that the base of the dune actually experienced some seaward advancement. The new method using the mobile laser scanning data appears to be more precise and will likely give more accurate results in future comparisons.

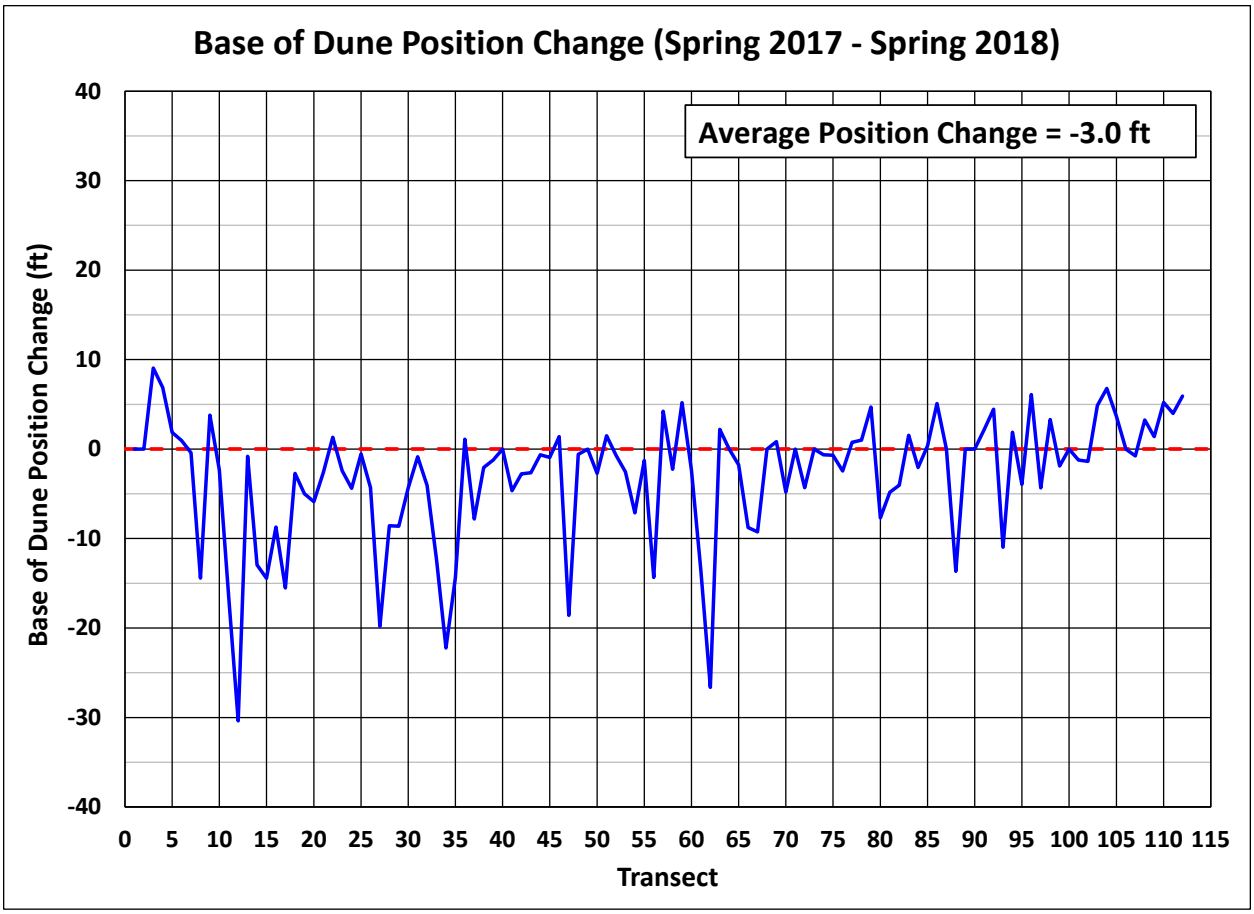


Figure 5-22. Base of Dune Position Change

5.3.10 Mobile Laser Scanner Analysis (2018)

As mentioned previously, in addition to beach profiles Geodynamics used a mobile laser scanner to collect additional topographic data in hotspot areas ranging from Transect 27 in Emerald Isle Central to Transect 82 in Atlantic Beach. It is hoped that this will increase knowledge of the dynamics present in the hotspot areas in Emerald Isle and Pine Knoll Shores. **Figure 5-23** presents the extents of the mobile laser scanner data collection.

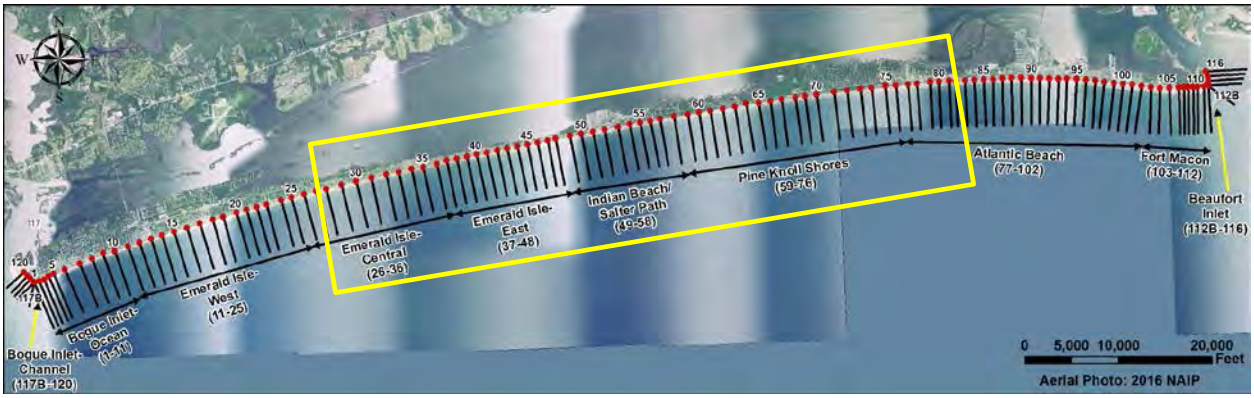


Figure 5-23. Mobile Laser Scanner Extents

The mobile laser scanner delivers high density elevation data from the seaward face of the dune (approximately +14 ft NAVD88) to the waterline (approximately 0 ft NAVD88), providing insight as to the morphology of the dry beach in between transects. From this data, extremely accurate DEM surfaces can be created, seamlessly covering the laser scanning extents. **Figure 5-24** presents an example 3-dimensional view of the surface created from the laser scanning data.

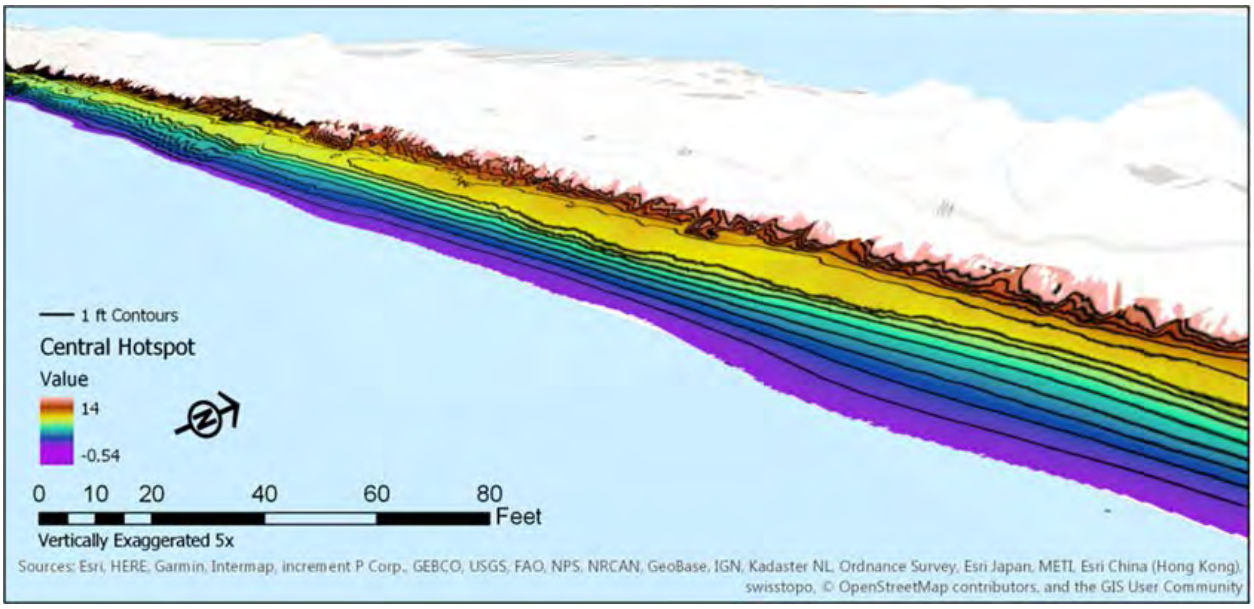


Figure 5-24. Example 3-Dimensional Laser Scanner Surface (Geodynamics, 2018)

Since this was the first year using this new technology, there is no comparison to be made to previous years. It is expected that the mobile laser scanning data will be collected twice a year, once during the spring survey and again in the fall/winter. It will also be collected in cases where a storm impacts the area and the post-storm survey and analysis is authorized. Therefore, starting with the 2019 monitoring report, surfaces from spring and fall/winter mobile laser scanning events will be compared to highlight areas of erosion and accretion. Although comparisons were not possible for this report, the DEM surfaces created from the 2018 mobile laser scanning data were examined in GIS to ascertain areas containing morphological details between transects that are not visible in the individual profiles. **Figure 5-25** presents examples of places where topographic elements on the beach are different in between transects. As can be seen, in Emerald Isle – Central, there appears to be a location between Transects 35 and 36 where the beach narrows significantly. In addition, at Indian Beach/Salter Path, the area between Transects 52 and 53 has a much different beach profile than at either of the transects. Figures showing the full extents of the DEM are presented in **Appendix B**.

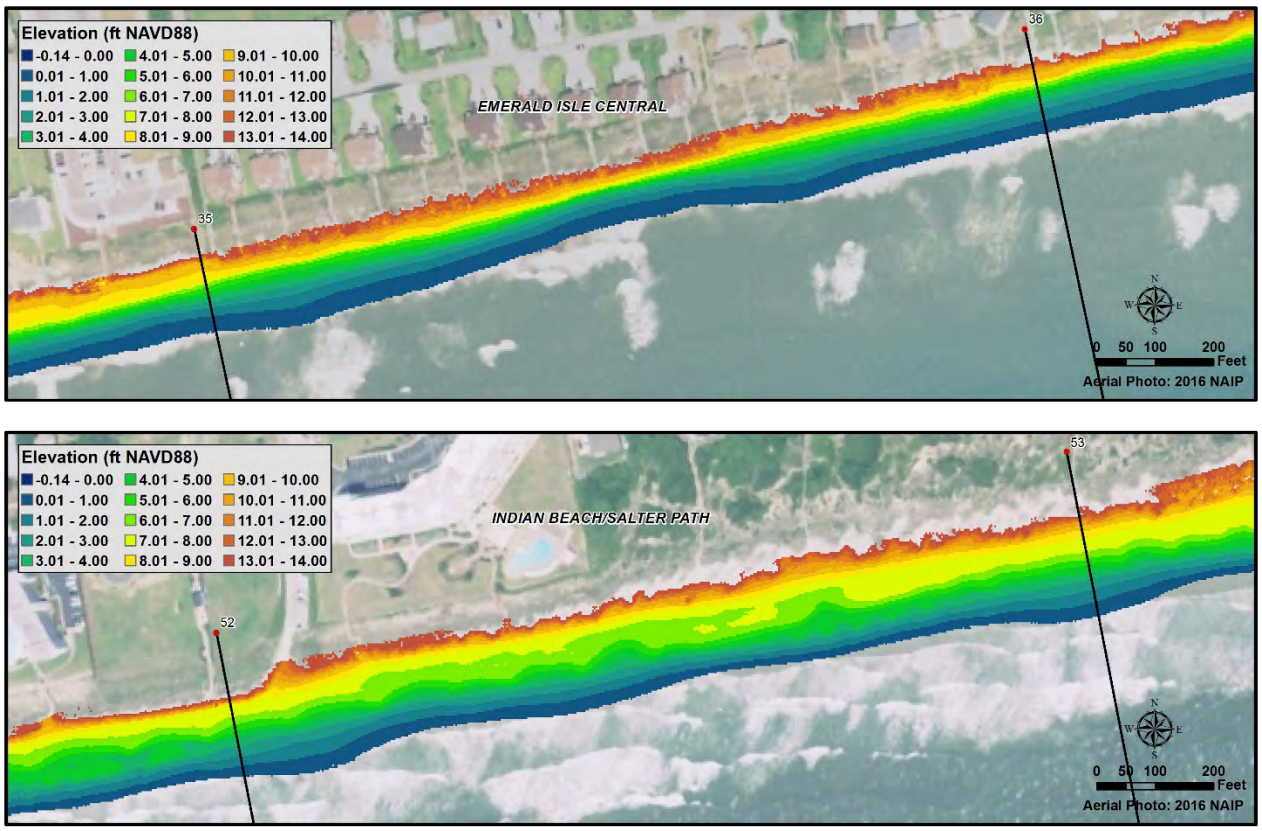


Figure 5-25. Mobile Laser Scanner Examples

5.4 Bear Island Shoreline and Volume Change Analysis (2017 – 2018)

This section discusses the results of the shoreline and volume change analysis for Bear Island. Key statistics were calculated to quantify average shoreline and volume changes including average shoreline change, average volume change, and cumulative volume change (e.g. total volume of material lost or gained along a section of shoreline). Evaluation of the computed statistics will take into account volume changes computed for portions of the profile above MHW (+1.7 ft NAVD88), above -5 ft NAVD 88, above -12 ft NAVD88, above -20 ft NAVD88, and above -30 ft NAVD88 in order to better understand onshore and offshore processes.

For reference, **Appendix C** contains plots of the shoreline and volume changes from the spring 2017 and spring 2018 surveys at each transect along Bear Island. **Appendix D** presents profile comparison plots for individual transects for the spring 2017 and spring 2018 surveys. **Appendix E** provides the computed shoreline changes and volume changes measured at each individual transect in tabular format.

Bear Island contains 18 transects spaced 1000 ft apart. **Table 5-13** presents a summary of average shoreline and volume changes occurring between 2017 and 2018 for the Bear Island region.

Table 5-13. Average Shoreline and Volume Change for Bear Island (2017 - 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.7 ft NAVD88	Average Volume Change Above +1.7 ft NAVD88	Cumulative Volume Change Above +1.7 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bear Island (Transects 1-18)	16,500	-23.6	-2.5	-40,795	-8.5	-140,969	-13.0	-214,546	-17.7	-292,108	-26.7	-441,223

Bear Island experienced a significant amount of landward recession of the shoreline at MHW over the past year, as shown in **Table 5-13**. The shoreline change plot in **Appendix C** indicates erosion of the shoreline at every transect. Volumetric calculations also indicate overall volume losses above all elevations analyzed with losses above -12 ft NAVD88 totaling -214,546 cy (-13.0 cy/ft). **Figure 5-26** displays the unit volume change at each transect on Bear Island. As can be seen, the entire island experienced erosion with the western end of the island experiencing the largest losses. It should be noted that there were two significant storm events in April 2018 with offshore wave heights reaching 14 ft (April 16) and 18 ft (April 24). Bear Island was surveyed on May 1, 2018 so the significant erosion experienced over the past year is likely, in part, due to the effects of the April 2018 storms.

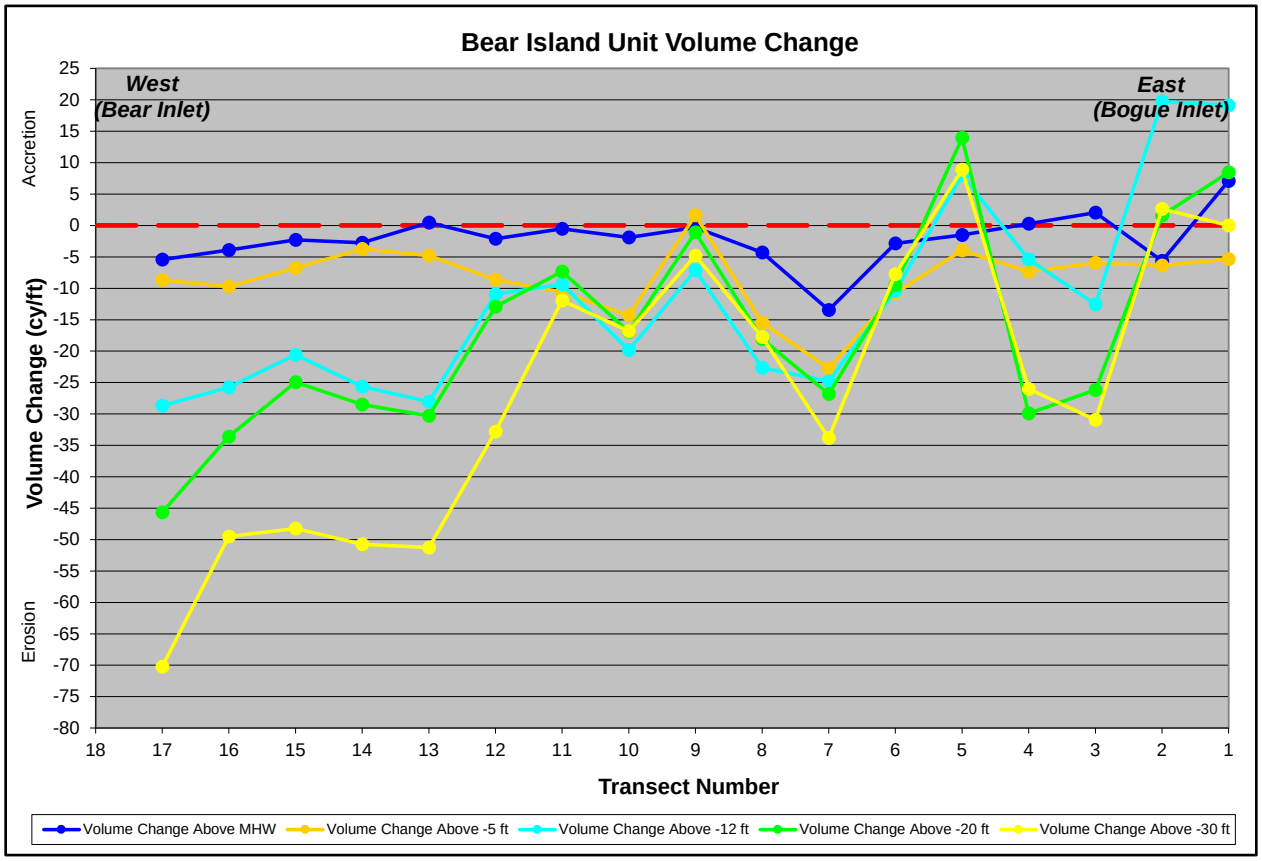
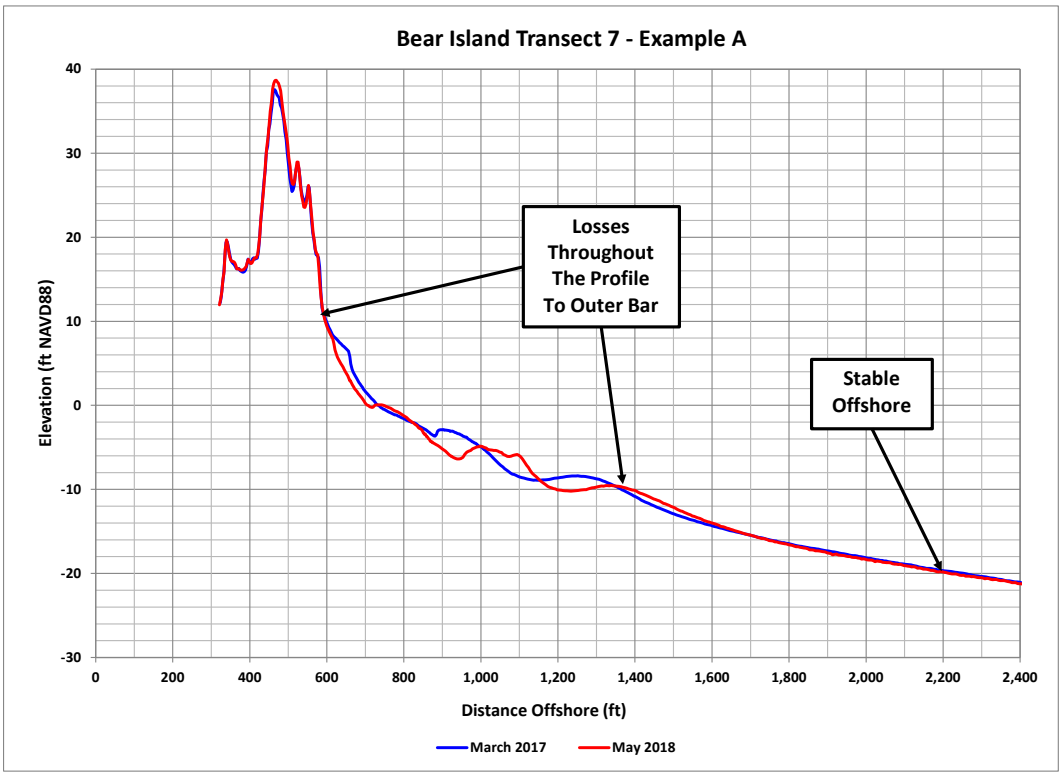


Figure 5-26. Bear Island Unit Volume Change (2017 - 2018)

Figure 5-27 presents example profiles from Bear Island showing typical profile behavior at the eastern end of the island where the losses were less substantial (see Example A) and the western

end of the island which exhibited more significant losses in material throughout the profile (see Example B).



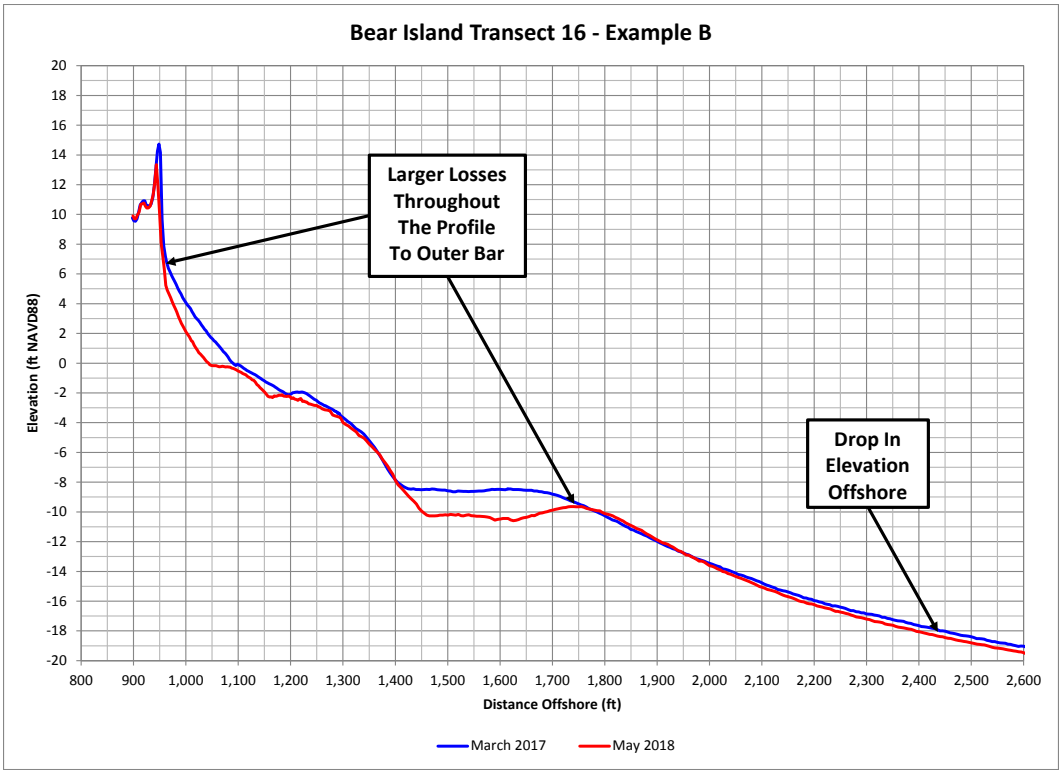


Figure 5-27. Bear Island Example Profiles

5.5 Shackleford Banks Shoreline and Volume Change Analysis (2017 – 2018)

This section discusses the results of the shoreline and volume change analysis for Shackleford Banks. Key statistics were calculated to quantify average shoreline and volume changes including average shoreline change, average volume change, and cumulative volume change (e.g. total volume of material lost or gained along a section of shoreline). Evaluation of the computed statistics will take into account volume changes computed for portions of the profile above MHW (+1.5 ft NAVD88), above -5 ft NAVD 88, above -12 ft NAVD88, above -20 ft NAVD88, and above -30 ft NAVD88 in order to better understand onshore and offshore processes.

For reference, **Appendix C** contains plots of the shoreline and volume changes from the spring 2017 and spring 2018 surveys at each transect along Shackleford Banks. **Appendix D** presents profile comparison plots for individual transects for the spring 2017 and spring 2018 surveys. **Appendix E** provides the computed shoreline changes and volume changes measured at each individual transect in tabular format.

Shackleford Banks is comprised of 24 transects and is a natural shoreline, receiving no nourishment. As a result, varying accretion and erosion occurs along the island. **Table 5-14** presents a summary of average shoreline and volume changes occurring between 2017 and 2018 for the Shackleford Banks region. Due to the erosional behavior of the western end of the island which began in 2010, statistics for the island have been divided between Transects 1-18 and Transects 19 – 22. It should be noted that Transects 23 and 24 no longer contain any dry land and were therefore not included in the statistical analysis.

Table 5-14. Average Shoreline and Volume Change for Shackleford Banks (2017 - 2018)

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Shackleford Banks (Transects 1-18)	35,331	-21.7	-1.4	-47,813	2.0	69,535	1.7	60,528	-0.04	-1,269	-11.2	-395,796
Shackleford Banks (Transects 19-22)	7,054	-140.7	-16.0	-113,132	-36.9	-260,599	-64.2	-452,937	-96.7	-682,036	-111.3	-784,870
Shackleford Banks (Transects 1-22)	42,385	-41.5	-3.8	-160,945	-4.5	-191,065	-9.3	-392,410	-16.1	-683,305	-27.9	-1,180,666

Table 5-14 indicates Transects 1 – 18, which comprise most of the island, experienced moderate landward recession of the shoreline at MHW of -21.7 ft. The remaining transects along Shackleford Banks (19-22) experienced extreme landward recession of the shoreline at MHW of -140.7 ft. Profile plots in **Appendix D** show significant erosion of the dunes and beachface for these transects.

Volumetrically, Transects 1-18 experienced minor accretion above -12 ft NAVD88 of +60,528 cy (+1.7 cy/ft). The remaining transects along Shackleford Banks (19-22) experienced significant losses in volume of approximately -452,937 cy (-64.2 cy/ft). As mentioned previously, significant erosion of the dunes and beachface along these transects is apparent in the profile plots in **Appendix D**. **Figure 5-28** displays the unit volume change at each transect on Shackleford Banks. It is evident from this figure that the majority of the loss on Shackleford Banks was located at Transects 19 through 22, adjacent to Beaufort Inlet. This behavior is not unexpected given the location of the deep draft channel being directly adjacent to this area of Shackleford Banks and the

recent history of significant erosion. The combination of the deep draft channel hydraulics, episodic dredging and shoaling, as well as barrier island morphology make this a very dynamic area. It should be noted that Shackleford Banks was surveyed just before the larger of the two April 2018 storm events previously mentioned. Although there was likely some impact from the first event, the eastern portion of island remained fairly stable.

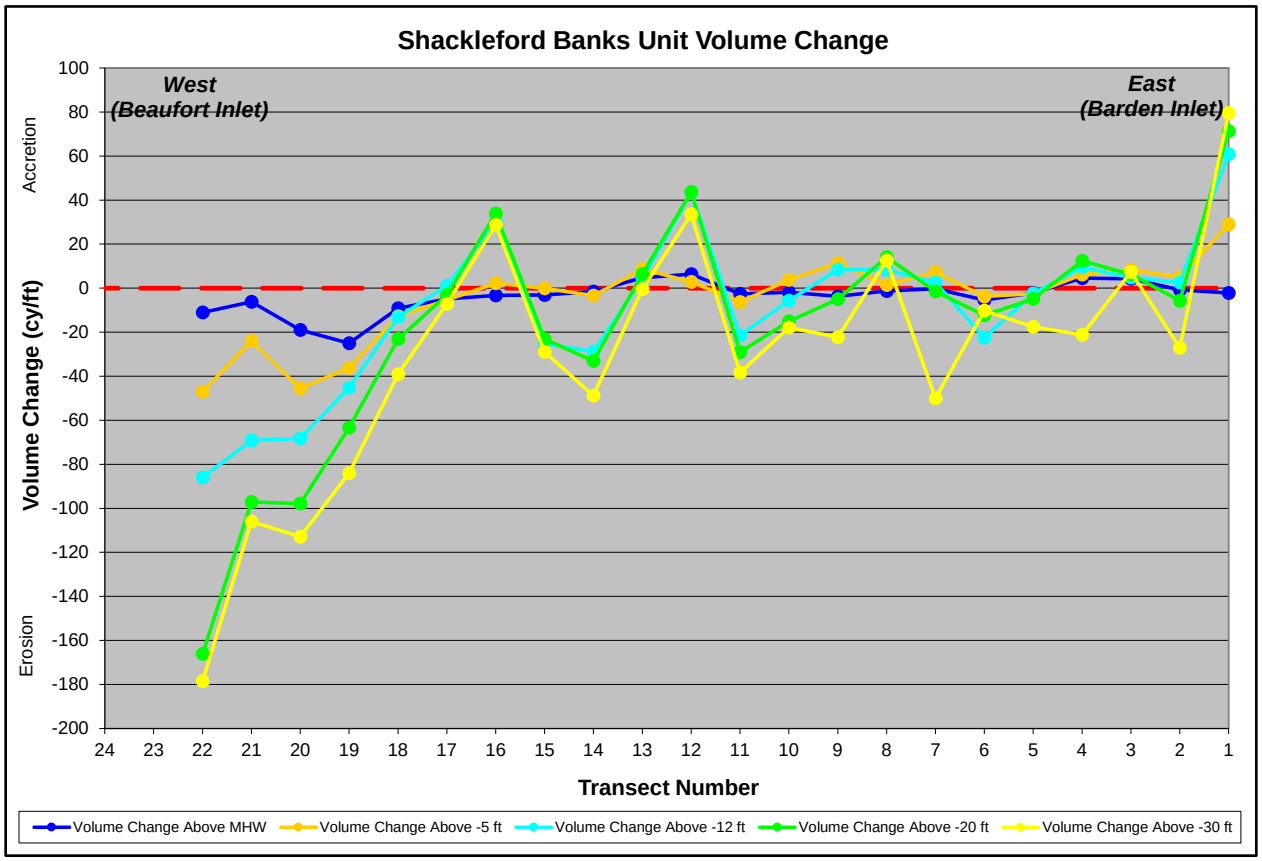
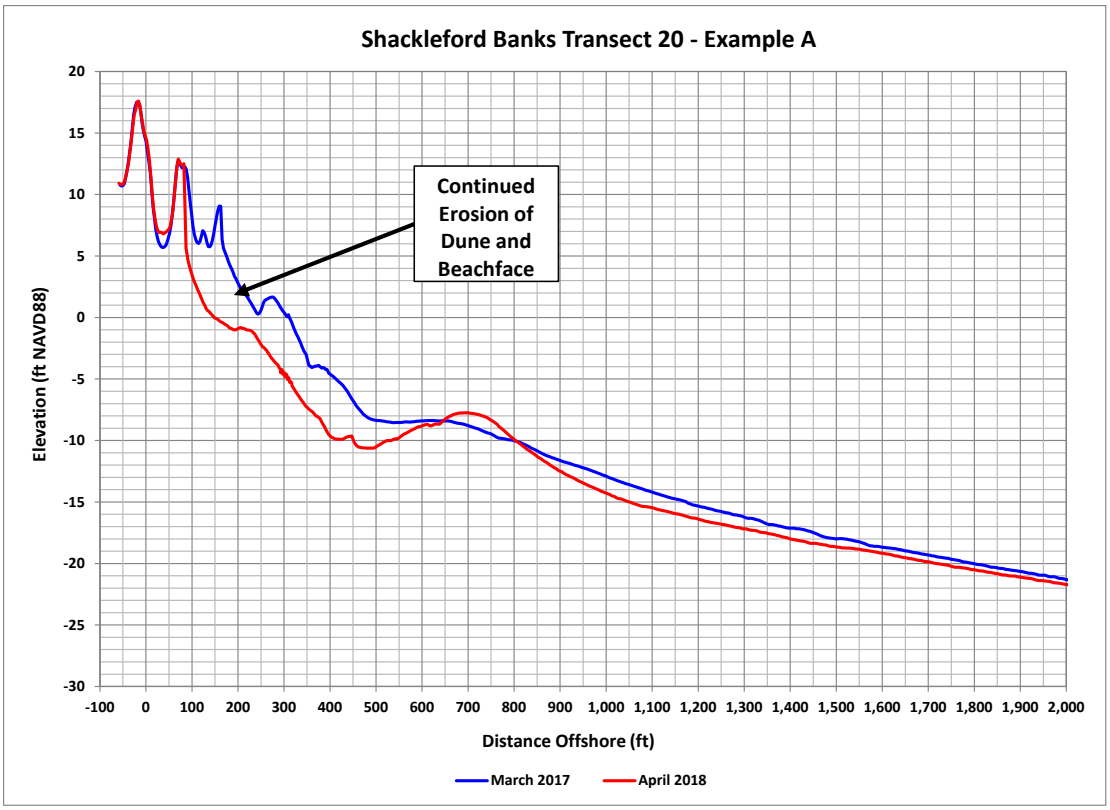


Figure 5-28. Shackleford Banks Unit Volume Change (2017 – 2018)

Figure 5-29 presents example profiles from Shackleford Banks showing extreme erosion of the dune and beachface at the western end of the island (see Example A) while the remainder of the island exhibited some erosion of the beachface which was subsequently captured immediately offshore along with a fairly large adjustment of the offshore bar (see Example B).



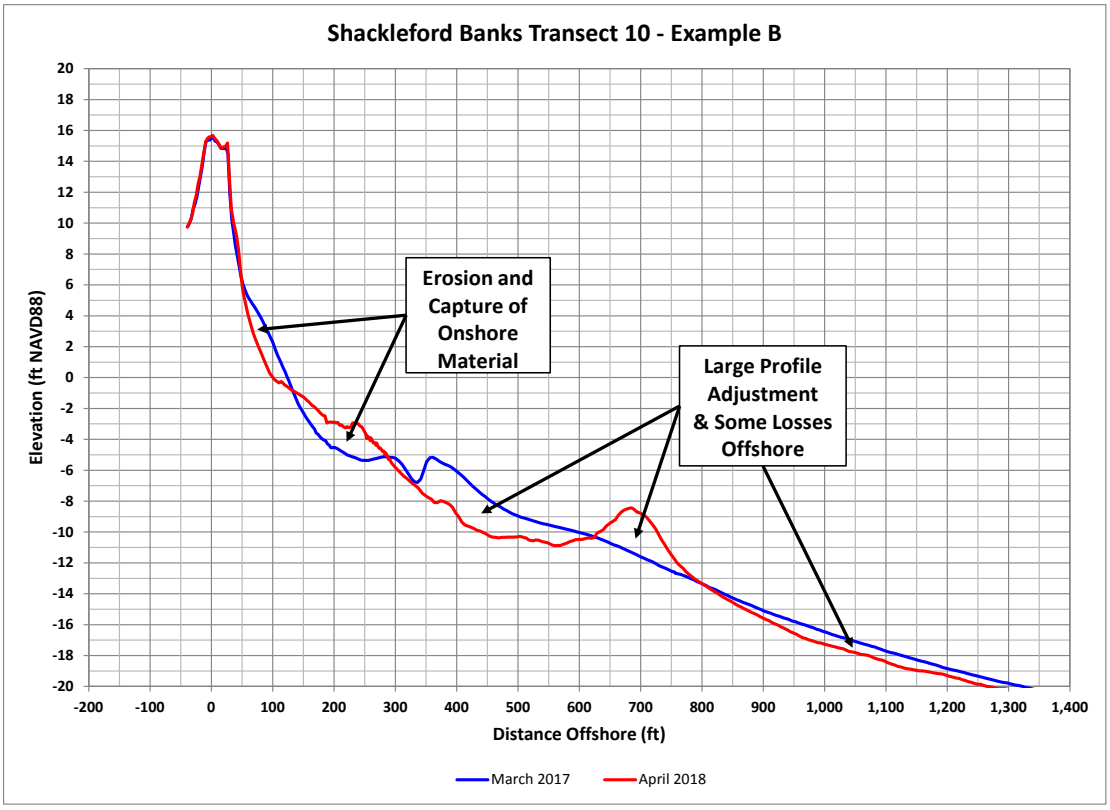


Figure 5-29. Shackleford Banks Example Profiles

5.6 Statistical Analysis of Recent Volume Change Trends (2008 – 2018)

Using the eleven most recent high quality survey datasets (2008-2018), statistical analyses were performed to determine if any long-term trends in ocean front behavior are visible for Bogue Banks, Bear Island, and Shackleford Banks. The average volume change per year and standard deviation was calculated for each transect using the volume changes from the current monitoring report along with the nine previous reports (M&N 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, and 2017). In areas where nourishment occurred, the amount of nourishment material was subtracted out in order to determine trends in beach change without the effects of the nourishment. For reference, **Appendix F** tabulates the statistical analysis of long-term trends.

5.6.1 Bogue Banks

To determine the long-term trends along Bogue Banks, annual volume changes from the monitoring reports were averaged at each transect. Nourishments within the time period from 2008 - 2018 (Post-Irene - February/March 2013 and MCH Maintenance Dredging in 2011, 2014, 2015, 2017) were subtracted out of the total volume change at each transect based on an average cubic yard per foot placed along each reach of beach in order to determine the background erosion rate. Therefore, these numbers are subject to some uncertainty since the same amount of nourishment was likely not placed at each transect. **Figure 5-30** shows the mean volume change with nourishment and **Figure 5-31** shows the mean volume change with the nourishment subtracted out from 2008-2018. In comparison of the two figures, the hotspots along Emerald Isle (Transects 34 – 45) and Pine Knoll Shores (Transects 62 – 72 and Transects 76 – 79) are very visible as well as the increased erosion rates in Atlantic Beach and Fort Macon when nourishment effects are subtracted out.

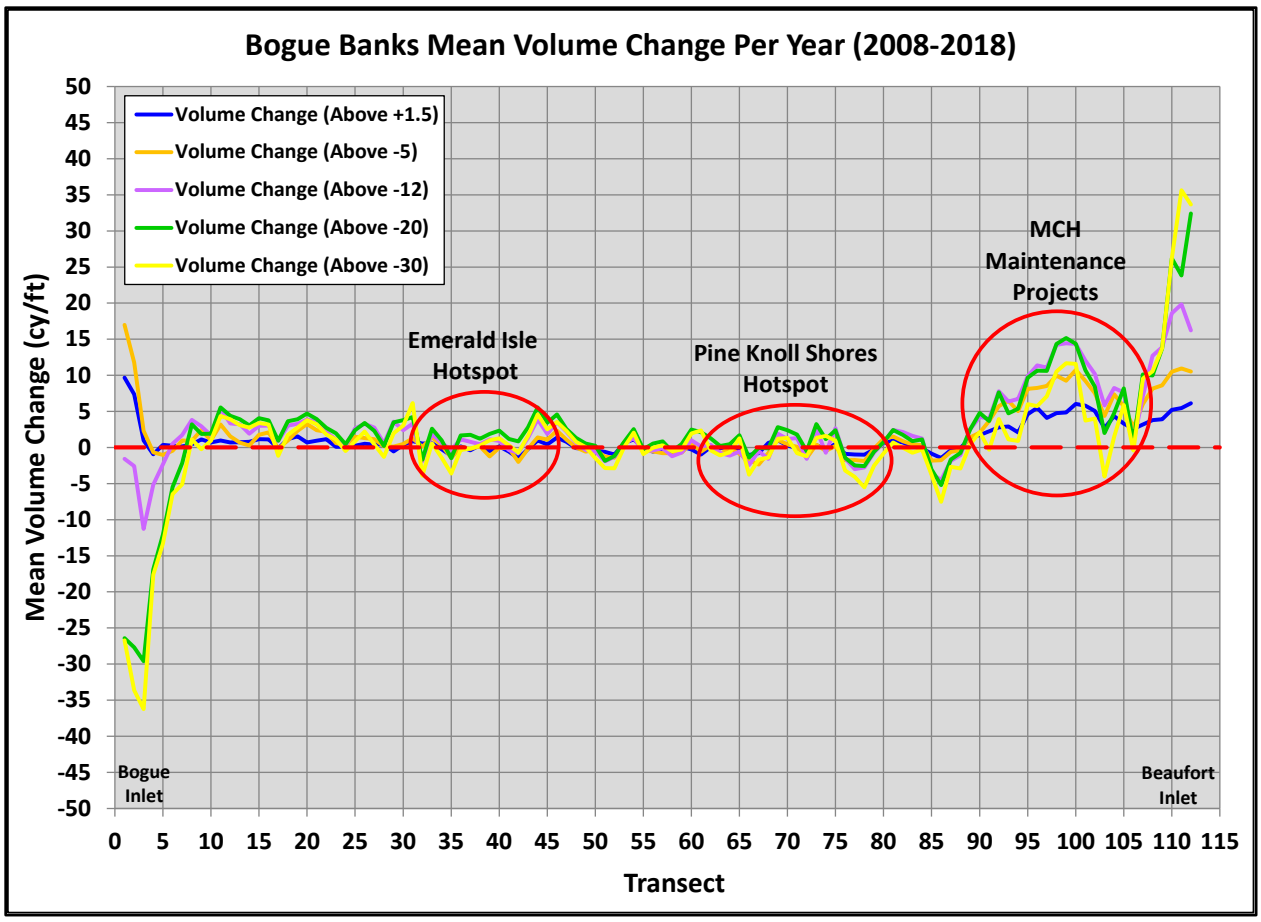


Figure 5-30. Bogue Banks Mean Volume Change (With Nourishment)

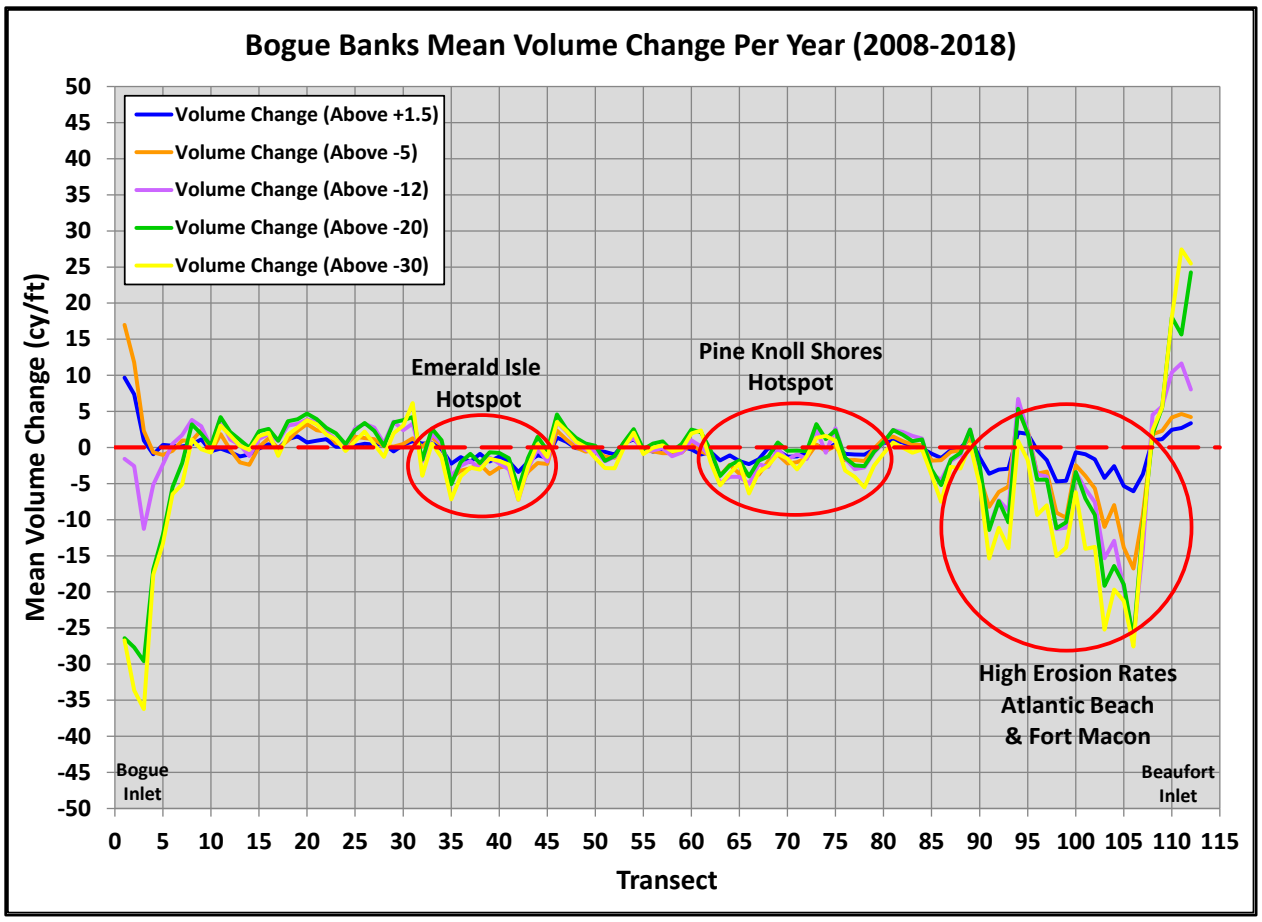


Figure 5-31. Bogue Banks Mean Volume Change (Without Nourishment)

The standard deviations of the average annual volume change (without nourishment) were also calculated for each referenced elevation included in the analysis. **Figure 5-32** through **Figure 5-36** shows the mean volume change per year with standard deviation bars at plus and minus one standard deviation for each of the referenced elevations.

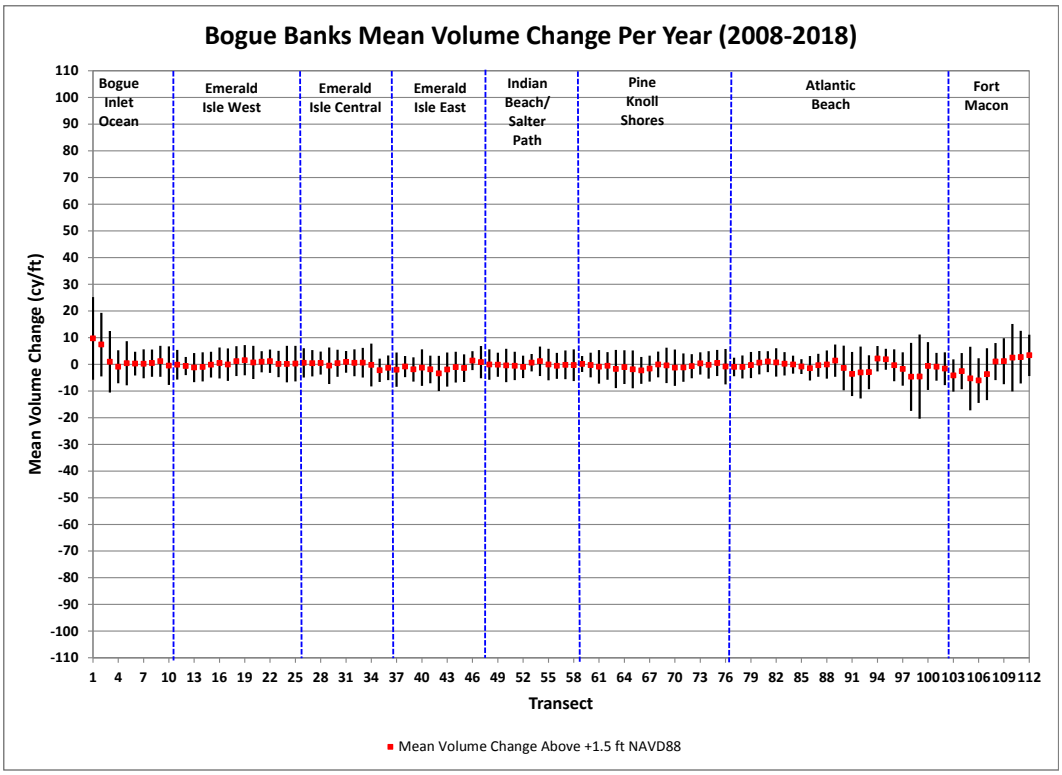


Figure 5-32. Bogue Banks Statistical Analysis of Volume Change Above +1.5 ft NAVD88

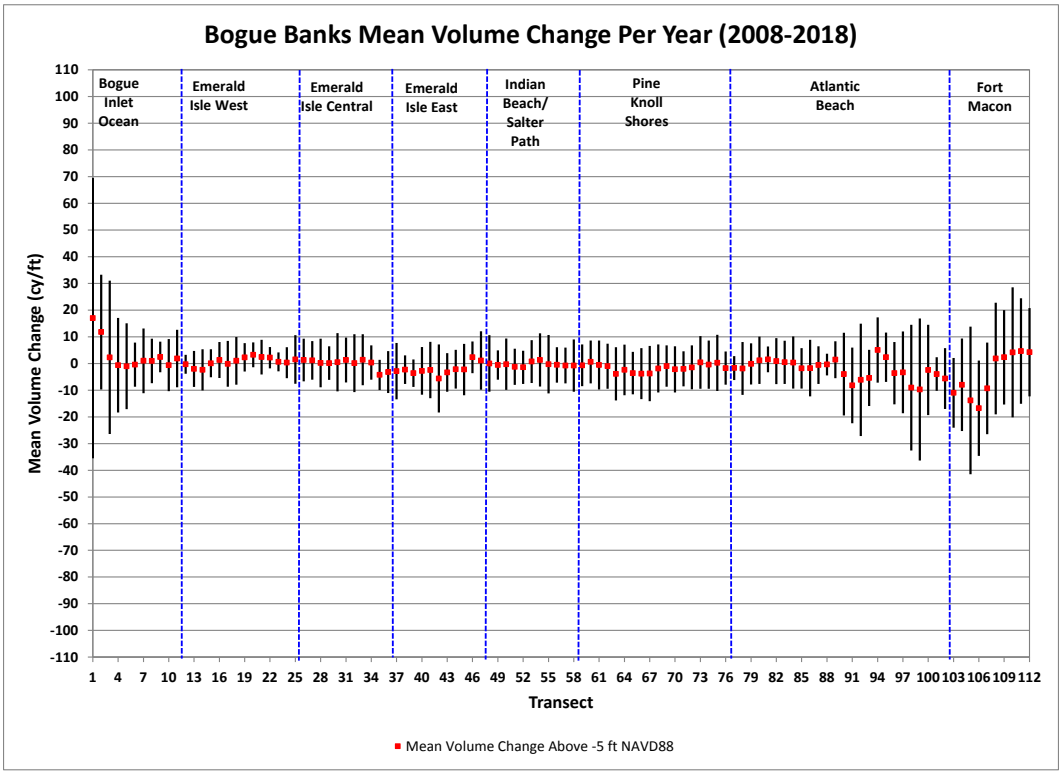


Figure 5-33. Bogue Banks Statistical Analysis of Volume Change Above -5.0 ft NAVD88

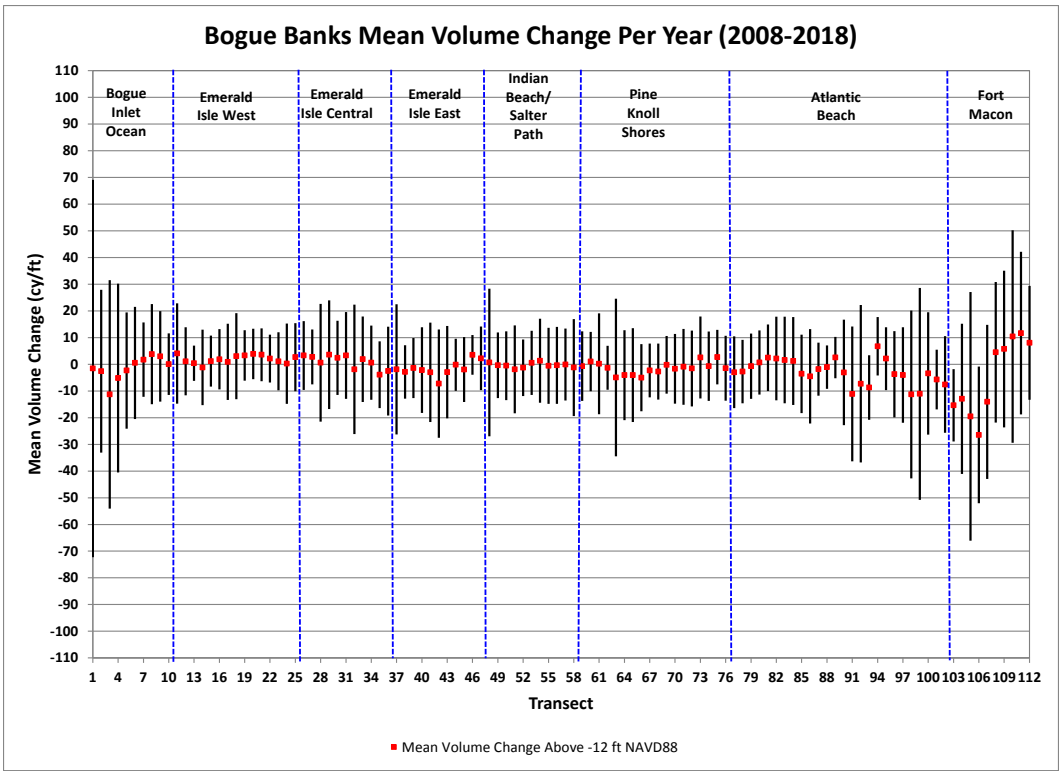


Figure 5-34. Bogue Banks Statistical Analysis of Volume Change Above -12.0 ft NAVD88

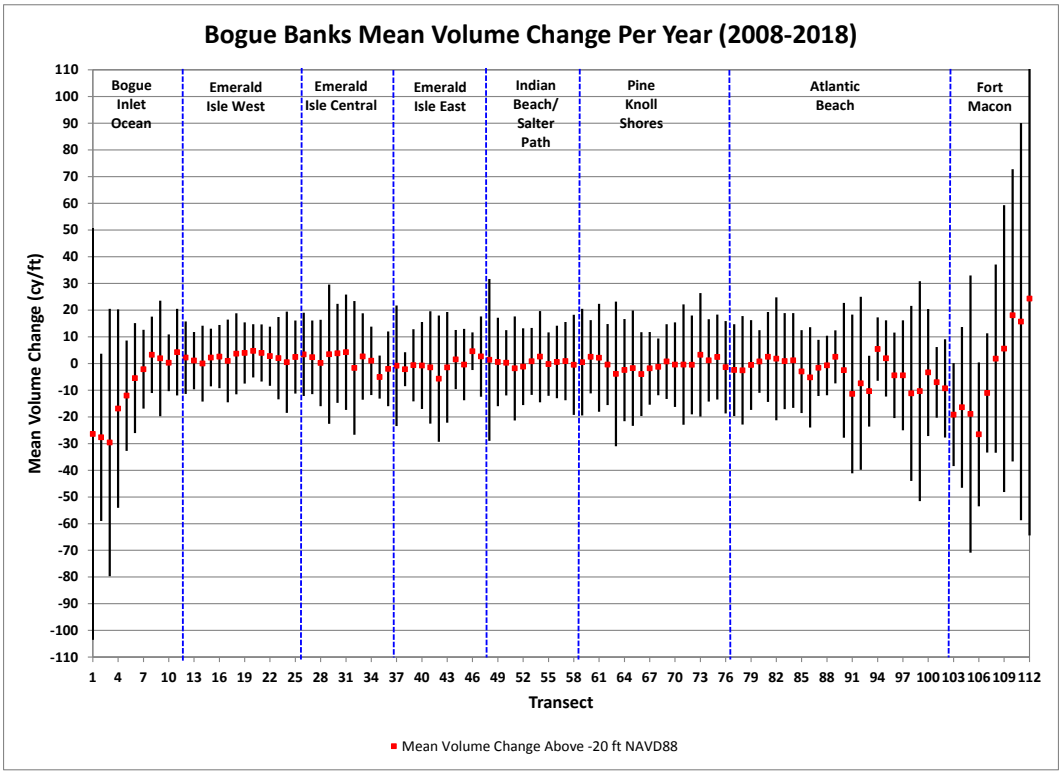


Figure 5-35. Bogue Banks Statistical Analysis of Volume Change Above -20.0 ft NAVD88

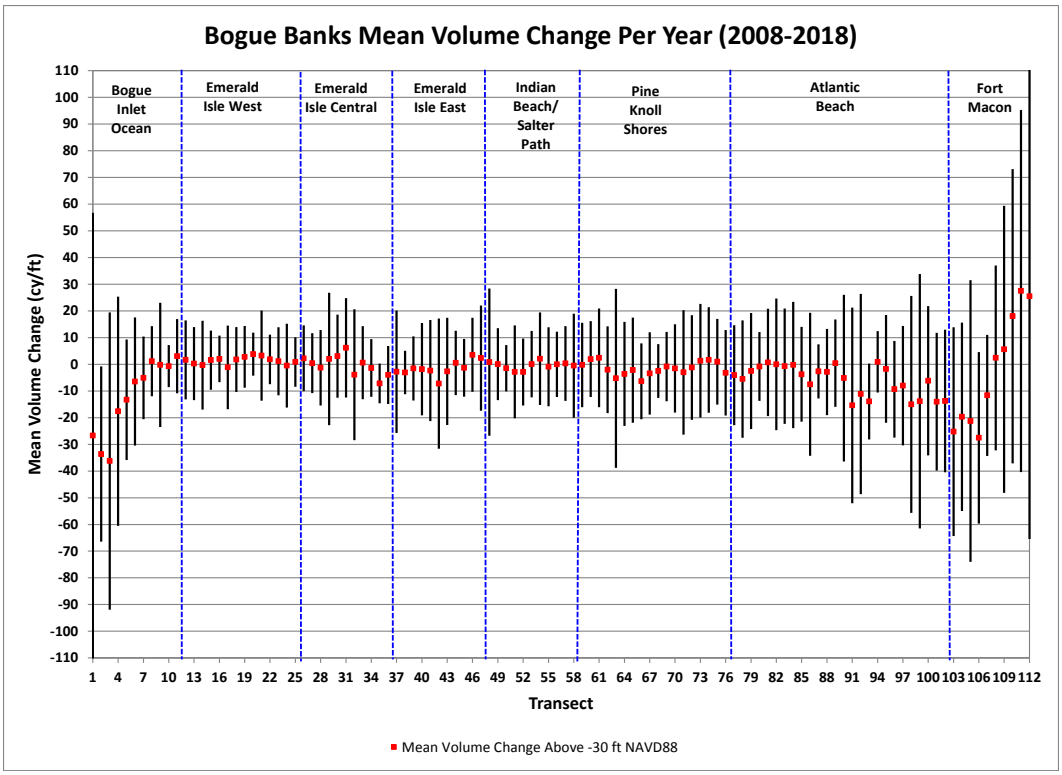


Figure 5-36. Bogue Banks Statistical Analysis of Volume Change Above -30.0 ft NAVD88

The variability in volume change increases with depth especially above MHW, -5 ft NAVD88, and -12 ft NAVD88. This is intuitive since the majority of sand movement historically happens in the subaerial profile with large fluctuations in the offshore bar position. The standard deviation of volume change above -20 ft NAVD88 and above -30 ft NAVD88 is not much higher than that values calculated for above -12 ft NAVD88. This implies there is not a large amount of additional sand movement at these lower depths. Also important is the standard deviation is much larger on either end of the island, as would be expected given the inlet effect on each end of the island. Changes near the inlets often fluctuate significantly each year. As more datasets are collected, average long-term trends will become more apparent.

5.6.2 Bear Island

To determine the longterm volume change trends along Bear Island, the average annual volume change rate was calculated at each transect based on changes calculated for the monitoring reports from 2008 to 2018. **Figure 5-37** shows the mean volume change per year from 2008-2018. Large losses near Bogue Inlet are very apparent. Erosion seems to be more significant on the western end of the island than the eastern end of the island. In fact, transects in the vicinity of Bogue Inlet show some accretional trends.

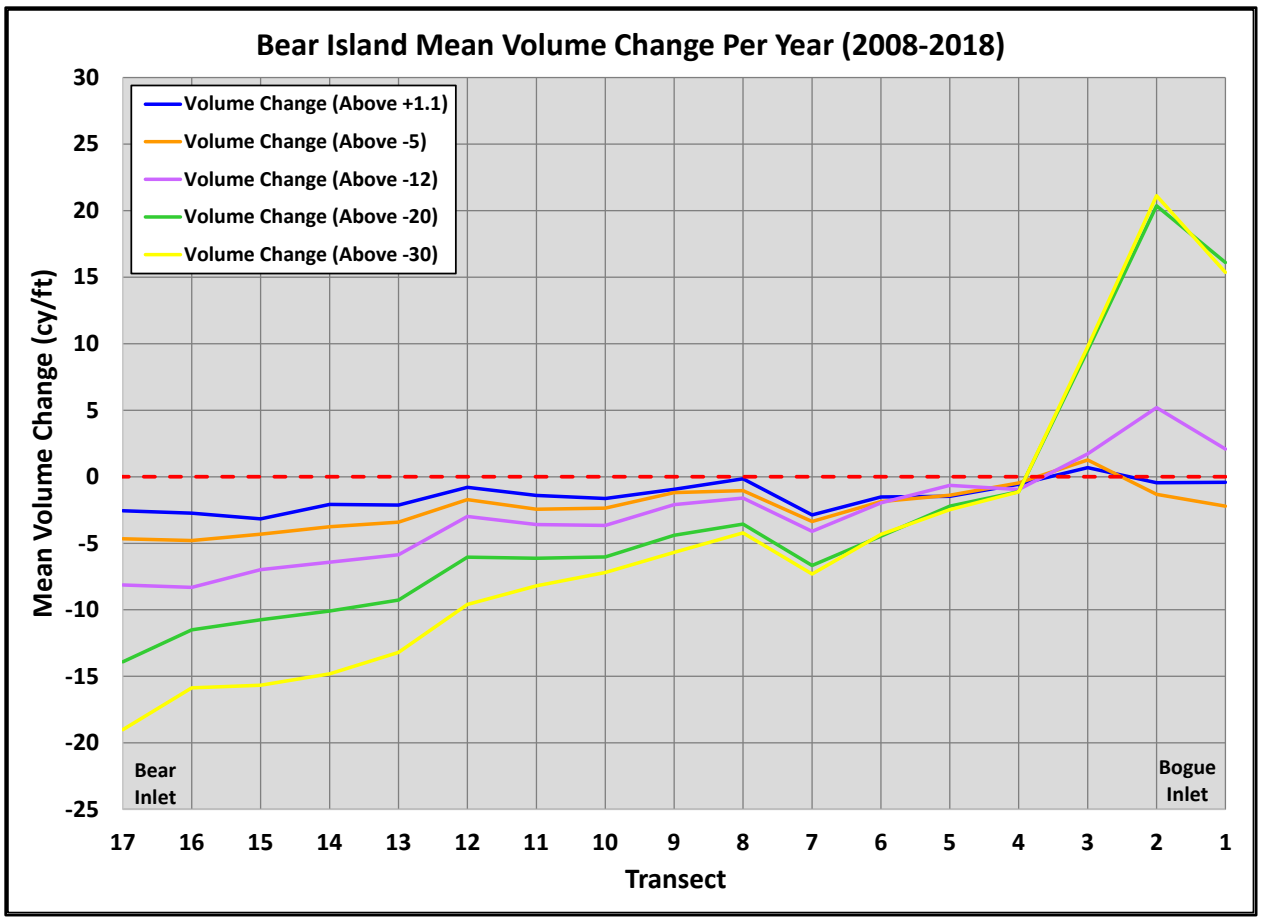


Figure 5-37. Bear Island Mean Volume Change

The standard deviations of the average annual volume change per year were also calculated for each referenced elevation included in the analysis. **Figure 5-38** through **Figure 5-42** shows the mean volume change per year with standard deviation bars at plus and minus one standard deviation for each of the referenced elevations.

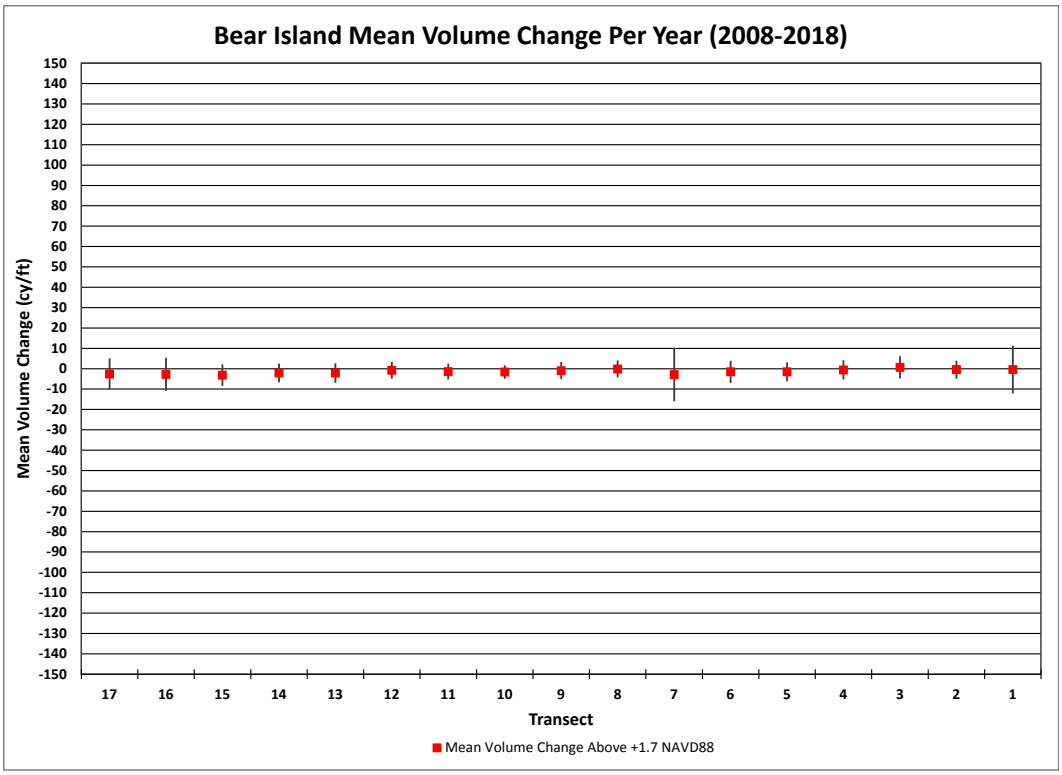


Figure 5-38. Bear Island Statistical Analysis of Volume Change Above +1.7 ft NAVD88

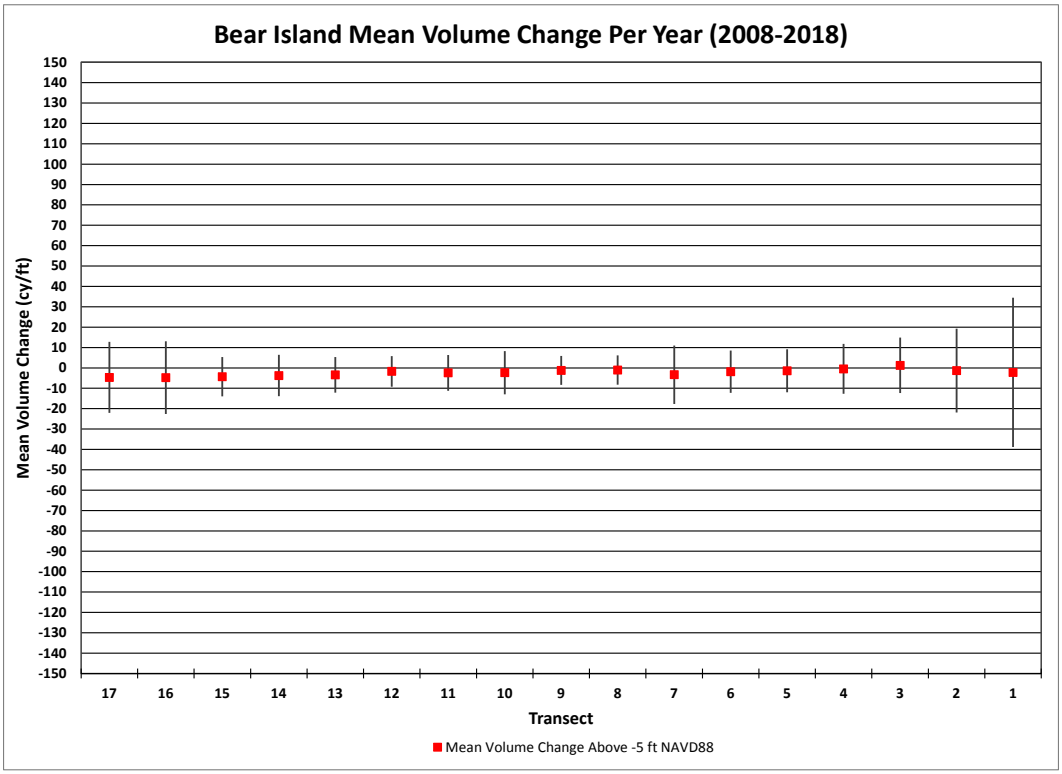


Figure 5-39. Bear Island Statistical Analysis of Volume Change Above -5.0 ft NAVD88

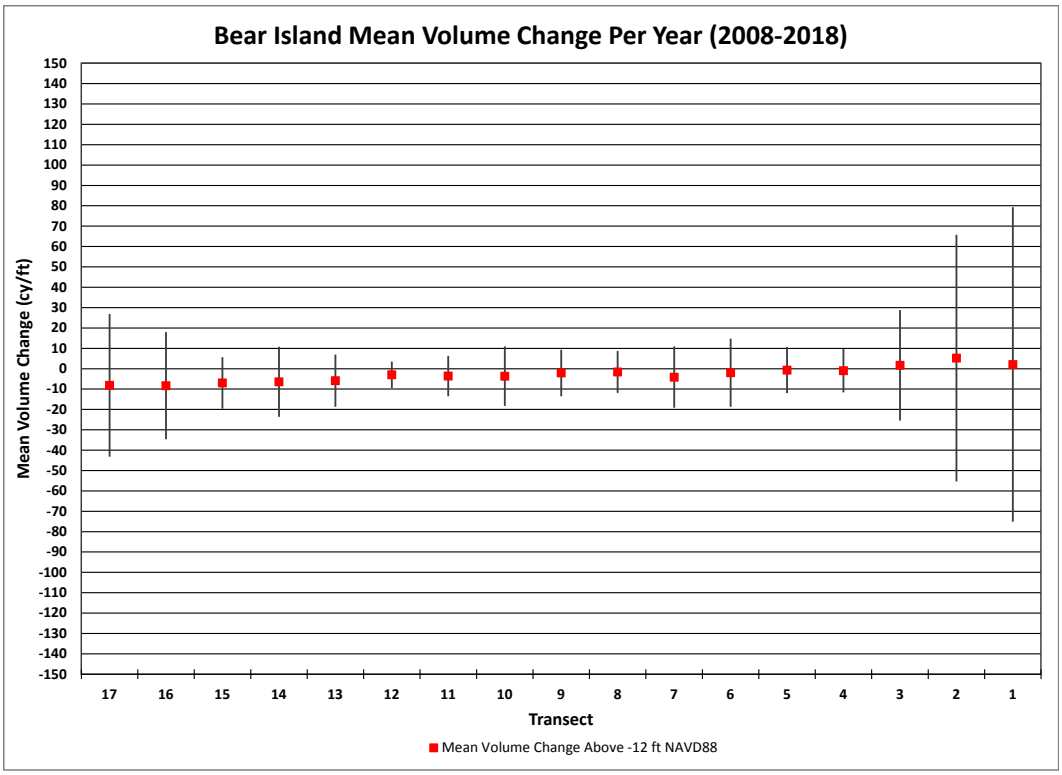


Figure 5-40. Bear Island Statistical Analysis of Volume Change Above -12.0 ft NAVD88

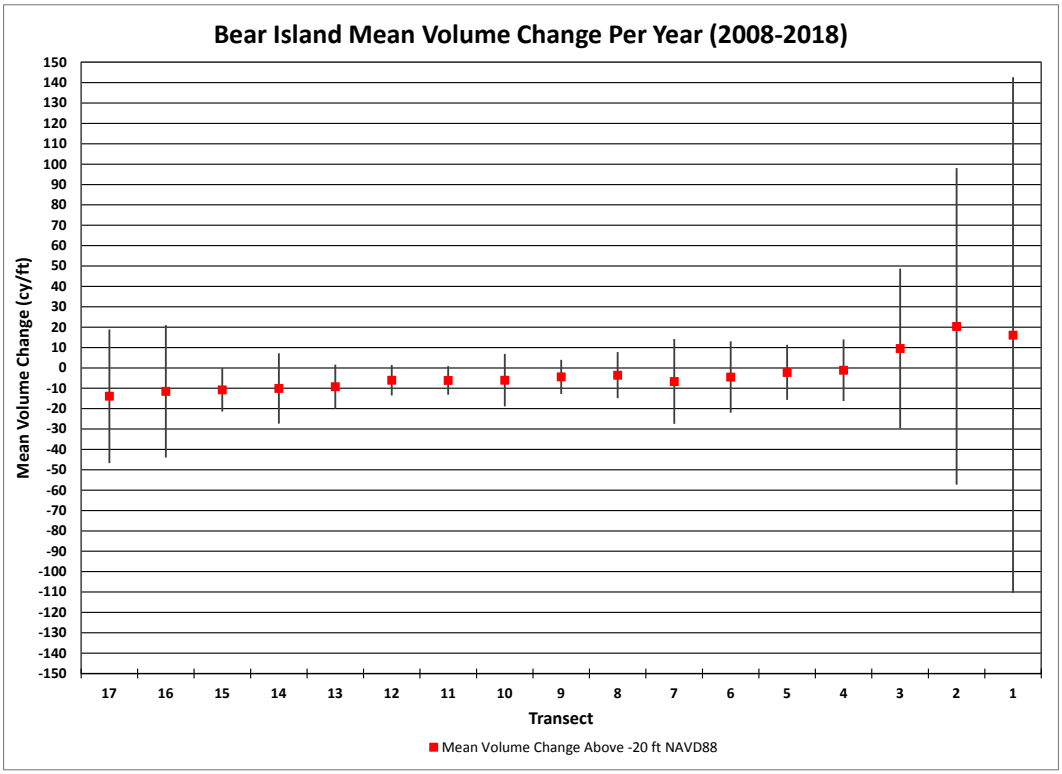


Figure 5-41. Bear Island Statistical Analysis of Volume Change Above -20.0 ft NAVD88

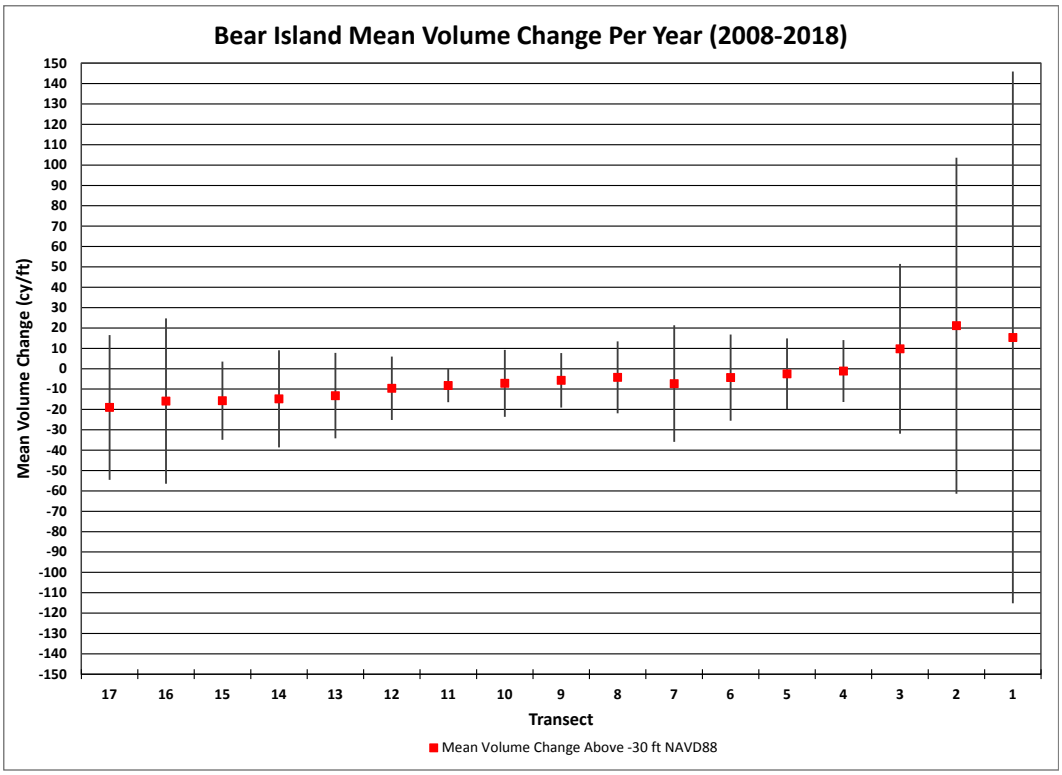


Figure 5-42. Bear Island Statistical Analysis of Volume Change Above -30.0 ft NAVD88

5.6.3 Shackleford Banks

To determine the longterm volume change trends along Shackleford Banks, the average annual volume change rate was calculated at each transect based on changes calculated for the monitoring reports from 2008 to 2018. **Figure 5-43** shows the mean volume change per year from 2008-2018. Large losses near Beaufort Inlet are very apparent while the remainder of the island is more stable with a slightly erosional trend, except in the immediate vicinity of Barden Inlet where there has been some accretion.

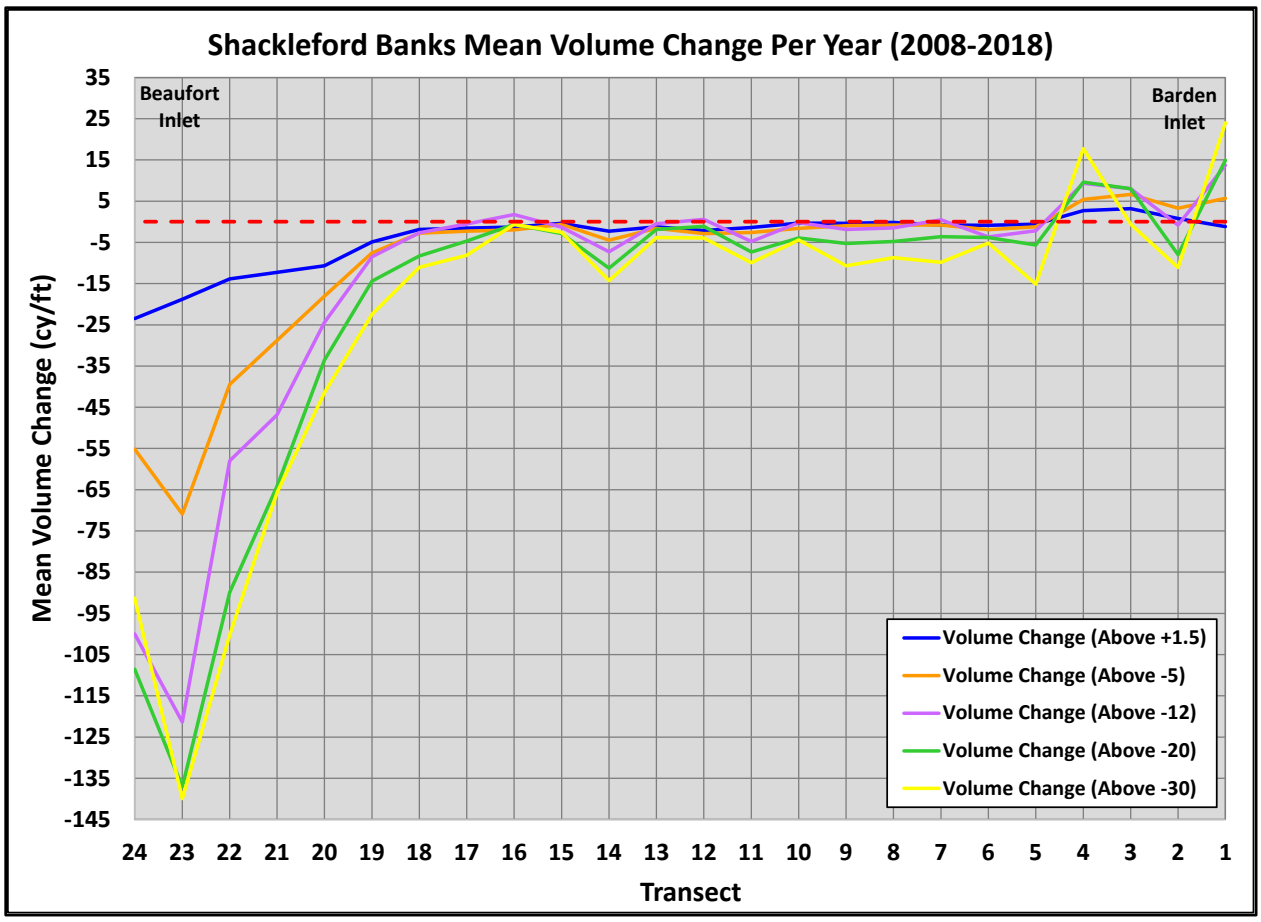


Figure 5-43. Shackleford Banks Mean Volume Change

The standard deviations of the average annual volume change were also calculated for each referenced elevation included in the analysis. **Figure 5-44** through **Figure 5-48** shows the mean volume change per year with standard deviation bars at plus and minus one standard deviation for each of the referenced elevations.

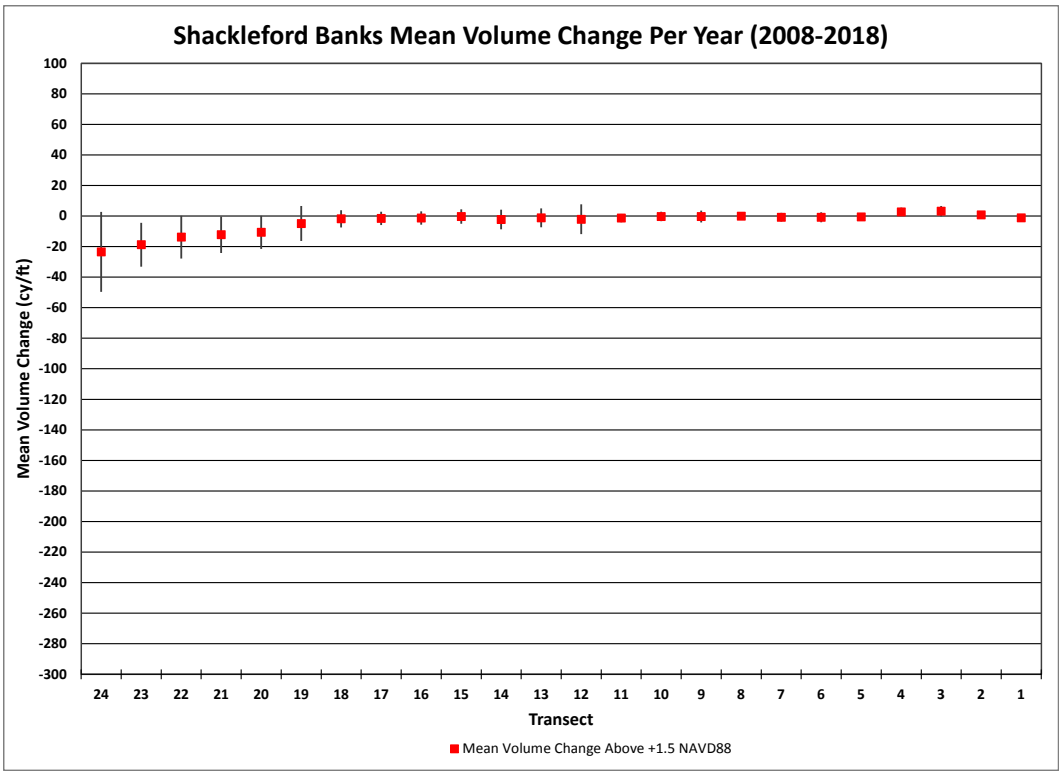


Figure 5-44. Shackleford Banks Statistical Analysis of Volume Change Above +1.5 ft NAVD88

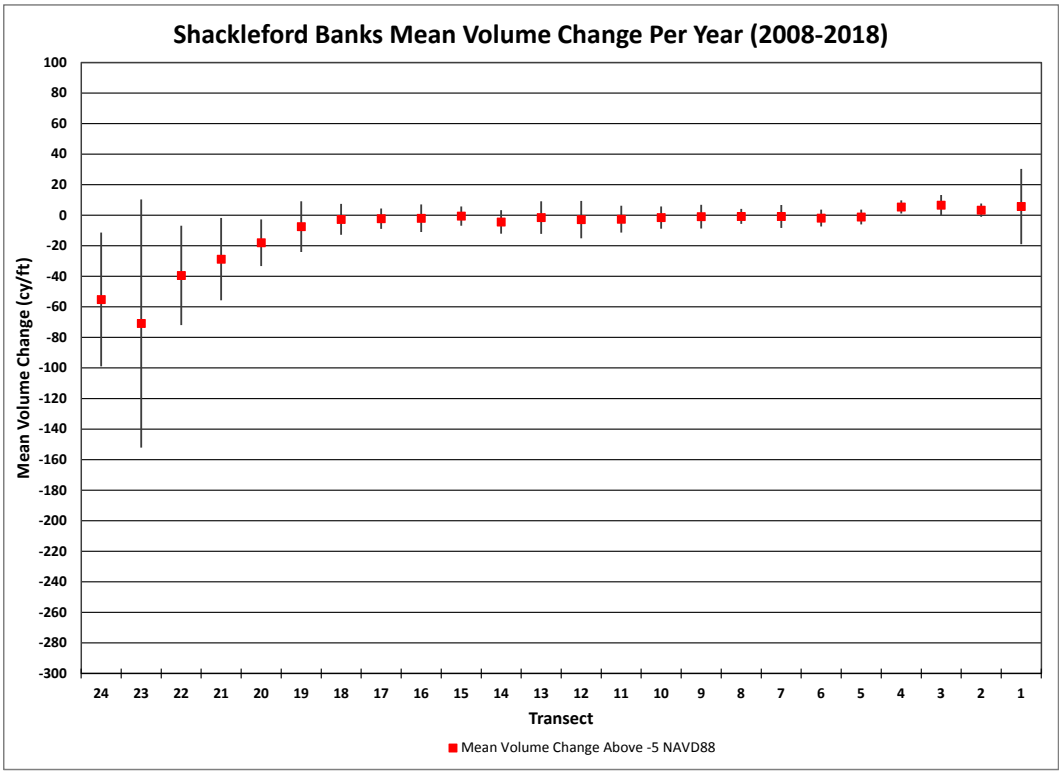


Figure 5-45. Shackleford Banks Statistical Analysis of Volume Change Above -5.0 ft NAVD88

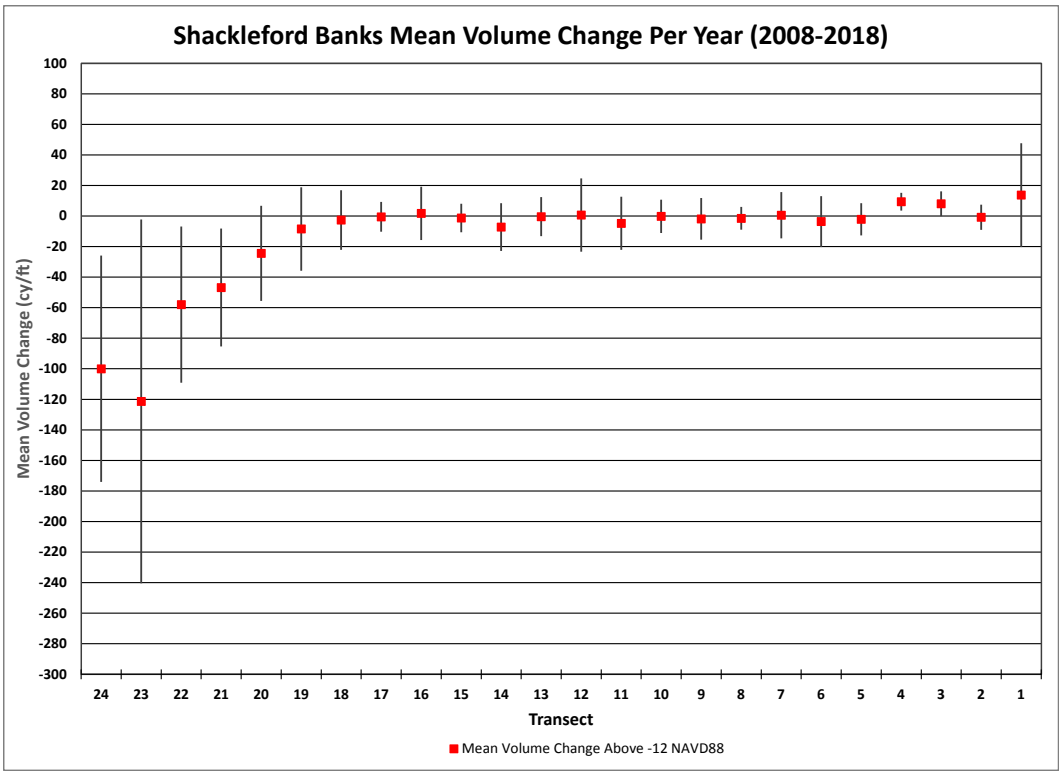


Figure 5-46. Shackleford Banks Statistical Analysis of Volume Change Above -12.0 ft NAVD88

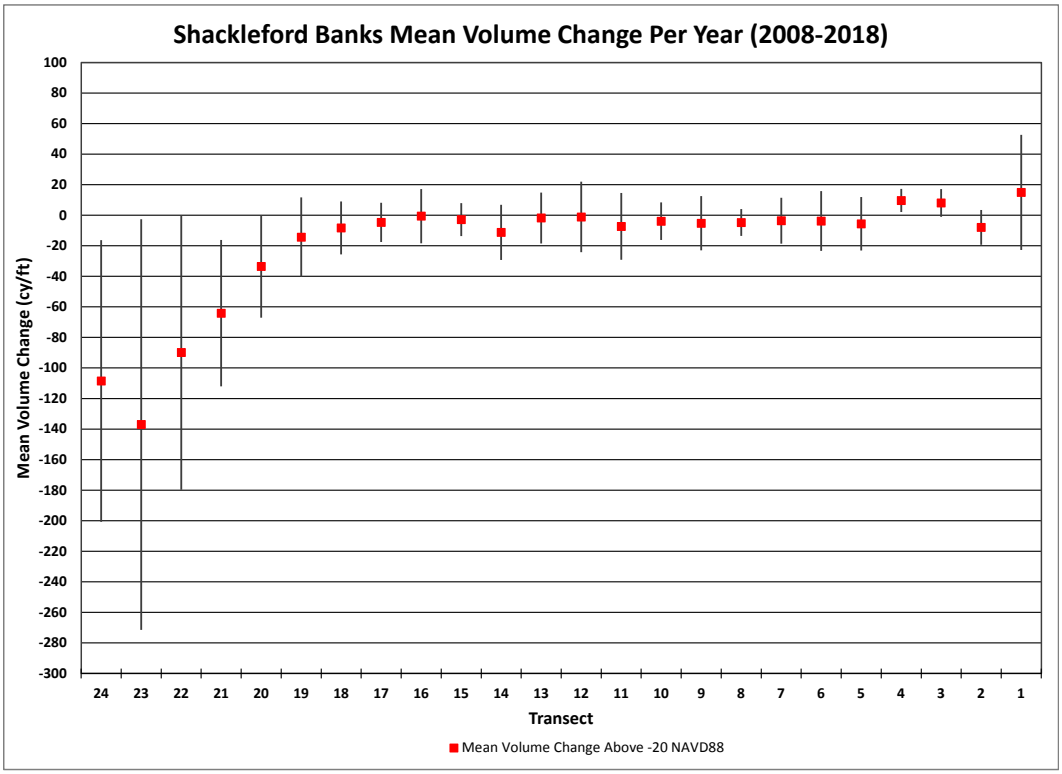


Figure 5-47. Shackleford Banks Statistical Analysis of Volume Change Above -20.0 ft NAVD88

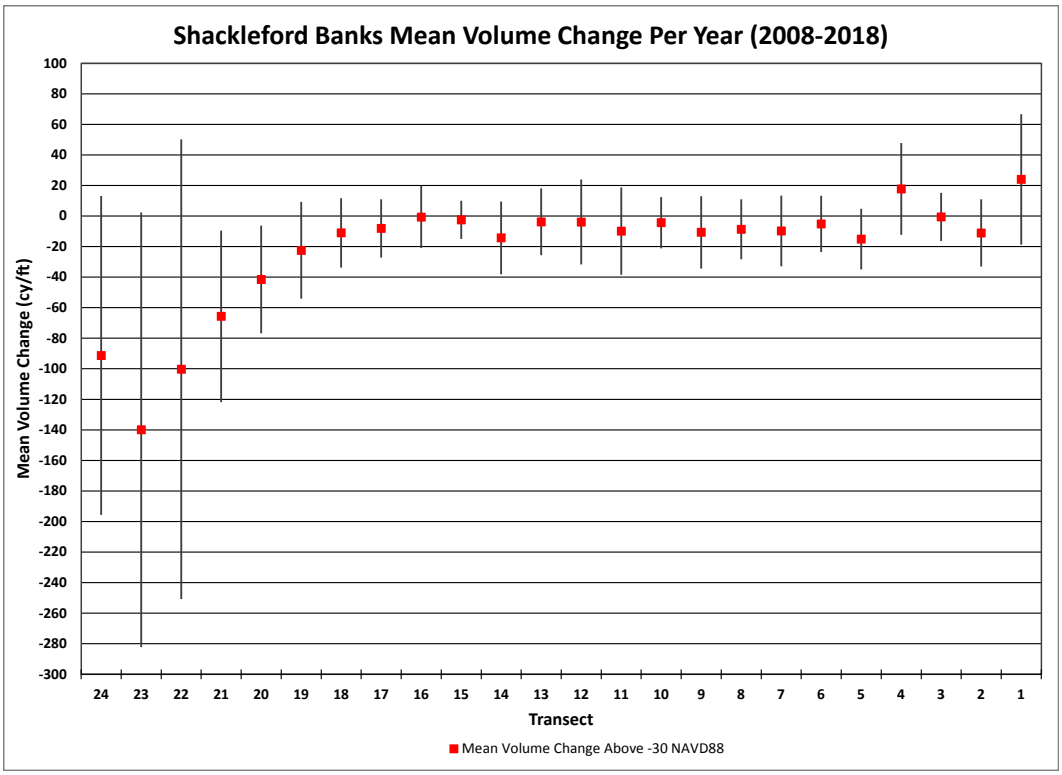


Figure 5-48. Shackleford Banks Statistical Analysis of Volume Change Above -30.0 ft NAVD88

5.7 Bogue Banks Master Beach Nourishment Plan Incorporation

Carteret County had developed a programmatic Environmental Impact Statement (EIS) which essentially outlines the nourishment needs (quantity, location, and timeframe) and sediment resources for Bogue Banks for the next 50 years. One environmental permit, obtained from review of the EIS, will be available to cover all nourishment actions for the next 50 years, eliminating the time-consuming process of permitting each individual project and allowing for placement of sand as needed. The annual monitoring efforts will decide the exact timing and extents of future nourishment projects by tracking the average profile volume in each management reach as compared to nourishment triggers that define the minimum profile volumes required to provide an equal level of protection along the Bogue Banks shoreline. While future nourishment events will be sequenced and designed based predominantly upon volumetric needs, other factors such as public perception with respect to berm width and leveraging economies of scale during individual dredge and beach fill events will also be considered.

5.7.1 Profile Volumes and Nourishment Triggers

As part of the Master Beach Nourishment Plan, volumetric triggers for each management reach, based on the profile volume from the foredune (landward most crest of primary dune) to the outer bar (above -12 ft NAVD88), were determined to provide equal protection along the Bogue Banks oceanfront. Based on the engineering analysis and historical and expected future funding levels, it was determined that Carteret County would be able to maintain protection from a 25-yr storm event. Detailed SBEACH modeling (1-D cross-shore) was used to determine the amount of material above -12 ft NAVD88 that is needed to provide a 25-yr event level of protection in each management reach. This is different for each reach depending on existing dune height, berm width,

offshore slope, etc. **Table 5-15** presents the management reaches and nourishment triggers along with the current average profile volume. As can be seen, each reach has a slightly different volume trigger, with an island wide weighted average of 233 cy/ft.

Table 5-15. Current Profile Volumes and Nourishment Triggers

Reach (Profiles)	Management Reach Length (ft)	2018 Volume Above -12 ft NAVD88 (cy)	25 yr LoP Nourishment Trigger (cy)
Bogue Inlet (1-11)	11,488	318	235
Emerald Isle West (12-25)	18,288	321	266
Emerald Isle Central (26-36)	15,802	308	211
Emerald Isle East (37-48)	13,220	277	221
Indian Beach/Salter Path (49-58)	12,850	293	224
Pine Knoll Shores (59-76)	23,878	262	211
Atlantic Beach (77-102)	26,176	337	254
TOTAL	**121,702**		
AVERAGE		**303**	**233**
		weighted	weighted

Figure 5-49 displays the average profile volume to the outer bar within each management reach for 2008 – 2018 along with the nourishment triggers. As can be seen, all management reaches currently contain average profile volumes above the nourishment triggers. However, Emerald Isle – East and Pine Knoll Shores are close to approaching the nourishment triggers and projects are in the process of being planned for winter 2018/2019 or winter 2019/2020. It is anticipated that the Master Beach Nourishment Plan – Project #1 will place material on Emerald Isle and Indian Beach/Salter Path, preferably during winter 2018/2019 if permitting can be finalized and feasible bid prices can be achieved, while Pine Knoll Shores is expected to collaborate with the USACE in winter 2019/2020 to do a delta project as an add on to the USACE project in Atlantic Beach. It is important to note that Hurricane Florence, which occurred in mid-September after completion of the annual analysis, is expected to have a large effect on the next expected nourishment project.

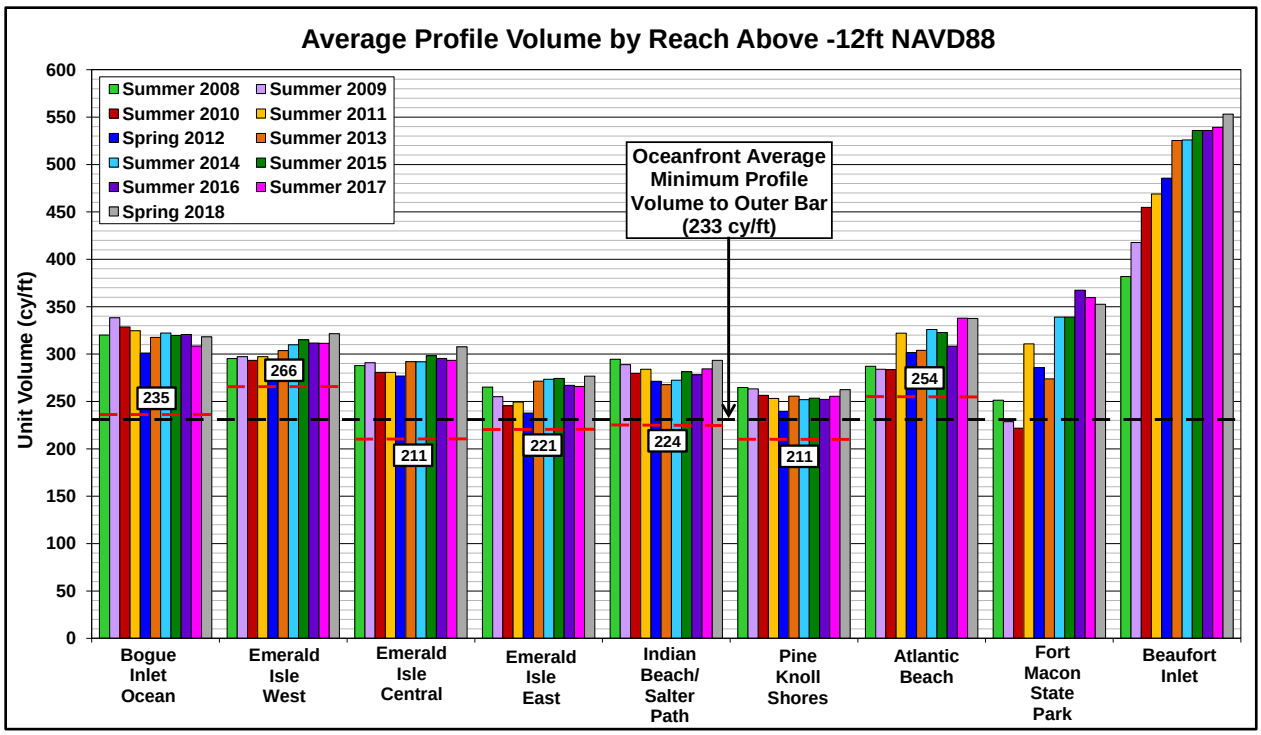


Figure 5-49. Profile Volumes and Nourishment Triggers

6.0 Summary

Comprehensive beach surveying of the Bogue Banks shoreline began in 1999 as a way to formulate the Bogue Banks Beach Restoration Project. In spring 2004, the Bogue Banks Beach and Nearshore Mapping Program was codified to continue assessing beach conditions and form strategies for future beach nourishment projects. Bear Island was added to the project in October 2004 and Shackleford Banks was added in May 2005. Surveys are performed annually during the spring/summer timeframe along all three islands. In addition, after large storm events, surveying is performed along Bogue Banks to assess damages. The most recent annual monitoring survey was completed during spring 2018 by Geodynamics. For this evaluation, the spring 2018 survey was compared with the spring 2017 survey. The profile data were used to compute shoreline change at MHW (+1.5 ft NAVD88 for Bogue Banks and Shackleford Banks and +1.7 ft NAVD88 for Bear Island) and volume change above MHW, -5 ft NAVD88 (wading depth), -12 ft NAVD88 (outer bar), -20 ft NAVD88 (approximate closure), and -30 ft NAVD88 (offshore).

Key statistics for individual reaches along Bogue Banks along with the entire oceanfront shoreline were as follows:

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bogue Inlet-Ocean (Transects 1-11)	11,488	17.2	4.8	54,775	9.4	107,982	9.7	111,015	1.0	11,111	-2.9	-33,285
Emerald Isle-West (Transects 12-25)	18,288	-1.7	1.5	28,131	3.2	58,041	10.1	184,840	5.4	99,547	-1.5	-26,579
Emerald Isle-Central (Transects 26-36)	15,802	-0.7	3.8	60,580	5.9	92,562	14.3	226,150	9.1	143,706	0.8	12,073
Emerald Isle-East (Transects 37-48)	13,220	-13.1	0.7	8,827	5.3	70,233	10.8	142,338	9.3	123,129	2.1	27,254
Indian Beach-Salter Path (Transects 49-58)	12,850	-3.6	2.5	31,890	5.8	73,935	8.9	113,963	5.9	76,006	-3.8	-48,504
Pine Knoll Shores (Transects 59-76)	23,878	-8.1	1.3	31,692	2.4	57,122	7.1	169,571	6.0	142,860	-5.7	-135,443
Atlantic Beach (Transects 77-102)	26,176	-22.9	-0.1	-1,979	-2.8	-73,190	-0.3	-6,993	-0.7	-19,485	-11.7	-306,958
Fort Macon State Park (Transects 103-112)	6,691	-4.0	4.0	26,602	0.7	4,697	-7.0	-46,689	-27.3	-182,394	-30.9	-206,691
Beaufort Inlet (Transects 112B-116)	2,000	41.7	5.8	11,511	10.0	20,091	14.0	28,041	8.3	16,583	6.4	12,857
Bogue Inlet-Channel (Transects 117-120)*	2,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Reach Length	Weighted Avg	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total	Weighted Avg	Total
FEMA Engineered Beach (Transects 1-76)	**95,527**	**-2.7**	**2.3**	**215,895**	**4.8**	**459,876**	**9.9**	**947,877**	**6.2**	**596,360**	**-2.1**	**-204,484**
Oceanfront (Transects 1-112)	**128,393**	**-6.9**	**1.9**	**240,517**	**3.0**	**391,383**	**7.0**	**894,195**	**3.1**	**394,481**	**-5.6**	**-718,133**

*Note: Due to the dynamic nature of Bogue Inlet, shoreline and volume calculations were not performed

The Bogue Banks oceanfront shoreline experienced an overall average landward recession at MHW of -6.9 ft over the past year. However, this is somewhat influenced by equilibration of the Atlantic Beach nourishment project. The remainder of the beach west of the nourishment project (FEMA engineered beach) experienced an overall landward recession of the shoreline at MHW of only -2.7 ft over the past year.

Despite shoreline recession, volumetrically, the Bogue Banks oceanfront experienced an overall volume gain above all elevations analyzed except above -30 ft NAVD88. Oceanfront volume gains increased moving down the profile from above MHW (+240,517 cy), to above -5 ft NAVD88 (+391,383 cy), to above -12 ft NAVD88 (+894,195 cy). This indicates a gain in material along each section of the profile out to the offshore bar. Volumes gains then decreased above -20 ft NAVDD88 (+394,481 cy) and turned into volume losses at -30 ft NADV88 (-718,133 cy). This indicates offshore losses that were limited to seaward of the offshore bar. Profile plots indicate several locations where there was a distinct decrease in elevation along the offshore portion of the profile. The same volume change pattern was experienced for just the FEMA engineered beach portion of Bogue Banks with increasing volume gains above MHW (+215,895 cy), -5 ft NAVD88 (+459,876 cy), and -12 ft NADV88 (+947,877 cy). Smaller gains were experienced above -20 ft NAVD88 (+596,360 cy) and losses experienced above -30 ft NAVD88 (-204,484 cy). The quiescent weather over the past year likely aided in beach recovery from storms which occurred during spring 2017 that caused some noticeable erosion of the beach. The only reach to experience losses at all elevations analyzed was Atlantic Beach. This was expected due to equilibration of the 2017 USACE project during the first year post-construction. However, losses from the project were considerably less than what often occurs immediately post-nourishment with only 131,500

cy of material being lost above -12 ft NAVD88 from Transects 91 to 100 out of 621,000 cy placed (approximately 21% loss).

The difference in position of the base of the dune was also analyzed. Results indicated overall erosion of the base of the dune. This appears to be inaccurate, given the results of the volume change analysis, and is likely the result of comparing dune base positions established from two different methods. A new method of locating the base of the dune was introduced in 2018. Previously, an ATV was driven along the base of the dune but it was highly subject to surveyor interpretation and accuracy was hard to achieve given the size of the ATV and obstacles inhibiting the vehicle from reaching the base of the dune. In 2018, a mobile laser scanner was used to achieve high density elevation data from the seaward face of the dune to the waterline. From this, the base of the dune where the slope breaks for the berm was extracted from a DEM surface created from the high density data. It appears that this method of locating the base of the dune is more precise and will provide more accurate results in future comparisons.

Key statistics calculated for Bear Island were as follows:

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.7 ft NAVD88	Average Volume Change Above +1.7 ft NAVD88	Cumulative Volume Change Above +1.7 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Bear Island (Transects 1-18)	16,500	-23.6	-2.5	-40,795	-8.5	-140,969	-13.0	-214,546	-17.7	-292,108	-26.7	-441,223

Bear Island experienced significant landward recession of the shoreline at MHW over the past year of -23.6 ft. Volumetric calculations also indicate overall volume losses above all elevations analyzed, with losses above -12 ft NAVD88 totaling -214,546 cy (-13.0 cy/ft). The entire island experienced erosion with the western end of the island experiencing the largest losses. It should be noted that there were two significant storm events in April 2018 with offshore wave heights reaching 14 ft (April 16) and 18 ft (April 24). Bear Island was surveyed on May 1, 2018 so the higher than average erosion experienced over the past year is likely due to the effects of the April 2018 storms.

Key statistics calculated for Shackleford Banks were as follows:

Reach (Transects)	Reach Length	Average Shoreline Change @ MHW +1.5 ft NAVD88	Average Volume Change Above +1.5 ft NAVD88	Cumulative Volume Change Above +1.5 ft NAVD88	Average Volume Change Above -5 ft NAVD88	Cumulative Volume Change Above -5 ft NAVD88	Average Volume Change Above -12 ft NAVD88	Cumulative Volume Change Above -12 ft NAVD88	Average Volume Change Above -20 ft NAVD88	Cumulative Volume Change Above -20 ft NAVD88	Average Volume Change Above -30 ft NAVD88	Cumulative Volume Change Above -30 ft NAVD88
	ft	ft	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy	cy/ft	cy
Shackleford Banks (Transects 1-18)	35,331	-21.7	-1.4	-47,813	2.0	69,535	1.7	60,528	-0.04	-1,269	-11.2	-395,796
Shackleford Banks (Transects 19-22)	7,054	-140.7	-16.0	-113,132	-36.9	-260,599	-64.2	-452,937	-96.7	-682,036	-111.3	-784,870
Shackleford Banks (Transects 1-22)	42,385	-41.5	-3.8	-160,945	-4.5	-191,065	-9.3	-392,410	-16.1	-683,305	-27.9	-1,180,666

Transects 1 – 18, which comprise most of the island, experienced moderate landward recession of the shoreline at MHW of -21.7 ft. The remaining transects along Shackleford Banks (19-22) experienced extreme landward recession of the shoreline at MHW of -140.7 ft. Volumetrically,

Transects 1-18 experienced minor accretion above -12 ft NAVD88 of +60,528 cy (+1.7 cy/ft). The remaining transects along Shackleford Banks (19-22) experienced significant losses in volume of approximately -452,937 cy (-64.2 cy/ft). Extreme erosion along the western end of the island, adjacent to Beaufort Inlet, has been a consistent trend since 2010. This behavior is not unexpected given the location of the deep draft channel being directly adjacent to this area of Shackleford Banks and the recent history of significant erosion. The combination of the deep draft channel hydraulics, episodic dredging and shoaling, as well as barrier island morphology make this a very dynamic area.

Carteret County has developed a programmatic Environmental Impact Statement (EIS) which essentially outlines the nourishment needs (quantity, location, and timeframe) and sediment resources for Bogue Banks for the next 50 years and is being used to obtain a permit to cover these activities. The annual monitoring efforts will decide the exact timing and extents of future nourishment projects by tracking the average profile volume in each management reach as compared to nourishment triggers that define the minimum profile volumes required to provide an equal level of protection along the Bogue Banks shoreline for a 25 yr storm event. Assessment of current conditions compared to the nourishment triggers defined in the Master Beach Nourishment Plan (engineering portion of the EIS) was completed as part of this report. The following table indicates that all management reaches currently contain average profile volumes above their individual nourishment triggers as well as the island wide average trigger of 233 cy/ft. However, Emerald Isle – East and Pine Knoll Shores are close to approaching the nourishment triggers and projects are in the process of being planned for winter 2018/2019 or winter 2019/2020. It is anticipated that the Master Beach Nourishment Plan – Project #1 will place material on Emerald Isle and Indian Beach/Salter Path, preferably during winter 2018/2019 if permitting can be finalized and feasible bid prices can be achieved, while Pine Knoll Shores is expected to collaborate with the USACE in winter 2019/2020 to do a delta project as an add on to the USACE project in Atlantic Beach. It is important to note that Hurricane Florence, which occurred in mid-September after completion of the annual analysis, is expected to have a large effect on the next expected nourishment project.

Reach (Profiles)	Management Reach Length (ft)	2018 Volume Above -12 ft NAVD88 (cy)	25 yr LoP Nourishment Trigger (cy)
Bogue Inlet (1-11)	11,488	318	235
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Emerald Isle Central (26-36)	15,802	308	211
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Indian Beach/Salter Path (49-58)	12,850	293	224
Pine Knoll Shores (59-76)	23,878	262	211
Atlantic Beach (77-102)	26,176	337	254
TOTAL	**121,702**		
AVERAGE		**303**	**233**
		weighted	weighted

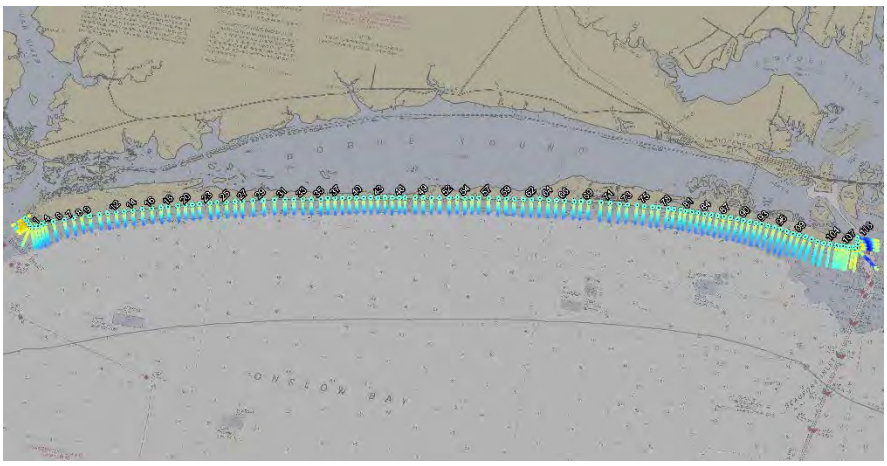
As noted, there are inevitable margins of uncertainty associated with hydrographic survey data that may reduce the accuracy of volumetric change analyses. The current estimate of uncertainty in the hydrographic portion of the survey is approximately ±0.11 ft. This results in a variability along the entire Bogue Banks shoreline of roughly ±811,000 cy when taking into account the portion of the profile seaward of the outer bar (approximately 1300 ft offshore) out to a depth of -30 ft NAVD88 (approximately 2850 ft offshore). Therefore, it is essential to thoroughly review the beach and bathymetric profiles using various analytical techniques and general engineering judgment to assure that results are not falsely interpreted. Future periodic survey evaluations will continue to improve on analysis techniques so that the rich survey data sets are best utilized.

APPENDIX A

Geodynamics Field Report

Carteret County Shore Protection Office
Beach Profile Monitoring Surveys
Carteret County, North Carolina

March-May 2018



DESCRIPTIVE REPORT

Contract / Project No.: #6668

Submitted by:

geodynamics
COMPLEX COASTAL CHANGE MADE CLEAR

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1.0 Introduction

1.1 Background

Geodynamics was contracted by the Carteret County Shore Protection Office (CCSPO) to map designated cross-section profiles, onshore and offshore of Carteret County beaches as well as Bear Island as part of the Bogue Banks Beach and Nearshore Mapping Program (BBBNMP). These efforts are divided into two separate products; seamless topographic – bathymetric elevations collected along predefined monitoring profiles and a continuous Digital Elevation Model (DEM) along Bogue Banks. This work utilizes hydrographic surveying techniques that meet or exceed the criteria outlined in the U.S. Army Corps of Engineers Hydrographic Surveying Manual, EM 1110-2-1003.

1.2 Survey Area

The survey covered approximately 34 NM of shoreline, including Bogue and Beaufort Inlets (Figure 1). Bounding coordinates of the planned survey lines are as follows; northwestern corner, 34°41’56.0” N, 077°10’28.4” W, and 34°36’33.4” N, 076°31’54.0” W for the southeast corner. The topo-bathy profile survey was conducted on and offshore Bear Island (18 profiles), Bogue Banks (122 profiles), and Shackleford Banks (24 profiles). Profile length varied from ~2000ft – 5000ft, with variations in the inlet areas. The DEM was generated using data from a fully calibrated Mobile Laser Scanner (MLS) system, used to collect millions of XYZ points, gridded into a 3 ft DEM for designated hotspot areas on Bogue Banks.

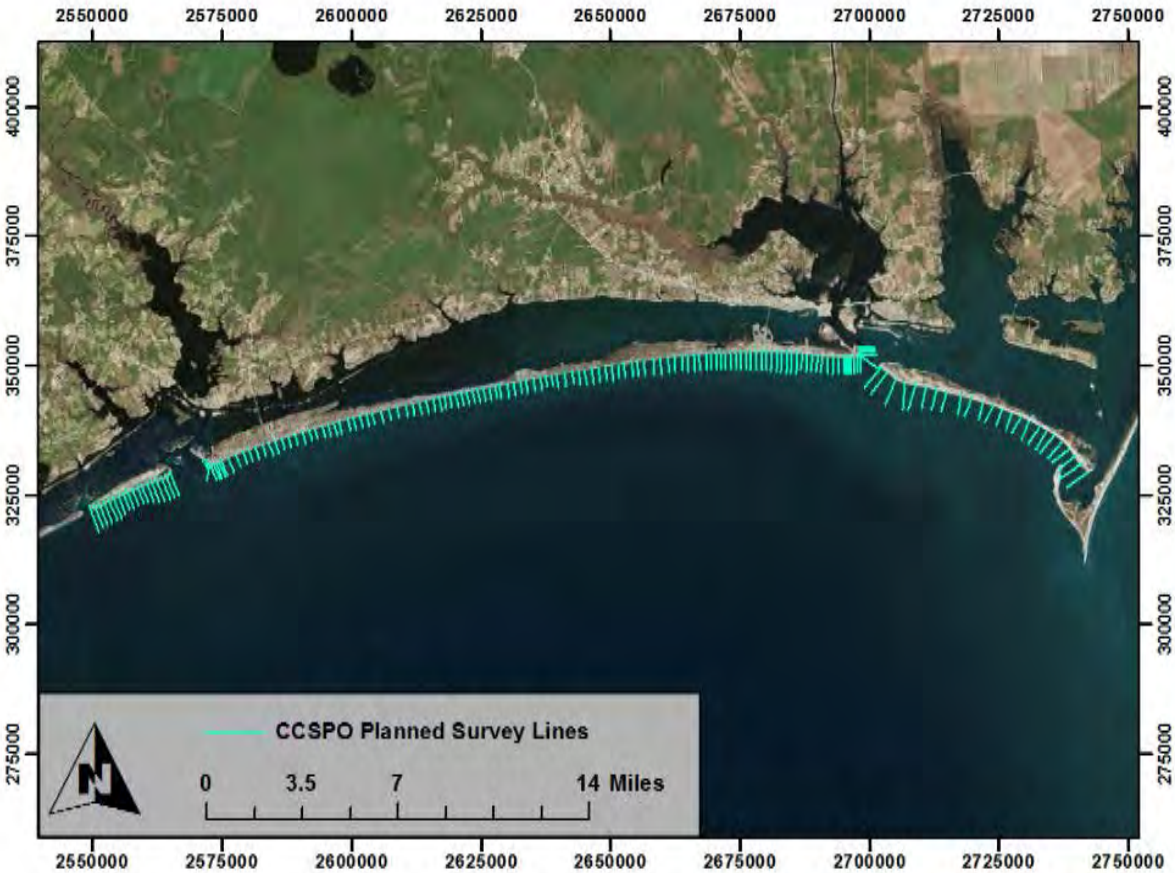


Figure 1. Planning map overview of survey lines for the BBBNMP.

1.3 Survey Objectives

As outlined in the official Scope of Work (SOW) (Appendix D), the specific goals of the surveys were to provide the following data products:

- Topo-Bathy Profiles
  - ASCII/Excel Data Files
    - Profile Location
    - Profile Number
    - Record Number
    - Method
    - Date
    - Time (UTC)
    - Easting (X)
    - Northing (Y)Elevation (Z_NAVD88)
  - Point Shapefiles with attached FGDC compliant metadata

- Arc-Grid DEM of Hotspots on Bogue Banks
    - DEM of survey locations gridded using Mobile Laser Scanner on the shoreface
- Contours and MHW Contour
    - ArcGIS compatible line shapefiles of contours and MHW contour for survey Bogue Banks Hotspot areas, and MHW for all of Bogue Banks
    - FGDC compliant metadata
- Project Deliverables
    - Survey Report
        - Written description of workflow to complete task order (start to finish) including flow chart diagram and detailed description of QA/QC process
        - Dates and times of each data collection activity
        - Atmospheric Conditions for each day of data collection activity
        - All Horizontal and Vertical Control used, including monument name, establishing agency, date established, description, and published horizontal and vertical values
        - TBM descriptions with vertical values
        - Copy of all field notes
        - Complete and detailed list of all survey equipment used, including copy of last factory calibration report
        - Metadata Records
        - Photographs of the site and any significant features or data collection techniques used

1.4 Report Purpose

The purpose of this document is to summarize the survey activities and report on the acquisition and processing methodology performed the project. This report also serves to provide illustrations and descriptions of deliverable items. For any additional information regarding survey activities, contact Geodynamics in Newport, North Carolina.

1.5 Survey Logistics

Survey activity was conducted between February 2018 and June 2018. Listed below is a generalized timeline of data acquisition (Table 1). A detailed field summary of daily activities related to the survey is presented in Appendix A. Profiles east of 90 on Atlantic Beach could not be collected until the Atlantic Beach nourishment project was completed (around the end of May). Therefore, these profiles were collected later than the remainder of Bogue Banks. Profiles 73 and 80 were recollected on the last survey leg because these profiles did not have sufficient overlap between topographic and hydrographic data upon the original collection of these profiles in April. See daily notes for more details (Appendix A).

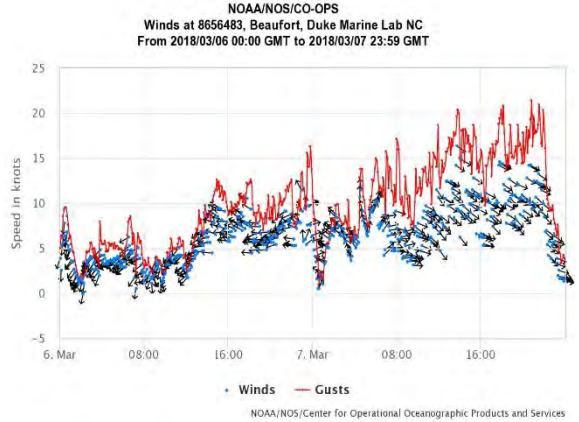
Table 1. Summary of Survey Activities

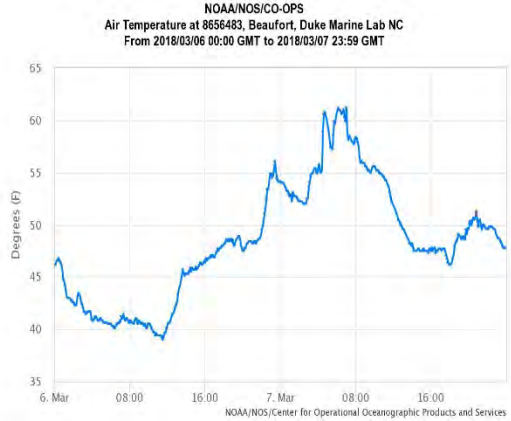
Date	Julian Day	Activity
3/6/18	65	Dune base topo data collection of Bogue Banks profiles 68-116 using RTK-Base station on “IMS BASE”.
3/7/18	66	Set up RTK-Base station on “ERBA BASE” Dune base topo data collection of Bogue Banks profiles 35-67.
3/8/18	67	Dune base topo data collection of Bogue Banks profiles 119-34 using RTK-Base station on “ERBA BASE” thus completing all the dune portions of the profiles on Bogue Banks
3/19/18	78	Topo crew collected surf zones from 116-103. Hydro crew collected all hydro from 116-103 and offshores from 102-60 using RTK-Base station on “IMS BASE”.
3/23/18	82	Topo crew collected surf zones from 120-102 thus completing the topo sections of the Bogue Banks profiles. Hydro crew collected all remaining surf zones and offshores, thus completing all hydro on Bogue Banks profiles. MLS data was acquired from EI to AB and was completed.
4/20/18	110	Topo crew collected all dune and surf zones on Shackleford Banks using RTK-Base station on “IMS BASE”.
4/21/18	111	Collected all hydro data of Shackleford Banks, thus completing the Shackleford Island survey.
5/1/18	101	Topo and Hydro crews collected all profiles on Bear Island using RTK-Base station “CGEI BASE” Thus completing all hydro and topo for Bogue Banks. Bogue Banks survey is complete, therefore, completing all surveys for BBBNMP 2018 annual survey.

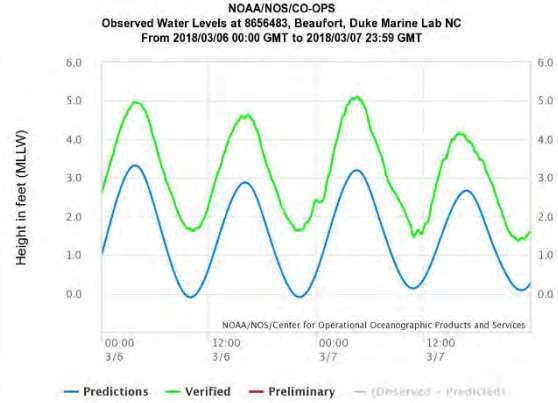
1.6 Survey Conditions

Survey activities were conducted whenever atmospheric and environmental conditions warranted. Listed below (Figure 2) are graphs of NOAA predicted and verified tide for Beaufort, NC (Station ID: 8656483) as well as surface wind and air temperature.

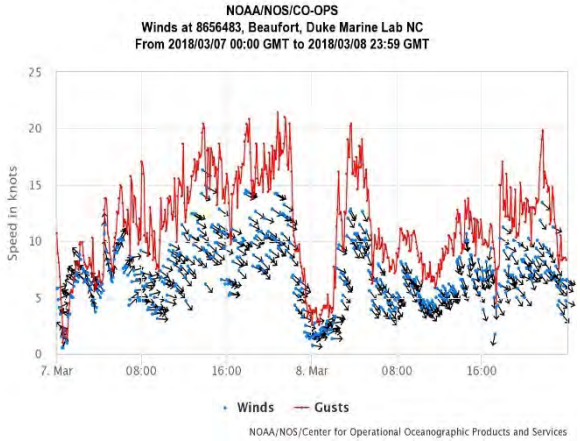
03/06/18-03/07/18: Bogue Banks Survey

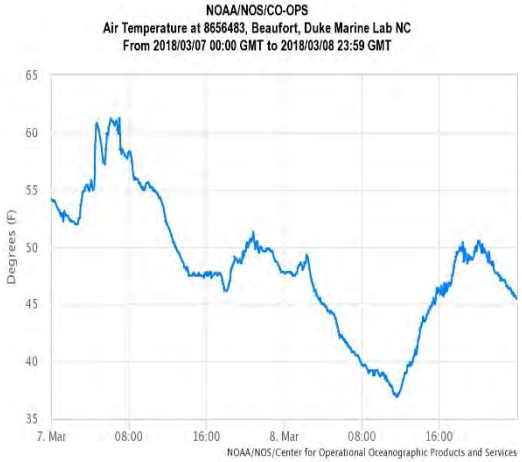


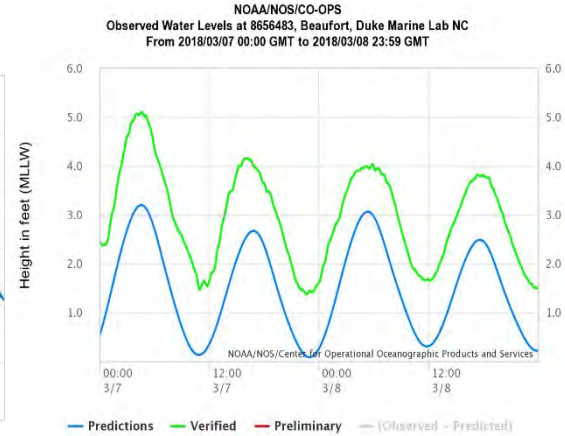




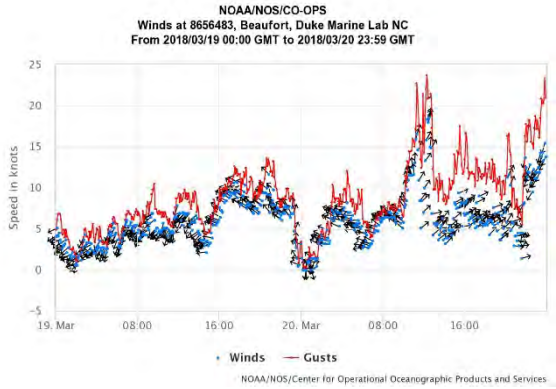
03/07/18 - 03/08/18: Bogue Banks Survey

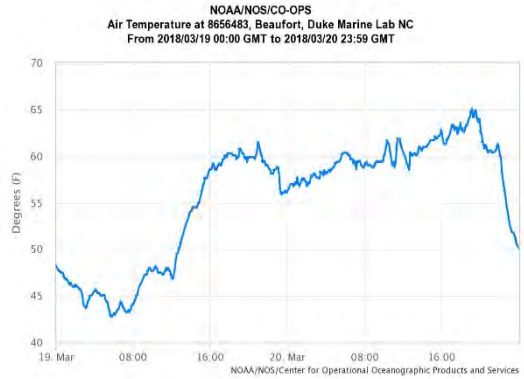


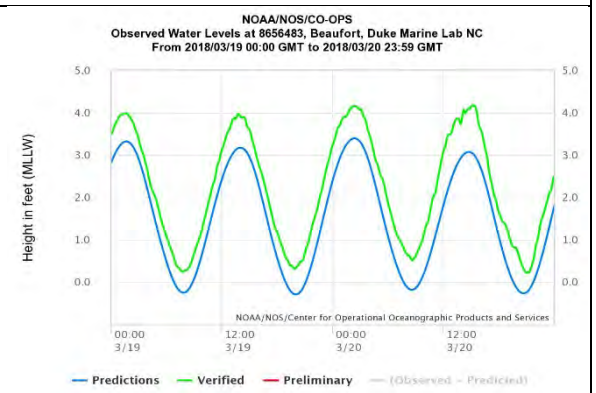




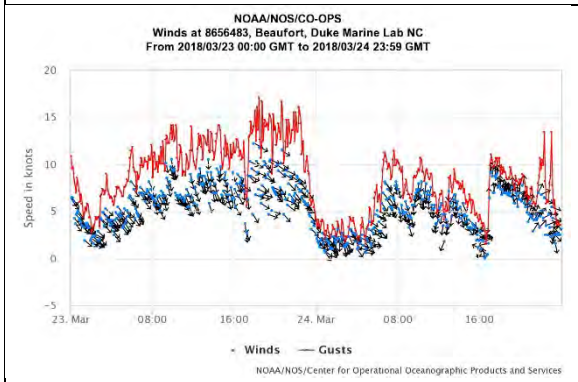
03/19/18- 03/20/18 Bogue Banks Survey

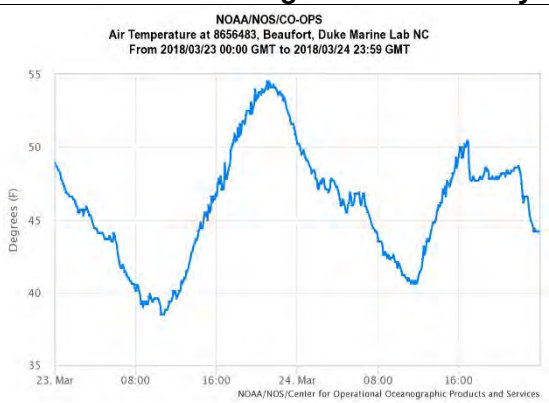


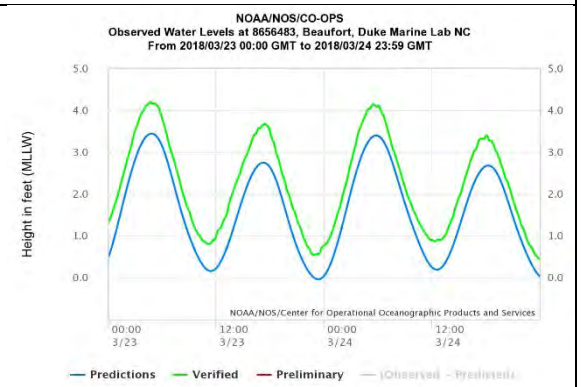




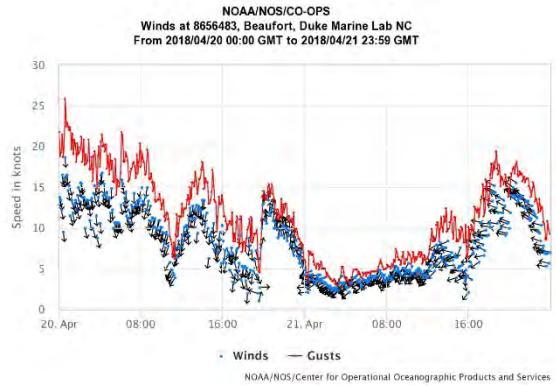
03/23/18-03/24/18 Bogue Banks Survey

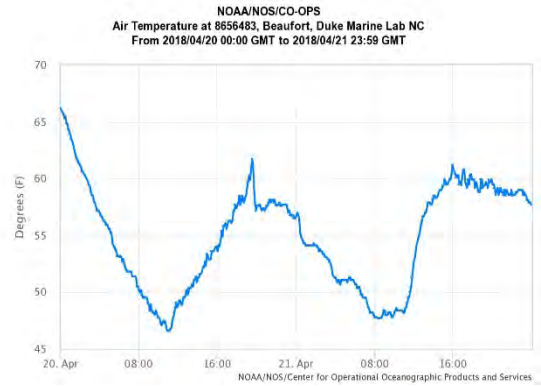


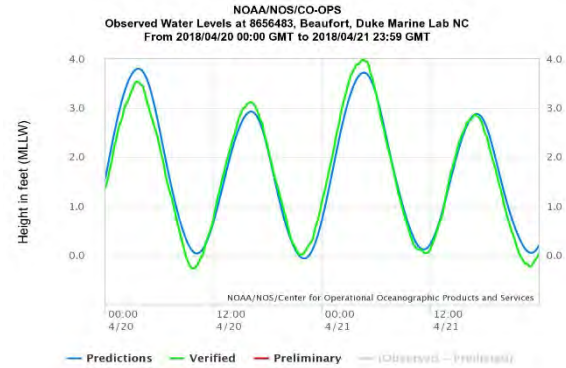




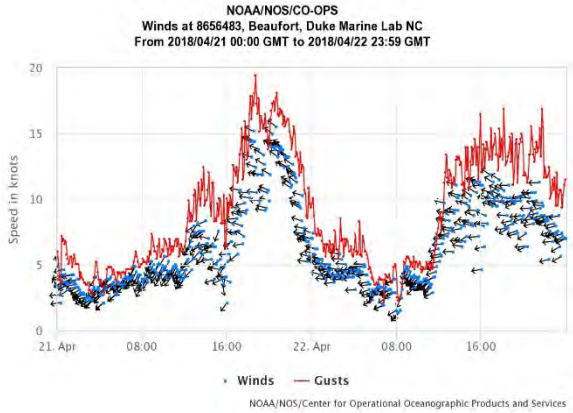
04/20/18- 04/21/18 Shackleford Banks Survey

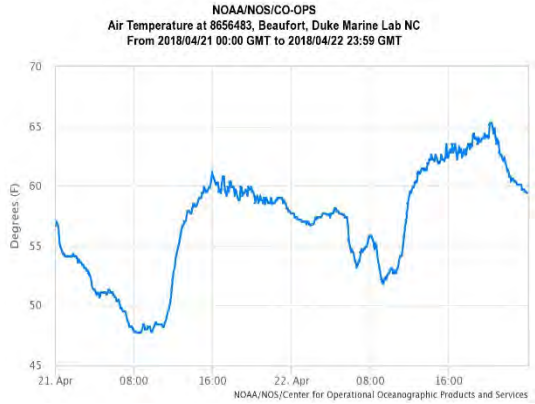


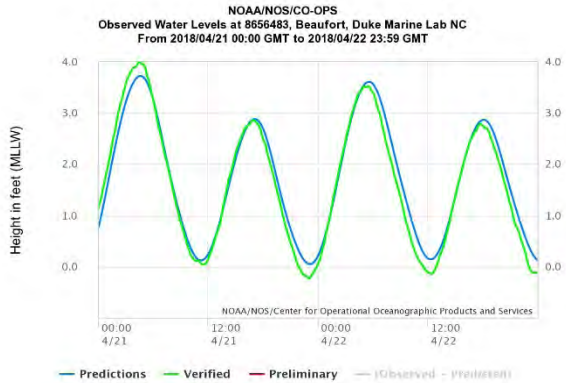




04/21/18-04/22/18: Shackleford Banks Survey







05/01/18- 05/02/18 Bear Island Survey

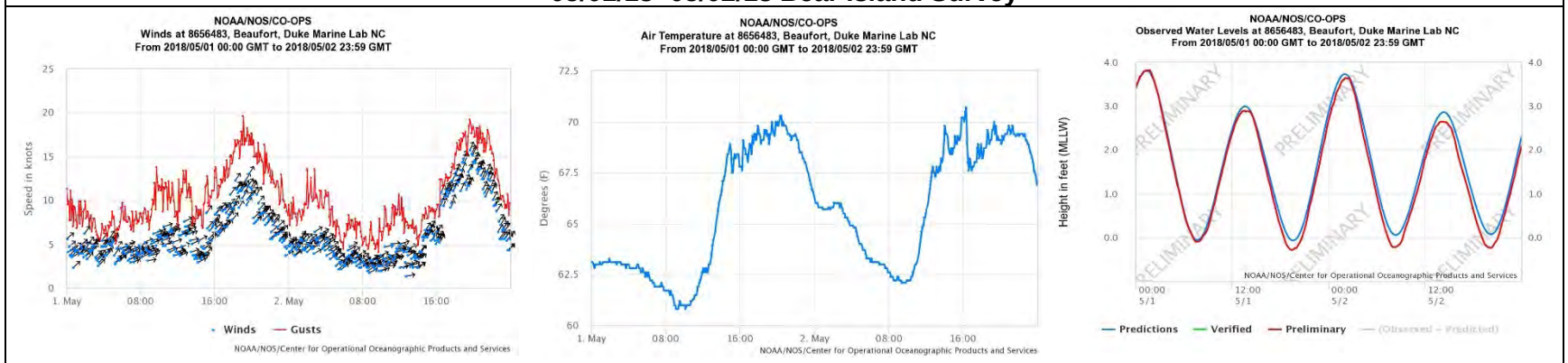


Figure 2. Atmospheric and tidal records for survey days.

1.7 Survey Personnel

All survey crew throughout the surveys were provided by Geodynamics. These personnel contributed to the vessel mobilization, data collection, vessel demobilization efforts, processing, and reporting (Table 2).

Table 2. List of Survey Personnel and Responsibilities

Survey Participant	Title	Affiliation
Ben Sumners	Lead Hydrographic Surveyor	Geodynamics
Aron Lembke	Captain, Survey & Logistics Manager	Geodynamics
Dave Bernstein	Project Manager	Geodynamics
Brandon Barnette	Field Surveyor	Geodynamics
Dan Ott	Captain, Hydrographic Surveyor	Geodynamics
Adam Powers	Field Surveyor	Geodynamics
Nick Damm	Field Surveyor	Geodynamics
Brian Johnson	Captain, Hydrographic Surveyor	Geodynamics

1.8 Navigation and Positioning

Each data point obtained during the hydrographic and topographic survey activities have a geographic location associated with it to facilitate database entry and display of these data within a GIS frame work. To more accurately position elevations, all elevations/soundings were collected with Real Time Kinematic (RTK) GPS corrections to provide < +/-0.20 ft vertical and < +/-1.0 ft horizontal accuracy, as requested per SOW. RTK-GPS corrections were generated from a Global Navigation Satellite System (GNSS) enabled, R7 Trimble receiver and broadcasted via 5 dB gain UHF antenna from the base station installed by Geodynamics at one of three locations, based on area to be surveyed and extents of UHF transmission (Table 3, Figure 3). HYPACK Max utilized an X/Y grid system based on the North American Datum of 1983 (NAD83), North Carolina State Plane Feet Zone 3200 (NC SPF83) and reduced from the ellipsoid using Geoid 2012A.

Table 3. RTK-GPS base station coordinates.

Base station Name	Latitude	Longitude	Ellipsoid Height (NAD83)	Orthometric Height
IMS BASE	34 43 25.39287 N	076 45 06.62217 W	-19.230 m	18.233 m
CGEI BASE	34 38 50.53087 N	077 05 46.14191 W	-35.469 m	1.697 m
ERBA BASE	34 40 32.92648 N	076 57 24.30785 W	-28.436 m	8.873 m

IMS Base

CGEI Base

ERBA Base

Figure 3. Photos showing the "IMS Base", "CGEI Base" and "ERBA Base" base stations from top to bottom.

A. TOPO-BATHY PROFILES

2.0 Singlebeam Sonar Survey Methodology

2.1 Equipment and Control

2.1.1 Vessels

2.1.1.1 R/V Echo

The R/V Echo served as the primary survey platform for nearshore singlebeam data acquisition (Figure 4, Table 4). The R/V Echo is specifically designed to be a vessel of opportunity for shallow water inshore and coastal ocean mapping. The R/V Echo is equipped with a thru-hull transducer that is tightly coupled with inertial navigation system (INS) for positioning and elevation. On-the-fly sound speed sensors and customized computer systems allow seamless logging of bathymetric data.

Figure 4: R/V Echo

Table 4: R/V Echo Vessel Specifications

Dimensions:	21' x 9' x 1.2'
USCG:	Designated Research Vessel
Flag:	U.S.
Registry:	North Carolina
Official Number:	NC 7341 DT
Tonnage:	1
Lab space:	1 open console operator station
Max Speed:	30 knots
Min. survey speed:	2.5 knots
Propulsion:	1 x 140 HP Suzuki 4-Stroke Outboard Motor -2011
Auxiliary Power:	24v DC battery bank and 12v DC parallel battery banks
Fuel capacity:	60 gallons
GPS:	Simrad
Sounder:	Lowrance StructureScan
Compass:	n/a
Radar:	n/a
Autopilot:	n/a
VHF:	Icom 25 watt
Internet:	Verizon 4G Jetpack

2.1.1.2 Software Systems Inventory

Software utilized throughout the project can be seen in Table 5.

Table 5: Software Systems Inventory

	Software	Version
Data Acquisition	HYPACK	2014
	Odom E-Chart	1.4.0
	POSView	8.21
	SeaCast	4.3.1
	NTRIP Client	2013.11.24
Data Processing	HYPACK	2016a
	POSPac	7.1 SP3
	ArcGIS	10.5
	MS Office	2016
	Surfer	9

2.1.1.3 Hardware Systems Inventory

Hardware utilized throughout the project can be seen in Table 6.

Table 6: R/V Echo Hardware Systems Inventory

	Hardware Equipment	Manufacturer	Model
Horizontal & Vertical Control	RTK Radio Modem	Trimble	TDL 450H
	RTK Radio Antenna	Pacific Crest	n/a
	GPS Antenna	Trimble	Zephyr
	Cellular Internet Card	Verizon	4G LTE JetPack
	POS MV	Applanix	WaveMaster
Echo Sounding	StructureScan	Simrad	1.7.0
	ODOM CV100	ODOM	CV100
	Operator Station	CCS-inc	FPC-04649
Attitude Positioning	Inertial Motion Unit (IMU)	Applanix	WaveMaster
	Position Compute System (PCS)	Applanix	WaveMaster
	Primary GPS Antenna (port)	Trimble	Zephyr
	Secondary GPS Antenna	Trimble	Zephyr
Sound Speed	Sound Profile Velocimeter	AML Oceanographic	Minos X SVP

2.1.1.4 Sonar Equipment

An Odom CV100 singlebeam sonar system was used to acquire singlebeam bathymetry data during the topo-bathy profile survey (Figure 5). The CV100 system operates at frequencies in the 200 kHz band; ideal for shallow depths. The transducer forms a 4 degree conical beam. With an operational depth range from <30 cm to 600 m and a ping rate up to 20 Hz, the CV100 is ideal for shallow water surveys (Table 7).

Table 7: CV100 specification

Frequencies.	200 kHz / 33 kHz
Maximum ping rate.	up to 20 Hz
Heave compensation	Yes
Depth resolution	1 cm
Transducer	Airmar SMSW200-4a

Figure 5: Odom CV100 digital echosounder mounted on the R/V Echo.

2.1.2 Vertical Control

The vertical datum for the final survey data is the North American Vertical Datum of 1988 (NAVD88). The ellipsoid-based real-time vertical water level corrections were reduced to the NAVD88 by integrating a local Geoid 2012A model in the singlebeam data processing stage.

2.1.3 Horizontal Control

Horizontal positioning and vessel attitude for singlebeam data was provided by the POS MV system and was corrected using Inertial-Aided Real-Time Kinematic (IARTK) technology. This system provides roll and pitch accuracy to 0.01°, heading to 0.02° (with a 2 m antenna baseline), heave accuracy to 5 cm or 5% (whichever is greater).

2.2 Singlebeam Data Acquisition

2.2.1 Data Acquisition Software

The HYPACK software suite was used during survey preparation to create survey line plans and evaluate the overall survey scheme. The initial line plan was created in HYPACK using a line spacing such to acquire survey data over pre-existing profiles developed by USACE. HYPACK was also used during the survey in order to record sounding and position data. HYPACK was also used to log targets of importance and provide the captain with line tracking.

The ODOM eChart software was used as a start-up interface to establish communications with the echosounder, check/verify essential echosounder settings and provide transmit and receive gain controls of the singlebeam echosounder.

The POSView software by Applanix was used with the POS MV system. The software provides the interface to view, monitor, and record tightly-coupled integration of the attitude measurements from the IMU and position and heading measurements recorded by the GPS. The recorded POSPac file which contained all of the attitude, positioning, heading, and error estimates of attitude and positioning provides a method to post-process attitude and navigation data in the event of RTK-GPS cycle slips.

2.3 Singlebeam Data Processing

2.3.1 Processing Workflow

Figure 6 illustrates the workflow in singlebeam sonar data processing.

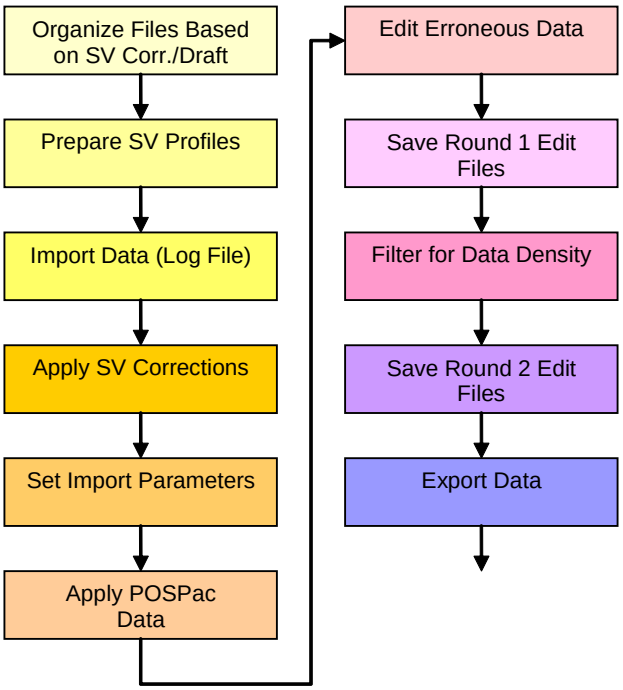


Figure 6: HYPACK singlebeam data processing workflow.

2.3.1.1 Corrections to Echo Soundings

2.3.1.2 POS MV WM Correctors

The Applanix POS MV unit was setup to receive phase-differential RTK position offsets from the RTK-GPS base station. This configuration allowed the POS MV to integrate decimeter positional solutions with highly-accurate vessel attitude positions obtained from the IMU. When the GAMS is online, positional solutions were being received from 5 or more satellite fixes with a Positional Dilution of Precision (PDOP) equal to or less than 3. When these conditions were not satisfied, the GAMS solution becomes dormant. The GAMS program continues to track satellites while in this state, but does not process the phase-differential corrections real-time.

A verification of the GAMS system was conducted prior to the start of the project. The values in use for this survey were obtained from a GAMS calibration that followed the auto-start procedure laid out in the POS MV V5 Installation and Operation Guide. The GAMS parameters in the setup menu were initially set to zero, with the exception of the heading calibration threshold which was set to 0.500°. The vessel then made aggressive figure-8 maneuvers until the GAMS solution came online and the values in the parameter setup menu were automatically updated. This calibration remains valid until vessel offsets are changed.

Due to inherent and common problems associated with RTK-GPS, such as cycle slips, high DOP periods, and data gaps, the POSPac data is routinely post-processed in the Applanix POSPac software suite. For this survey, however, RTK-GPS quality was excellent during hydrographic data collection and adding the processed POSPac data to the final data was deemed unnecessary. The POSPac data were processed only to verify and provide quality assurance for the RTK-GPS data.

2.3.1.3 Dynamic Draft Correctors

Dynamic draft is the summation of the static draft and settlement and squat corrections, and is a required corrector for the echo soundings. Dynamic draft was accounted for in the echo soundings by using RTK-GPS ellipsoid-based vertical corrections. The combined correctors work to continuously factor out the static draft, settlement, and squat of the survey vessel.

2.3.1.4 Sound Speed Correctors

The AML Oceanographic Minos X SVP (Figure 7) sound velocimeter was used during the survey in order to obtain accurate sound speed profiles throughout the survey area.

The Minos X system onboard R/V Echo comprises a sound speed probe which logs casts throughout the day and is later connected to a computer where the survey technician downloads the sound speed profile data.

Figure 7: AML Oceanographic Minos X Velocimeter.

Sound speed profiles were taken at the start of each survey day, and again throughout the day as warranted by the survey area and water properties. Sound speed profiles were also acquired when the survey vessel moved to a different location in the survey area (Figure 8). Each sound speed cast was assessed in processing to determine water properties in a specific zone of the survey area.

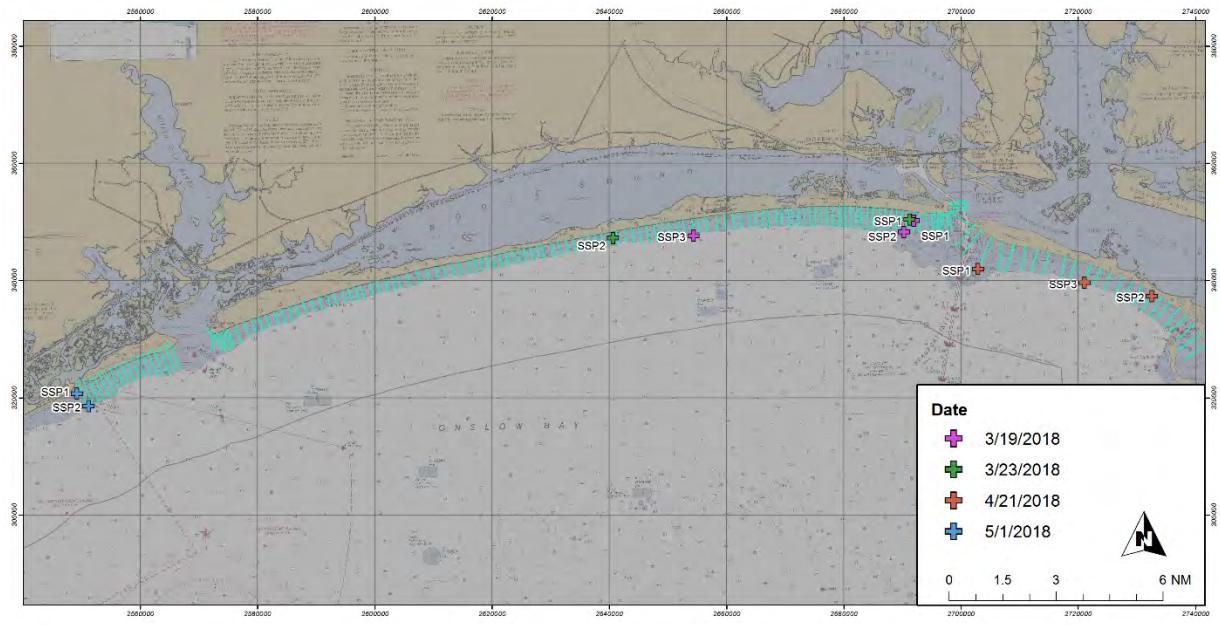


Figure 8: Sound speed profile locations for singlebeam survey operations.

2.3.1.5 Water Level Correctors

RTK-GPS based tidal measurements were continuously recorded throughout the survey by HYPACK Survey. The GPS height determined by the POS MV was integrated into the raw singlebeam sonar data during data acquisition in real time. After importing the raw singlebeam data in HYPACK, the GPS tide was merged with the heave such to provide accurate tidal corrections and subtract vessel heave from the final elevations.

2.4 Quality Control

2.4.1 Singlebeam Data Acquisition and Monitoring

At the start of each survey day, a series of pre-survey protocols were run to aid in quality control and to determine any possible errors/issues prior to surveying. For hydro, the GAMS parameters and POS MV installation parameters located under the installation settings of the POS MV were all checked each day prior to enabling Ethernet logging of POSPac data.

Data was collected at vessel speeds of approximately 3 - 10 kt. The HYPACK data acquisition software provides data waterfalls and coverage indicators, which allowed for real-time monitoring of the data quality and coverage. Data displays in HYPACK Survey were used to monitor all survey parameters and the quality of data being recorded.

Sound speed profiles were acquired routinely and when the survey vessel moved to a different location within the survey area. Each successive sound speed cast was compared and assessed to determine the optimal casts per reach of profiles.

2.4.2 Singlebeam Calibration Checks

The R/V Echo has a built-in transducer in the rear of the starboard hull. Geodetic and mechanical bar index checks have been performed to calibrate for a constant, electronic offset, inherent in all

singlebeam systems (Figure 9). Please refer to Appendix C: Singlebeam Echosounder Calibration Report, for more details.

Figure 9: Image illustrating the mechanical bar check of sonar index.

A more recent technique to calibrate sonars for sound velocity is a digital bar check, or sound speed cast (Figure 8). Similar to performing a bar check, in theory, digital bar checks are a safer and more efficient alternative to traditional bar checks, and are critical to sonar data acquisition in shallow, inter-tidal, coastal zones. Therefore, in order to maintain the best data quality across vast areas in this dynamic coastal environment, the traditional mechanical bar check (Figure 9) is only used to verify the sonar system index since corrections are made to the transducer (not the waterline) and sound speed profiles correct the sounder for speed of sound in the water column.

3.0 Topographic Elevation Data Methodology

3.1 Equipment and Control

3.1.1 Survey Equipment

A Trimble R7 RTK-GNSS rover backpack system was used to acquire topographic data during the survey. The Trimble R7 RTK-GNSS receiver integrates GNSS observables with real-time RTK network corrections to provide centimeter-level position and elevation. The RTK-GNSS data is output from the R7 receiver at 10 Hz to the Panasonic Tough book FZ-M1 data acquisition tablet PC (Table 8). An ATV is used to transport personnel between profiles, as well as a platform to collect MLS data (Figure 10).

Figure 10: ATV used for transportation.

3.1.2 Hardware Systems Inventory

Table 8: Hardware Systems Inventory

Hardware Equipment	Manufacturer	Model
Acquisition PC	Panasonic	Toughbook FZ-M1
GPS Receiver	Trimble	R7
GPS Antenna	Trimble	Zephyr 2

3.1.3 Vertical and Horizontal Control Equipment

Horizontal and vertical positioning for topographic data was acquired by a Trimble R7 RTK-GNSS system. The topographic rover received and integrated the differential corrections from the RTK-GNSS base station for centimeter-level positioning.

3.1.4 Software Systems Inventory

Software utilized throughout the project can be seen in Table 9.

Table 9: Software Systems Inventory

	Software	Version
Data Acquisition	HYPACK	2015
	NTRIP Client	2013.11.24
Data Processing	HYPACK	2016a
	ArcGIS	10.5
	MS Office	2016
	Surfer	9

3.1.5 Data Acquisition Software

The HYPACK software suite was used during survey preparation in order to create profile line plans. The initial line plan was supplied by USACE Wilmington District. HYPACK was also used during the survey to collect topographic data, as well as for in-field quality control and real-time quality assessment.

3.1.6 Data Processing Software

HYPACK was used to manipulate and process the topographic data. The Singlebeam Editor in HYPACK was used to import, clean, and thin the data.

ArcGIS is a complete Geographic Information Systems (GIS) software package. All survey area maps, coverage extents, and final chart products were created using ArcGIS.

3.2 Quality Control

3.2.1.1 Procedures

3.2.1.2 Survey Planning

All survey line planning was completed in HYPACK. The landward extent of topographic data collection was set to provide coverage to the extents of prior USACE topographic data. All profiles were generated from predefined start point, distances, and azimuths per USACE.

3.2.1.3 Topographic Data Acquisition and Monitoring

At the start of each survey day, a series of pre-survey protocols were run to aid in quality control and to determine any possible errors/issues prior to surveying. Each surveyor's backpack antenna draft was checked and input in the HYPACK survey software. Data acquisition was performed by experienced surveyors, walking as upright and consistent as possible while following the planned survey line, as to mimic the topography. The surveyor constantly monitored GPS status, off-line value, distance from baseline (DBL), previous data coverage, and overall morphology along the profile. To ensure ample topographic data overlap with the hydrographic data, the

surveyor would plot the targets acquired during the surfzone hydrographic survey. These targets indicated how far the surveyor needed to go down the profile and into the surfzone. Upon completion of a survey day and throughout the day, data was thoroughly reviewed and various profiles overlaid on previous profile data for an in-field quality assurance check.

3.3 Topographic Data Processing

Topographic data processing occurred in HYPACK Singlebeam Editor software and follows the general procedure illustrated in Figure 11.

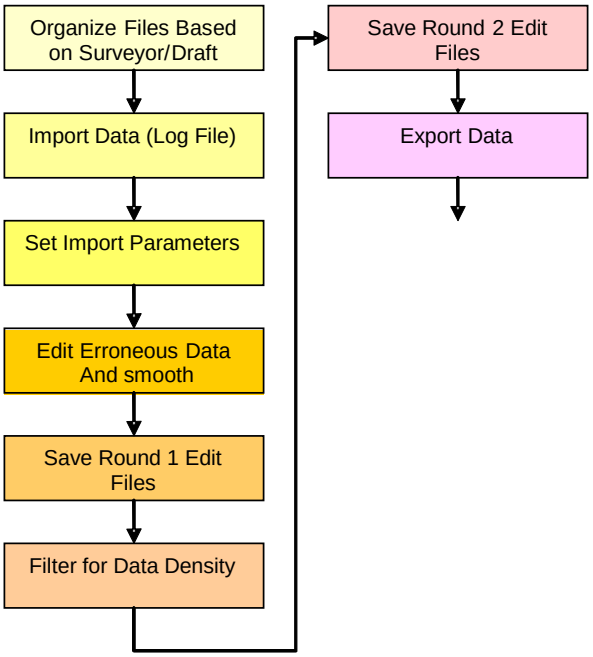


Figure 11: HYPACK topographic data processing workflow

4.0 Mobile Laser Scanning Data Acquisition and Processing

4.1 Equipment

4.2 Mobile Laser Scanning Equipment

MLS topographic data were collected using a RIEGL VZ-400-i 3D laser scanning system. The MLS was mounted on a Polaris ATV approximately eight feet above the terrain (Figure 12). This system was coupled with its own internal navigation and attitude system, the POS MV OceanMaster (OM), whose IMU is placed directly below the laser scanner to minimize lever arms and potential sources of alignment errors. The MLS and POS MV were integrated into QINSy, a comprehensive software suite utilized for survey planning, survey acquisition and alignment verification. POSView was utilized to monitor real-time GNSS health as well as log all navigation / attitude data for post-processing. The MLS was setup to scan the human eye field of view (from 70-130 degrees) at a scanning resolution of 0.180° at 80 kHz measurement rate and a high speed scan rate. Additionally, the MLS was setup in radar mode, therefore, the laser rotates a full 360° during data collection.

Figure 12: The Polaris ATV with the custom mount for mobile laser scanning (MLS) acquisition.

4.3 Hardware

4.3.1.1 Hardware Systems Inventory

Table 10: Laser Scanning Hardware Systems Inventory

Hardware Equipment	Manufacturer	Model
Laser Scanner	Riegl	VZ-400i 3D
Acquisition Laptop	Dell	Rugged Laptop
Cellular Internet	Verizon	JetPack 4G
Inertial Motion Unit (IMU)	Applanix	65
Position Compute System (PCS)	Applanix	OceanMaster
Primary GNSS Antenna (port)	Trimble	AT1675-540TS
Secondary GNSS Antenna	Trimble	AT1675-540TS

4.3.2 Software

4.3.2.1 Software Systems Inventory

Table 11: Software Systems Inventory

	Software	Version
Data Acquisition	QINSy	8.16.0
	POSView	8.21
Data Processing	Qimera	1.6.1, 64 Bit
	ArcGIS	10.5
	POSPac MMS	7.1
	Hypack	2016a

4.3.2.2 Data Acquisition Software

QINSy software suite was used to collect MLS data and provide real-time QC and QA of the MLS data.

The POSView software by Applanix was used with the POSMV OM system. The software provides a tightly-coupled integration of the attitude measurements recorded by the Inertial Motion Unit (IMU) and the position measurements recorded by the GNSS. POSView allowed the survey technician to monitor the attitude and positioning accuracy throughout the survey. POSView logged a POSPac file which contained all of the error estimates for attitude and positioning.

4.3.2.3 Data Processing Software

The POSPac MMS software by Applanix was used to post-process attitude and navigation data collected in POSView. By post-processing the attitude and navigation data stored in the POSPac data file with a logged GNSS observable file from the base station, common artifacts of RTK-GNSS can most often be eliminated and the overall accuracy of the attitude and navigation can be increased. Therefore, POSPac data is routinely post-processed in the Applanix POSPac software suite. For this survey, POSPac data was post-processed to correct MLS data where quality of GNSS collection was slightly degraded.

Qimera was used to integrate the post-processed GPS solution and manipulate and process the laser scanner data in both 2D and 3D. In Qimera, a 2 ft surface of the beach face was created using the MLS data. Upon cleaning the data for errors and noise, the Export Dynamics Surface tool was used to export the surface as an ASCII file. This ASCII was then extracted to the mid-beach portion of the profiles in HYPACK and was also used in DEM generation. The Singlebeam Editor in HYPACK was then used to clean, merge, and thin the profile data.

4.4 Quality Control

4.4.1 Procedures

4.4.1.1 Survey Planning

Pre-survey checks were done to ensure the laser was mounted properly. Integrated systems were tested at the Morehead City office facility prior to on-site mobilization.

4.4.1.2 Laser Scanning Data Acquisition

At the start of the survey day, a series of pre-survey protocols were run to aid in QC and to determine any possible errors/issues prior to surveying. The POS MV OM installation parameters located under the installation settings of the POS MV OM were all checked each day prior to enabling Ethernet Logging of POSPac data.

All laser data acquisition was completed using QINSy software. Data acquisition was performed at speeds of approximately 5 knots along the main beach face, between the bottom of the first dune and the waterline. The QINSy data acquisition software produced a constantly-updated OTF gridding, which allowed for real-time monitoring of the data coverage. Data displays in QINSy software and POS MV OM were used to monitor all survey parameters and the quality of data being recorded.

4.5 Corrections to Laser Data

4.5.1 Sensor Offsets

The vessel offsets are measured with respect to the vessel's reference point, located at the top center of the IMU. The vessel offsets are entered into POSView to ensure an accurate merging of the IMU data with the MLS data.

4.5.2 POS/WM Correctors

The Applanix POSMV OM unit was setup to receive phase-differential RTK position offsets from the base station. This configuration allowed the POS MV OM to integrate decimeter positional solutions with highly-accurate vessel attitude positions obtained from the IMU. When the GAMS is online, positional solutions were being received from 5 or more satellite fixes with a PDOP equal to or less than 3. When these conditions were not satisfied, the GAMS solution becomes dormant and survey operations halted. The GAMS program continues to track satellites while in this state, but does not process the phase-differential corrections real-time.

Verification of the calibration of the GAMS system was conducted at the start of survey on 4/11/18 on site, following the auto-start procedure laid out in the POS MV V5 Installation and Operation Guide. To calibrate the GAMS system, GAMS parameters in the setup menu are initially set to zero, with the exception of the heading calibration threshold which was set to 0.500°. The platform then makes aggressive figure-8 maneuvers until the GAMS solution came online and the values in the parameter setup menu were automatically updated.

4.5.3 Dynamic Draft Correctors

Dynamic draft is the summation of the static draft and settlement and squat corrections, and is a required corrector for the MLS data. Dynamic draft was accounted for in the MLS data by using RTK-GNSS. The ellipsoid-based vertical corrections received from the RTK-GNSS base station provided the survey vehicle with an accurate real-time elevation based on the vehicle's position.

The combined correctors work to factor out the static draft, settlement, and squat of the survey vehicle.

4.6 Data Processing

4.6.1 Laser Scanning Data Processing

MLS data was processed using Qimera. The data was filtered by height to remove unwanted data landward of the first dune and seaward of 0' NAVD88. In addition, to reduce the millions of points to a manageable dataset and remove fliers, a medium spline filter was run on all the data. Once the data was filtered it was hand cleaned to remove any errant data points the filters missed.

4.6.1.1 Processing Workflow

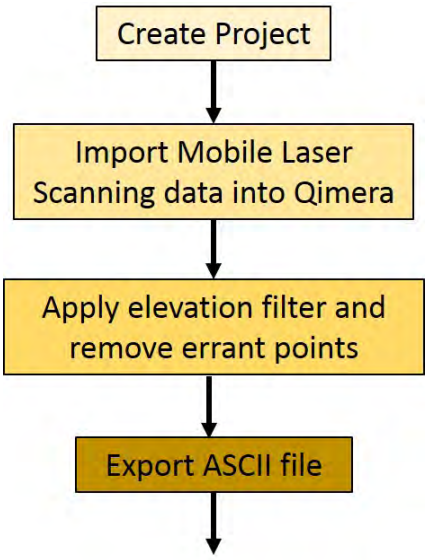


Figure 13: Qimera data processing workflow

4.6.1.2 Correctors Applied in Post-Processing

Due to inherent and common problems associated with RTK-GNSS, such as cycle slips, high DOP periods, and data gaps, the POSPac data is routinely post-processed in the Applanix POSPac software suite. For this survey, POSPac data was post-processed and utilized for MLS data to fix areas of slight degraded GNSS quality.

5.0 Topo-Bathy Profile Merging

The production of seamless topo-bathy profiles follows the general procedure illustrated in Figure 14. XYZ data from a 2 ft MLS grid was trimmed to the mid-beach extents, and Topographic and bathymetric portions of the profiles are merged in HYPACK following independent processing procedures. Overlap was assessed and cleaned for consistency where necessary. Profile elevation data was generated in formats required by the SOW. Completed profiles for all Bogue Banks, Bear Island, and Shackleford Banks are shown in Figure 15, Figure 16 and Figure 15, respectively.

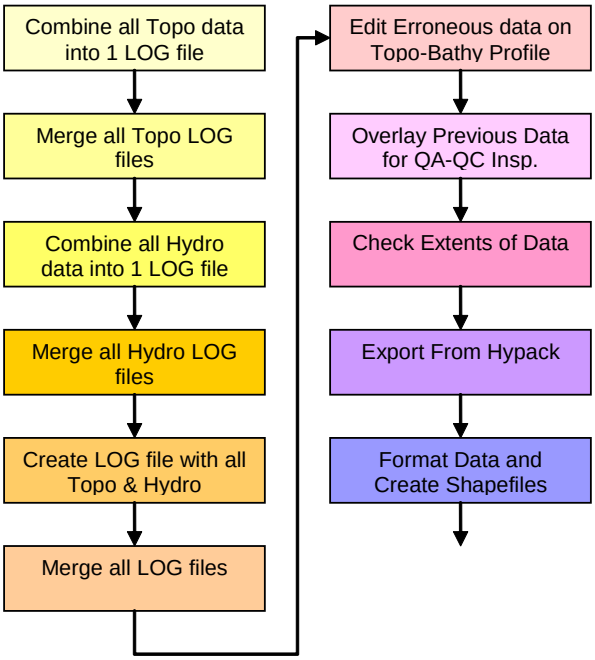


Figure 14: HYPACK topo-bathy profile data processing workflow

Rigorous QA-QC assessments are performed on the final topo-bathy profiles to ensure the accurate data products. For topographic data, in the less variable dune areas, current data is overlaid with previous data and the horizontal and vertical alignment is evaluated. For hydrographic data, in the furthest offshore sections, elevations are compared where they are expected not to significantly change. The following maps (Figure 15 – Figure 17) illustrate depths and extents of the topo-bathy profiles. The merged topo-bathy profiles are examined one-by-one to review the overlap of topographic and hydrographic data to guarantee reliable surfzone data and overlap (Figure 18).

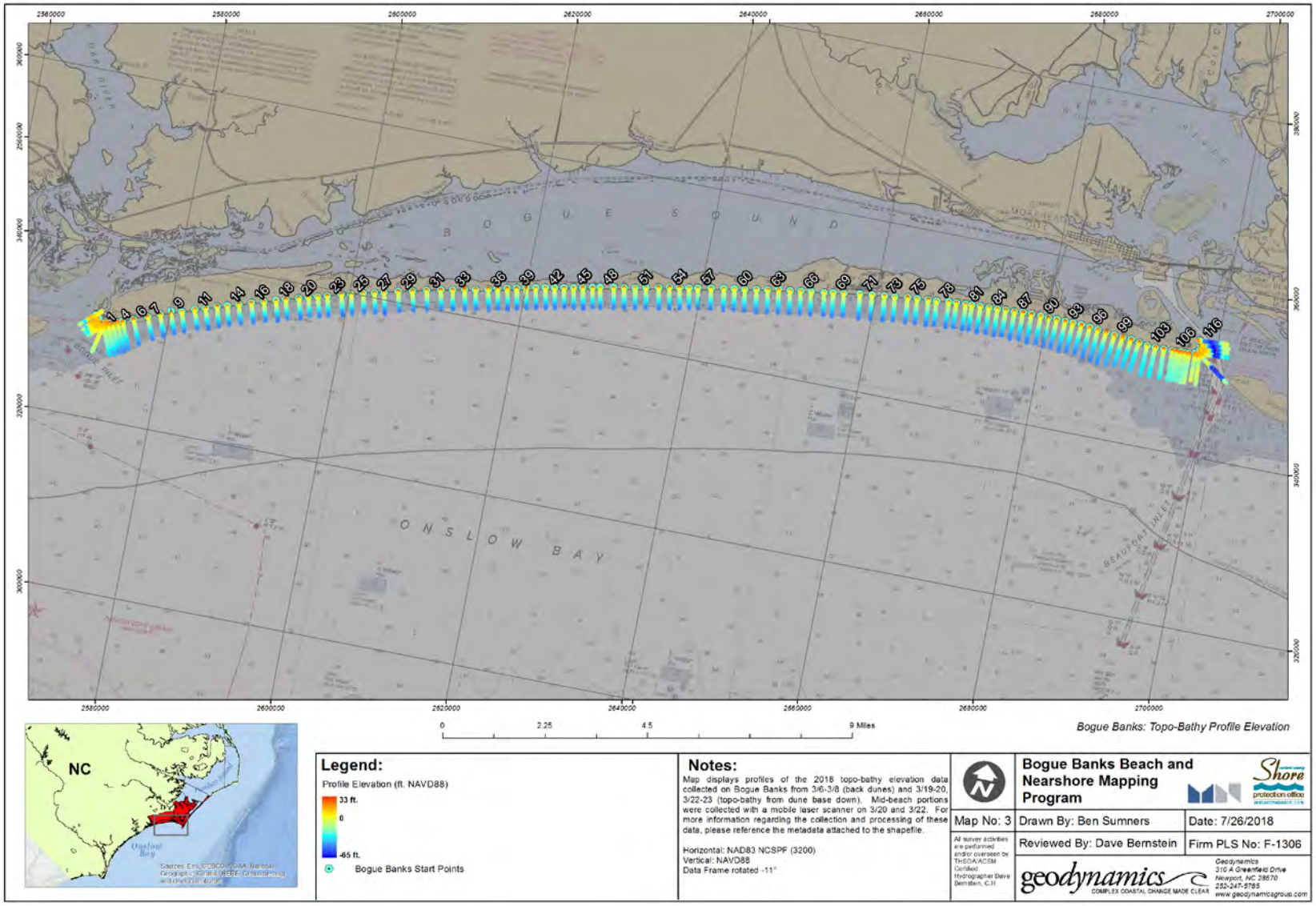


Figure 15: Topo-bathy profiles for Bogue Banks

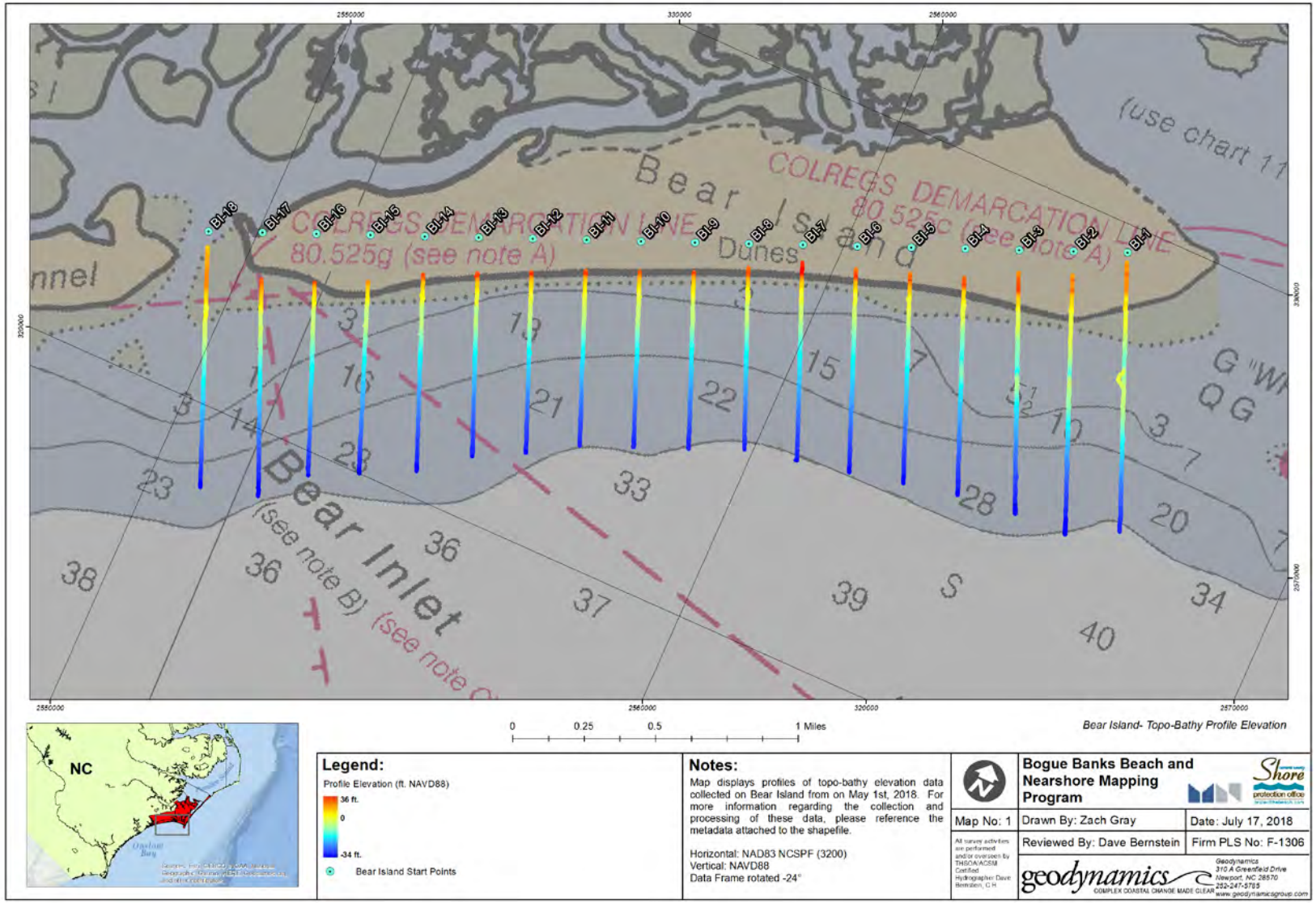


Figure 16: Topo-bathy profiles for Bear Island.

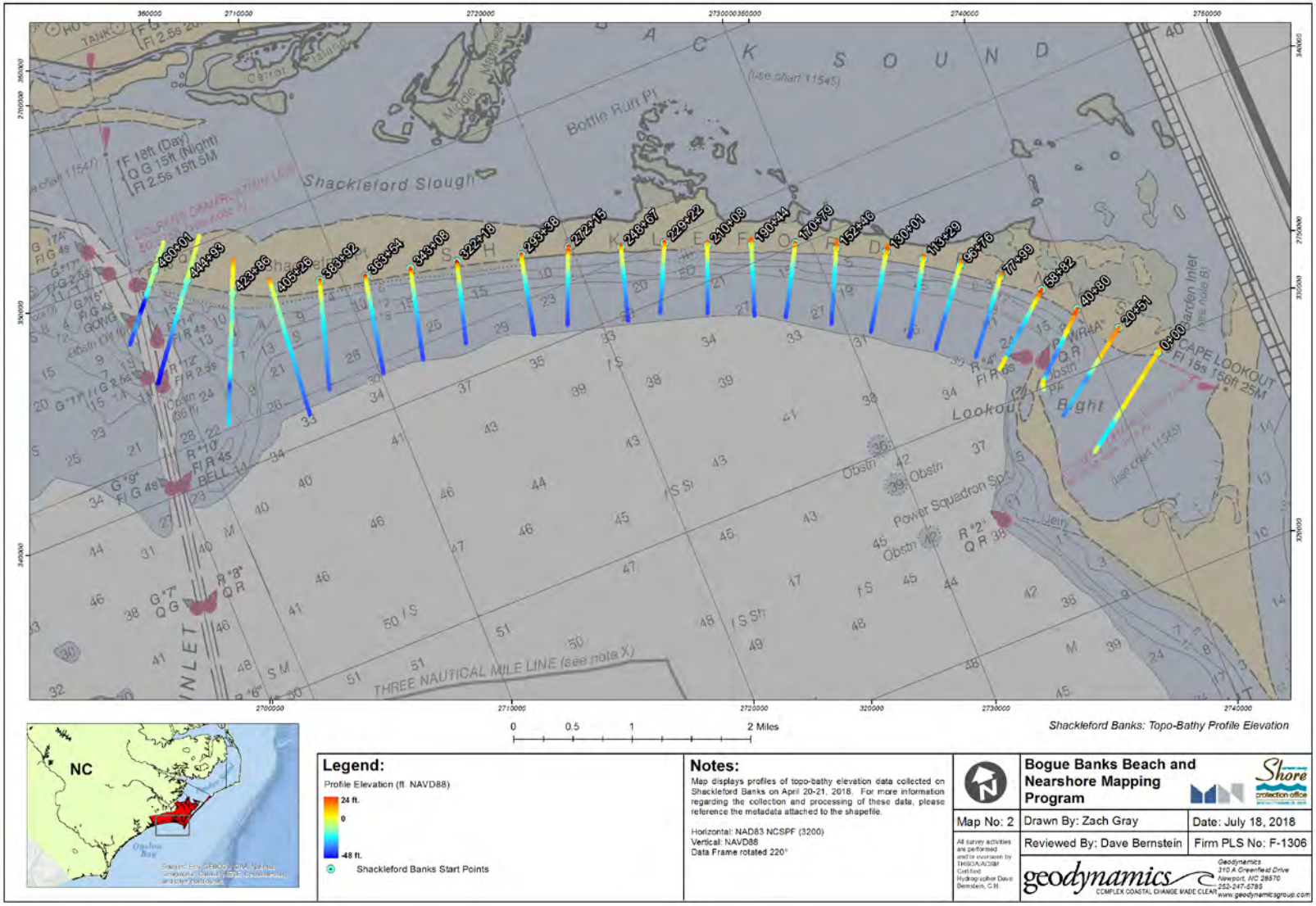


Figure 17: Topo-bathy profiles for Shackleford Banks.

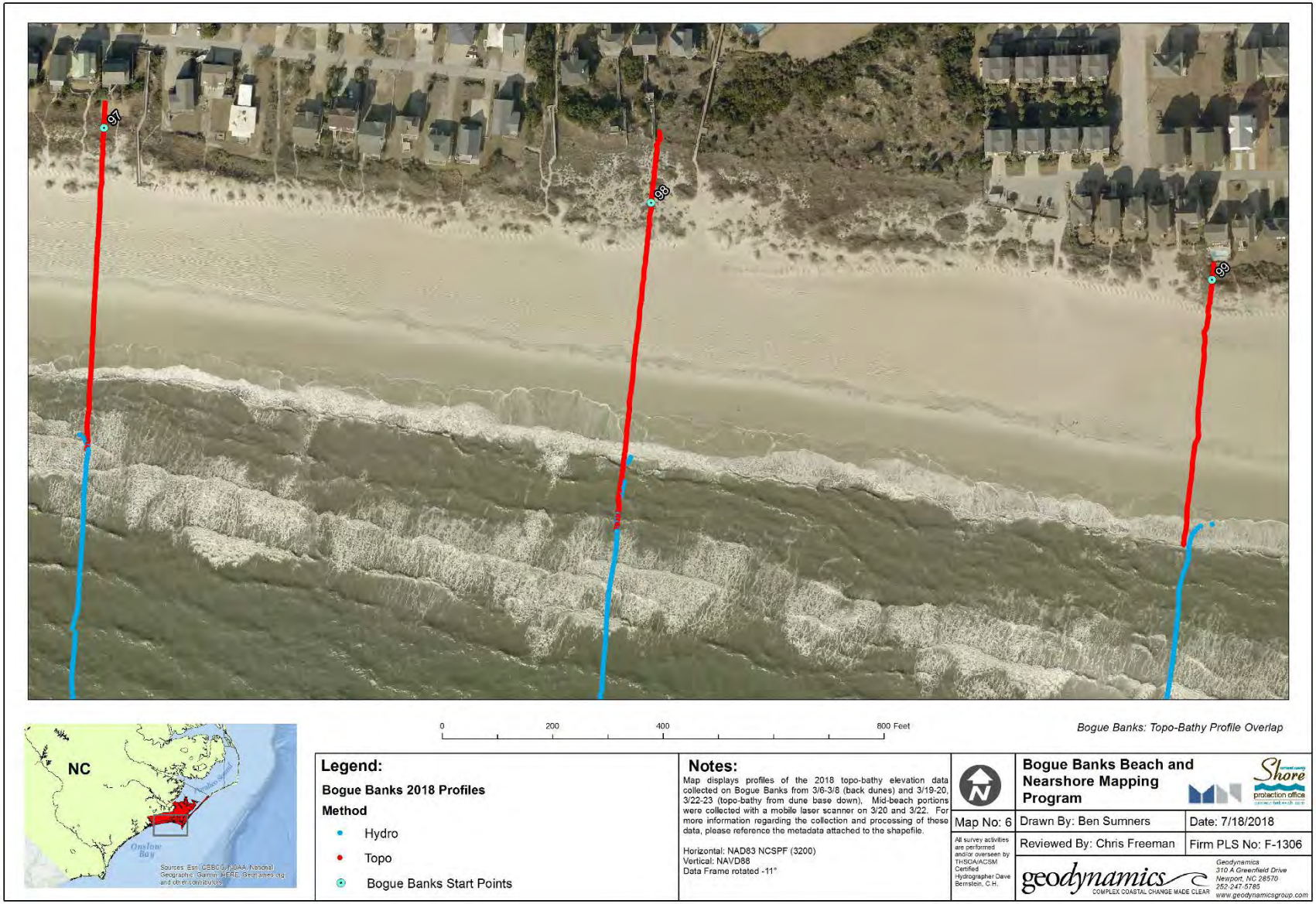


Figure 18: Typical topo-bathy overlap for BBNMP.

B. HOTSPOT DIGITAL ELEVATION MODELLING

A 3 ft cell sized DEM was developed using the mobile laser scanner data for three areas defined as Hotspots, labelled West, Central, and East (Figure 19). The DEM was cleaned and developed in Qimera and exported for ArcGIS analysis. These DEMs are annual products, and following the first year, will be differenced to analyze change within these areas. Landward and seaward extents will vary between years, depending on the overall shape of the beach, dune base, width of beach, and tidal level during the time of the survey, but will capture dune base to MLLW contour each year. Figure 20 displays a detailed 3D example of the shoreface captured by the MLW for a portion of the Central Hotspot DEM.

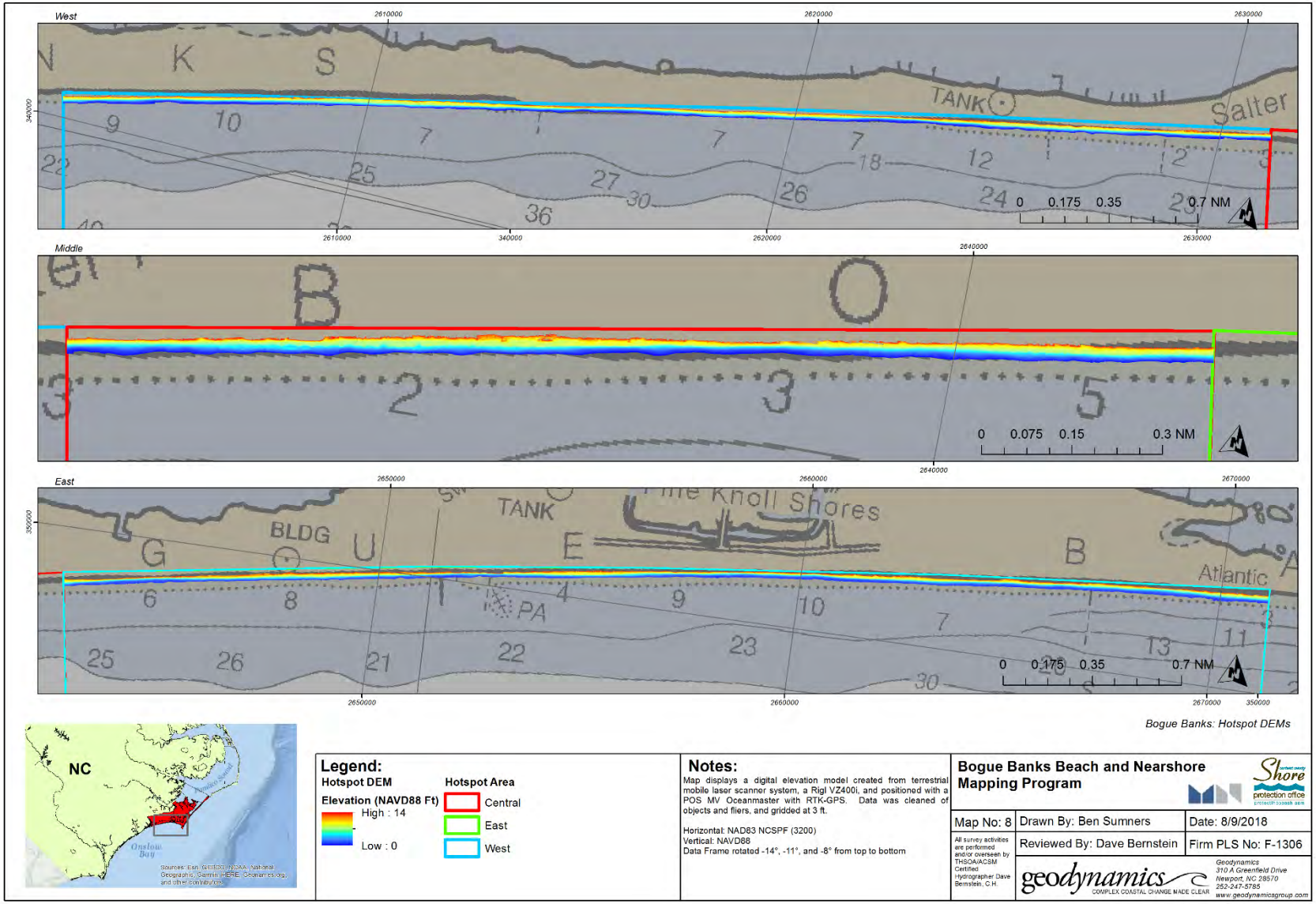


Figure 19: DEM generated defined Hotspot, for Bogue Banks.

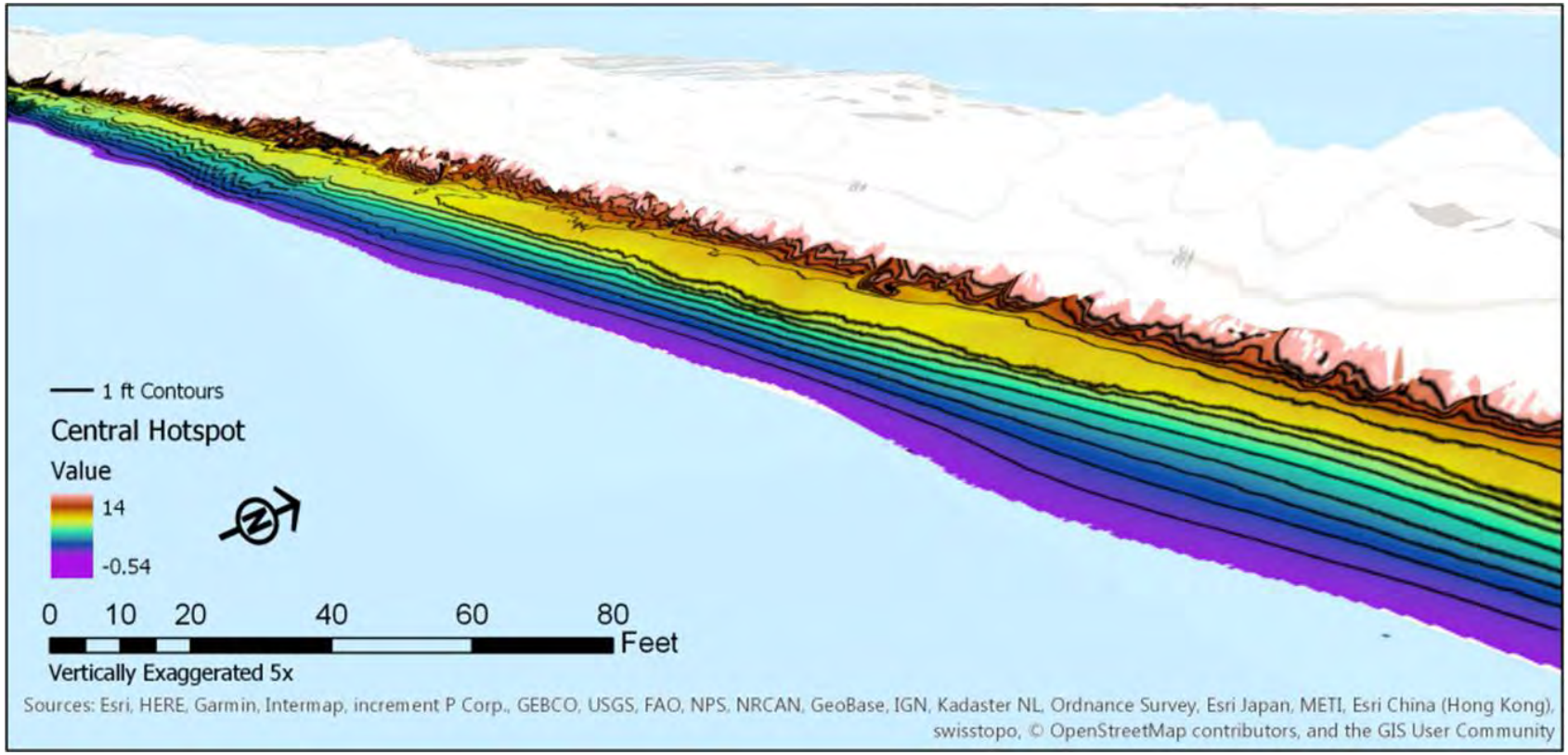


Figure 20: A zoomed-in view of the Bogue Banks Central Hotspot DEM with 1 ft contours.

C. QUALITY ASSURANCE

5.1 Digital Elevation Model: Chart Comparison

DEMs have been developed in the past using a combination of topo-bathy profiles and ATV tie-lines, developed with a range of kriging variogram parameters among multiple grids, and stitched together to create one complete DEM for each island. For the 2018 – 2022 surveys, MLS data is now used for DEM generation, targeted at three main hotspots across Bogue Banks. As the accuracy and parameters are drastically different than previous methods, a comparison to previous datasets will not be made until 2019, when consecutive datasets of the same resolution, and acquisition methods are available. Figure 20 above displays a detailed, 3D view of a portion of the Central Hotspot, showing a level of detail only obtainable with MLS systems.

5.2 Topo-bathy Profile and Tie-line Overlap Comparison

A statistical comparison was made between the XYZ dataset extracted from a 3 ft MLS grid, along with the topographic data acquired with the traditional RTK-GPS Backpack method for dunes and surf zones (Figure 21). A search radius of 2 ft was used to look for MLS points and compare their elevations with the backpack acquired elevations. The statistics show the data are within 0.01 ft on average, and report a standard deviation of 0.5 ft, indicating good agreement considering the variability of beach slopes surveyed with this detail and the variable elevations of shoreface features that may be up to 2 ft apart horizontally.

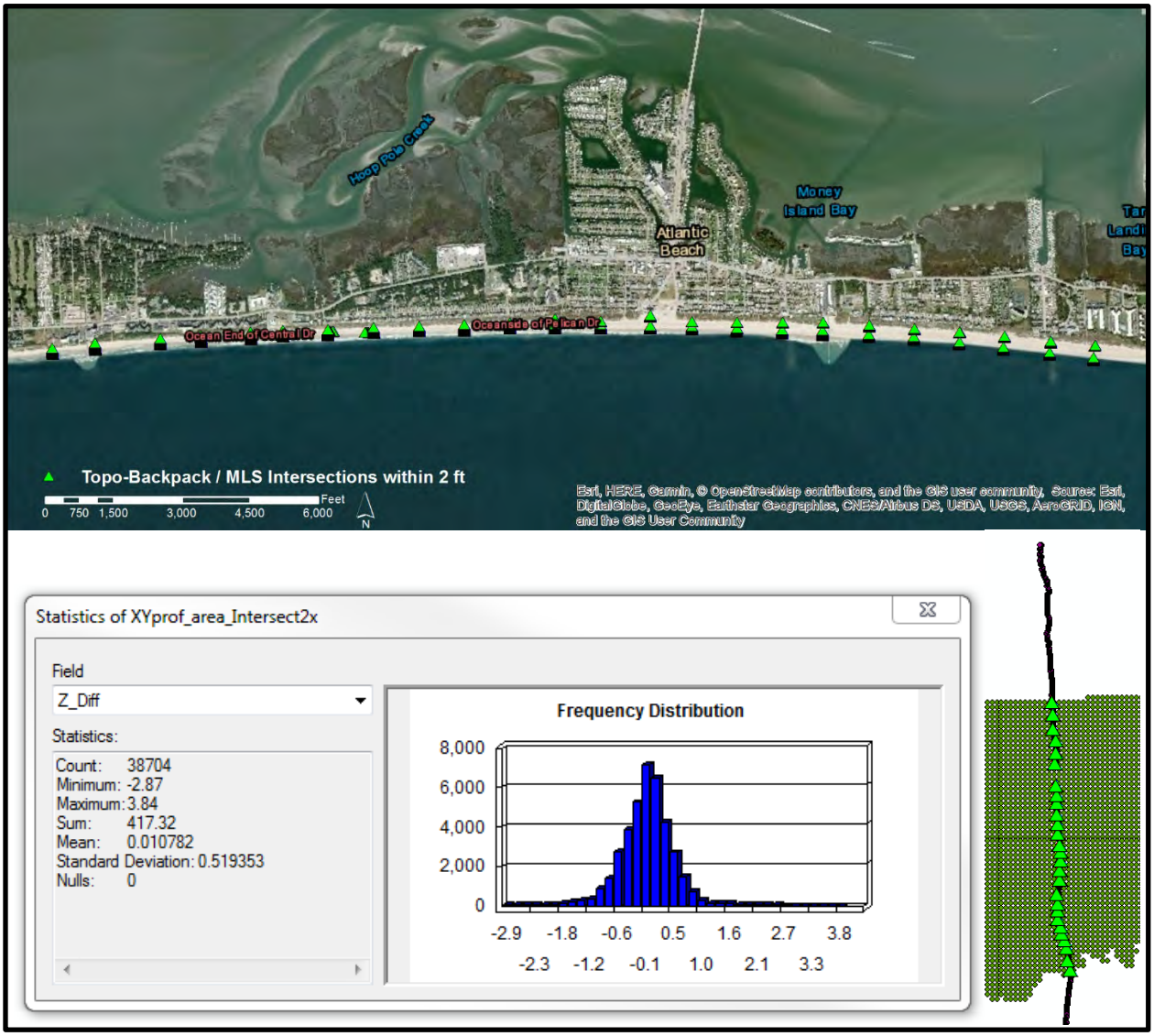
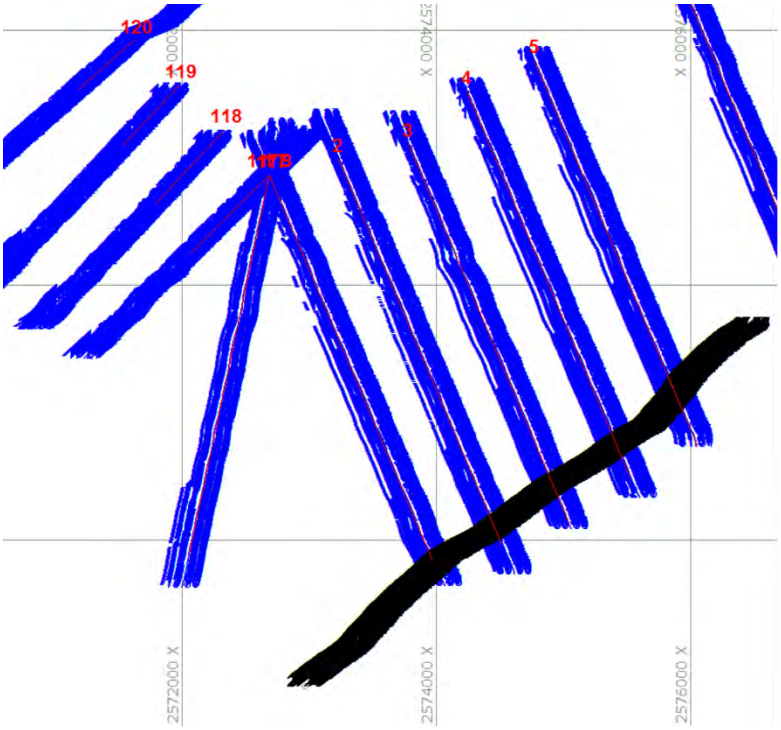


Figure 21: Statistical comparison of the overlap from XYZ extracted from a 3 ft MLS grid, and compared to the backpack acquired topo data for a portion of Atlantic Beach. The top image shows the location of the intersections computed, and the lower right image displays a common example of the overlap between the datasets, and the points within 2ft of each other that are used for statistics as triangles.

5.3 Cross-line Validation

An additional means of validating hydrographic datasets is comparing two perpendicular acquired datasets. This method resolves any potential dimensional control offsets in the vessel configuration that go unnoticed when collected in the same direction repeatedly. A cross line collected on 6/6/18 in the offshore portions of profiles 1 – 5 showed excellent repeatability, validating the vessel configuration and software setup.



Line	3/8/2018 (blue)	6/6/2018 (black)	Z Diff
1	24.81	24.79	0.02
2	26.05	26.04	0.01
3	27.42	27.49	-0.07
4	28.74	28.82	-0.08
5	28.55	28.69	-0.14
		Average =	-0.05
		StDev =	0.07

Figure 22. Cross-line statistics for hydrographic data collected near Bogue Inlet.

D. CONCLUDING REMARKS

Survey data collected for the Bogue Banks Beach and Nearshore Mapping Program project meets and exceeds the requirements set forth in the USACE provided SOW, including the criteria for Class 1 Hydrographic Surveys as outlined in the U.S. Army Corps of Engineers Hydrographic Surveying Manual, EM 1110-2-1003 and Hydrographic Surveying and Engineering Circular, EC 1130-2-210.

The topographic-bathymetric profiles along Bogue Banks showed excellent agreement to prior surveys. All attempts were made so that topographic and hydrographic prior extents met the 2017 survey. Any notable obstructions on profiles causing offline distances greater than previous surveys are supplied as a KML file with georeferenced photos for profiles 1, 2, 5, 74 on Bogue Banks. Also, as the east end of Shackleford Banks continues to erode, more profiles that were topo-hydro are becoming solely hydro profiles.

The application of using MLS data to collect mid-beach portions of data, generate the MHW contour, and extract the dune base was successful while improving the overall product accuracy. This dataset will provide a thorough means to assess shoreface erosion in the following years and in the event of a major storm.

APPENDIX A: SURVEY ACTIVITY LOGS

Daily Survey Field Notes

Date:	3/6/2018	**Day of Year:**	65
Time SOS (local):	9:30	**Time EOS(local):**	13:00
Project:	CCSPO Spring 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:			
Topo Crew:	Nick Damm	Brian Johnson	

Atmospheric Conditions		**Water Conditions**	
Sky:	Partly Cloudy	**Swell:**	N/A
Wind Speed:	5-10 KT	**Chop:**	N/A
Wind Direction:	ESE	**Temp:**	N/A
Temp:	40-50 F		

Survey Activities

Control

Crew checked benchmark "Anchorage" using base station "IMS". The base station "IMS" was installed on Monday (3/5/2018) and the crew checked benchmark "Betty" that same day. All benchmark checks were successful.

Topo

The topo crew drove the truck and trailer (with ATVs) to Fort Macon. Nick started working on profile 116 at the far end of Fort Macon and completing dune sections working west. Brian started on profile 68 completing dune sections of the profile and working east. The two met at profile 100 completing the dune sections of profiles 116-68. The crew then headed back to the shop.

Hydro

N/A

Daily Survey Field Notes

Date:	3/7/2018	**Day of Year:**	66
Time SOS (local):	9:00	**Time EOS (local):**	16:00
Project:	CCSPO Spring 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:			
Topo Crew:	Nick Damm	Dan Ott	

Atmospheric Conditions		**Water Conditions**	
Sky:	Partly Cloudy	**Swell:**	N/A
Wind Speed:	15-20 KT	**Chop:**	N/A
Wind Direction:	WNW	**Temp:**	N/A
Temp:	50-60 F		

Survey Activities

Control

The topo crew setup the base station at ERBA and checked in on mark "Mechelle" using the base station. The crew also checked in on Mechelle using the NC CORS VRS network. All checked out successfully.

Topo

The topo crew drove the truck and trailer with ATVs to ERBA. After setting up the base, Dan started working dune sections on profile 35 and working east. Nick recovered some dune sections on profile 74, 72, and 70 where GPS quality was poor the day before. Nick then walked entire dune sections from profiles 67-59 working west. The two met up on profile 59; all dune profiles from 116-35 were completed.

Hydro

N/A

Daily Survey Field Notes

Date:	3/8/2018	**Day of Year:**	67
Time SOS (local):	8:30	**Time EOS(local):**	13:00
Project:	CCSPO Spring 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:			
Topo Crew:	Nick Damm	Brian Johnson	

Atmospheric Conditions		**Water Conditions**	
Sky:	Clear	**Swell:**	N/A
Wind Speed:	10-15 KT	**Chop:**	N/A
Wind Direction:	NW	**Temp:**	N/A
Temp:	40-50 F		

Survey Activities

Control

The crew check in on benchmark "Mechelle" with the NC CORS VRS Network and from base station "ERBA".

Topo

Brian dropped Nick off at Emerald Isle point and Nick collected dune portions of the profiles from 119-18 working east. Brian parked the truck and trailer with ATVs at ERBA and worked east from profile 34 collecting dune portions of the profiles. The two then met up on profile 18. This completed all the dune portions of the profiles on Bogue Banks.

Hydro

N/A

Daily Survey Field Notes

Date:	3/19/2018	**Day of Year:**	78
Time SOS (local):	8:00	**Time EOS(local):**	19:00
Project:	CCSPO Spring 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:	Aron Lembke	Dan Ott	
Topo Crew:	Brandon Barnette	Brian Johnson	

Atmospheric Conditions		**Water Conditions**	
Sky:	Clear	**Swell:**	0 - 0.5 ft
Wind Speed:	0-5 KT	**Chop:**	0 - 0.5 ft
Wind Direction:	ENE	**Temp:**	40-50 F
Temp:	50-60 F		

Survey Activities

Control

Crew checked in on benchmark "Geodynamics" on IMS Base station and it checked out well.

Topo

Crew left shop and arrived on location at Fort Macon. Brandon drove the ATV while Brian walked surf zones. Brian started on line 116 and worked west to line 103. Crew reviewed data onsite. Brian then walked a portion of dunes on line 96 to make sure of proper overlap with laser data.

Hydro

Hydro crew left the marina and headed to survey location. Crew started surf zones on line 116 and worked west to line 103. The crew ran out of tide so they began working offshores from line 103 east to 116. Crew then picked back up at line 102 and worked west to line 60 on offshores. Hydro crew then returned to marina.

Daily Survey Field Notes

Date:	3/20/2018	**Day of Year:**	79
Time SOS (local):	8:00	**Time EOS(local):**	19:00
Project:	CCSPO Spring 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:			
Topo Crew:	Brian Johnson		

Atmospheric Conditions		**Water Conditions**	
Sky:	Clear	**Swell:**	
Wind Speed:		**Chop:**	
Wind Direction:		**Temp:**	
Temp:	50-60 F		

Survey Activities

Control

Crew checked in on benchmark "Geodynamics" on IMS Base station and it checked out well.

Topo

Brian parked at the Iron Steamer on Pine Knoll shores and prepared the laser and ATV for collection. Brian began collecting from Iron Steamer to Fort Macon and collected on the way back as well to ensure overlap and quantity of data. After Brian double checked data for saturation at Iron Steamer, he demobilized and returned to the shop.

Hydro

N\A

Daily Survey Field Notes

Date:	3/22/2018	**Day of Year:**	81
Time SOS (local):	8:00	**Time EOS(local):**	17:00
Project:	CCSPO Spring 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:			
Topo Crew:	Dan Ott	Brian Johnson	

Atmospheric Conditions		**Water Conditions**	
Sky:	Clear	**Swell:**	
Wind Speed:		**Chop:**	
Wind Direction:		**Temp:**	
Temp:	50-60 F		

Survey Activities

Control

Crew checked in on benchmark "Geodynamics" on IMS Base station and it checked out well.

Topo

Dan and Brian parked at the Coast Guard Station on Emerald Isle and prepared the laser and ATV for collection. Dan began collecting at the Emerald Isle Point to a little past where the Emerald Isle boat ramp is on the sound side; he also collected on the way back as well to ensure overlap and quantity of data. After the survey Dan and Brian double checked data back at the Coast Guard station, then demobilized back to the shop.

Hydro

N\A

Daily Survey Field Notes

Date:	3/23/2018	**Day of Year:**	82
Time SOS (local):	5:00	**Time EOS(local):**	20:00
Project:	CCSPO Spring 2018		
Survey Location:	Bogue Banks, NC		
Hydro Crew:	Aron Lembke	Dan Ott	
Topo Crew:	Nick Damm	Brian Johnson	Brandon Barnette / Adam Powers

Atmospheric Conditions		**Water Conditions**	
Sky:	Clear	**Swell:**	0 - 0.5 ft
Wind Speed:	5-15 KT	**Chop:**	0 - 0.5 ft
Wind Direction:	NNW	**Temp:**	40-50 F
Temp:	40-50 F		

Survey Activities

Control

Topo crew checked marks "Mechelle" using the base station "ERBA." Benchmark "LOON" was checked off base station "CGEI", and benchmark "Geodynamics" was checked using the base station "IMS." All benchmark checks were successful.

Topo

Topo crew began collecting surf zones at first light. The topo crew split up into two crews. Brian, Nick, and Adam drove the ATVs to ERBA while Brandon and Ben drove the third ATV to the Atlantic Beach Circle. Brian began collecting laser data where he finished the day before. He collected to where he finished on March 20th and collected on the way back to ensure overlap. With Adam as his driver, Nick started walking the topo surf zone portion of the profiles. Nick started at profile 40 and worked east. Brandon drove Ben as Ben walked topo surf zones starting at profile 102 and working west. The two topo surf zone crews met at profile 65. Nick and Adam then headed back to ERBA to meet up with Brian, who finished laser around the same time. Brandon and Ben headed back to the circle. All topo crews then headed back to the shop to check over data. As the tide dropped out to an adequate level in the afternoon, Nick dropped Ben off at Emerald Isle point and Ben collected topo surf zones from profile 120 to 25 working east. Nick then drove to ERBA and collected topo surf zones from profile 40-26. Therefore, all topo surf zones for Bogue Banks were completed.

Hydro

Crew left marina and headed to survey site. Hydro crew started surf zones at line 102 and worked west to line 120. After completing surf zones the Hydro crew began working on offshores starting at line 120 and worked east to line 59. After completing offshores the crew reviewed the days data. Upon completion of the review the crew recovered a partial line on profile 39. Crew then headed to line 120 to finish the inside section of the line in the old Coast Guard inlet. Crew reviewed all data, pulled the boat out and demobilized to the shop.

Daily Survey Field Notes

Date:	4/21/2018	**Day of Year:**	111
Time SOS (local):	7:30	**Time EOS(local):**	16:30
Project:	CCSPO Spring 2018		
Survey Location:	Shackleford		
Hydro Crew:	Brandon Barnette	Nick Damm	
Topo Crew:			

Atmospheric Conditions		**Water Conditions**	
Sky:	Clear	**Swell:**	0 - 0.5 ft
Wind Speed:	5-10 KT	**Chop:**	0 - 0.5 ft
Wind Direction:	NNE	**Temp:**	50-60 F
Temp:	50-60 F		

Survey Activities

Control

Control check was conducted on benchmark "Anchorage" using IMS base station. Benchmark check was succesful.

Topo

N/A

Hydro

Hydro crew got underway from the Anchorage marina in the morning. RV Echo gained RTK corrections via base station setup on IMS. Hydro crew started offshores on line 424 and worked east to line 293. The tide was coming in so the Hydro crew started surf zones at 424 and worked west to line 460. Crew then picked up on line 405 and worked surf zones to line 0. Crew reviewed surf zone data and resumed offshores on line 0 and worked west to line 272. Hydro crew reviewed data for quality and returned to Anchorage marina to demobilization RV ECHO.

Daily Survey Field Notes

Date:	5/1/2018	**Day of Year:**	121
Time SOS (local):	7:45	**Time EOS(local):**	16:00
Project:	CCSPO 2018		
Survey Location:	Bear Island		
Hydro Crew:	Aron Lembke	Dan Ott	
Topo Crew:	Brandon Barnette	Adam Powers	

Atmospheric Conditions		**Water Conditions**	
Sky:	Clear	**Swell:**	0 - 0.5 ft
Wind Speed:	5-10 KT	**Chop:**	0.5 - 1.0 ft
Wind Direction:	WSW	**Temp:**	60-70 F
Temp:	60-70 F		

Survey Activities

Control

Control check was conducted on benchmark "CG TBM" using the coast guard base station. Check was succesful.

Topo

Crew arrived at Bear Island and unloaded the ATV off of the Echo. After prepping gear and ATV, Brandon started on line 1 and worked west to line 11 while Adam drove. Adam replaced Brandon and started on line 12 working west to line 18. Crew took lunch while waiting on the tide to drop. Brandon started surf zones on line 18 and worked east to line 1. After completion of all profiles the crew did a quick data review while waitng to be ferried back to Emerald Isle. The crew took the base station down at the Coast Guard station and returned to the shop.

Hydro

Hydro crew dropped the topo crew off on Bear Island and started surf zones on profile 1 working west to line 18. Upon completion of the surf zone sections of the profiles the crew started working the offshore sections. Crew started at line 18 and worked east to line 1. After completion of the Bear Island profiles the crew overlooked all Hydro data collected that day. After an overview of the data the crew started helping the topo crew demobilize the ATV from Bear Island back to Emerald Isle.

APPENDIX B: HYDROGRAPHIC SURVEY CONRTOL CALIBRATION

Survey Control

geodynamics

Project Timeframe:	3/06/2018-5/01/2018
Project:	Carteret County Shore Protection Office- Annual Beach Profile Survey
Survey Location:	Bogue Banks, Bear Island, Shackleford Banks, Carteret County, North Carolina
Survey Crew:	Nick Damm, Brandon Barnette, Dan Ott, Ben Sumners, Aron Lembke, Brian Johnson, Adam Powers
Coordinate System/Units:	NAD83 NC State Plane — Units: SPM — Repeater Use:
Vertical:	NAVD88 — Geoid: 2012a
Basestation Equipment:	Receiver: Trimble R7 — GPS Antenna: Zephyr II Geodetic (55971) — Radio: TDL 450 — Radio Broadcasting: 5 dB UHF Antenna

Notes: This project was conducted over a period of 5 months during times of optimal weather and tidal conditions. Due to the extent of the survey area, multiple base stations were used. For the survey of Shackleford Banks, as well as the eastern portions of Bogue Banks, base station "IMS_BASE" was used. For the central portion of Bogue Banks, base station "ERBA_BASE" was utilized. Base station "CGEI_BASE" was used for the western portion of Bogue Banks, as well as for Bear Island. To maximize efficiency in the field, RTK-VRS via the NC CORS Network was utilized for the Shackleford Banks, a small portion of Bear Island and Bogue Banks, and the majority of the ATV defines in Bogue Banks.

Basestation Information

Designation: IMS BASE
PID: N/A
H Order: N/A
V order: N/A
Geoid: 2012a

State Plane Coordinates
Easting (X): 815483.954
Northing (Y): 110347.272
Z: 18.233

WGS-84 Coordinates
Longitude: 76 45 06.62217
Latitude: 34 43 25.39287
Elevation (m): -19.23

Notes: Semi-permanent fully GNSS enabled base station installed and monitored by Geodynamics. Used for Shackleford Banks and eastern portions of Bogue Banks.

Basestation Information

Designation: ERBA BASE
PID: N/A
H Order: N/A
V order: N/A
Geoid: 2012a

State Plane Coordinates
Easting (X): 796830.552
Northing (Y): 104528.609
Z: 8.873

WGS-84 Coordinates
Longitude: 76 57 24.30785
Latitude: 34 40 32.92648
Elevation (m): -28.436

Notes: Semi-permanent fully GNSS enabled base station installed and monitored by Geodynamics. Used for the middle portions of Bogue Banks.

Basestation Information

Designation: CGEI BASE
PID: N/A
H Order: N/A
V order: N/A
Geoid: 2012a

State Plane Coordinates
Easting (X): 784119.165
Northing (Y): 101220.147
Z: 1.697

WGS-84 Coordinates
Longitude: 77 05 46.14191
Latitude: 34 38 50.53087
Elevation (m): -35.469

Notes: Fully GNSS enabled base station installed and monitored by Geodynamics. Used for Bear Island as well as the western extents of Bogue Banks.

The following tables display coordinate and site information on any benchmarks checked for this project

Benchmark Station Reference

Designation: Betty
PID: DK7224
H Order: N/A
V order: N/A
Geoid: 2012a

State Plane Coordinates

Easting (X):	815363.576
Northing (Y):	110403.810
Z:	6.190

Notes: NGS Benchmark located near on the sidewalk across from the Division of Marine Fisheries in Morehead City. Benchmark used for checking in on base station IMS BASE as well as NC CORS VRS Network.

Benchmark Station Reference

Designation: Geodynamics
PID: N/A
H Order: N/A
V order: N/A
Geoid: 2012a

State Plane Coordinates

Easting (X):	810156.520
Northing (Y):	112888.161
Z:	5.016

Notes: Geodynamics installed benchmark located at Geodynamics office in Newport, NC. Benchmark used for checking in on IMS Base as well as NC CORS VRS network.

Benchmark Station Reference

Designation: CGEI TBM
PID: N/A
H Order: N/A
V order: N/A
Geoid: 2012a

State Plane Coordinates

Easting (X):	784154.480
Northing (Y):	101228.661
Z:	1.353

Notes: Geodynamics installed TBM located in the Coast Guard Station Emerald Isle parking lot. TBM used for checking in on CGEI BASE as well as NC CORS VRS network.

Benchmark Station Reference

Designation: Mechelle
PID: AC7469
H Order: N/A
V order: Second, Class II
Geoid: 2012a

State Plane Coordinates

Easting (X):	798733.751
Northing (Y):	105153.439
Z:	5.343

Notes: NGS Benchmark located in Salter Path at the northeast intersection of HWY 58 and 15th street. Benchmark was used for checking in on ERBA BASE.

Benchmark Station Reference

Designation: Loon
PID: AC7493
H Order: N/A
V order: Second, Class II
Geoid: 2012a

State Plane Coordinates

Easting (X):	788335.750
Northing (Y):	102904.505
Z:	3.928

Notes: NGS benchmark located in Emerald Isle near the Emerald Plantation shopping center sign. Benchmark was used for checking in on the NC CORS VRS network.

Benchmark Report

Date	Time	Weather	Benchmark	N	E	Z	ΔN	ΔE	ΔZ
3/5/2018	11:18:23	Clear	Betty	110403.83	815363.56	6.211	-0.017	0.020	-0.021
	Basestation Used:IMS								
3/5/2018	11:18:32	Clear	Betty	110403.83	815363.56	6.210	-0.019	0.020	-0.020
	Basestation Used:IMS								
3/6/2018	8:56:20	Overcast	Anchorage	107716.68	817528.63	2.562	-0.020	0.024	0.012
	Basestation Used:IMS								
3/6/2018	8:56:27	Overcast	Anchorage	107716.68	817528.63	2.563	-0.021	0.025	0.011
	Basestation Used:IMS								
3/6/2018	8:56:36	Overcast	Anchorage	107716.68	817528.63	2.561	-0.021	0.026	0.013
	Basestation Used:IMS								
3/7/2018	11:07:27	Overcast	Mechelle	105153.44	798733.72	5.344	-0.003	0.033	-0.001
	Basestation Used:ERBA								
3/7/2018	11:07:35	Overcast	Mechelle	105153.44	798733.72	5.339	-0.003	0.032	0.004
	Basestation Used:ERBA								
3/7/2018	11:09:21	Overcast	Mechelle	105153.46	798733.74	5.295	-0.023	0.010	0.048
	Basestation Used:NC CORS VRS								
3/7/2018	11:09:29	Overcast	Mechelle	105153.46	798733.74	5.293	-0.022	0.009	0.050
	Basestation Used:NC CORS VRS								
3/8/2018	9:31:27	Clear	Mechelle	105153.46	798733.77	5.283	-0.019	-0.014	0.060
	Basestation Used:NC CORS VRS								
3/8/2018	9:31:41	Clear	Mechelle	105153.45	798733.76	5.275	-0.008	-0.011	0.068
	Basestation Used:ERBA								
3/8/2018	12:12:29	Clear	Mechelle	105153.45	798733.72	5.362	-0.010	0.033	-0.019
	Basestation Used:ERBA								
3/8/2018	12:19:07	Clear	Mechelle	105153.46	798733.74	5.320	-0.022	0.012	0.023
	Basestation Used:ERBA								
3/19/2018	9:41:01	Overcast	Geodynamics	112888.17	810156.52	5.037	-0.011	-0.001	-0.021
	Basestation Used:IMS								
3/23/2018	9:42:43	Clear	Mechelle	105153.45	798733.72	5.341	-0.012	0.031	0.002
	Basestation Used:ERBA								
3/23/2018	9:43:37	Clear	Mechelle	105153.45	798733.72	5.346	-0.015	0.029	-0.003
	Basestation Used:ERBA								
3/23/2018	9:58:26	Clear	loon	102904.49	788335.71	3.909	0.016	0.045	0.019
	Basestation Used:CGEI								
4/18/2018	8:34:03	Clear	Betty	110403.825	815363.546	6.213	-0.015	0.030	-0.023
	Basestation Used:IMS with Repeater								
4/20/2018	5:50:31	Clear	Anchorage	107716.675	817528.631	2.566	-0.015	0.027	0.008
	Basestation Used:IMS								
4/21/2018	4:41:29	Clear	Anchorage	107716.678	817528.636	2.559	-0.018	0.022	0.015
	Basestation Used:IMS								
	Basestation Used:								

GPS consistency (measured in meters)

Average Easting (X) error	0.020
Average Northing (Y) error	-0.014
Average Elevation error	0.011

APPENDIX C: SINGLEBEAM ECHOSOUNDER CALIBRATION REPORT

R/V ECHO MARCH 2017

ODOM CV100 CALIBRATION

Contact: Geodynamics
319 A Greenfield Drive
Newport, NC 28570
252-247-5785
www.GeoDynamicsGroup.com

SYSTEM INFORMATION

Vessel:	R/V Echo	Sonar Type:	ODOM CV100
Date:	3/10/2017	Sonar Head Serial #(s):	n/a
Personnel:	Baker, K., Lembke, A., Damm, N	PU Serial #:	26068
		Sonar Software:	eChart
Positioning System	POSMV WM V5	Sonar Frequency:	200 kHz
POSMV Serial #	6577	Swath Width:	4°
GPS Antennas	AT1675-540TS (2 antennas)	Sound Speed Sensor at Sonar:	n/a
IMU Type	37	Sound Speed Profiler:	AML Minos -SV sensor 200936
			Pressure sensor 304496

CALIBRATION DETAILS

Location:	Masonboro Inlet, NC
Weather	Clear skies, 50 - 60°
Wind	10-15 kts WSW
Seas	0' swell, 0-0.25' chop
Sound Speed (avg)	1505 m/s

Approximate Position:	Deg	Min	Sec
Lat:	34°	11'	03"
Long:	77°	48'	38"

GPS Corrections

GPS Correction:	RTK-GPS		
Correction Type:	CMR+		
Station Name	WBHI		
Coordinates:	Deg	Min	Sec
Lat:	34°	13'	13.51178" N
Long:	77°	47'	06.85398" W
Ellips. Height (m) :	-10.142		

Sonar Offsets / Biases

	X (m)	Y (m)	Z (m)
Position	0.000	0.000	0.000
Draft	0.000	0.000	0.000
Index	0.000	0.000	0.090

POSMV Configuration

Lever Arms	X (m)	Y (m)	Z (m)
Ref. to IMU Lever Arm	0.000	0.000	0.070
Ref. to Primary GPS	0.016	-0.01	-2.063
Ref. to Vessel Lever Arm	-0.292	0.745	0.648
Ref. to Sensor 1	-0.292	0.745	0.648
Ref. to COG	0.000	0.000	0.290
	X (deg)	Y (deg)	Z (deg)
IMU w.r.t. Ref. Frame	1.000	-0.200	0.000

Note: The Sensor 1 offset is referenced to the sonar head.

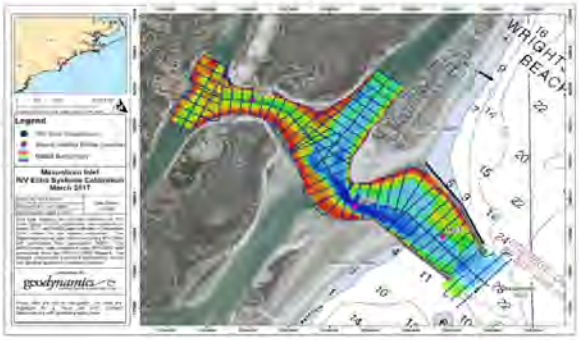
GAMS Parameters

Two Antenna Sep (m)	1.997	Baseline Vector		
Heading Cal.Threshold	0.500	X (m)	Y (m)	Z (m)
Heading Correction (deg)	0.000	1.997	0.015	0.003

Index Check

Bar Value (ft)	Sonar Value (ft)
2.000	1.700
3.000	3.050
6.000	6.000
10.000	10.000
15.000	15.000
20.000	20.000
15.000	15.000
20.000	20.000

Systems Calibration Area Basemap

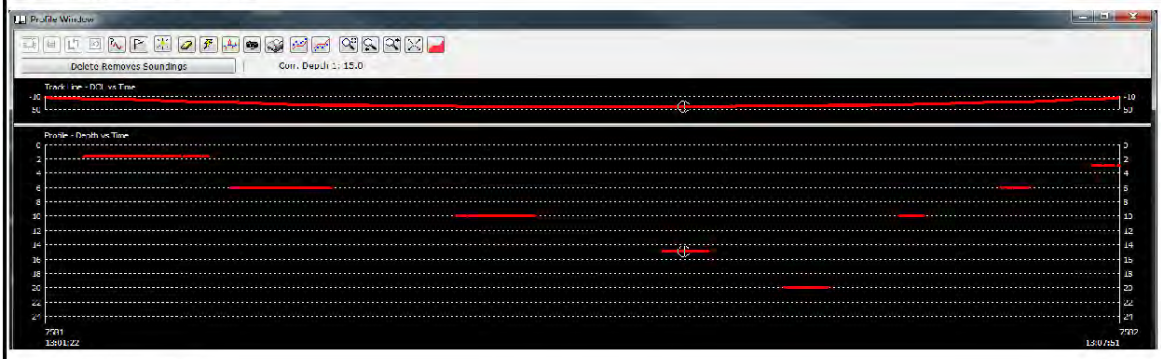


Notes:

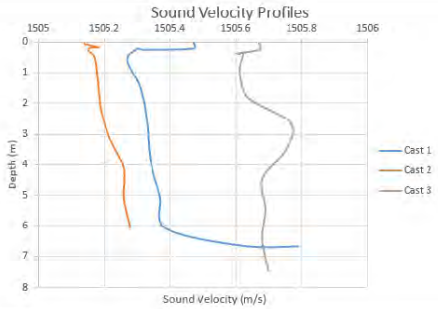
Calibration test performed in a previously surveyed area in Masonboro Inlet. The R/V Echo singlebeam data was collected with an Odom CV100 in March 2017. Multibeam data was collected in Novermber 2016 with the R/V 4-Points, a professionally surveyed research vessel which has been compared with excellent agreement to numerous USACE, NOAA, and private companies within the industry.The singlebeam survey was conducted using RTK-GPS with corrections from basestation "WBHI". The MBES survey was conducted using RTK-GPS with corrections from the NCGS CORS Network. The dataset comparison produced satisfactory results with general agreement between systems. Additionally, the bar check performed in March 2017 on the Odom CV100 system in Banks Channel, Wrightsville Beach, NC confirmed the index value in use and provided further confidence in the system.

Patch Test BIAS Verification Images

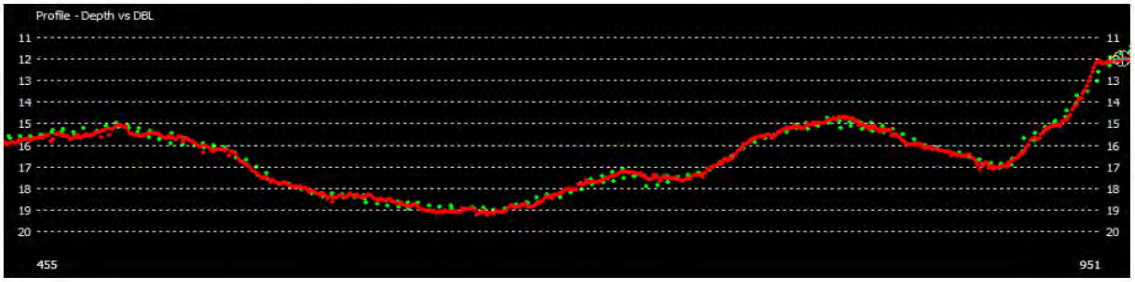
Bar Check for Index Verification



Sound Speed Verification



Horizontal and Vertical Alignment Final Verification



Sound Velocity X-change Sensor Calibration Report

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Certificate of Calibration

Asset Serial Number:	201370
Calibration Type:	SVX (External)
Certification Date:	October 24, 2017
Calibration Range:	1414 to 1509 m/s
Sensor Range:	1375 to 1625 m/s
Residual (RMSE):	0.000 m/s
Standards:	Hart 1560\3611,

Coefficients

Coefficient A:	0.000000E+0	Coefficient H:	1.945860E-7
Coefficient B:	0.000000E+0	Coefficient I:	0.000000E+0
Coefficient C:	1.488374E-6	Coefficient J:	0.000000E+0
Coefficient D:	1.945849E-7	Coefficient K:	0.000000E+0
Coefficient E:	-1.726562E-5	Coefficient L:	0.000000E+0
Coefficient F:	1.952026E-7	Coefficient M:	0.000000E+0
Coefficient G:	1.522537E-6	Coefficient N:	0.000000E+0

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Robert Haydock
President, AML Oceanographic

AML Oceanographic certifies that the asset described above has been calibrated or recalibrated with equipment referenced to traceable standards. If this instrument or sensor has been re-calibrated, please be sure to update your records. Please also ensure that you update the instrument's coefficient values in any post-processing software that you use, if necessary.

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Pressure X-change Sensor Calibration Report

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Certificate of Calibration

Asset Serial Number:	005551
Calibration Type:	Pressure
Certification Date:	October 24, 2017
Sensor SN:	B00091
Calibration Range:	0 to 49 dBar
Sensor Range:	0 to 50 dBar
Residual (RMSE):	0.003 %FS
Standards:	Paro 785

Coefficients

Coefficient A:	-5.995391E+0	Coefficient H:	0.000000E+0
Coefficient B:	0.000000E+0	Coefficient I:	2.792297E-10
Coefficient C:	0.000000E+0	Coefficient J:	0.000000E+0
Coefficient D:	0.000000E+0	Coefficient K:	0.000000E+0
Coefficient E:	9.390680E-4	Coefficient L:	0.000000E+0
Coefficient F:	0.000000E+0	Coefficient M:	-7.284422E-16
Coefficient G:	0.000000E+0	Coefficient N:	0.000000E+0

AML Oceanographic

Robert Haydock
President, AML Oceanographic

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APPENDIX D: SCOPE OF WORK

Description of Work for Annual & Post-Storm Beach Profile Monitoring Surveys: Bogue Banks Beach & Nearshore Mapping Program Years 2018 - 2022

1. General & Location of Work. Geodynamics, under contract for Moffatt & Nichol (M&N), will perform seamless topographic and bathymetric beach profile surveys of beaches within Carteret and Onslow County. The work shall primarily consist of surveying and mapping of designated onshore and offshore profiles established on Shackleford Banks, Bogue Banks, and Bear Island, North Carolina, also referred to as the Bogue Banks Beach & Nearshore Mapping Program (BBBNMP). The work includes elevation and positioning data collected along specified azimuths at specified intervals primarily along the existing profiles stations (CCSPO 2010+), with additional inlet and QA/QC profiles developed by Geodynamics / Moffat & Nichol. The final profile stationing and the horizontal limits of the areas to be surveyed annually and post-storm are shown in Figures 1-3. Additionally, topographic laser lidar scanning surveys will be conducted to provide more detailed survey information within a designation "hot spot" area (Figure 4). All survey designs have been approved by the Carteret County Shore Protection Manager.

2. Survey Control. For the contract period, all work shall be relative to the current North American Datum (NAD) of 1983 (2011) North Carolina State Plane Survey Feet in the horizontal plane and the North American Vertical Datum (NAVD) of 1988 Survey Feet in the vertical plane and will use the local geoid model (Geoid 12b) to transform Global Position System (GPS) based ellipsoidal heights to orthometric elevations. A detailed geodetic control survey will be performed prior to all shoreline mapping activities to document Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS) and the North Carolina GNSS Real-Time Network (NCRTN) accuracy, to determine basestation location, assess accuracy at range and to establish daily benchmark "check-in" points (Figure 5). The series of RTK-GNSS basestations will be established as the primary control network to provide elevation and positioning corrections to the survey crews; however, the NCRTN may also be used in areas with poor RTK-GNSS communication. Geodynamics shall furnish M&N with information on all horizontal and vertical control and daily control checks used to complete the surveys for each survey report.

3. Topographic Data Collection (Profiles). The topographic data collection for this project will consist of elevation and positioning data collected along specified azimuths at specified intervals on the approved profile stationing design (Figures 1-3). The landward extent of topographic data collection in areas with coastal infrastructure will be to the farthest extent inland that can be achieved with GNSS data collection techniques. In areas with no infrastructure breaks, the landward extent will be over the primary dune at a minimum such that dune and over-wash related storm impacts can be assessed (in general to the extents of existing data). Elevations shall be continuously collected using GNSS platforms (backpack, rod, atv) and processed elevations shall be at a spacing not to exceed 10 feet and all data will be collected within +/- 25 feet of the profile line. All topographic data collected from the berm to a depth sufficient to meet overlap requirements shall be collected no greater than 4 hours bounding the low tide. Geodynamics will perform the topographic surveys in a manner to limit acts that may cause erosion or damage to existing dunes or vegetation. Geodynamics shall utilize RTK / RTN-GNSS surveying techniques that meet or exceed the USACE *Recommended Survey Elevation Accuracies Common to Various Shore Protection Projects (Table 11-1* EM 1110-2-1003 Nov 2013). Geodynamics shall provide a record of quality control and assurance performed prior to, during and after each survey to be included in the final survey report.

   3.1. MHW / Dune Base Location (Mobile Laser Scanning). Over previous contract years, the acquisition of the MHW contour and Dune Base was acquired through direct measurement techniques using a roving GNSS-based survey system collected from a calibrated all-terrain vehicle. Over the 2018-2022 contract, Geodynamics will acquire these data using mobile laser

scanning techniques which will allow for better long-term analysis of these data but also provide high-resolution 3D topographic data available for use in assessing post-storm morphology change if needed. A similar acquisition strategy will be employed by making use of a calibrated laser-based all-terrain vehicle.

4. Hydrographic Data Collection. The hydrographic data collection for this project will consist of bathymetric data collected along specified azimuths at specified intervals along the established profile stationing. The offshore extent of hydrographic data collection on the established profile will be a minimum of 5000' from the baseline or -30' NAVD 88 whichever is furthest. This includes shore-normal profiles with adjacent nearshore shoal features but generally excludes profiles in the vicinity of tidal inlets. Soundings shall be continuously collected using a survey-grade 200 kHz digital echosounding device compensated for motion, sound speed and positioned with RTK or RTN-GPS corrections. All processed soundings shall be at a spacing not to exceed 10 feet and all data will be collected within +/- 25 feet of the profile. All hydrographic data collected in the surfzone shall be sufficient to meet overlap requirements shall be collected no greater than 4 hours bounding the high tide. Geodynamics shall utilize hydrographic surveying techniques that meet or exceed the USACE *Recommended Survey Elevation Accuracies Common to Various Shore Protection Projects (Table 11-1* EM 1110-2-1003 Nov 2013). Post-processing of attitude and navigation data collected from the survey vessel is acceptable and encouraged, especially when the accuracy and repeatability of the final bathymetry is improved. Geodynamics shall provide a record of quality control and assurance performed prior to, during and after each survey to be included in the final survey report.

5. Yearly "Hotspot" Survey (Topo / Bogue Banks Only). To better define and understand the long-term processes observed within the erosional "Hotspot" areas along Bogue Banks, Geodynamics will acquire two 3D laser-based topographic surveys a year along the stretch of shoreline illustrated in Figure 4. The first survey of each year will be acquired simultaneously with the yearly profiles and the second survey will be collected sometime in the late fall / early winter upon completion of the Atlantic Hurricane Season and / or as directed by M&N. High-resolution surfaces will be generated for each dataset and Quality Controlled by Geodynamics. The general workflow is as follows:

   5.1. Grid Data & Extents. Geodynamics will work with M&N to select the data extents that will be used for each survey to ensure continuity. Grids will be generated at the highest allowable resolution to balance file size while maintaining detail. Once the final resolution is set, Geodynamics will use the same resolution for each of the datasets.

   5.2. In-House QA-QC. Geodynamics will perform and report on, a basic set of QA-QC procedures to ensure accuracy prior to delivery. Currently, Geodynamics is not tasked to perform any analysis or volume calculations on these data.

6. Post-Storm Survey (As Directed by M&N / CCSPO). M&N and the CCSPO, in the event of a Federally Declared Disaster or any storm of significance, may choose to acquire a Post-Storm Survey. In this situation, all Pre-Storm profiles will be acquired along Bogue Banks only; unless specified otherwise. In addition, 3D laser-based topographic surveys, per section 5, will also be acquired in the "hotspot" area. Geodynamics is required to maintain close communications with M&N and the CCSPO up to and following a storm event in order to efficiently collect these data in the timeliest manner.

7. General QA/QC & Survey Requirements

   7.1. RTK / RTN-GPS & GNSS Requirements. Geodynamics will primarily utilize Real-Time GPS / GNSS corrections from the established basestation network. However, in areas with poor base communications or repeated Ultra-High Frequency (UHF) traffic the NC Geodetic Survey RTN will be utilized to obtain Geodetic-GNSS corrections. For the contract period, Geoid12b shall be used to reduce GNSS-based ellipsoidal heights to orthometric elevations. Update rates from the GPS / GNSS receiver to the data collection processor shall operate at a minimum of 5 Hz to a

maximum of 20 Hz and masking angles are not to exceed 15 degrees. Geodynamics is required to augment the Hydrographic RTK / RTN-GPS & GNSS data with appropriate heave, pitch, and roll corrections from an inertial navigation system. Static GPS / GNSS observables will be acquired at the GPS basestations during each hydrographic survey to allow for hydrographic position and attitude post-processing. Geodynamics shall provide a record of vertical and horizontal control utilized during surveys and the daily RTK / RTN-GPS "check-in" calculations to be included in the final survey report.

7.2. Sound Speed. Sound speed profiles will be collected within the USACE standard requirement of a minimum 2 casts per day. However, it is also Geodynamics standard practice to acquire additional sound speed profiles in and around tidal inlets, when noticeable change in surface water properties occur and when long stretches of area are covered. Sound speed profiling equipment calibrations and the corresponding documentation will be included in the final survey report.

7.3. Sonar Calibration. The echosounder shall be calibrated such to provide the most accurate and repeatable soundings possible. Echosounder index and draft calibrations should be performed at least once per year and if any system changes are made. Additionally, a conventional bar check or sounding-to-survey rod check shall be performed at least once per year and if any system changes are made. Echosounder calibrations will be documented and included in the final survey report.

7.4. Laser Calibration. The laser shall be calibrated with a full patch test prior to data collection each time it is mobilized. Static object or buildings will be scanned in multiple directions and distances in order to account for the offset values needed to ensure consistent and accurate data collection.

7.5. Line Tracking Requirements. All hydrographic and topographic data collection shall not vary more than 25 feet horizontally from the specified azimuths shown in Figures 1-3 except in areas where obstructions are present. In such instances, complete notes identifying the obstruction shall be taken and submitted in the required survey report. Alongshore laser scanning data will be acquired in a manner that best suites the data over a fixed tracking requirement.

7.6. Overlap Requirements (Profiles). Geodynamics is required to overlap topographic and hydrographic data a minimum of 10 feet over a minimum of 50% of the specified profile azimuths; however, certain scenarios such as sharp turns that may cause spikes or other erroneous data points, will be edited to achieve at least 6 feet of quality overlap data to fully assess all QA/QC parameters. Overlap will be assessed in real-time and at the end of each day. Those profiles not meeting the specification will be reacquired to meet the overlap requirement. All efforts will be made to achieve the overlap specification safely; however, it should be noted that no guarantee exist that overlap can be achieved due to site specific conditions. Regardless, all topographic data in the swash zone will be collected 4 hours bounding the low tide and all hydrographic data in the swash zone will be collected no more than 4 hours bounding the high tide. Every effort must be made to ensure that either the topographic or hydrographic survey party will have knowledge of the furthest extents such that maximum overlap can be achieved. Geodynamics will ensure that overlapping data will not exceed a maximum vertical difference of 0.5 feet over a distance of 10 feet or greater along a specified line.

7.7. Temporal Requirements. All efforts shall be made to acquire a complete set of profiles at the end of each survey day. The overlap timing of the topographic and hydrographic portion of the profile shall be scheduled so as not to exceed a maximum of 48 hours. However, the stable portion of dunes within the monitoring area can be collected well in advance of the primary survey efforts. Overlapping segments that exceed the maximum Temporal Requirement will be reacquired in their entirety. Spatially, Geodynamics is to make every effort to only survey the

stretch of shoreline, including the surfzone overlap, which can be achieved within the forecasted weather window to avoid any morphological changes that may occur during a weather delay. To maintain the temporal continuity between shoreline reaches, Geodynamics has been authorized by M&N to acquire topo/bathy data at Shackleford Banks, Bogue Banks and Bear Island independently from one another if necessary to achieve this Temporal Requirement.

7.8. Quality Control. Data for each profile line and the overall survey shall be quality-control checked for the following concerns:

- Profile coverage from landward limits to seaward limits including overlap
- Capture of all features along profile
- Required accuracies
- Required horizontal and vertical datum
- Proper motion sensor and sound speed corrections
- Data collection within required offset limits
- Cross lines over a minimum of 3 profiles within each survey compartment collected at different tide stages for quality control and assurance.
- Laser data to a base surface devoid of structures, people, etc.

7.9. Systems Calibration and Checks. Geodynamics shall calibrate and check both topographic and hydrographic systems in accordance with all appropriate USACE Standards. A digital log containing the results of all calibrations and checks shall be supplied to M&N for the final survey report.

8. Clearances & Permits. Geodynamics shall acquire all Clearances & Permits necessary to obtain the required data. Clearances / Permits for Shackleford Banks and Bear Island will go through the National Park Service and Hammocks Beach State Park respectively. Official clearances for Bogue Banks will be obtained through the various Town Managers and / or Police Departments. All parties will be advised initially on the target month and then informed once the weather window is known and mobilization begins. Geodynamics cannot guarantee that survey permission will be granted by individual homeowners; however, all attempts will be made to ensure data is collected to the furthest landward extent of the profile as possible. All discussion for access to private or public property or restricted waters and airspace must be kept on file and made available to include in the survey report if deemed necessary.

9. Required Deliverables. Geodynamics is required to deliver corrected profile data in XYZ ASCII format, profile data as an ESRI ArcGIS shape file or feature class, metadata and pertinent QA/QC sections for the Written Survey Report.

9.1. Profile Data. All profiles shall be fully edited for erroneous data (spikes), motion, tides and sound speed. Overlap on each profile will be analyzed for the specifications and that the data are in the proper vertical and horizontal datum's.

9.1.1. ASCII Data Files. An ASCII text file of the final data shall be delivered with a descriptive header containing the following eight (8) columns and generally in BMAP format:

- Profile
- Profile Number
- Survey Type using numerator tag (ex. Topo 1 or Hydro 2)
- Date
- Easting (X)
- Northing (Y)
- Elevation (Z)
- Distance from Beginning of Line (DBL)

9.2. GIS Compatible Files. Geodynamics shall deliver profile data in a format compatible with ESRI ArcGIS 10.5 or higher and in such a manner as to easily import into the Carteret County's coastal GIS database.

9.2.1. Topo/Bathy Beach Profiles. All merged topo/bathy profiles as an ESRI .shp file.

9.2.2. "Hotspot" DEM's. Alongshore laser-based topographic survey data of the "hotspot" area will be provided as a digital elevation model. Data will be delivered in ArcGrid format.

9.2.3. MHW Contour. The mean high-water contour produced from the alongshore data will be provided as an ESRI shapefile or feature class for Bogue Banks only.

9.2.4. Dune Base Line. The dune base line produced from the alongshore data will be delivered as an ESRI shapefile or feature class for Bogue Banks only.

9.3. Metadata Record. An FGDC compliant metadata record for each survey shall be created using ESRI ArcGIS ArcCatalog 10.5 or higher. Appropriate information shall be entered in all required fields. The metadata record shall be submitted with all other digital files required in the deliverable to M&N.

9.4. Written Survey Report. A general written report summarizing all pertinent data collection activities shall be submitted as an Microsoft Word file to incorporate into the overall survey / analysis report generated by M&N. The following items shall generally be included in the survey and QA/QC portion of the master report:

- Dates and times of each data collection activity
- Atmospheric conditions including temperature, wind direction, wind speed, *tide stage, and wave conditions for each day of data collection activity*
- All horizontal and vertical control used and will include monument name, establishing agency, date established, description, and published horizontal and vertical values
- Temporary Bench Marks (TBM) descriptions with vertical values (if applicable)
- Record of horizontal and vertical calibration of the survey vessel and daily topographic benchmark checks for each survey
- All field notes including descriptions of obstructions preventing data collection along specified azimuths
- General description of all equipment used

9.5. Data QA Comparison. Geodynamics performs a wide range of comprehensive QA comparisons / procedures on all datasets to ensure accuracy and continuity between each successive survey. However, Geodynamics is not required to provide this information but can be obtained upon request.

9.6. PLS Certification. All topographic and hydrographic profile work performed by Geodynamics shall be approved and sealed by a Professional Land Surveyor (PLS) licensed in the State of North Carolina. All hydrographic data shall also be reviewed and accepted by a Certified Hydrographer (CH) with the Hydrographic Society of America (THSOA) or Category A/B (CAT A/B) certification from an International Hydrographic Organization (IHO) sanctioned program. All final data, GIS data products and cartographic products shall be reviewed and accepted by a certified GIS Professional (GISP or ESRI).

10. Technical POC. All technical questions concerning survey work under this task order shall be directed to Chris Freeman and / or Dave Bernstein at (252) 247-5785.

11. Administrative POC. All non-technical questions concerning administrative or contractual matters under this task order shall be directed to Johnny Martin at (919) 781-4626.

12. Schedule of Work & Completion Date. Upon commencement of work and weather permitting, fieldwork for the BBBNMP annual surveys should begin March / April of each year and proceed such that the survey data acquisition phase shall be completed no later than 1 August of each year. Safety of the field crew is the priority, followed by data quality and timeliness of schedule respectively. Geodynamics is to use judgment on the exact days of data collection for both safety and data quality concerns and scheduling of surveys will be coordinated in advance with M&N, the Carteret County Shore Protection Manager and local authorities. Data analysis, documentation, and computer files should be delivered to M&N by 15 August of each year pending the ultimate schedule for data acquisition which is solely dictated by the weather, tide stage and surface conditions. This schedule is subject to adjustment by Geodynamics for documented conditions beyond the control of the parties hereto. Post-storm surveys will be completed at the direction of Carteret County and Moffatt & Nichol.

13. Deliver To. All survey work completed by Geodynamics shall be delivered to:

    Johnny Martin / Nicole Vanderbeke
    Coastal Engineer / Project Manager
    Moffatt & Nichol Engineers
    4700 Falls of the Neuse Rd. Suite 300
    Raleigh, NC 27609-6275
    Or via FTP / Sharefile

14. Public Interaction. Geodynamics is working on the BBBNMP as a representative of Carteret County and Moffatt & Nichol Engineers and will conduct its work in a professional manner that is respectful of the public. At no time shall Geodynamics knowingly damage private or public property, display public indecency or enter into any argumentative conversations with the public. Conversations with the public shall be cordial and limited to general information about the survey operation. Questions relating to beach renourishment, individual profile analysis, political involvement or any such question outside this Scope of Work shall be directed to:

    Greg “Rudi” Rudolph
    Shore Protection Manager
    Carteret County Shore Protection Office
    grudolph@carteretcountygov.org
    252-393-2663

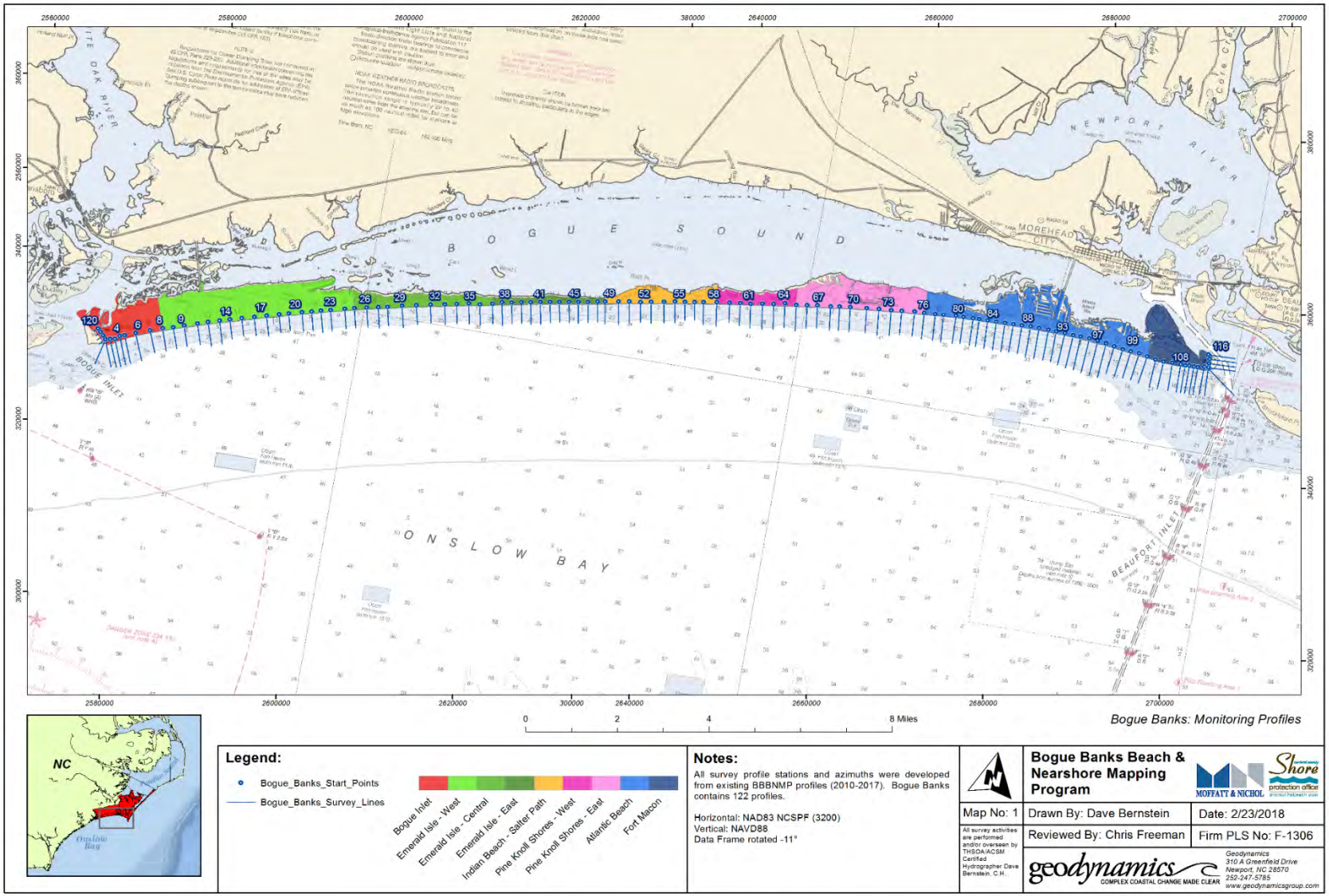


Figure 1. Survey profile map for Bogue Banks

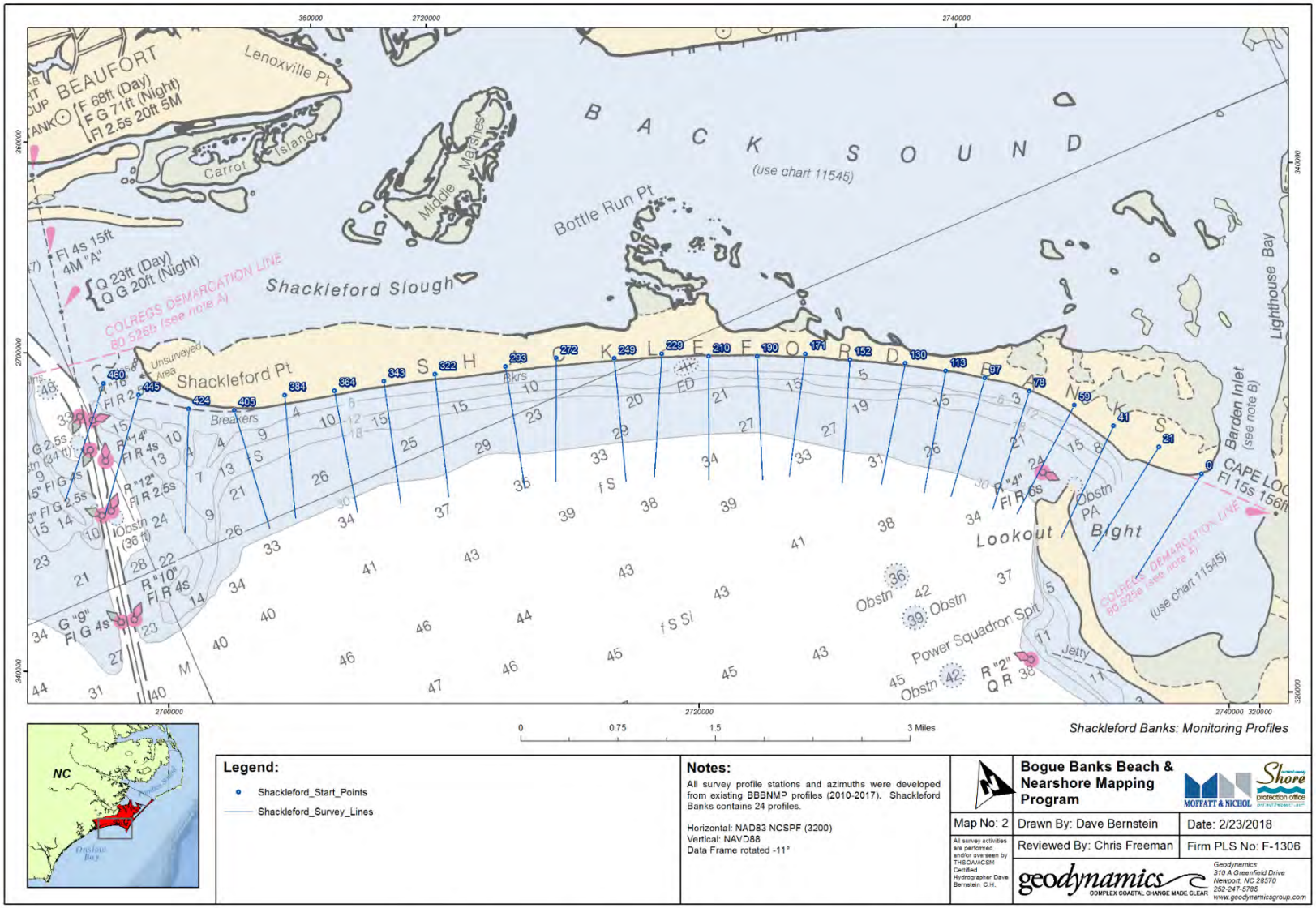


Figure 2. Survey profile map for Shackleford Banks

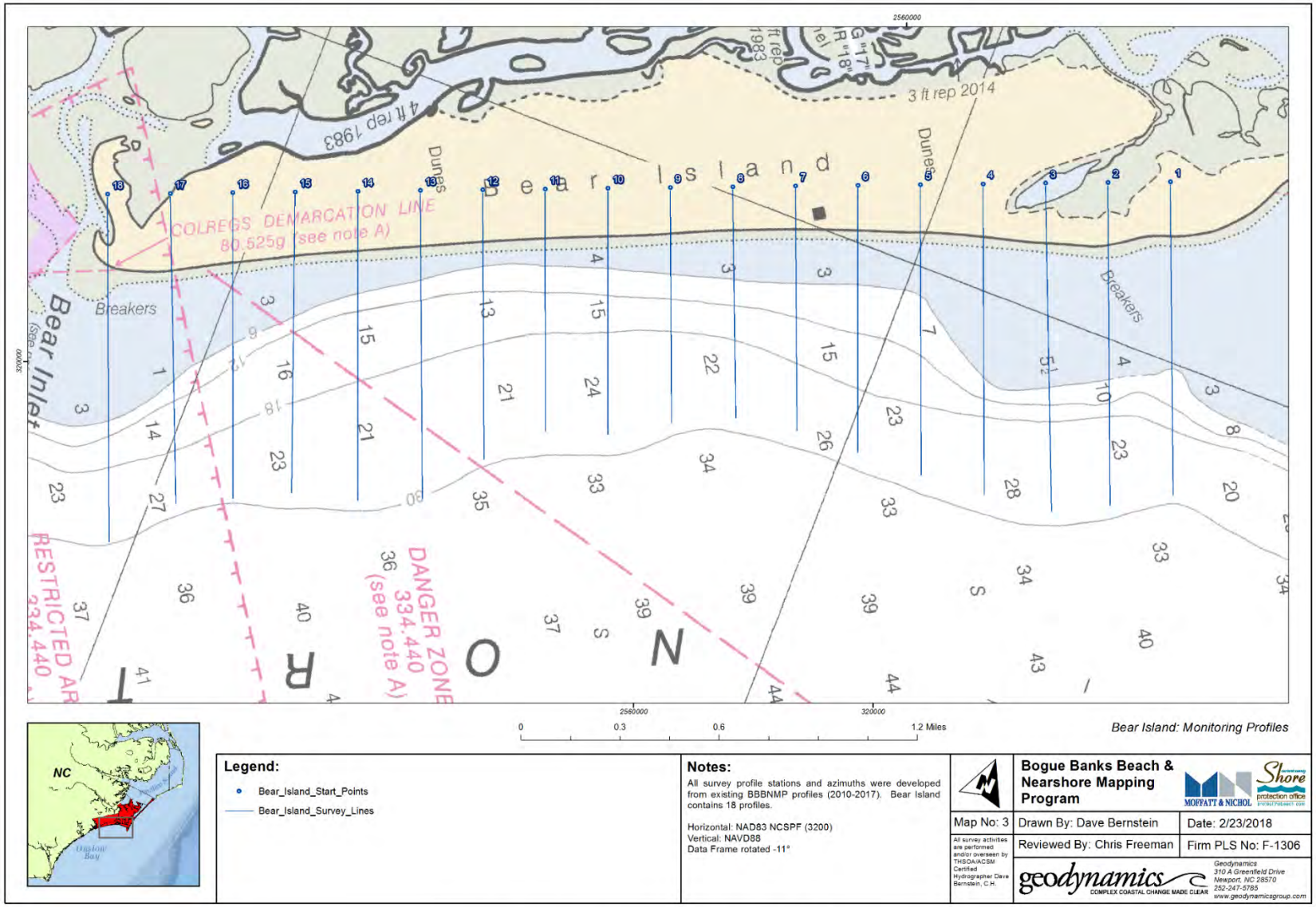


Figure 3. Survey profile map for Bear Island.

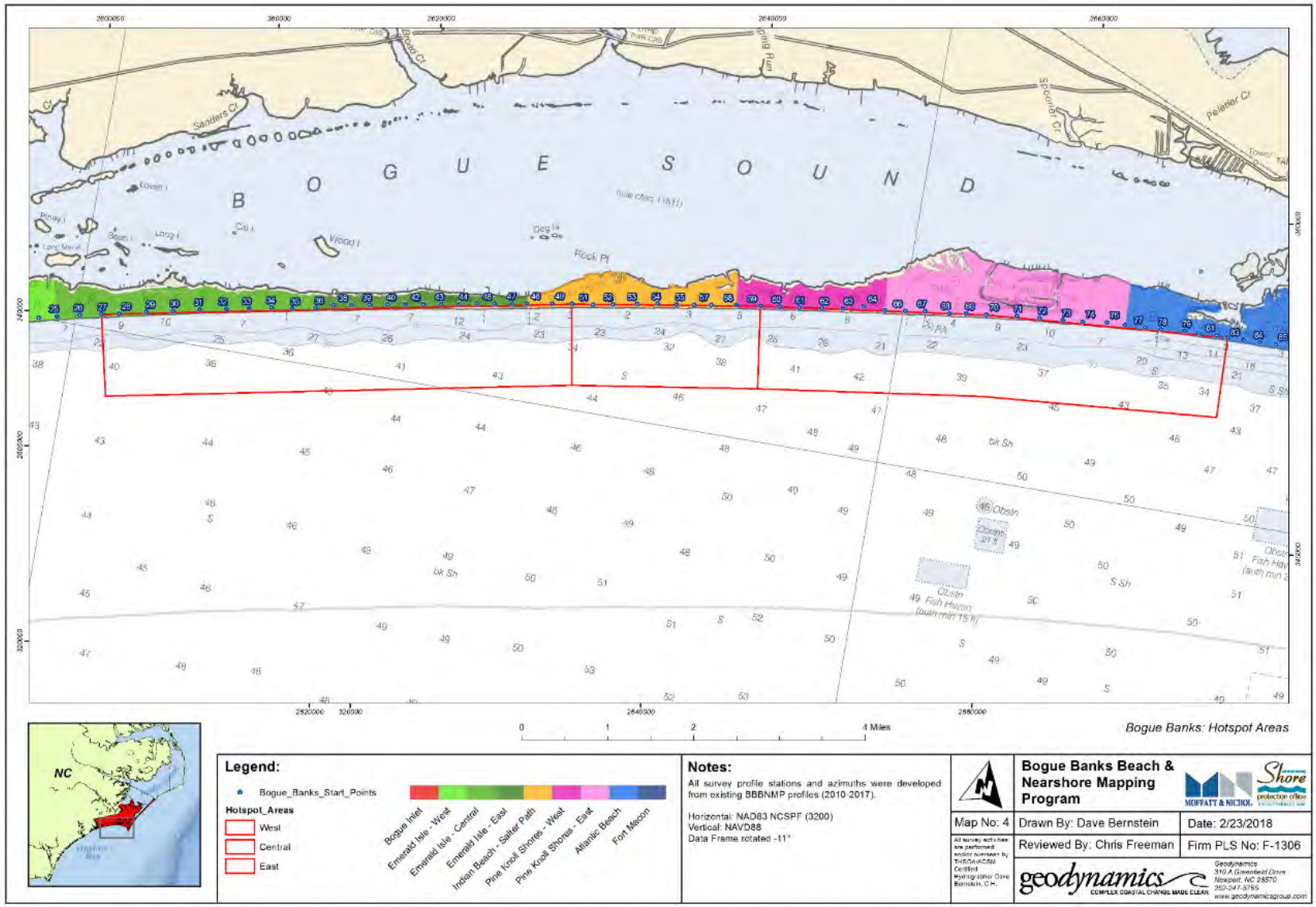


Figure 4. Bogue Banks "Hotspot" Topographic Survey Boundary.

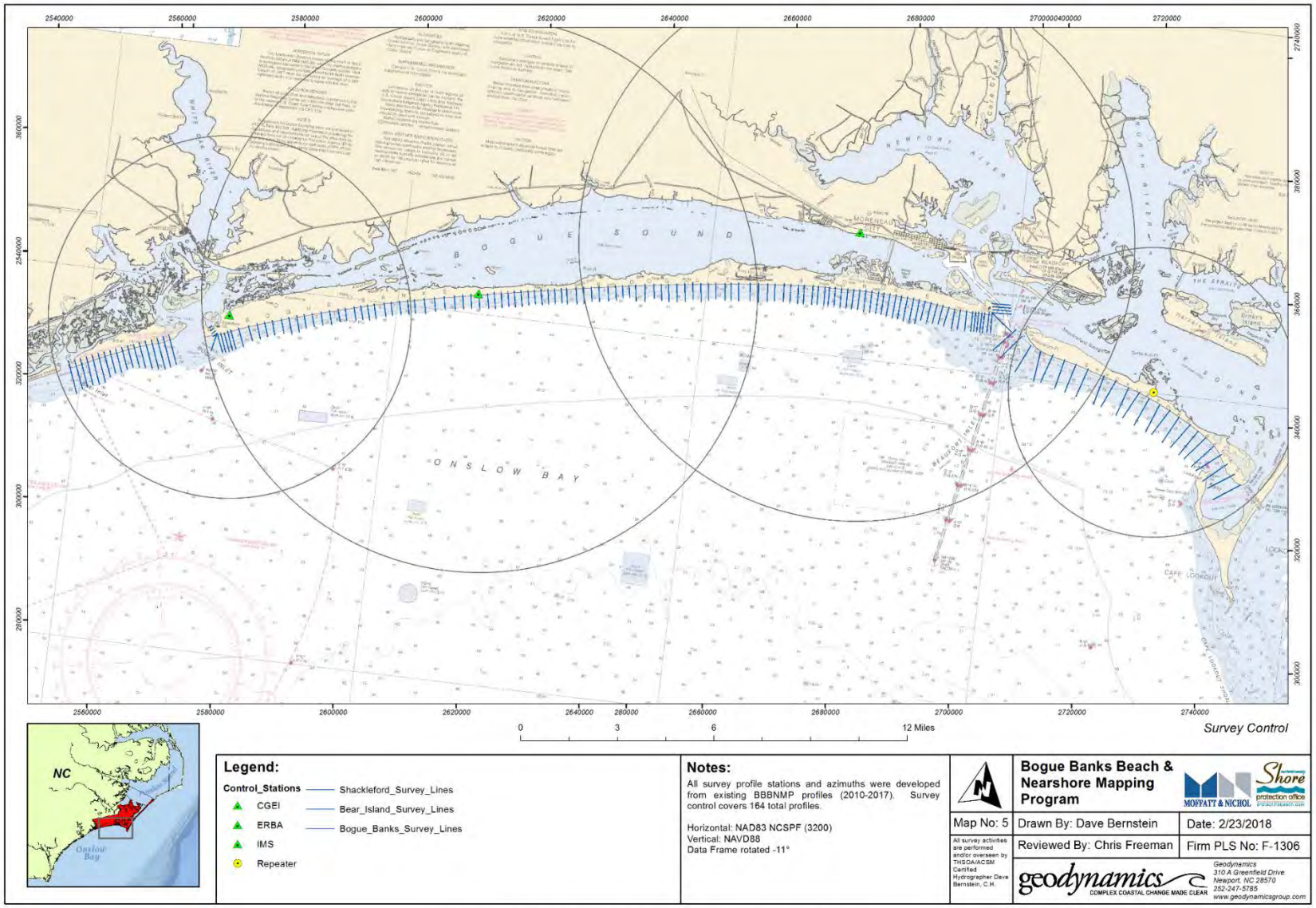


Figure 5. Control used for the BBNMP.

APPENDIX B

MHW Shoreline & Hotspot DEM Surface

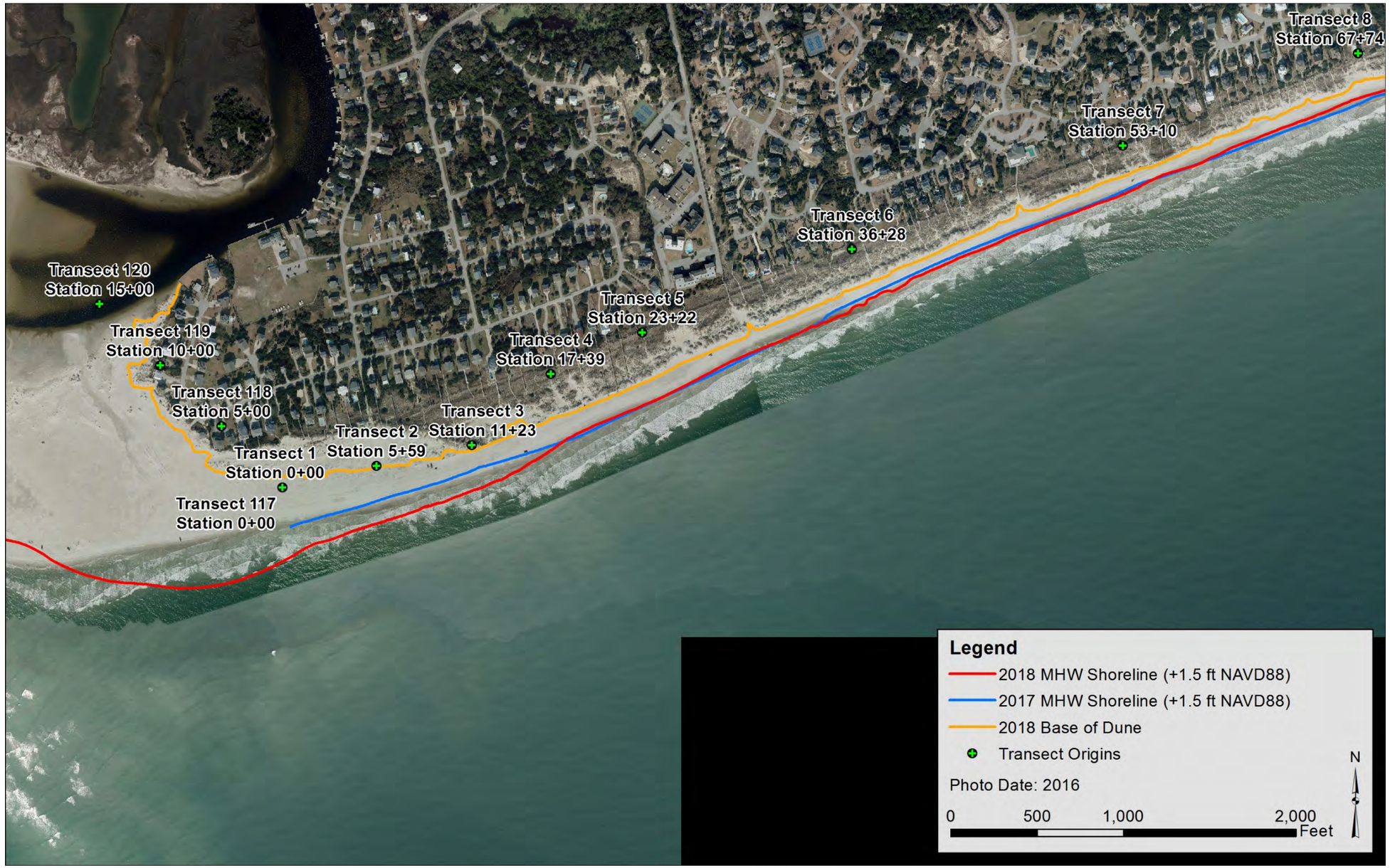


Figure B-1. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

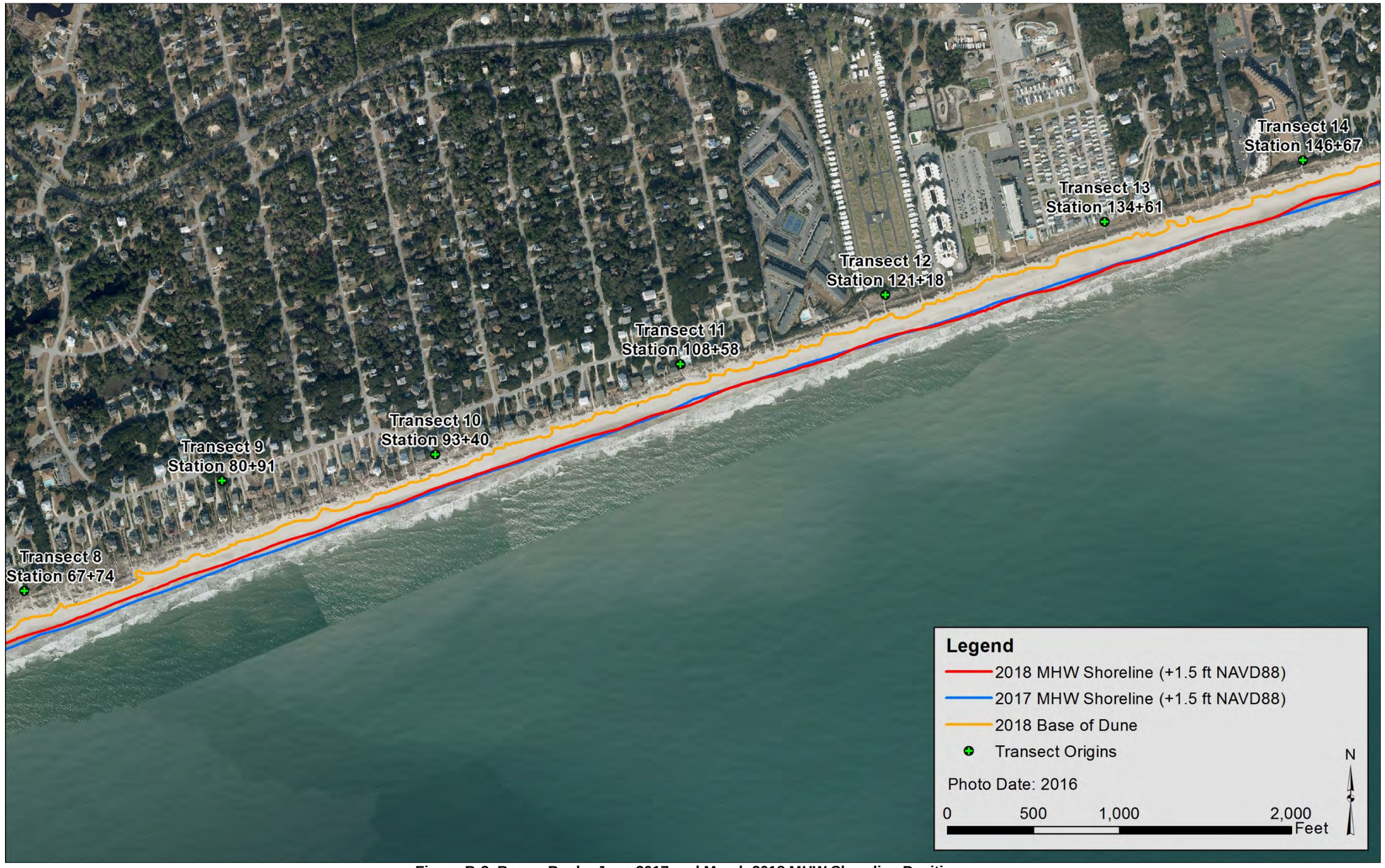


Figure B-2. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

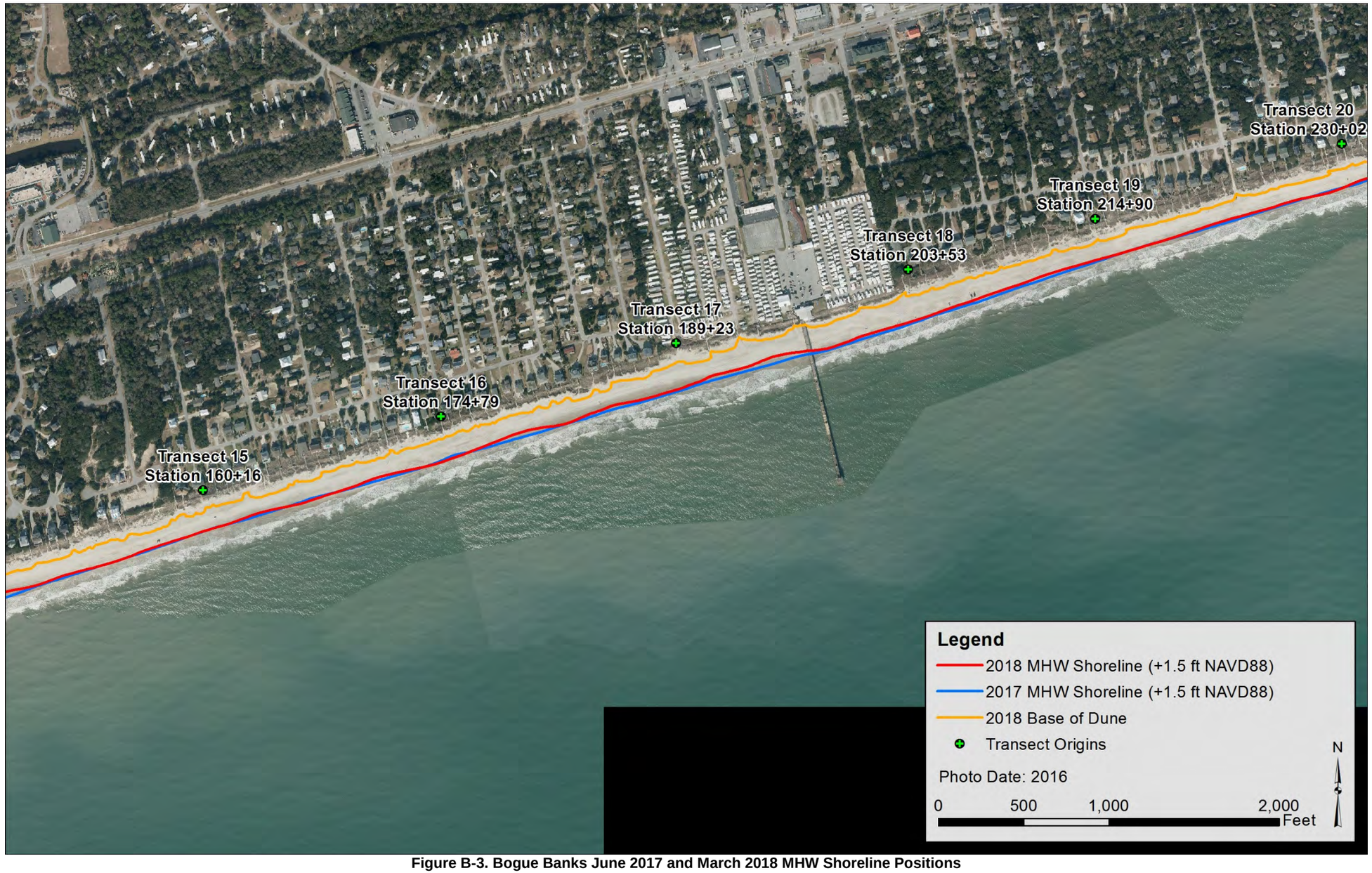


Figure B-3. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

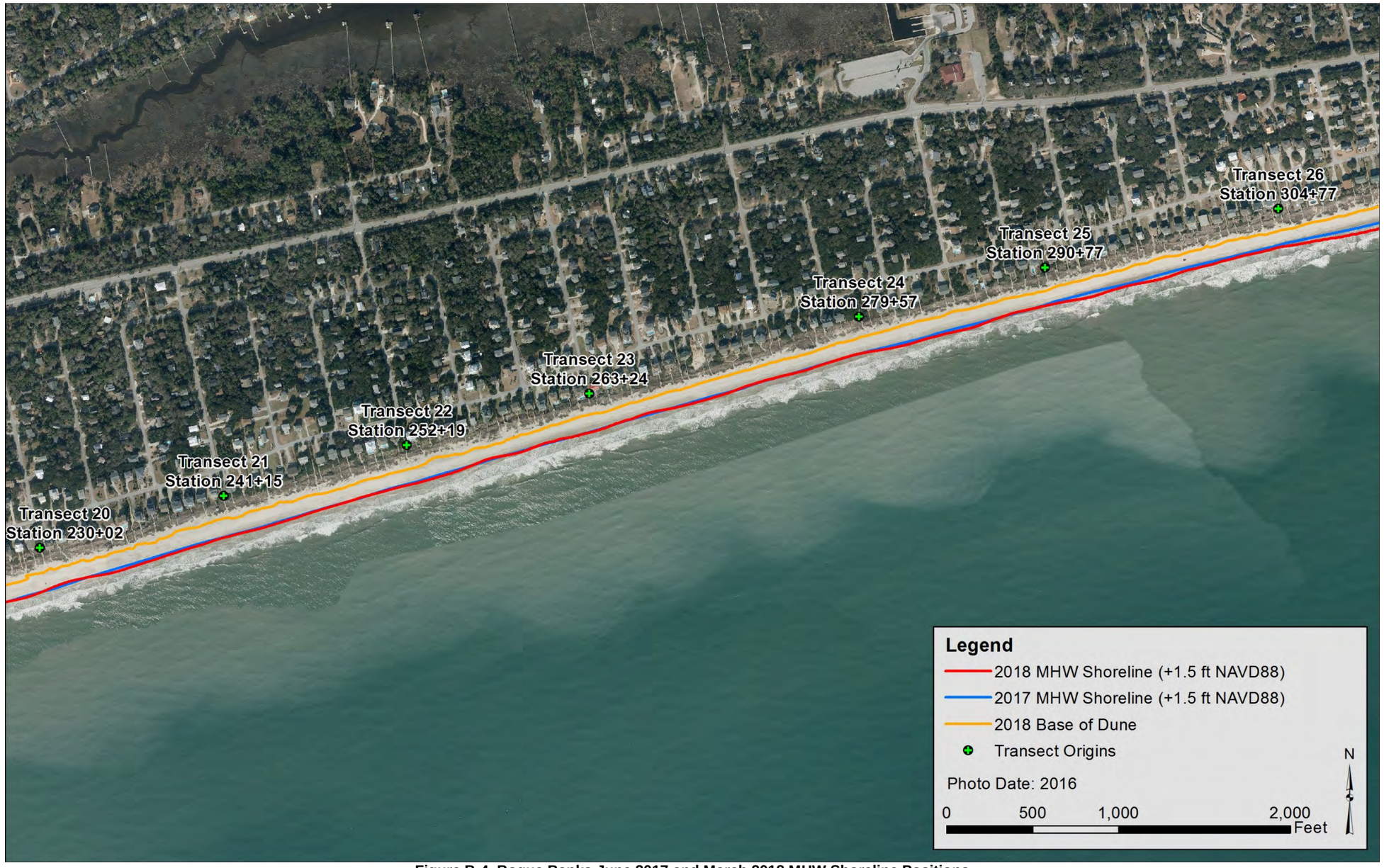


Figure B-4. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

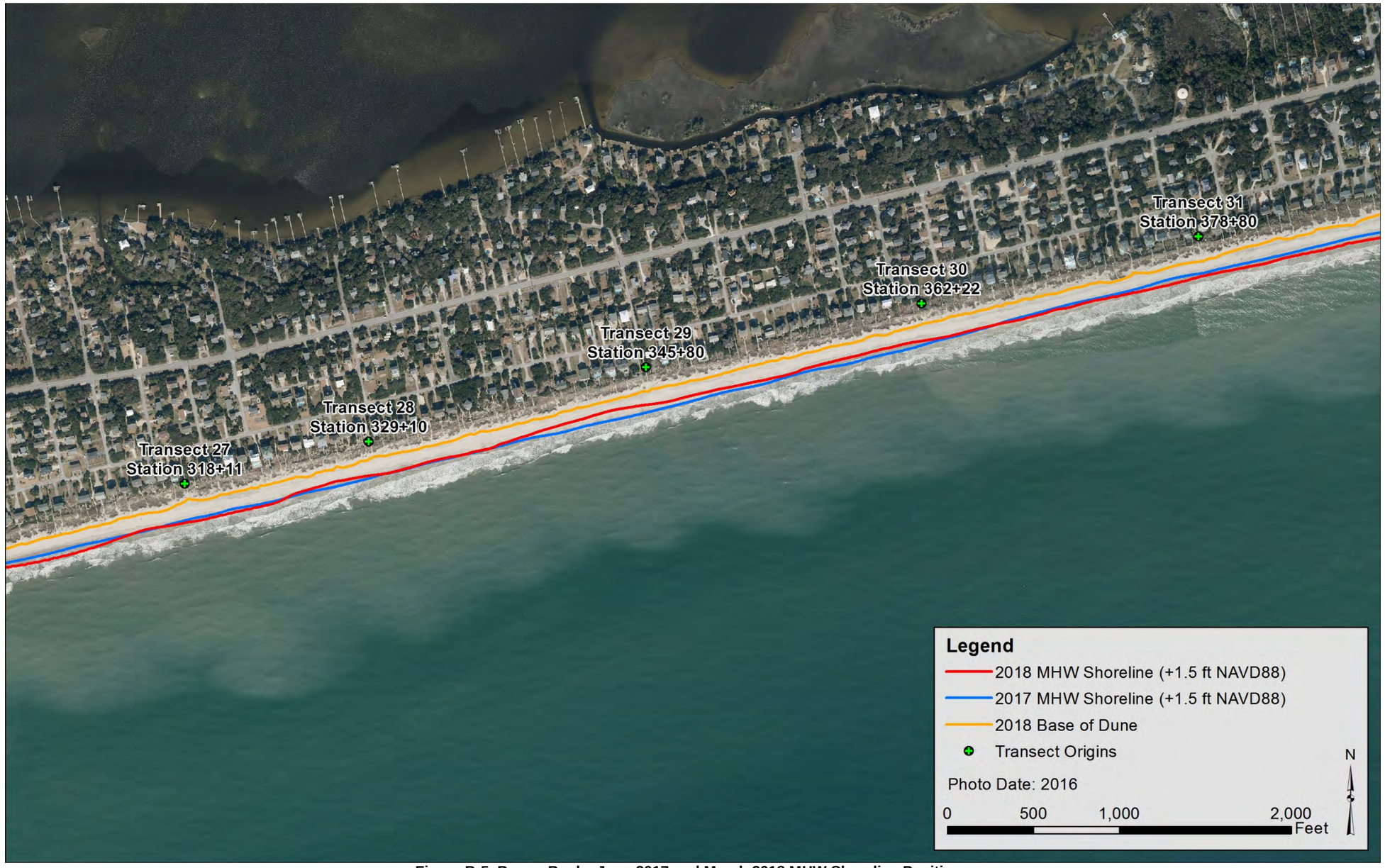


Figure B-5. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

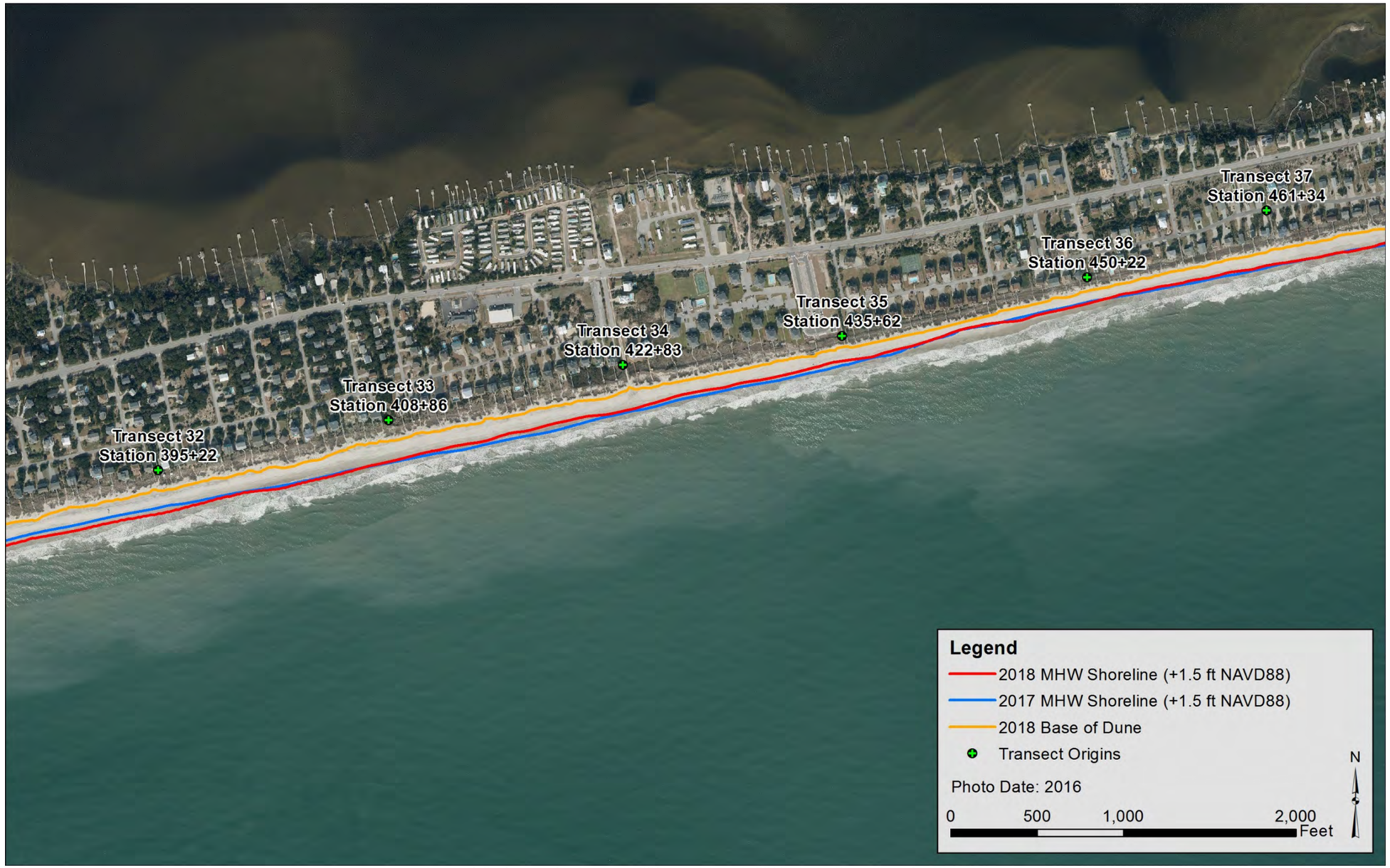


Figure B-6. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

Figure B-7. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

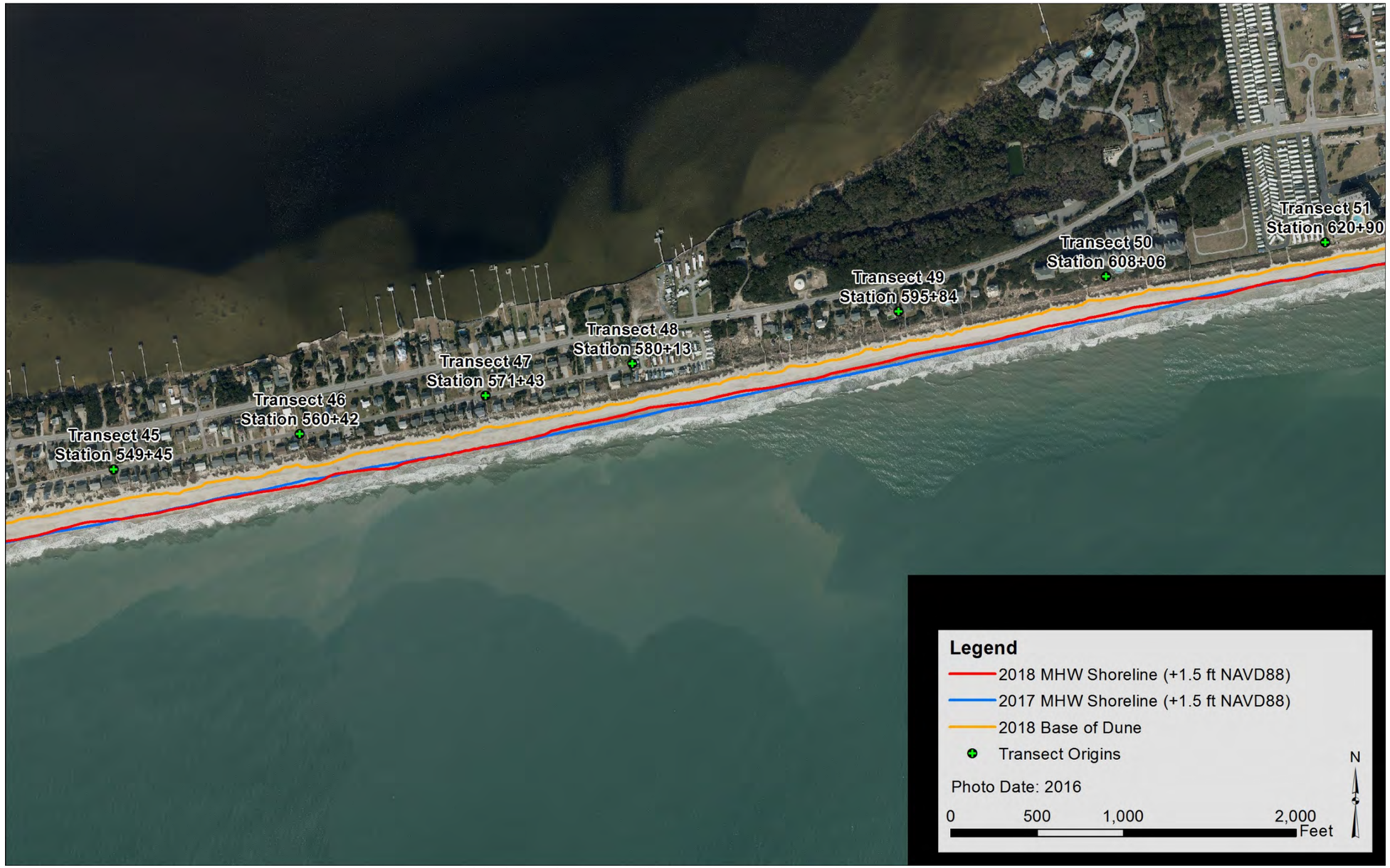


Figure B-8. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

Figure B-9. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

Figure B-10. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

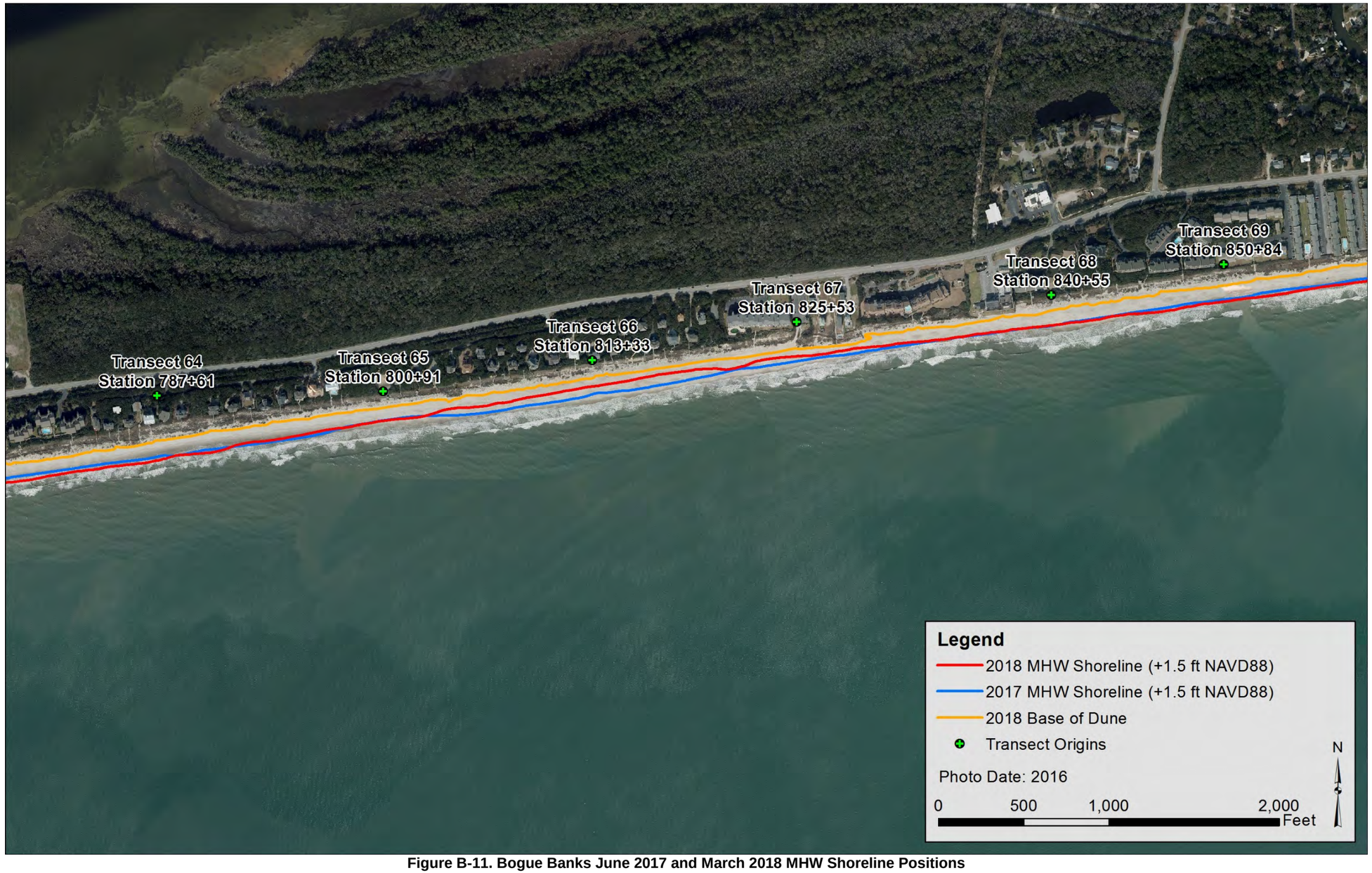


Figure B-11. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

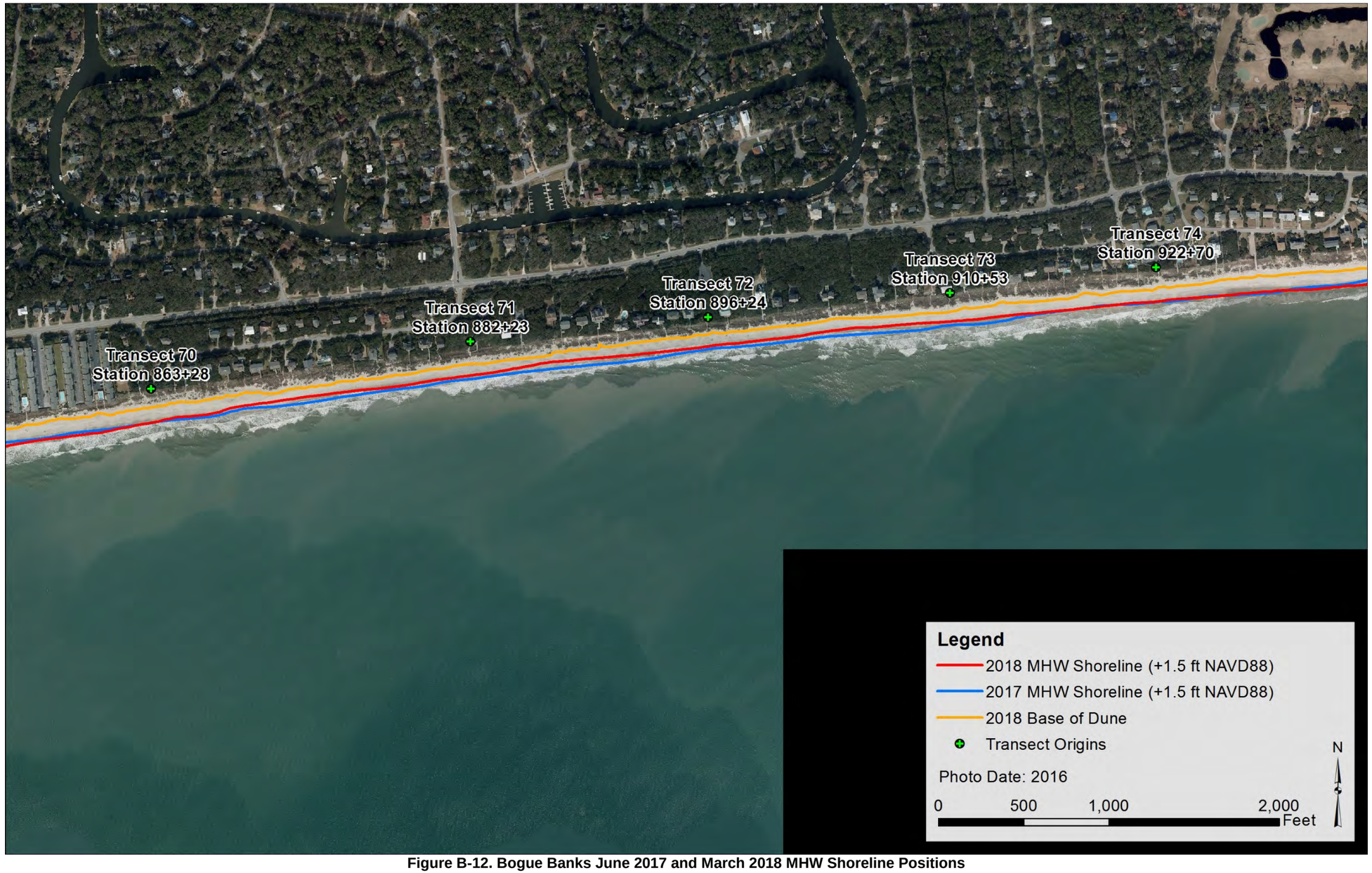


Figure B-12. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

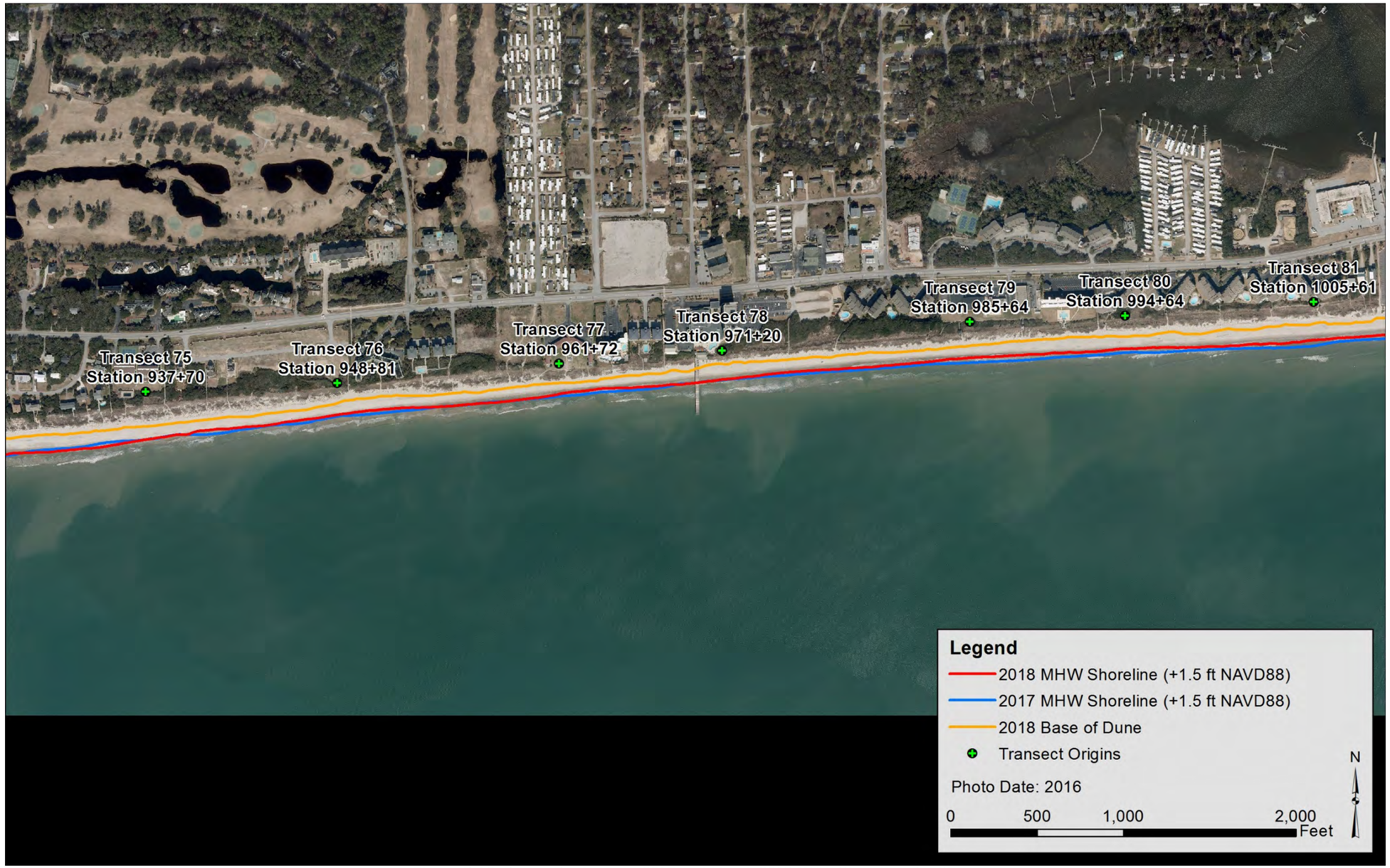


Figure B-13. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

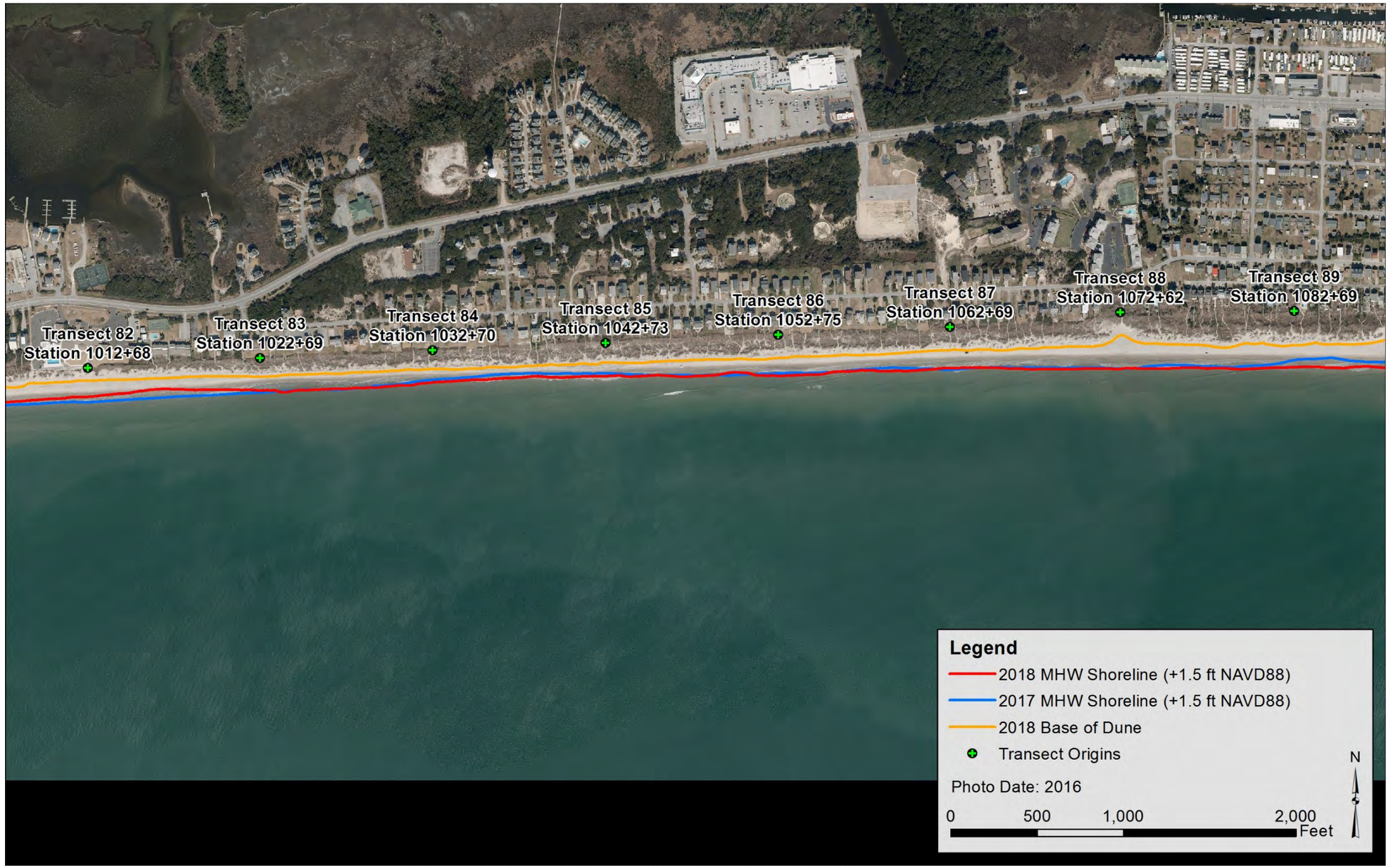


Figure B-14. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

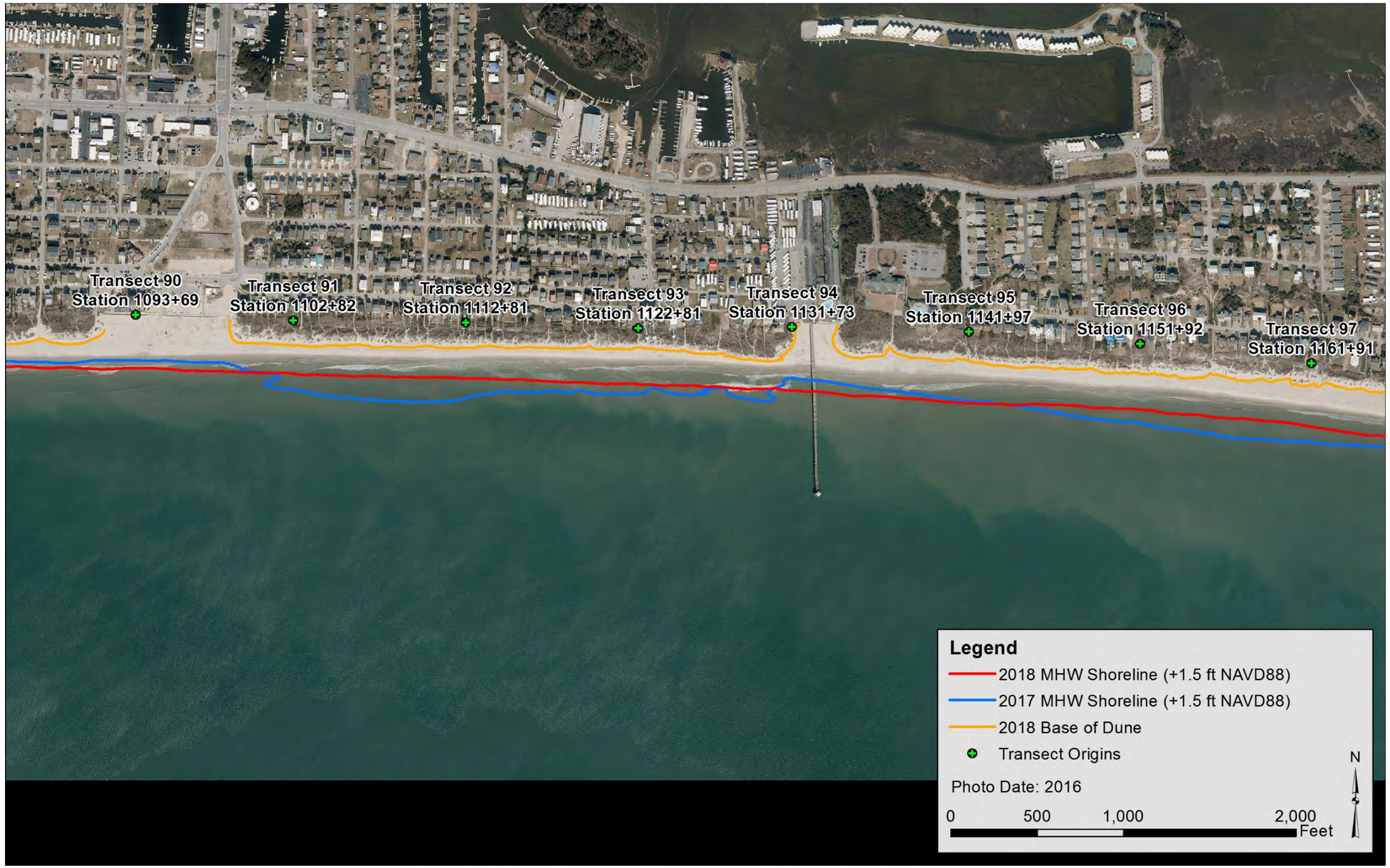


Figure B-15. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

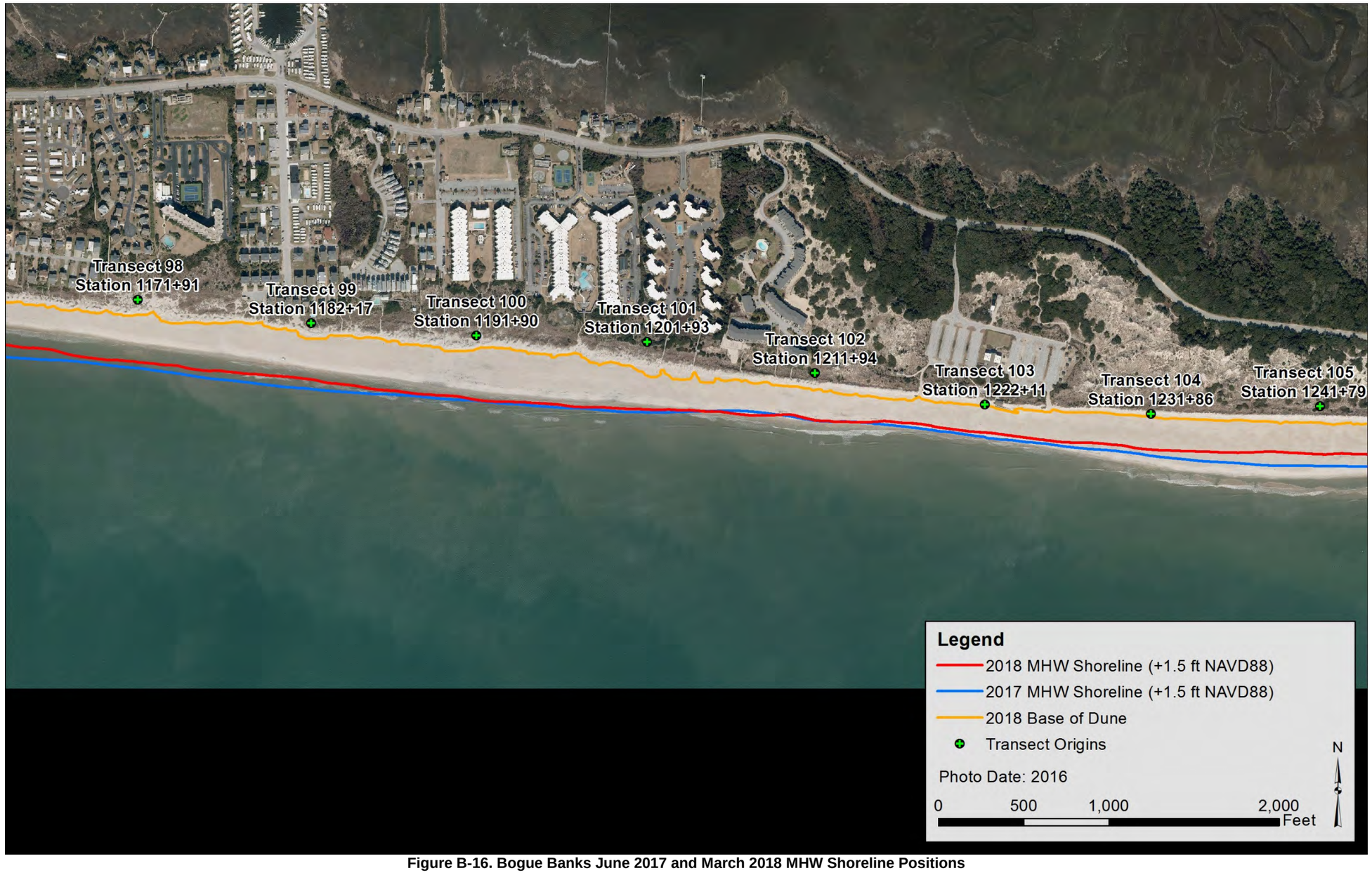


Figure B-16. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

Figure B-17. Bogue Banks June 2017 and March 2018 MHW Shoreline Positions

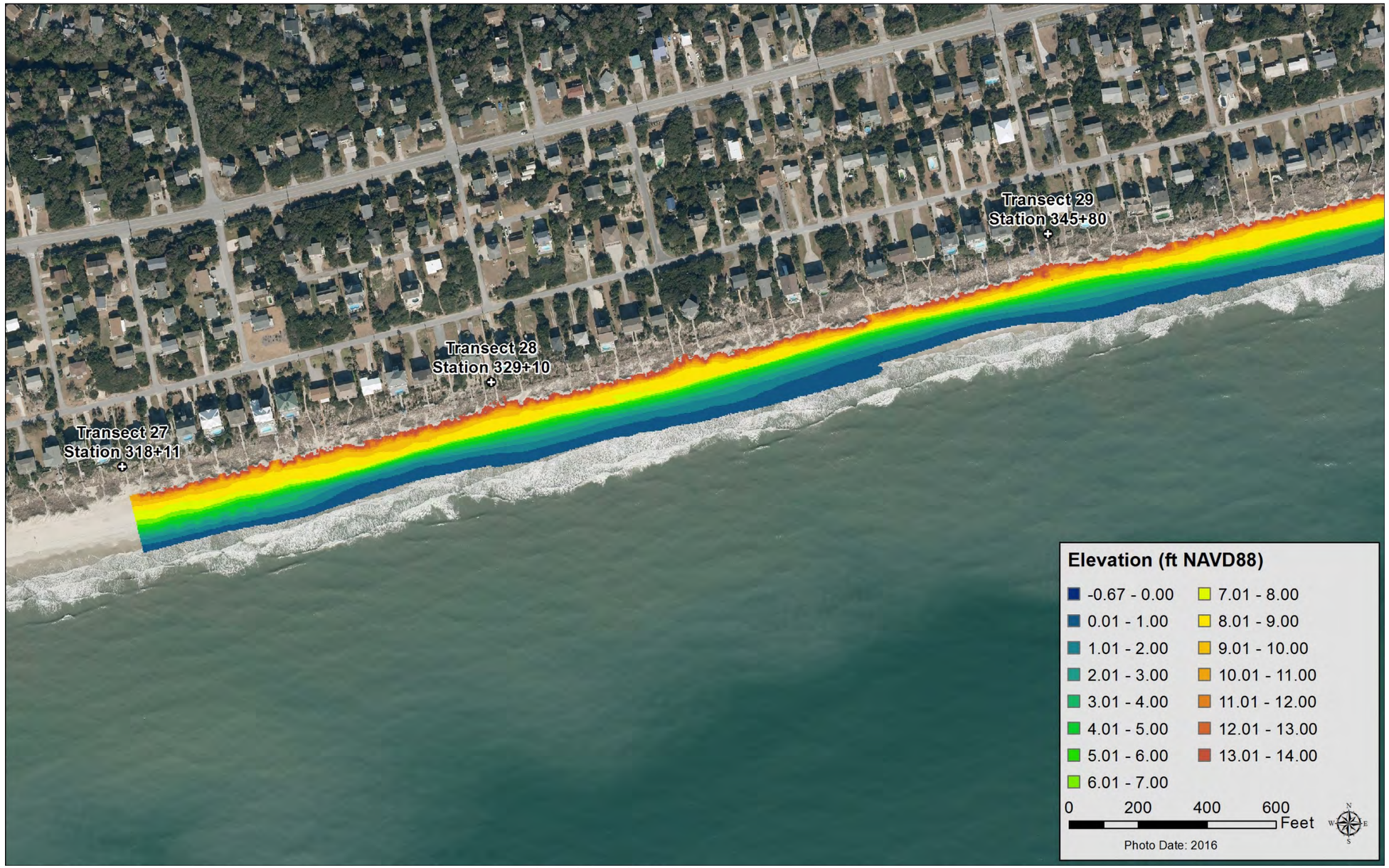


Figure B-18. Bogue Banks 2018 Hotspot Laser Scanner DEM

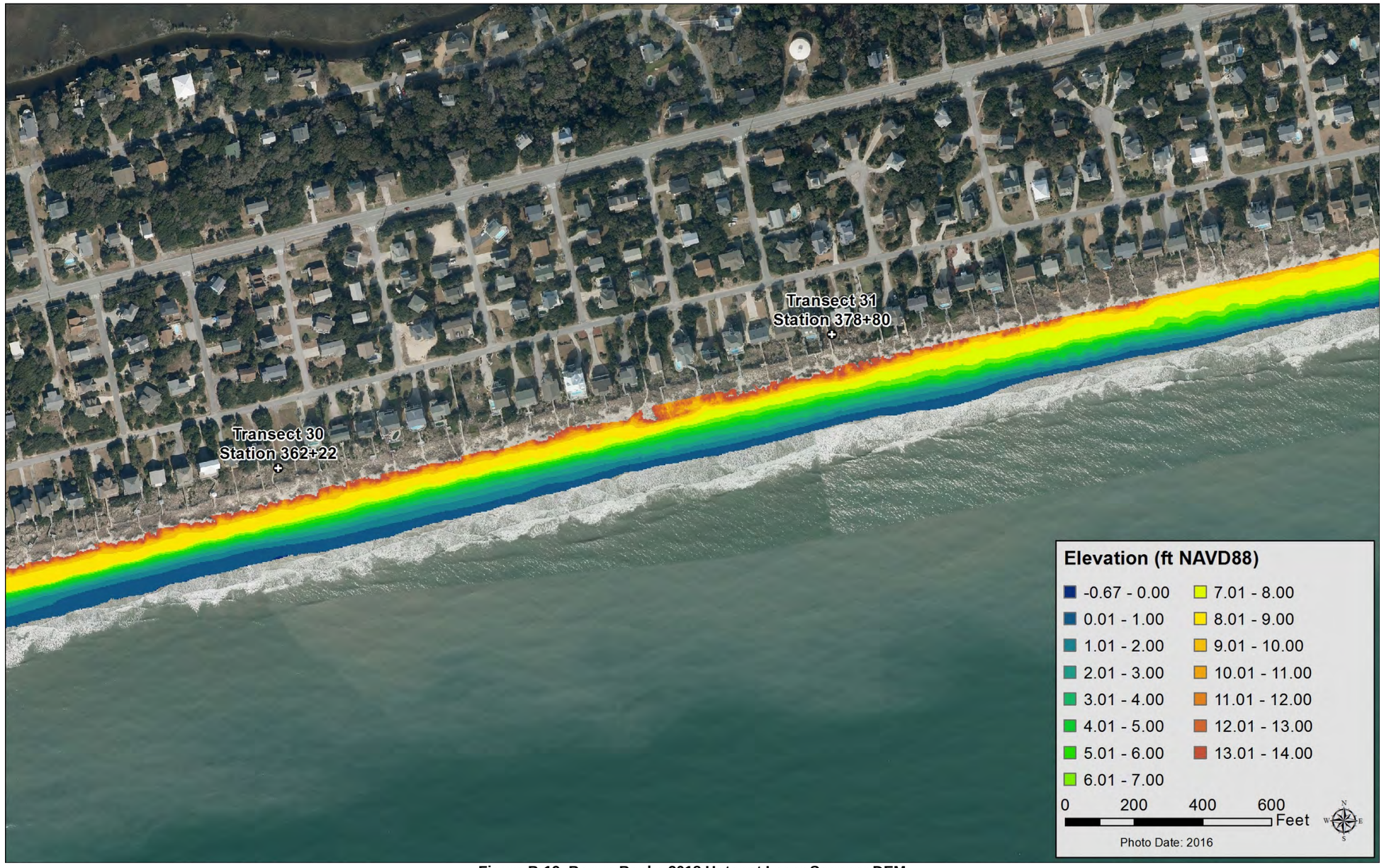


Figure B-19. Bogue Banks 2018 Hotspot Laser Scanner DEM

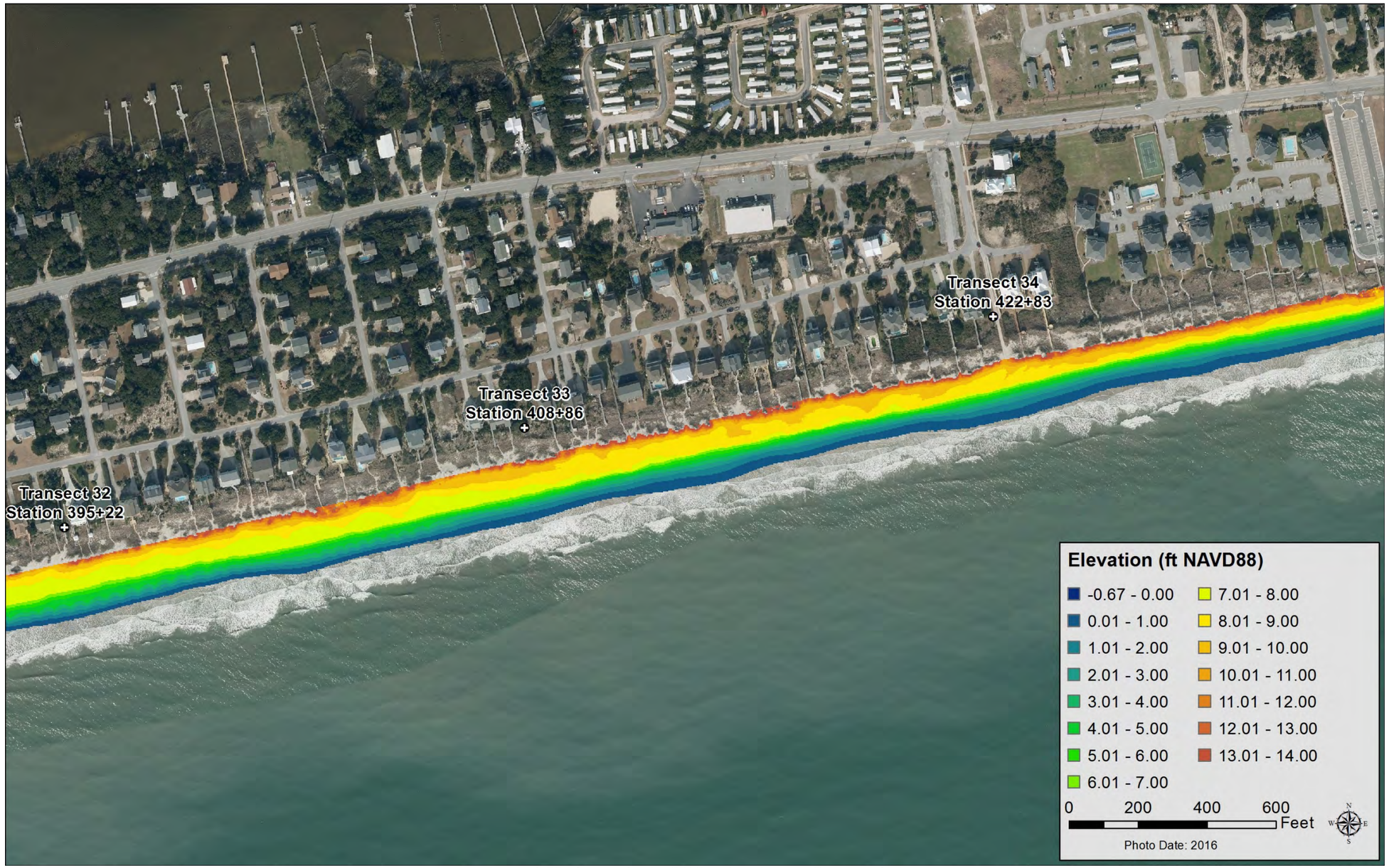


Figure B-20. Bogue Banks 2018 Hotspot Laser Scanner DEM

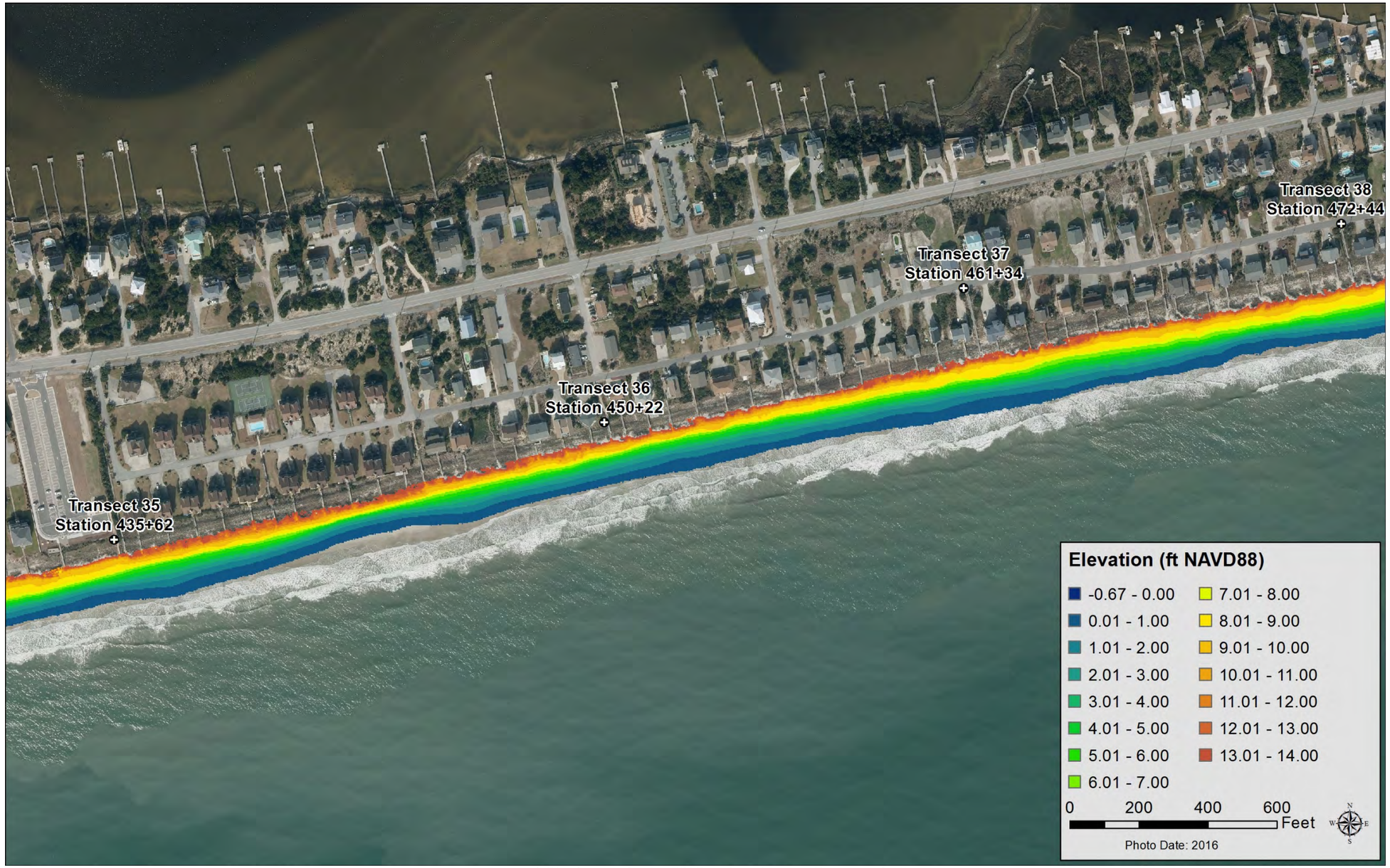


Figure B-21. Bogue Banks 2018 Hotspot Laser Scanner DEM

Figure B-22. Bogue Banks 2018 Hotspot Laser Scanner DEM

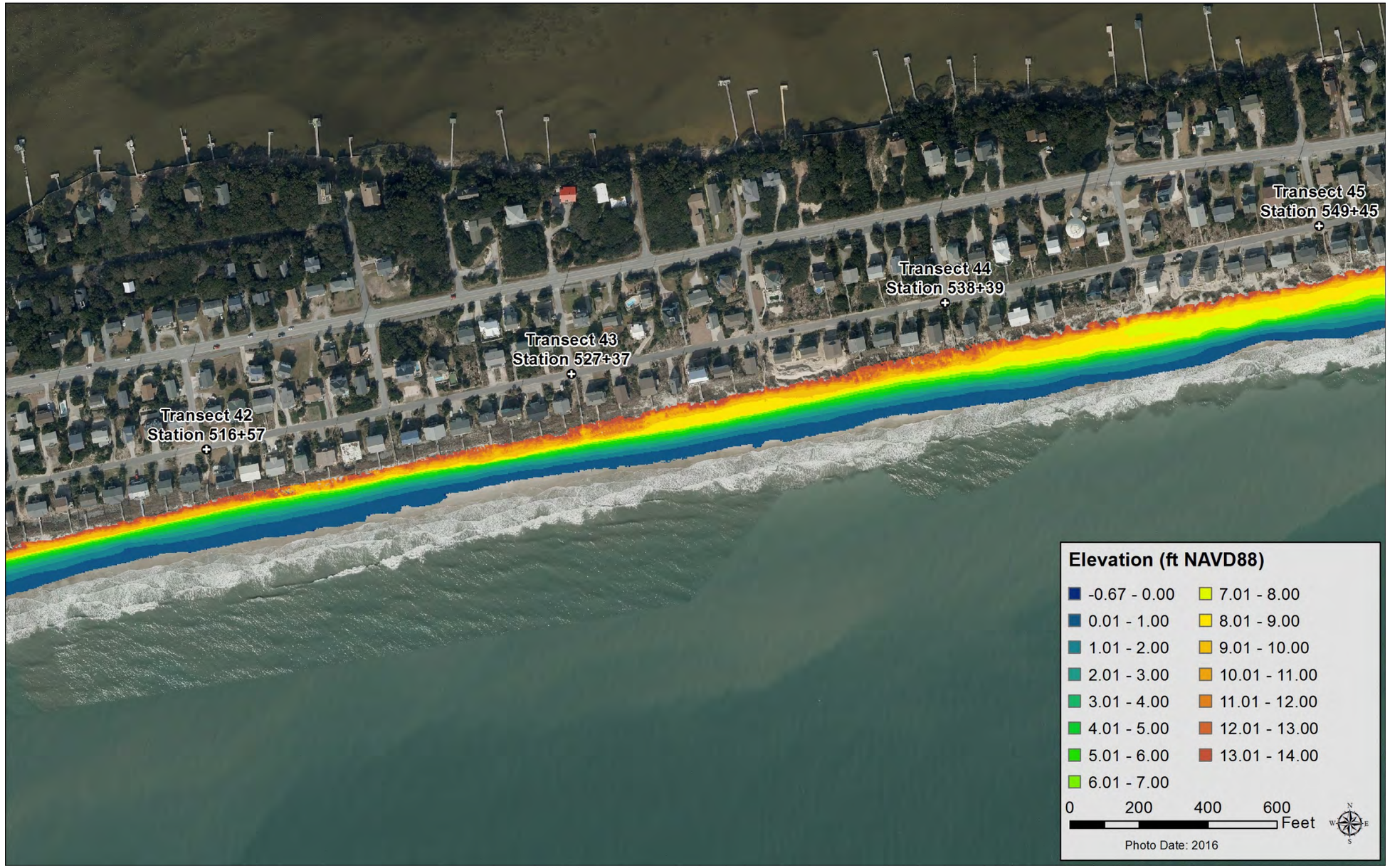


Figure B-23. Bogue Banks 2018 Hotspot Laser Scanner DEM

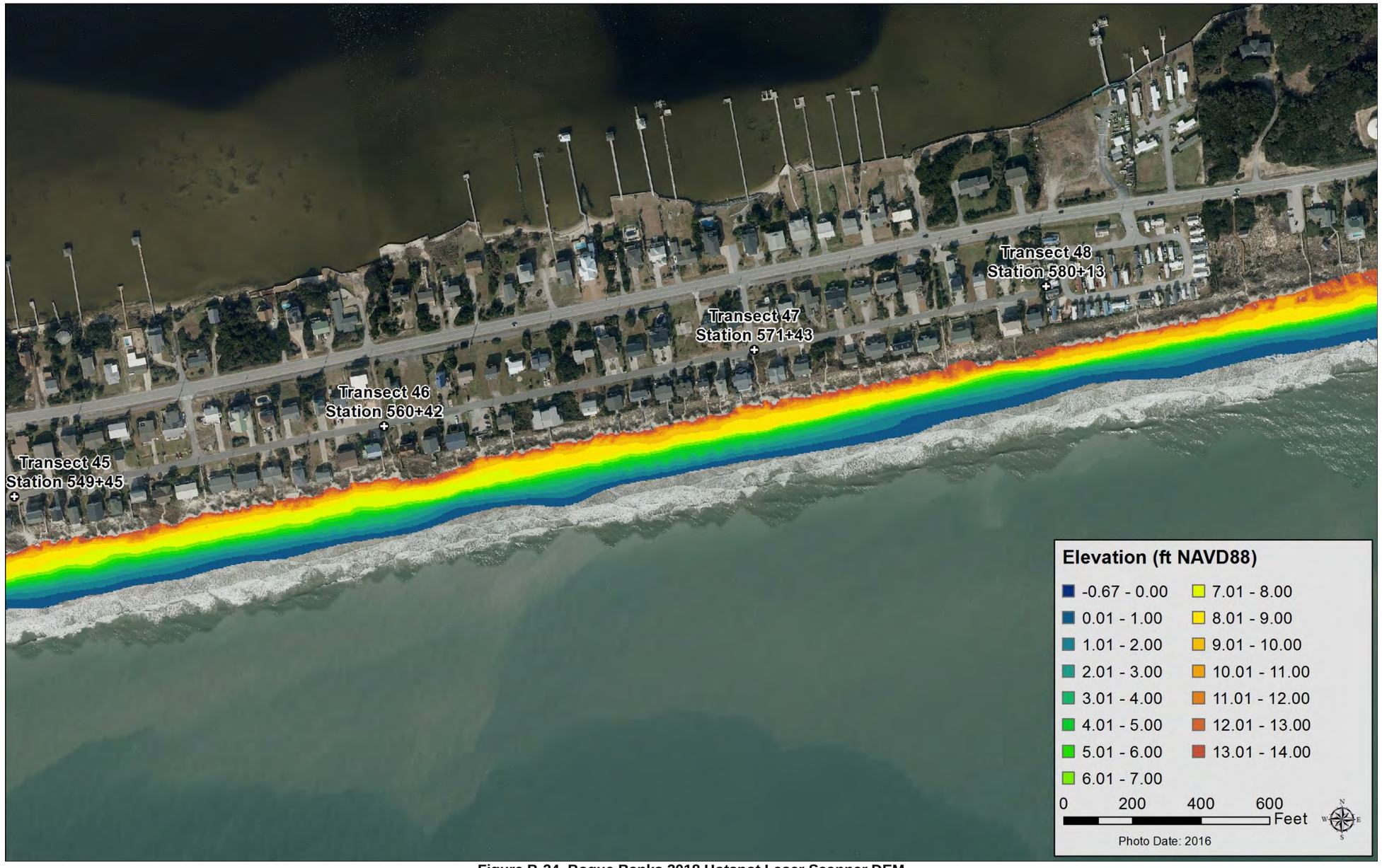


Figure B-24. Bogue Banks 2018 Hotspot Laser Scanner DEM

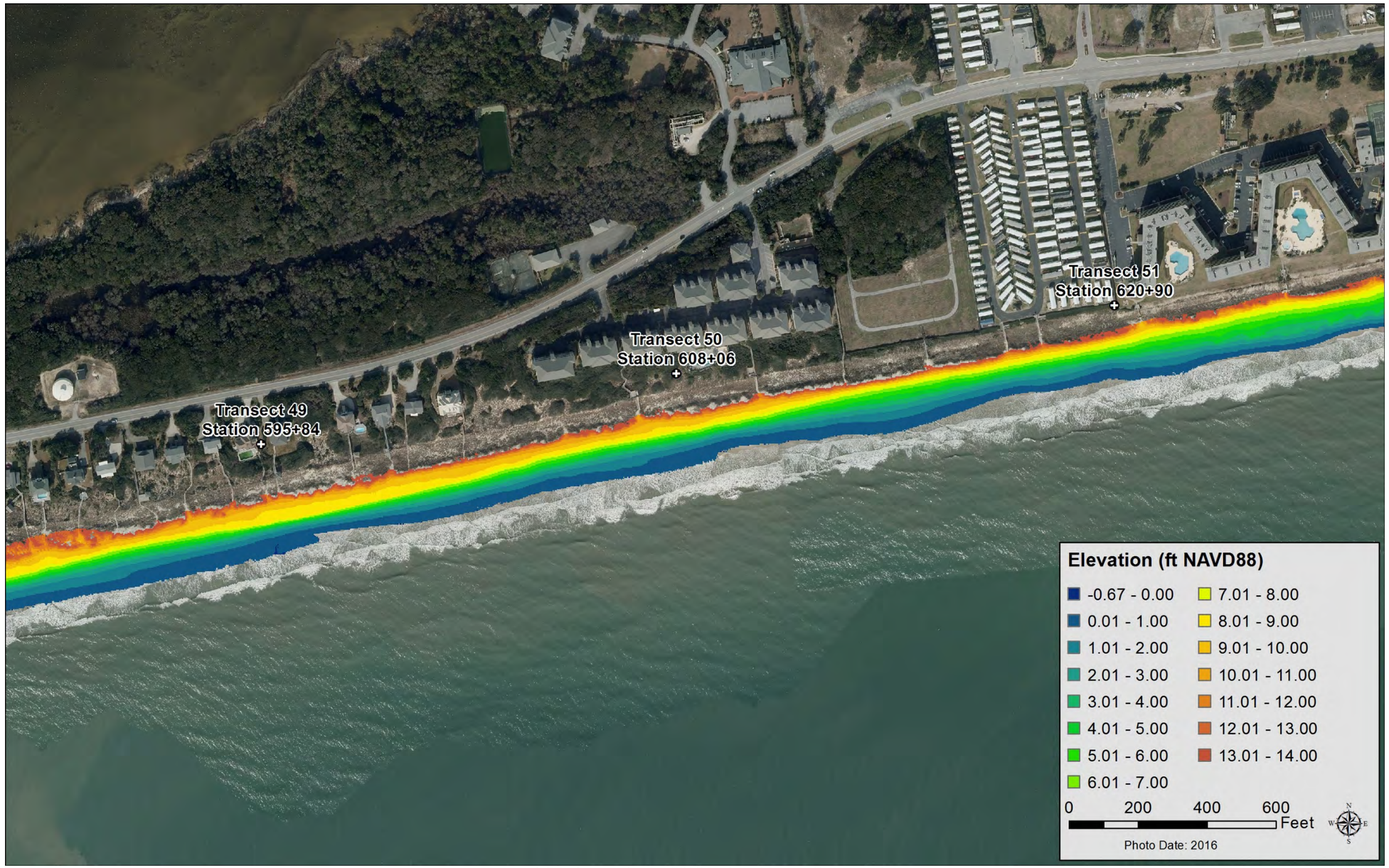


Figure B-25. Bogue Banks 2018 Hotspot Laser Scanner DEM

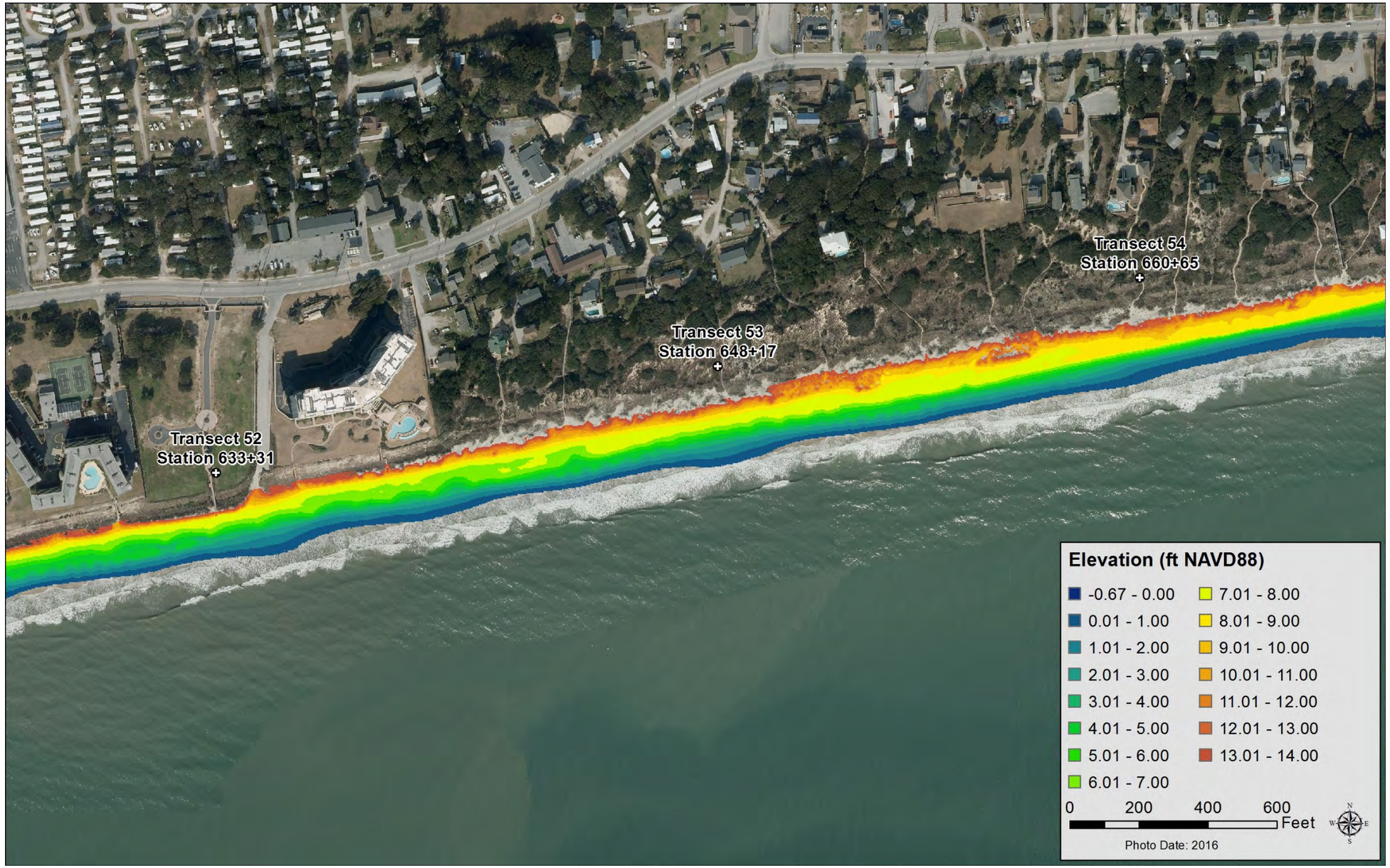


Figure B-26. Bogue Banks 2018 Hotspot Laser Scanner DEM

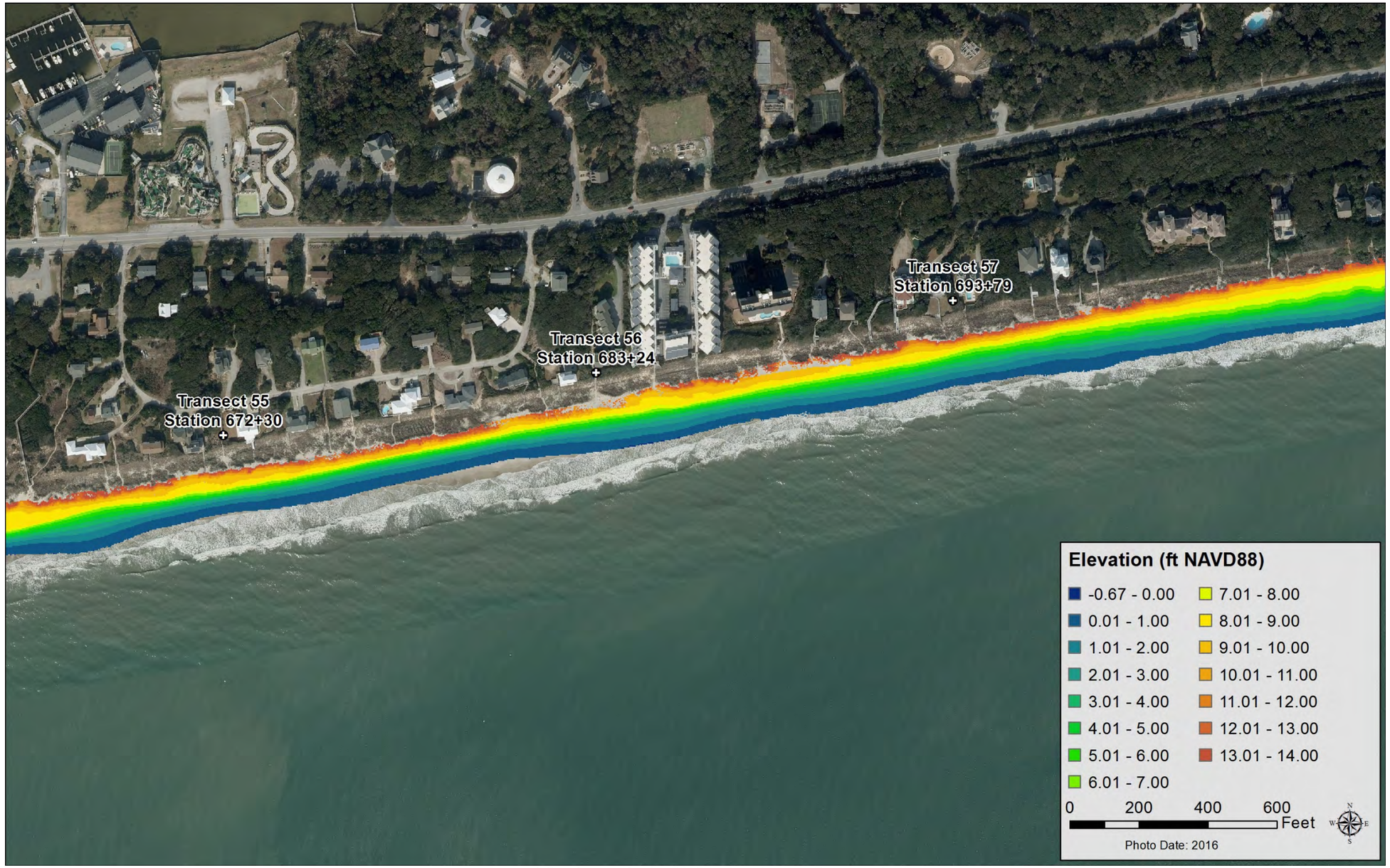


Figure B-27. Bogue Banks 2018 Hotspot Laser Scanner DEM

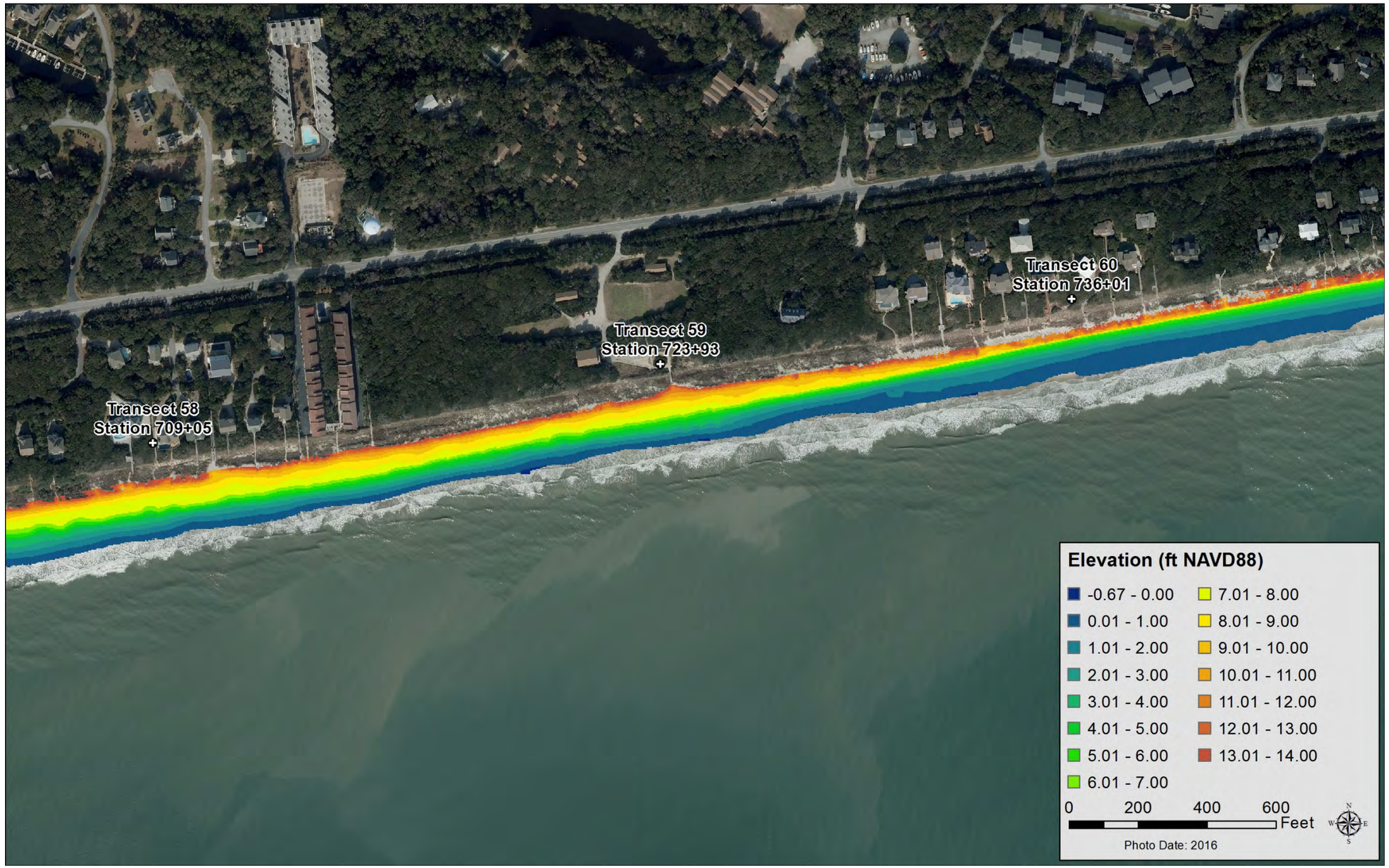


Figure B-28. Bogue Banks 2018 Hotspot Laser Scanner DEM

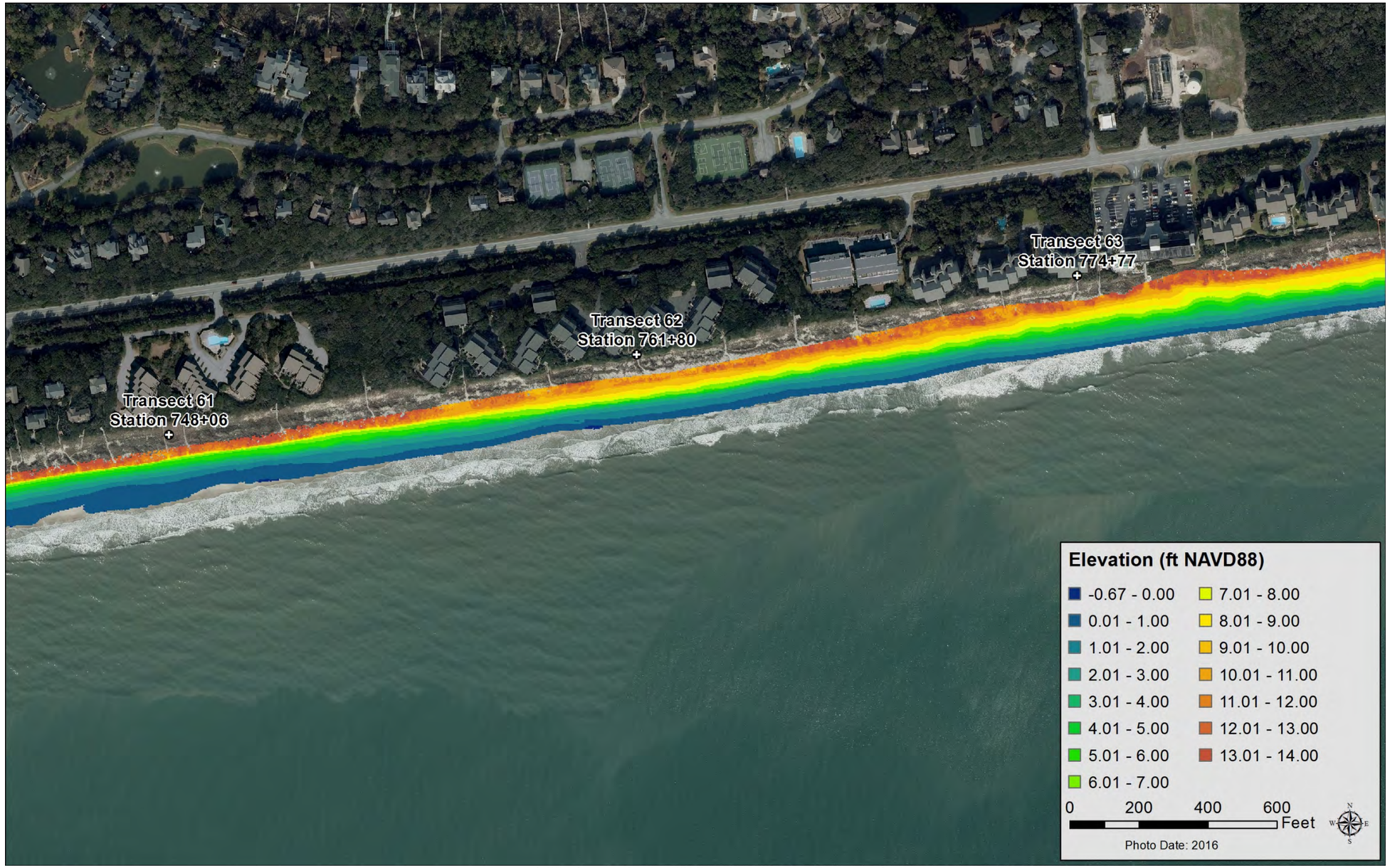


Figure B-29. Bogue Banks 2018 Hotspot Laser Scanner DEM

Figure B-30. Bogue Banks 2018 Hotspot Laser Scanner DEM

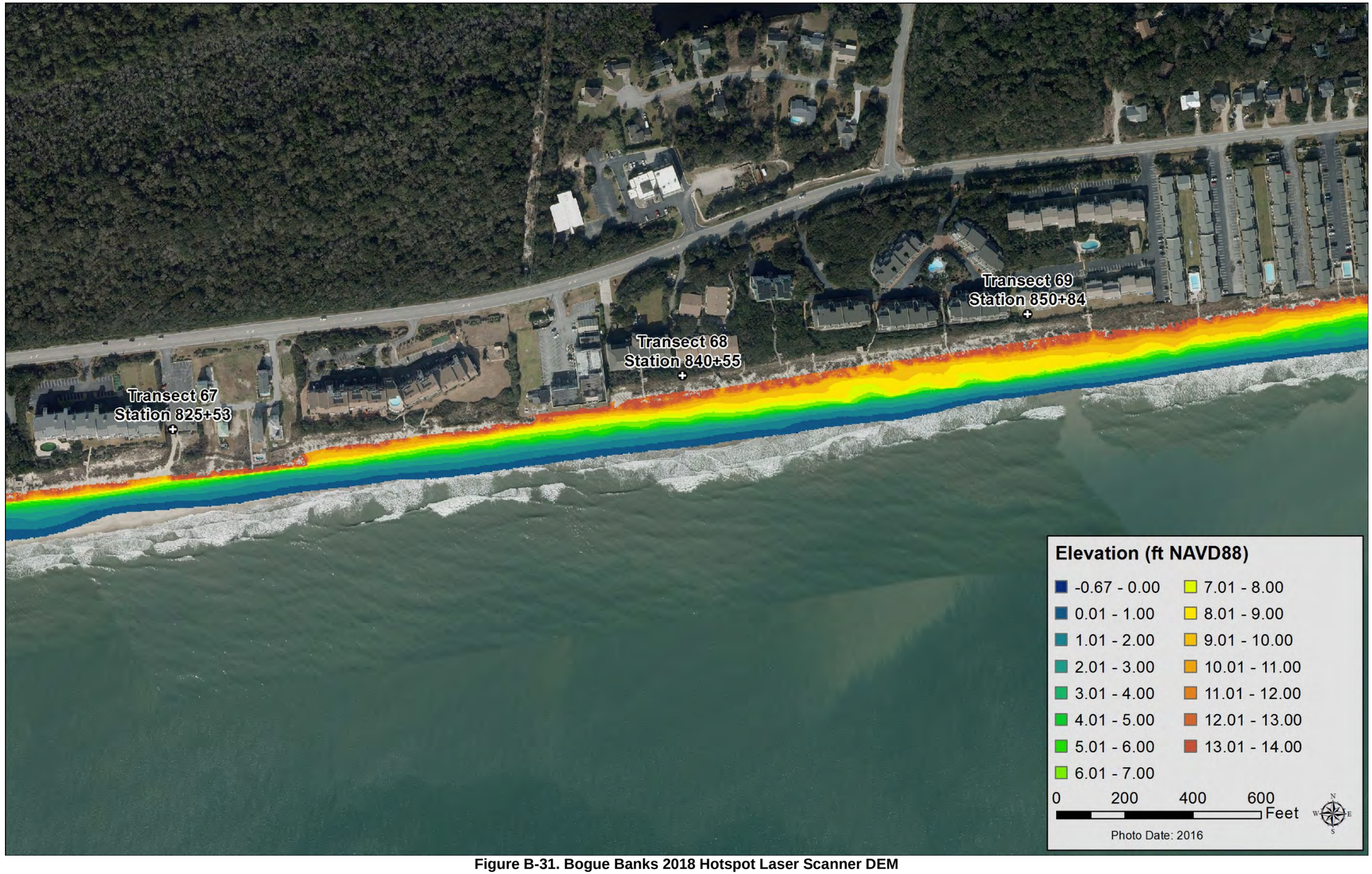


Figure B-31. Bogue Banks 2018 Hotspot Laser Scanner DEM

Figure B-32. Bogue Banks 2018 Hotspot Laser Scanner DEM

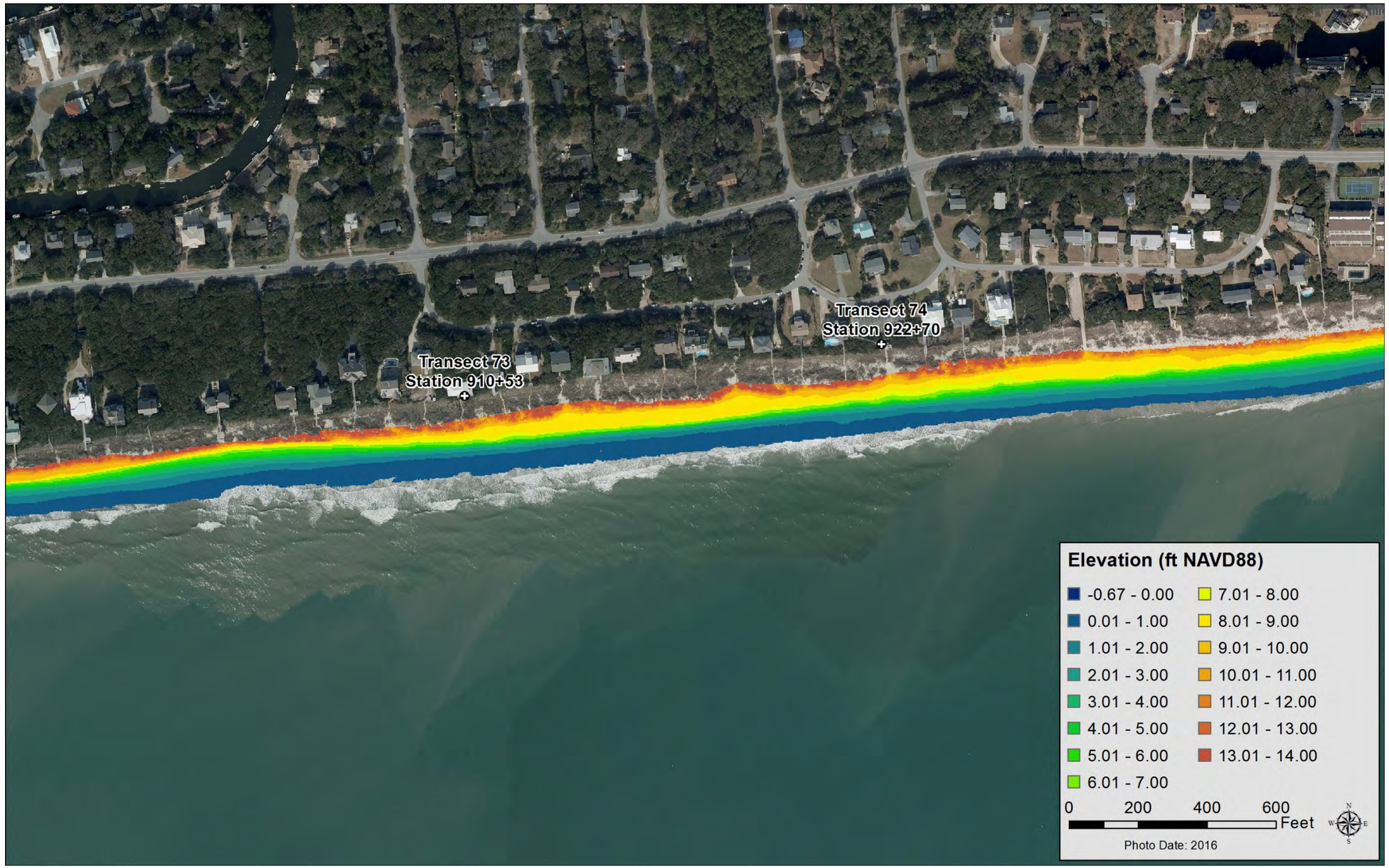


Figure B-33. Bogue Banks 2018 Hotspot Laser Scanner DEM

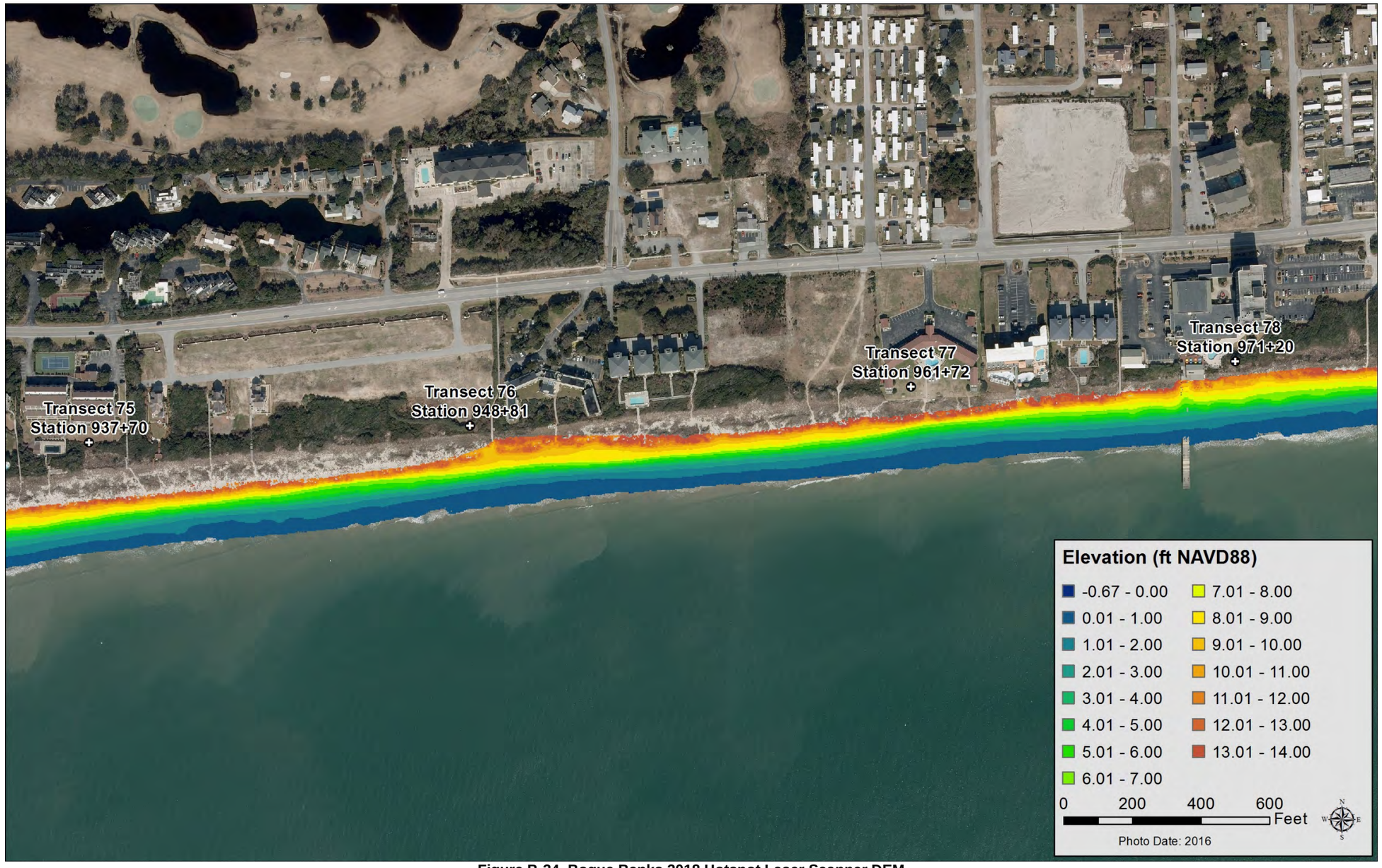


Figure B-34. Bogue Banks 2018 Hotspot Laser Scanner DEM

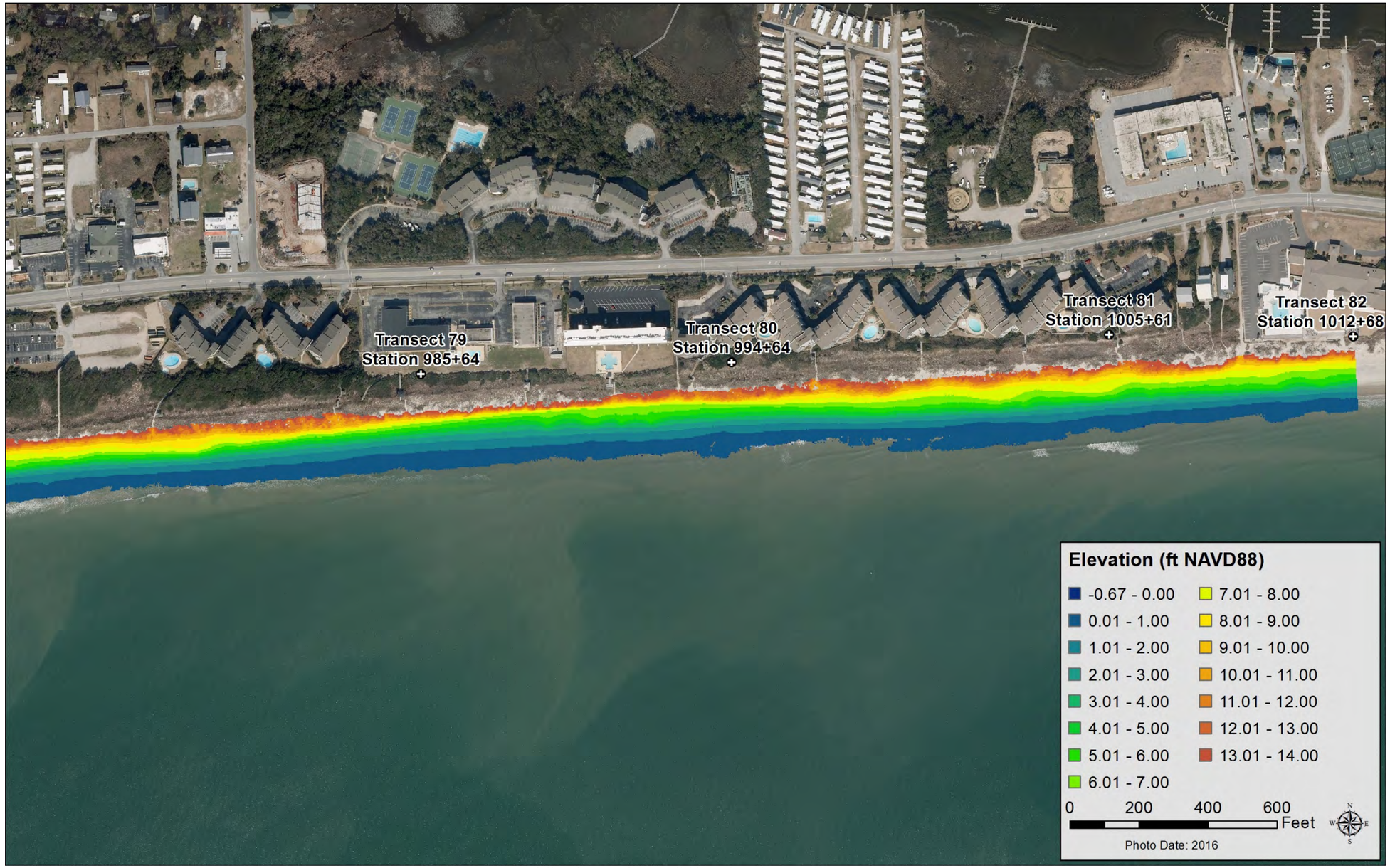


Figure B-35. Bogue Banks 2018 Hotspot Laser Scanner DEM

APPENDIX C

Shoreline & Volume Change Plots

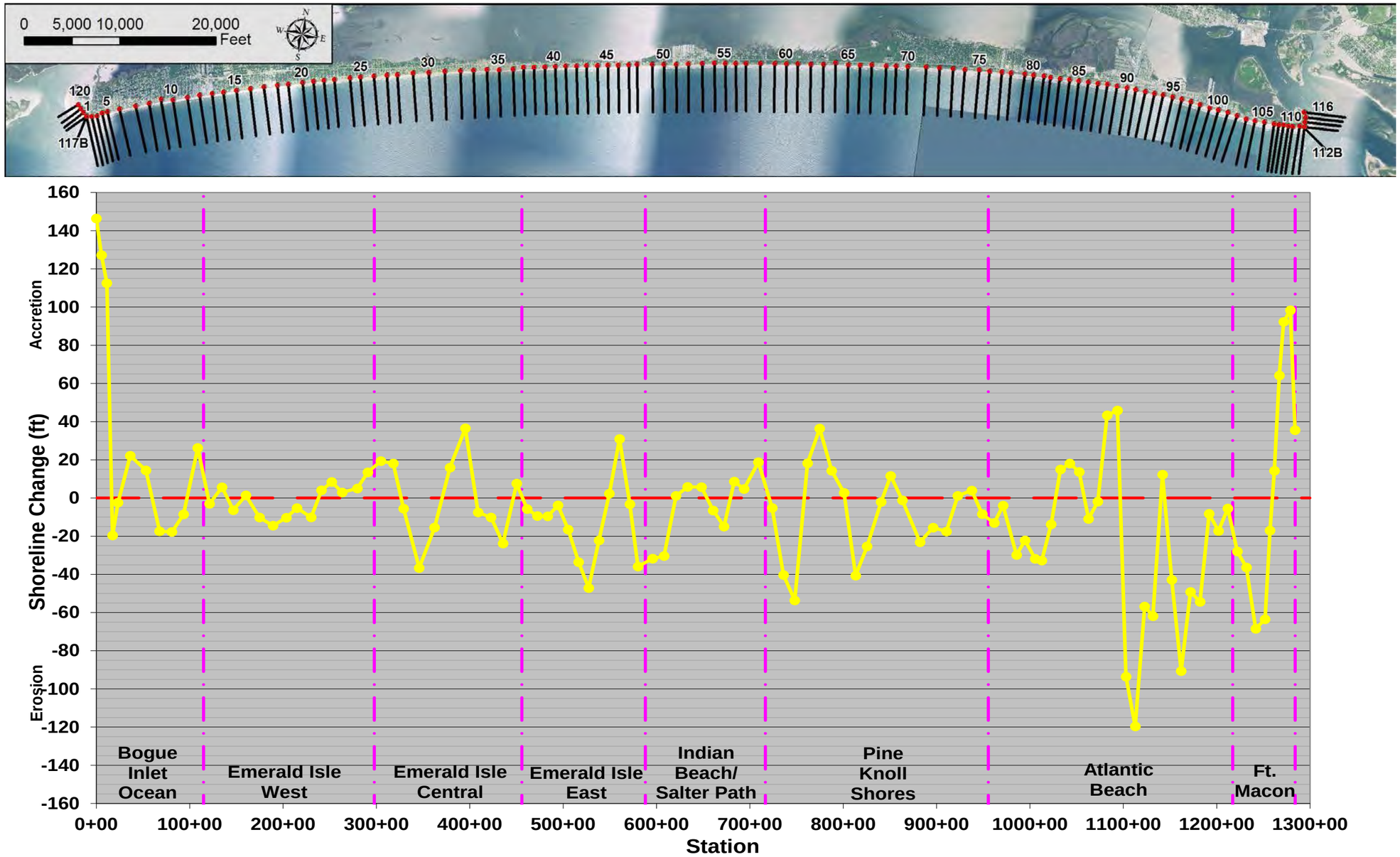


Figure C-1. Shoreline Change for Bogue Banks (2017 - 2018)

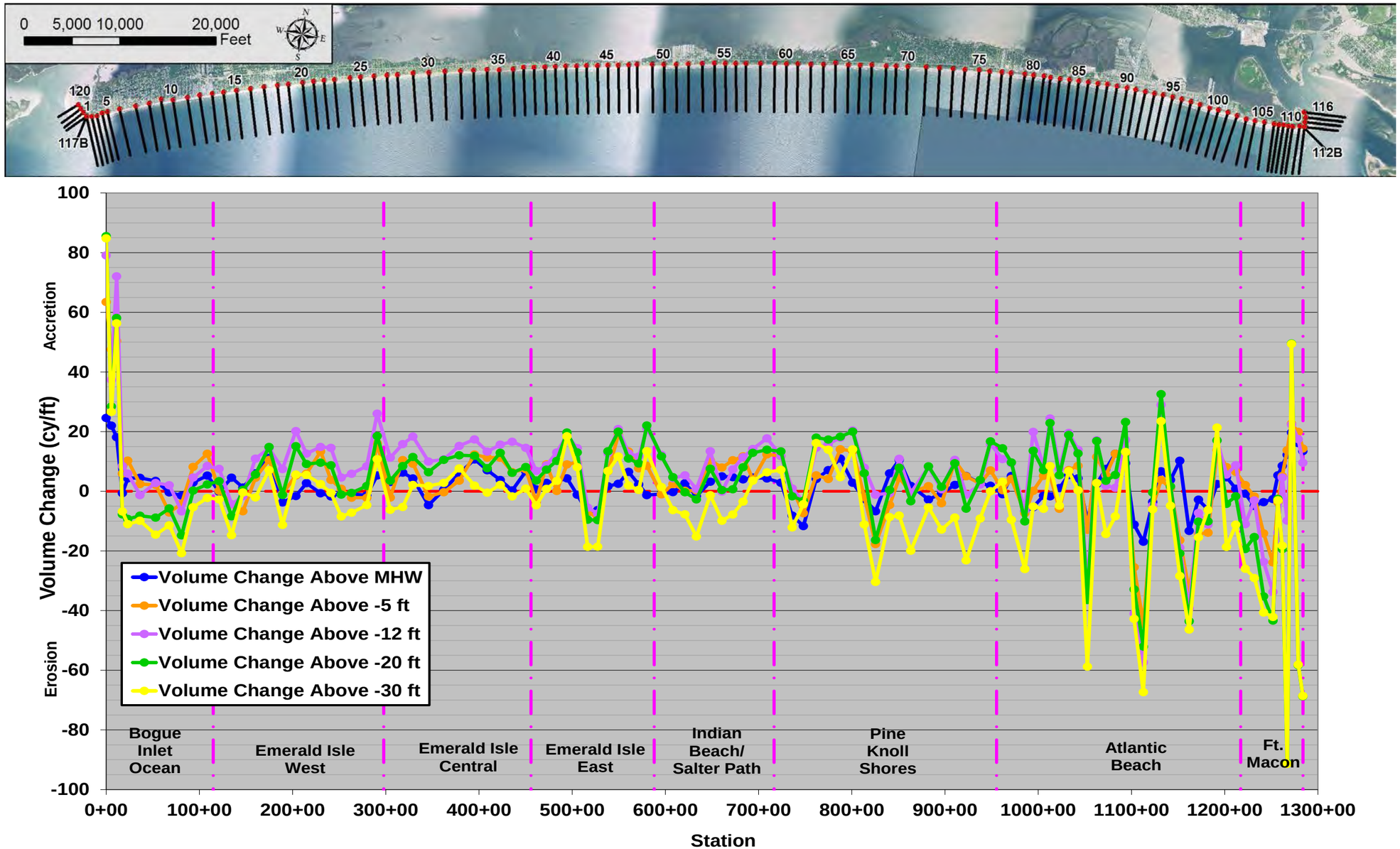
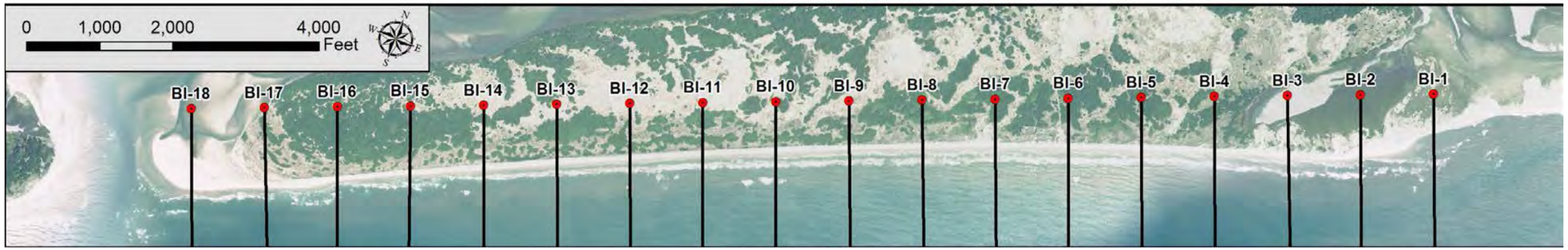


Figure C-2. Volume Change for Bogue Banks (2017 - 2018)



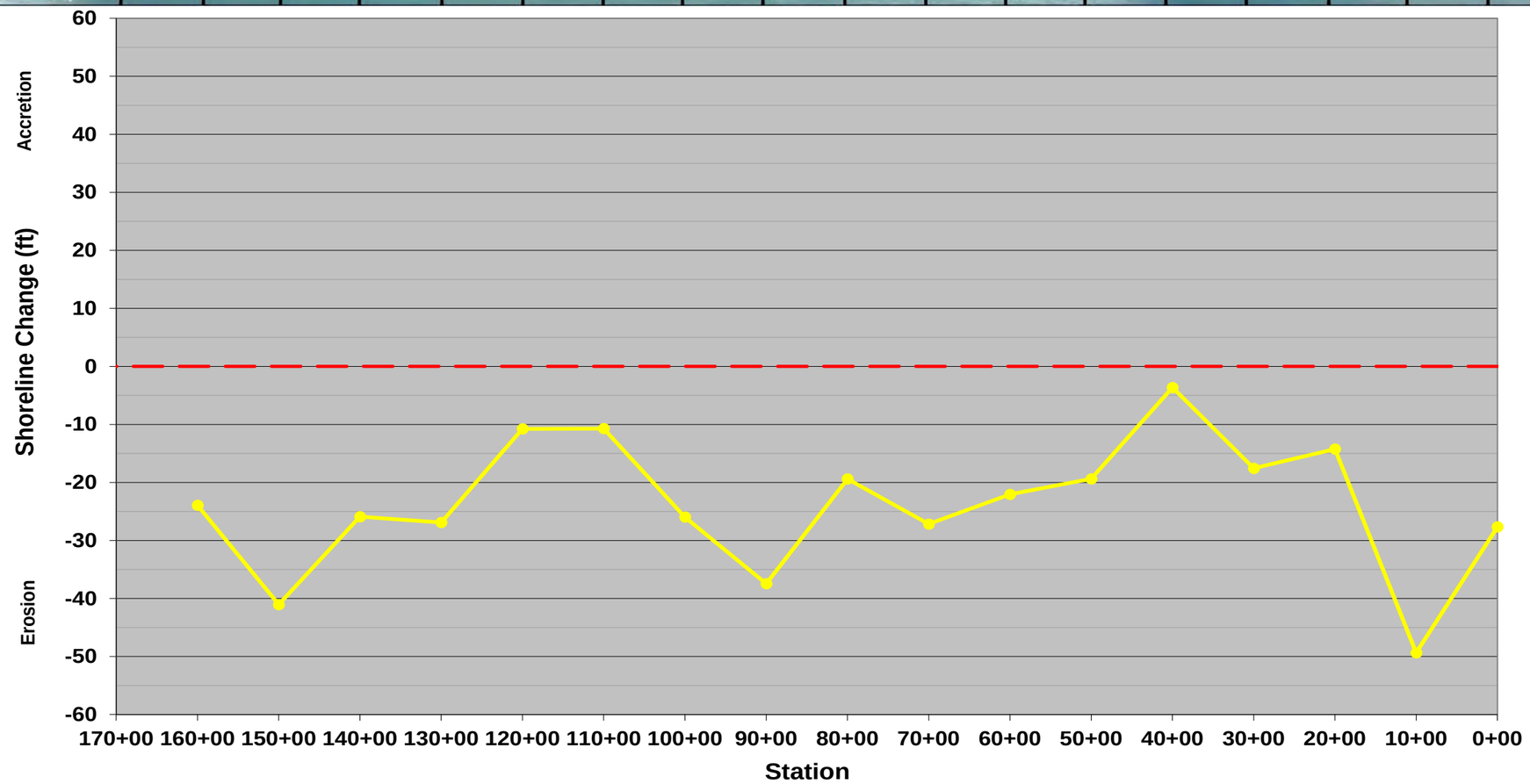


Figure C-3. Shoreline Change for Bear Island (2017 - 2018)

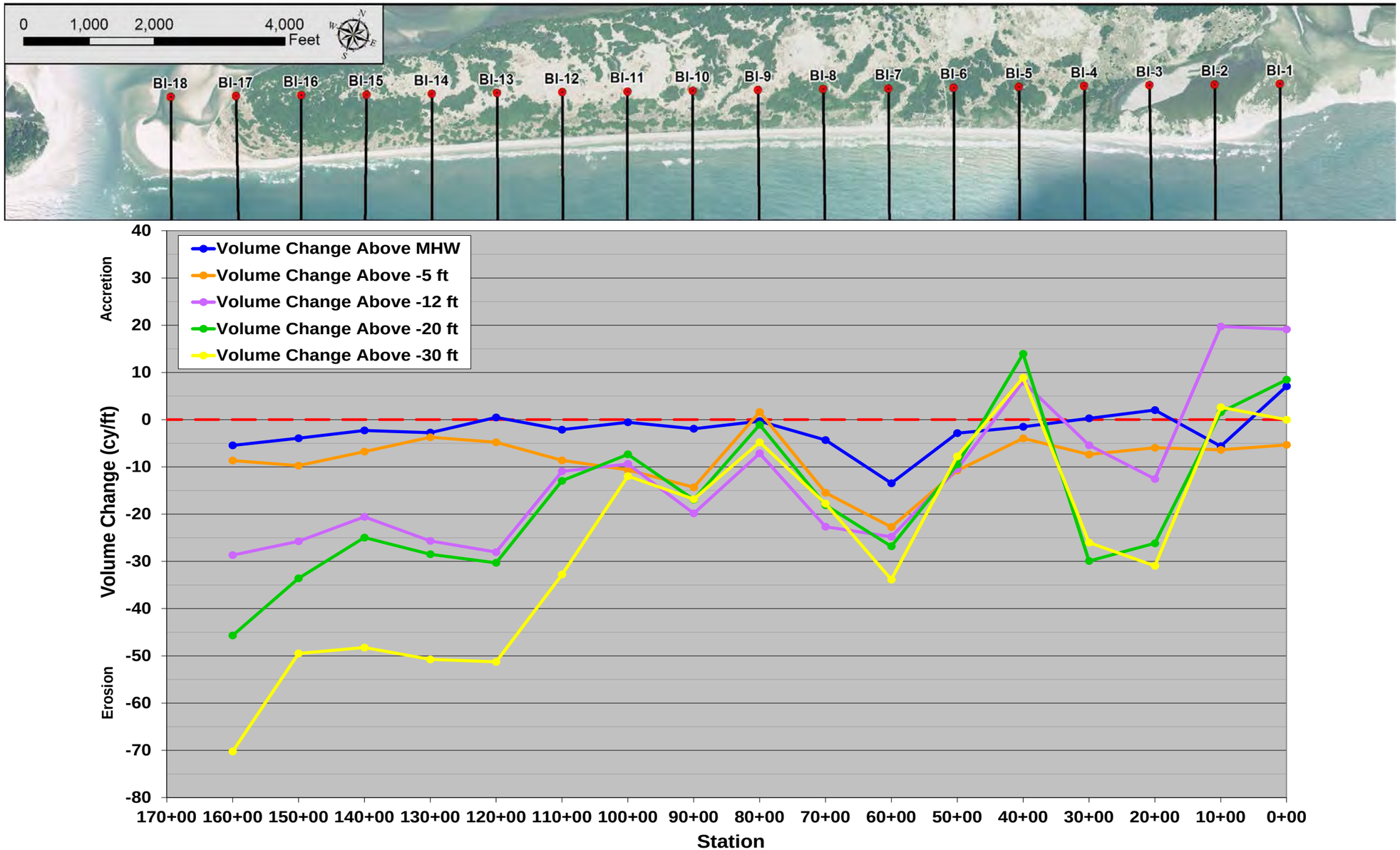


Figure C-4. Volume Change for Bear Island (2017 - 2018)

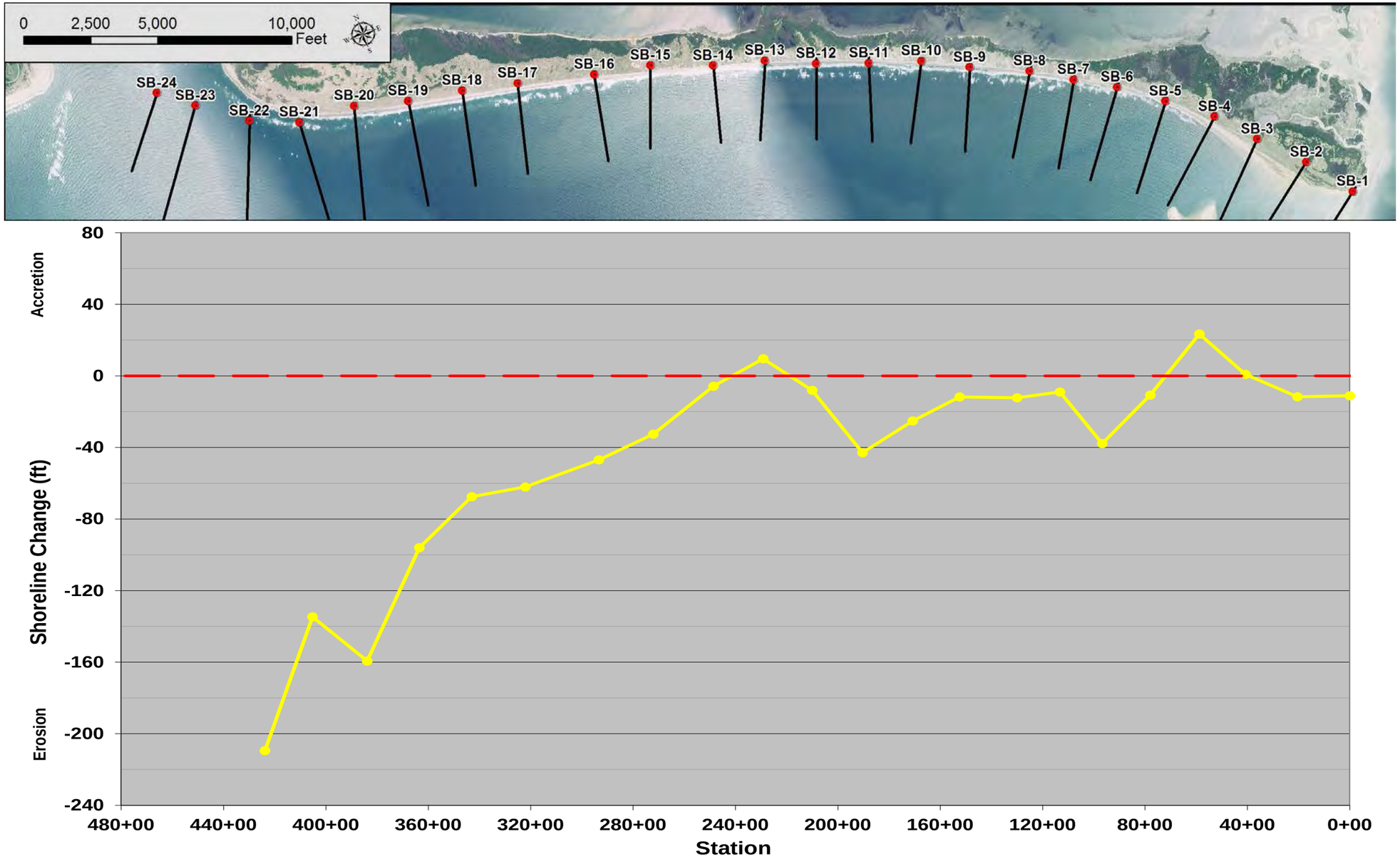


Figure C-5. Shoreline Change for Shackleford Banks (2017 - 2018)

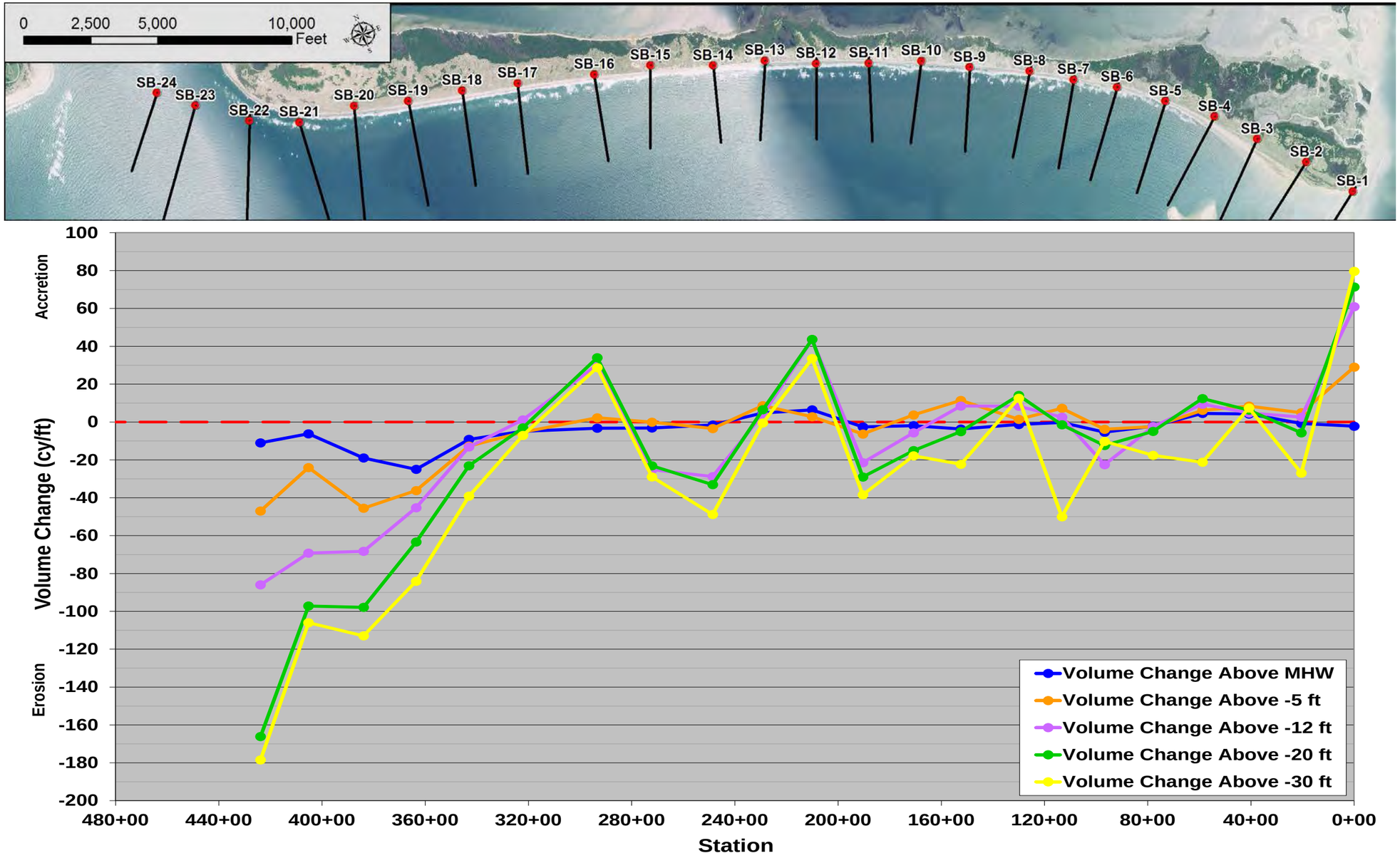


Figure C-6. Volume Change for Shackleford Banks (2017 - 2018)

APPENDIX D

Survey Profile Comparison Plots

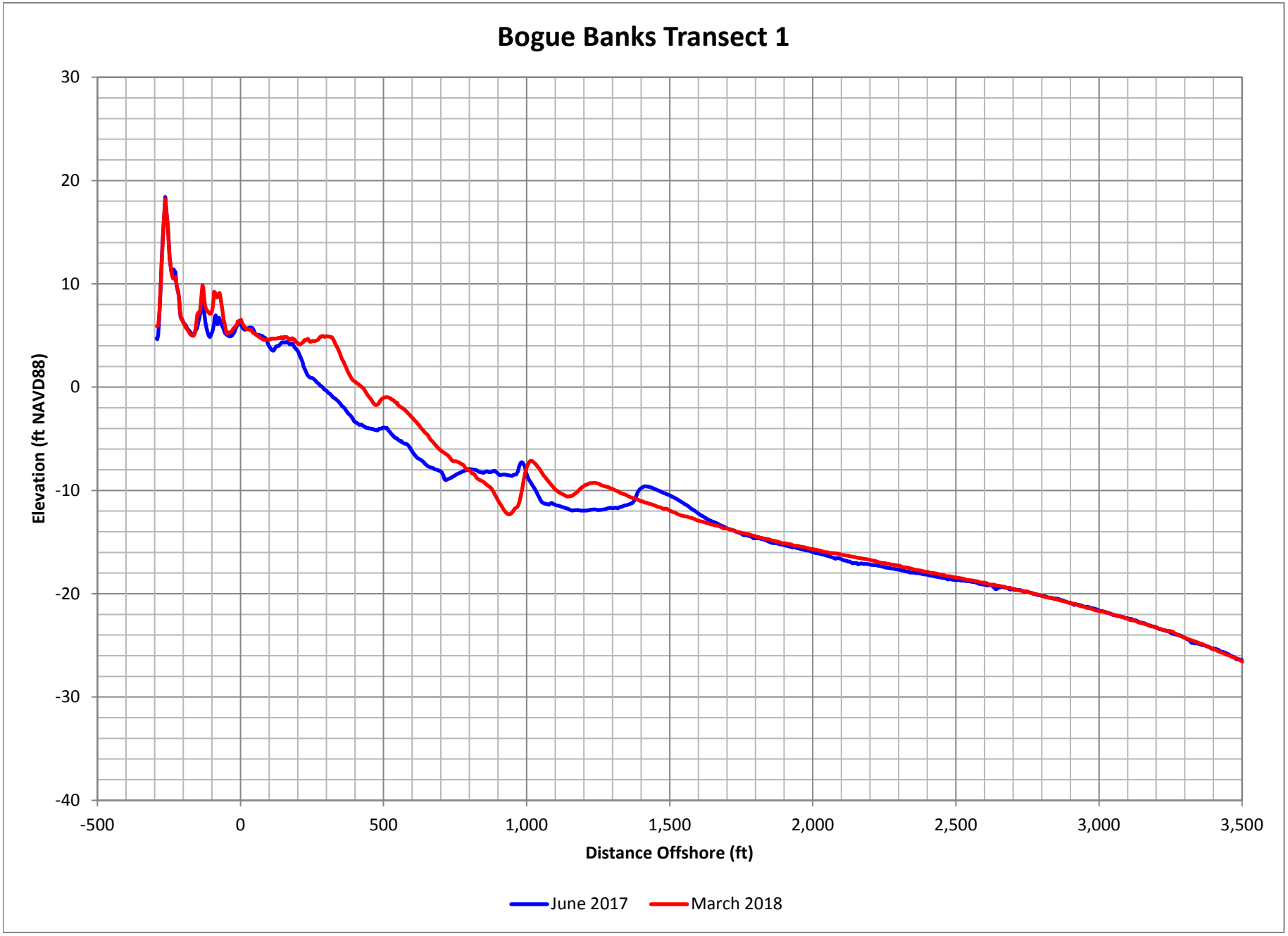


Figure D-1. Bogue Banks Profile Comparison Plot

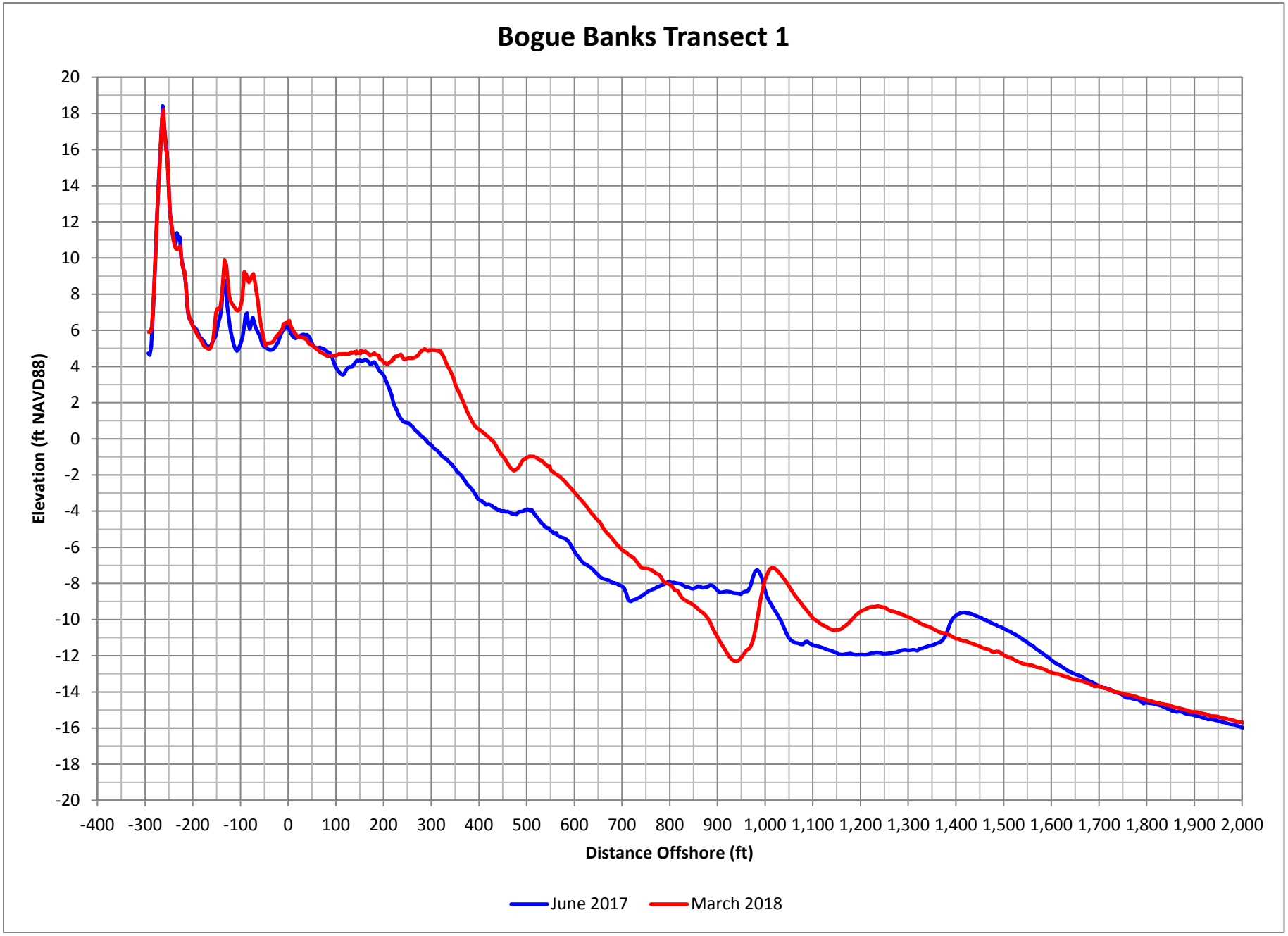


Figure D-2. Bogue Banks Profile Comparison Plot

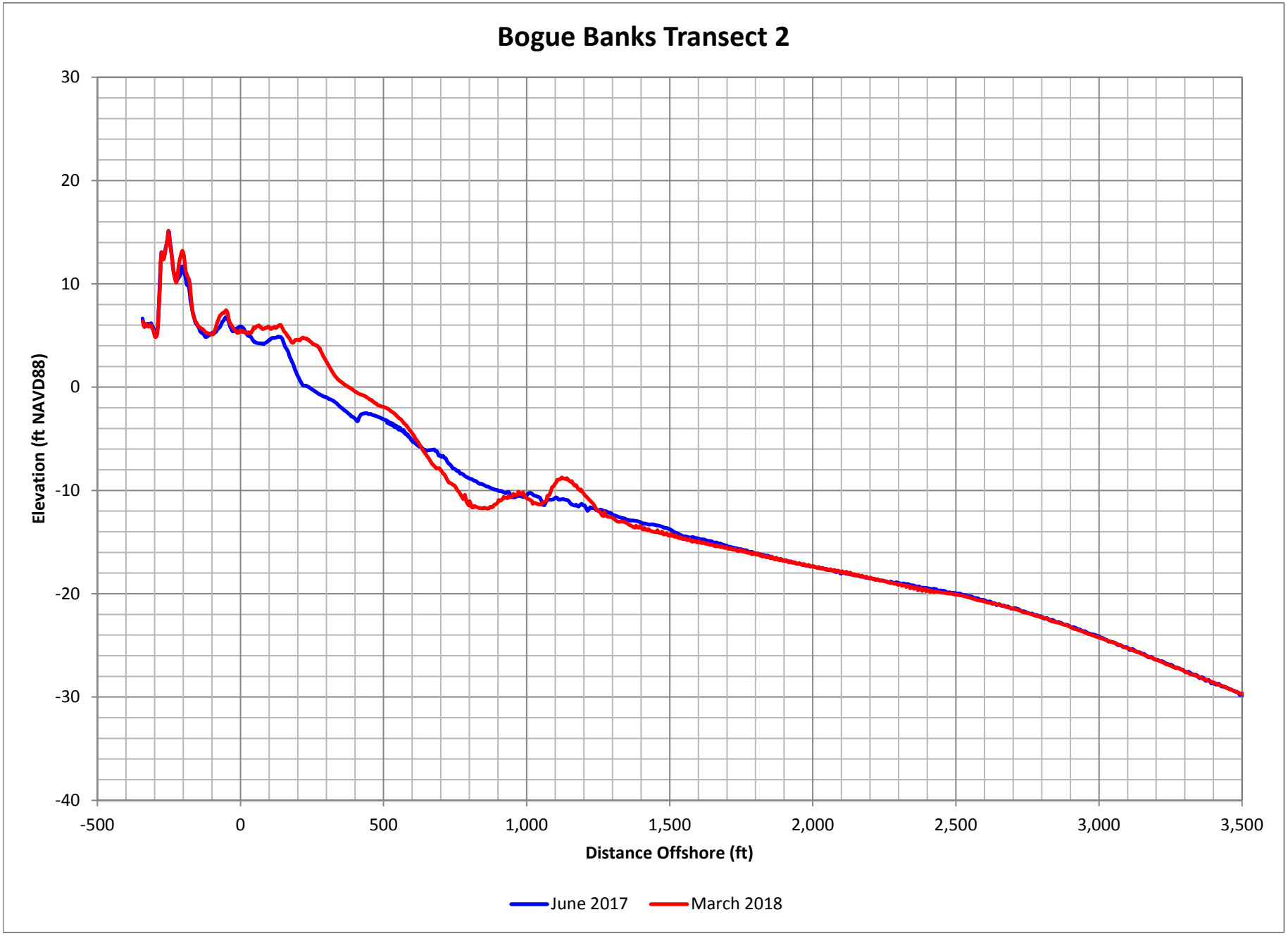


Figure D-3. Bogue Banks Profile Comparison Plot

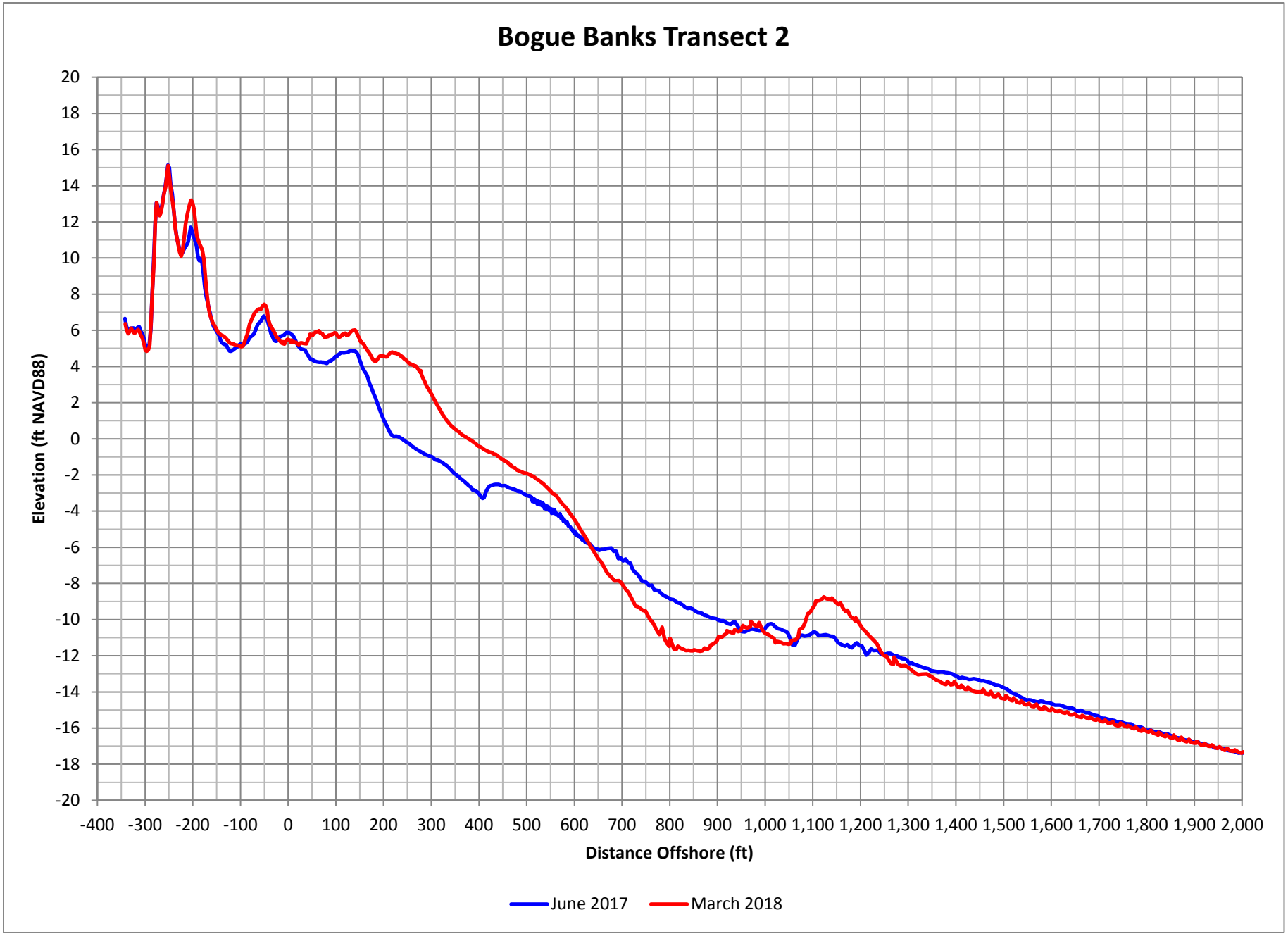


Figure D-4. Bogue Banks Profile Comparison Plot

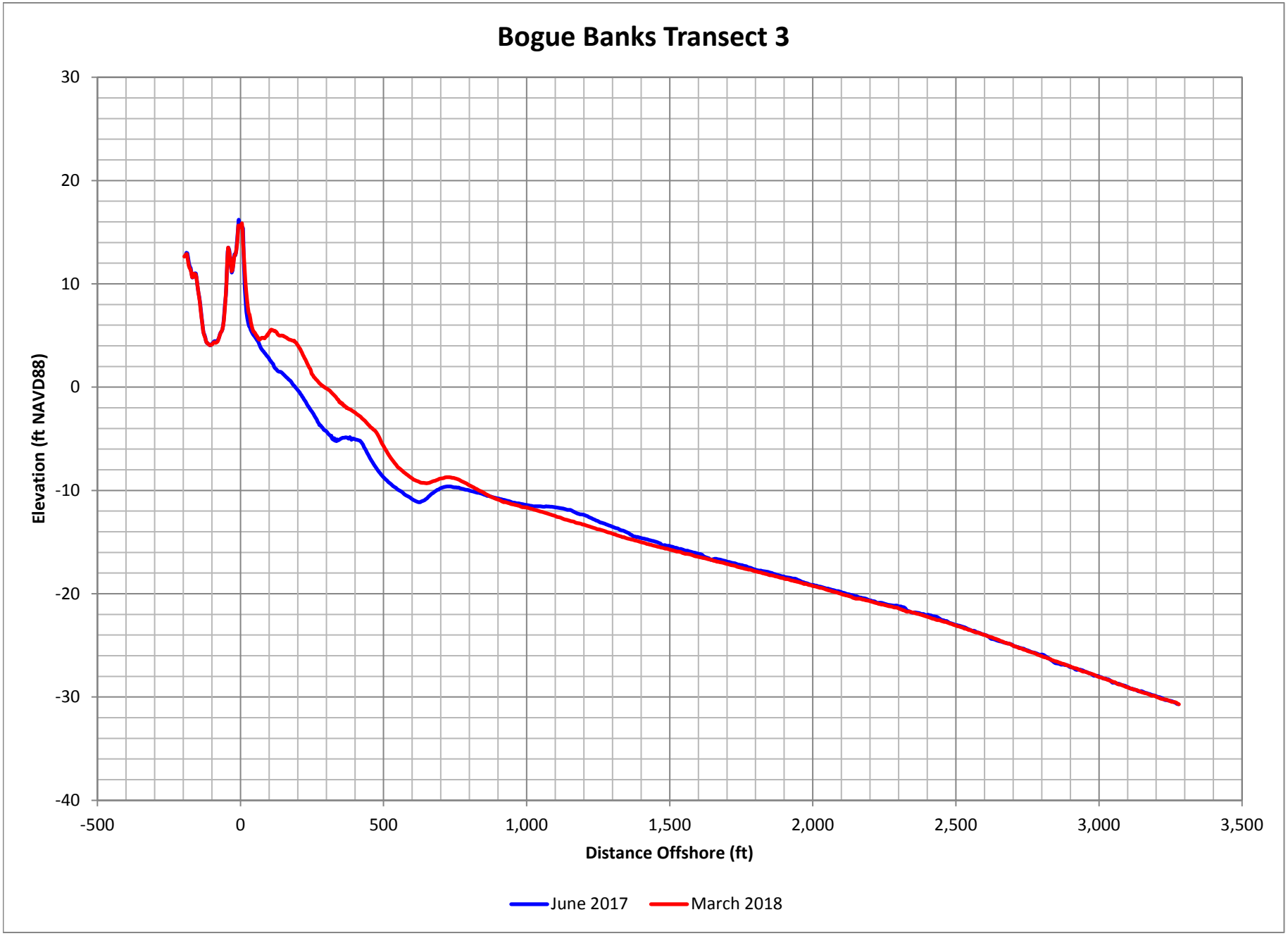


Figure D-5. Bogue Banks Profile Comparison Plot

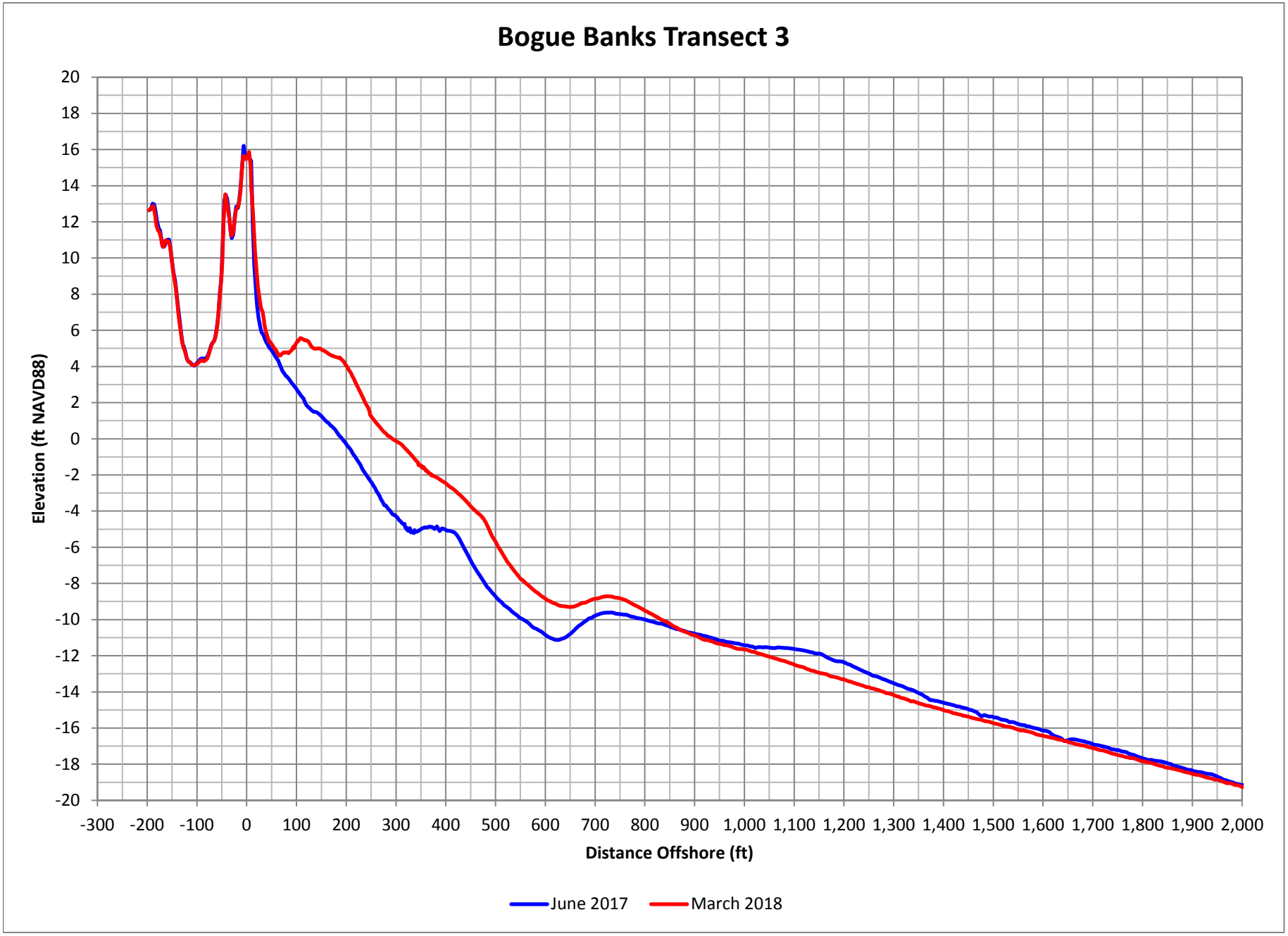


Figure D-6. Bogue Banks Profile Comparison Plot

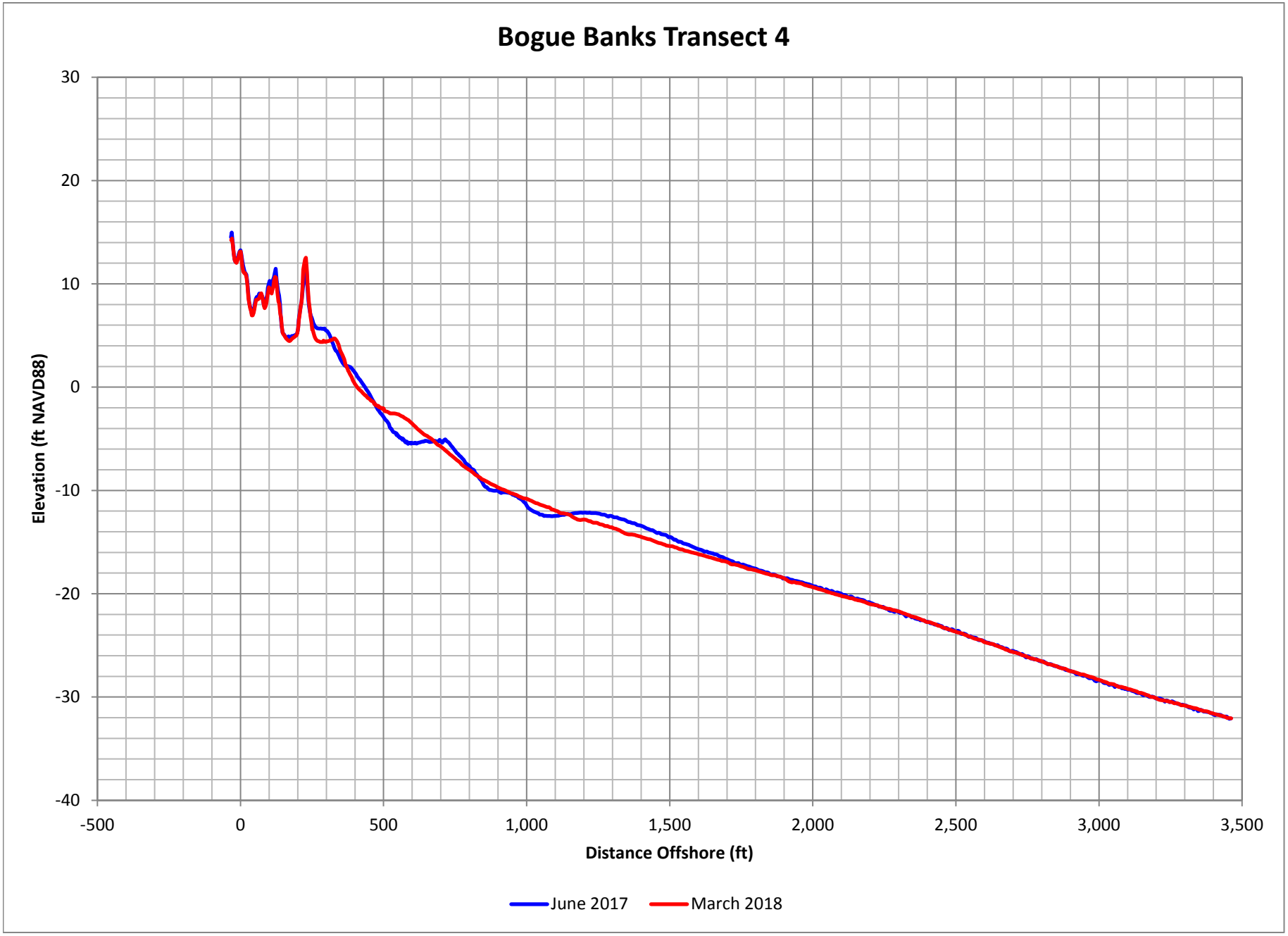


Figure D-7. Bogue Banks Profile Comparison Plot

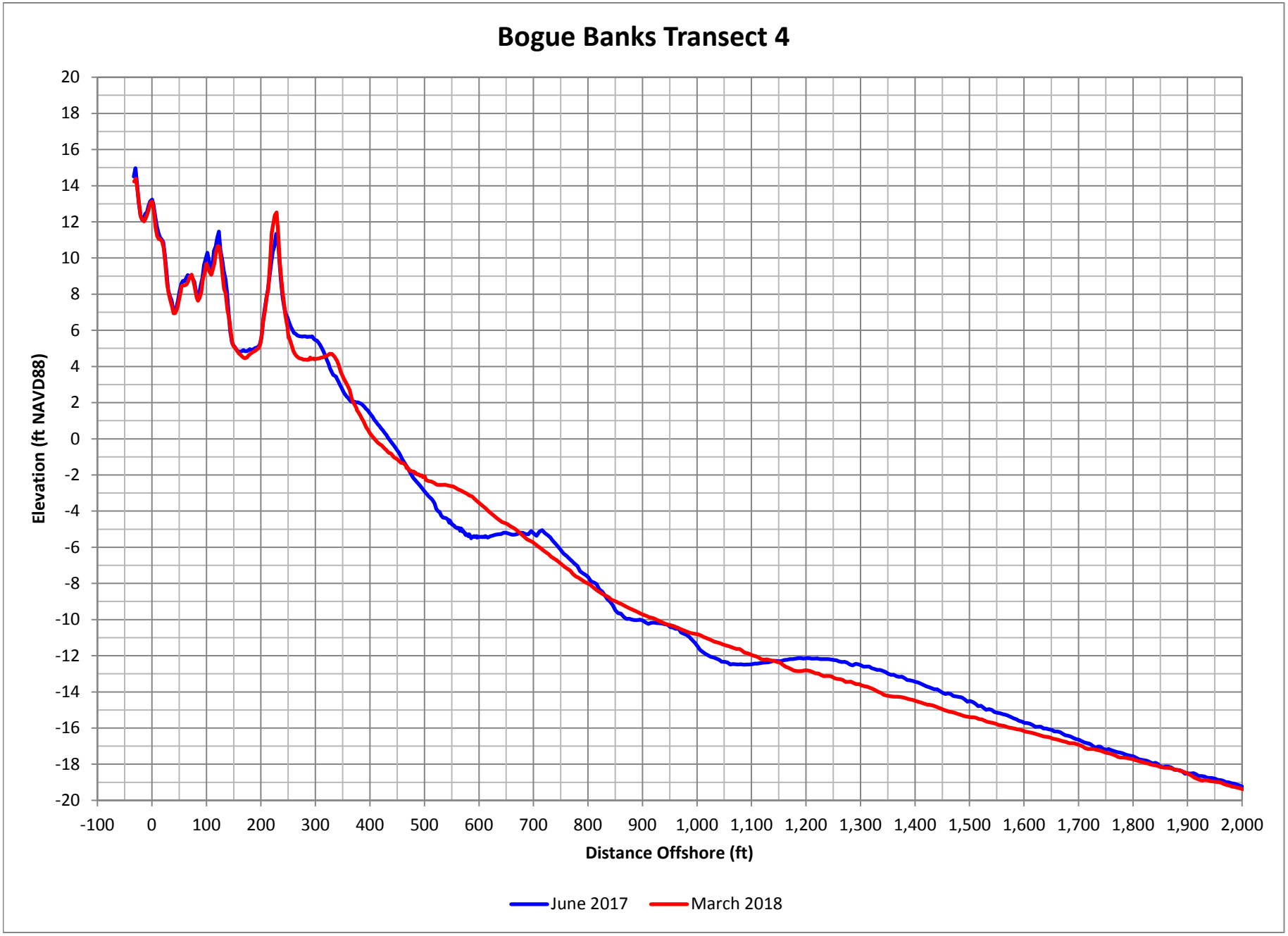


Figure D-8. Bogue Banks Profile Comparison Plot

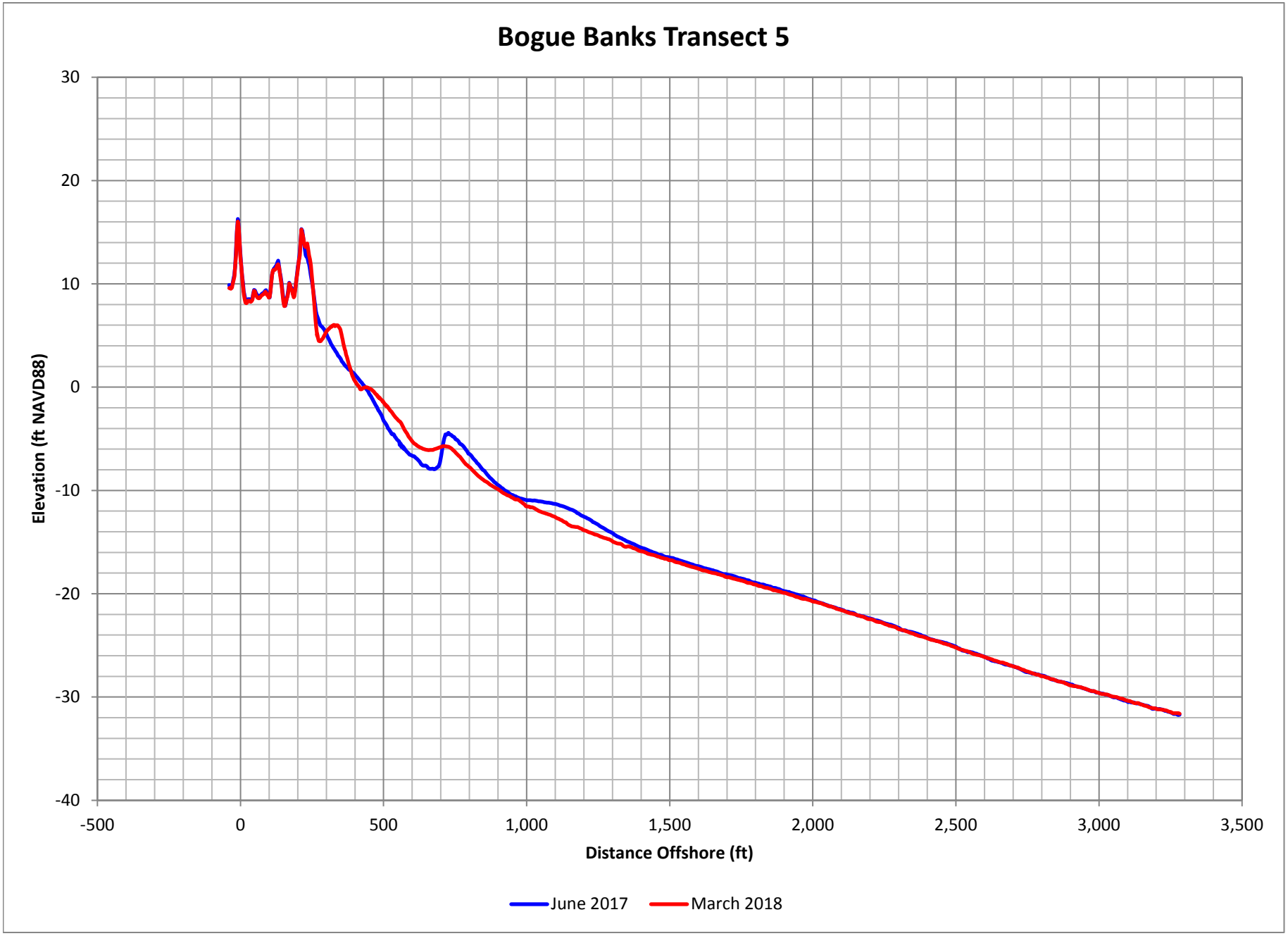


Figure D-9. Bogue Banks Profile Comparison Plot

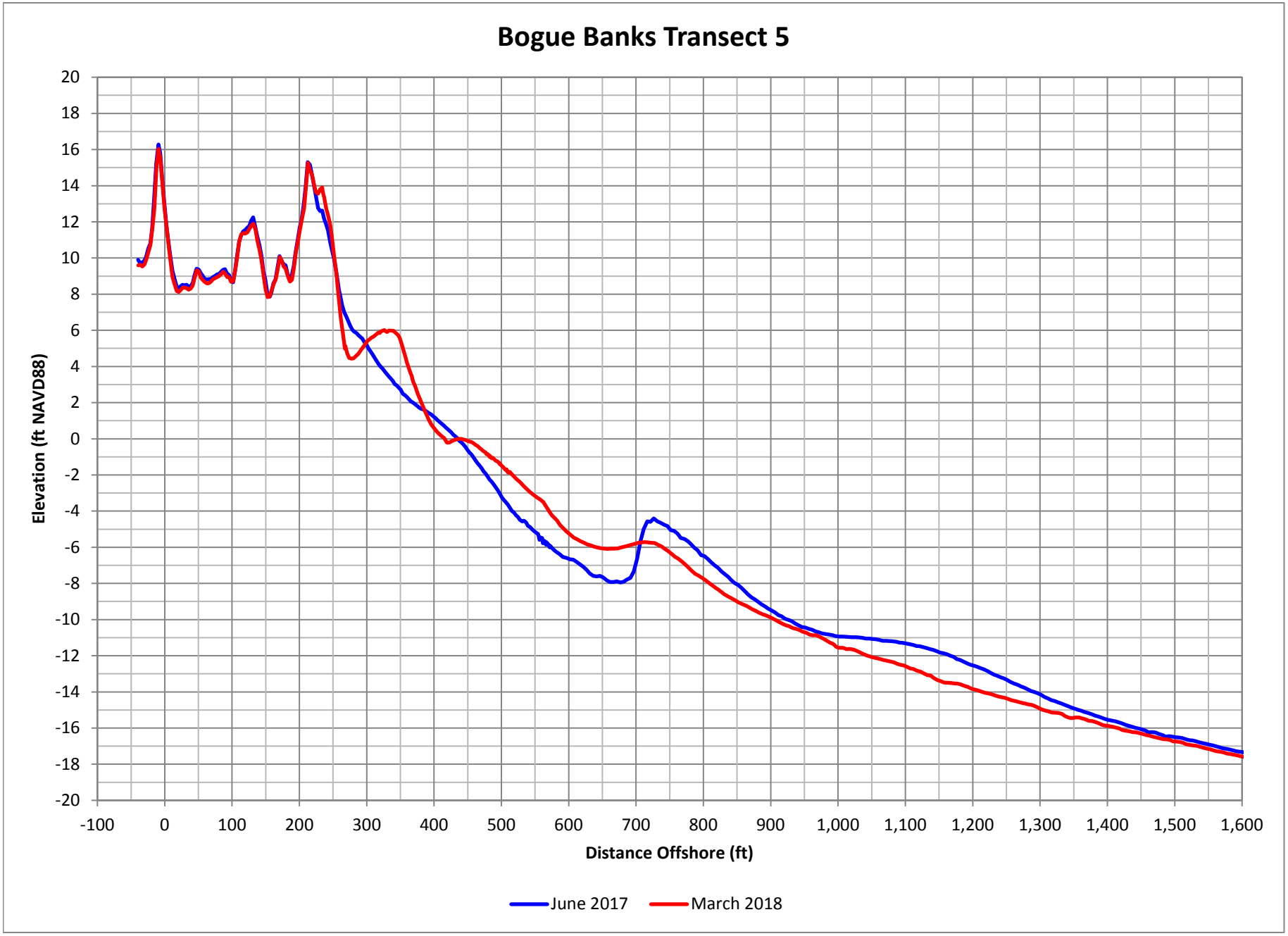


Figure D-10. Bogue Banks Profile Comparison Plot

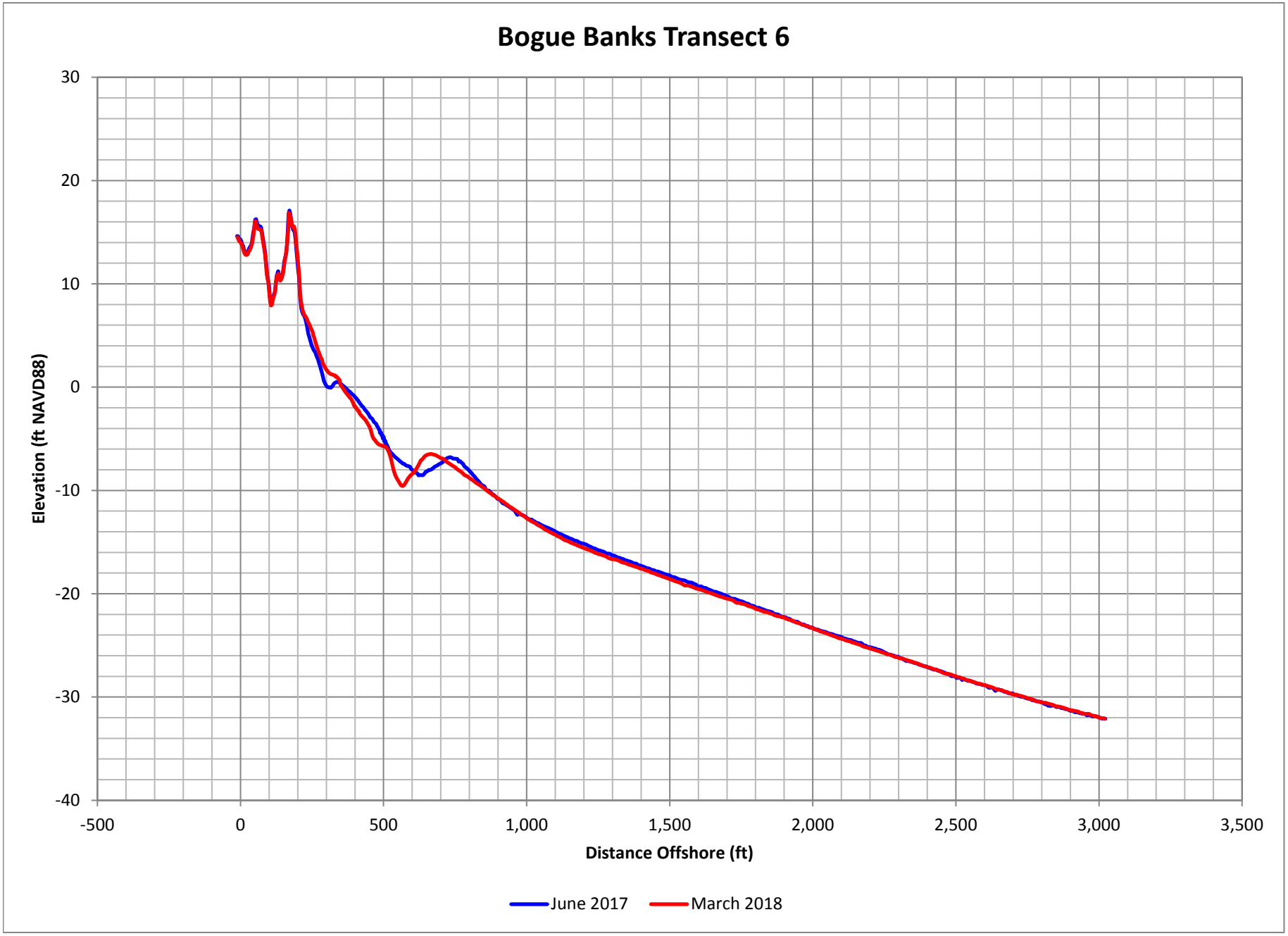


Figure D-11. Bogue Banks Profile Comparison Plot

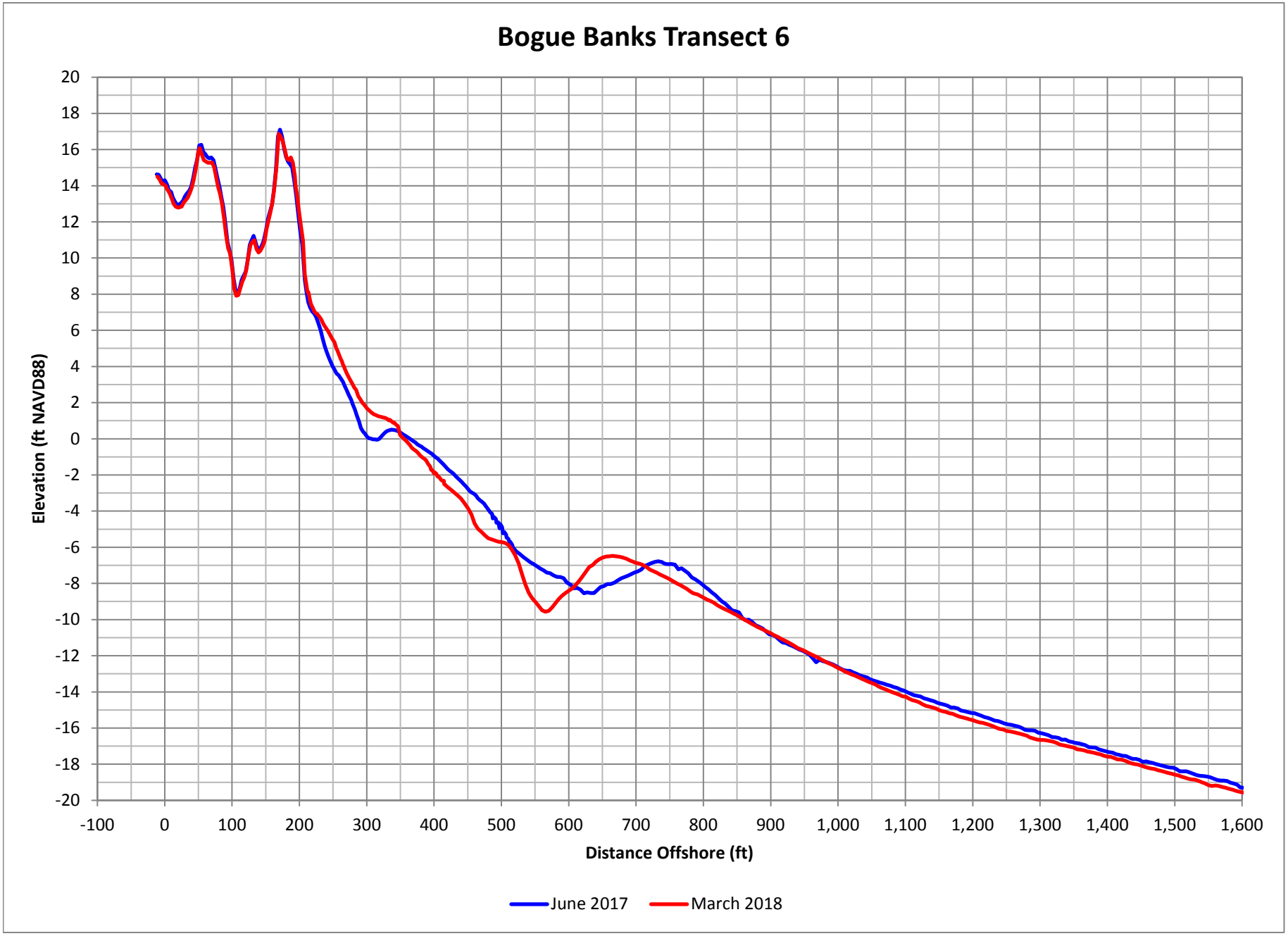


Figure D-12. Bogue Banks Profile Comparison Plot

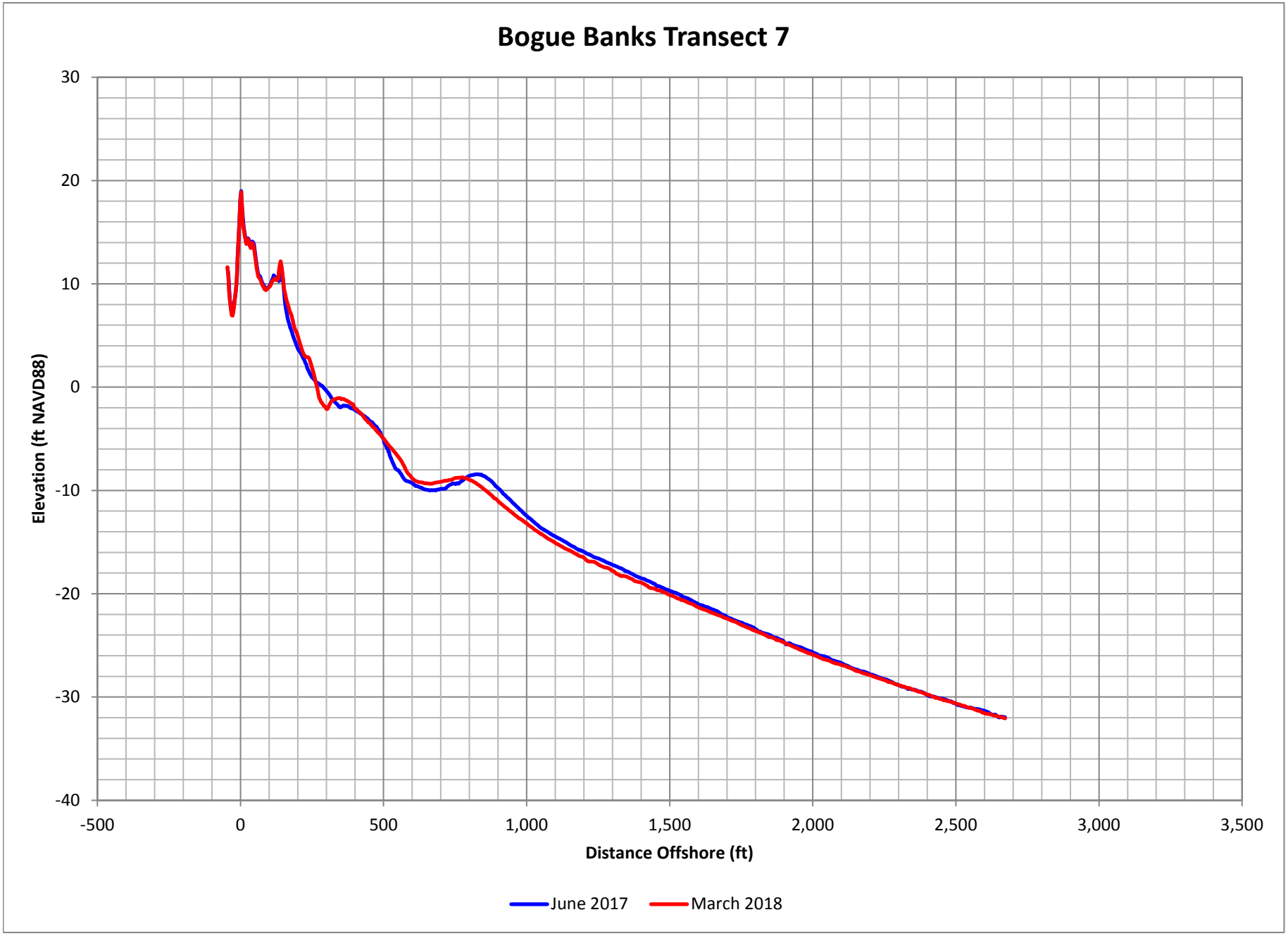


Figure D-13. Bogue Banks Profile Comparison Plot

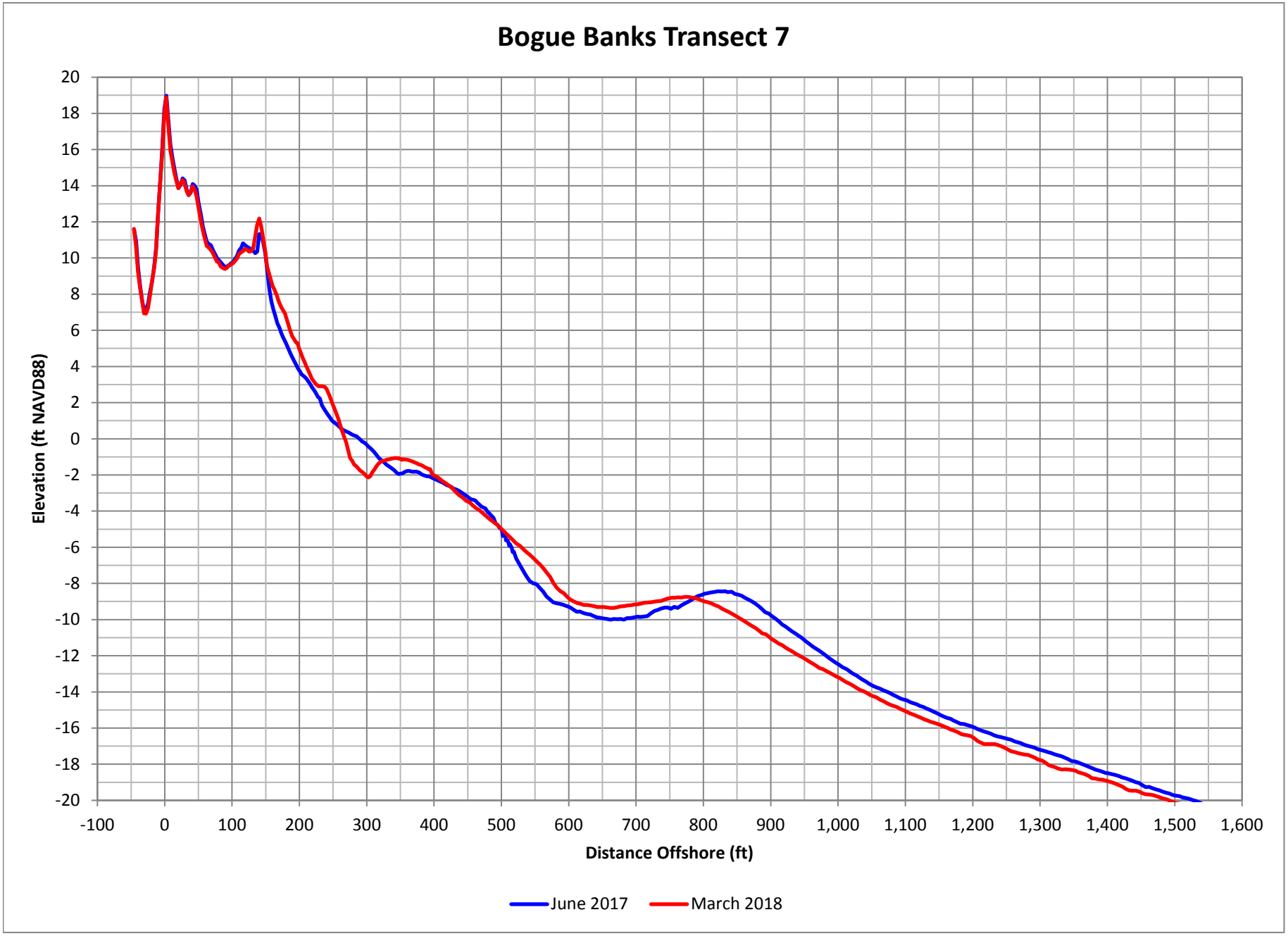


Figure D-14. Bogue Banks Profile Comparison Plot

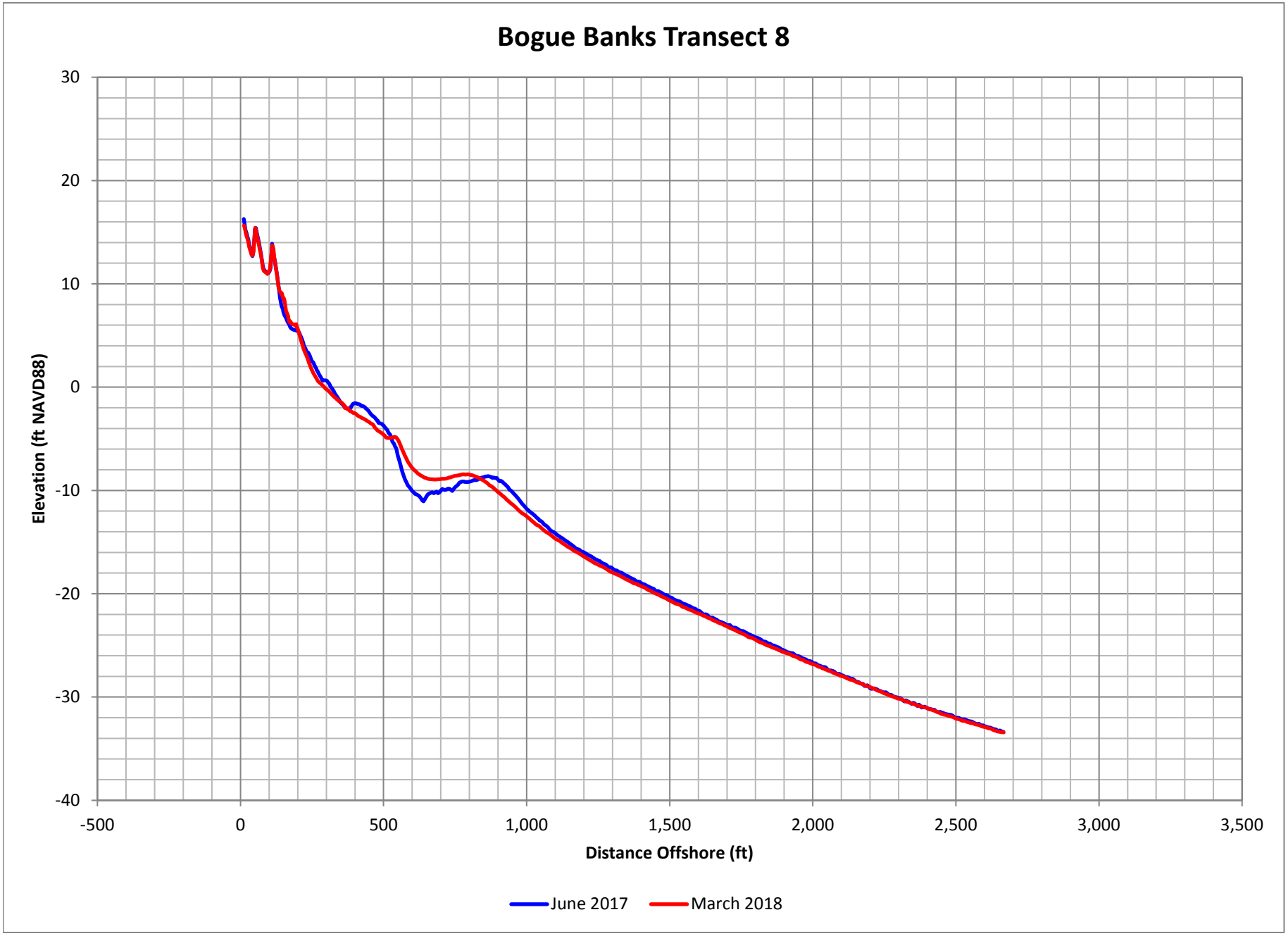


Figure D-15. Bogue Banks Profile Comparison Plot

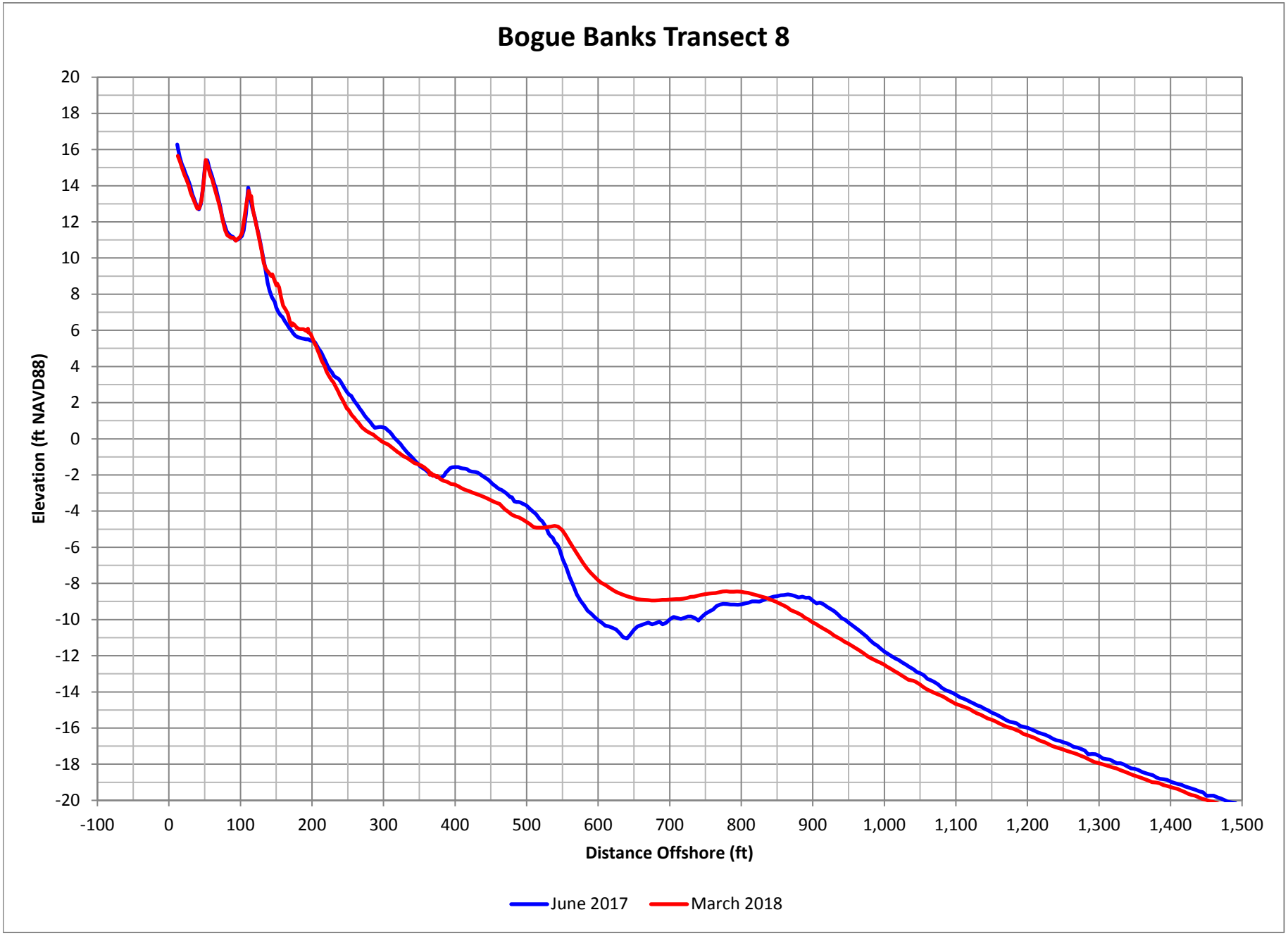


Figure D-16. Bogue Banks Profile Comparison Plot

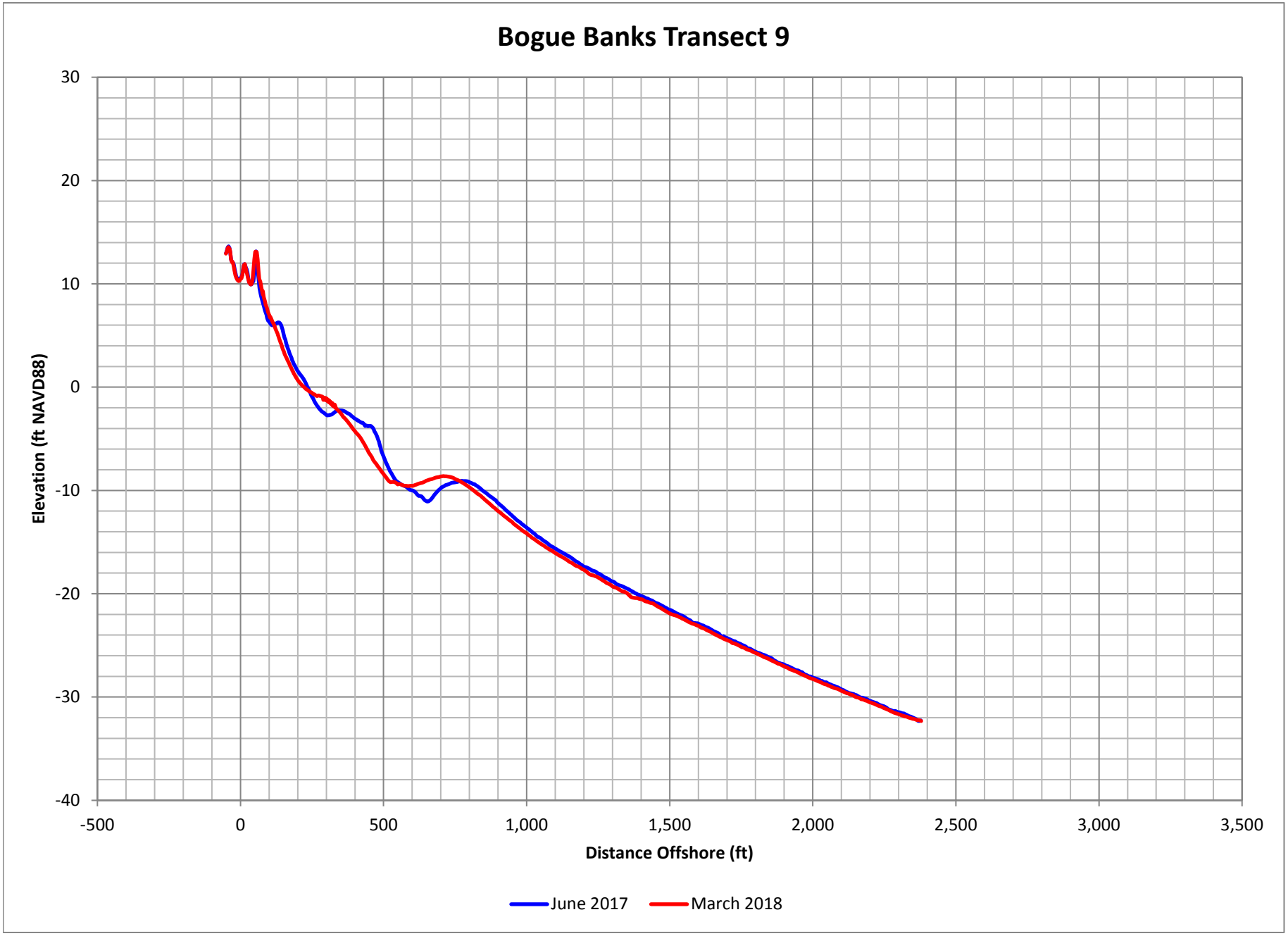


Figure D-17. Bogue Banks Profile Comparison Plot

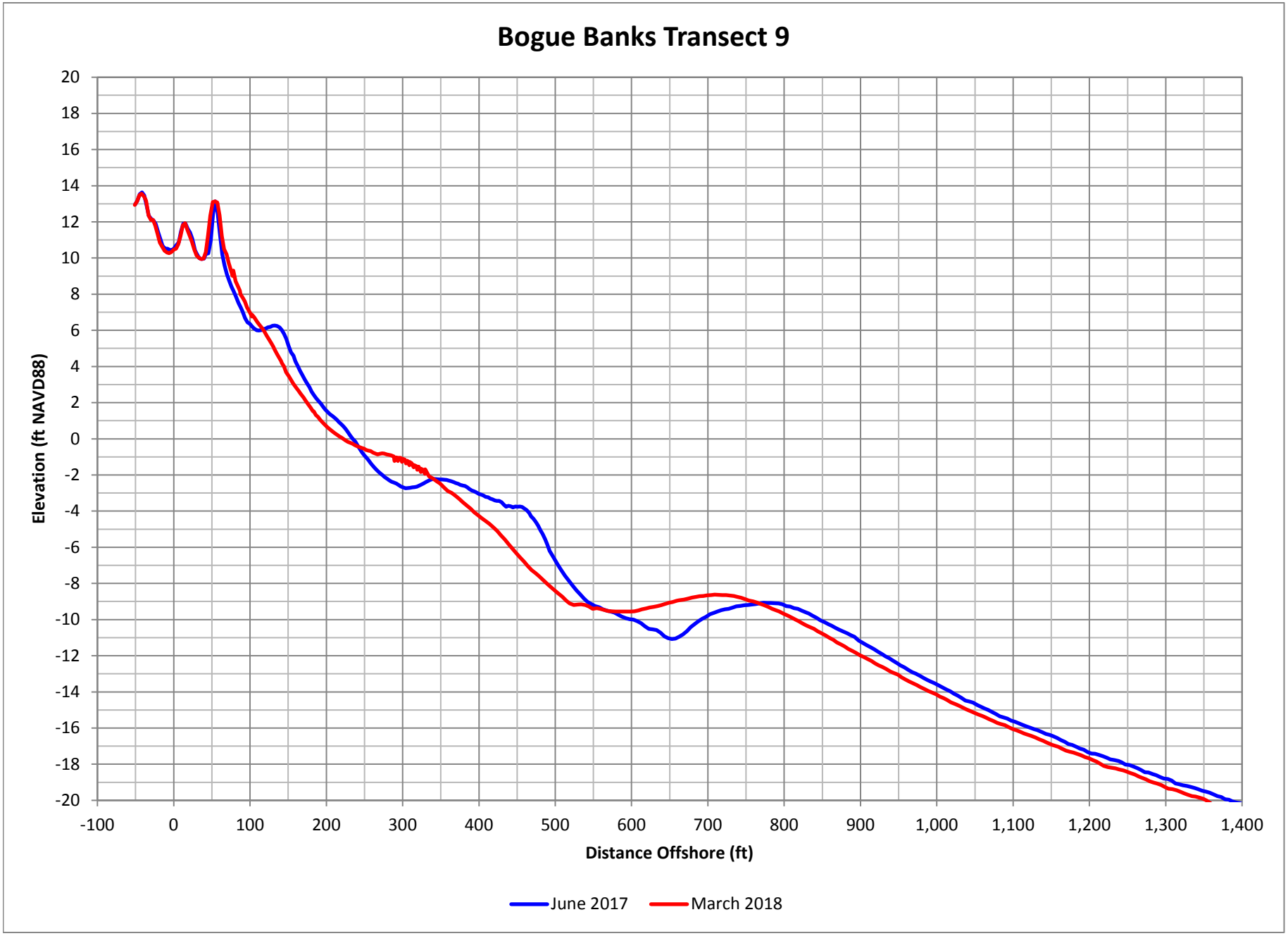


Figure D-18. Bogue Banks Profile Comparison Plot

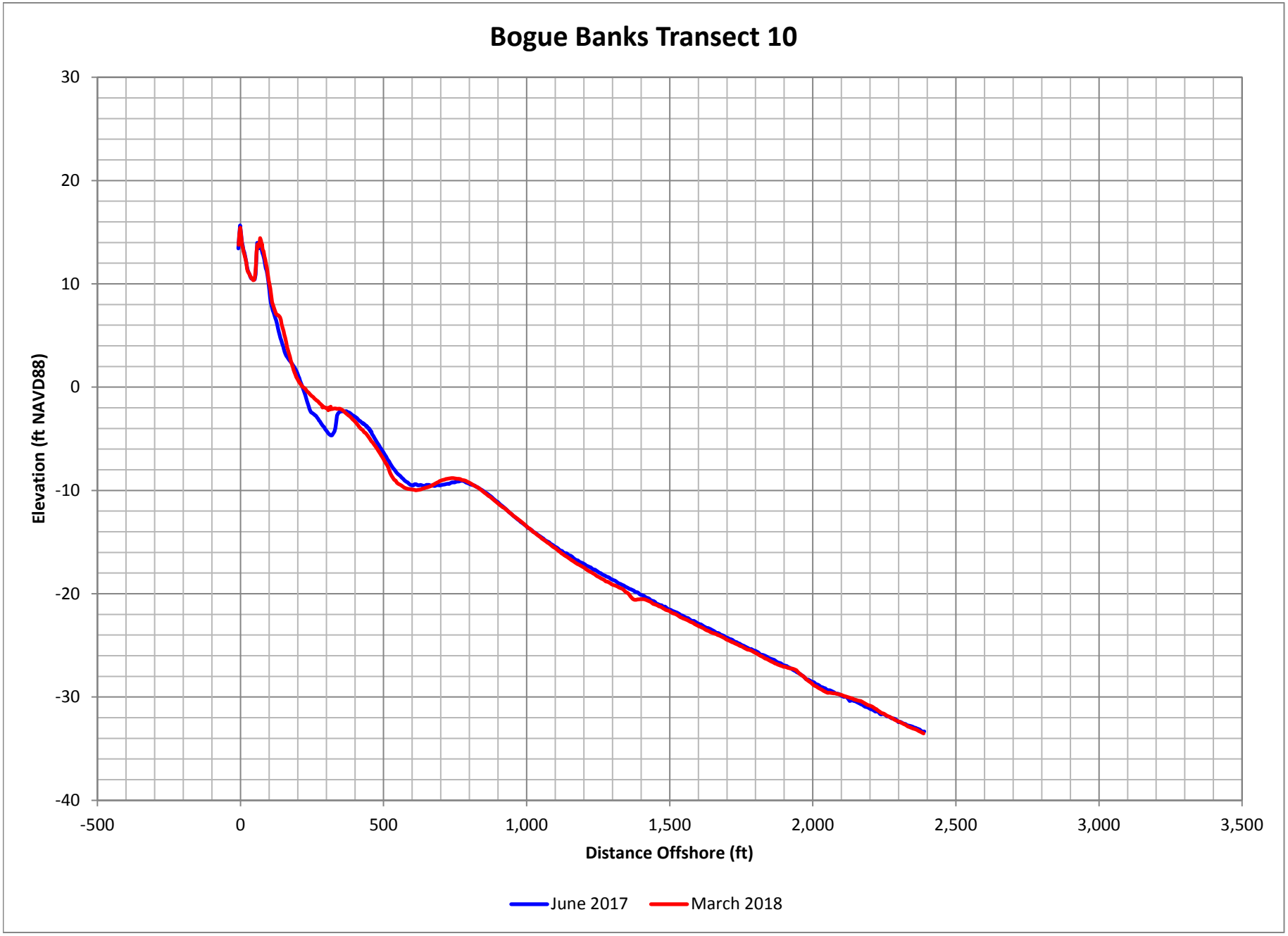


Figure D-19. Bogue Banks Profile Comparison Plot

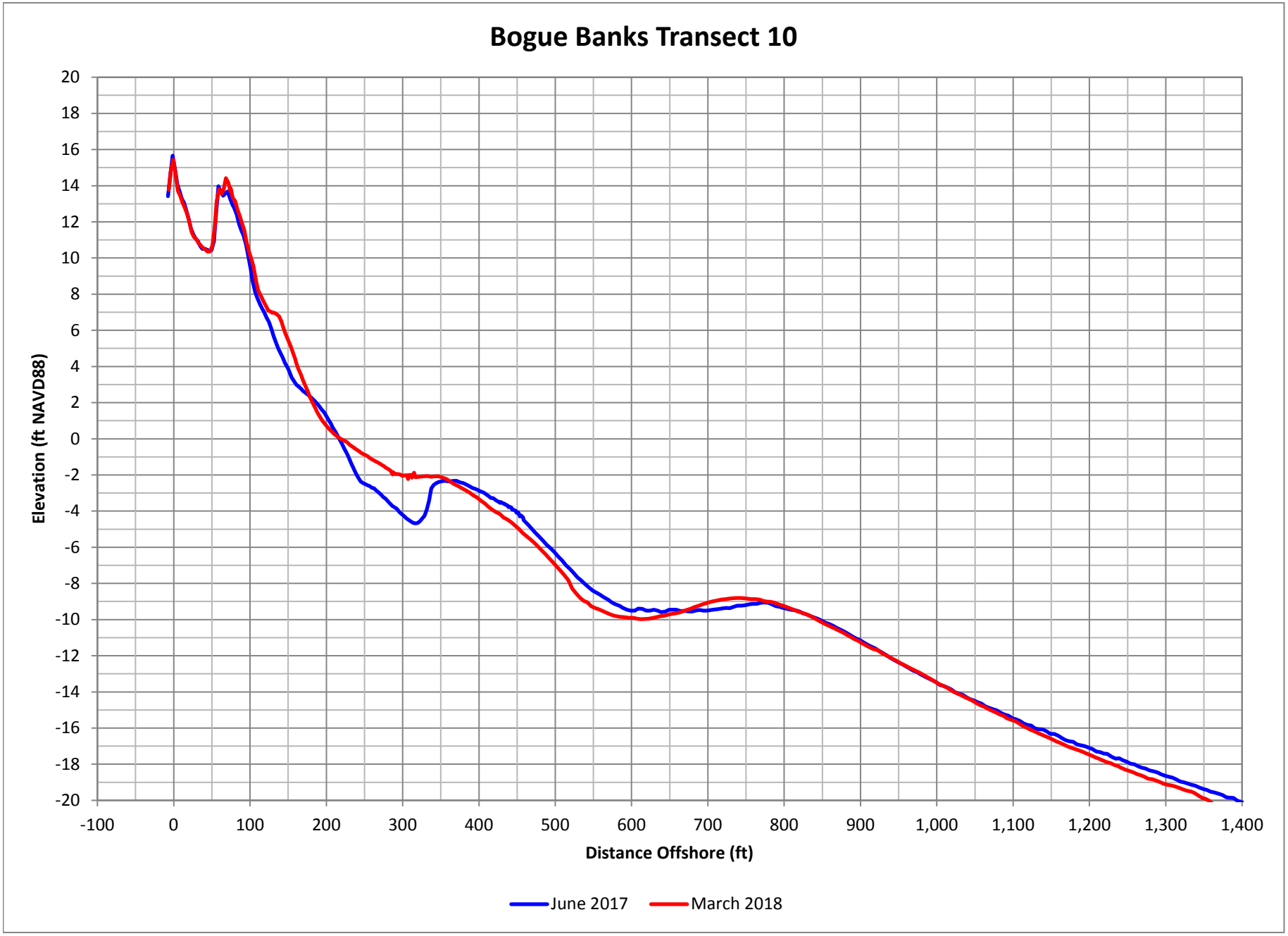


Figure D-20. Bogue Banks Profile Comparison Plot

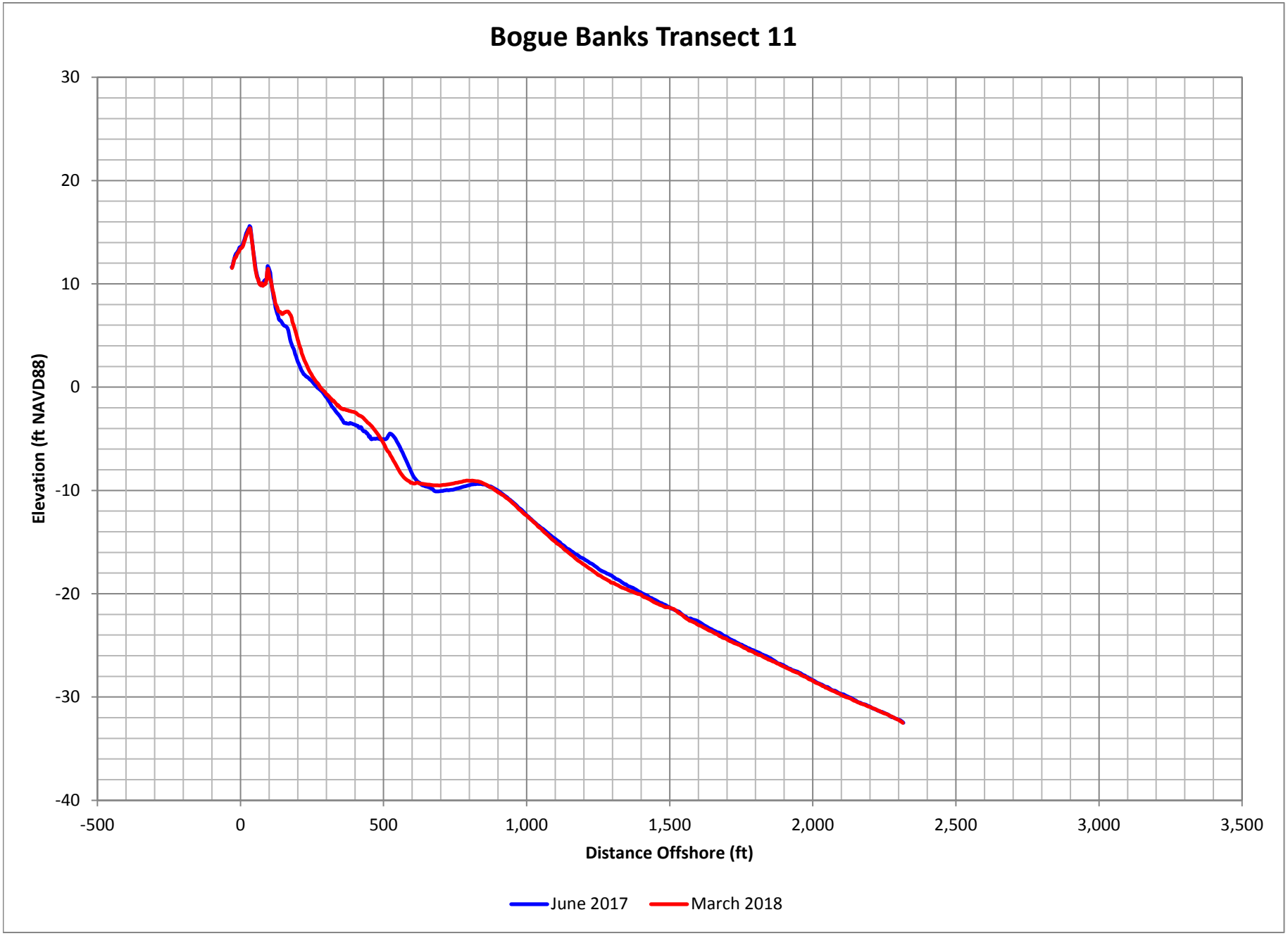


Figure D-21. Bogue Banks Profile Comparison Plot

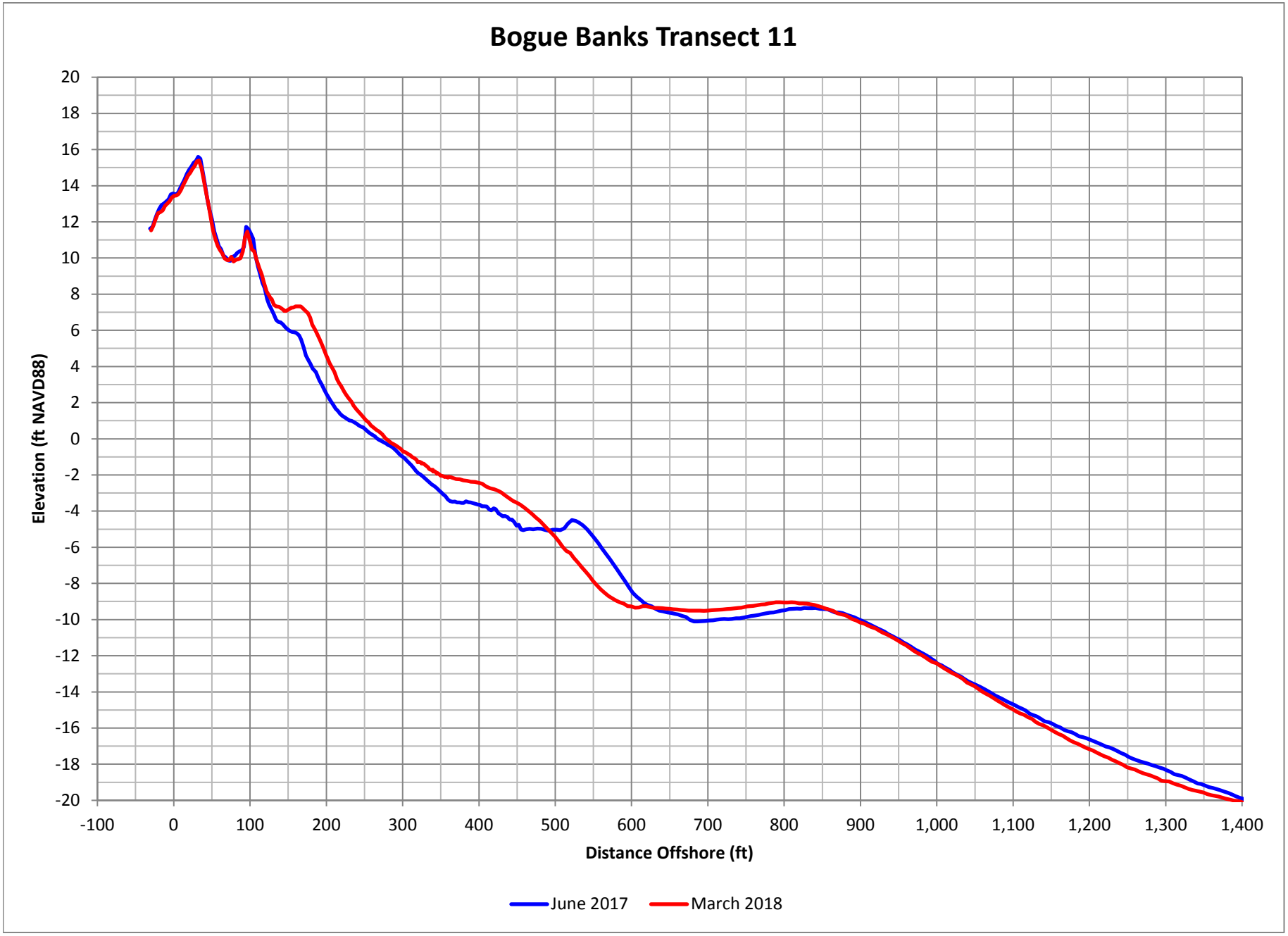


Figure D-22. Bogue Banks Profile Comparison Plot

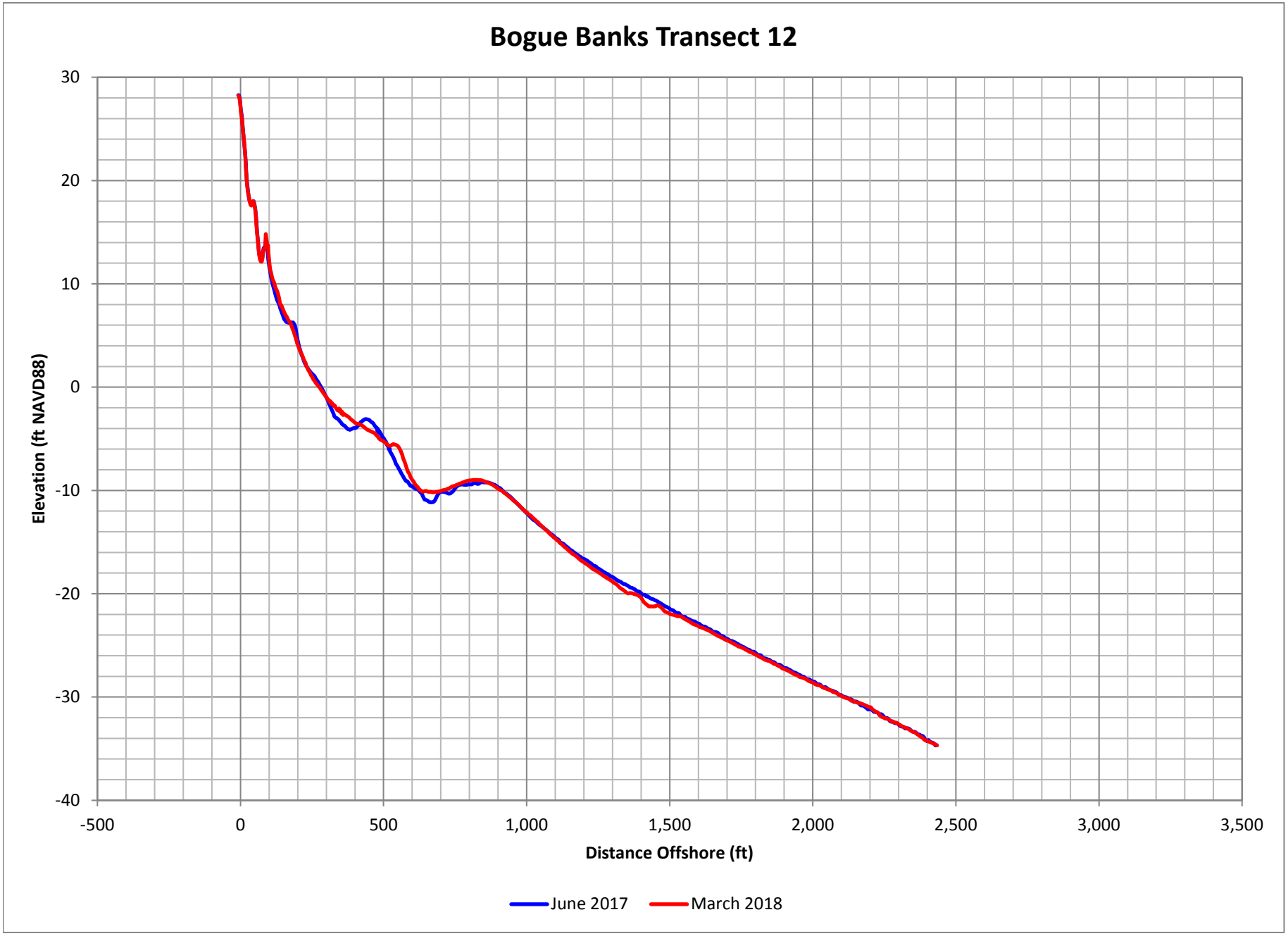


Figure D-23. Bogue Banks Profile Comparison Plot

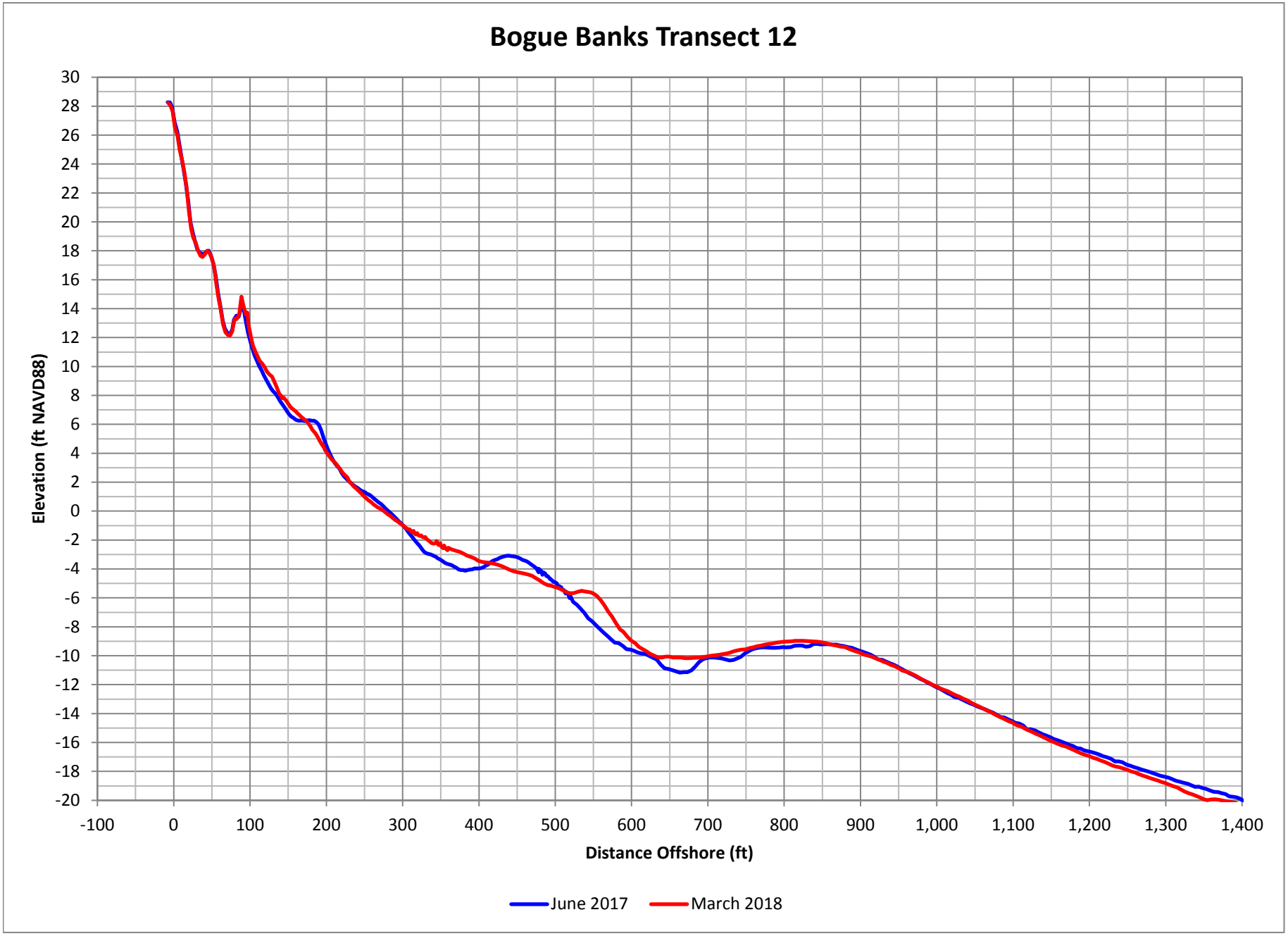


Figure D-24. Bogue Banks Profile Comparison Plot

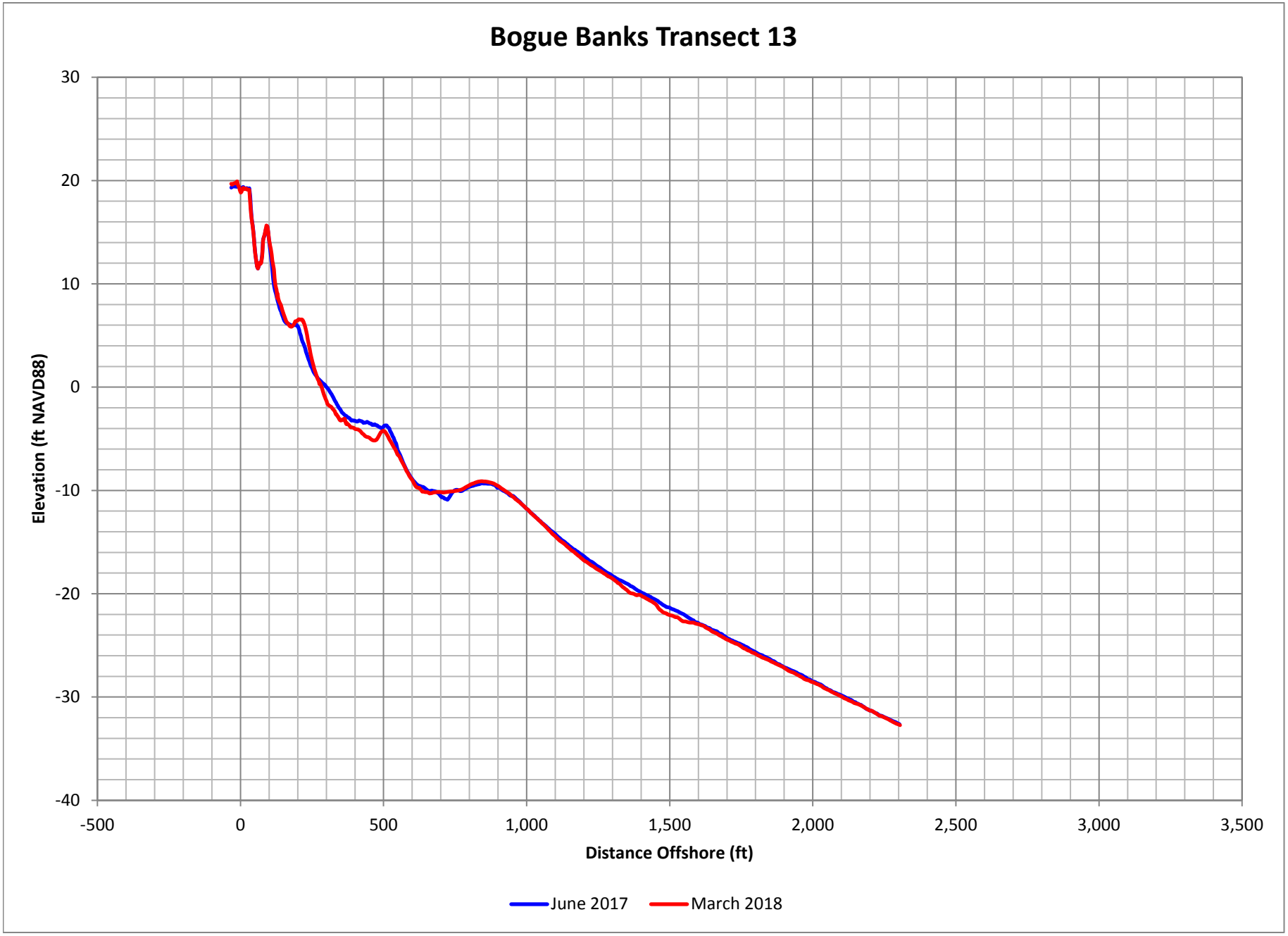


Figure D-25. Bogue Banks Profile Comparison Plot

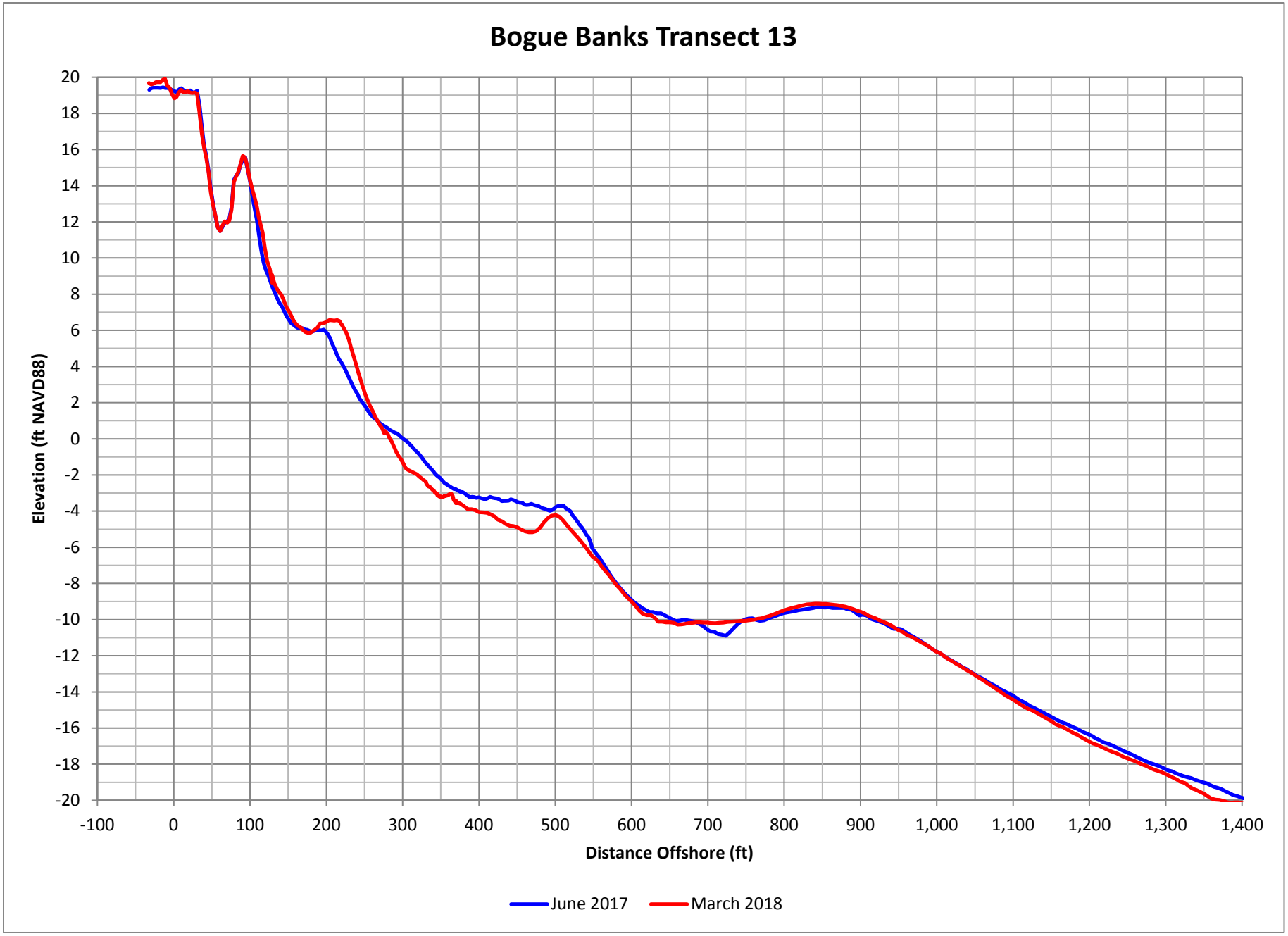


Figure D-26. Bogue Banks Profile Comparison Plot

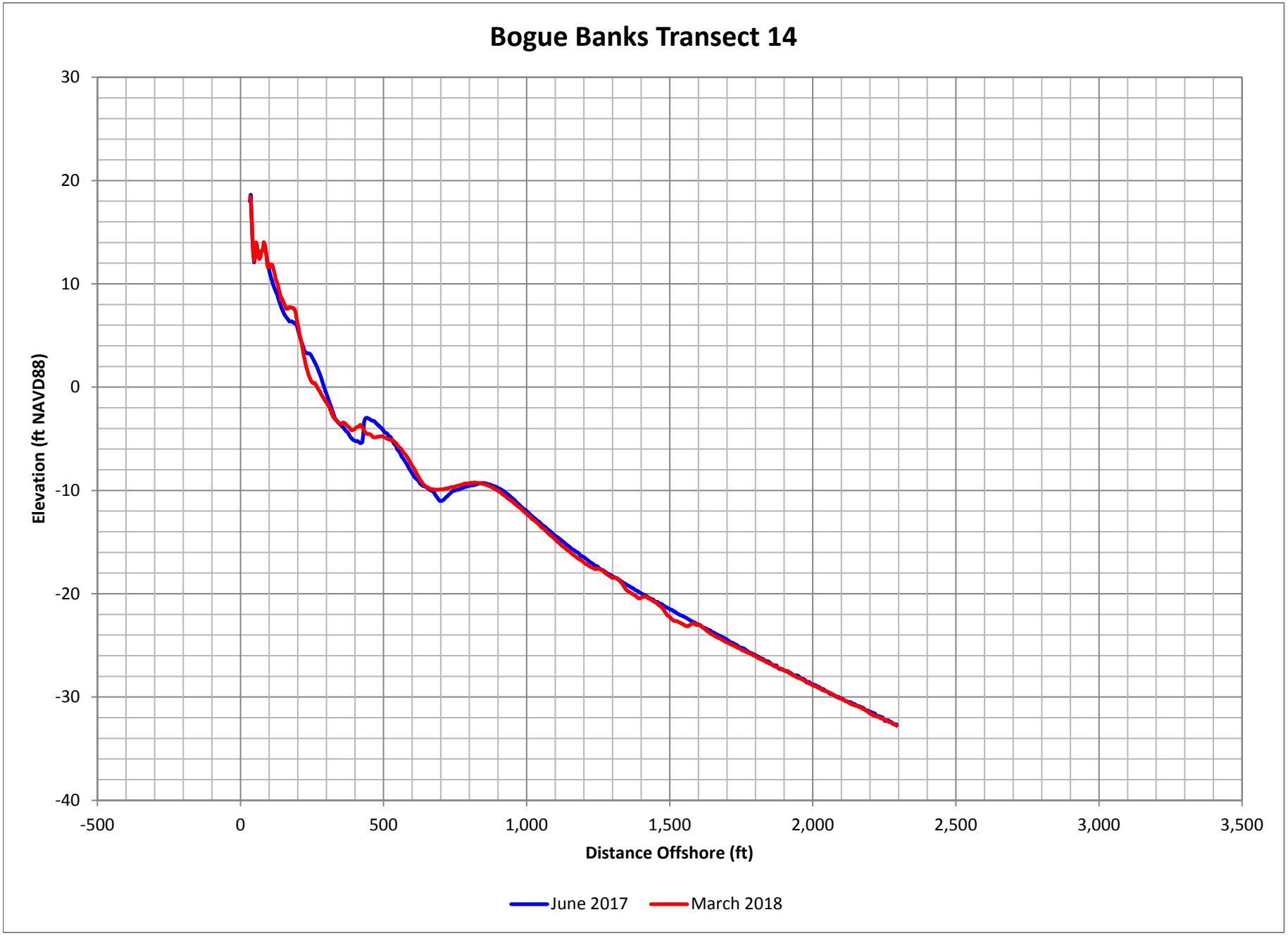


Figure D-27. Bogue Banks Profile Comparison Plot

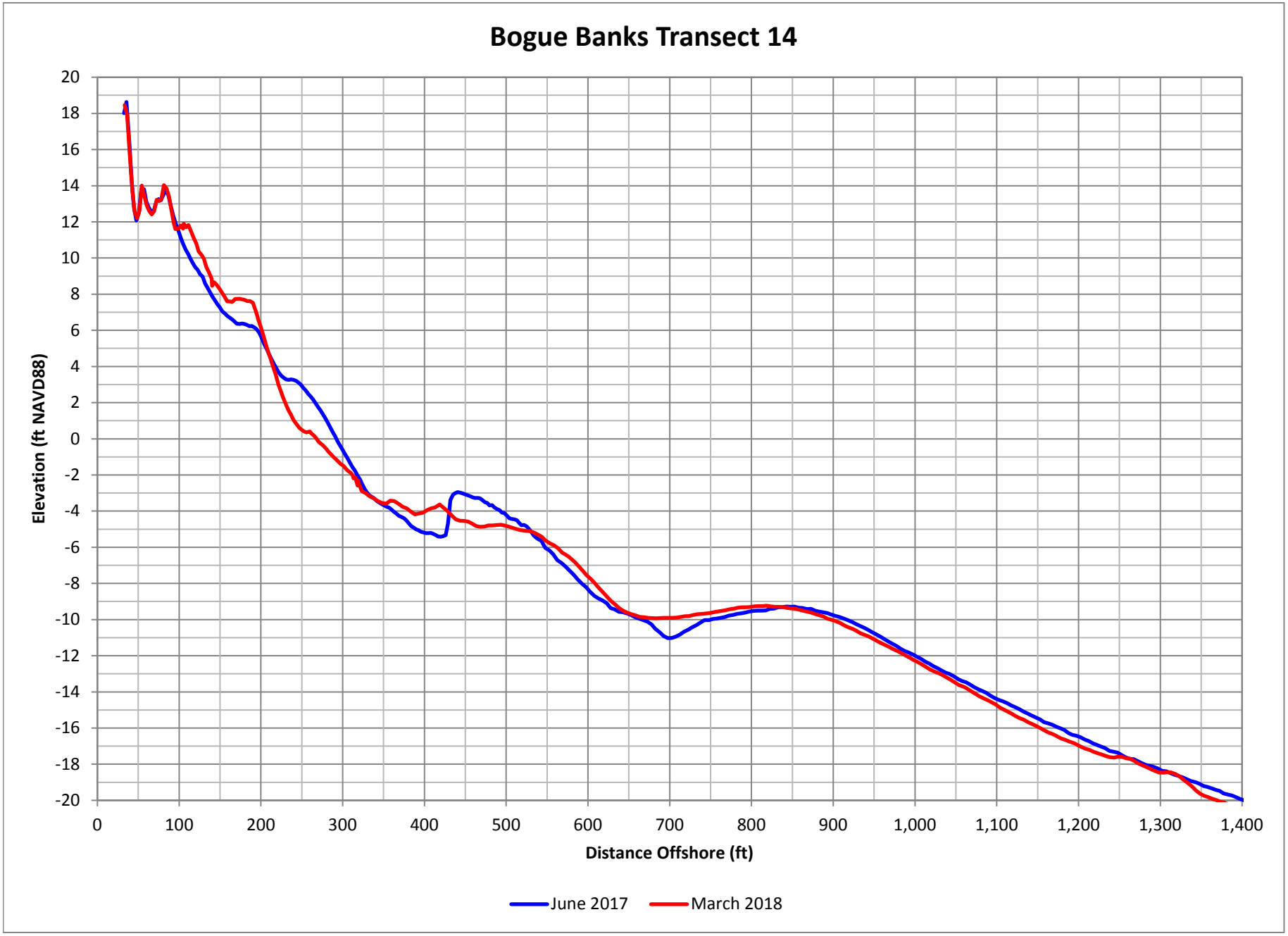


Figure D-28. Bogue Banks Profile Comparison Plot

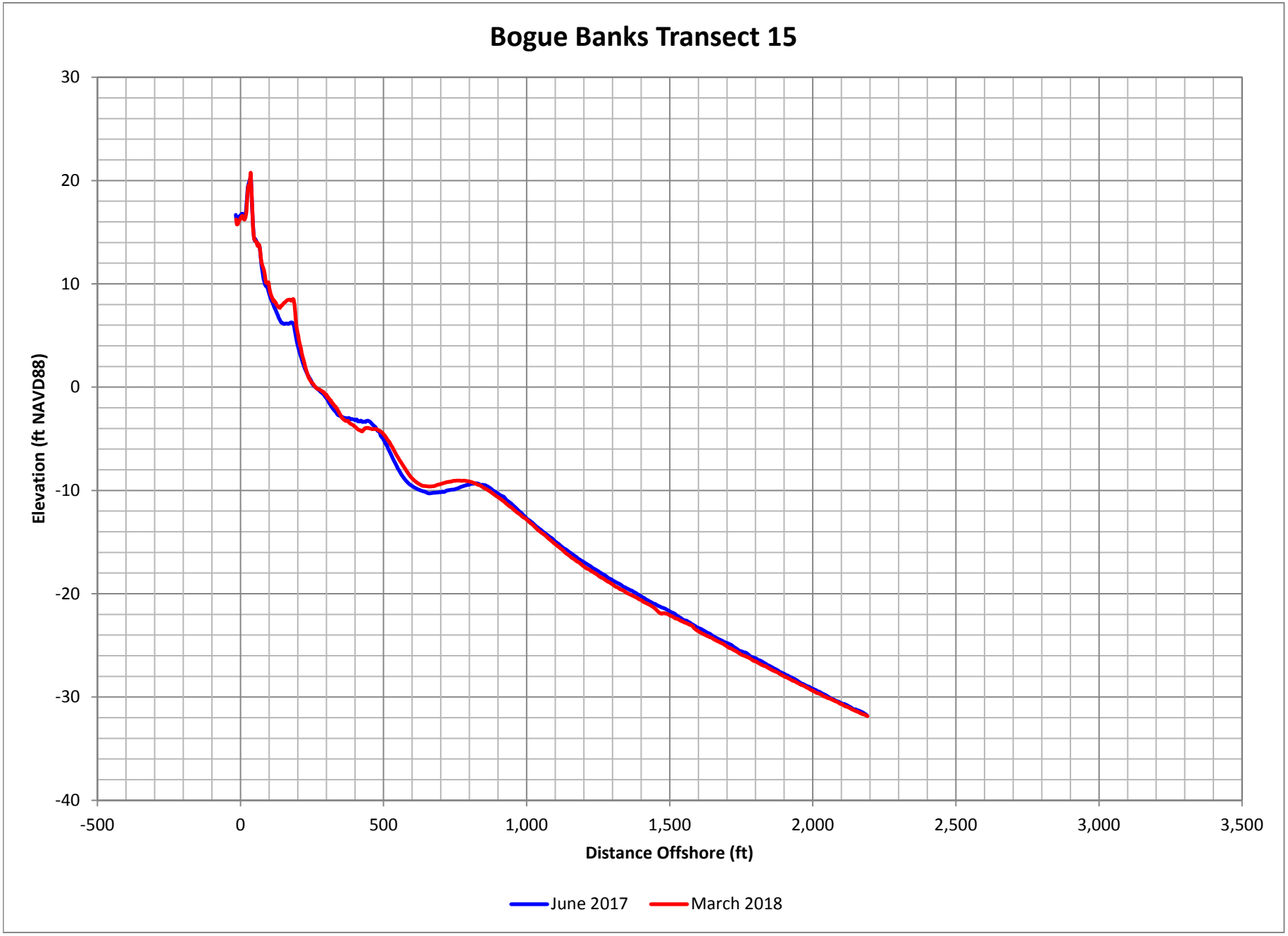


Figure D-29. Bogue Banks Profile Comparison Plot

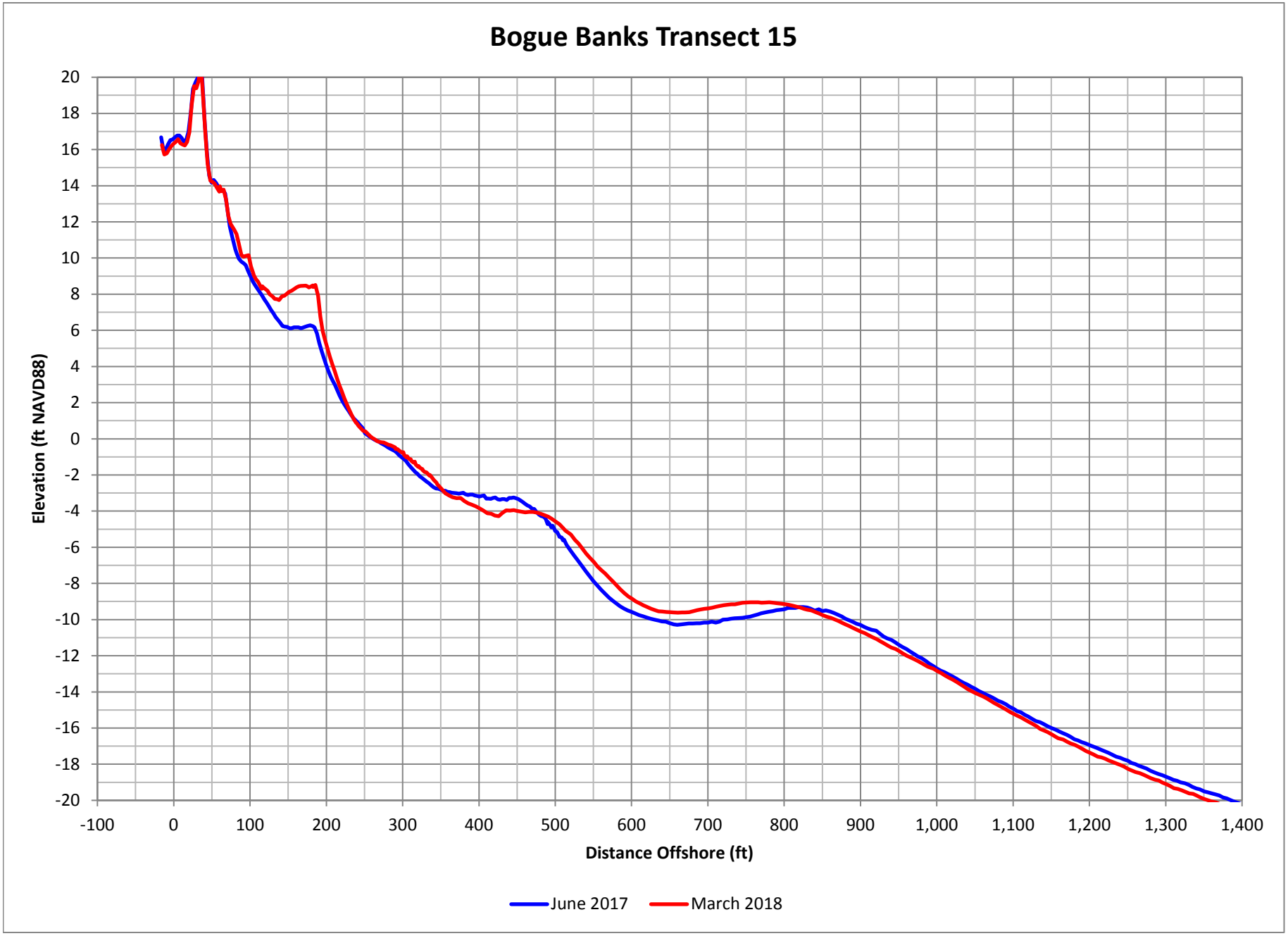


Figure D-30. Bogue Banks Profile Comparison Plot

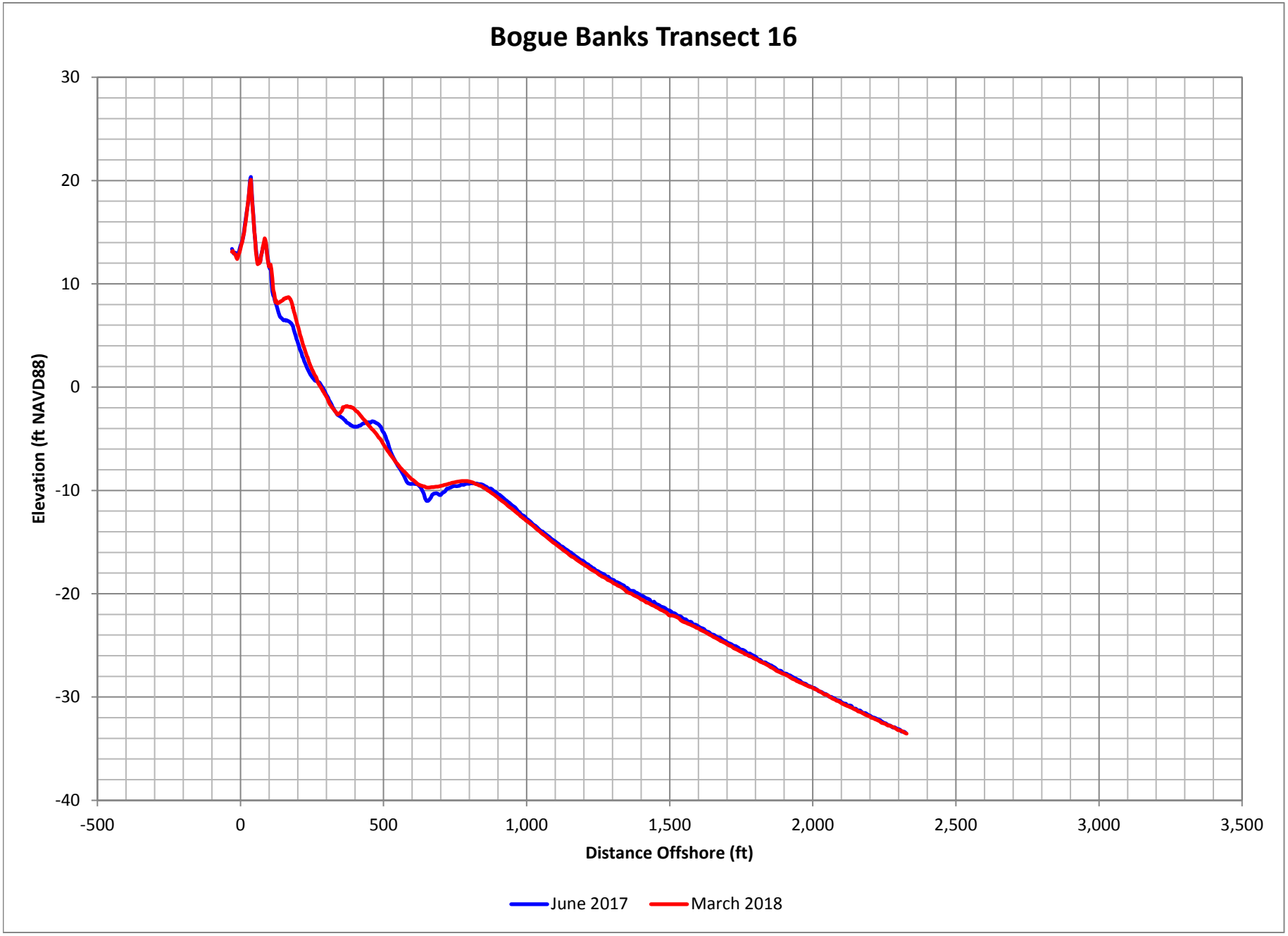


Figure D-31. Bogue Banks Profile Comparison Plot

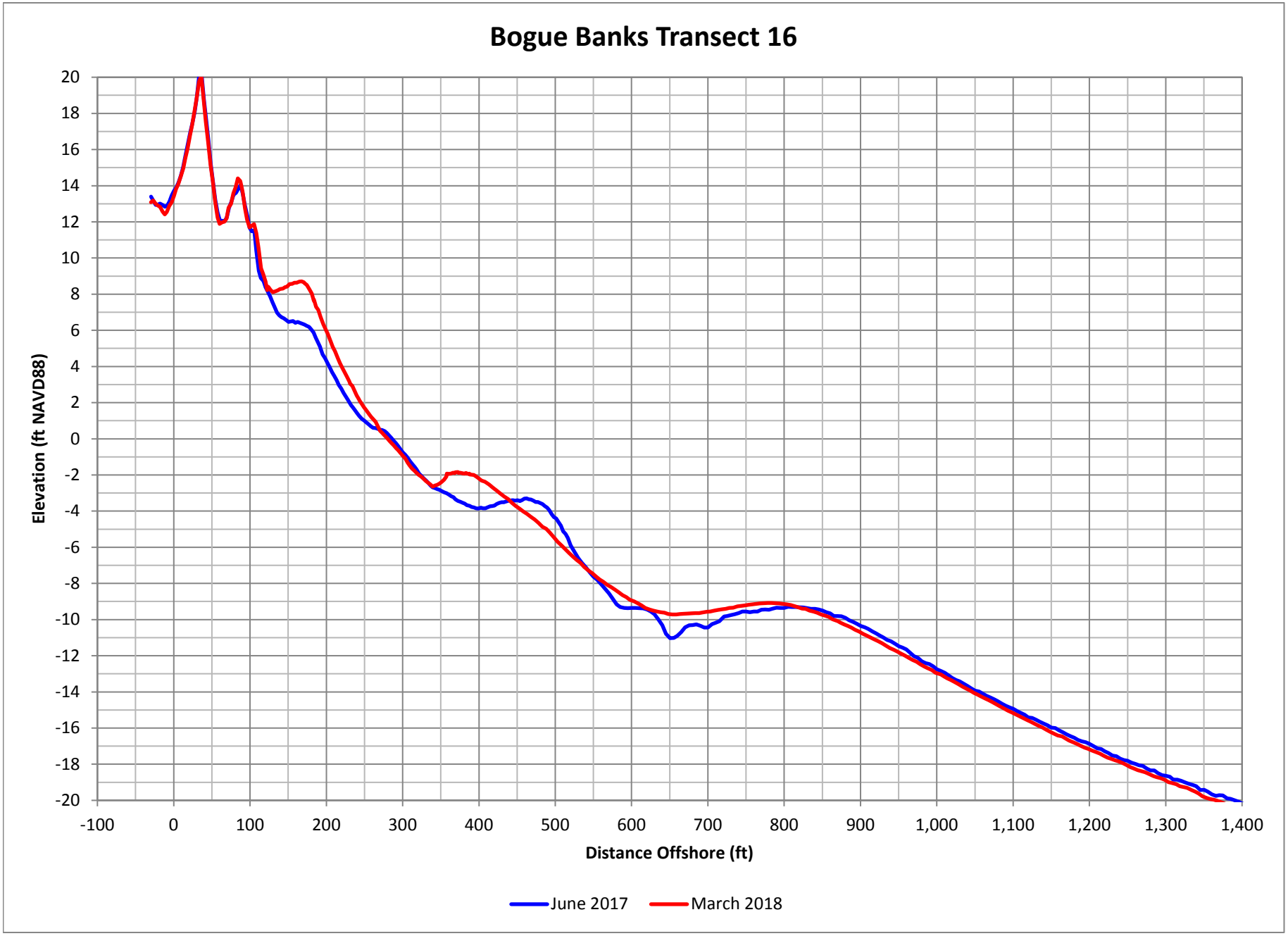


Figure D-32. Bogue Banks Profile Comparison Plot

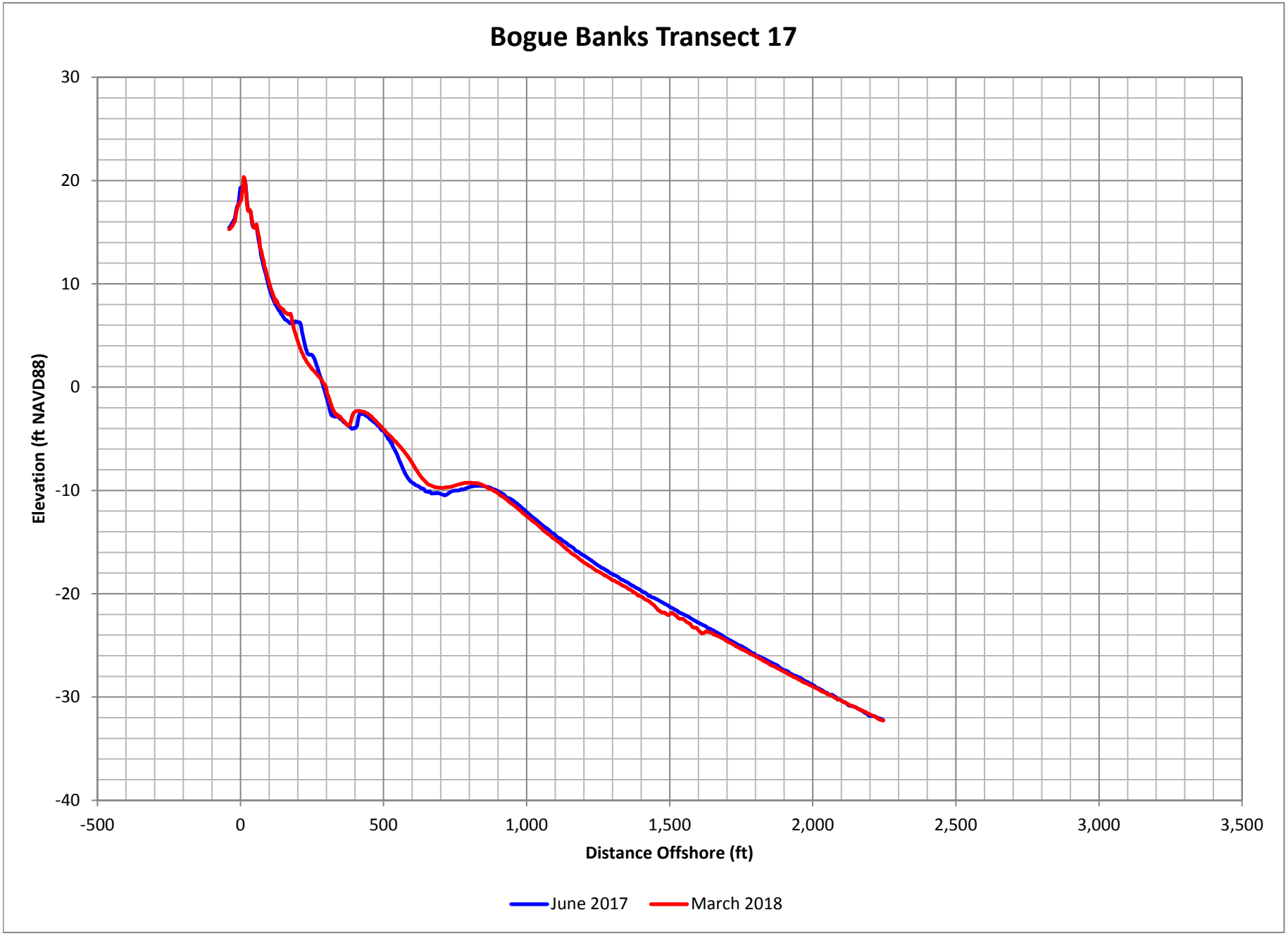


Figure D-33. Bogue Banks Profile Comparison Plot

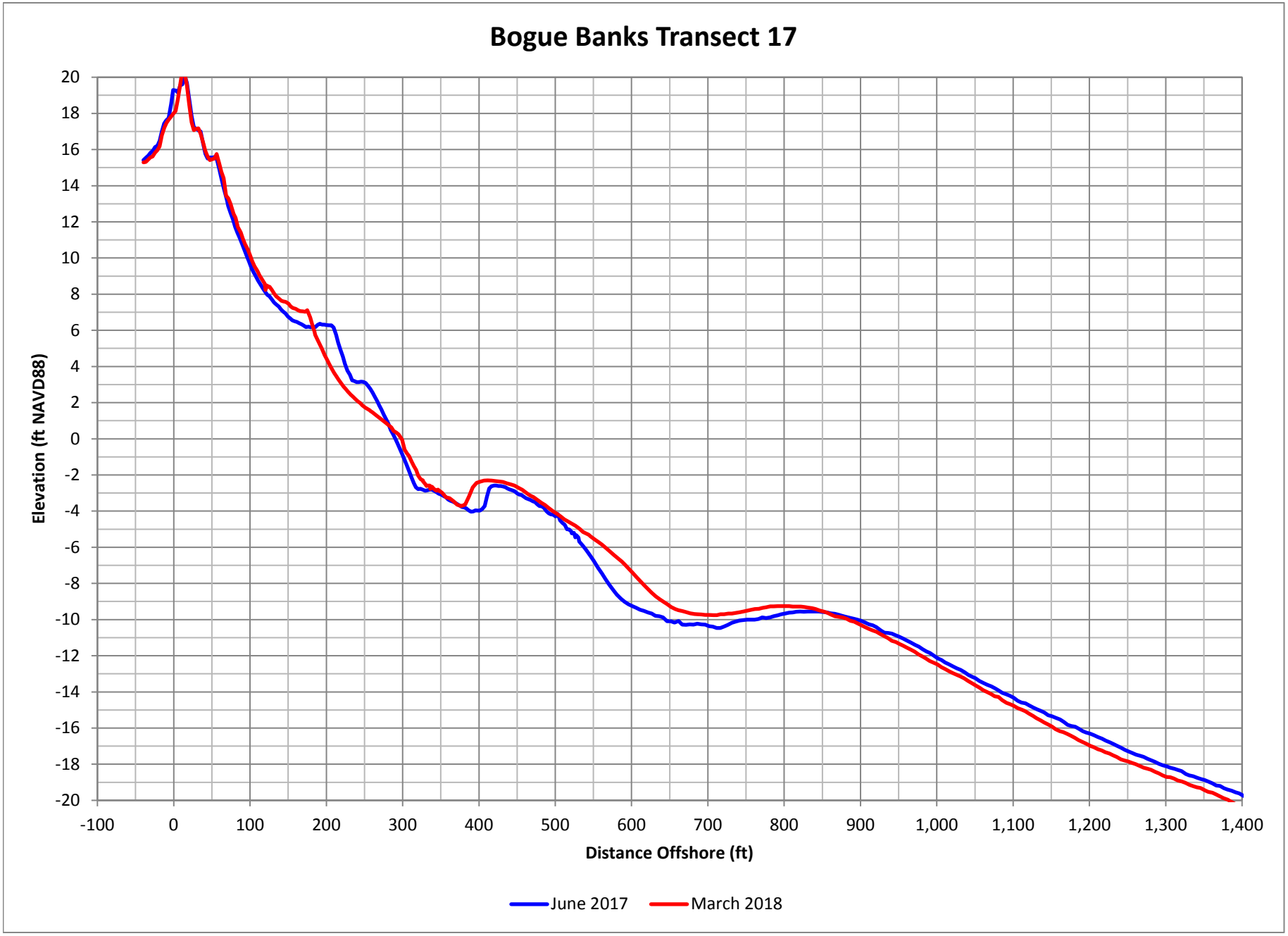


Figure D-34. Bogue Banks Profile Comparison Plot

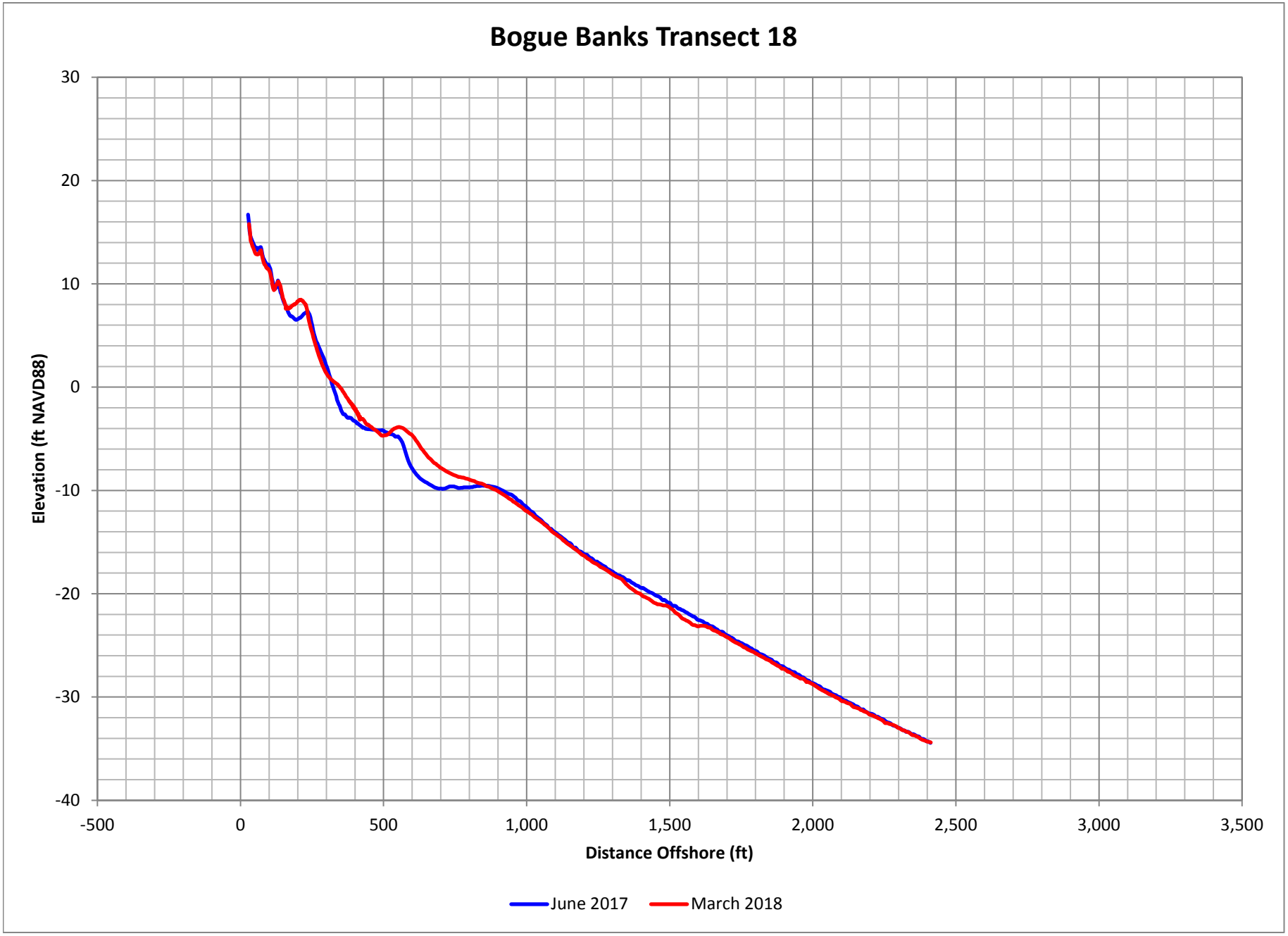


Figure D-35. Bogue Banks Profile Comparison Plot

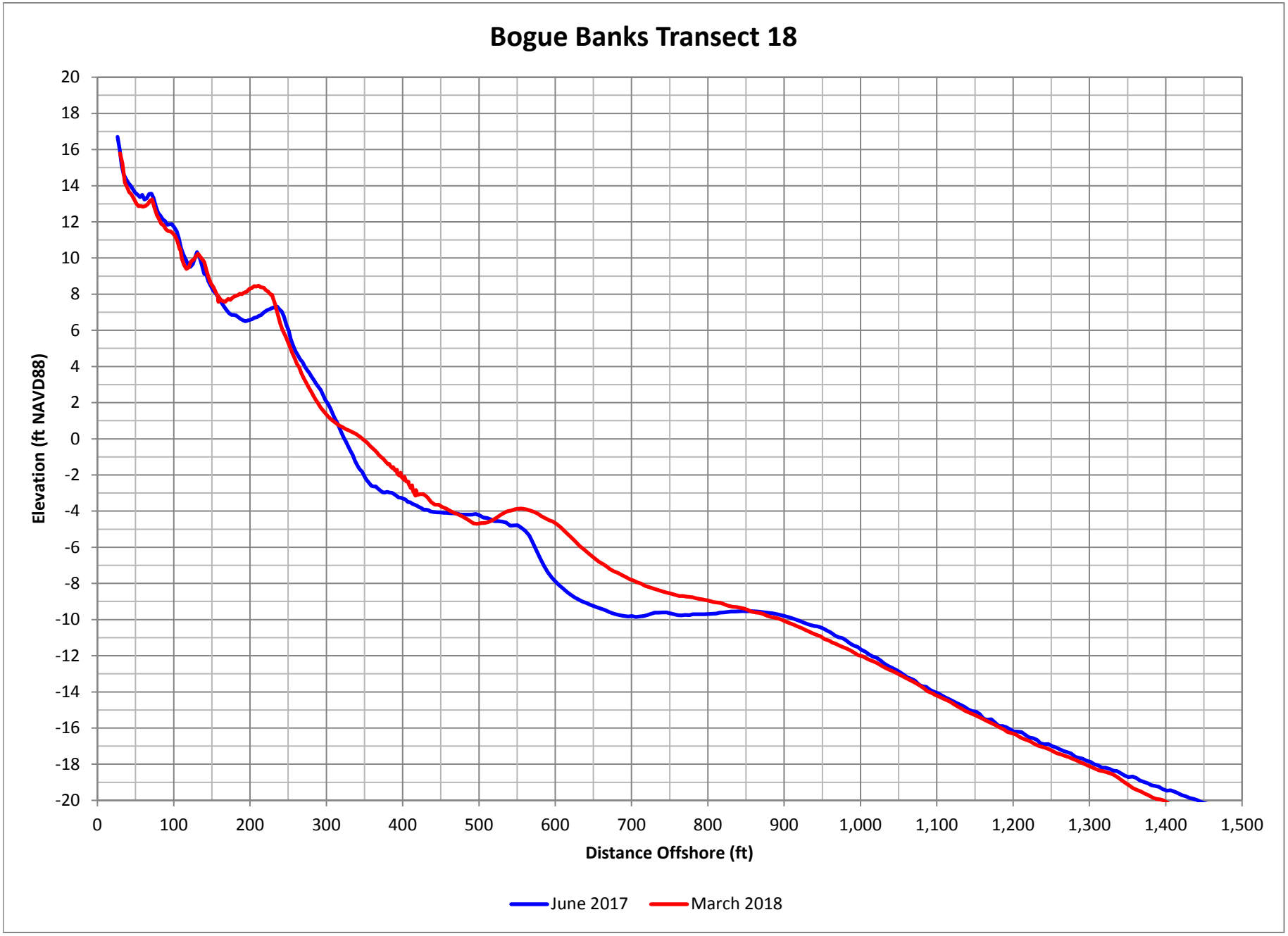


Figure D-36. Bogue Banks Profile Comparison Plot

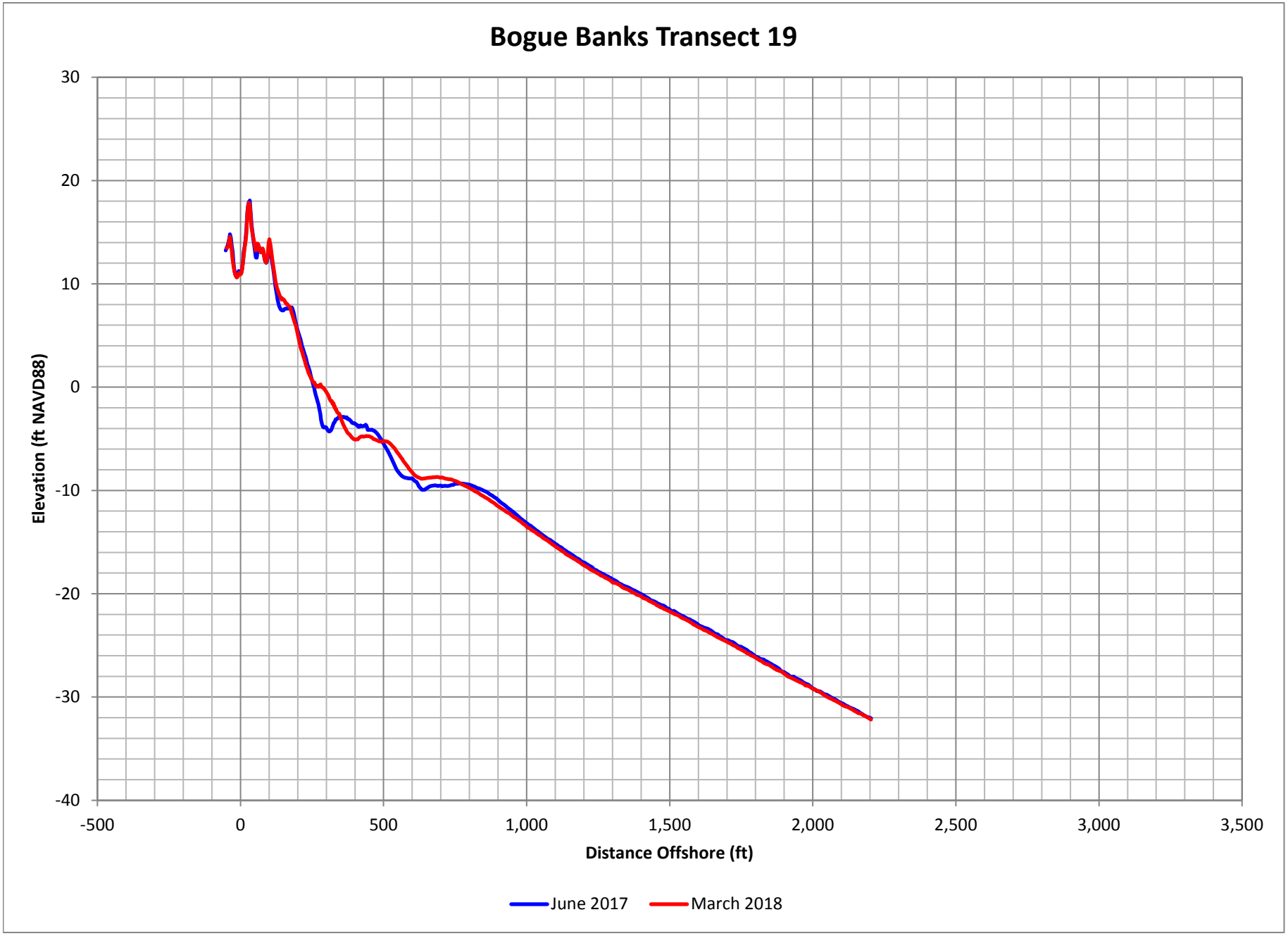


Figure D-37. Bogue Banks Profile Comparison Plot

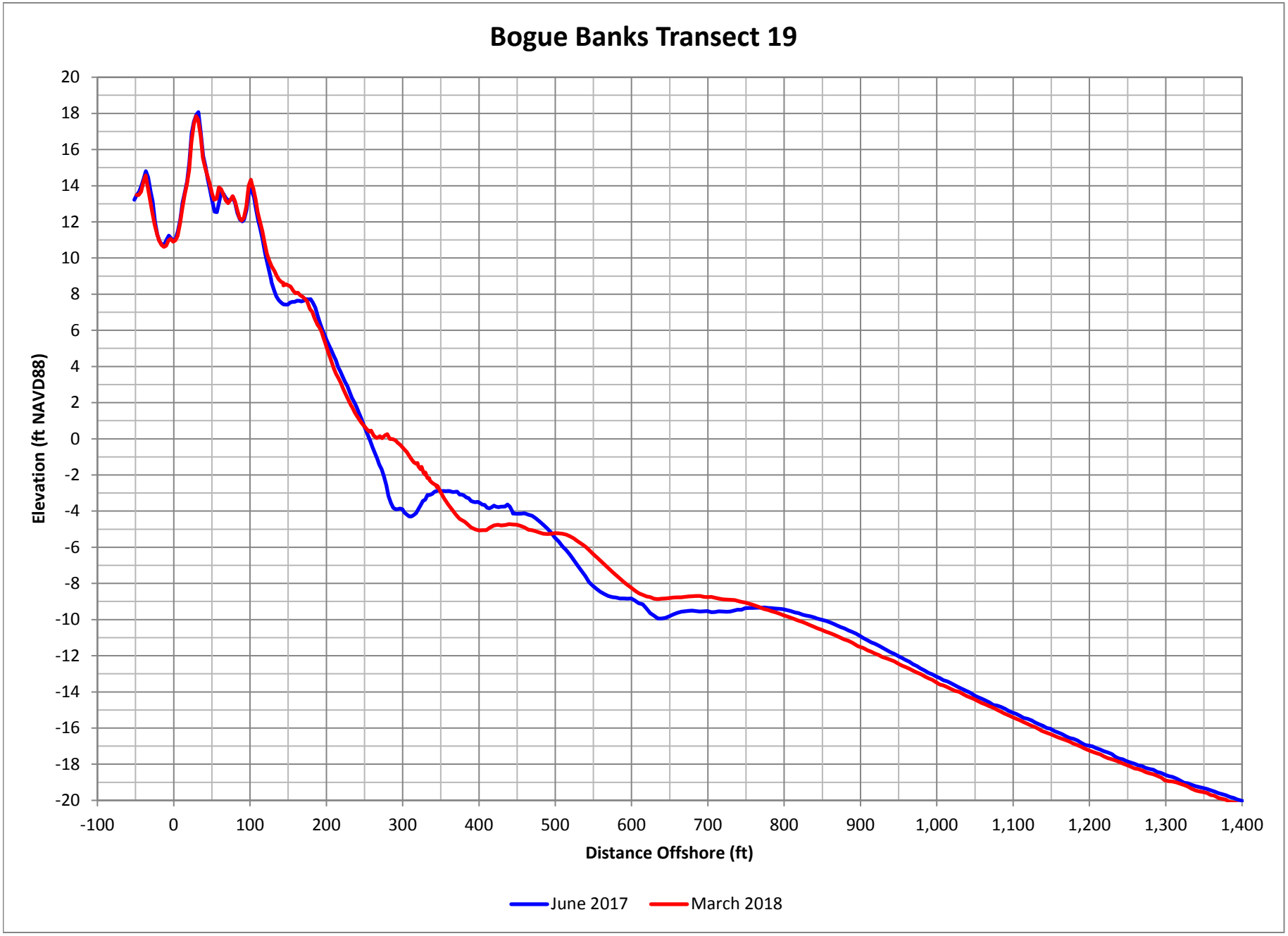


Figure D-38. Bogue Banks Profile Comparison Plot

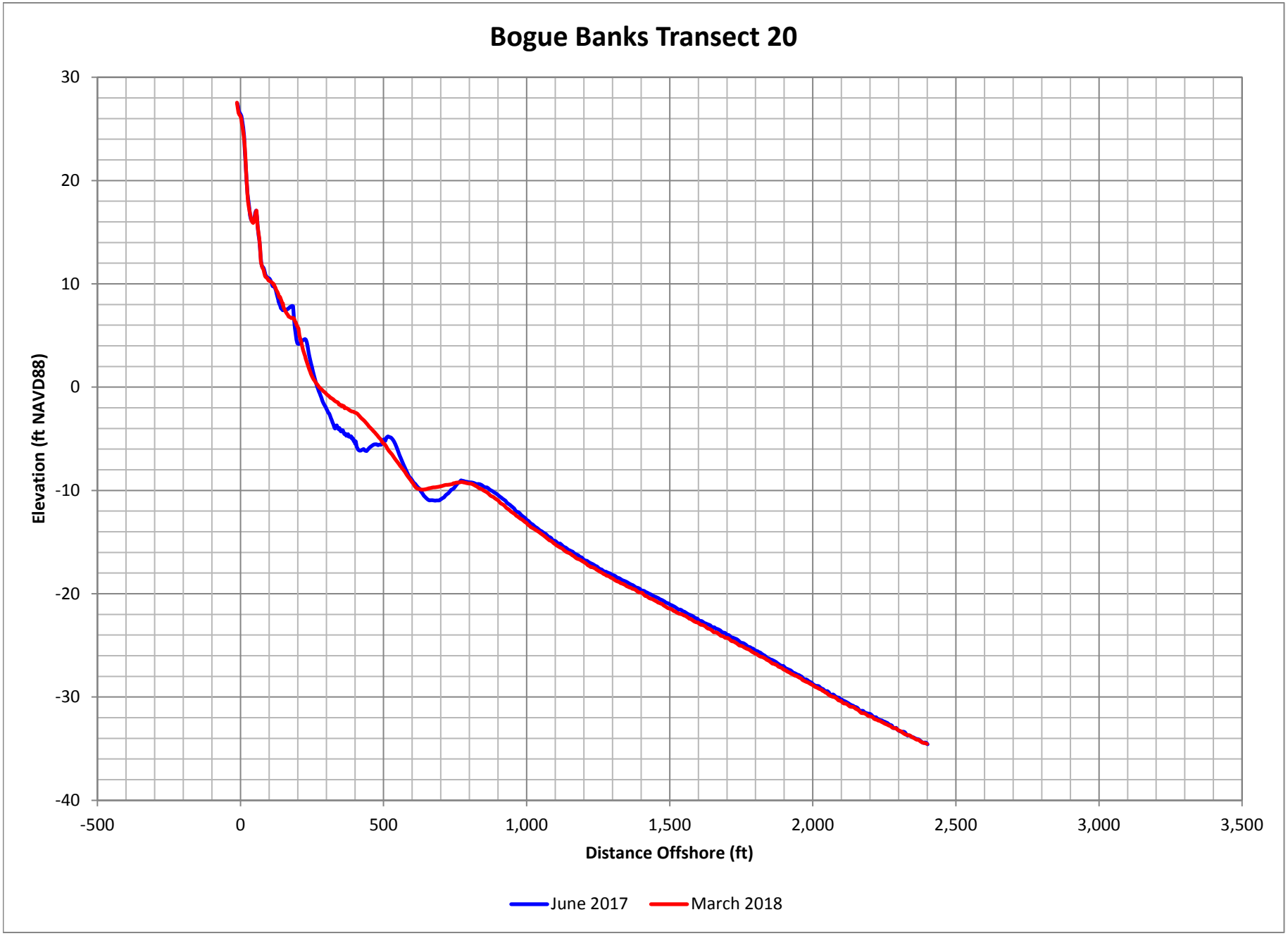


Figure D-39. Bogue Banks Profile Comparison Plot

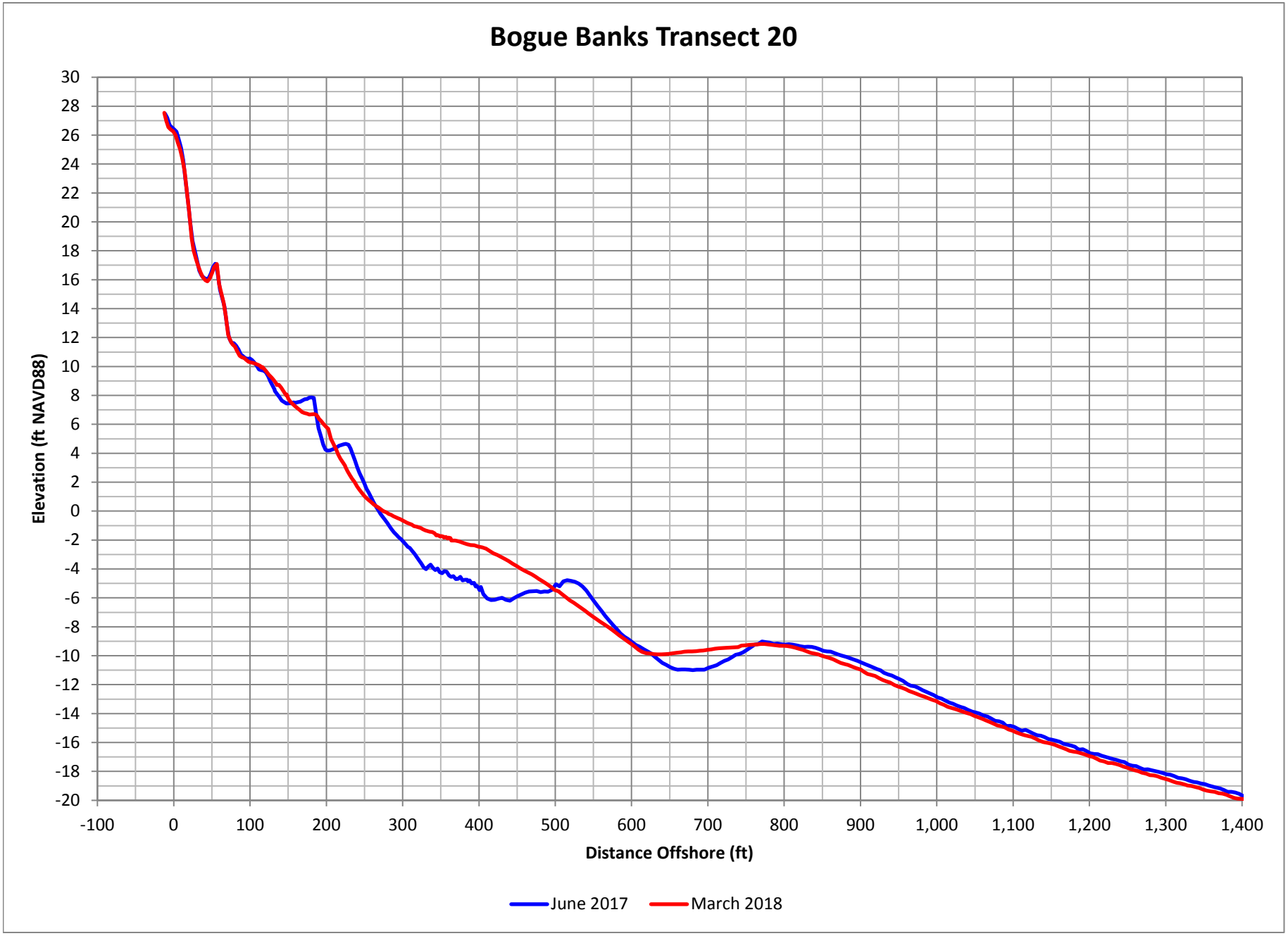


Figure D-40. Bogue Banks Profile Comparison Plot

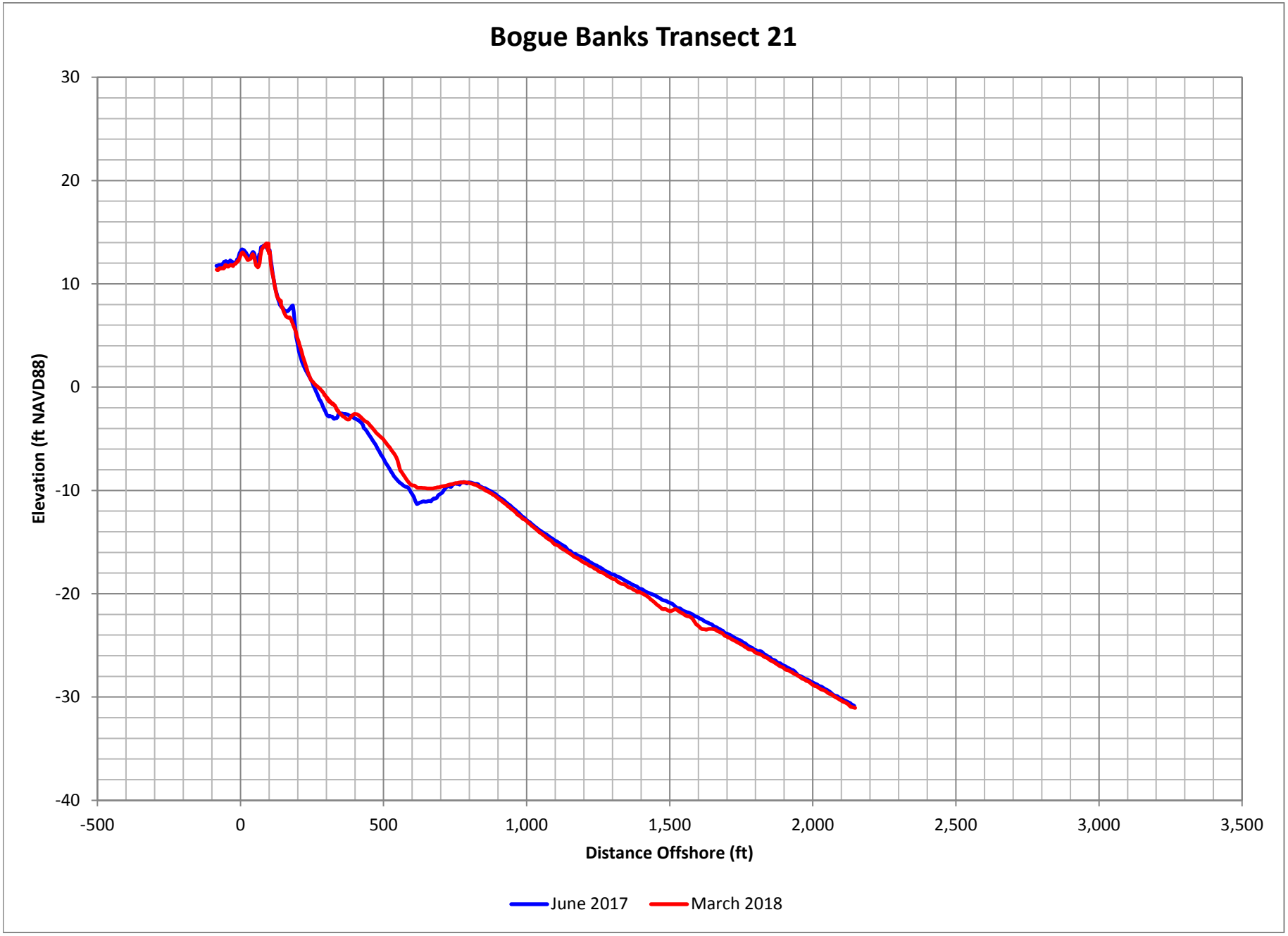


Figure D-41. Bogue Banks Profile Comparison Plot

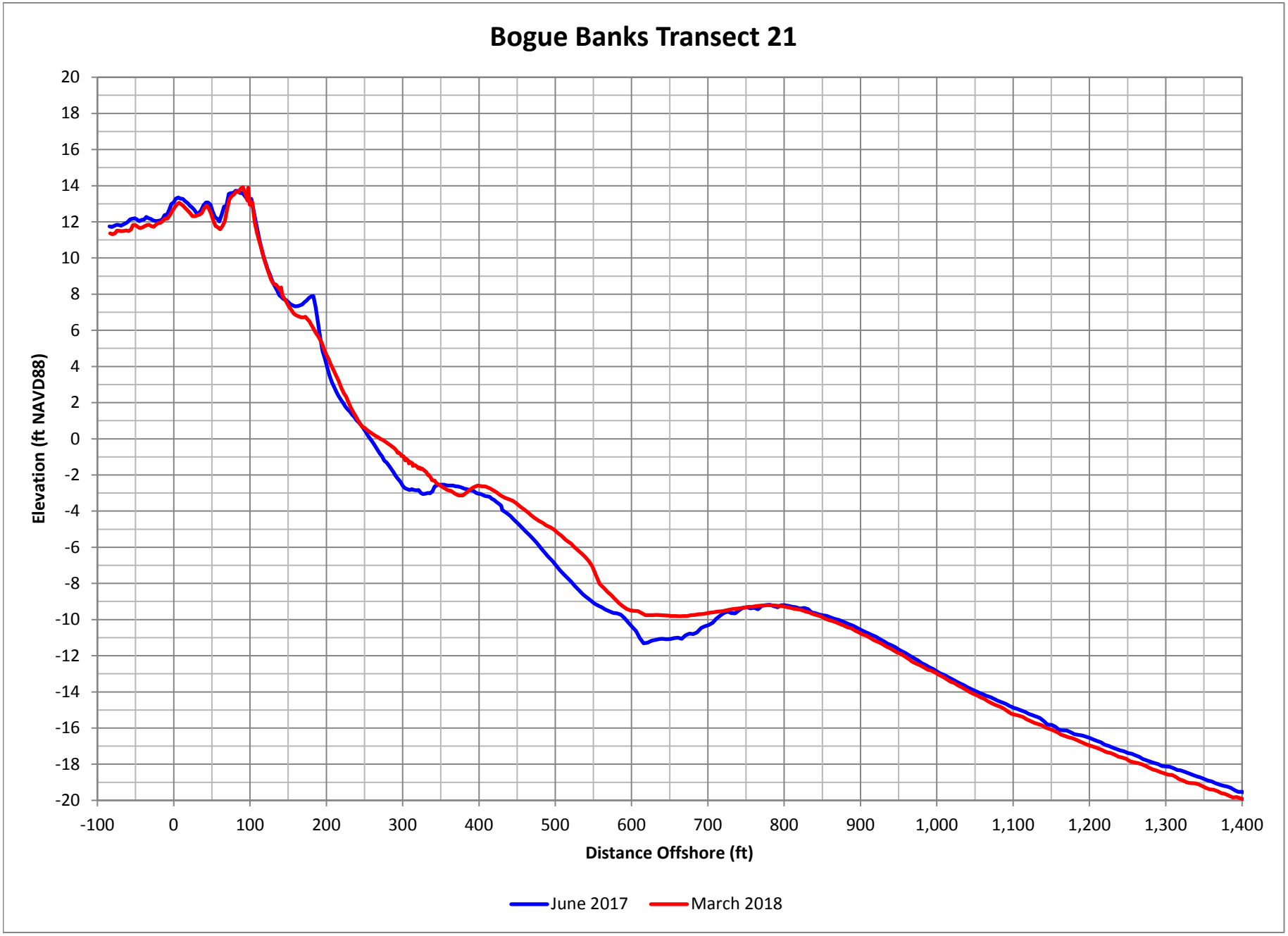


Figure D-42. Bogue Banks Profile Comparison Plot

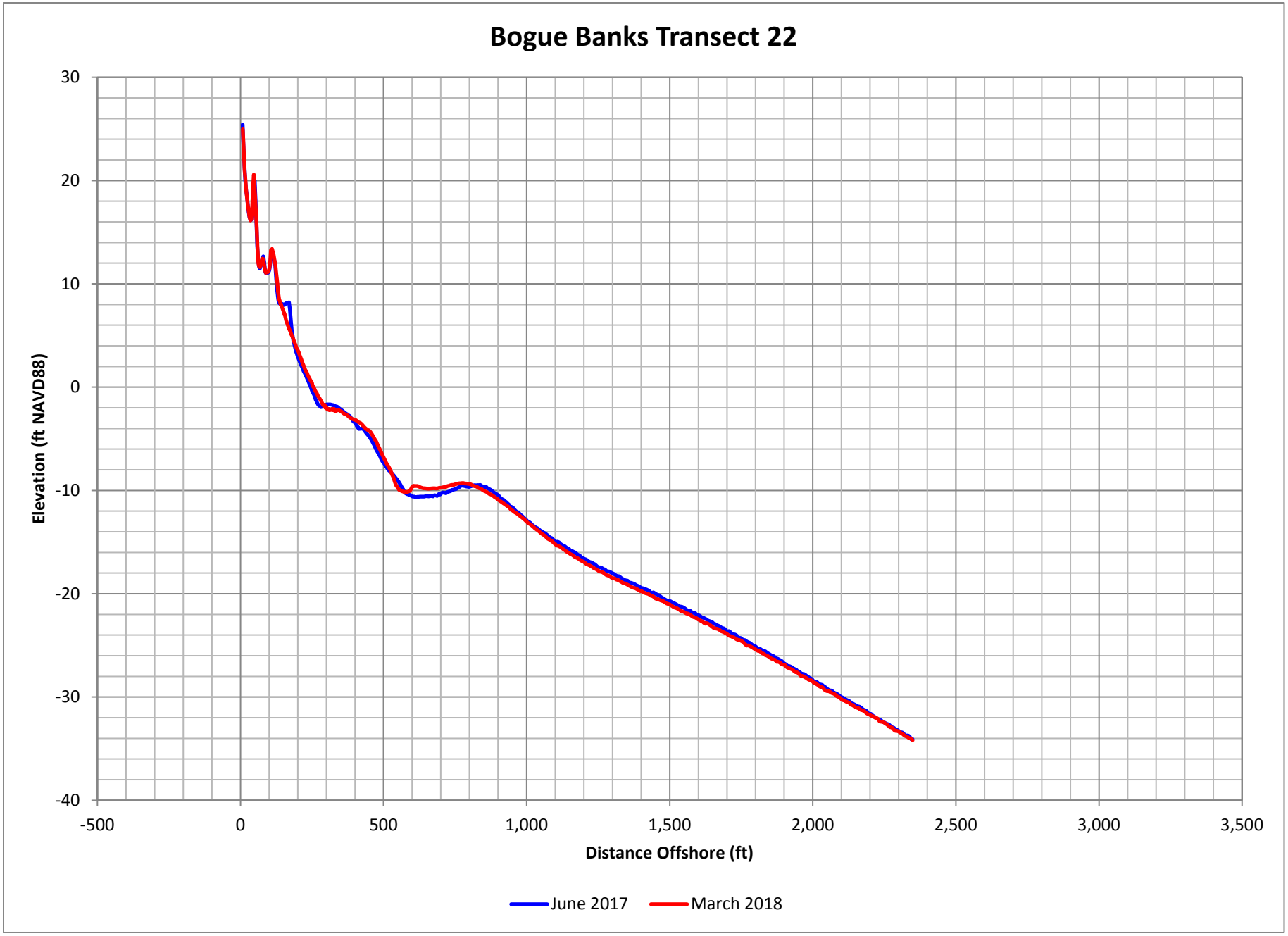


Figure D-43. Bogue Banks Profile Comparison Plot

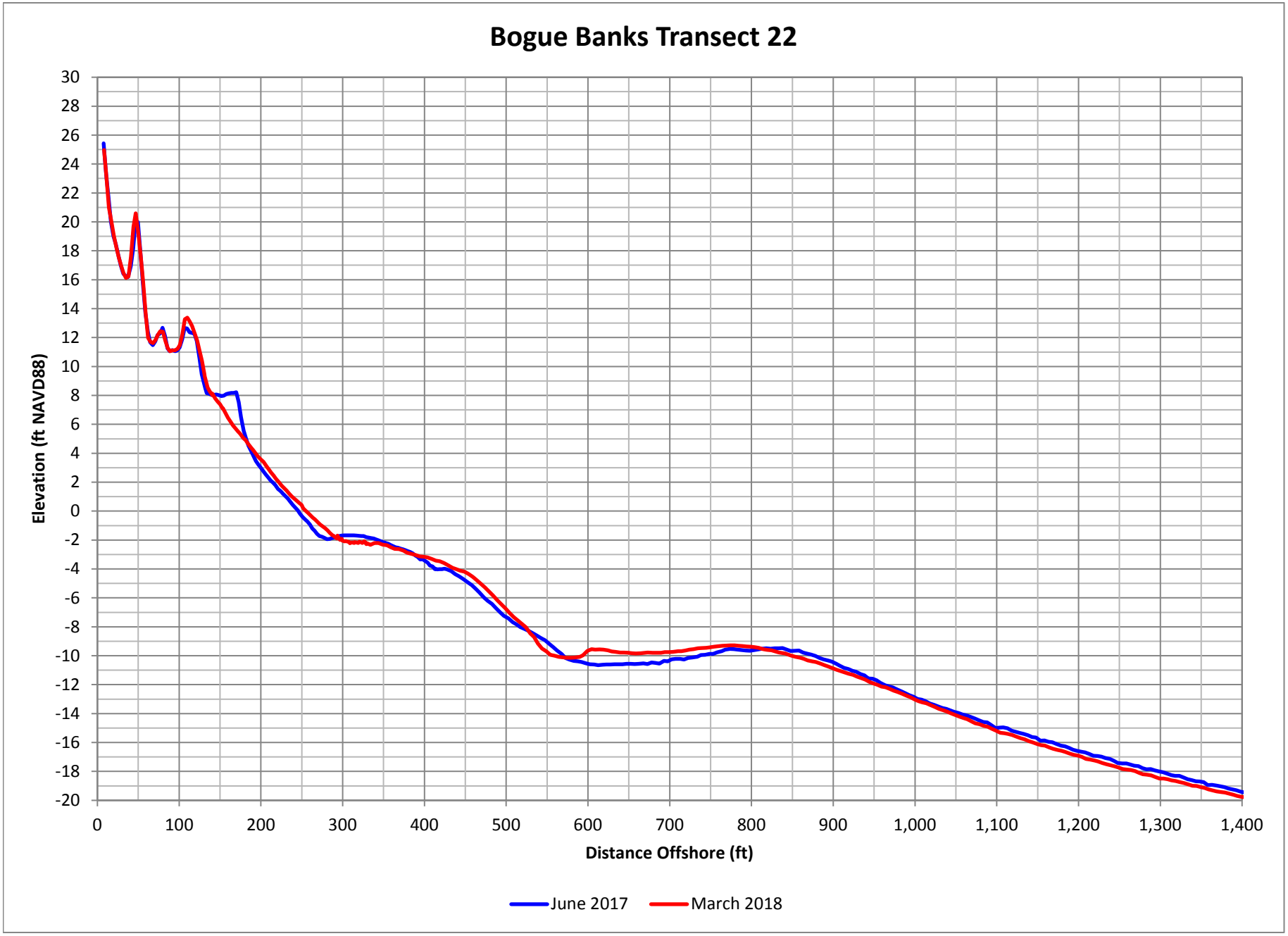


Figure D-44. Bogue Banks Profile Comparison Plot

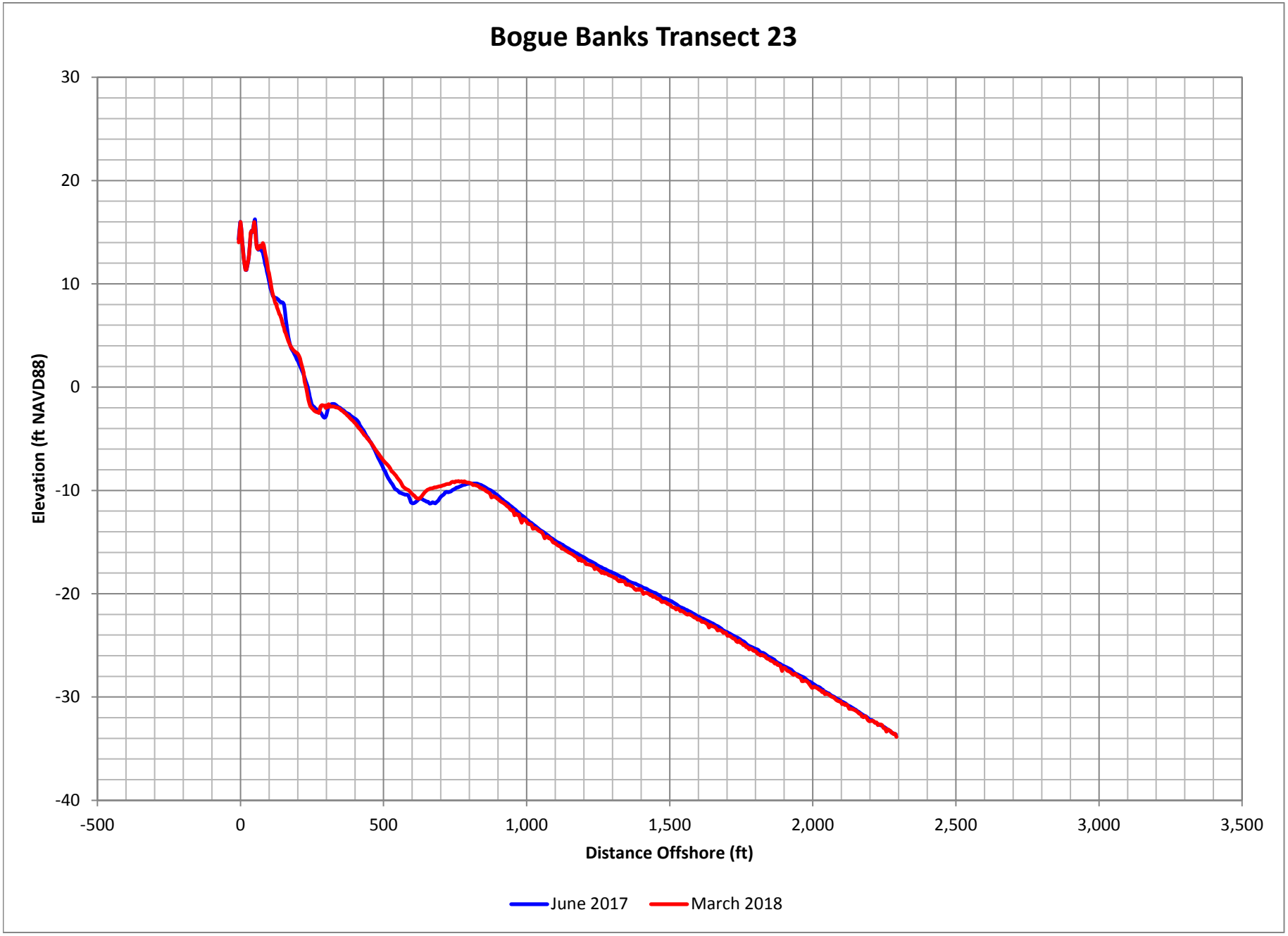


Figure D-45. Bogue Banks Profile Comparison Plot

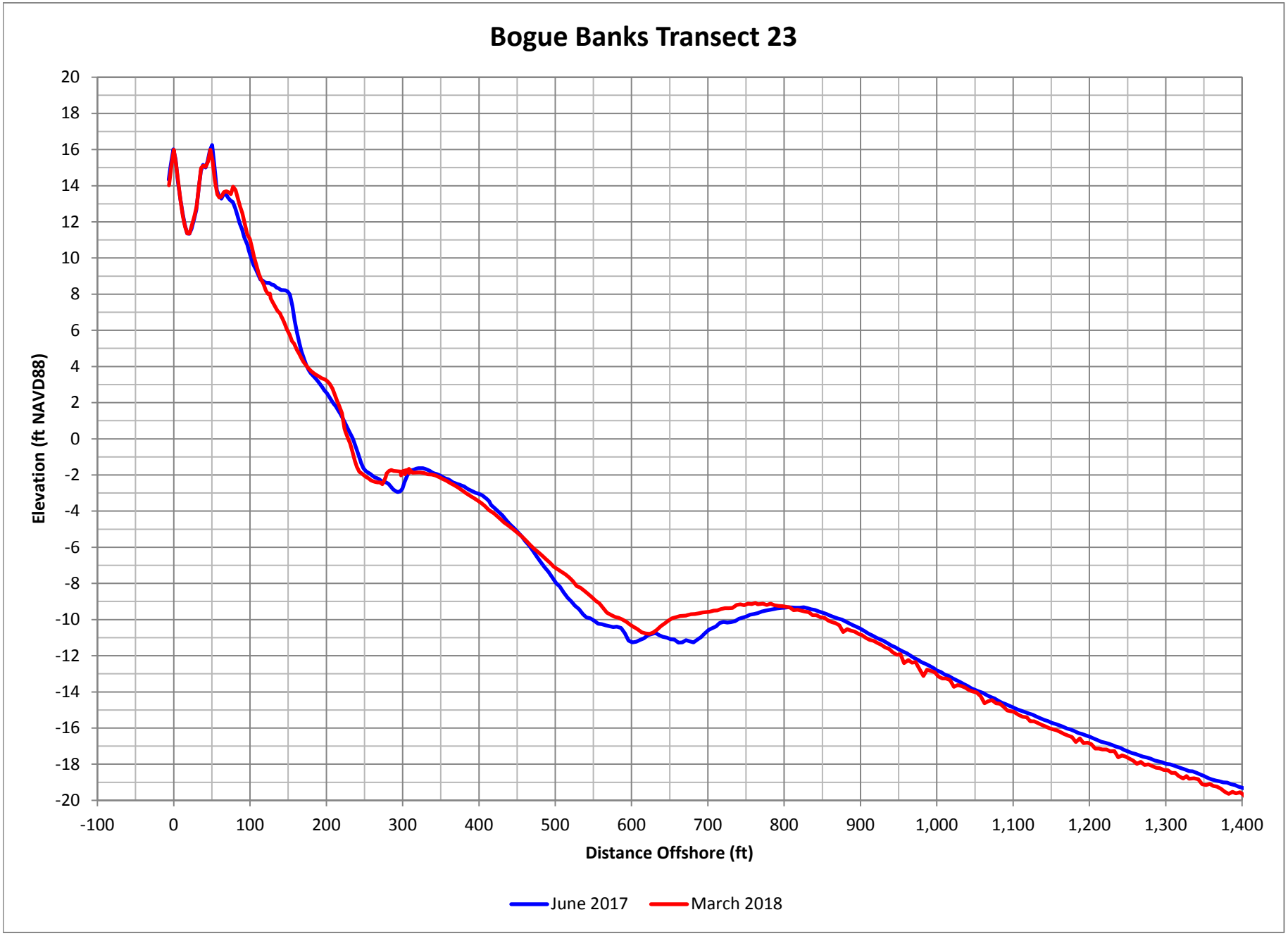


Figure D-46. Bogue Banks Profile Comparison Plot

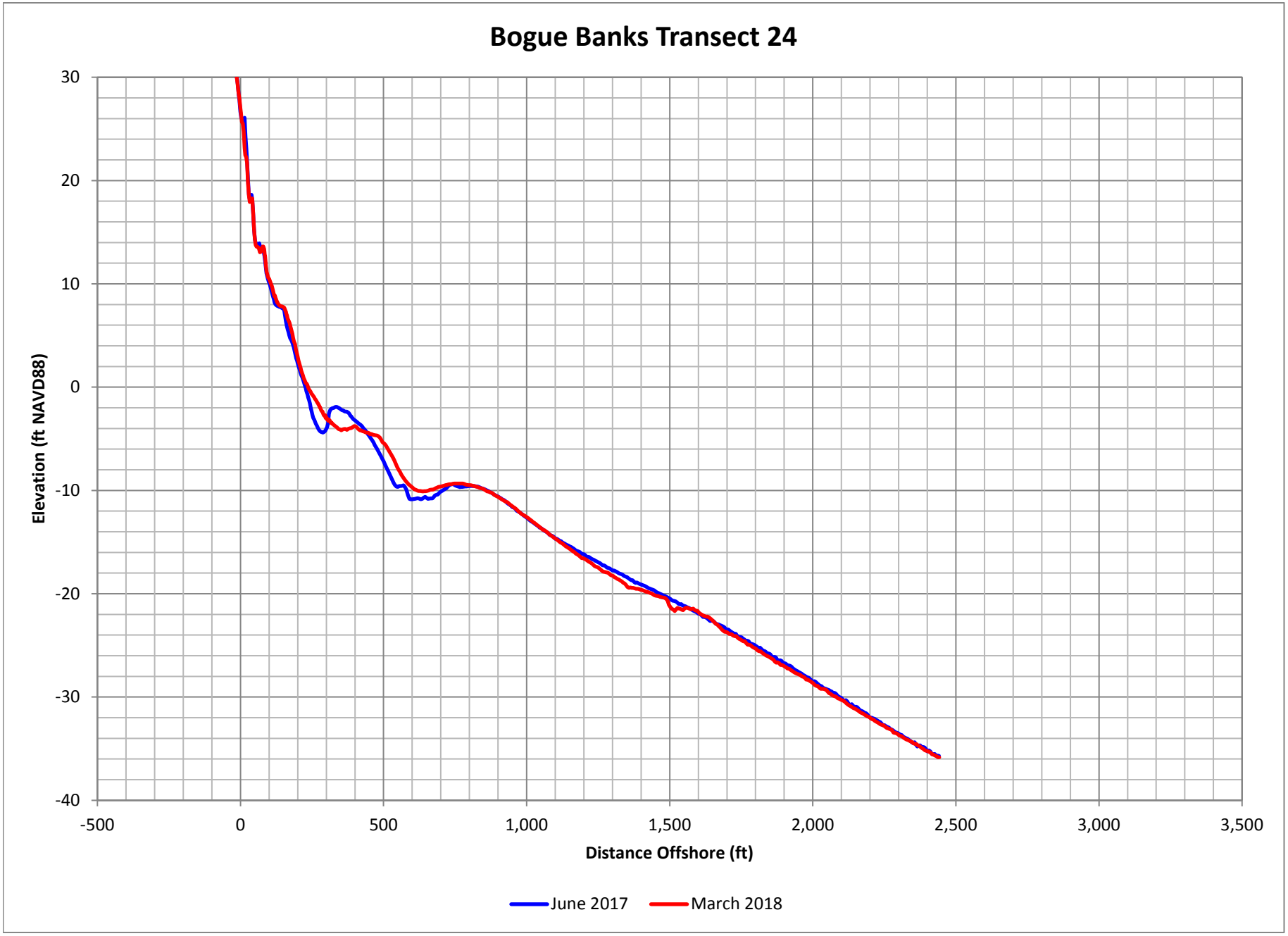


Figure D-47. Bogue Banks Profile Comparison Plot

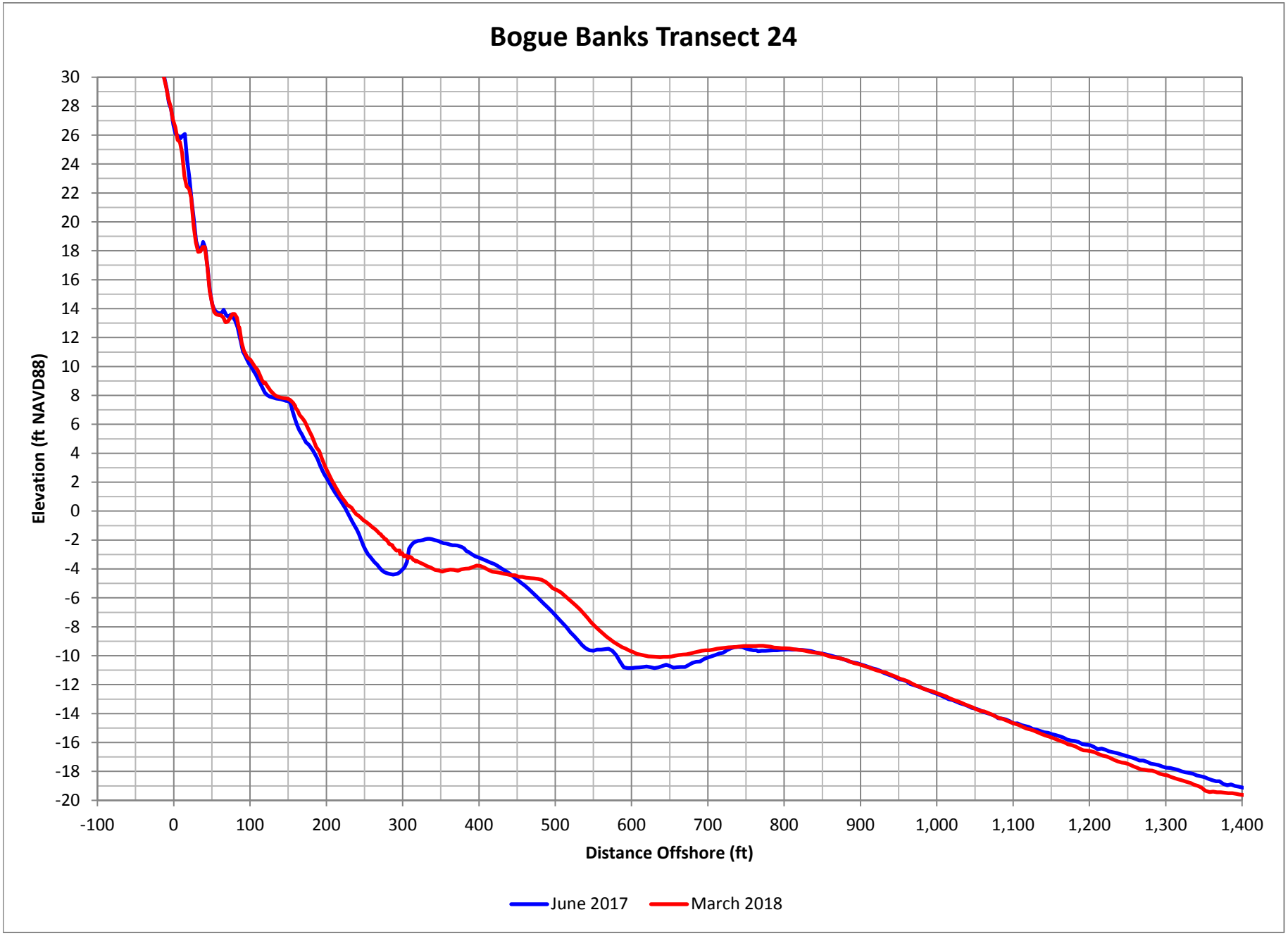


Figure D-48. Bogue Banks Profile Comparison Plot

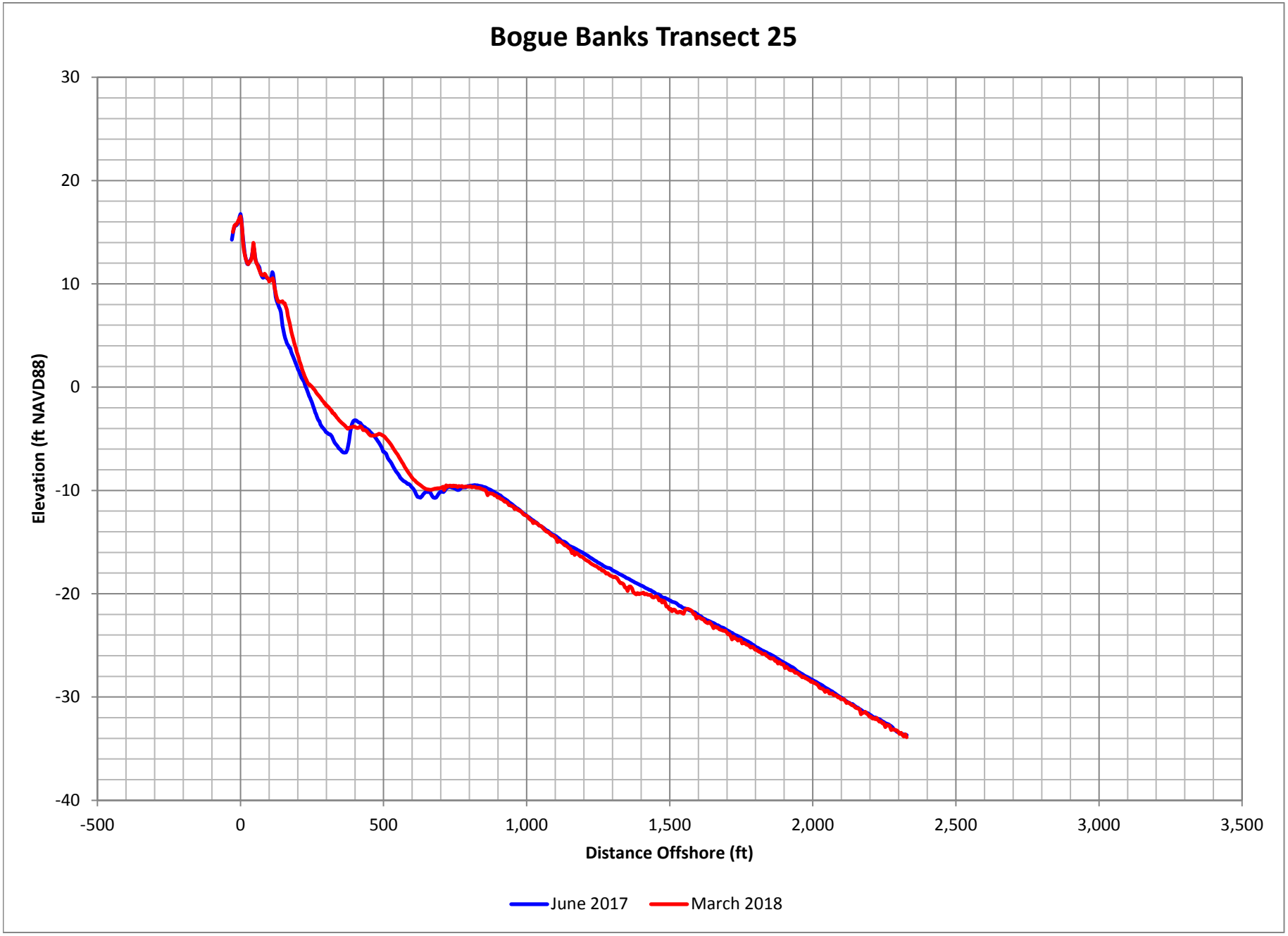


Figure D-49. Bogue Banks Profile Comparison Plot

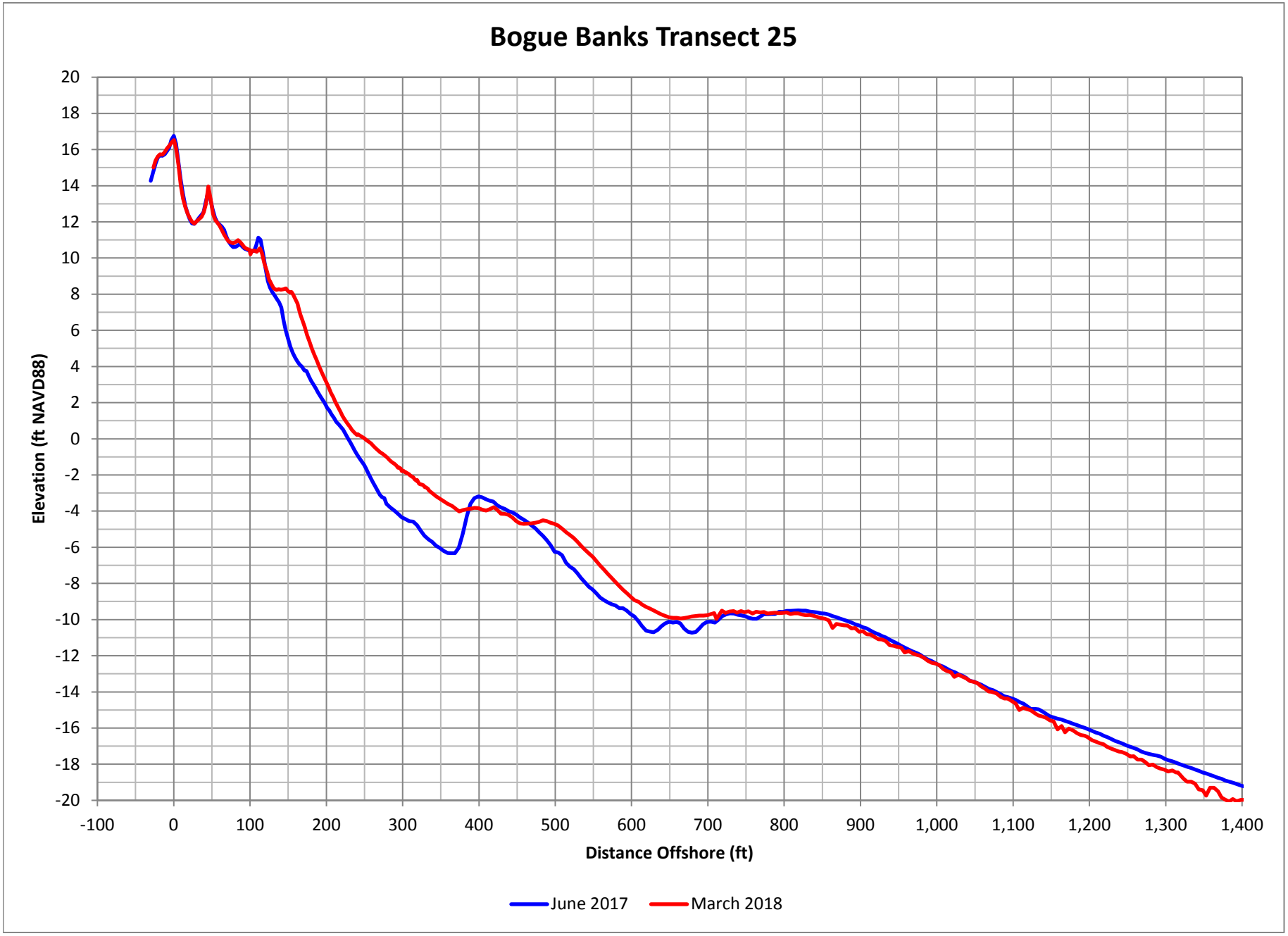


Figure D-50. Bogue Banks Profile Comparison Plot

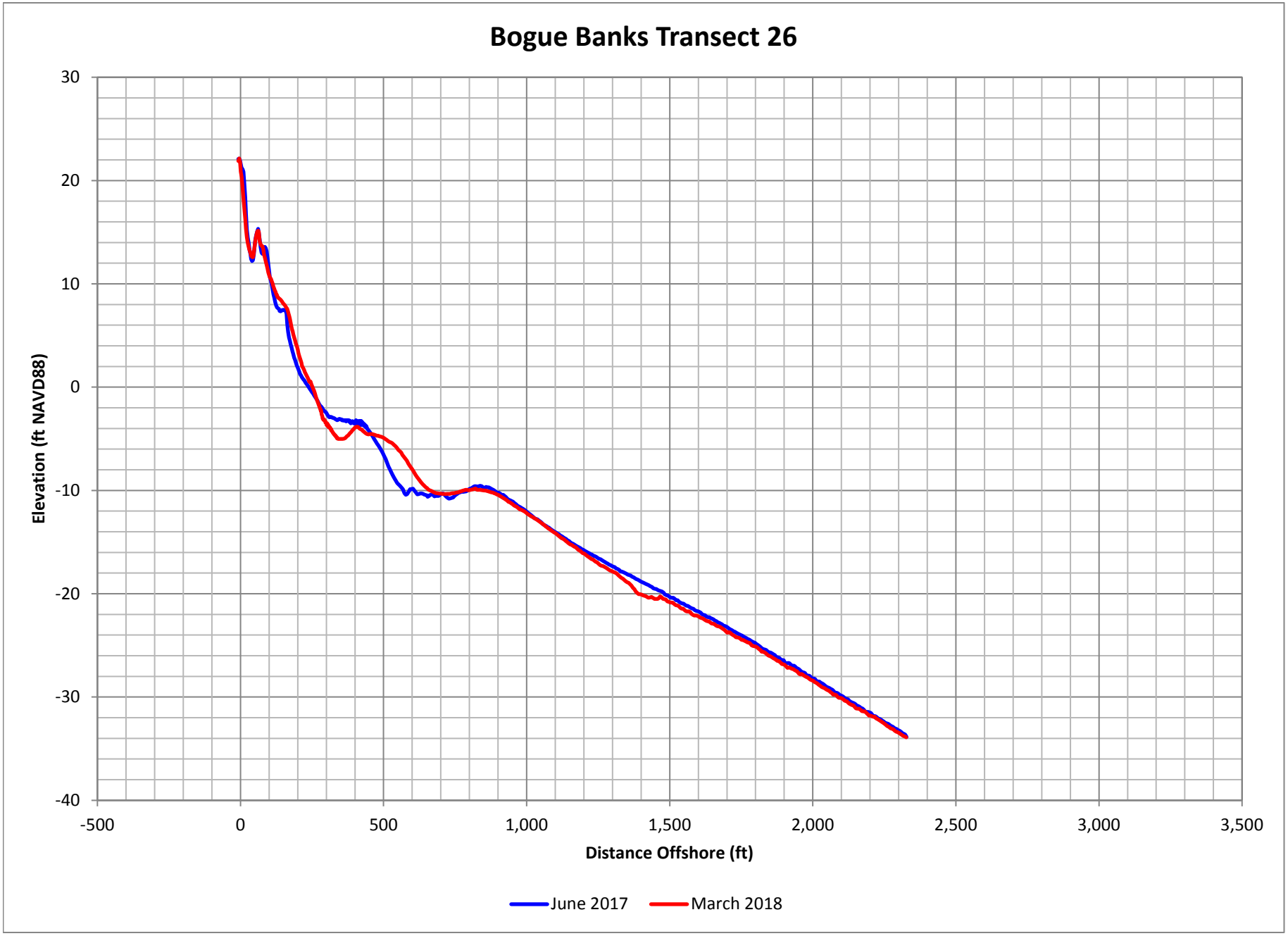


Figure D-51. Bogue Banks Profile Comparison Plot

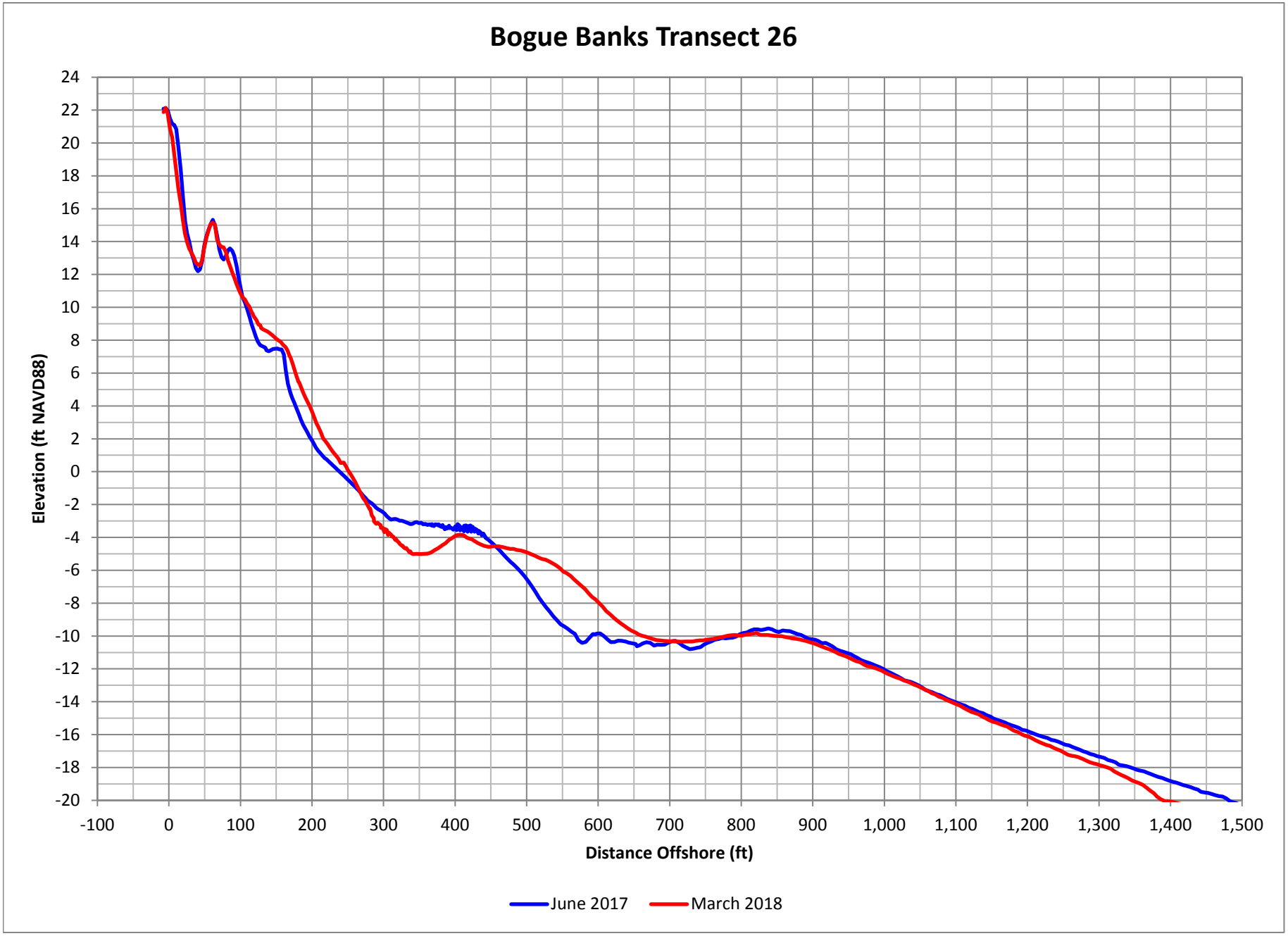


Figure D-52. Bogue Banks Profile Comparison Plot

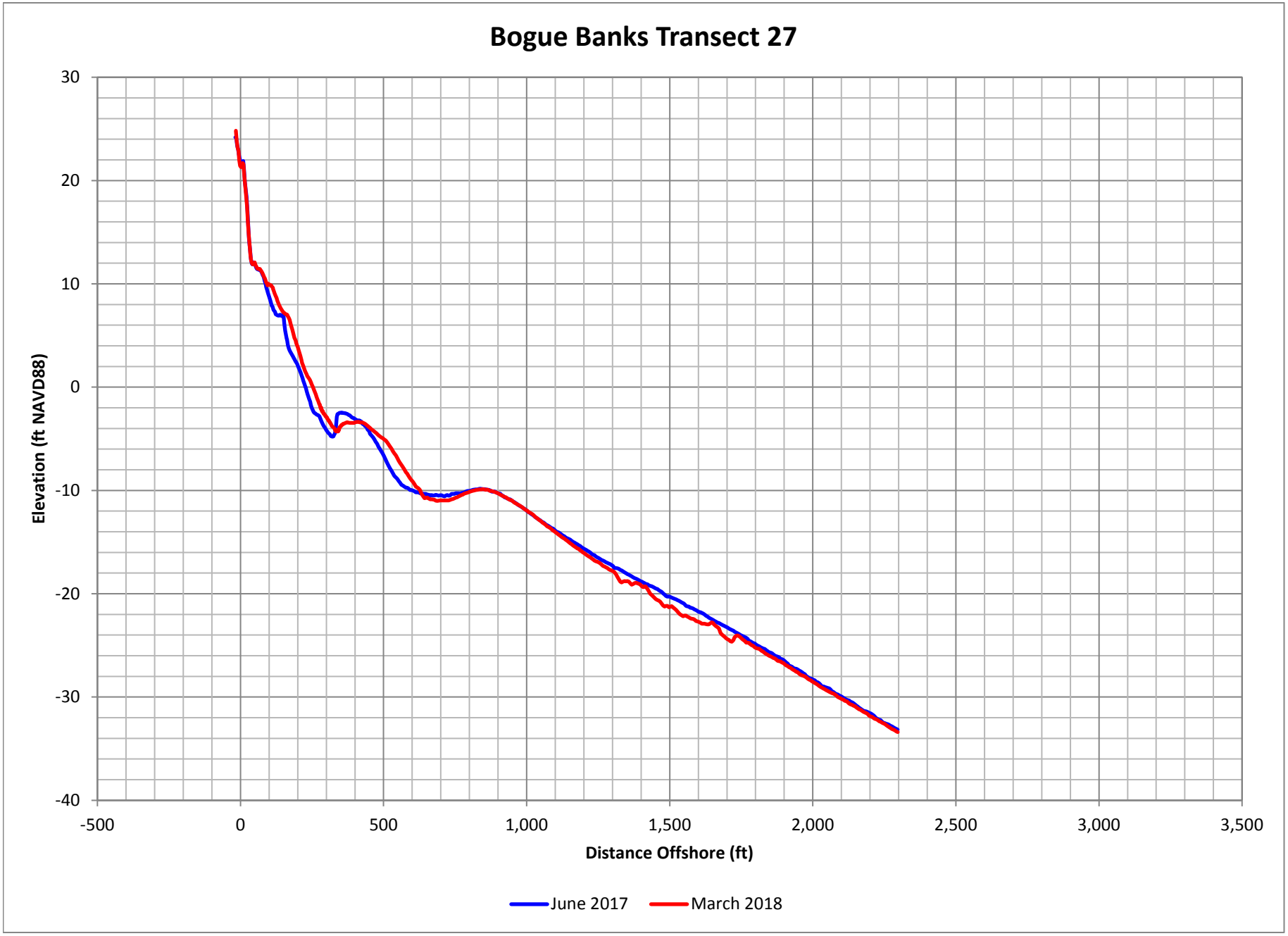


Figure D-53. Bogue Banks Profile Comparison Plot

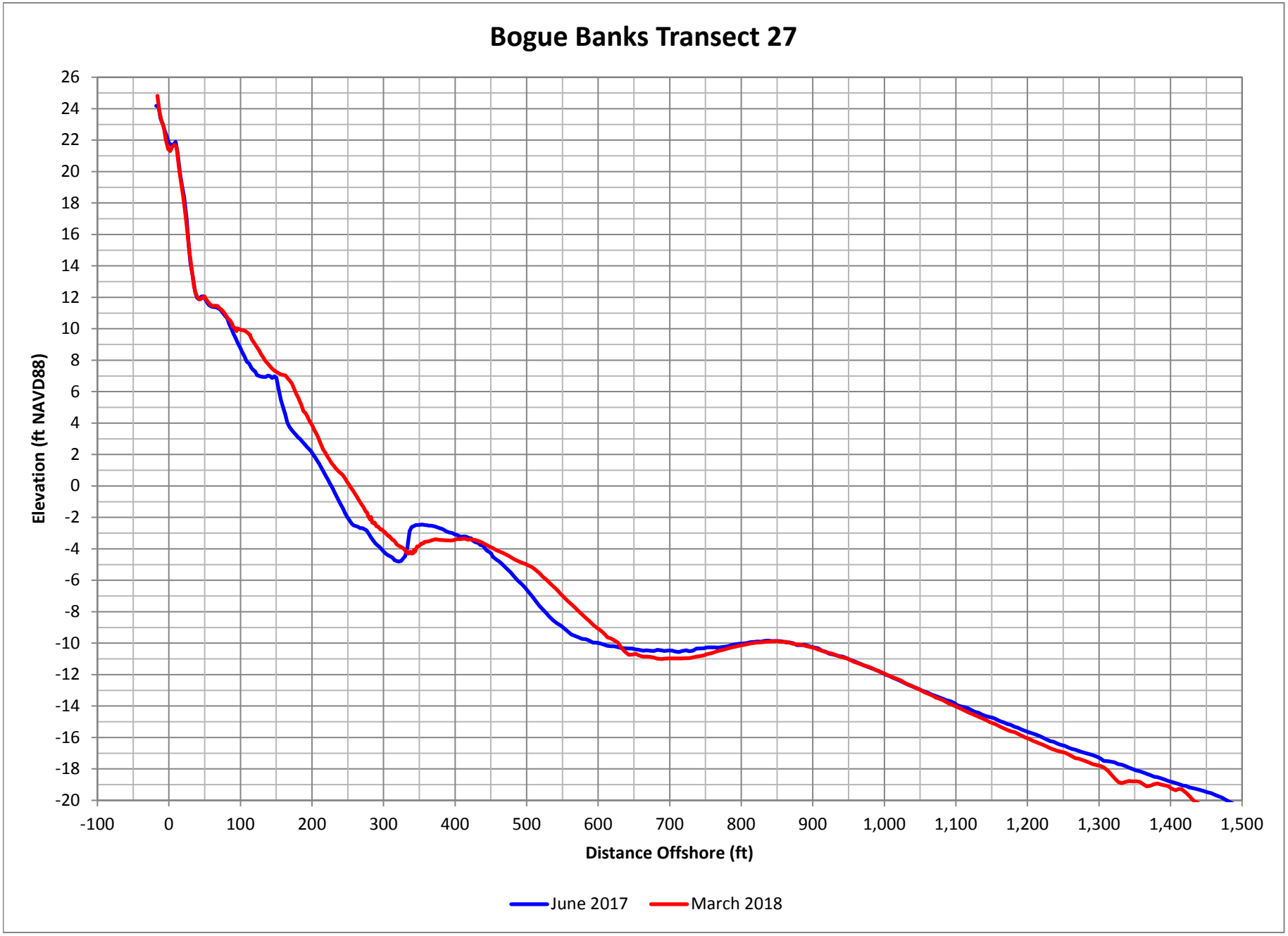


Figure D-54. Bogue Banks Profile Comparison Plot

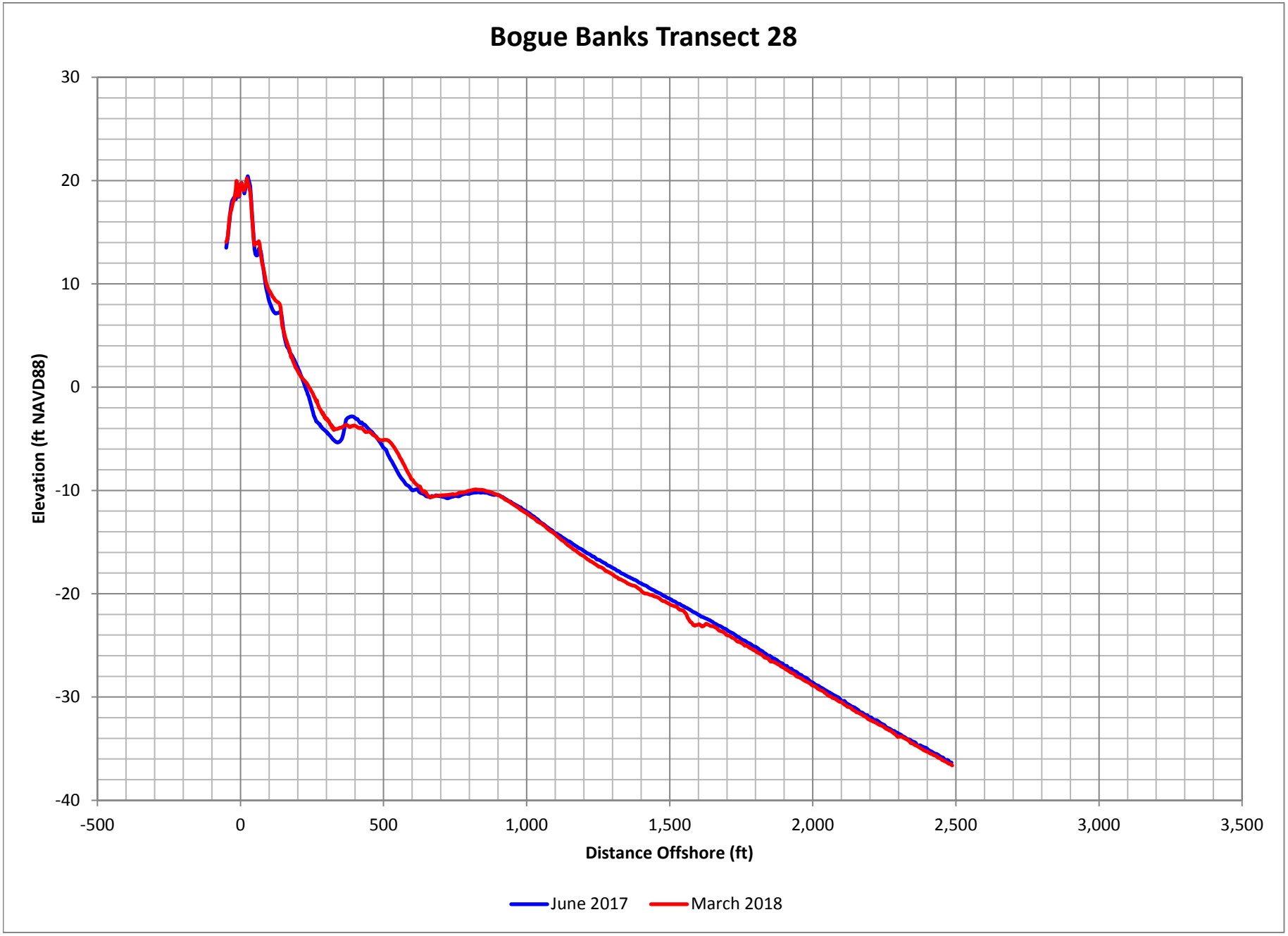


Figure D-55. Bogue Banks Profile Comparison Plot

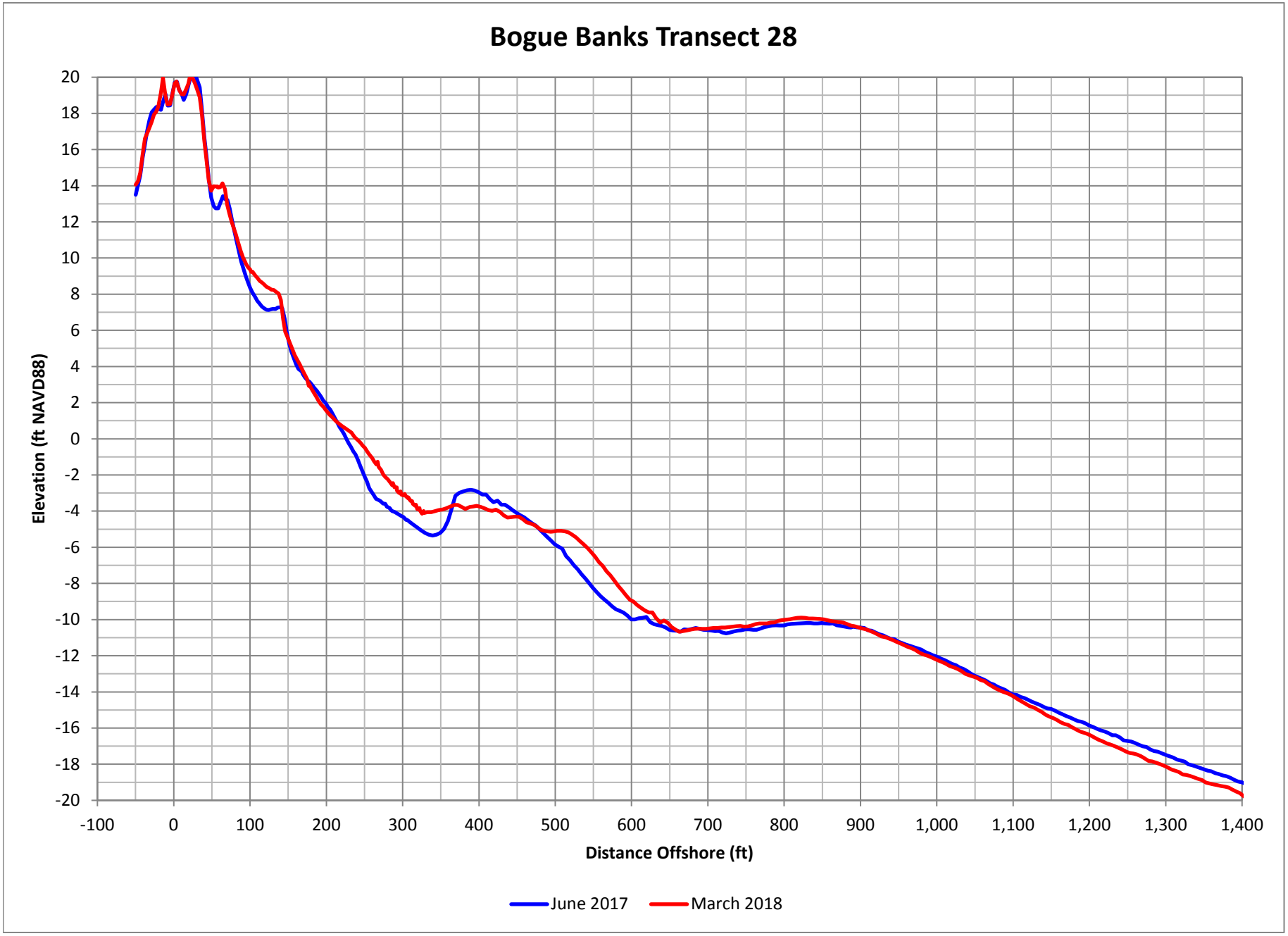


Figure D-56. Bogue Banks Profile Comparison Plot

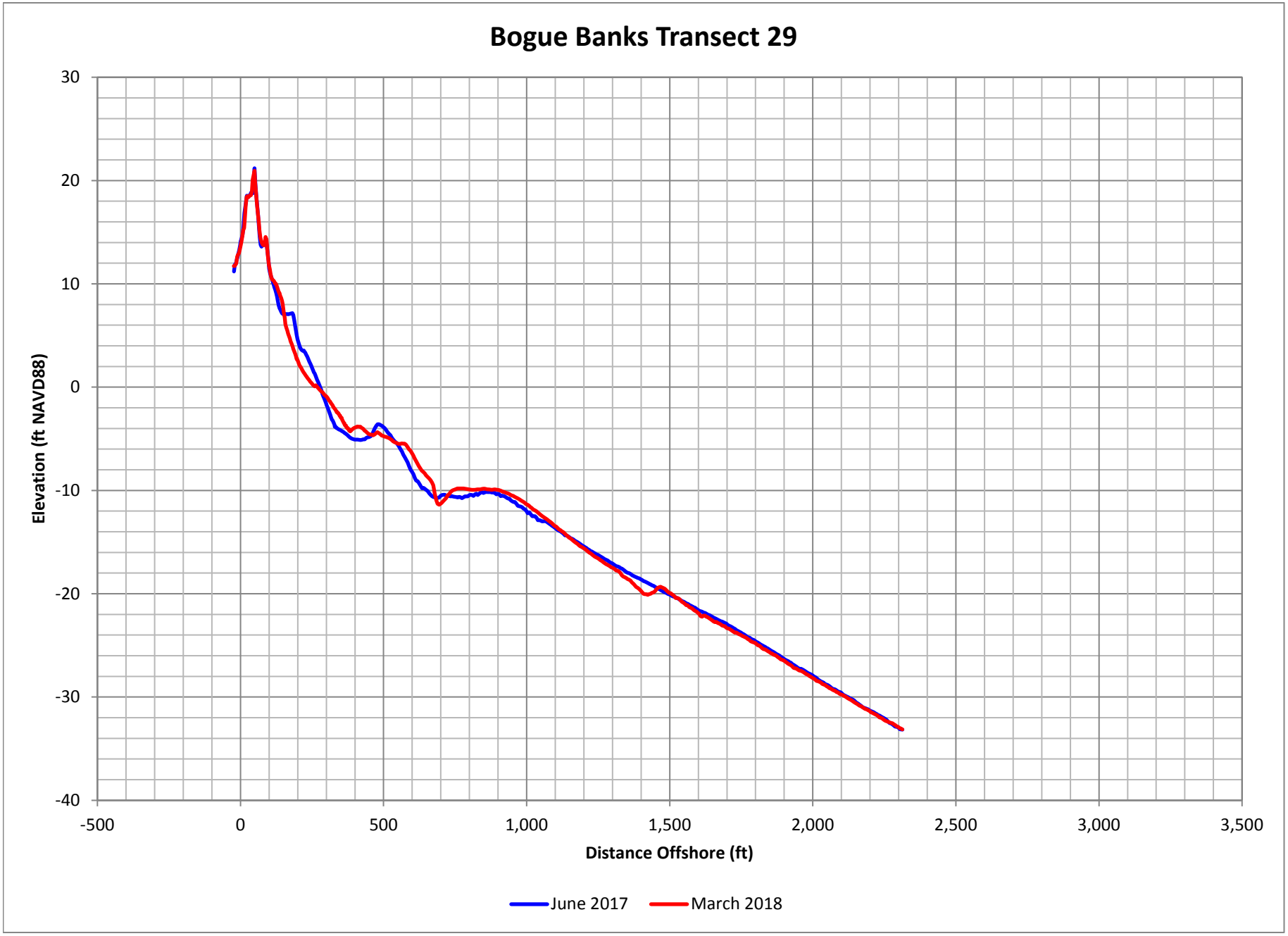


Figure D-57. Bogue Banks Profile Comparison Plot

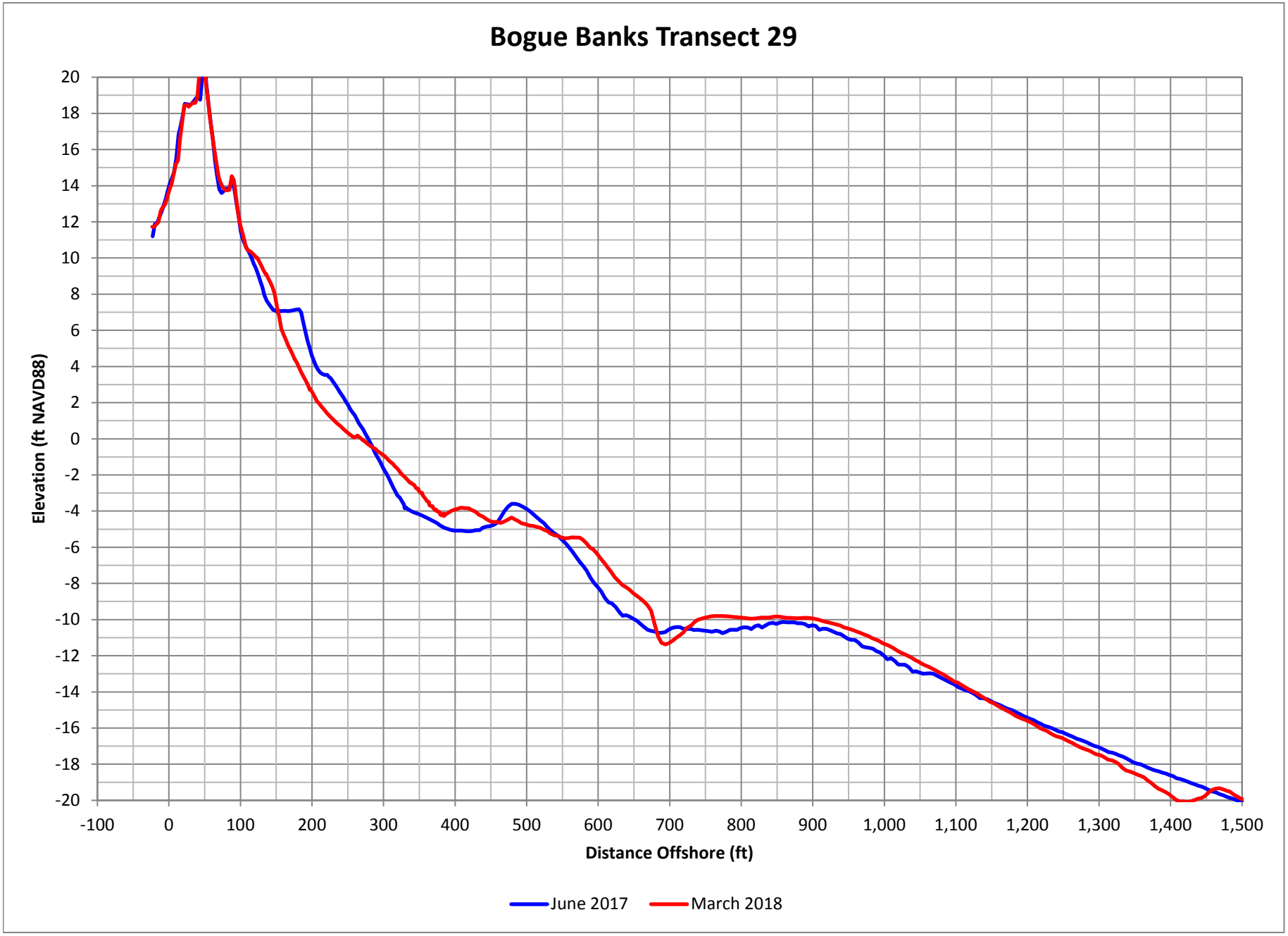


Figure D-58. Bogue Banks Profile Comparison Plot

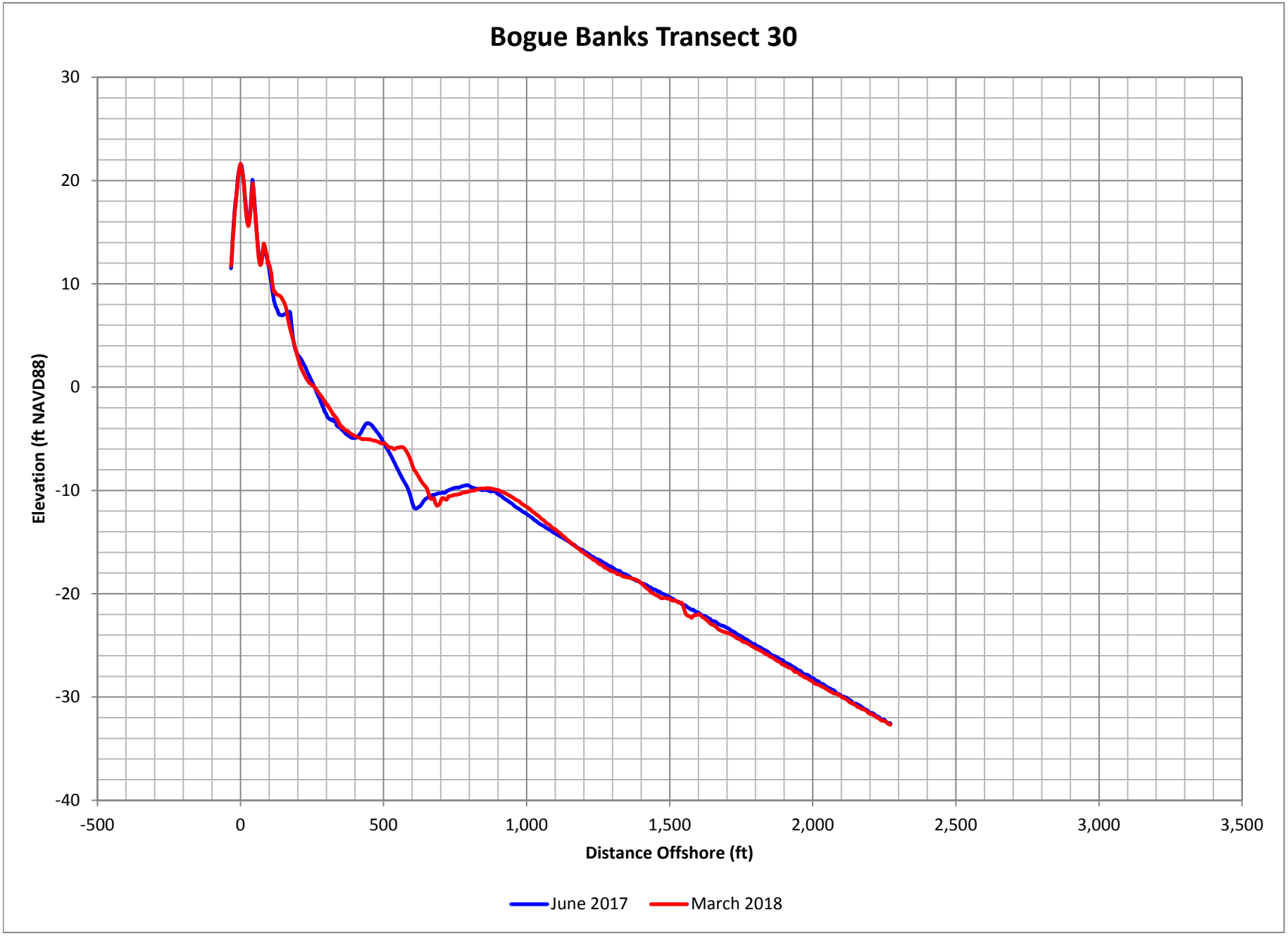


Figure D-59. Bogue Banks Profile Comparison Plot

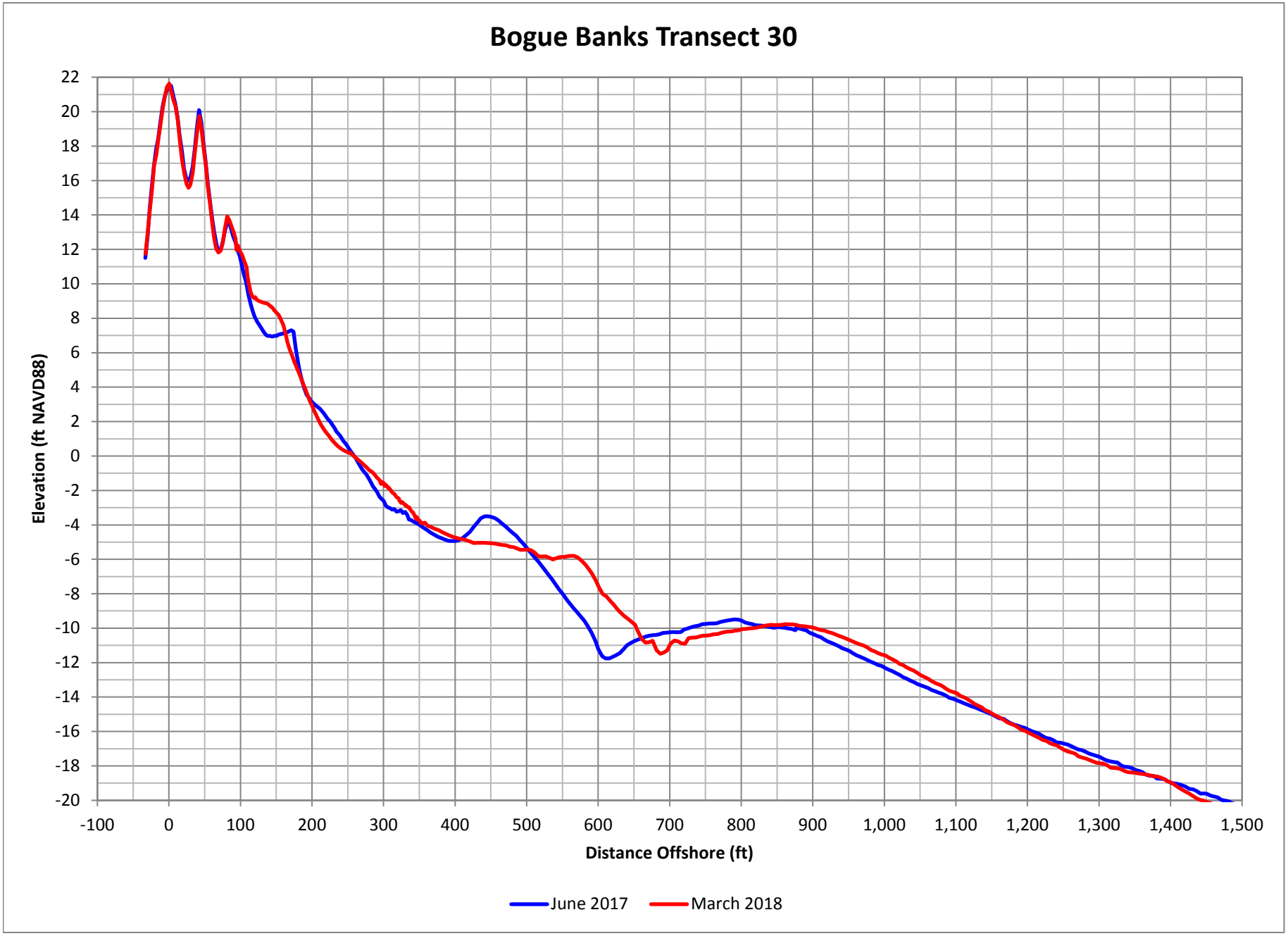


Figure D-60. Bogue Banks Profile Comparison Plot

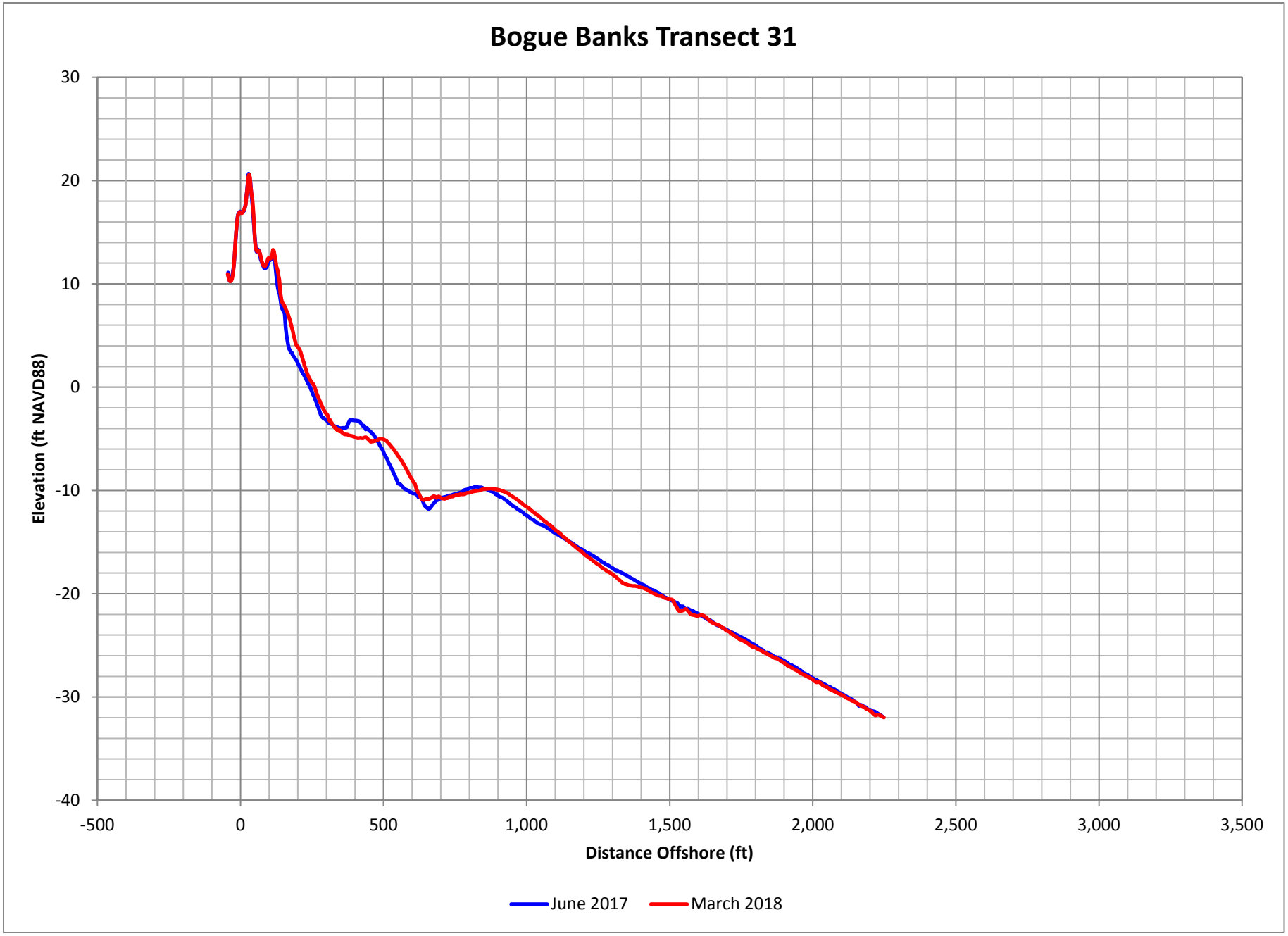


Figure D-61. Bogue Banks Profile Comparison Plot

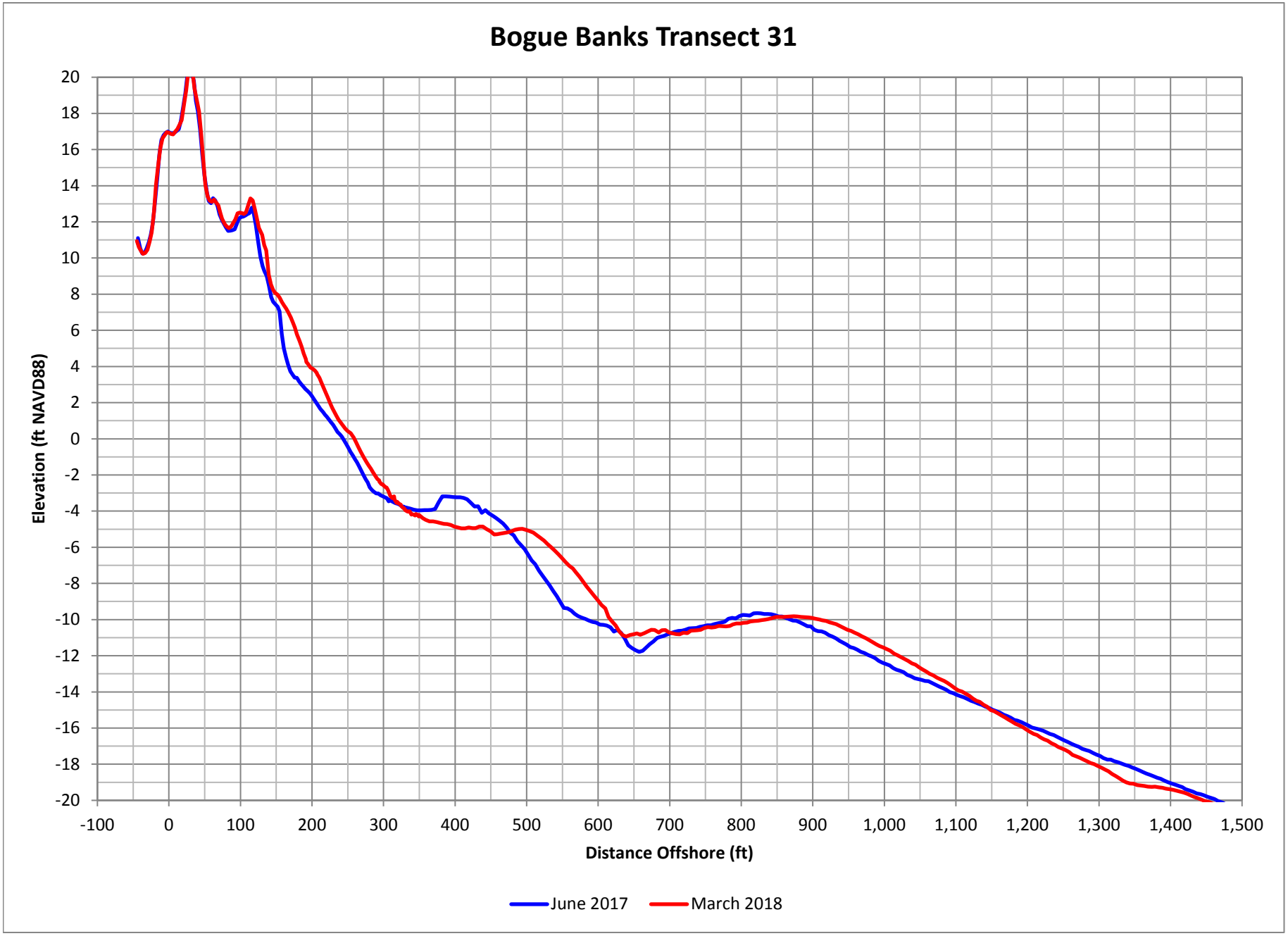


Figure D-62. Bogue Banks Profile Comparison Plot

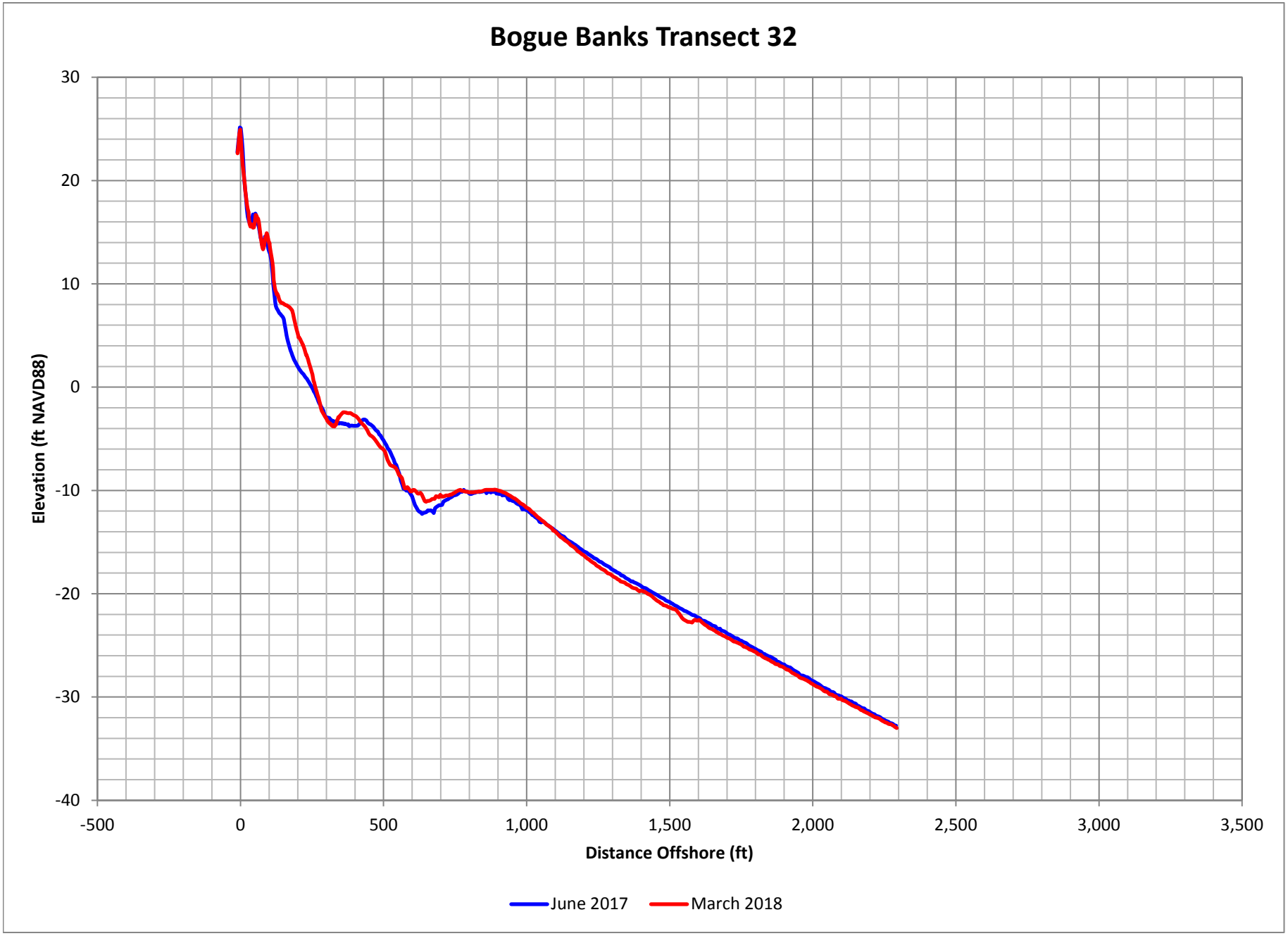


Figure D-63. Bogue Banks Profile Comparison Plot

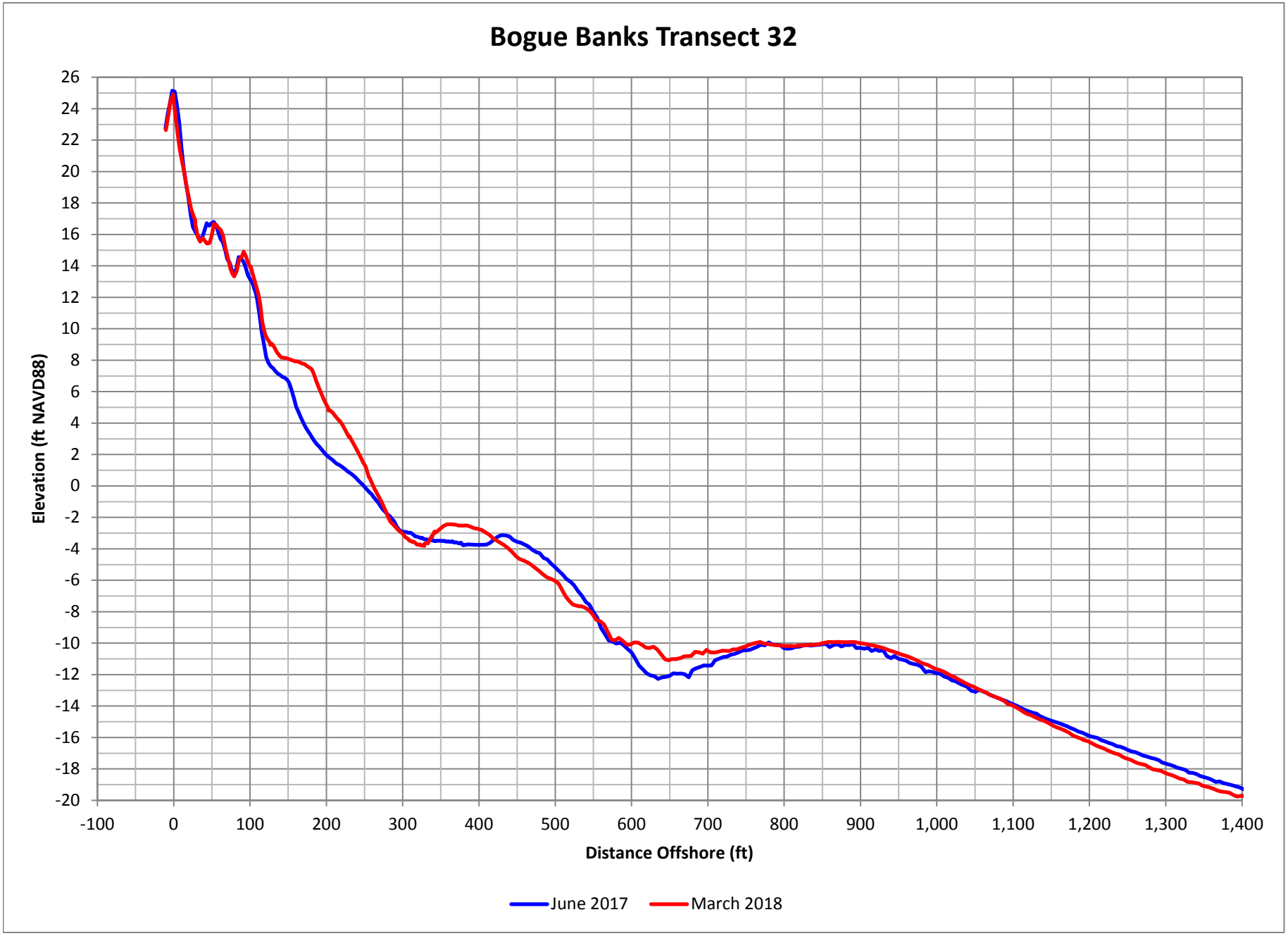
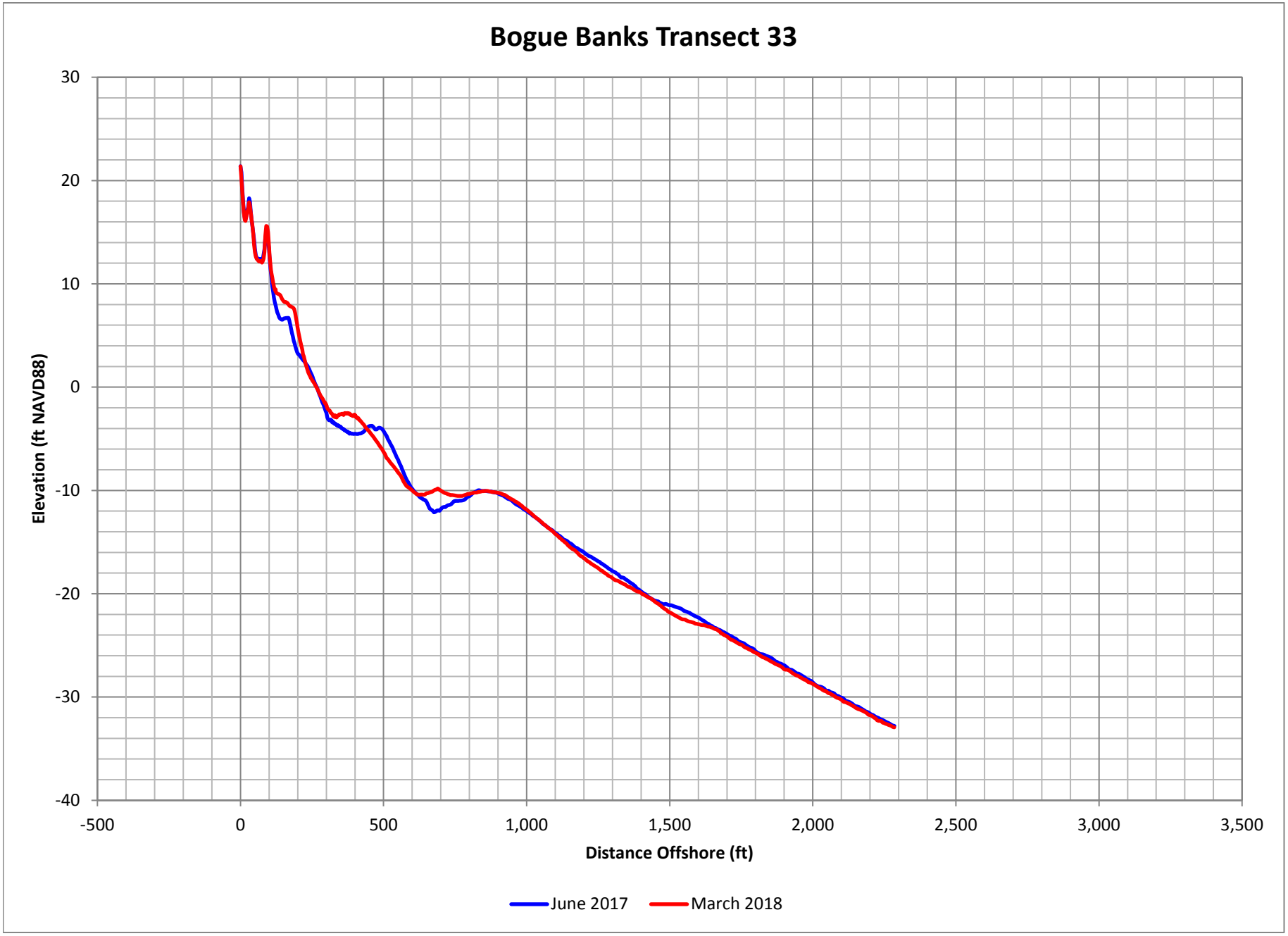


Figure D-64. Bogue Banks Profile Comparison Plot



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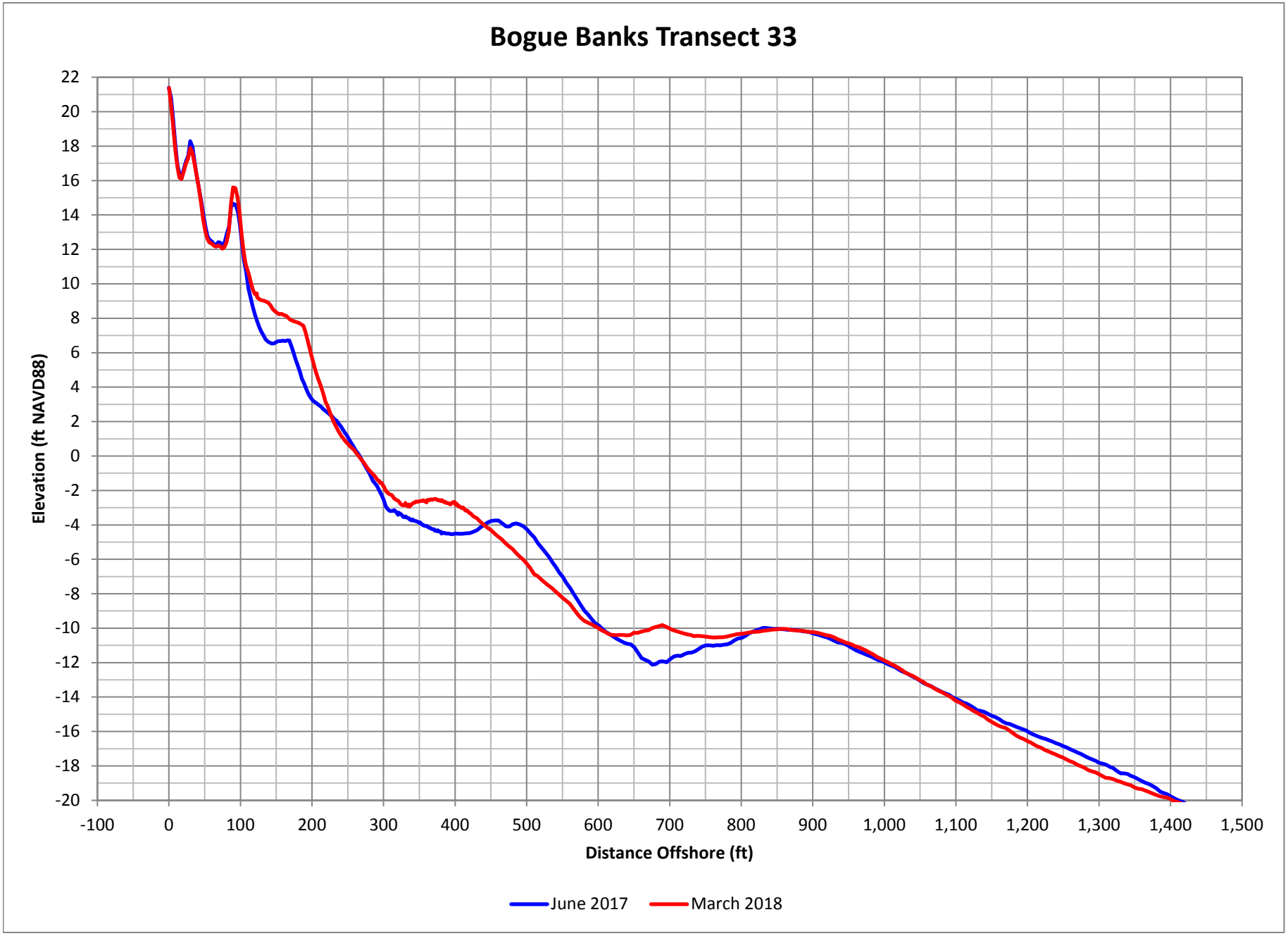
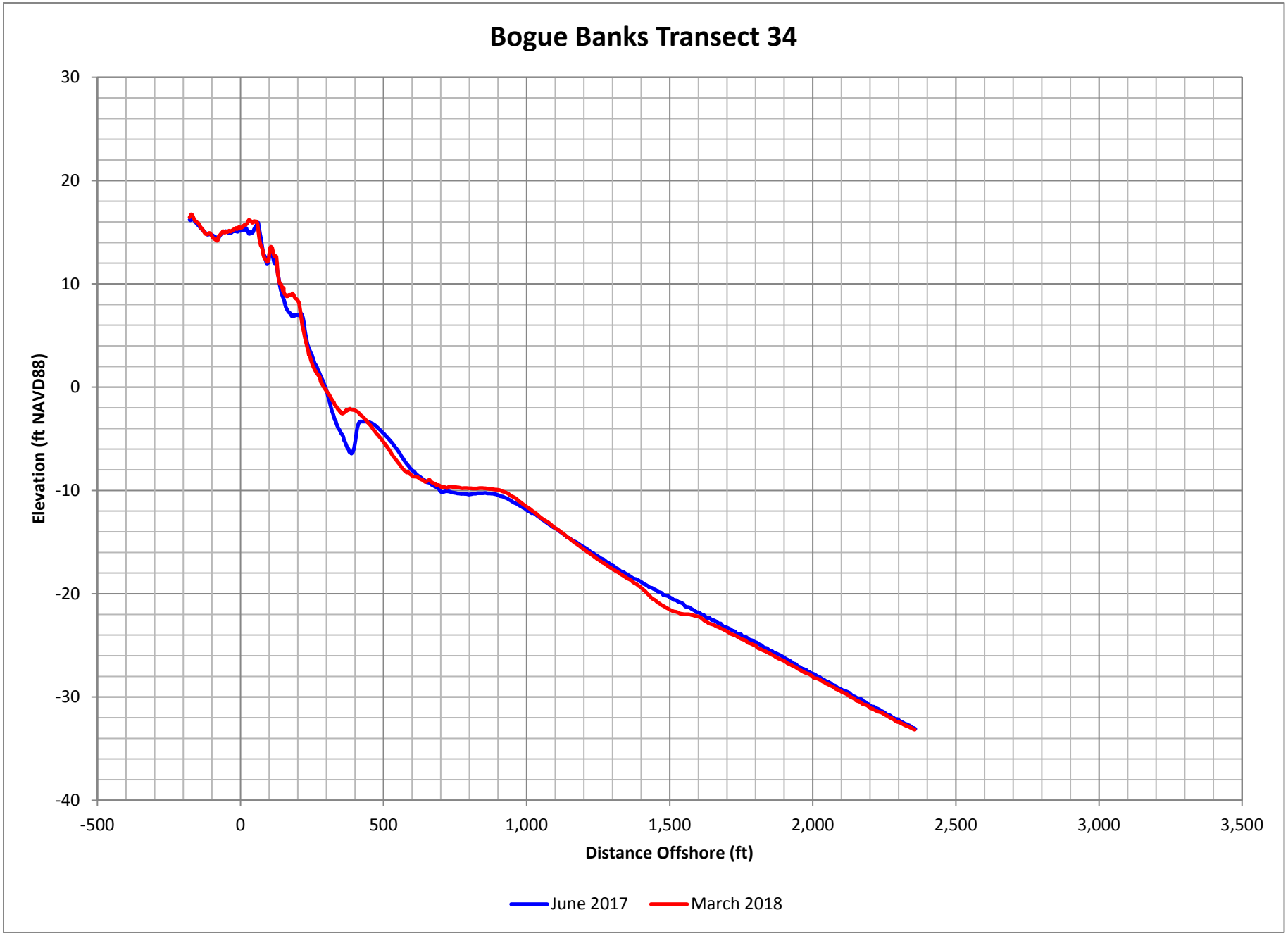


Figure D-66. Bogue Banks Profile Comparison Plot



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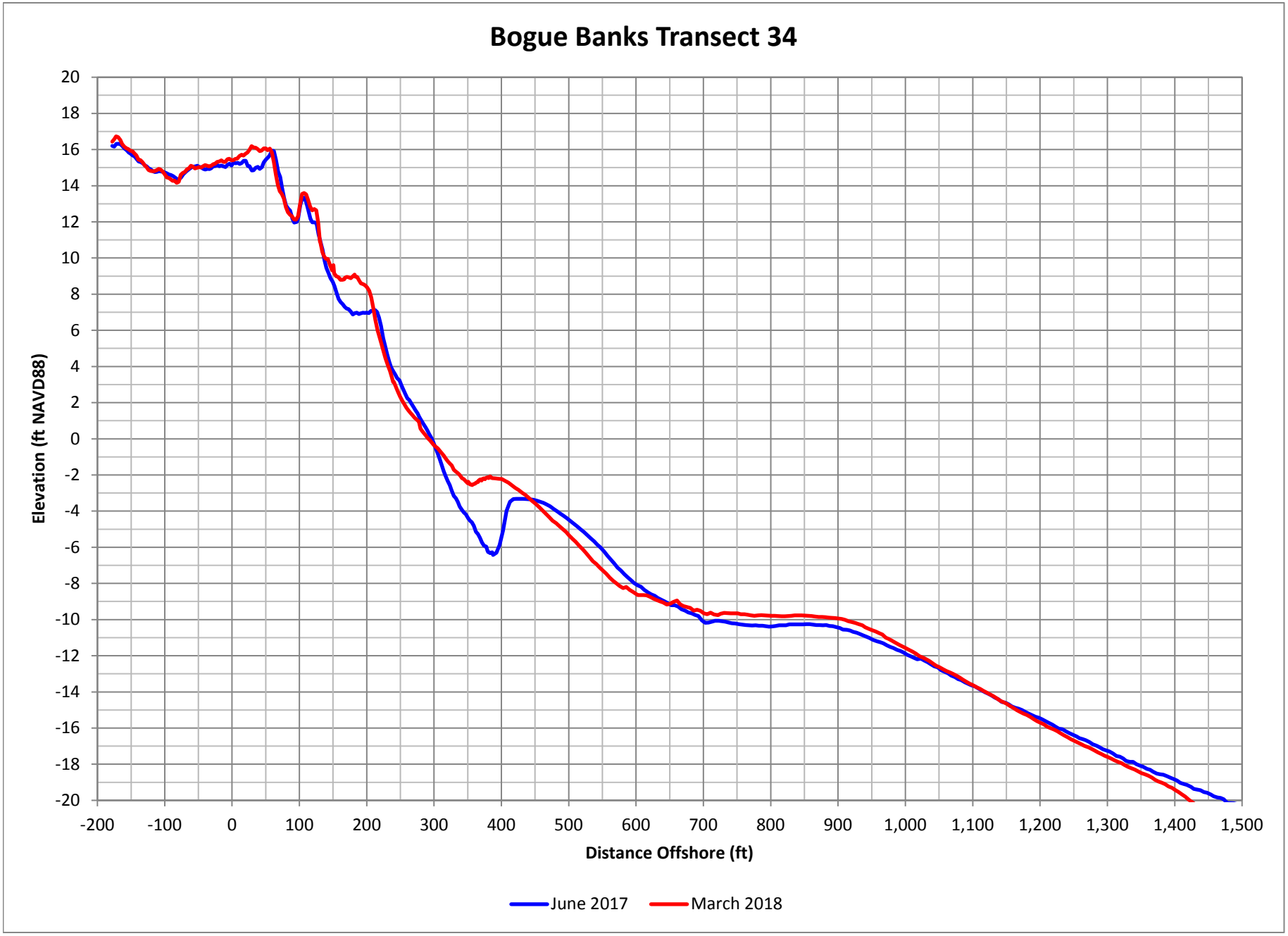
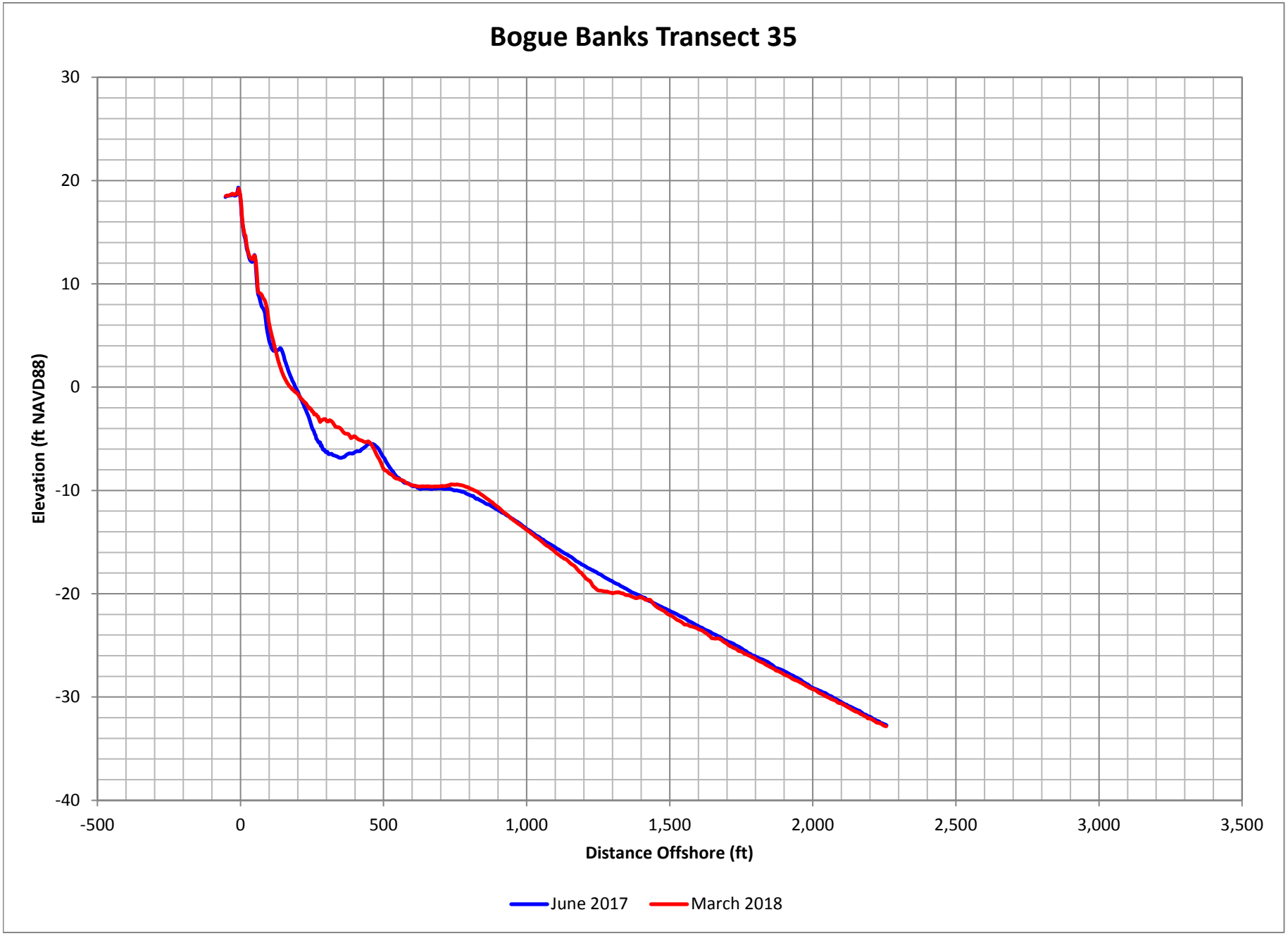


Figure D-68. Bogue Banks Profile Comparison Plot



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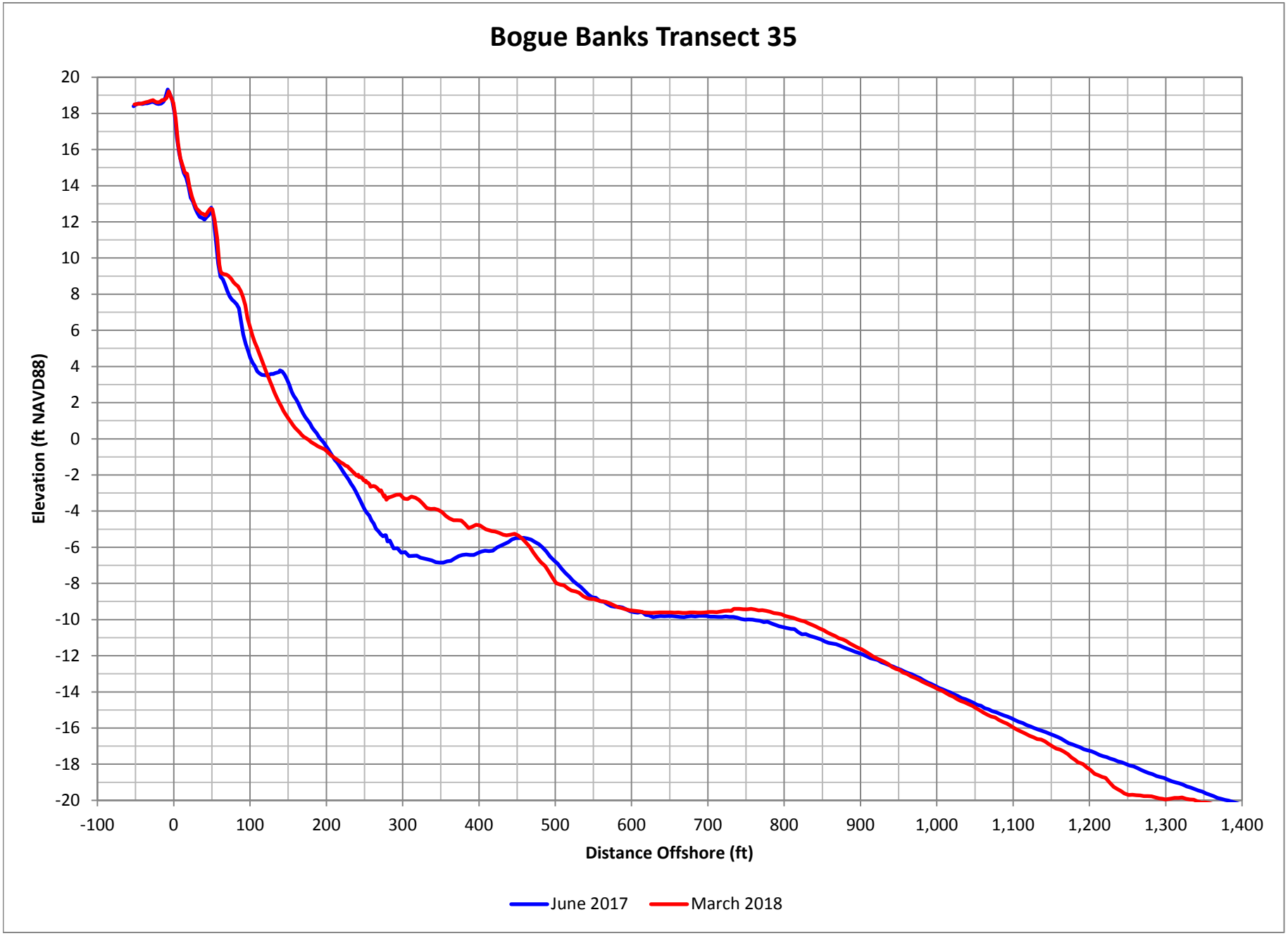


Figure D-70. Bogue Banks Profile Comparison Plot

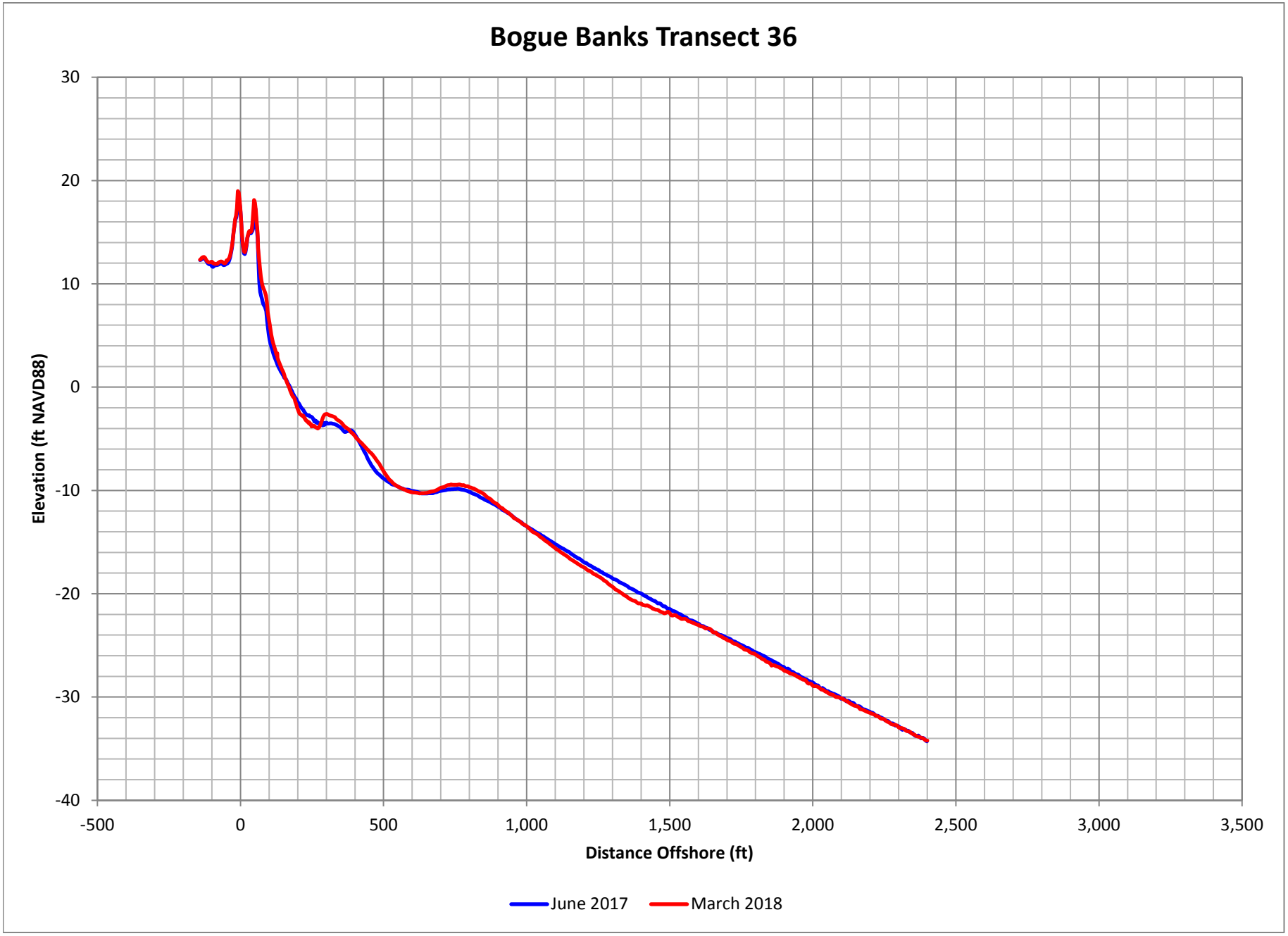
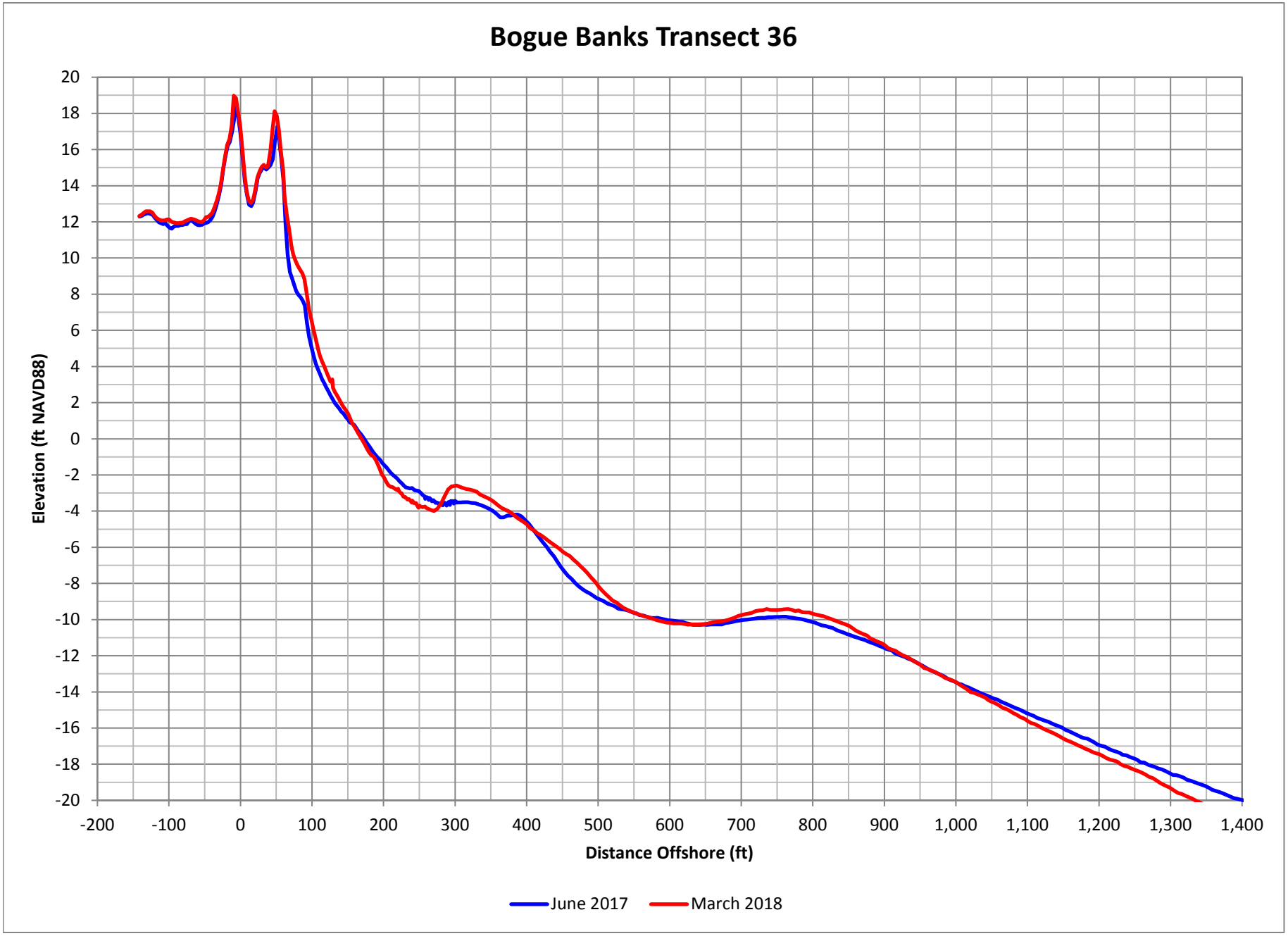


Figure D-71. Bogue Banks Profile Comparison Plot



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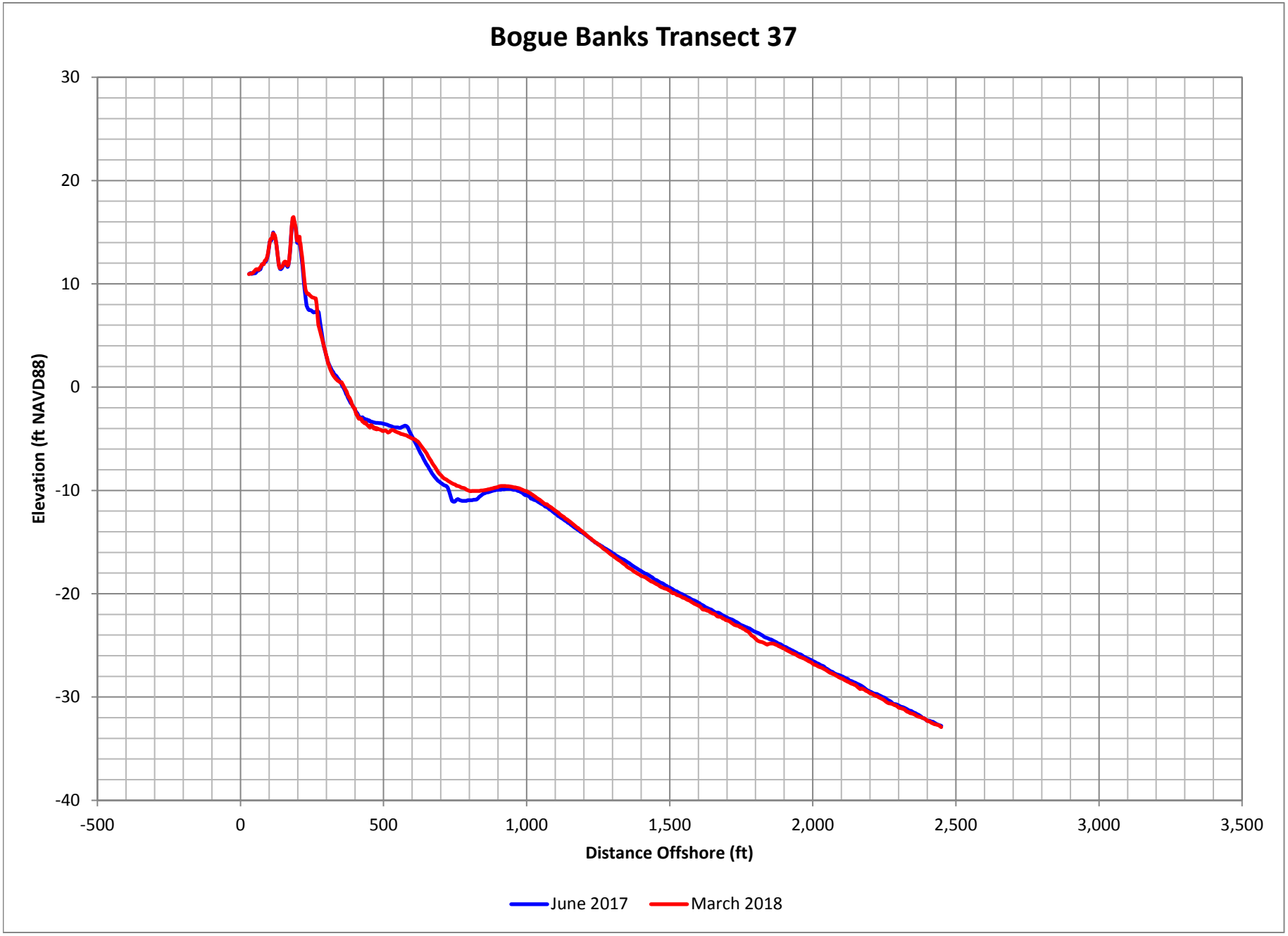


Figure D-73. Bogue Banks Profile Comparison Plot

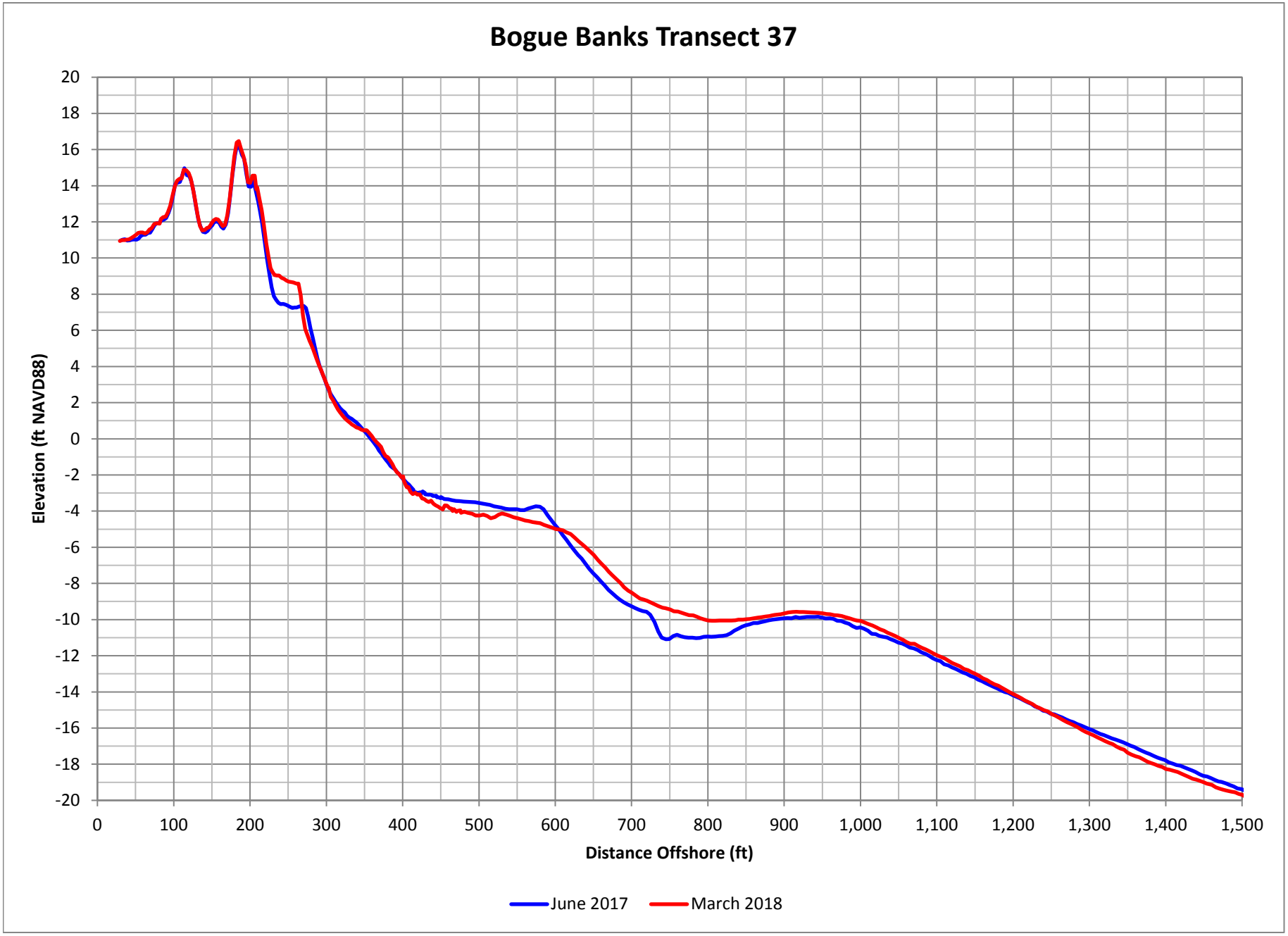


Figure D-74. Bogue Banks Profile Comparison Plot

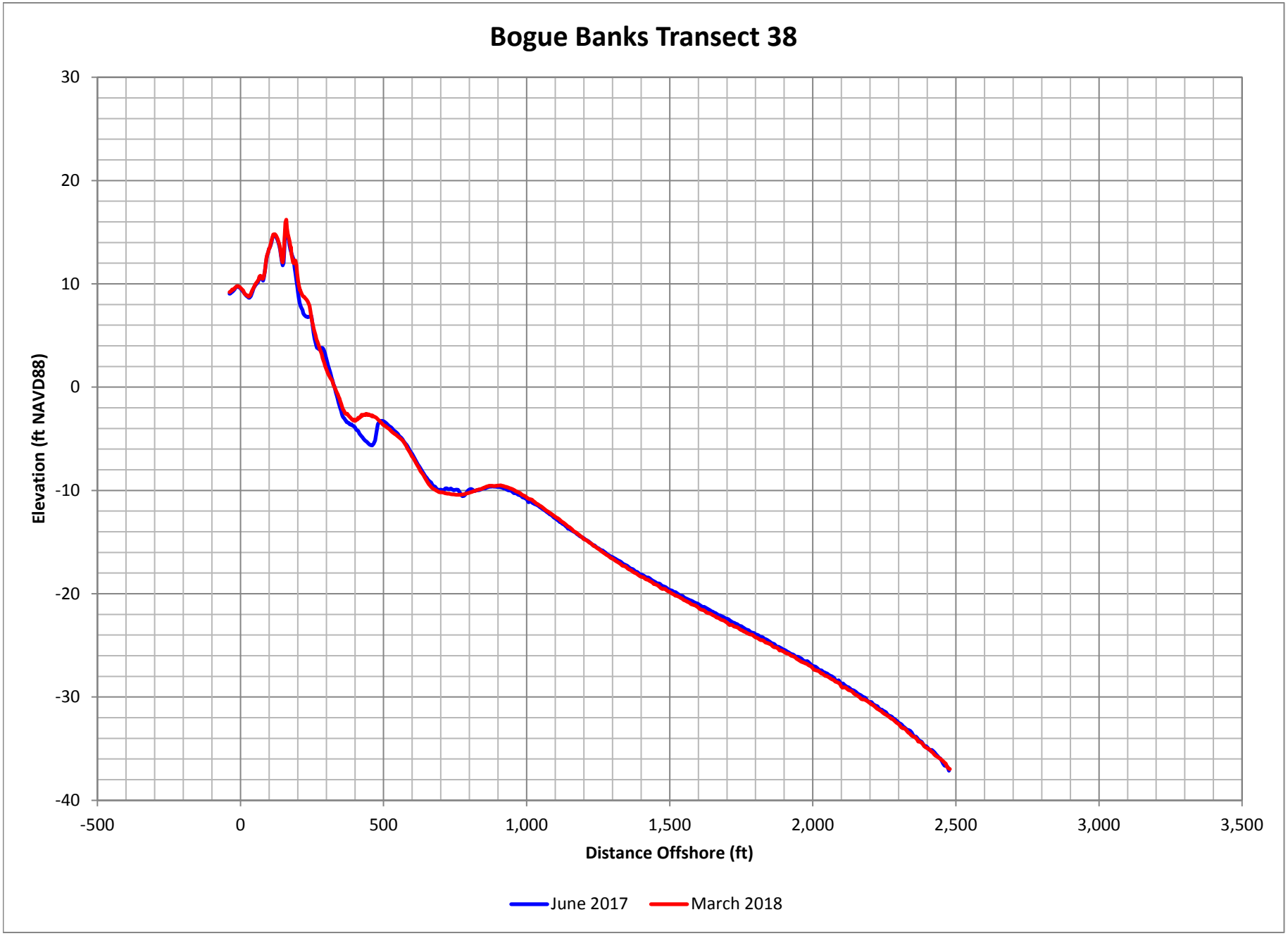
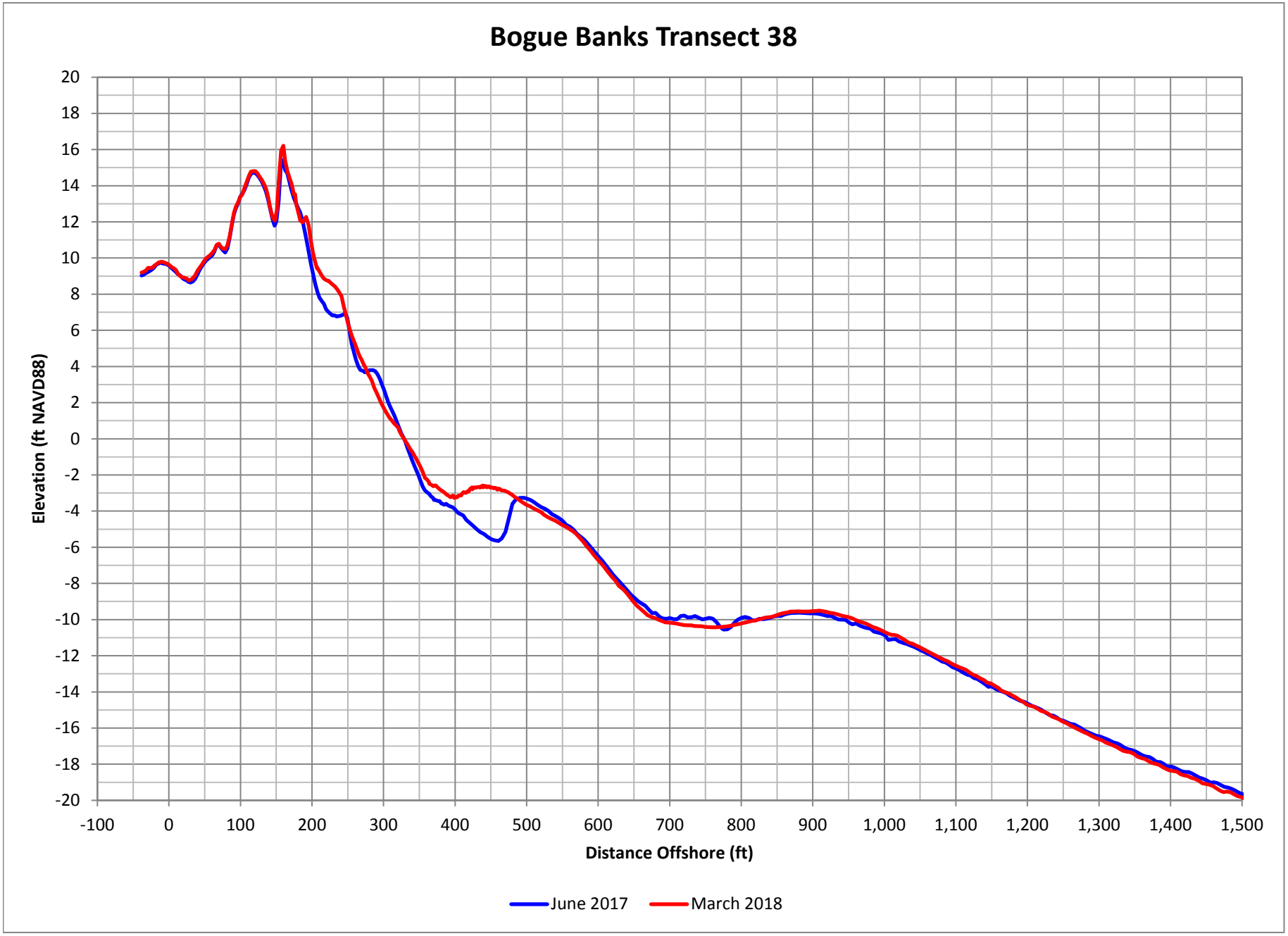


Figure D-75. Bogue Banks Profile Comparison Plot



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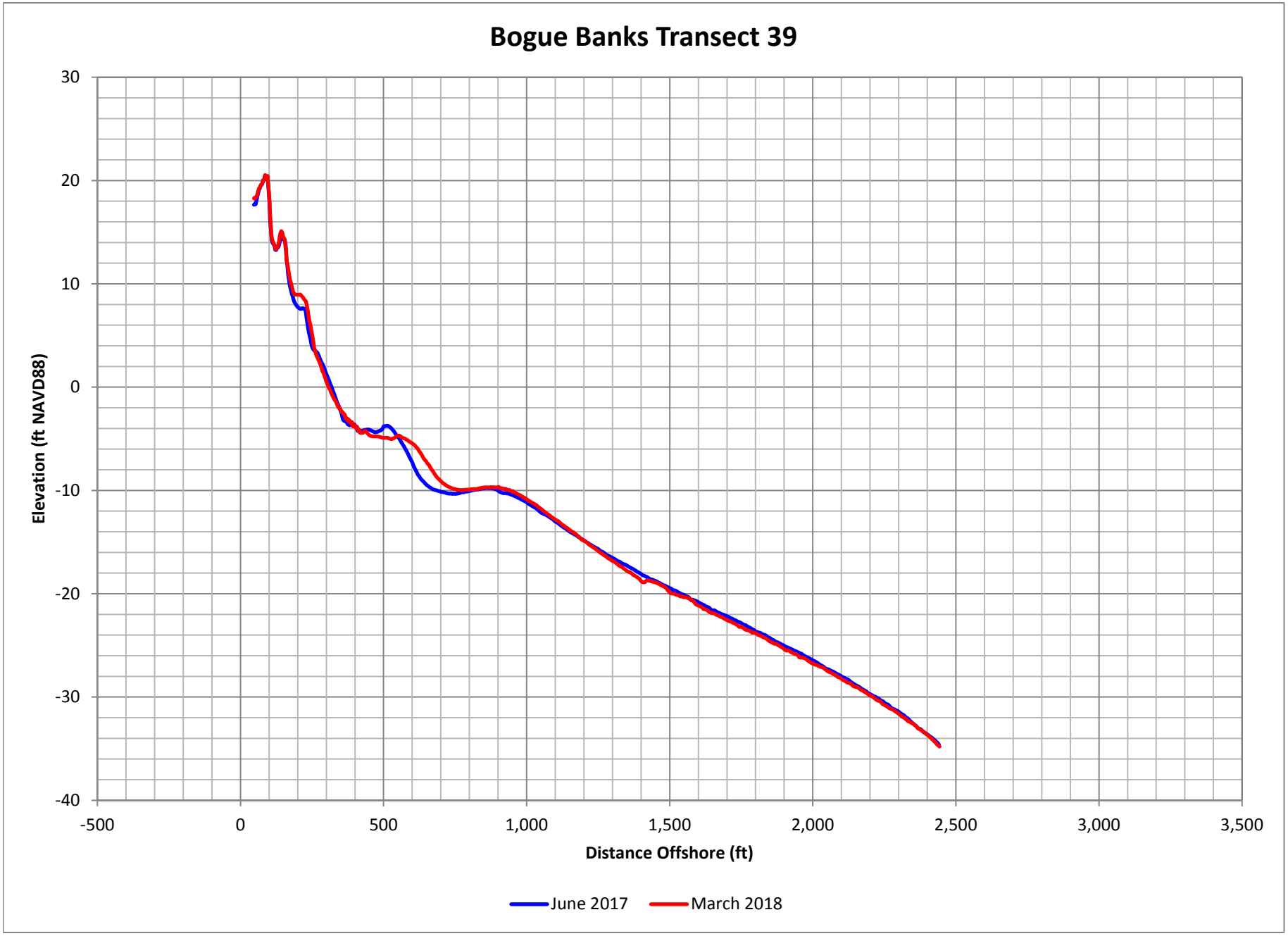


Figure D-77. Bogue Banks Profile Comparison Plot

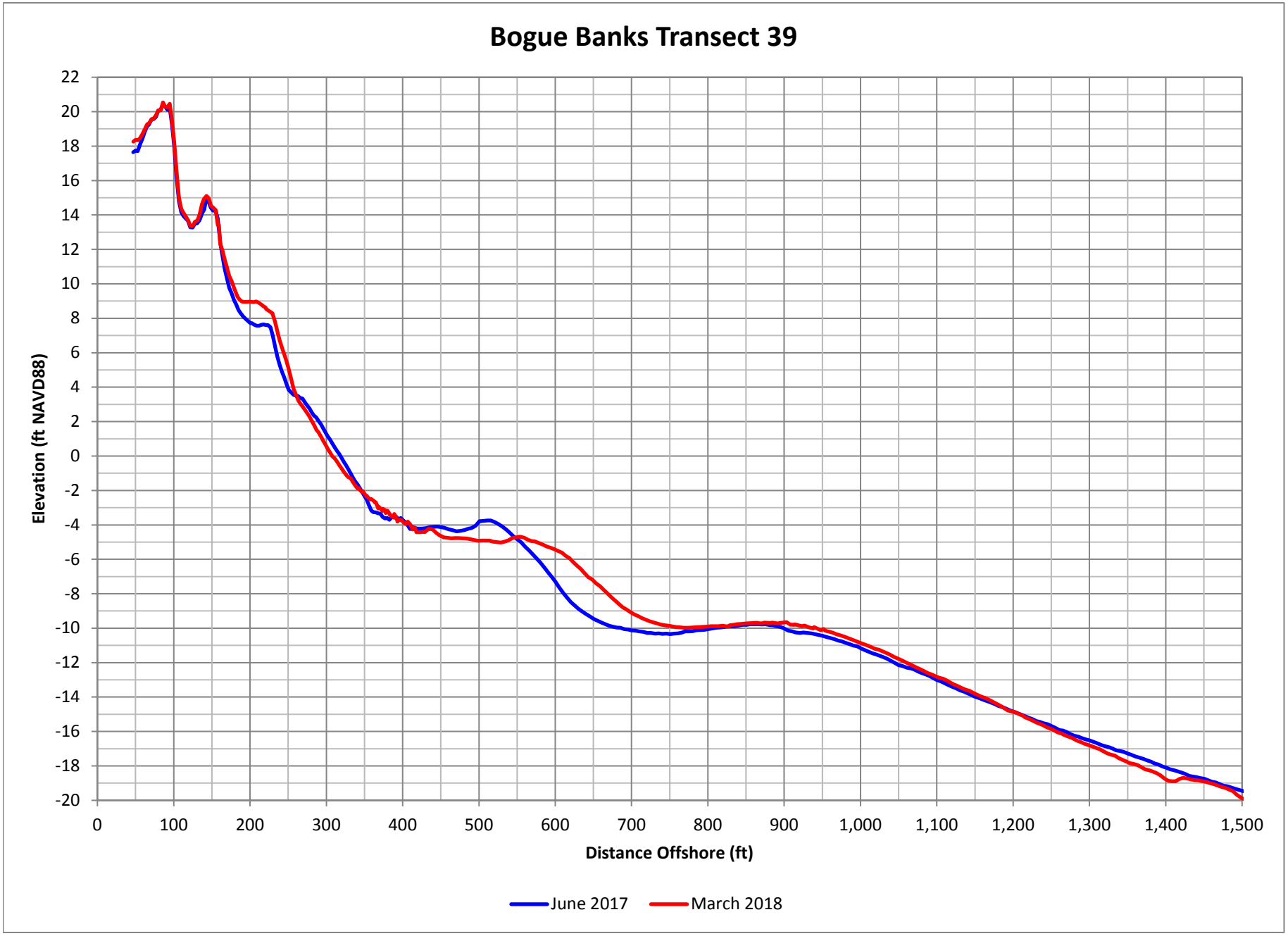


Figure D-78. Bogue Banks Profile Comparison Plot

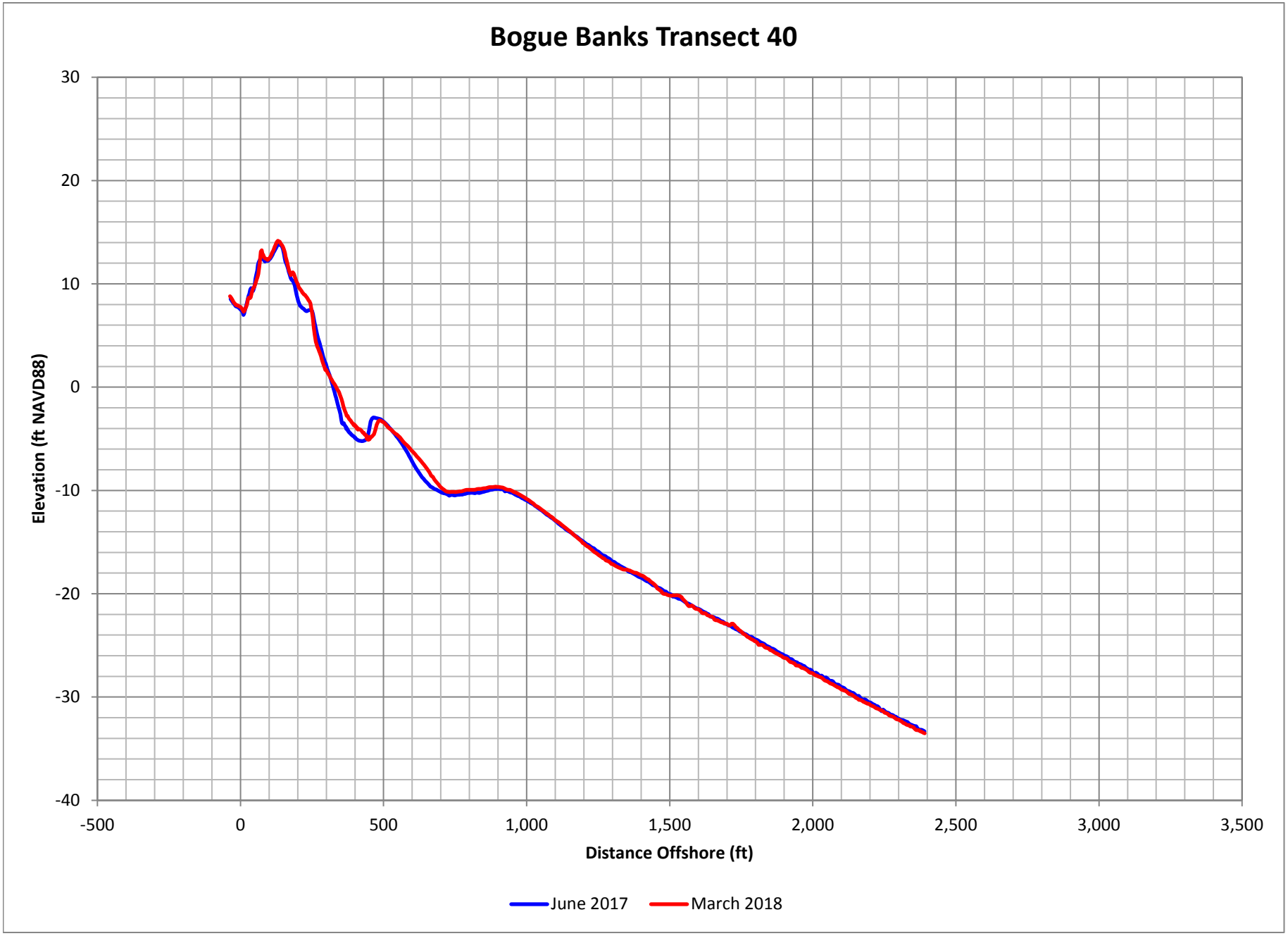


Figure D-79. Bogue Banks Profile Comparison Plot

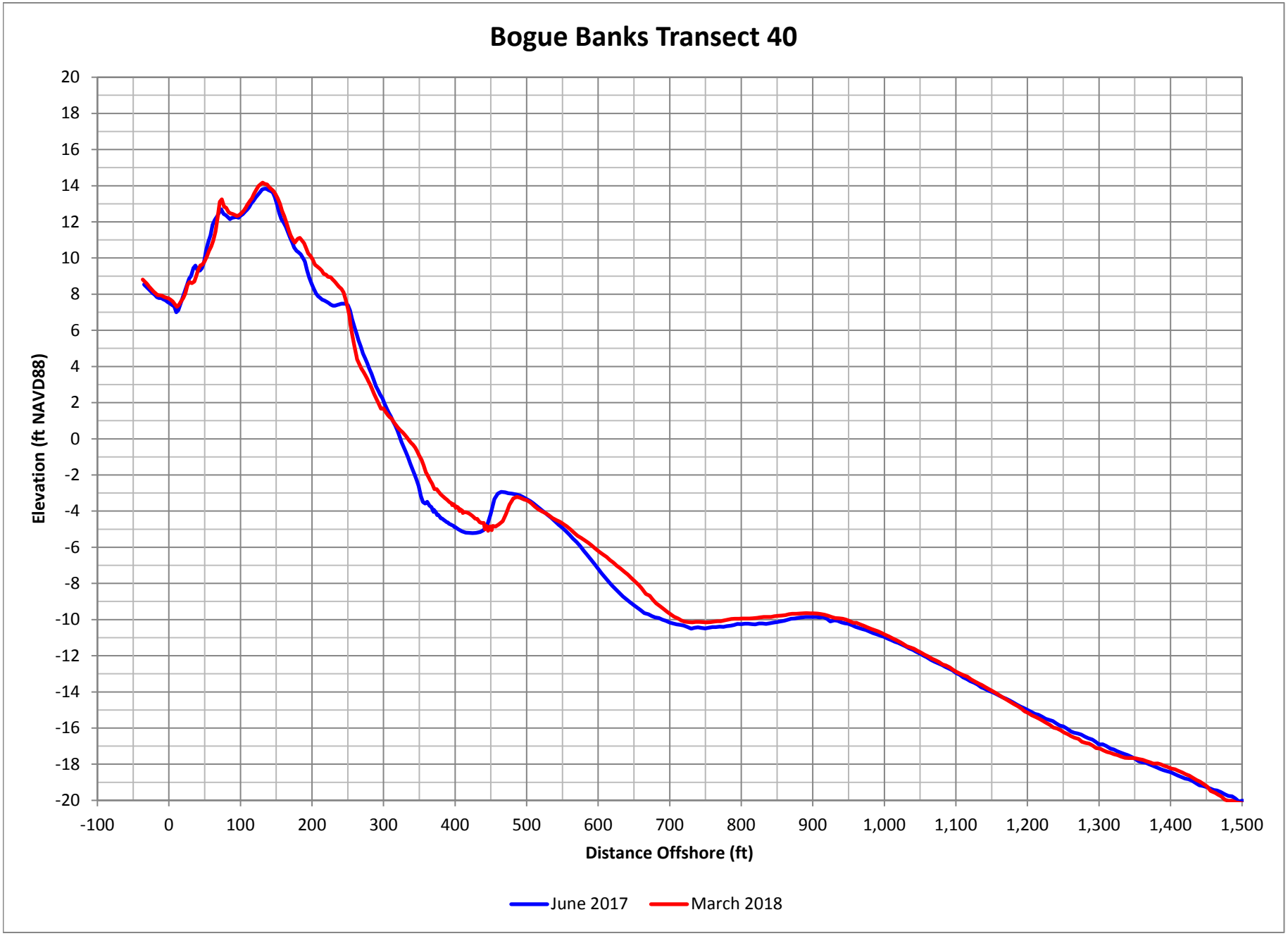
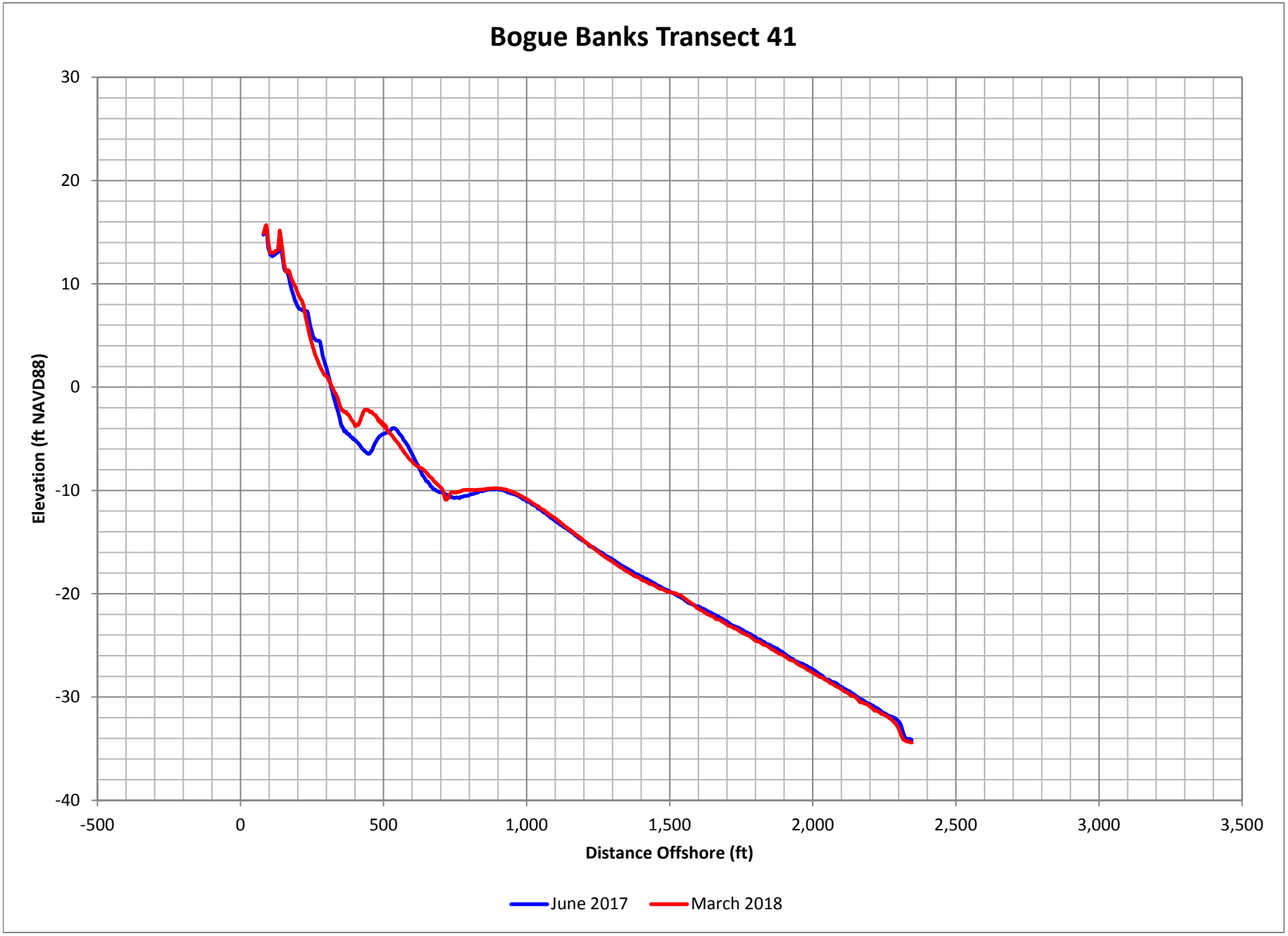


Figure D-80. Bogue Banks Profile Comparison Plot



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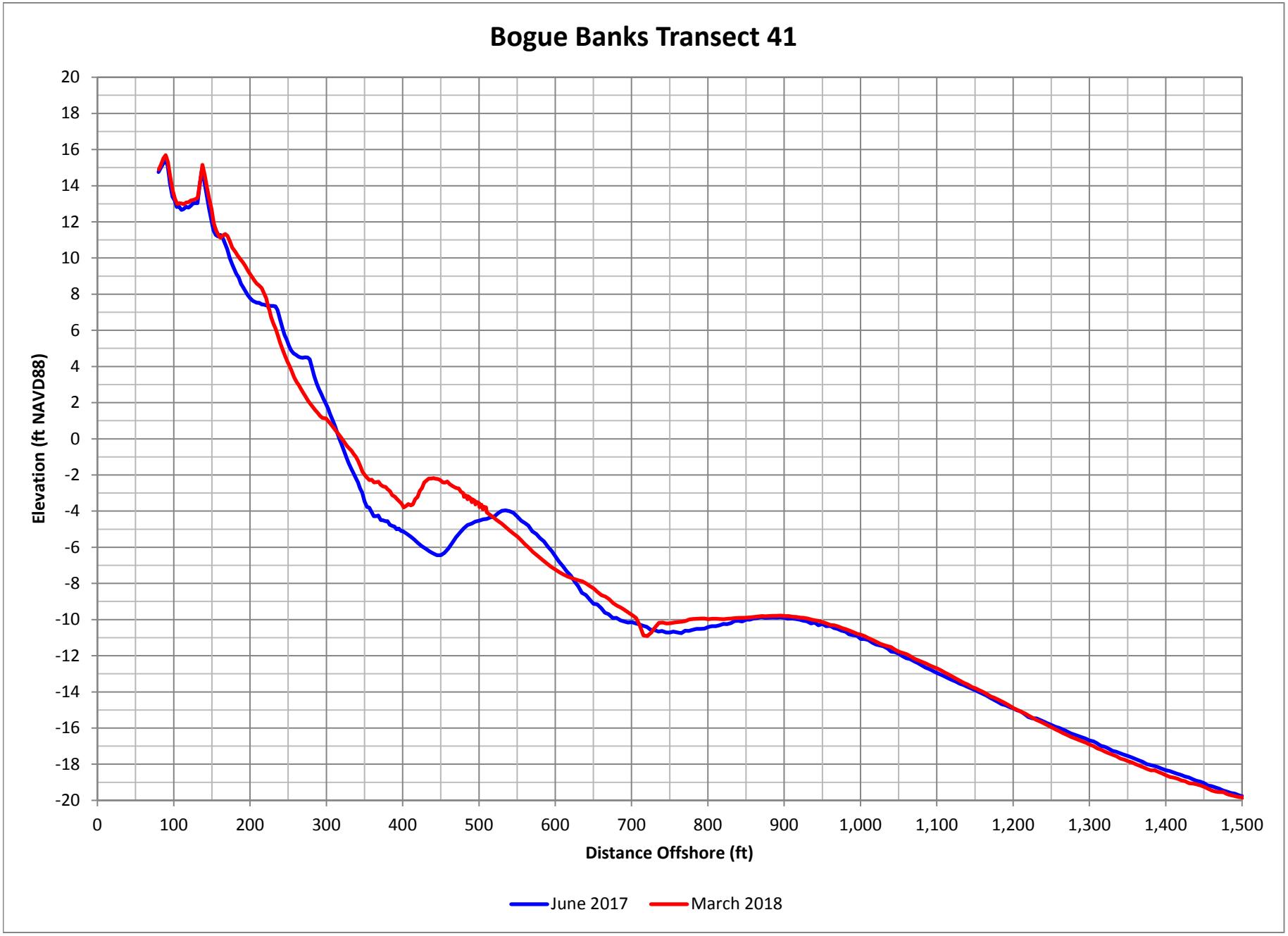


Figure D-82. Bogue Banks Profile Comparison Plot

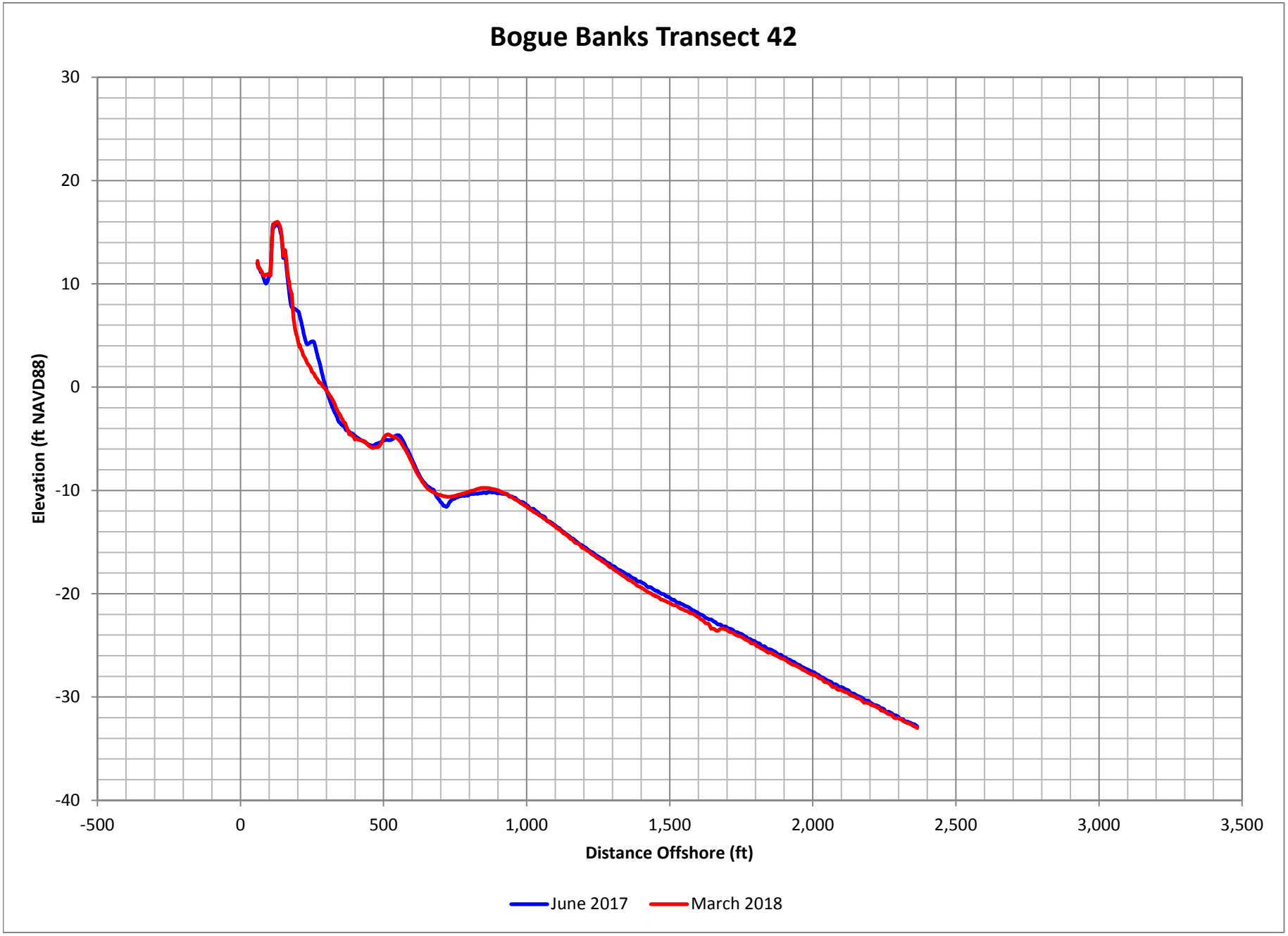


Figure D-83. Bogue Banks Profile Comparison Plot

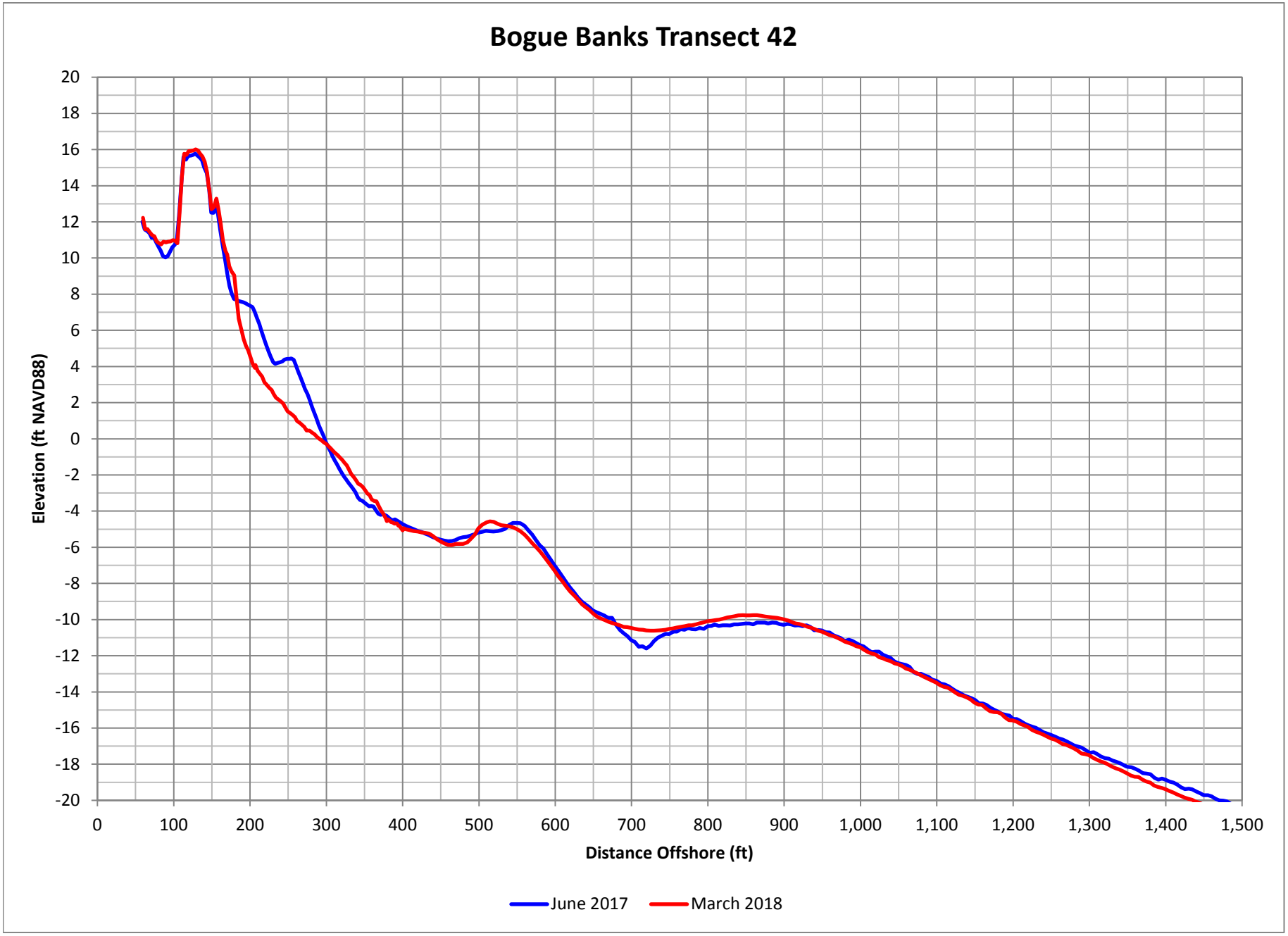
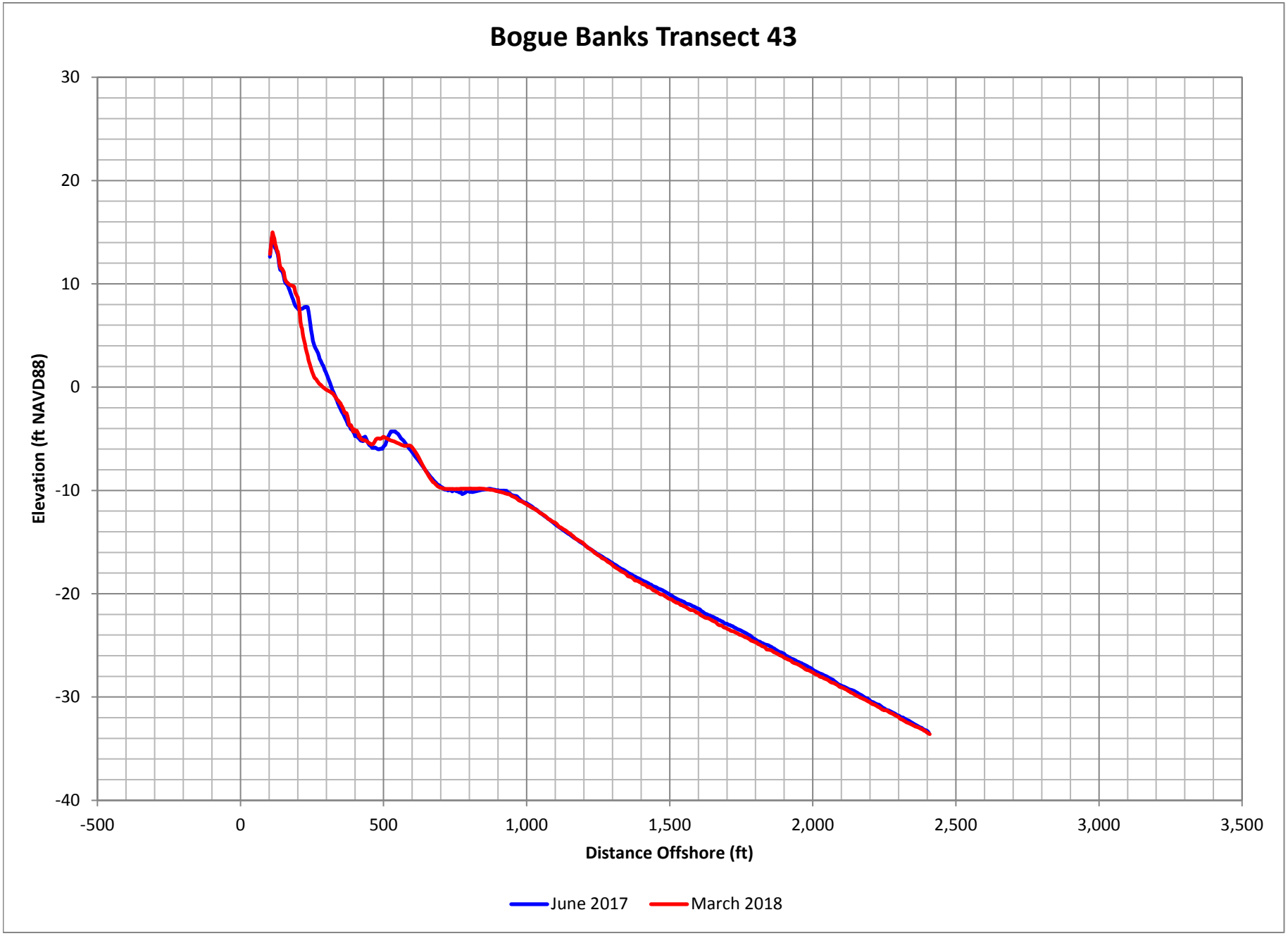


Figure D-84. Bogue Banks Profile Comparison Plot



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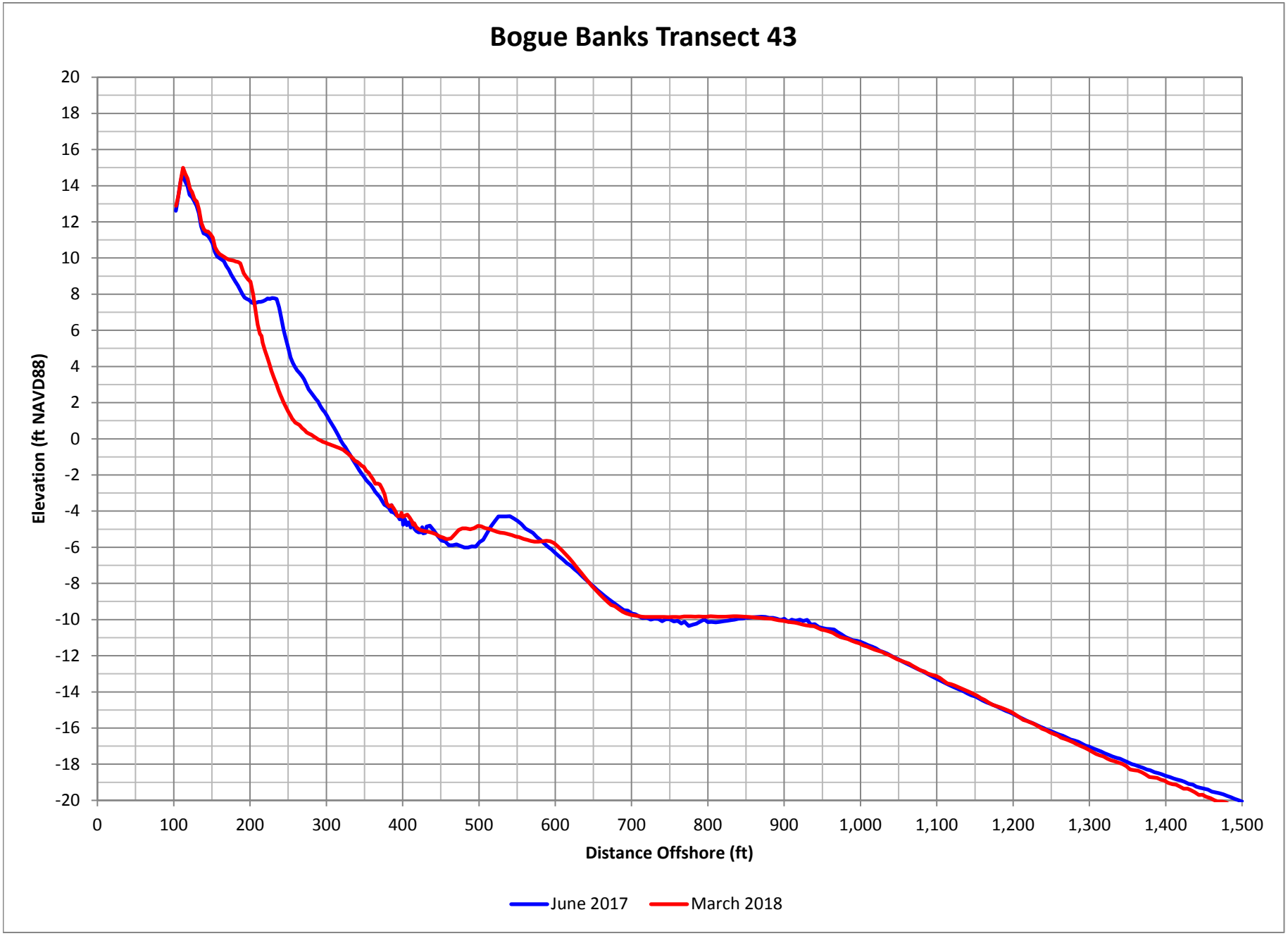


Figure D-86. Bogue Banks Profile Comparison Plot

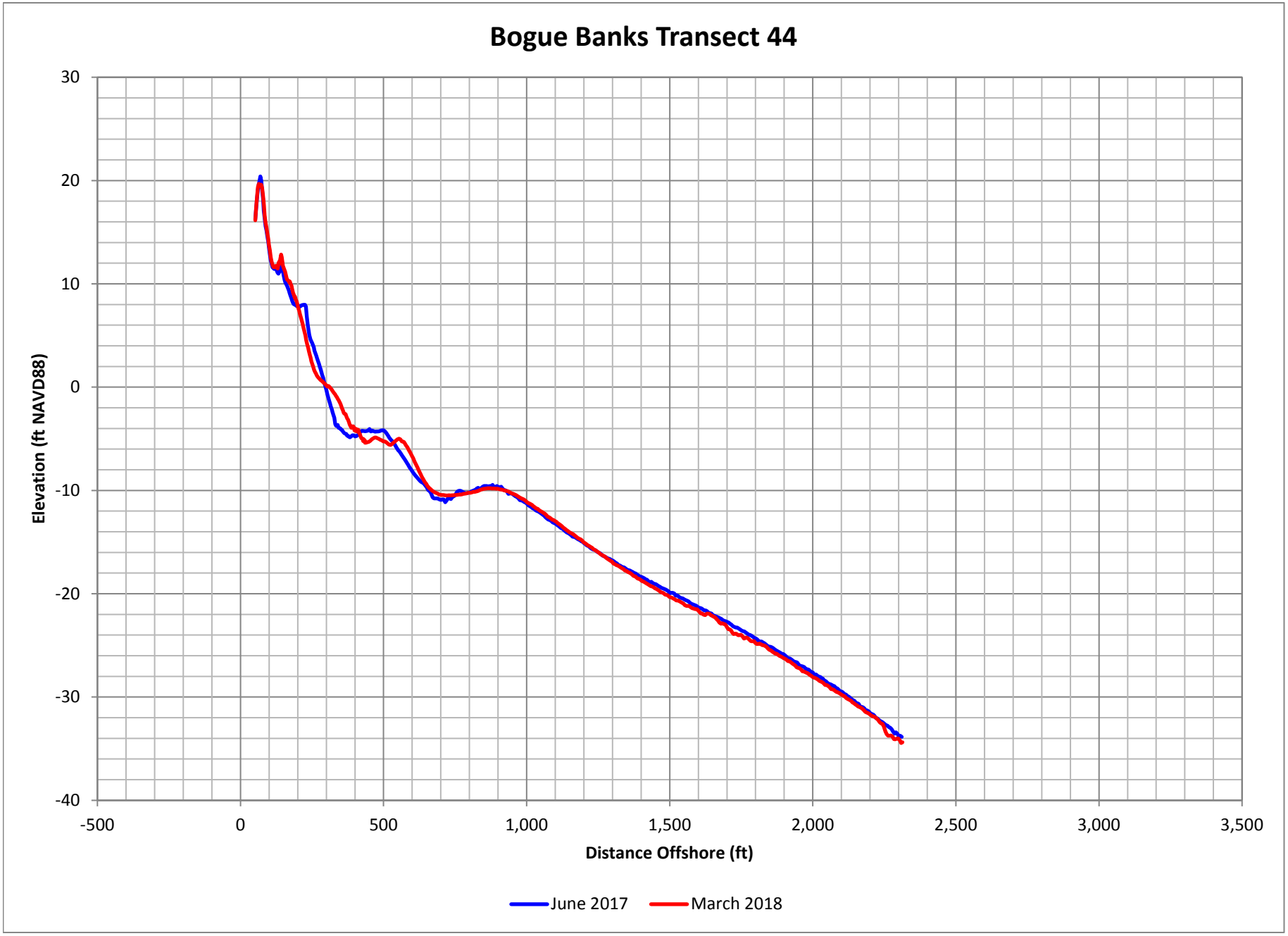


Figure D-87. Bogue Banks Profile Comparison Plot

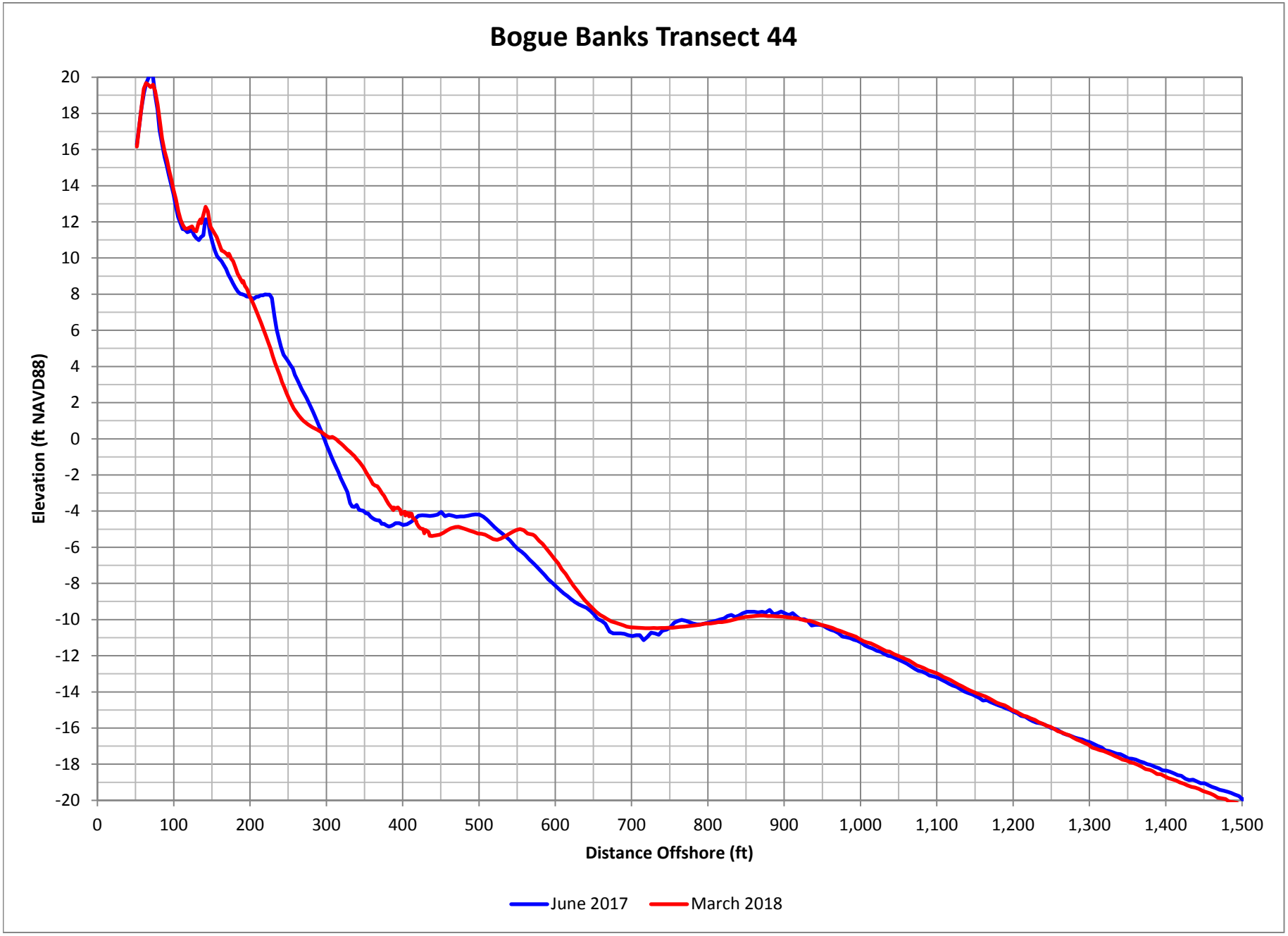


Figure D-88. Bogue Banks Profile Comparison Plot

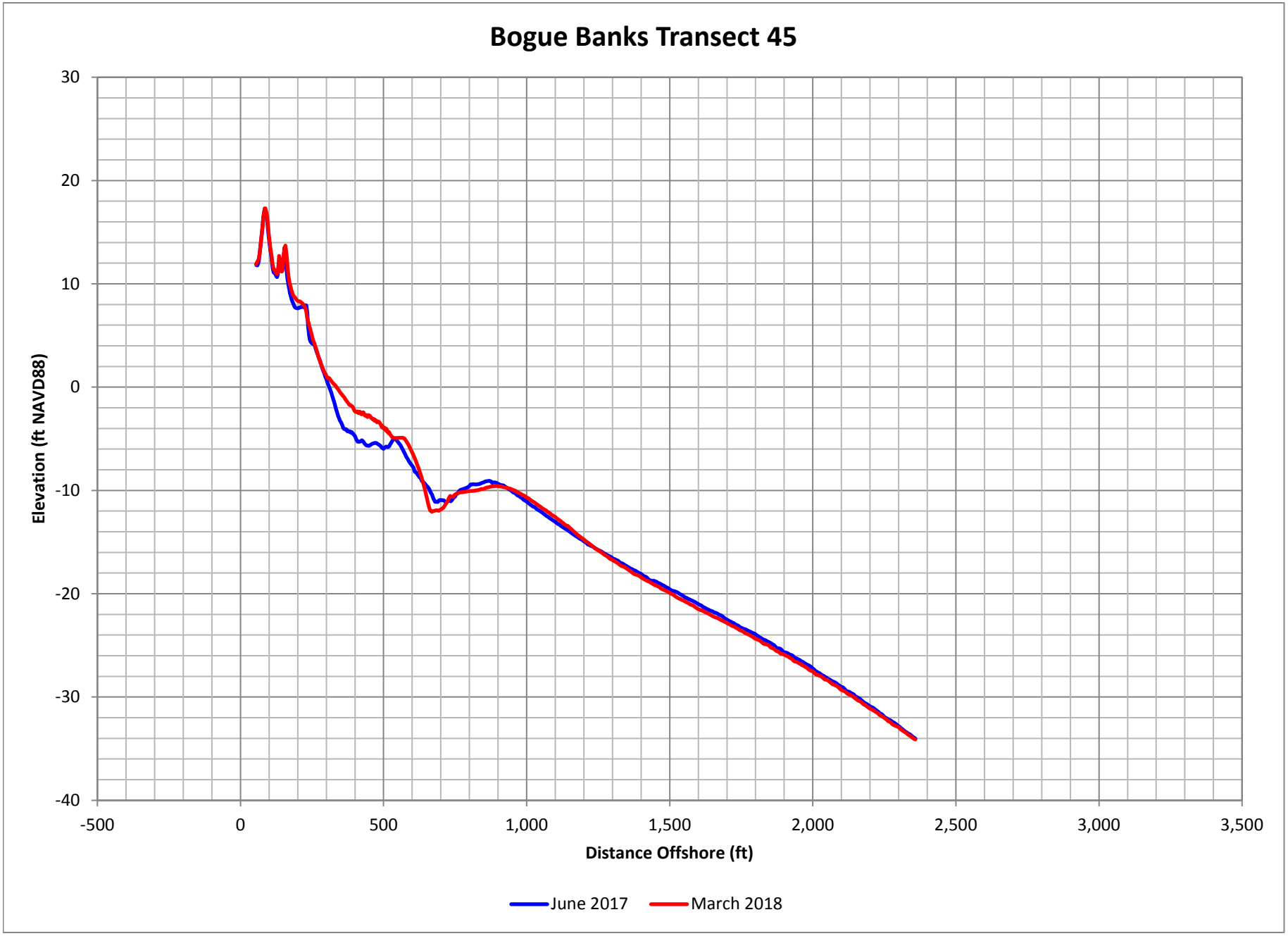


Figure D-89. Bogue Banks Profile Comparison Plot

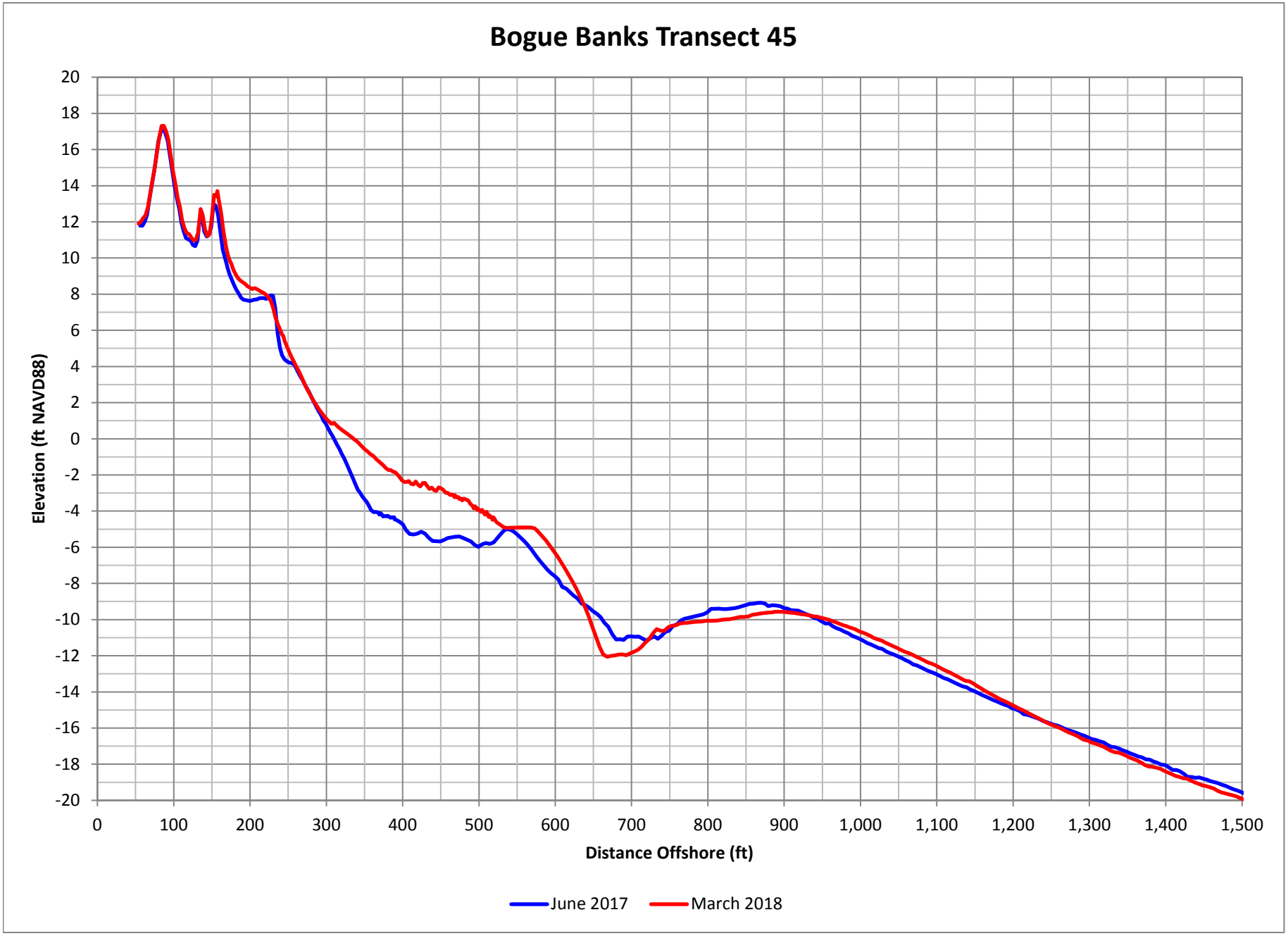


Figure D-90. Bogue Banks Profile Comparison Plot

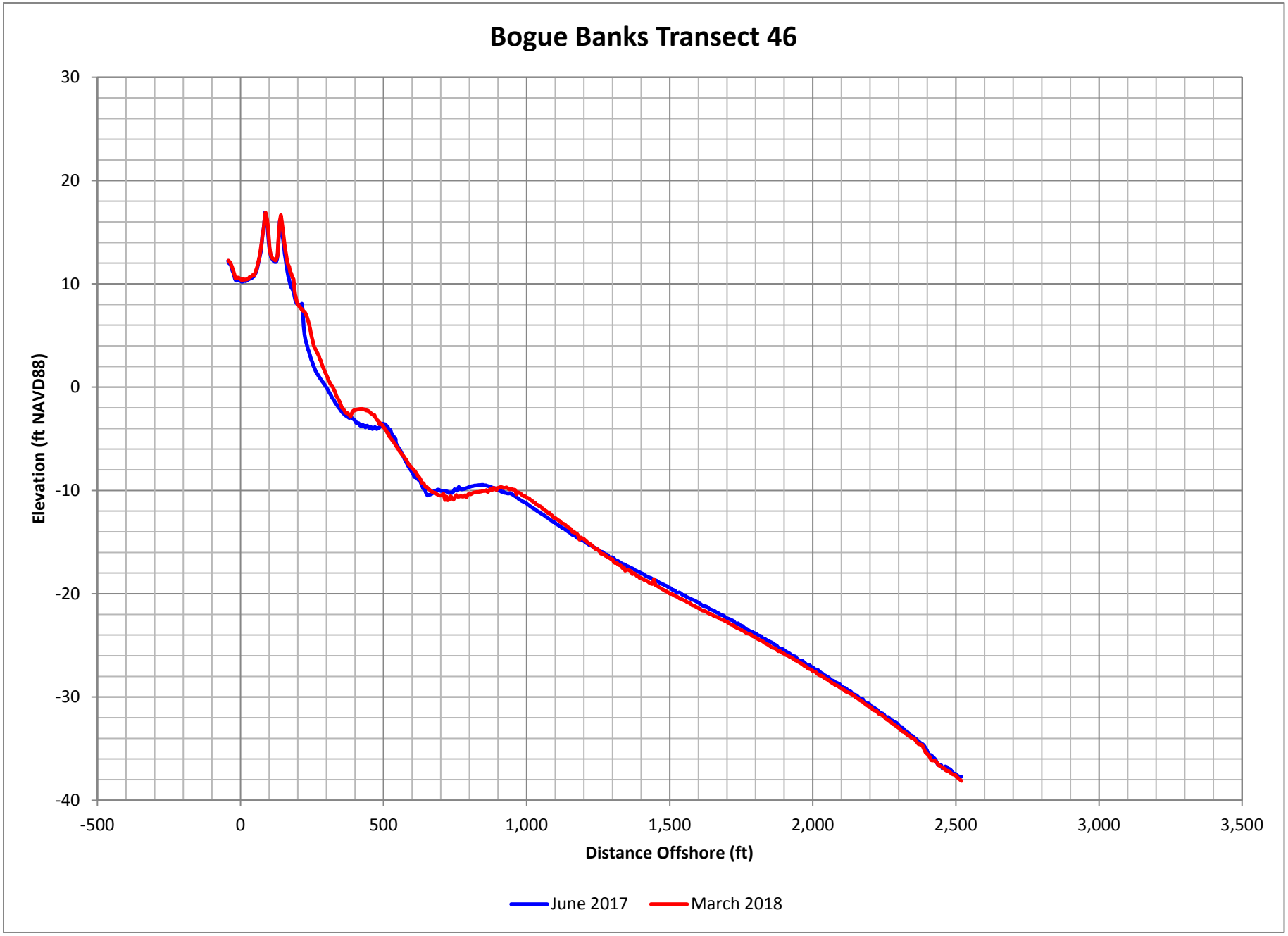


Figure D-91. Bogue Banks Profile Comparison Plot

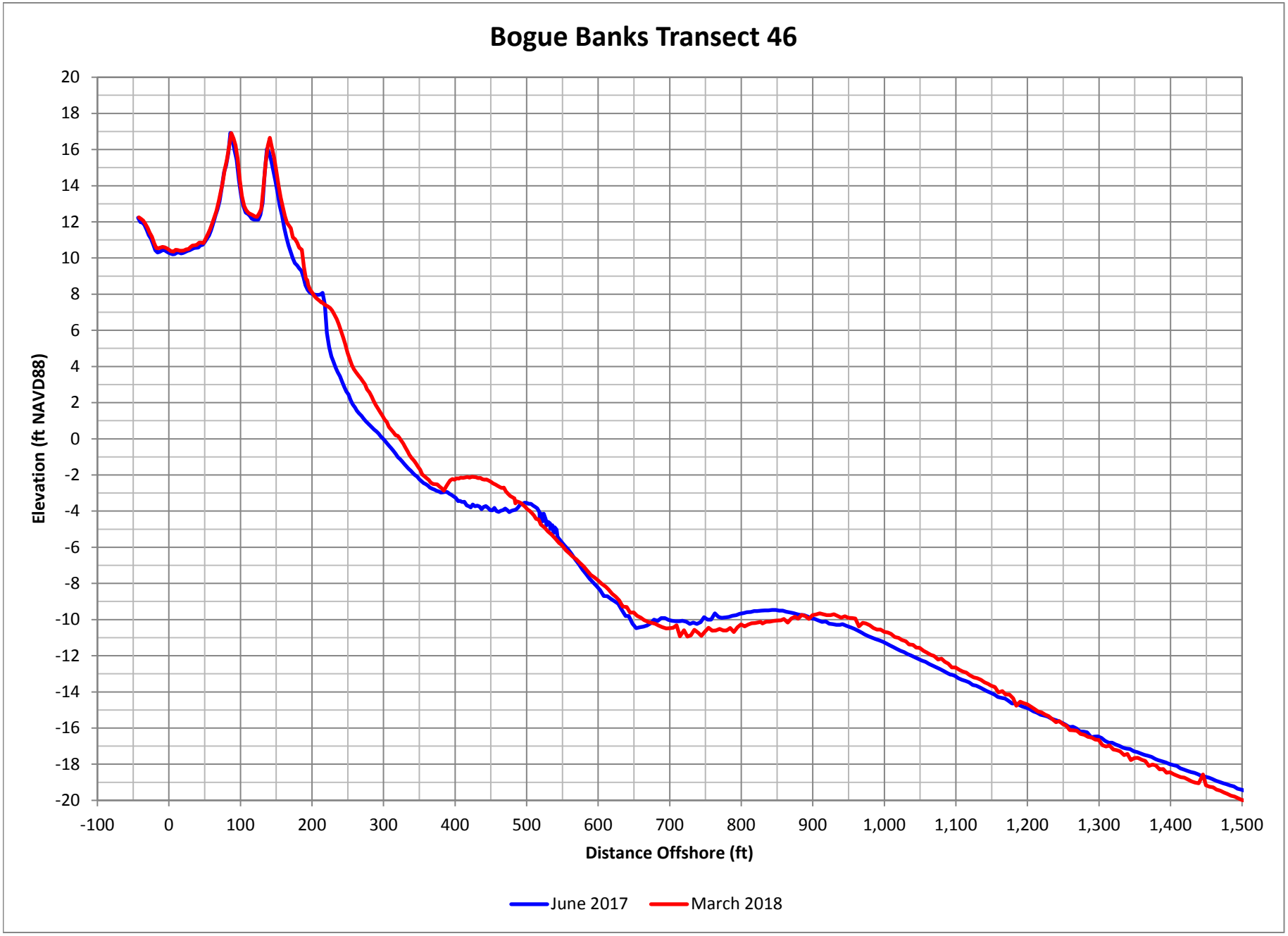


Figure D-92. Bogue Banks Profile Comparison Plot

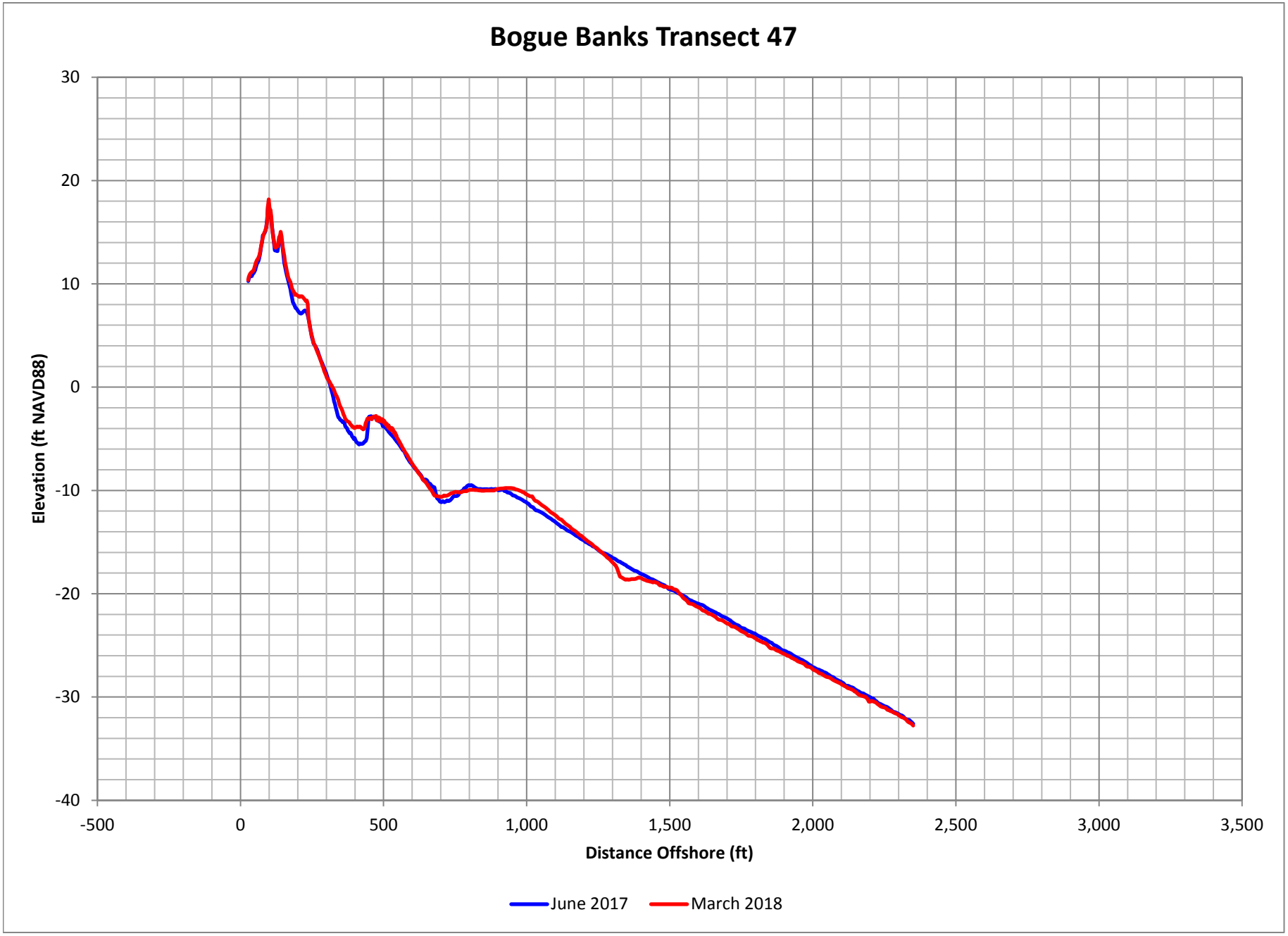


Figure D-93. Bogue Banks Profile Comparison Plot

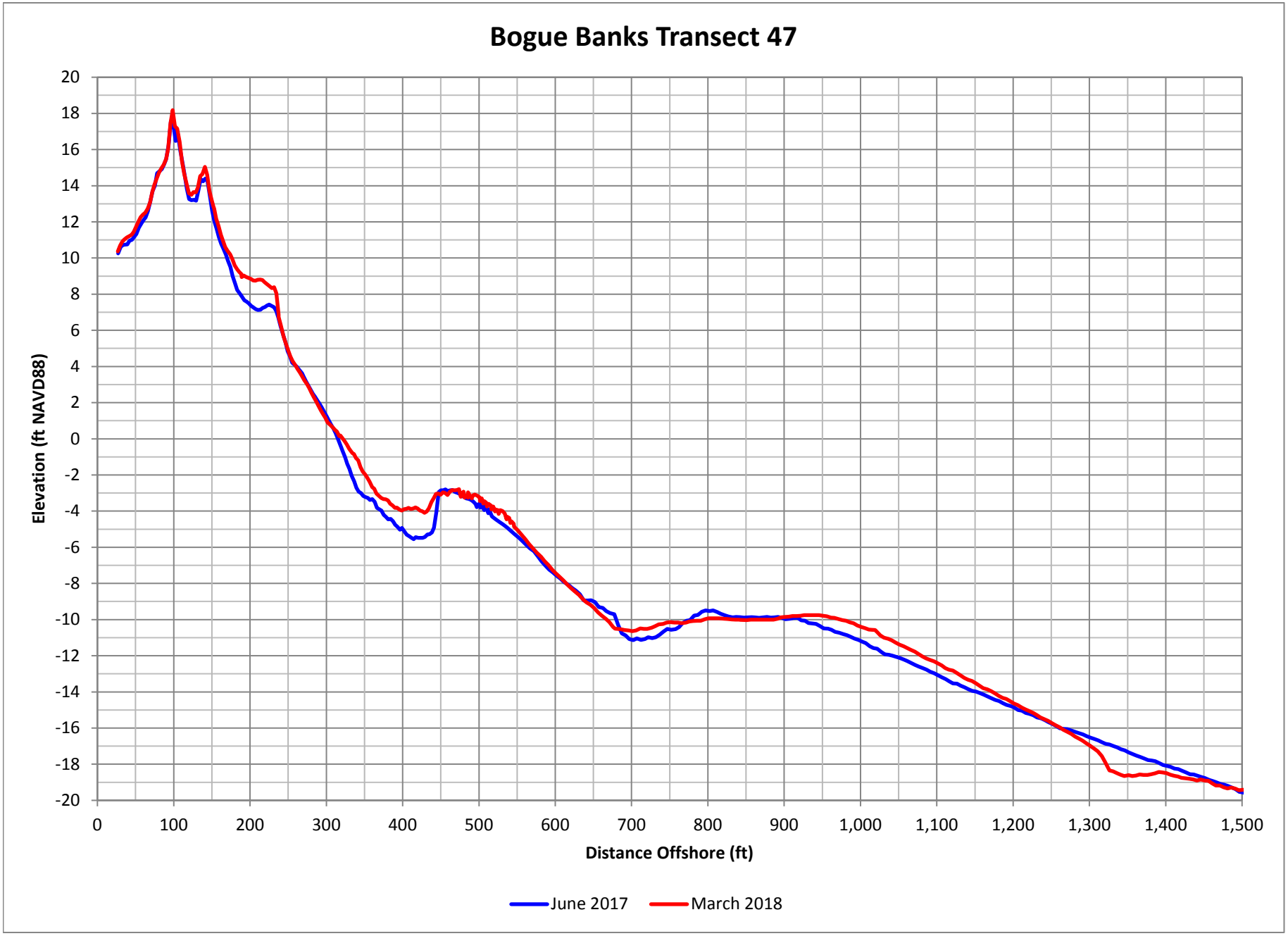


Figure D-94. Bogue Banks Profile Comparison Plot

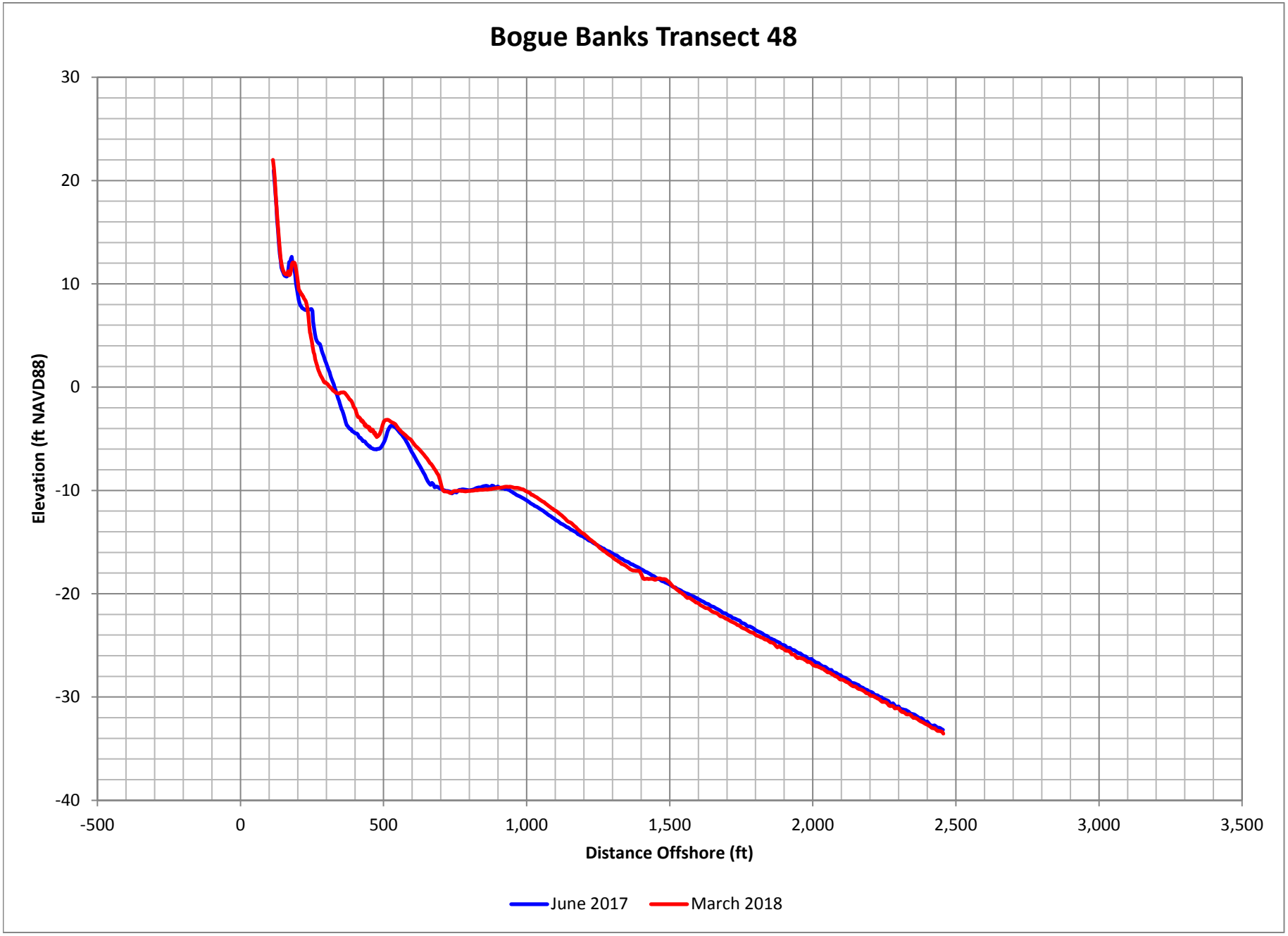


Figure D-95. Bogue Banks Profile Comparison Plot

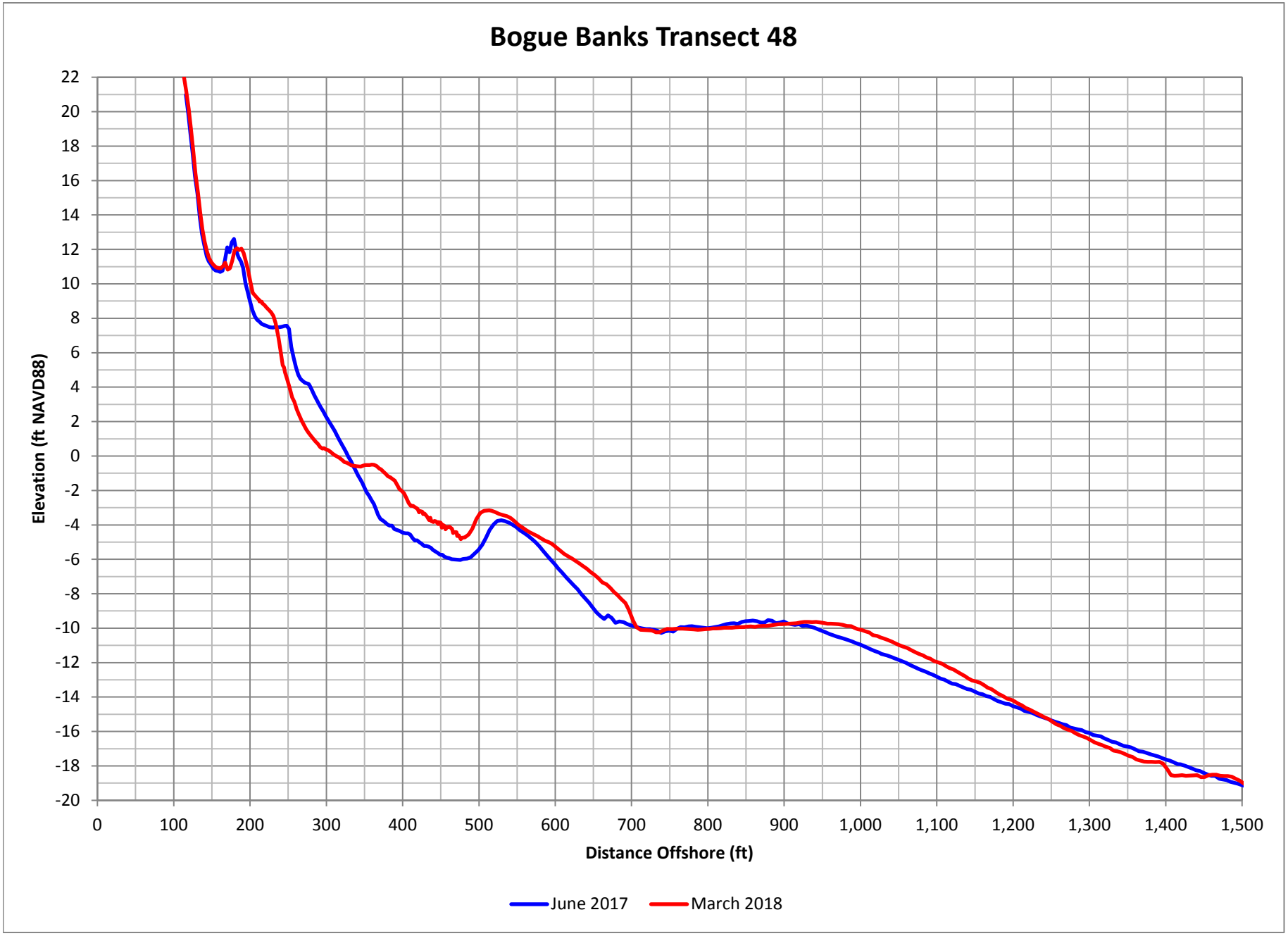


Figure D-96. Bogue Banks Profile Comparison Plot

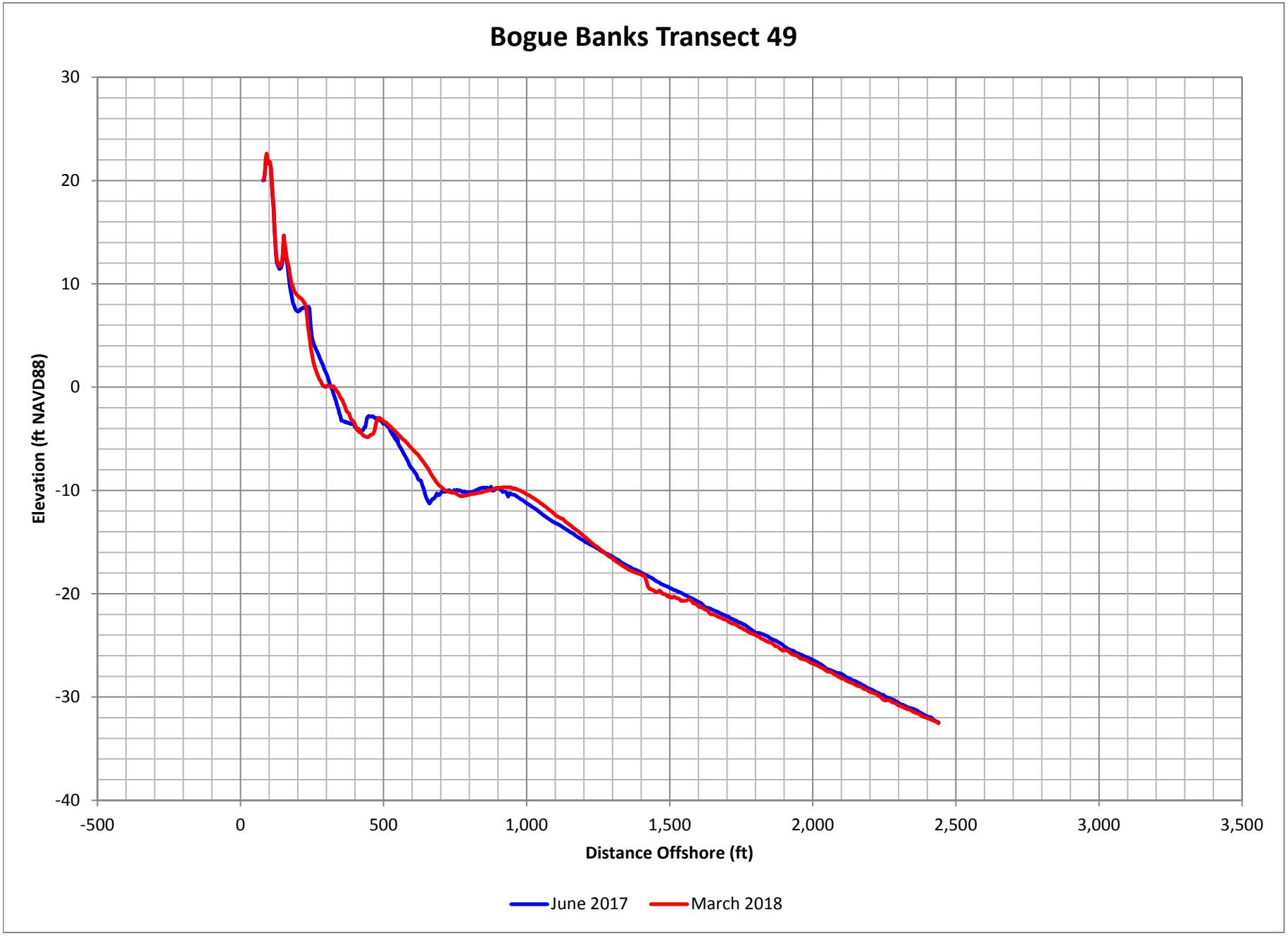


Figure D-97. Bogue Banks Profile Comparison Plot

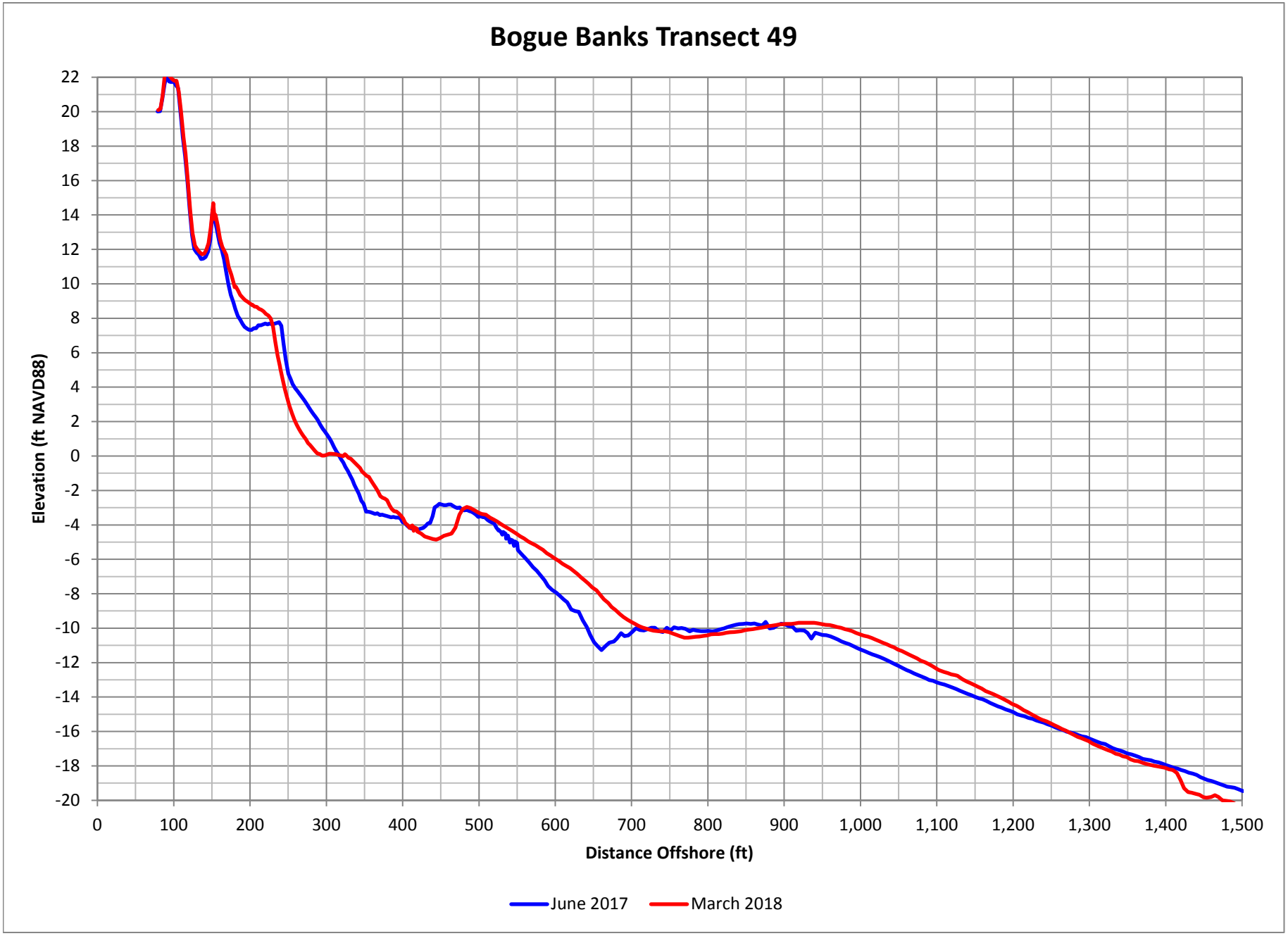


Figure D-98. Bogue Banks Profile Comparison Plot

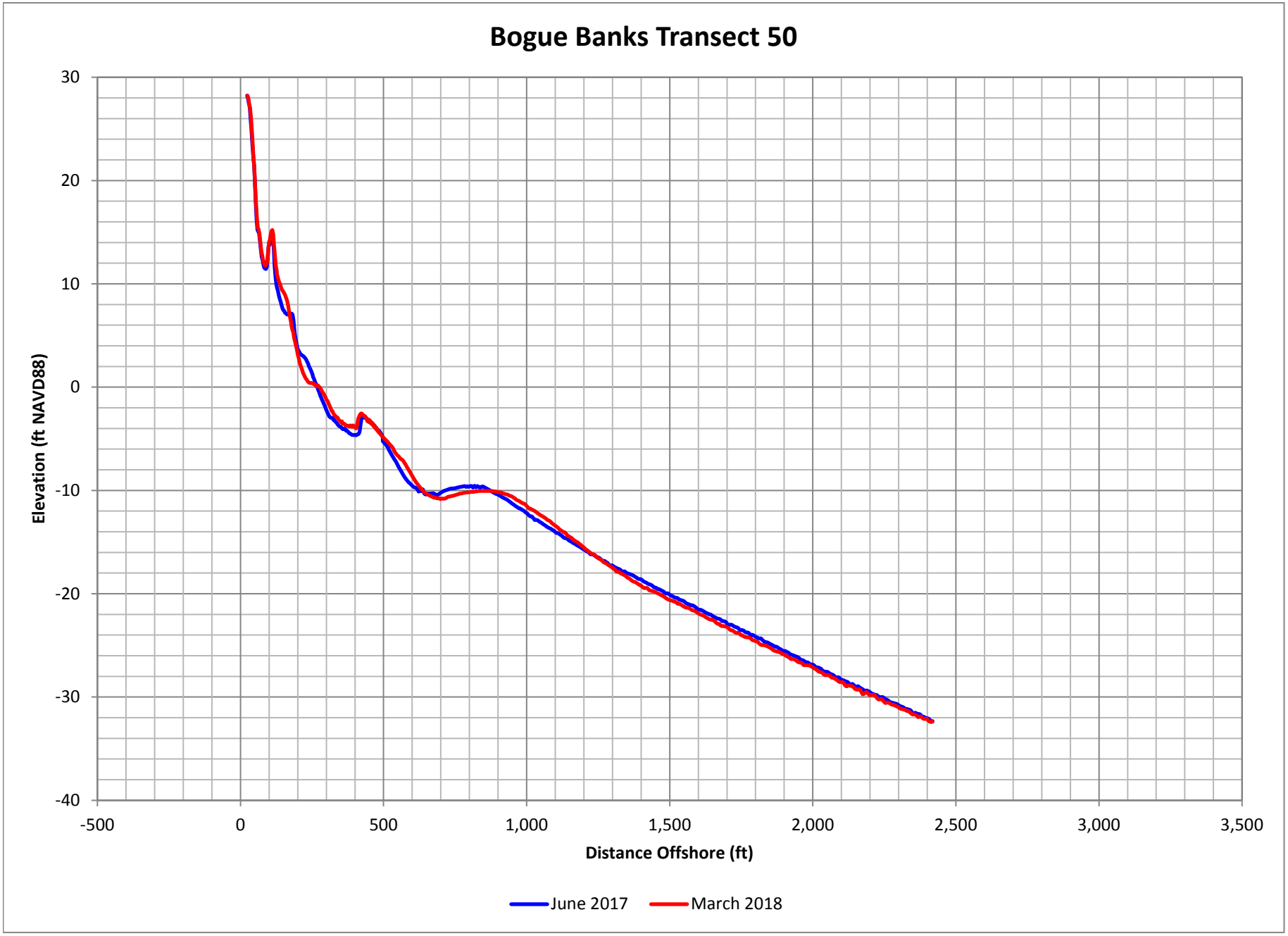


Figure D-99. Bogue Banks Profile Comparison Plot

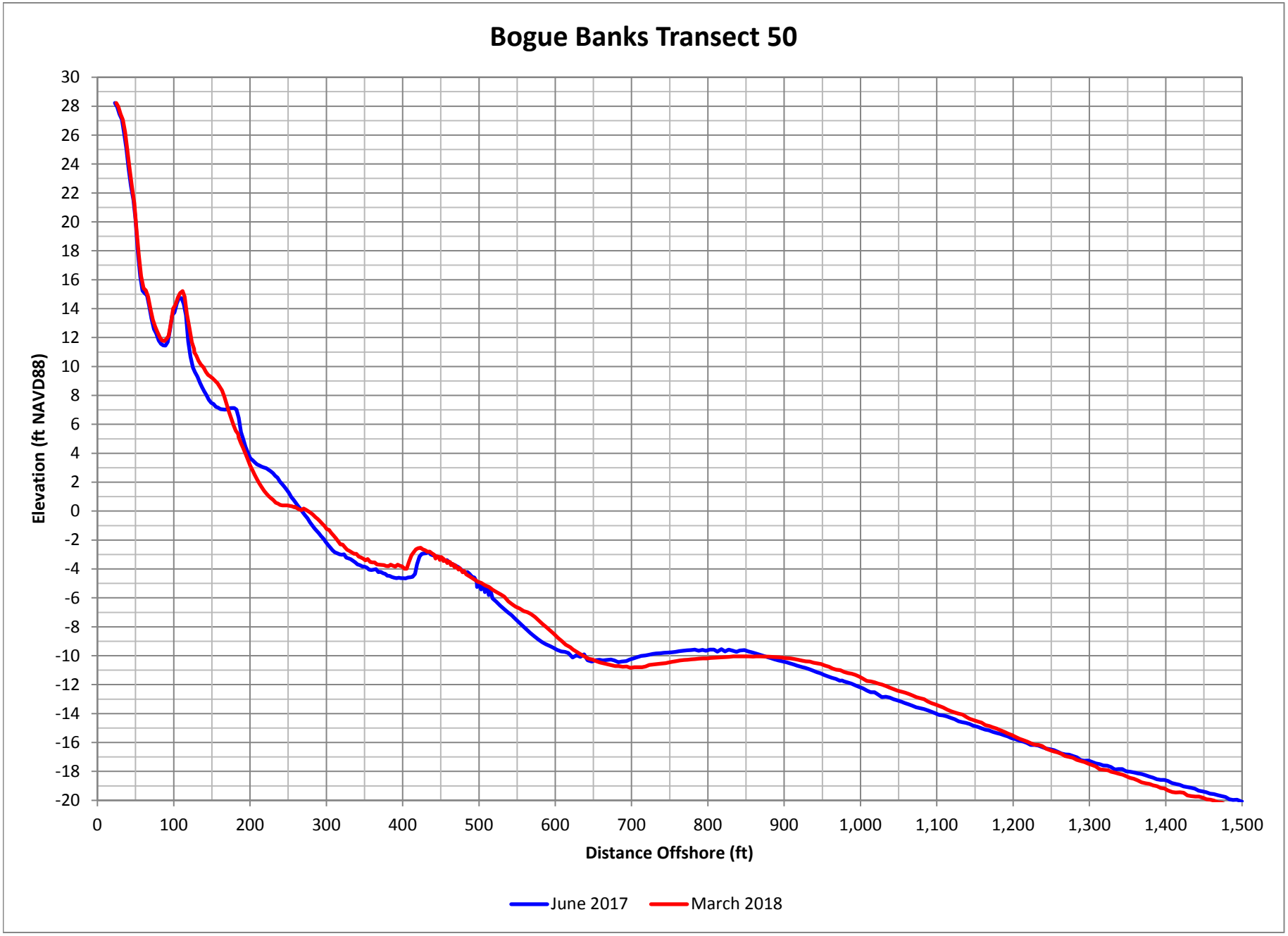


Figure D-100. Bogue Banks Profile Comparison Plot

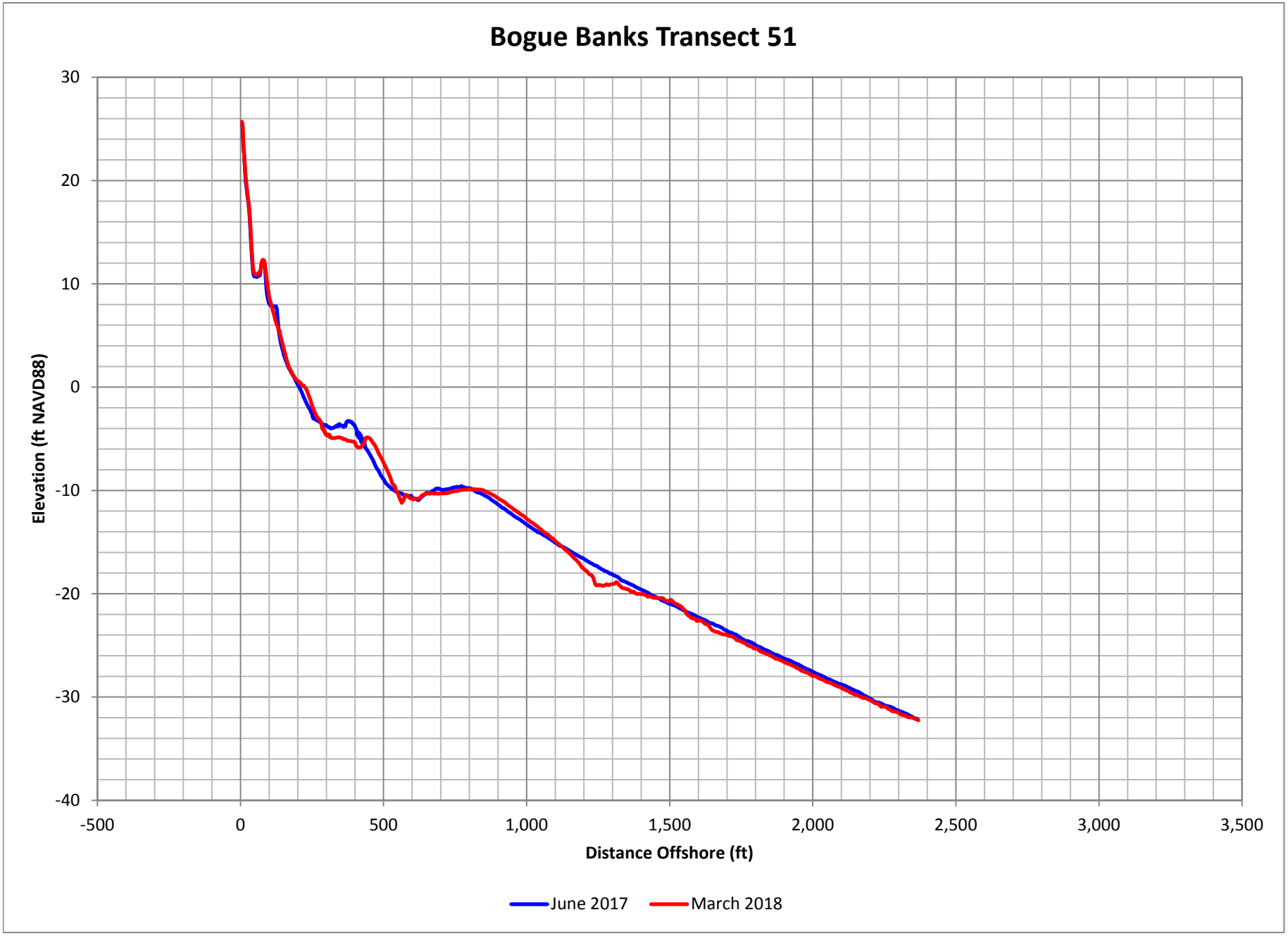


Figure D-101. Bogue Banks Profile Comparison Plot

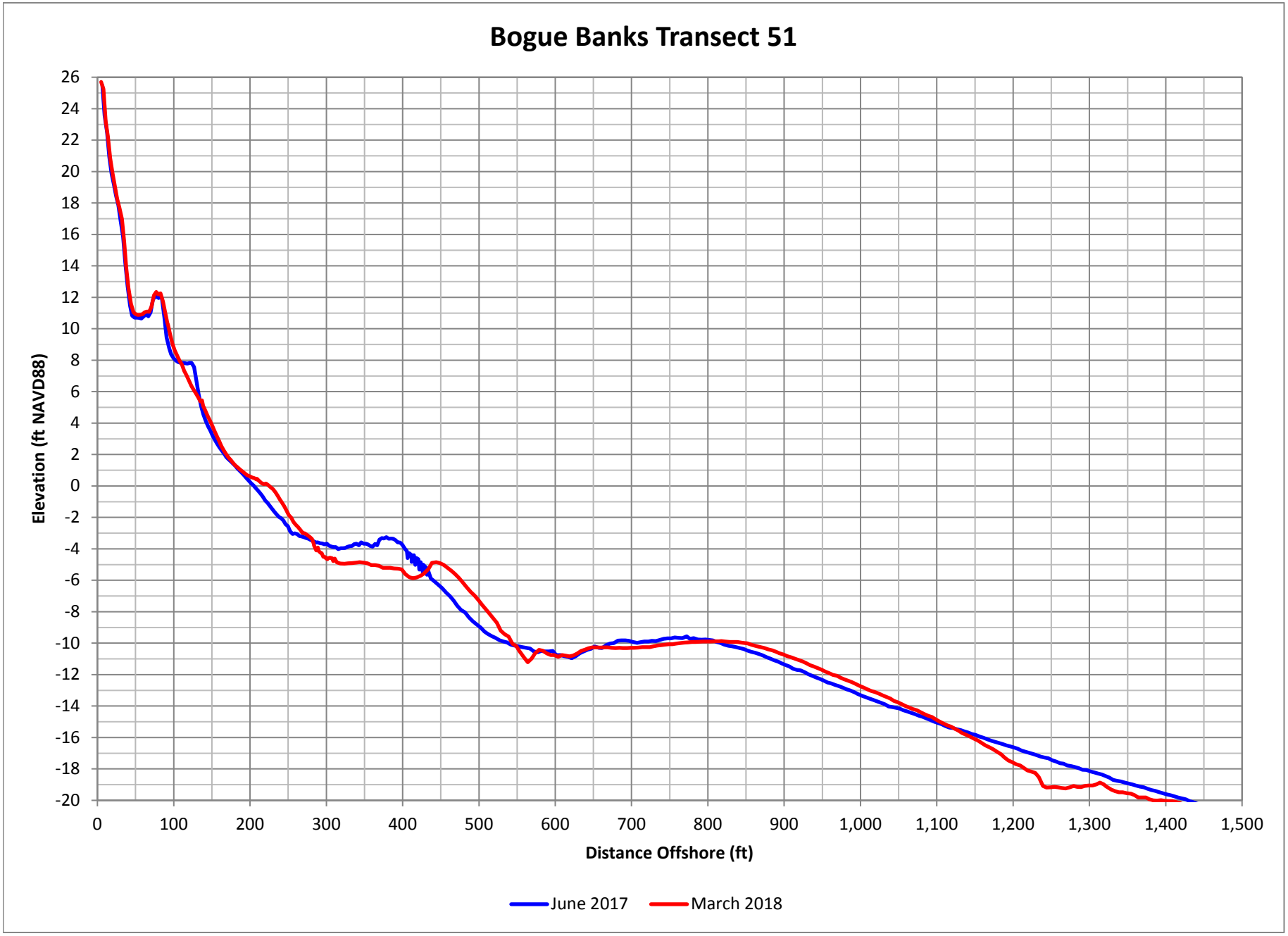


Figure D-102. Bogue Banks Profile Comparison Plot

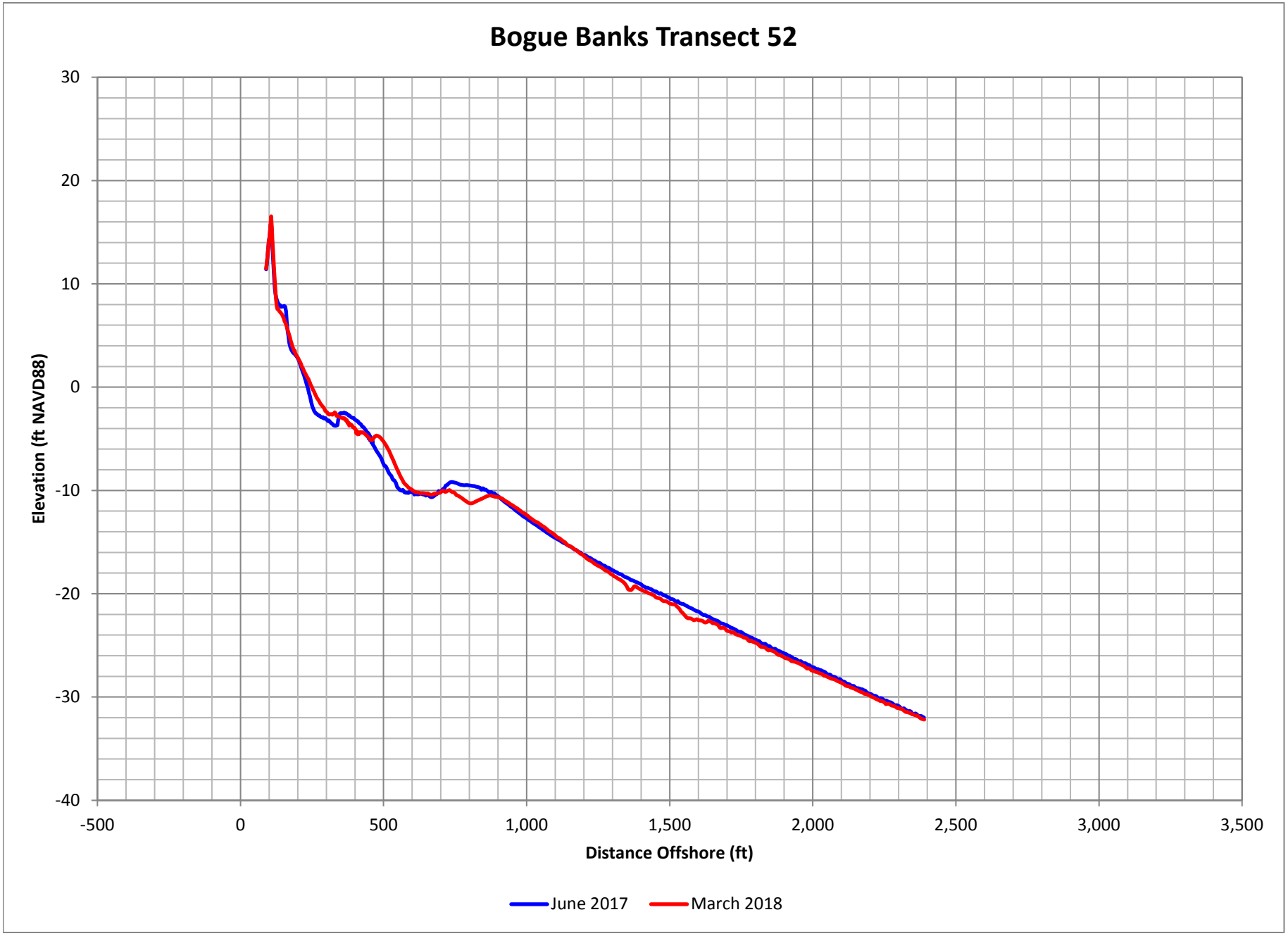


Figure D-103. Bogue Banks Profile Comparison Plot

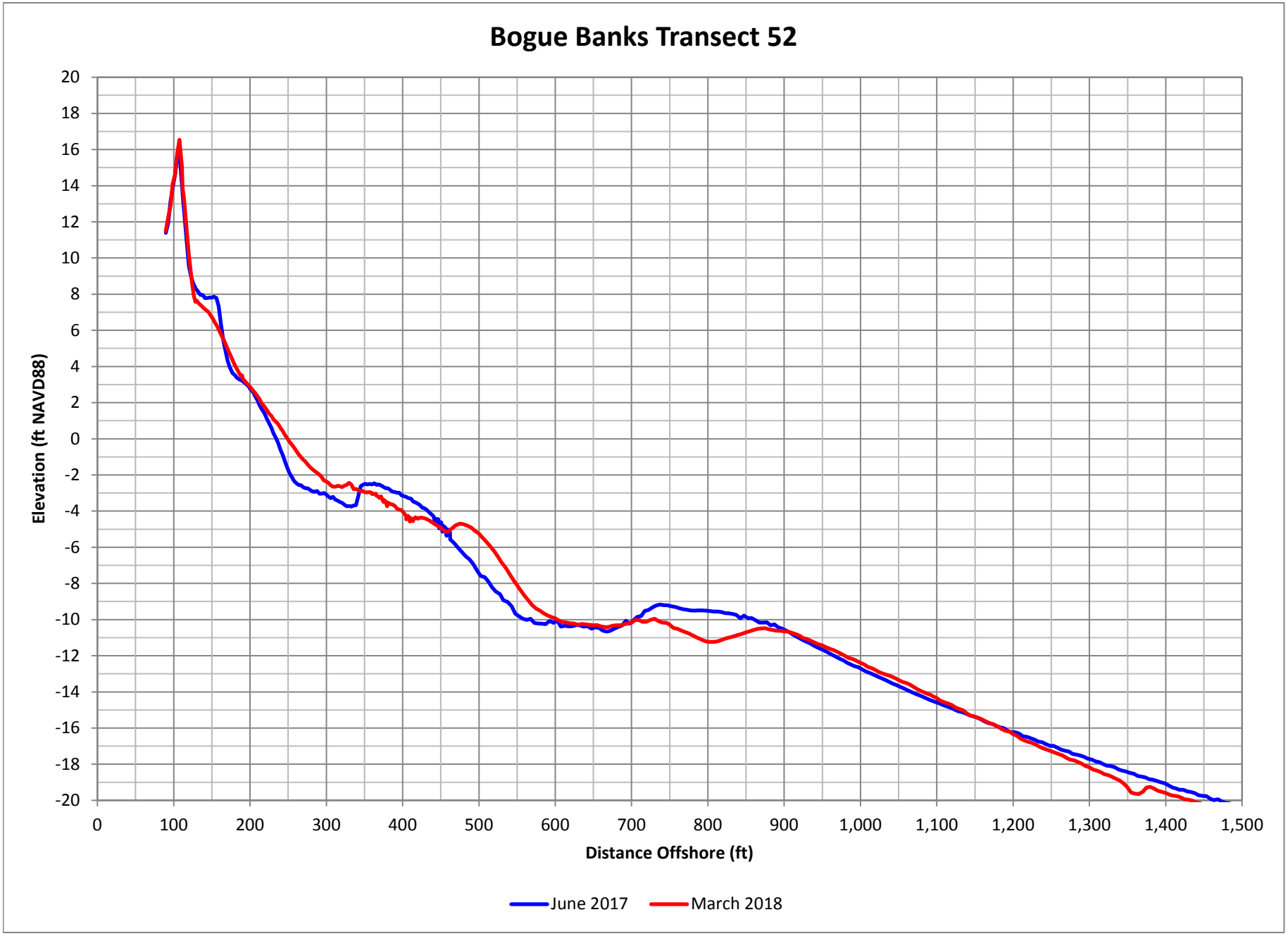


Figure D-104. Bogue Banks Profile Comparison Plot

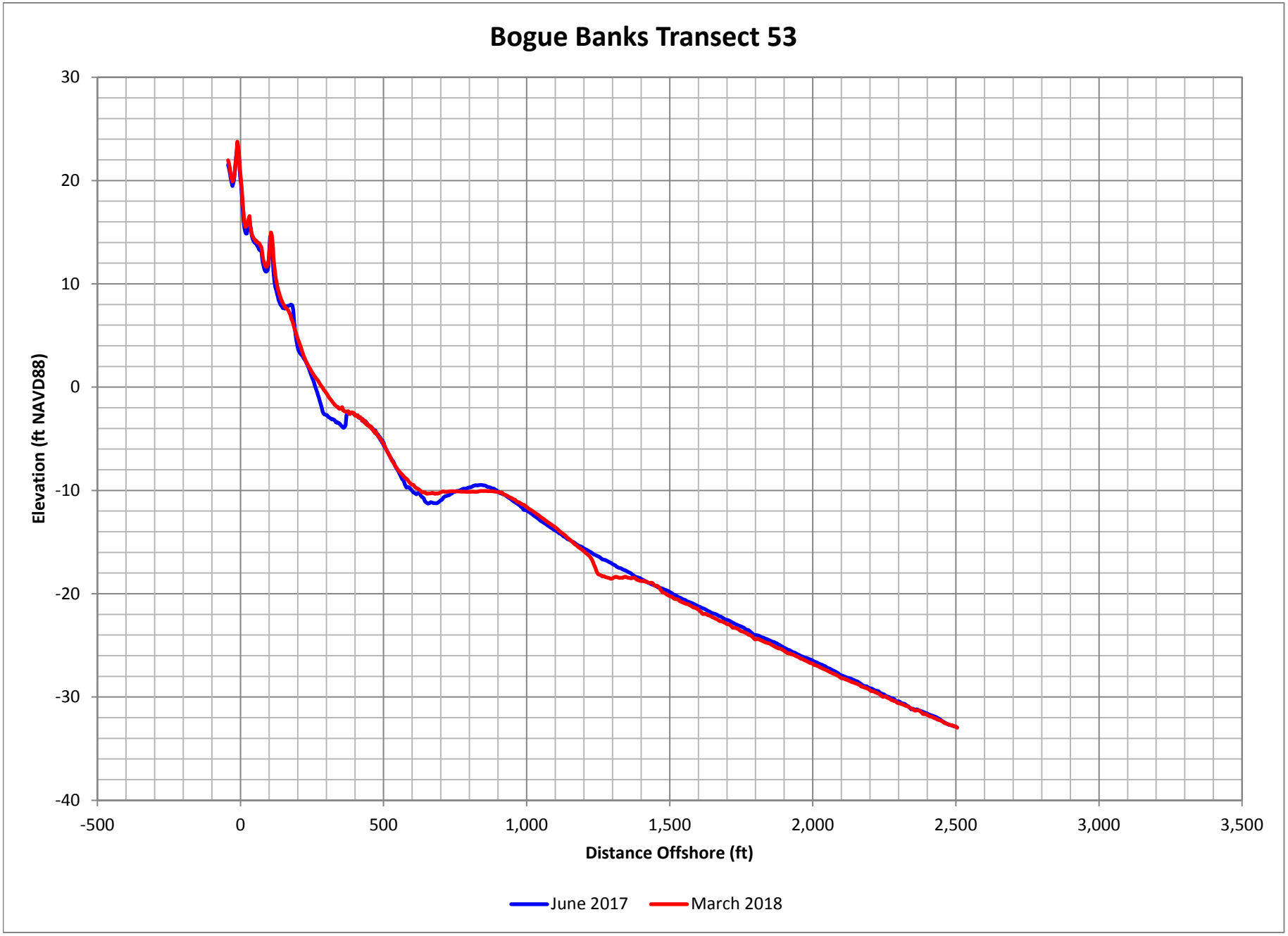


Figure D-105. Bogue Banks Profile Comparison Plot

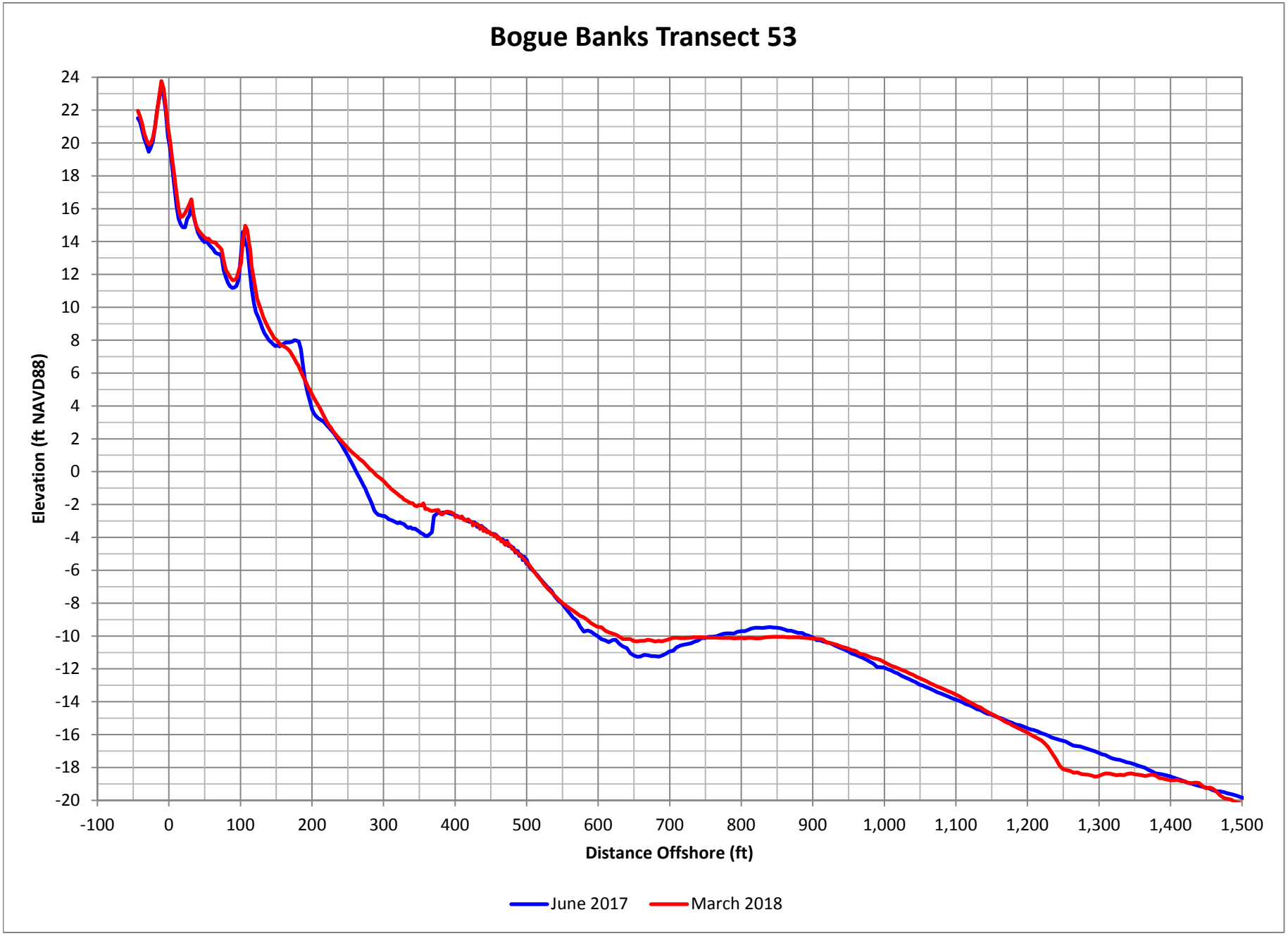


Figure D-106. Bogue Banks Profile Comparison Plot

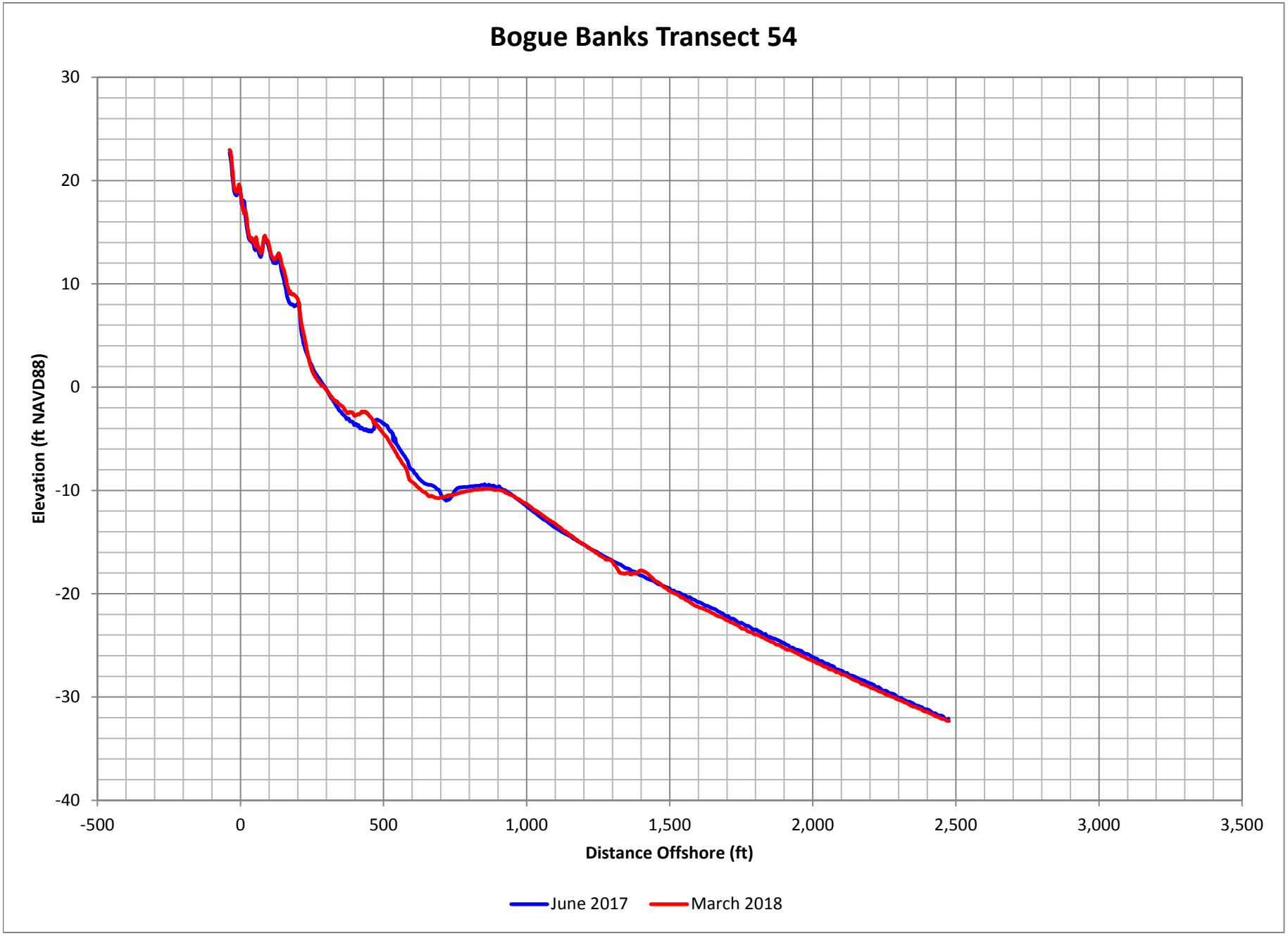


Figure D-107. Bogue Banks Profile Comparison Plot

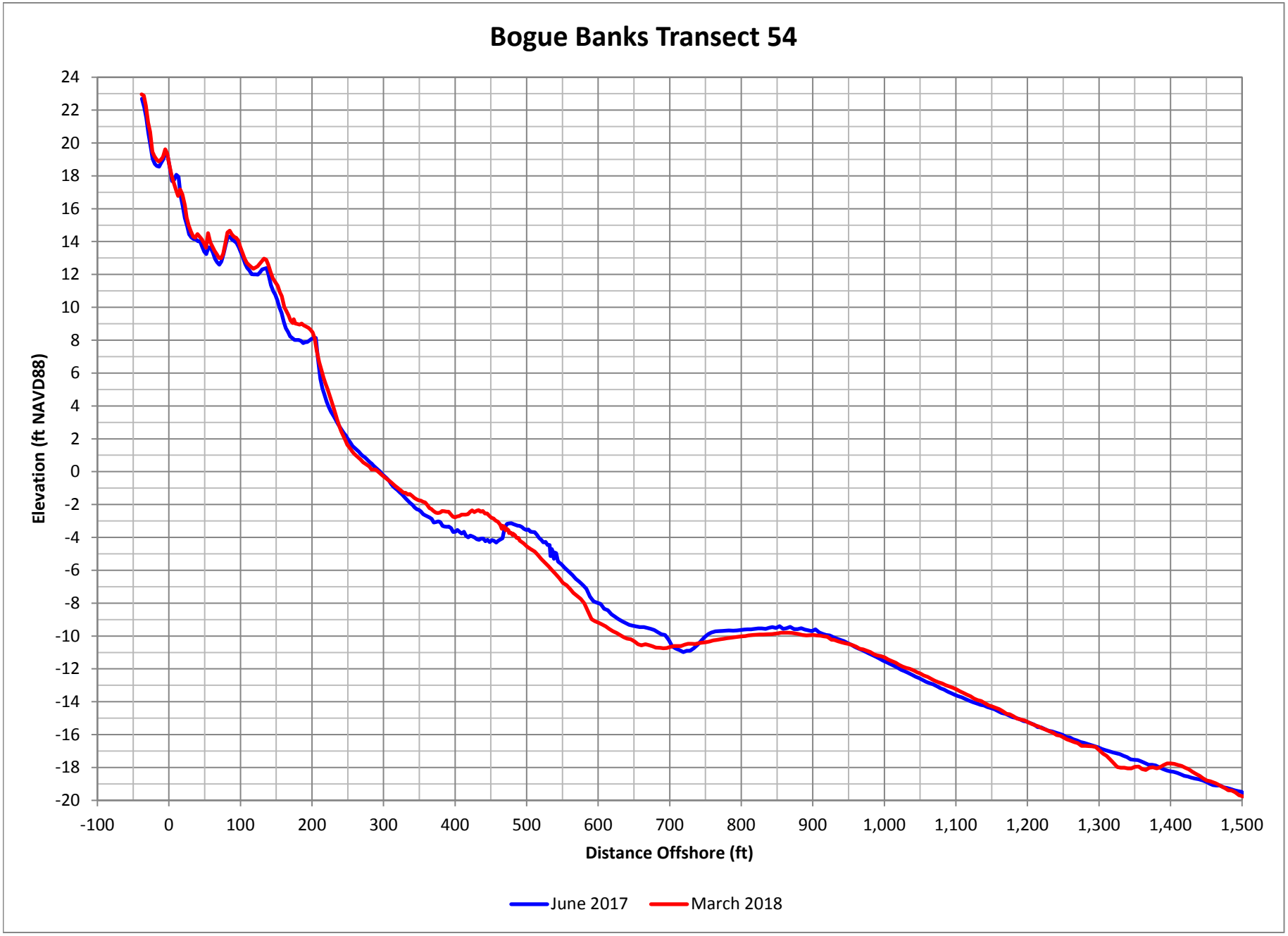


Figure D-108. Bogue Banks Profile Comparison Plot

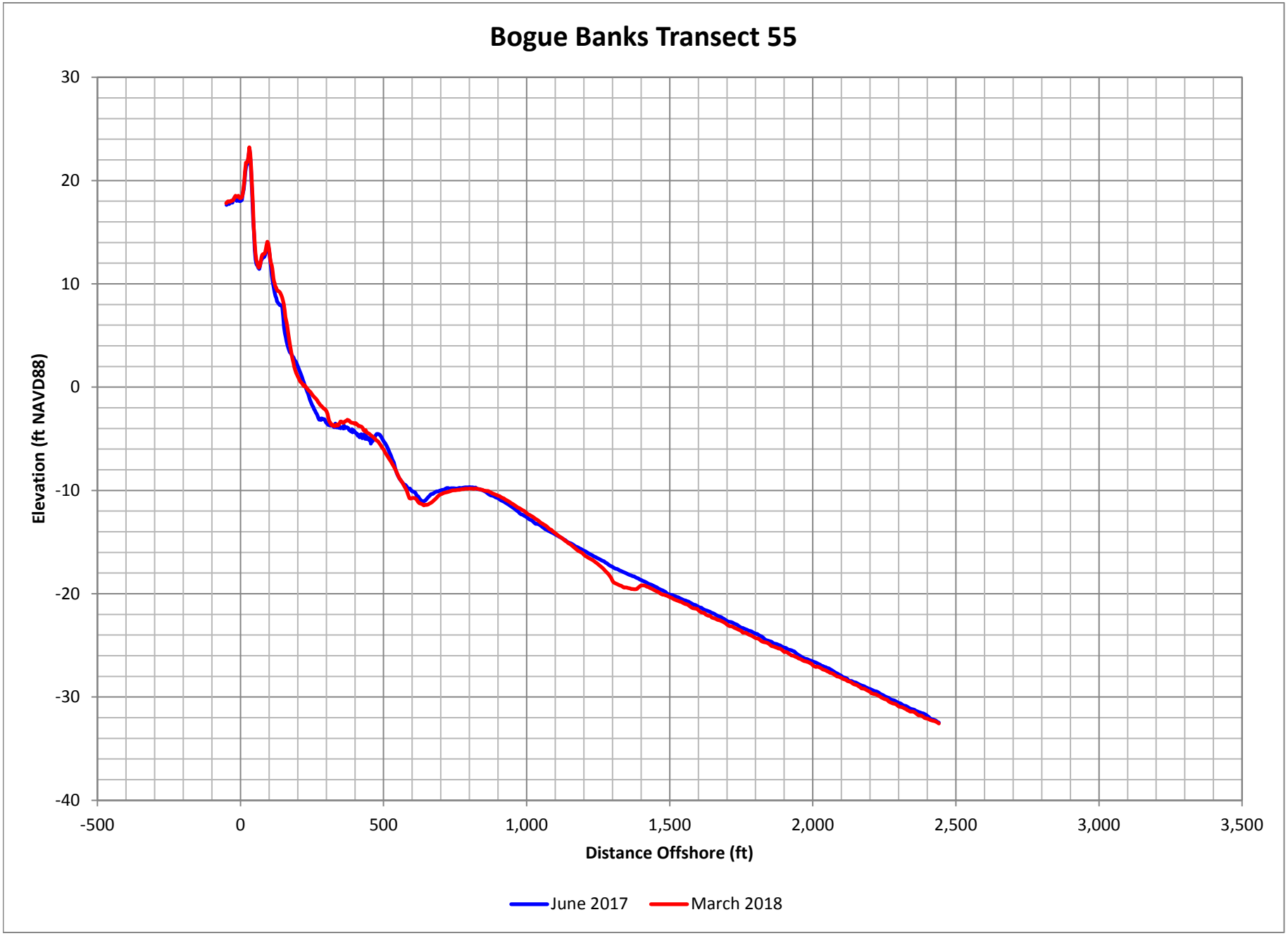


Figure D-109. Bogue Banks Profile Comparison Plot

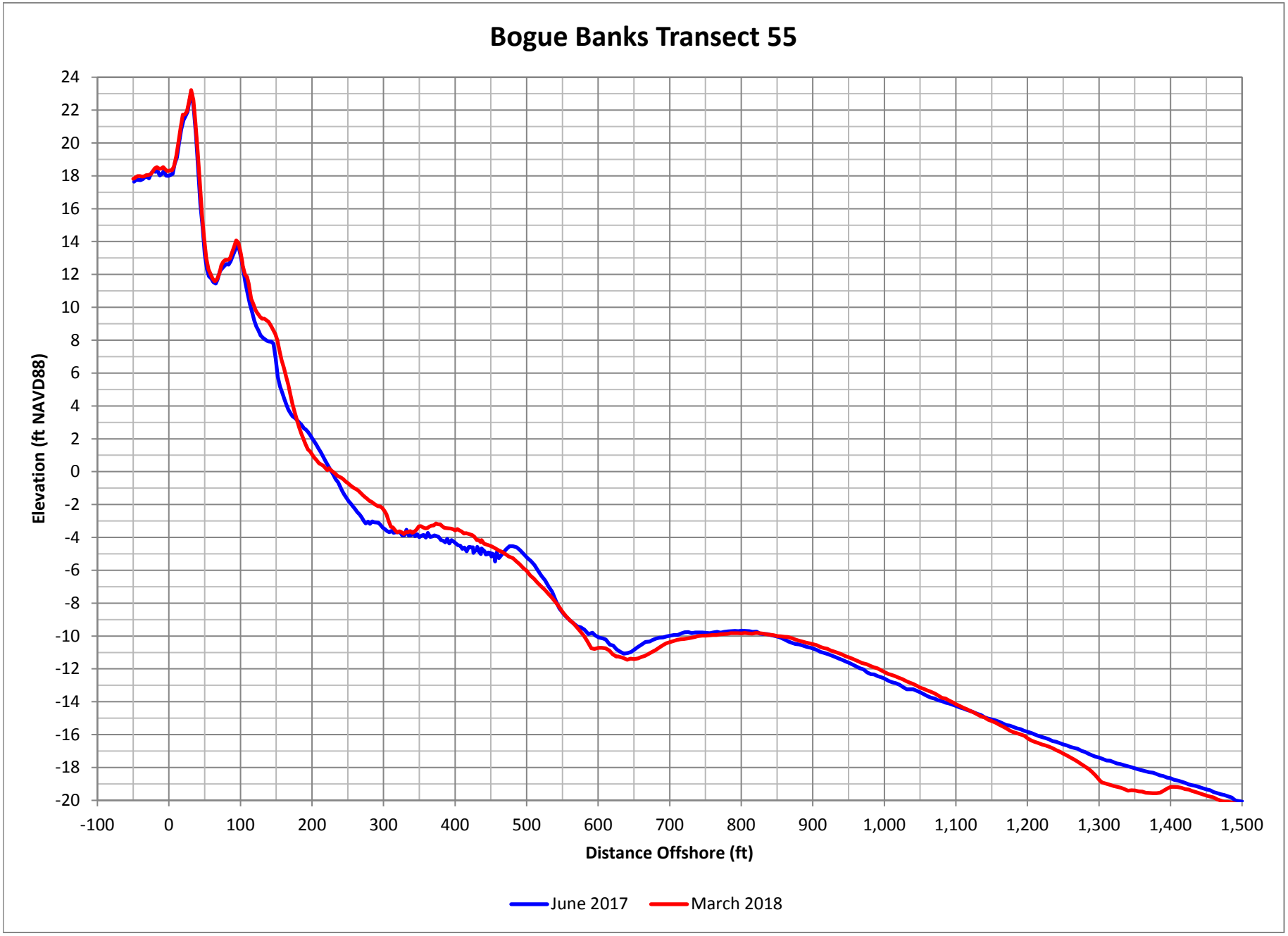


Figure D-110. Bogue Banks Profile Comparison Plot

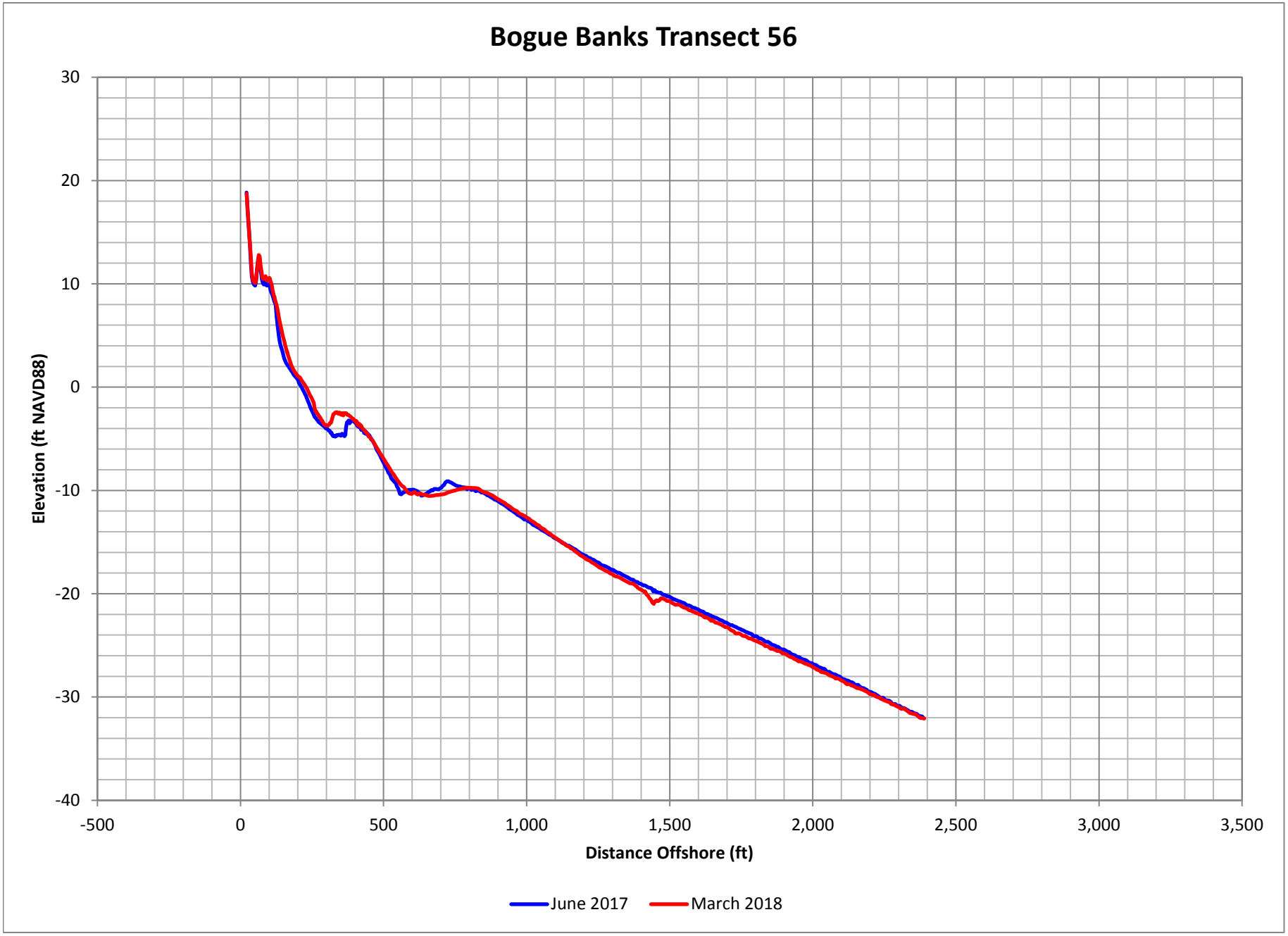


Figure D-111. Bogue Banks Profile Comparison Plot

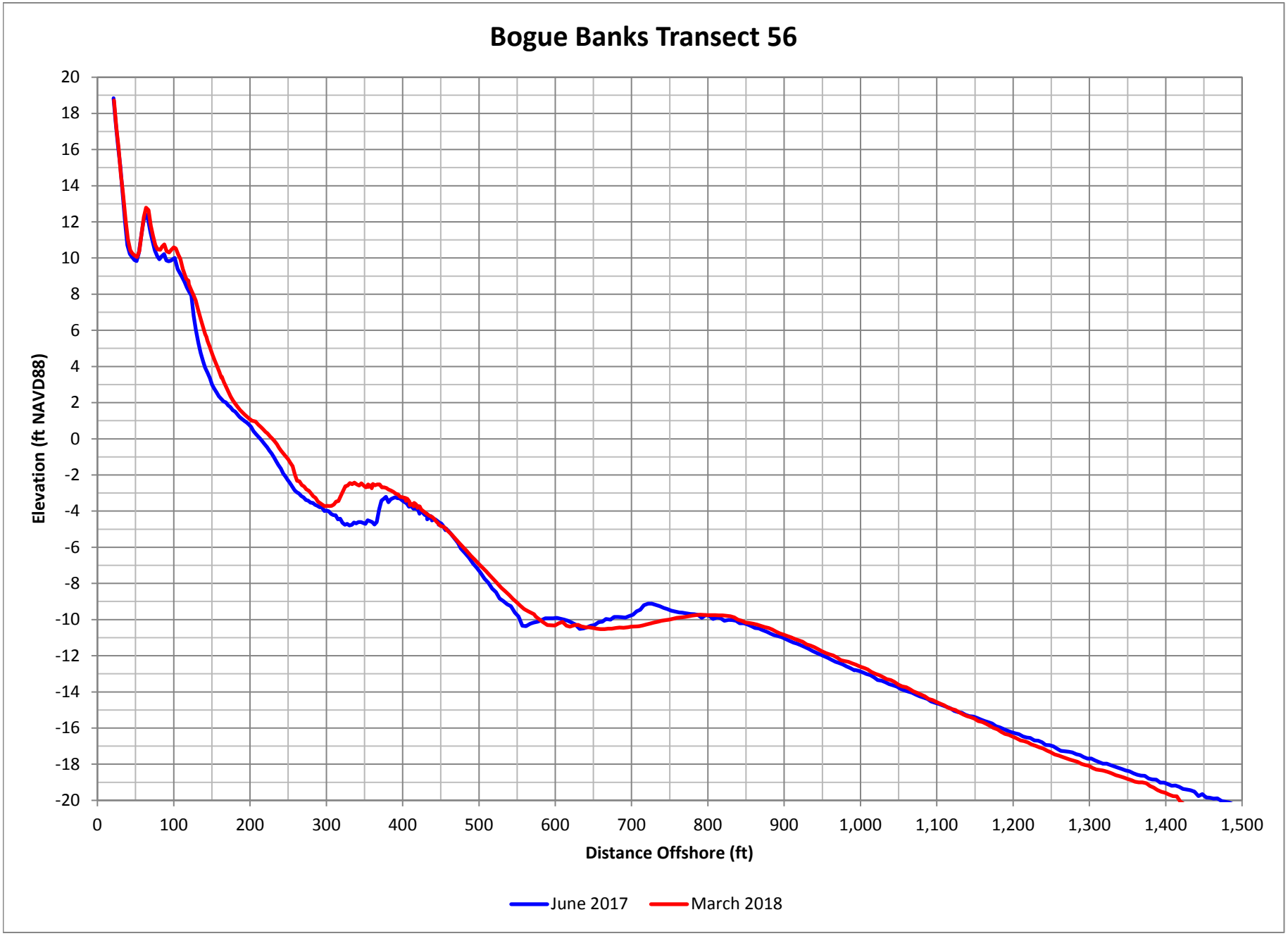


Figure D-112. Bogue Banks Profile Comparison Plot

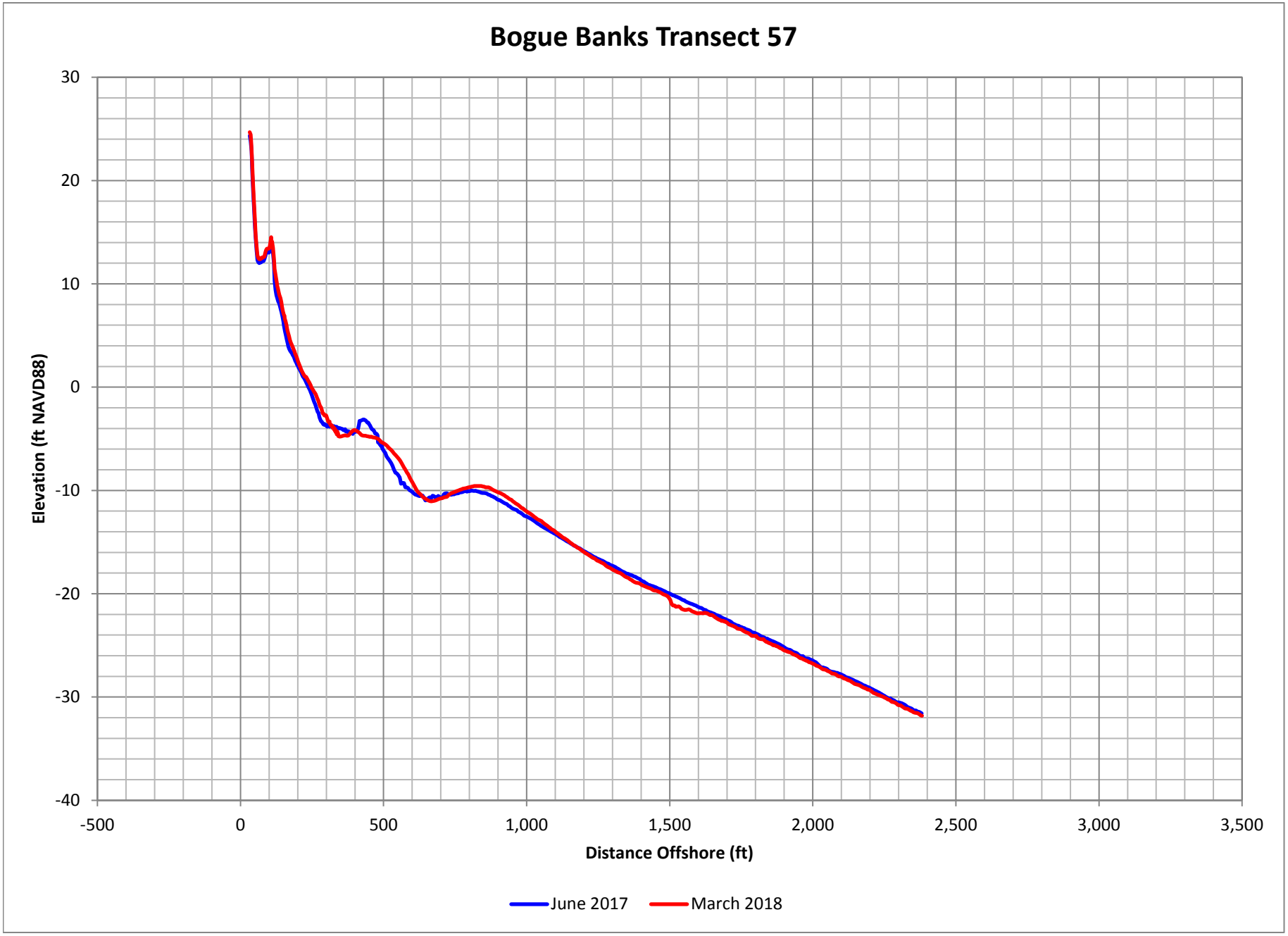


Figure D-113. Bogue Banks Profile Comparison Plot

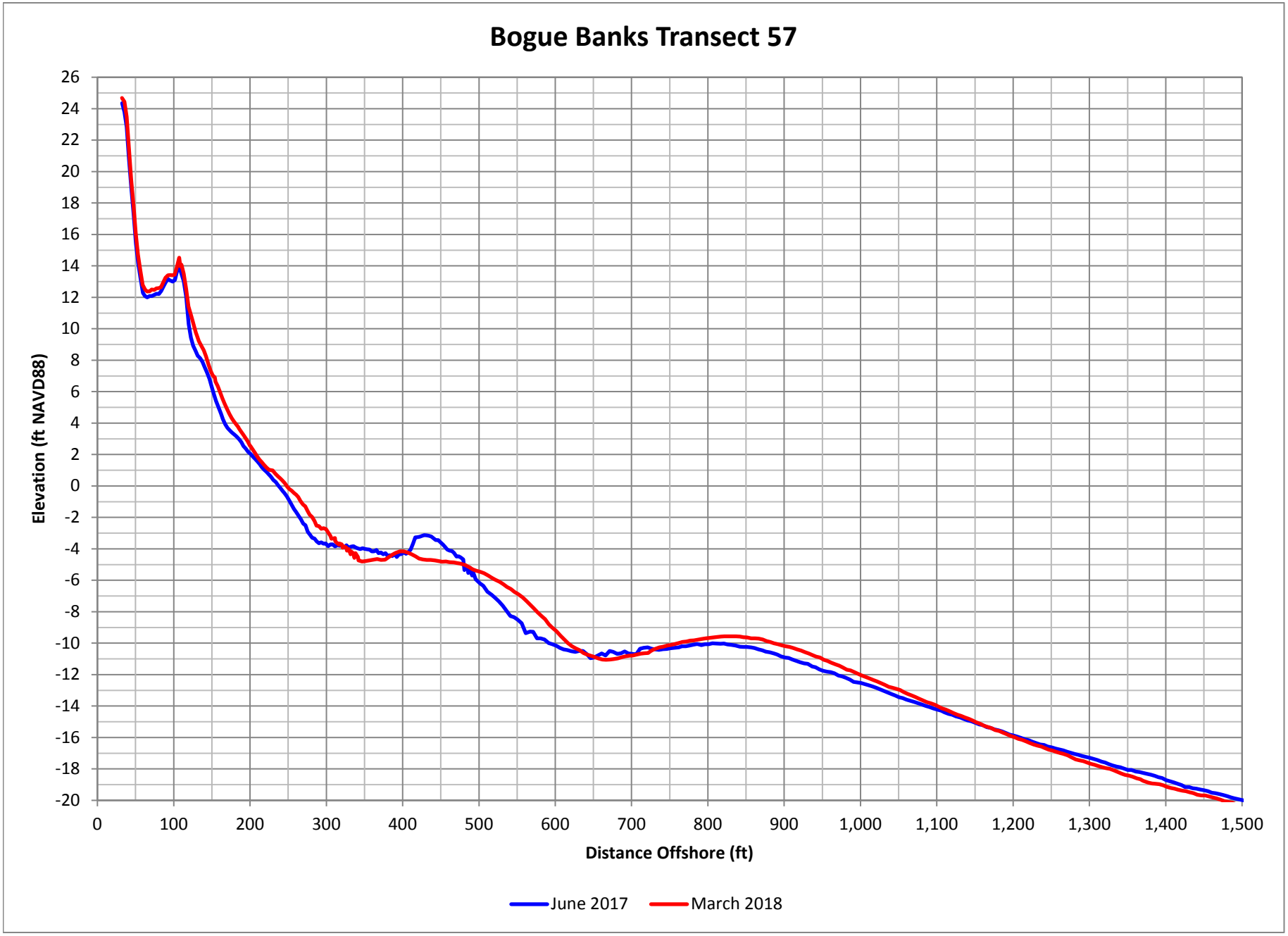


Figure D-114. Bogue Banks Profile Comparison Plot

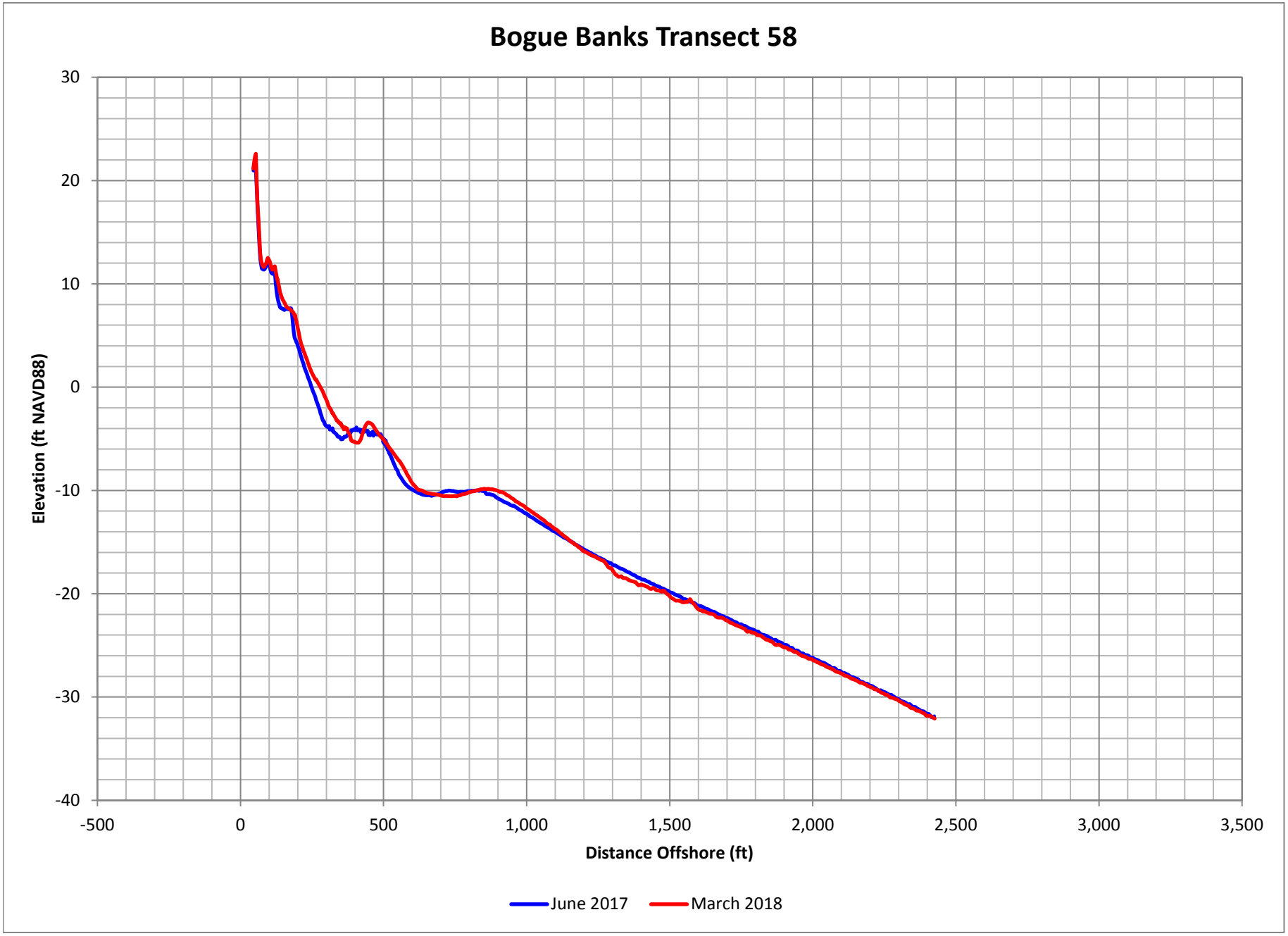


Figure D-115. Bogue Banks Profile Comparison Plot

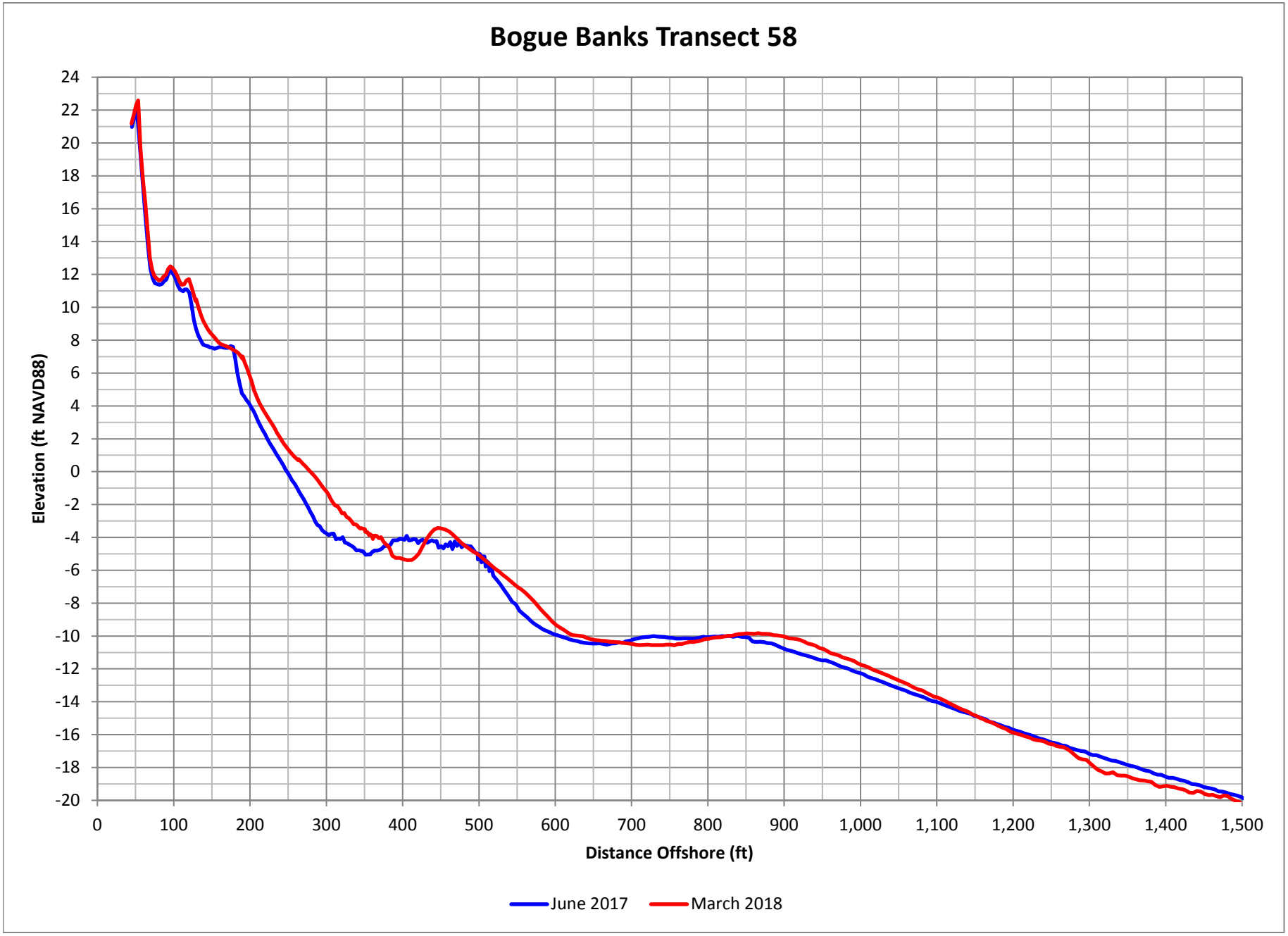


Figure D-116. Bogue Banks Profile Comparison Plot

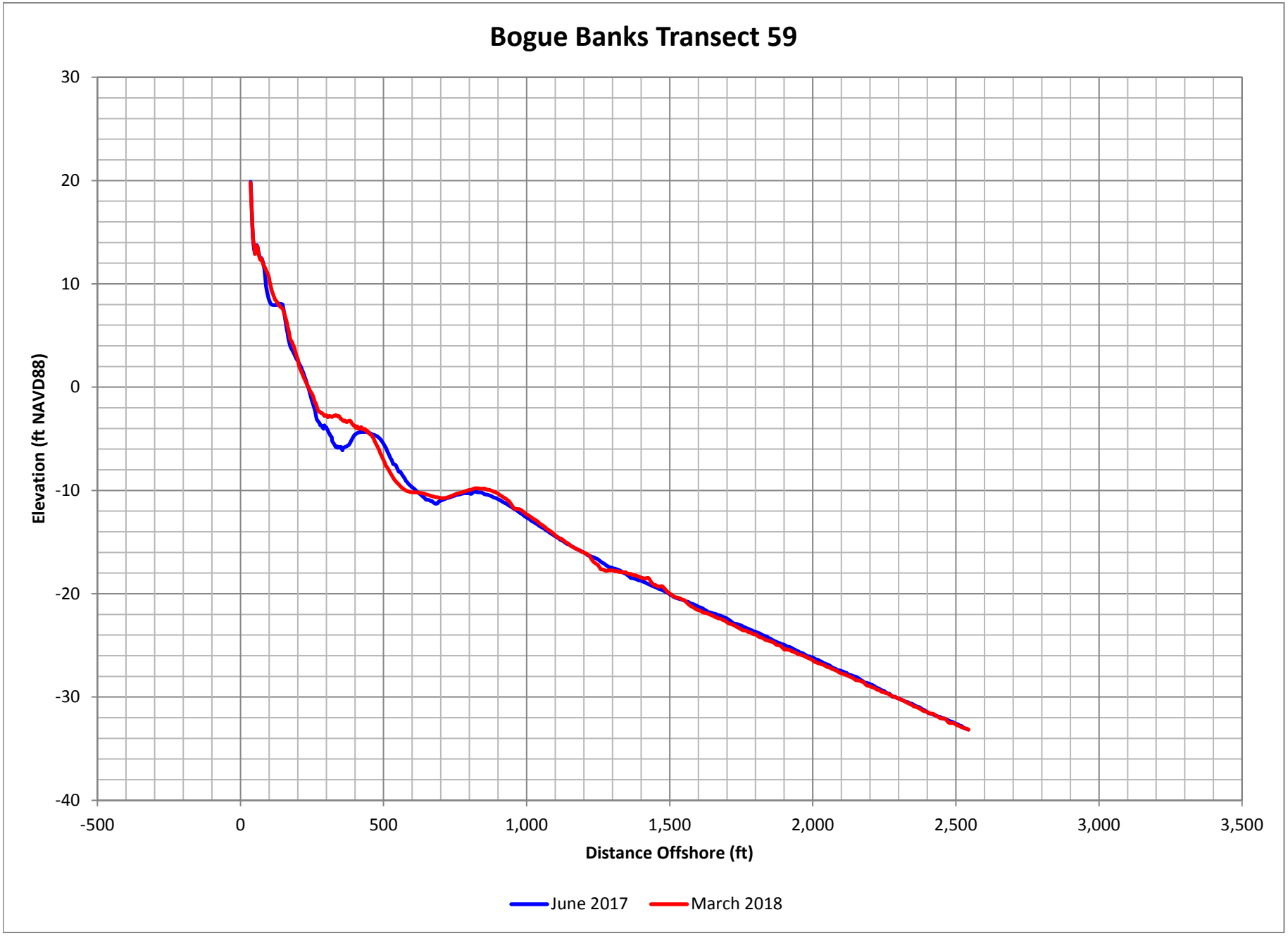


Figure D-117. Bogue Banks Profile Comparison Plot

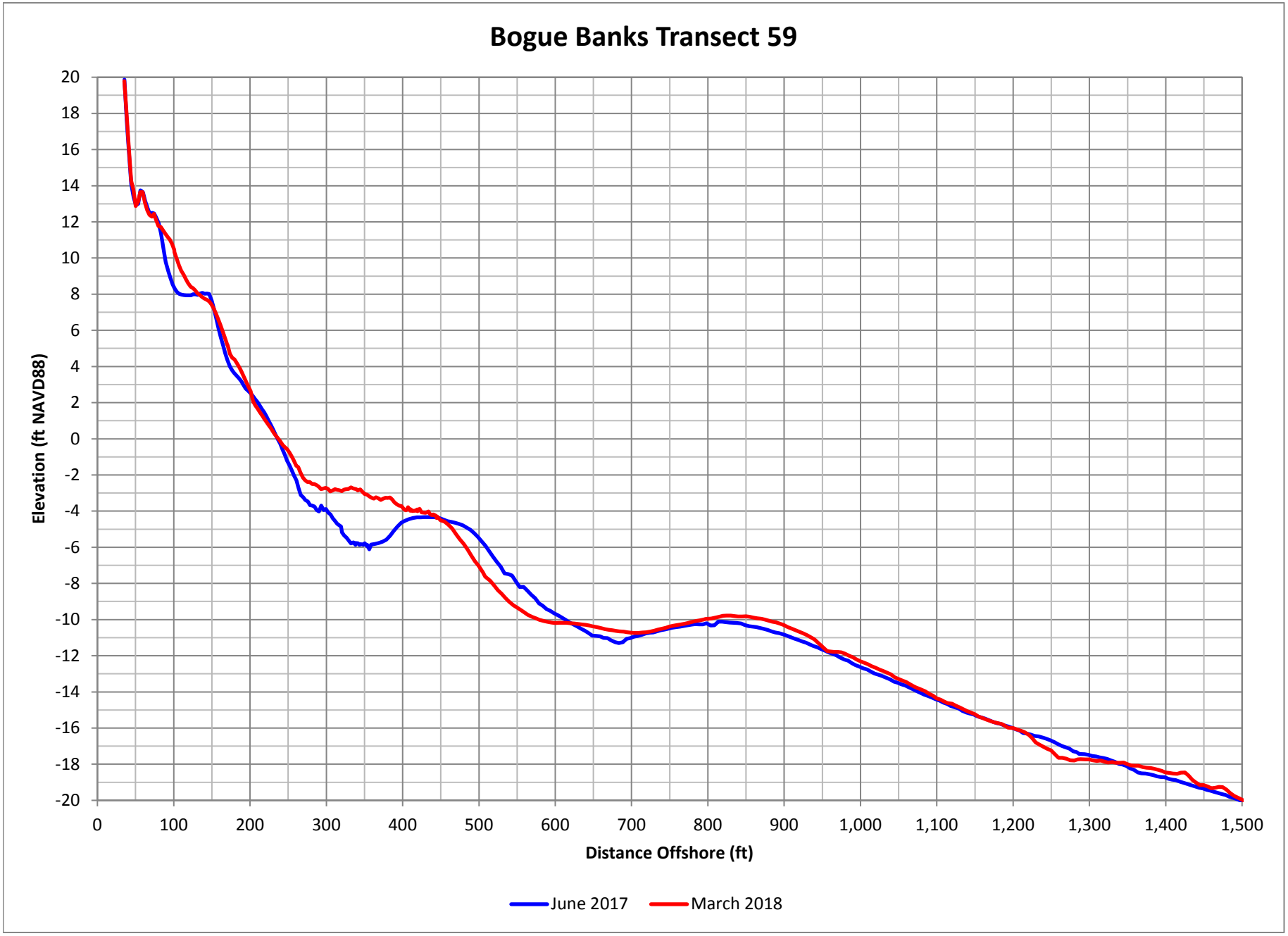


Figure D-118. Bogue Banks Profile Comparison Plot

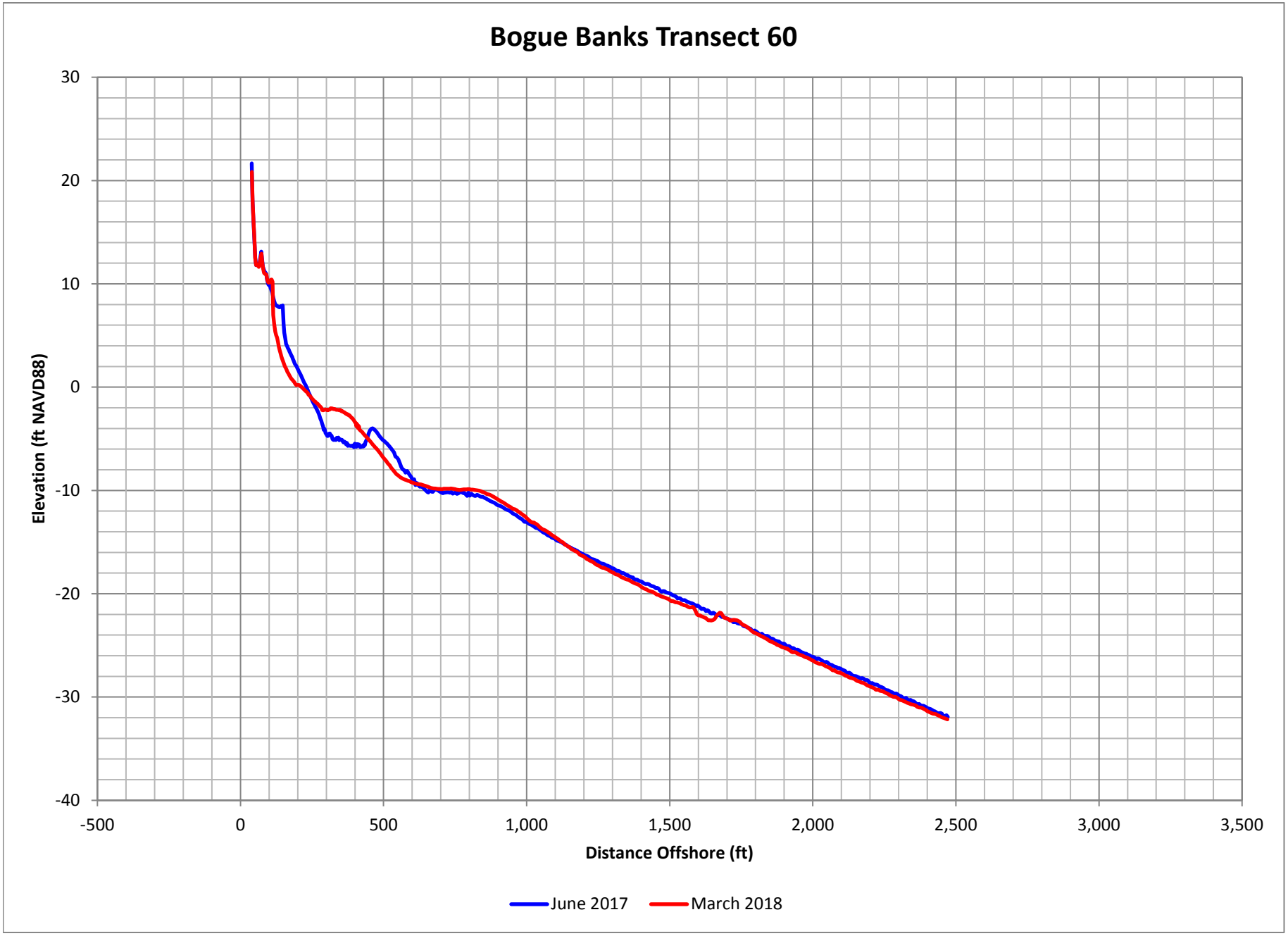


Figure D-119. Bogue Banks Profile Comparison Plot

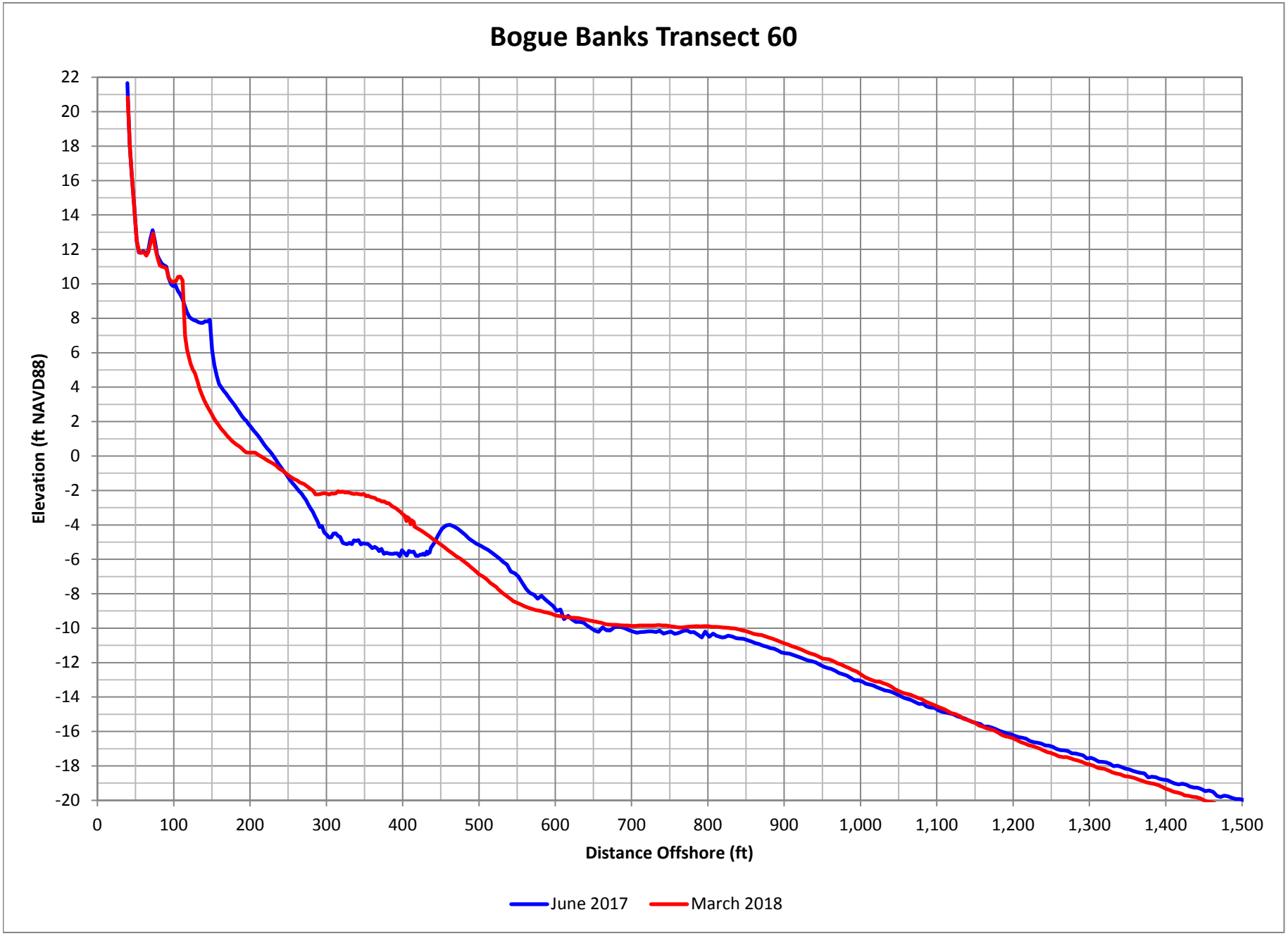


Figure D-120. Bogue Banks Profile Comparison Plot

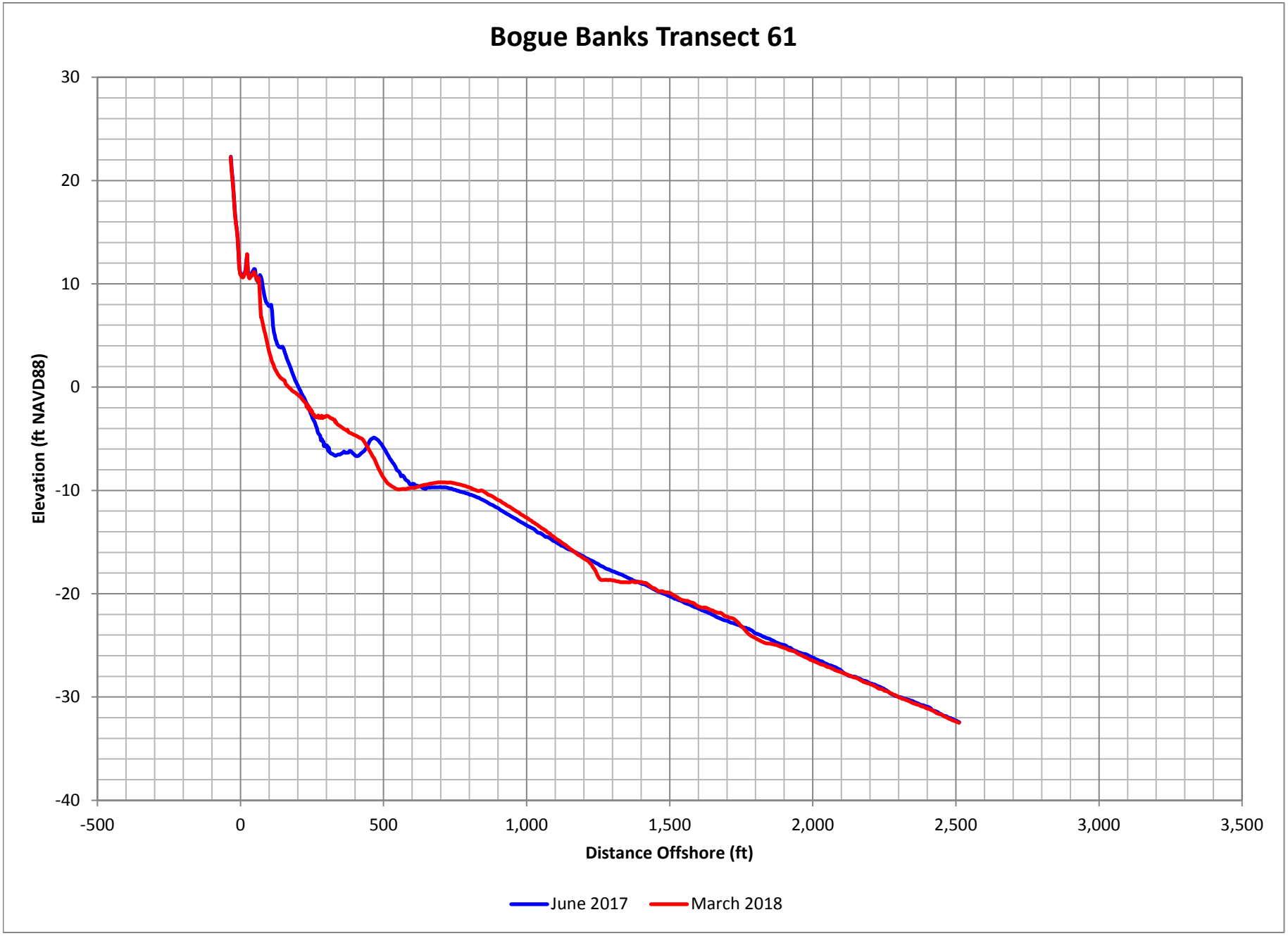


Figure D-121. Bogue Banks Profile Comparison Plot

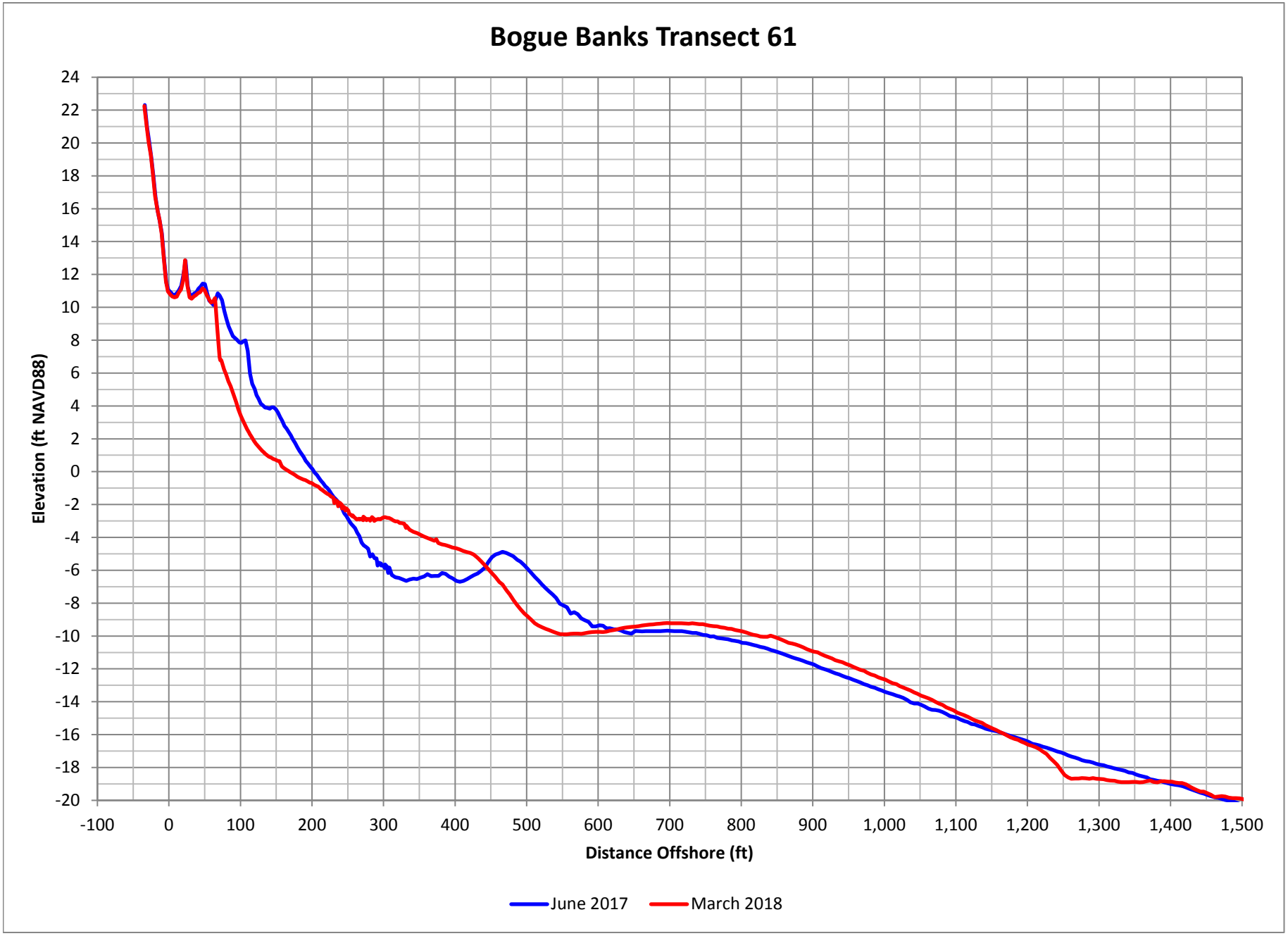


Figure D-122. Bogue Banks Profile Comparison Plot

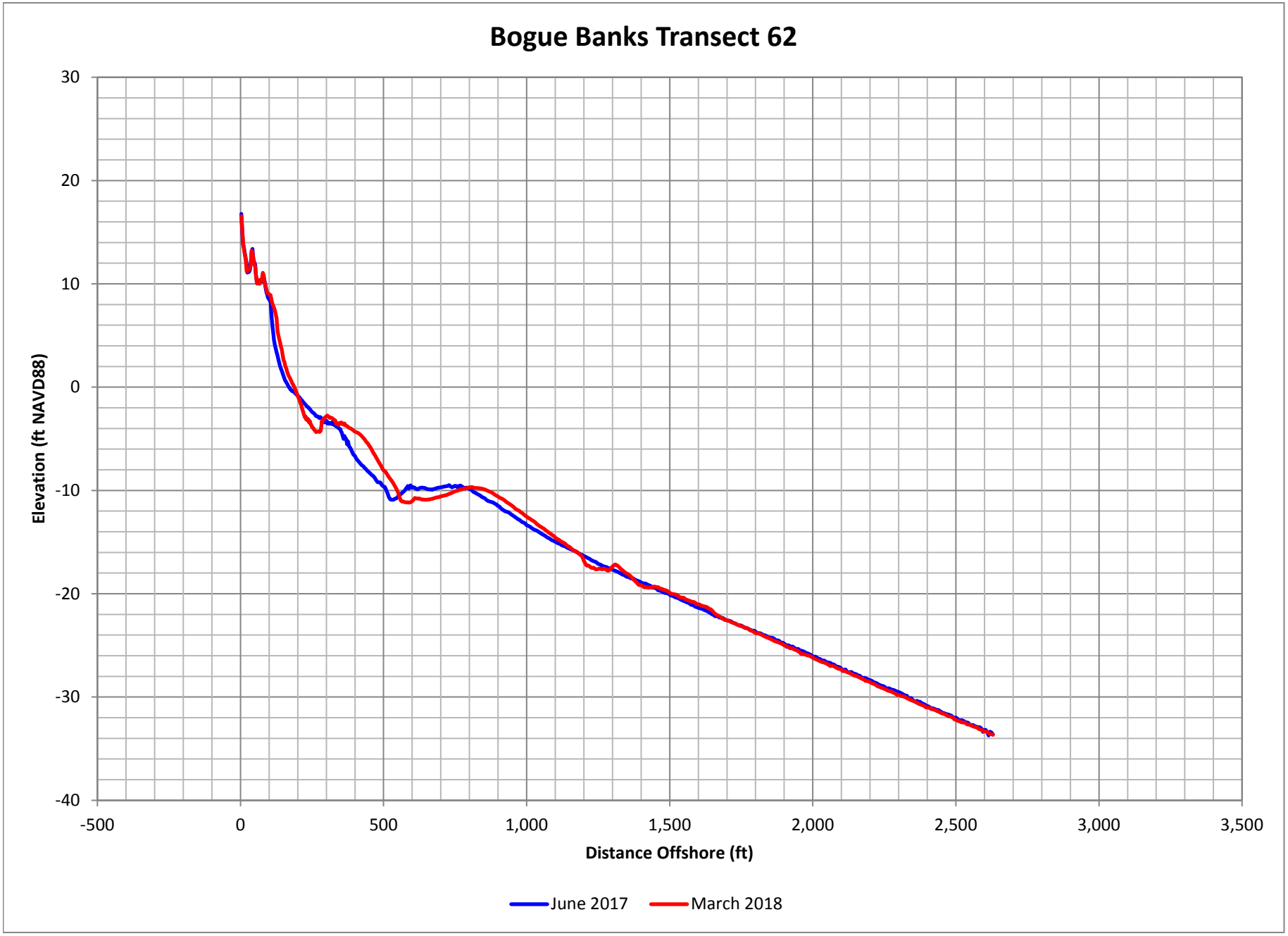


Figure D-123. Bogue Banks Profile Comparison Plot

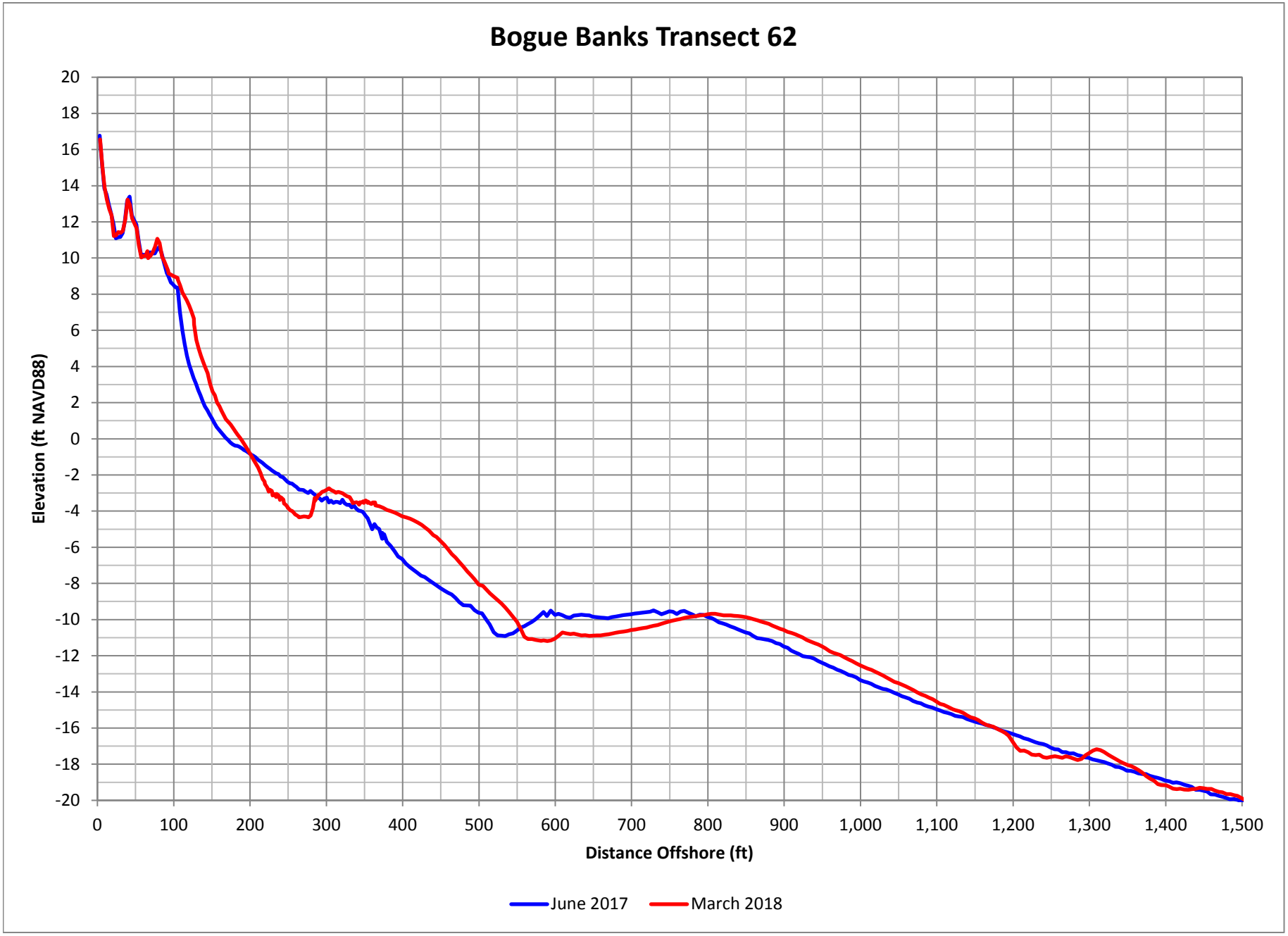


Figure D-124. Bogue Banks Profile Comparison Plot

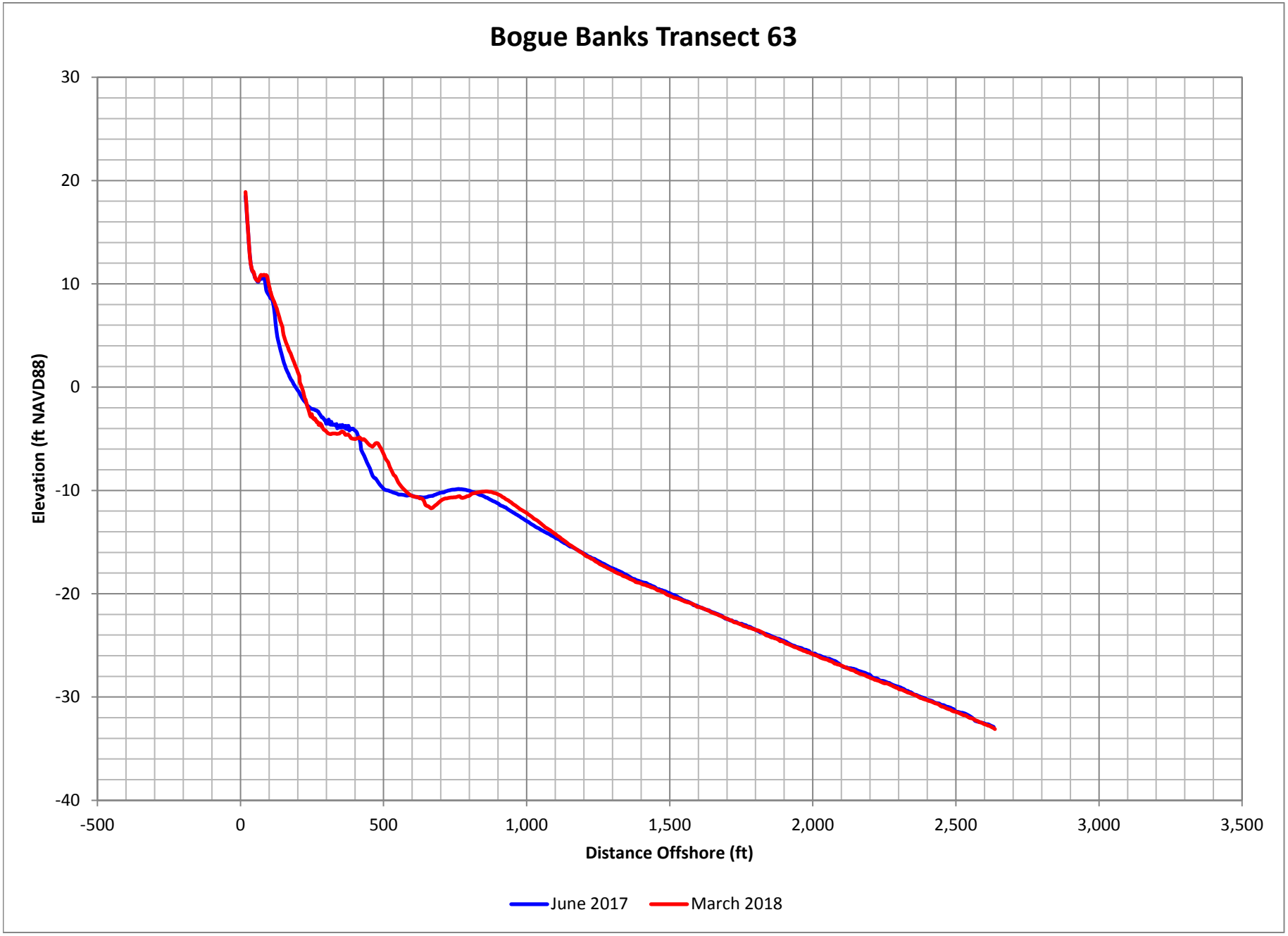


Figure D-125. Bogue Banks Profile Comparison Plot

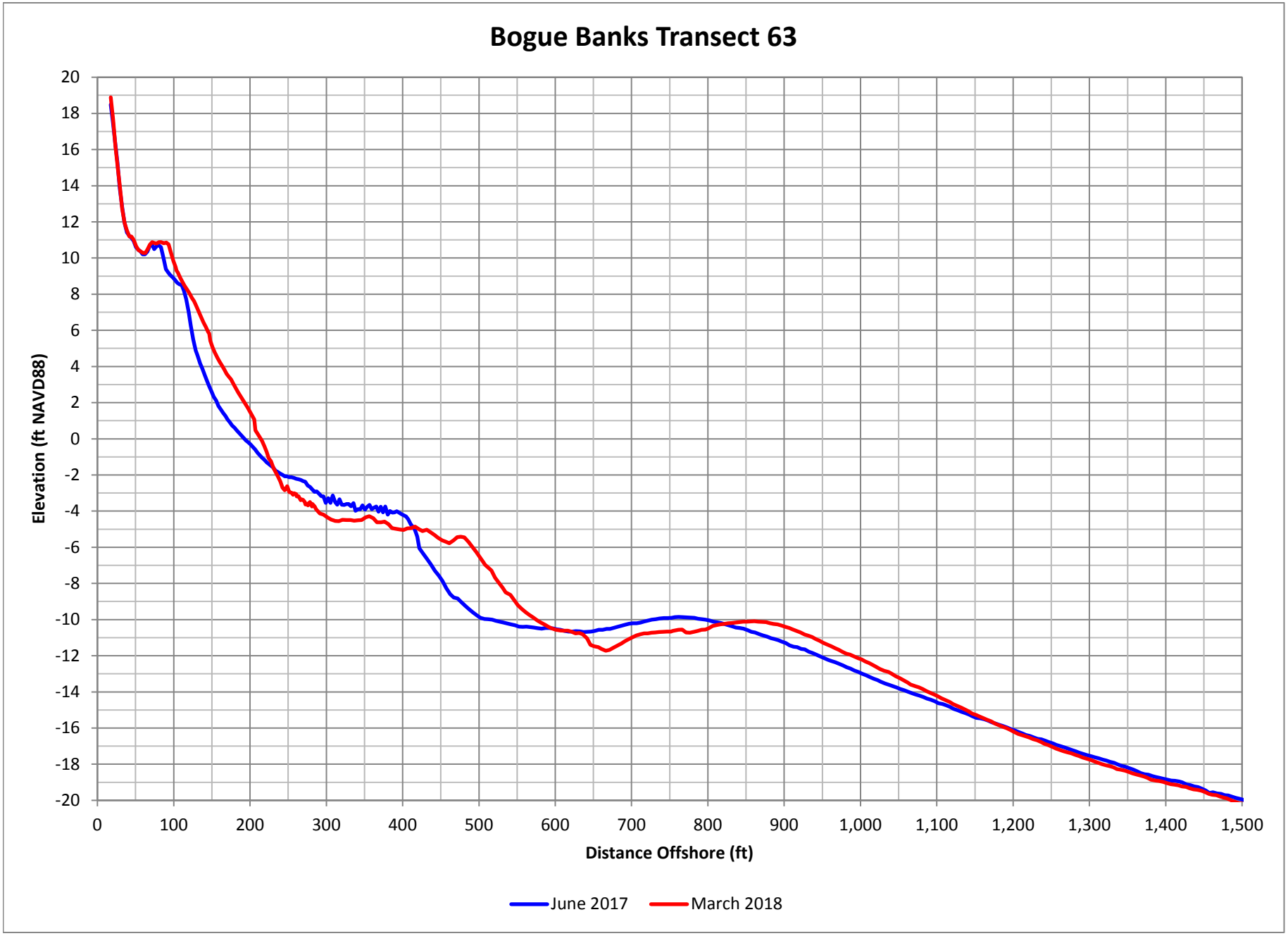


Figure D-126. Bogue Banks Profile Comparison Plot

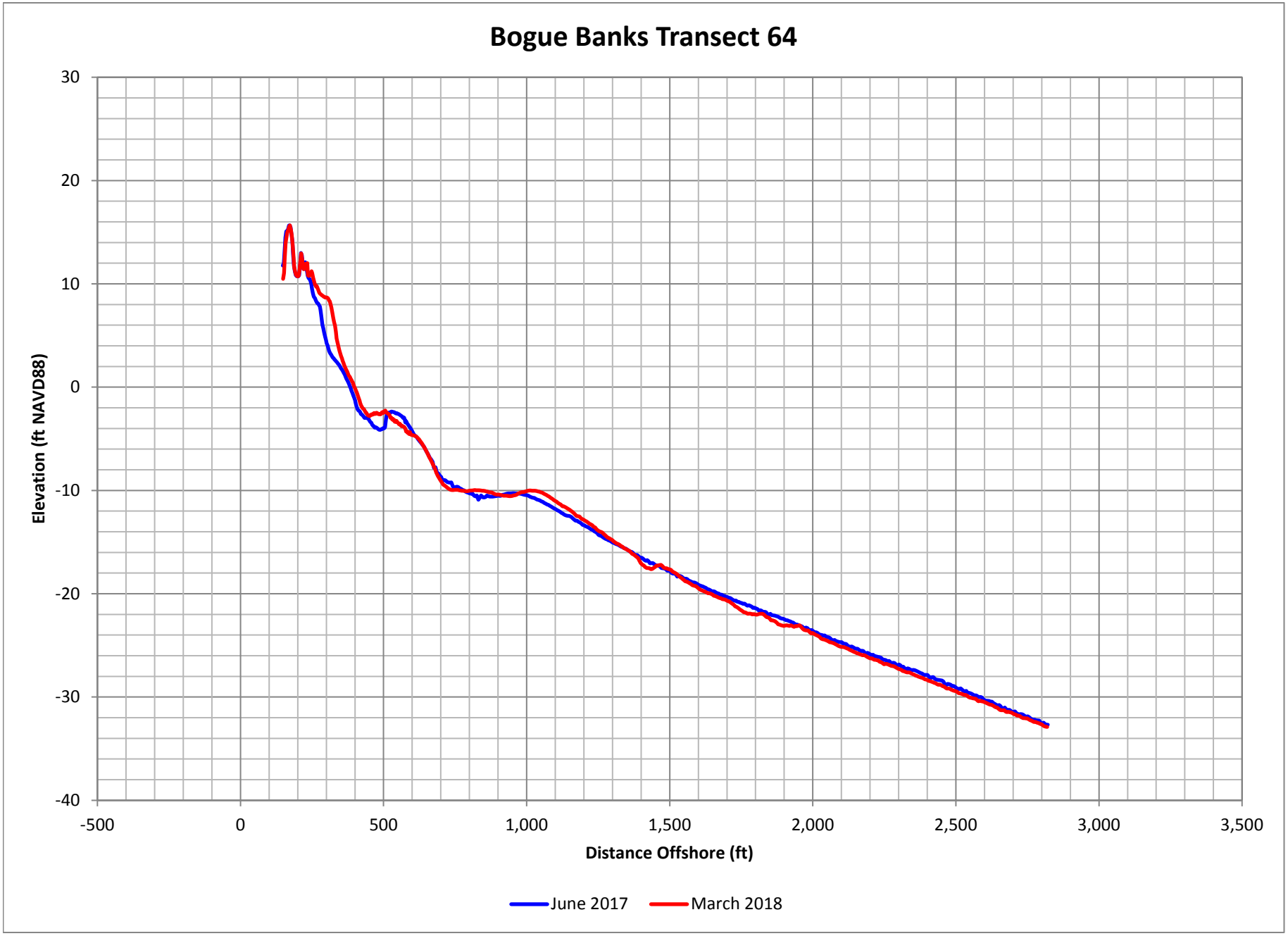


Figure D-127. Bogue Banks Profile Comparison Plot

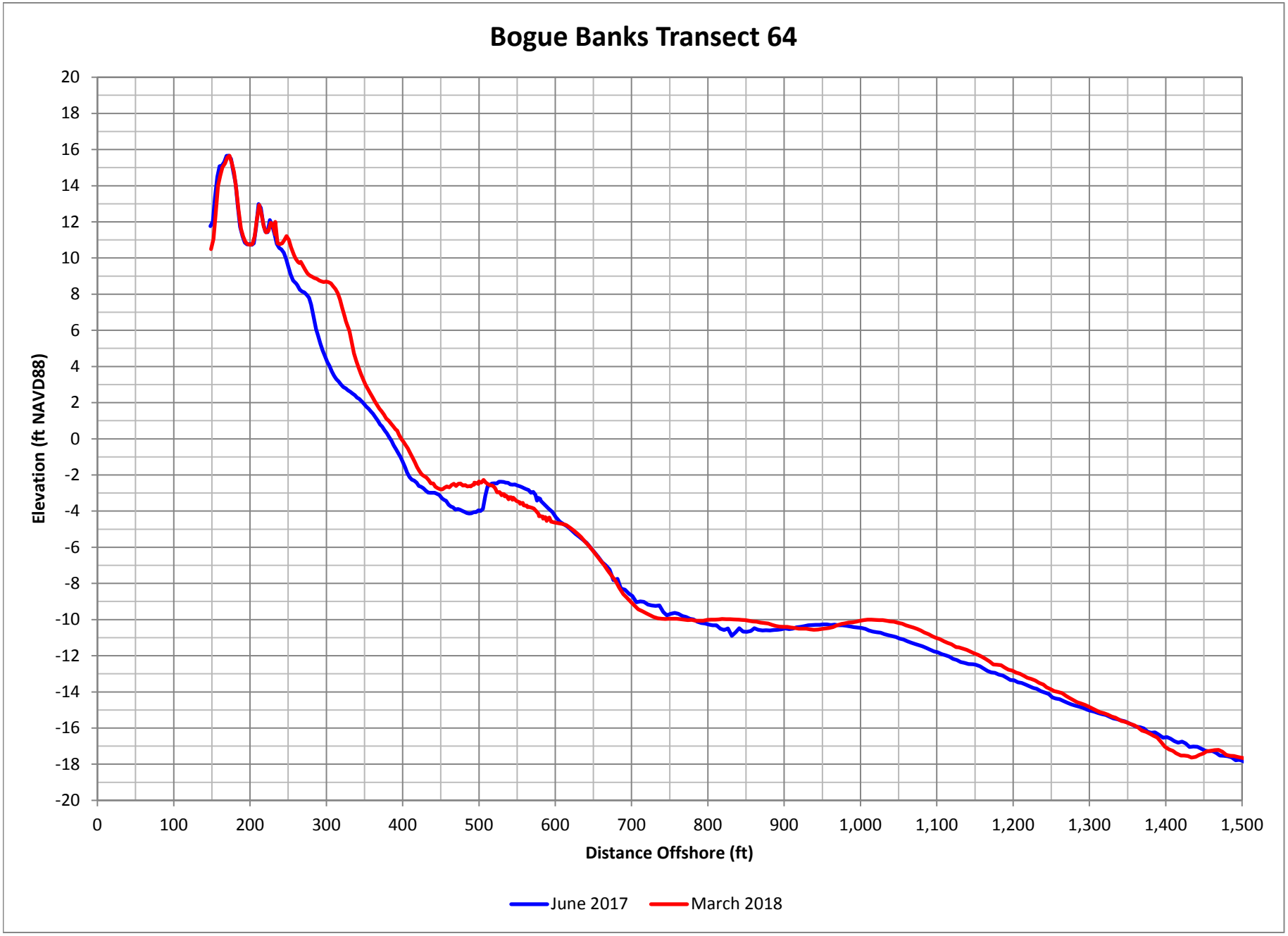


Figure D-128. Bogue Banks Profile Comparison Plot

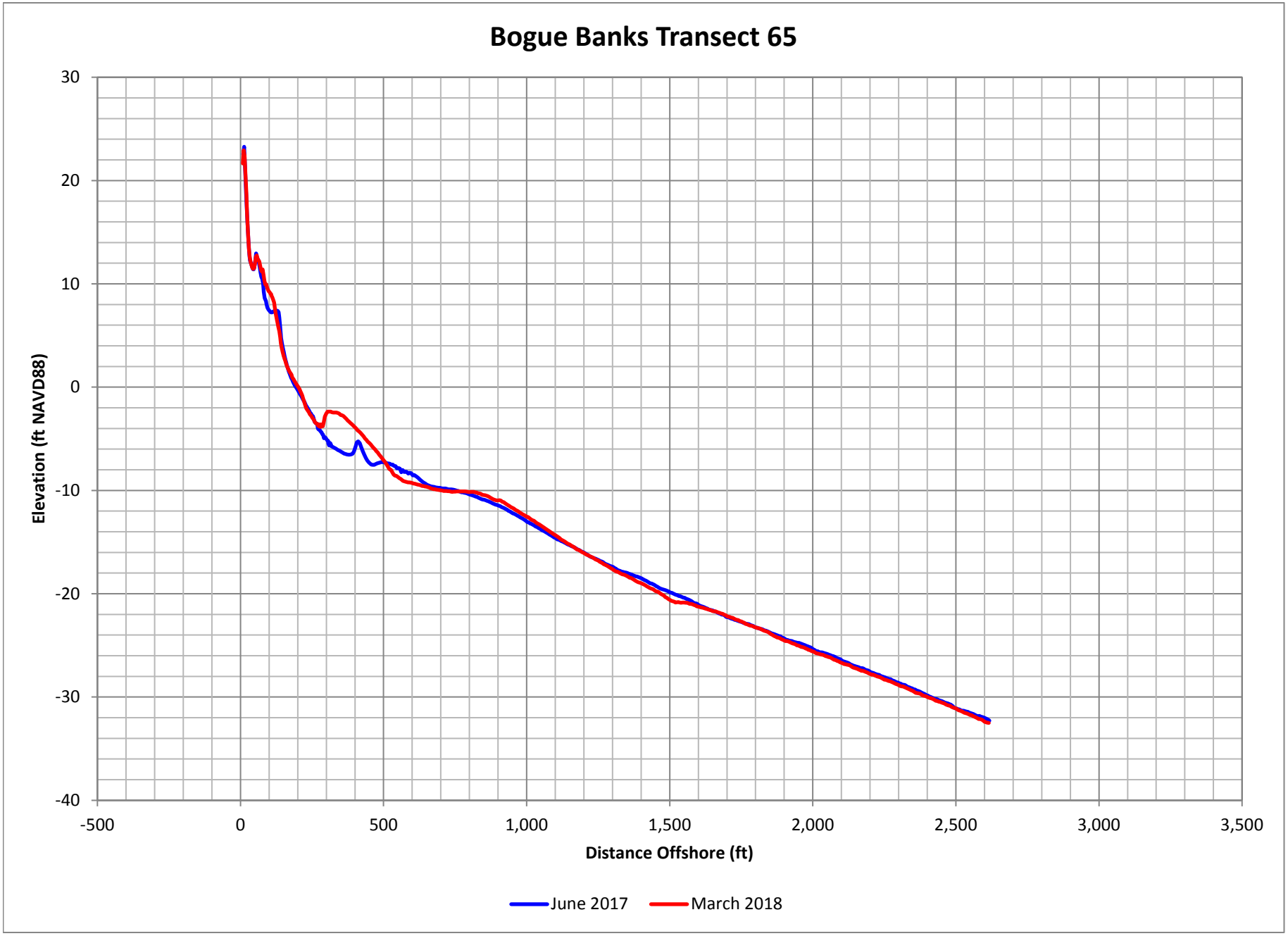


Figure D-129. Bogue Banks Profile Comparison Plot

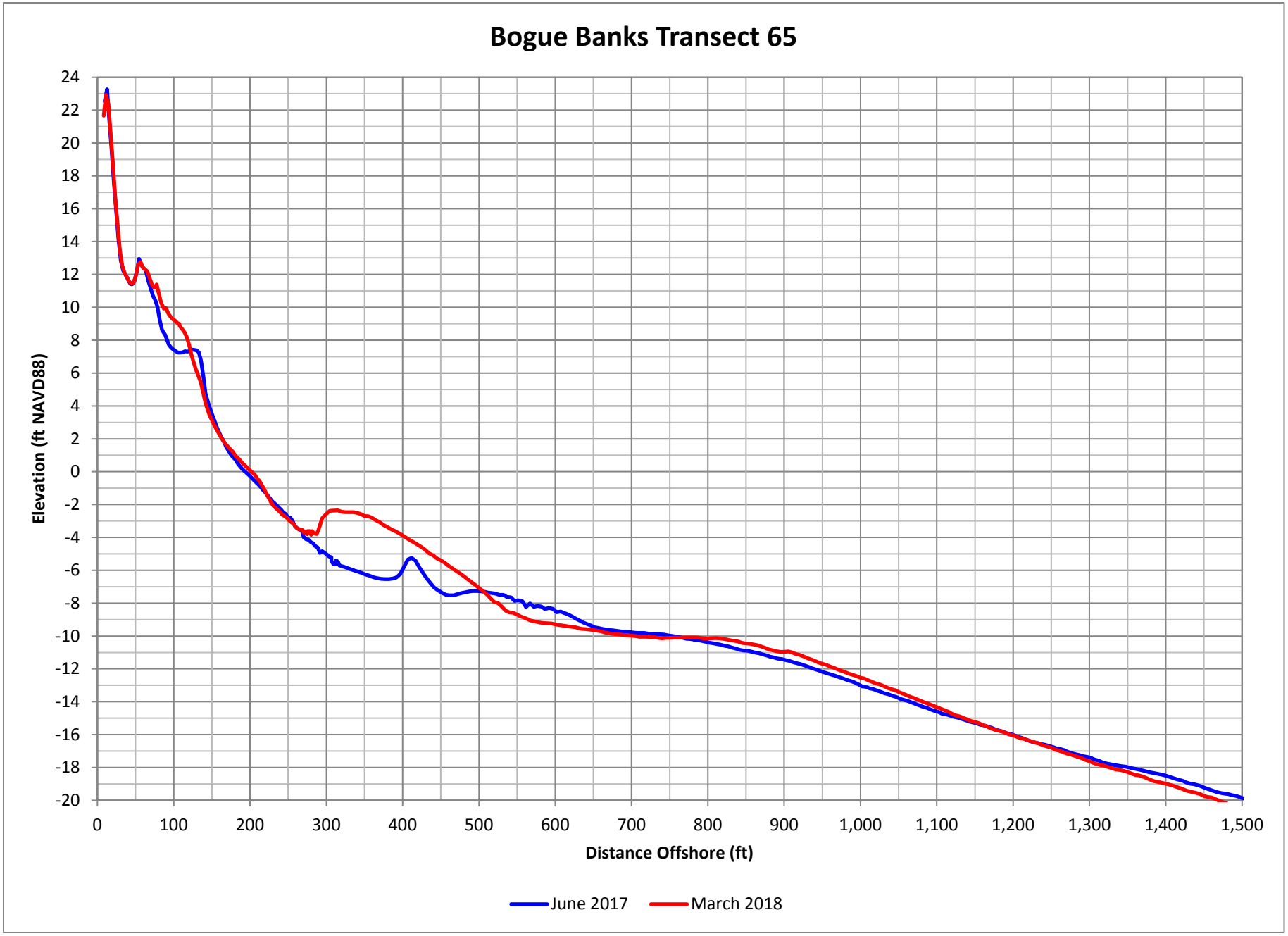


Figure D-130. Bogue Banks Profile Comparison Plot

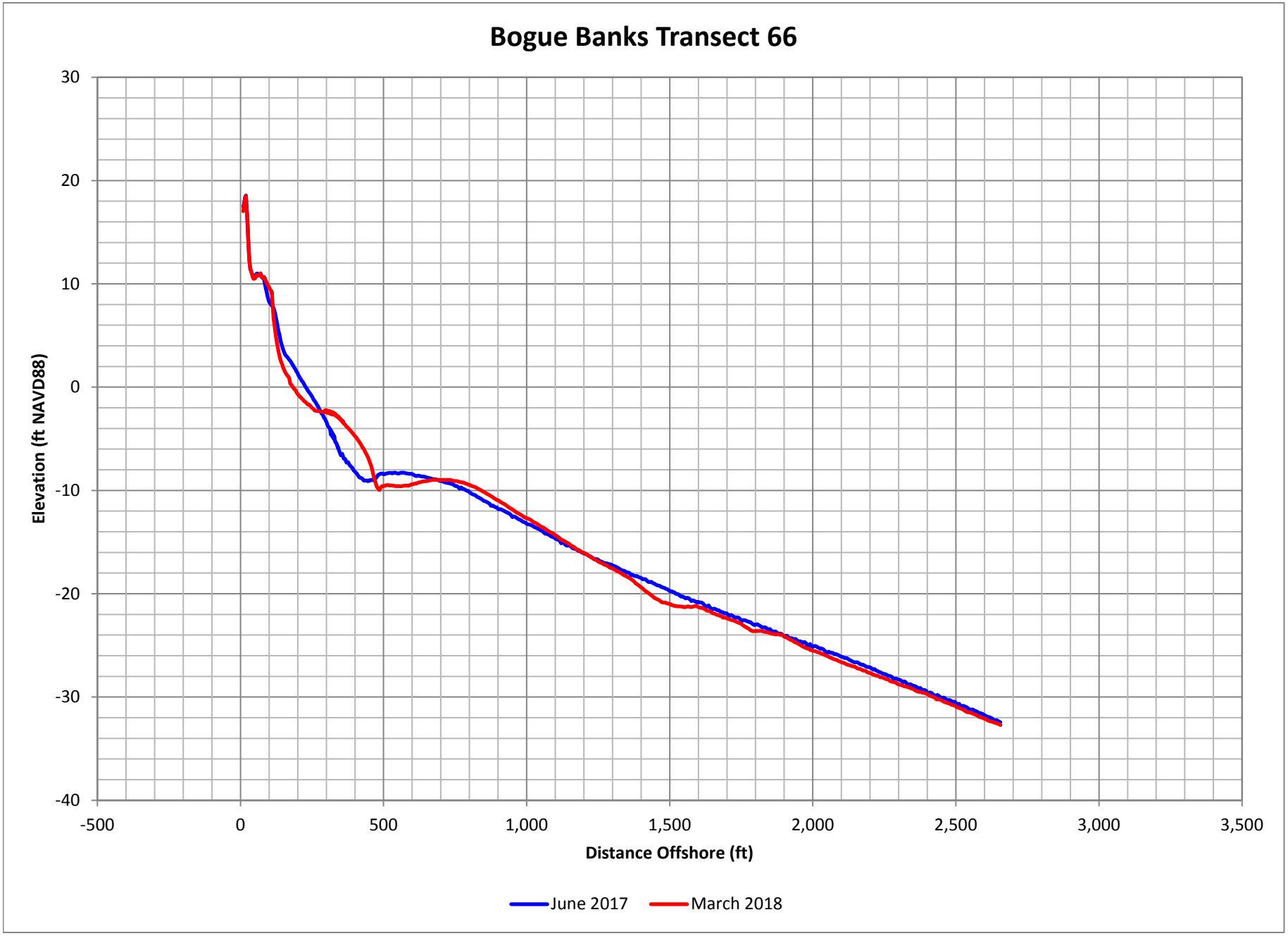


Figure D-131. Bogue Banks Profile Comparison Plot

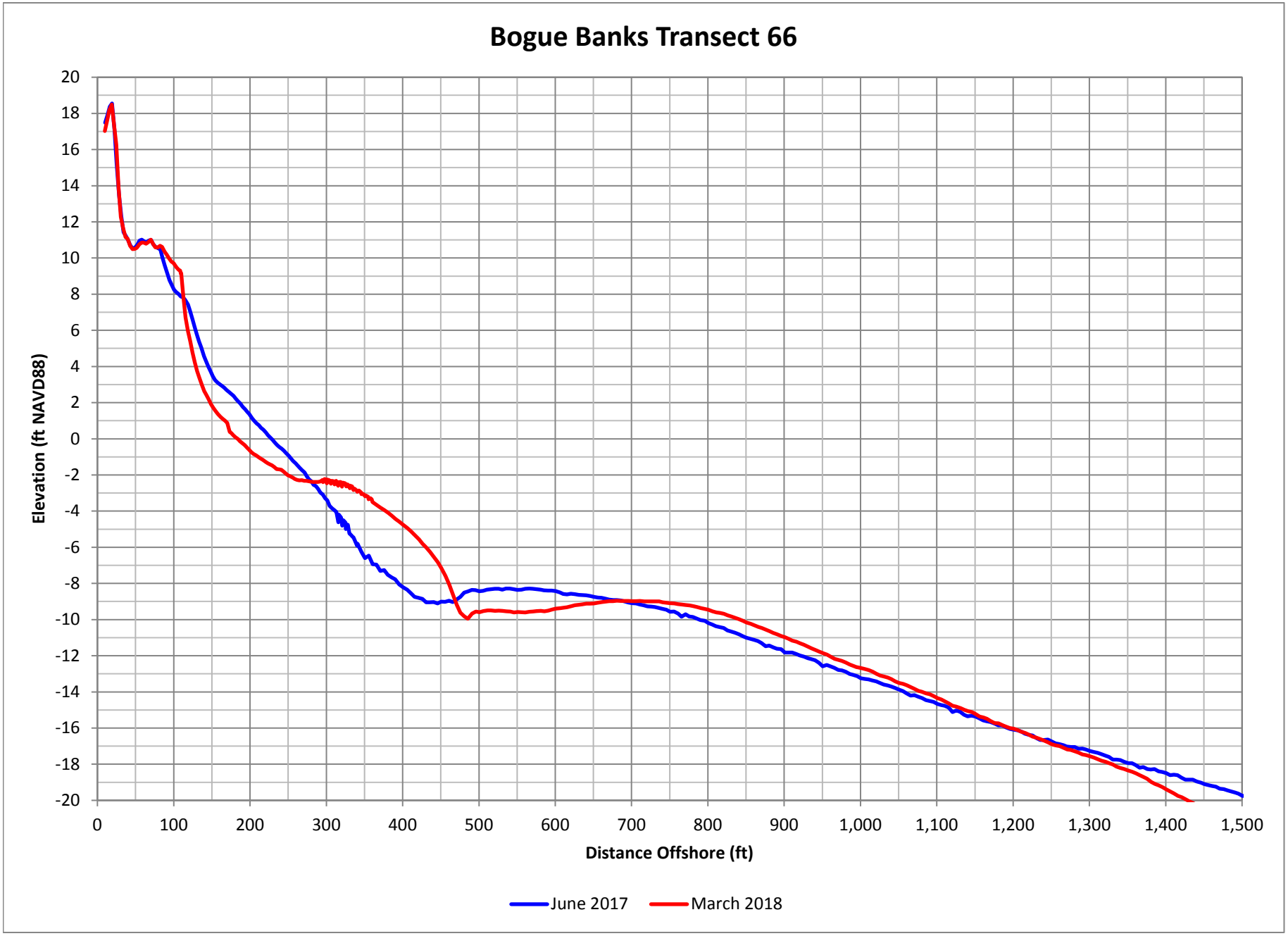


Figure D-132. Bogue Banks Profile Comparison Plot

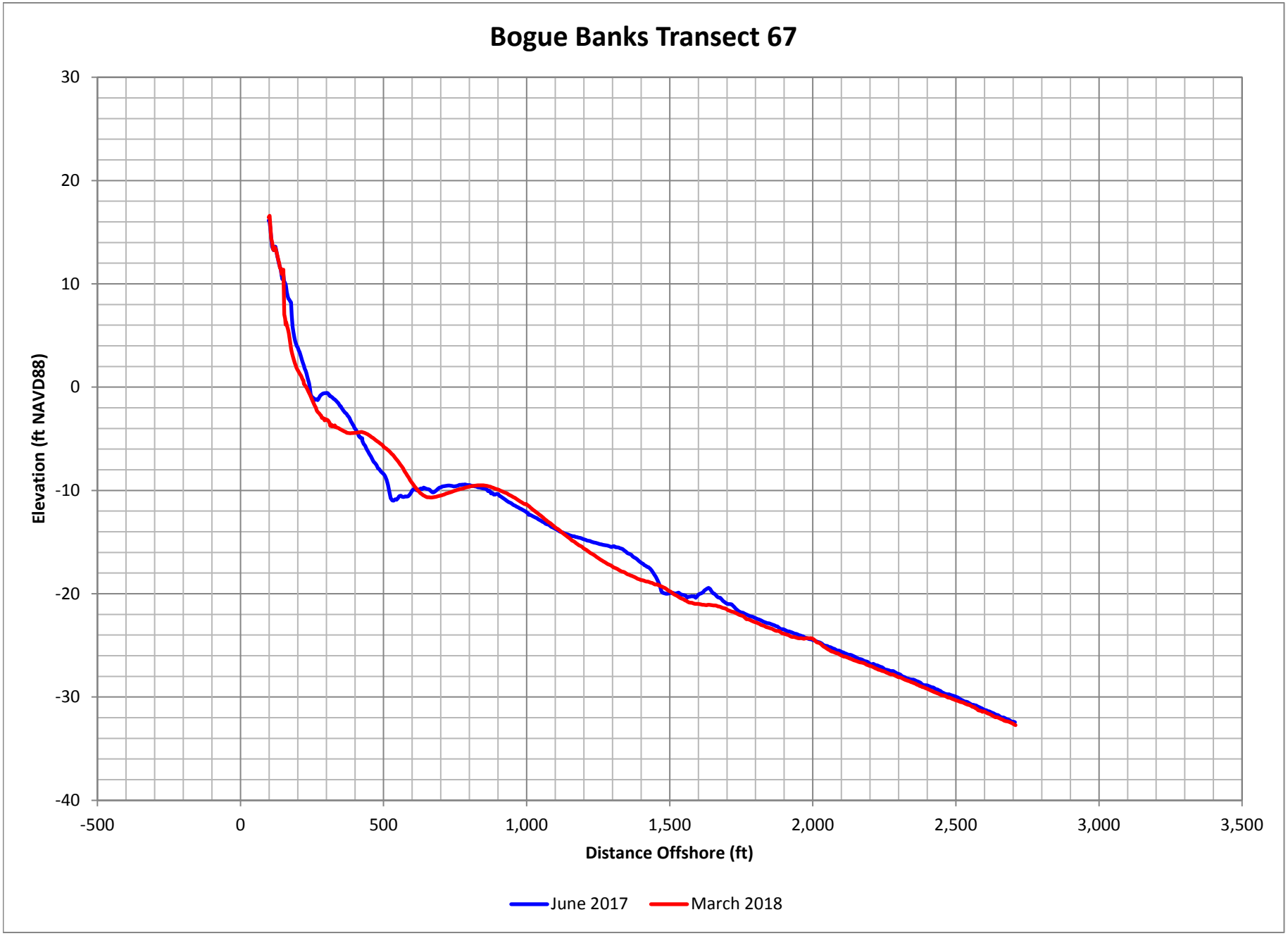


Figure D-133. Bogue Banks Profile Comparison Plot

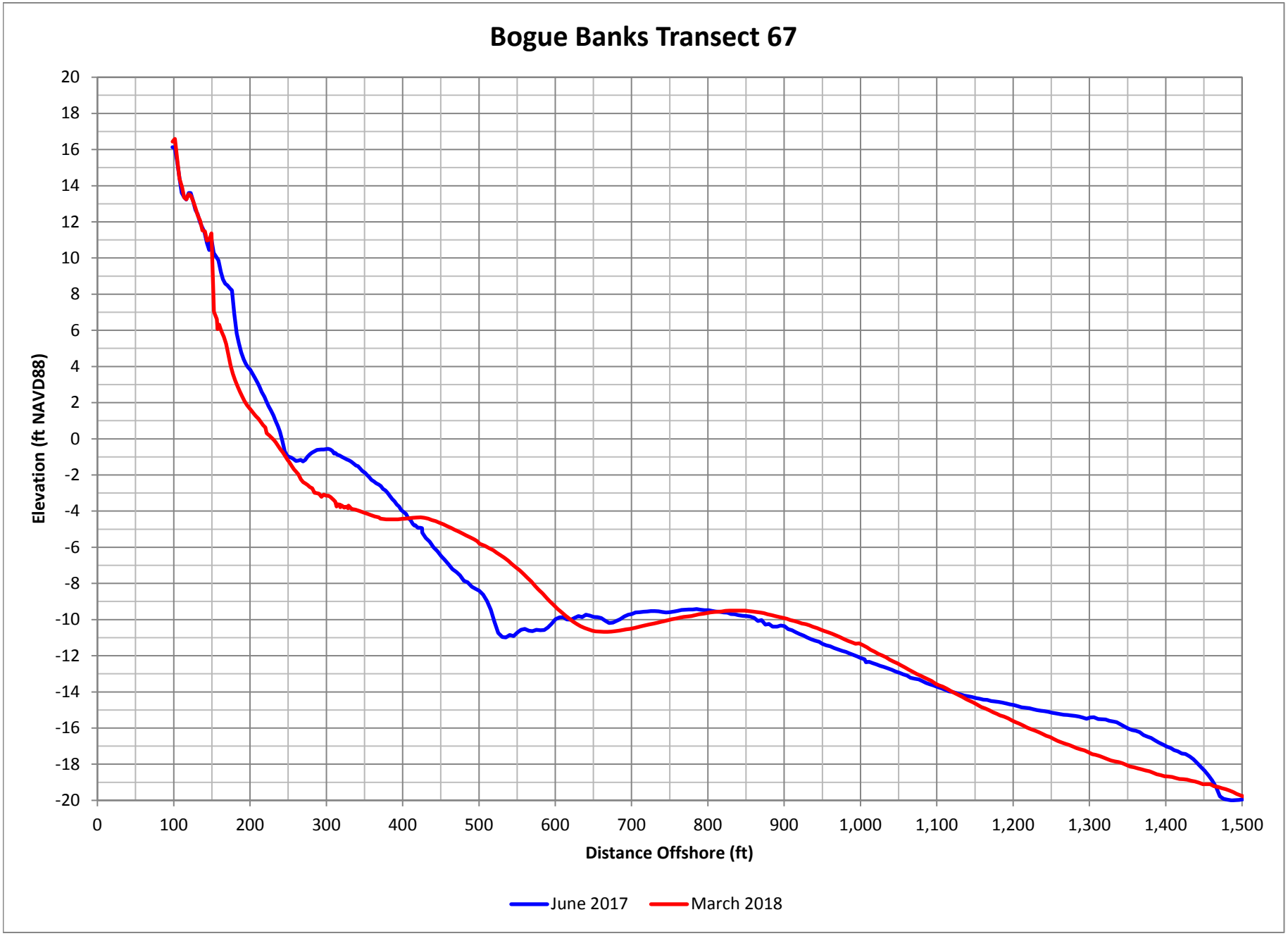


Figure D-134. Bogue Banks Profile Comparison Plot

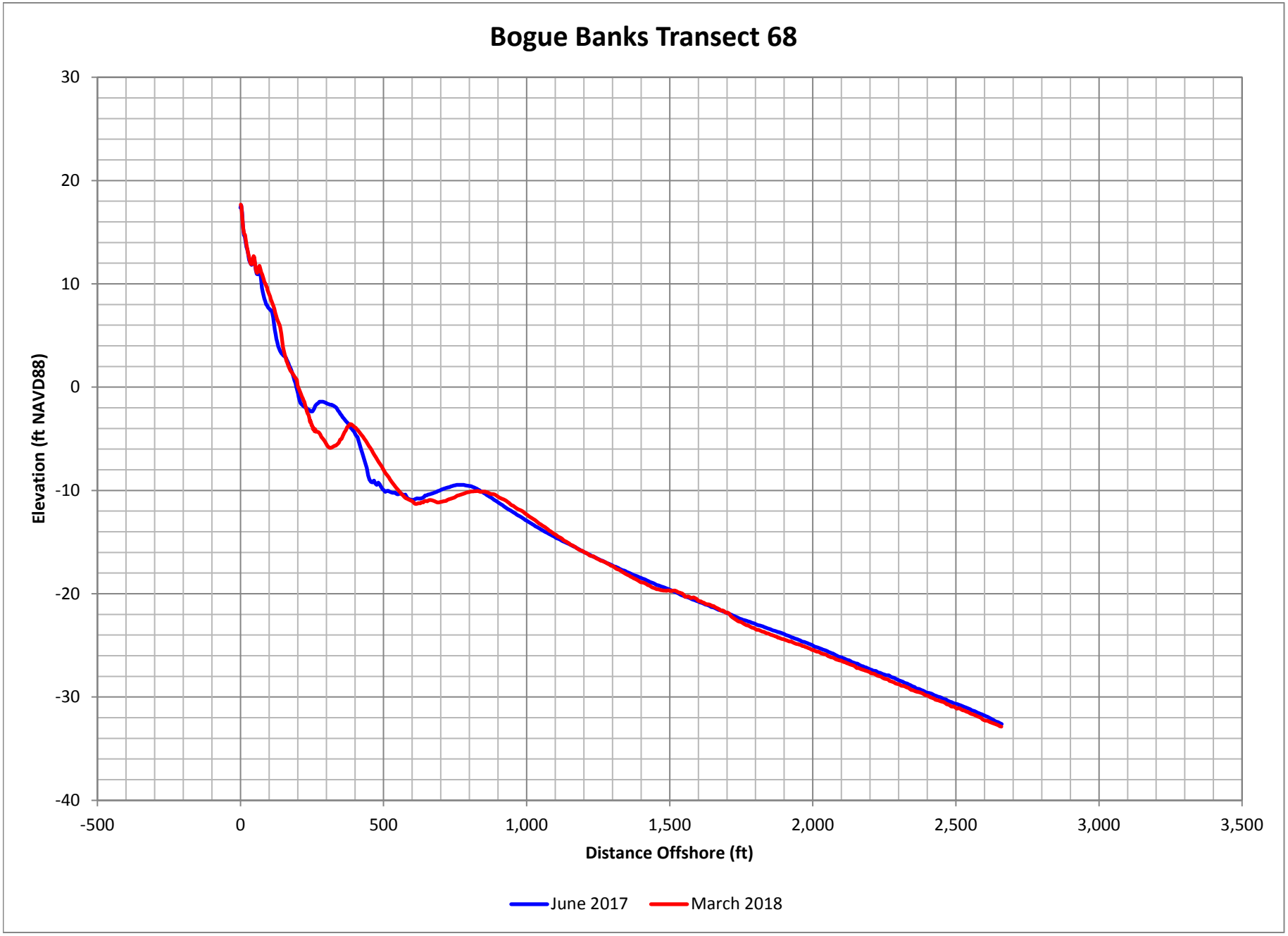


Figure D-135. Bogue Banks Profile Comparison Plot

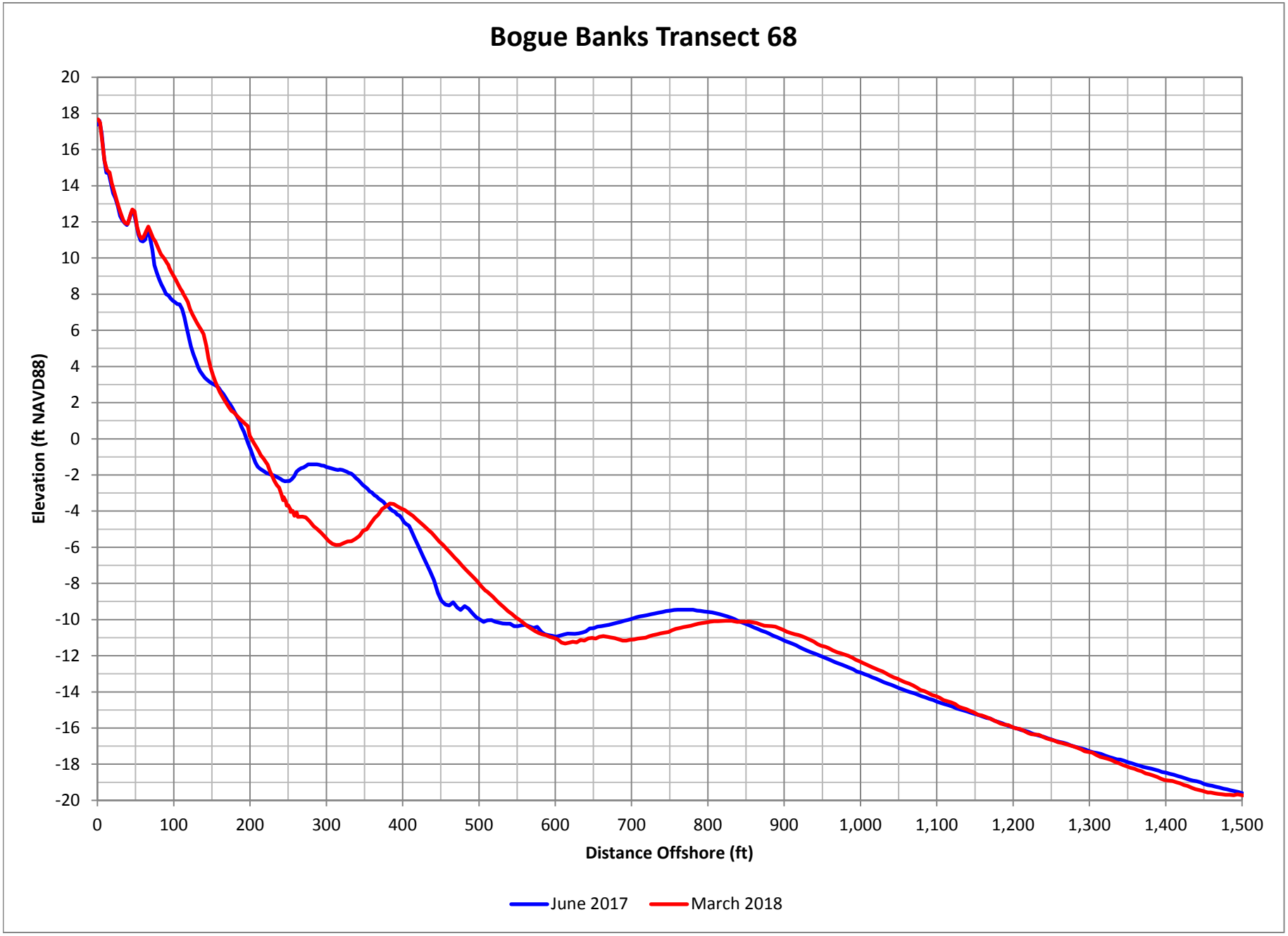


Figure D-136. Bogue Banks Profile Comparison Plot

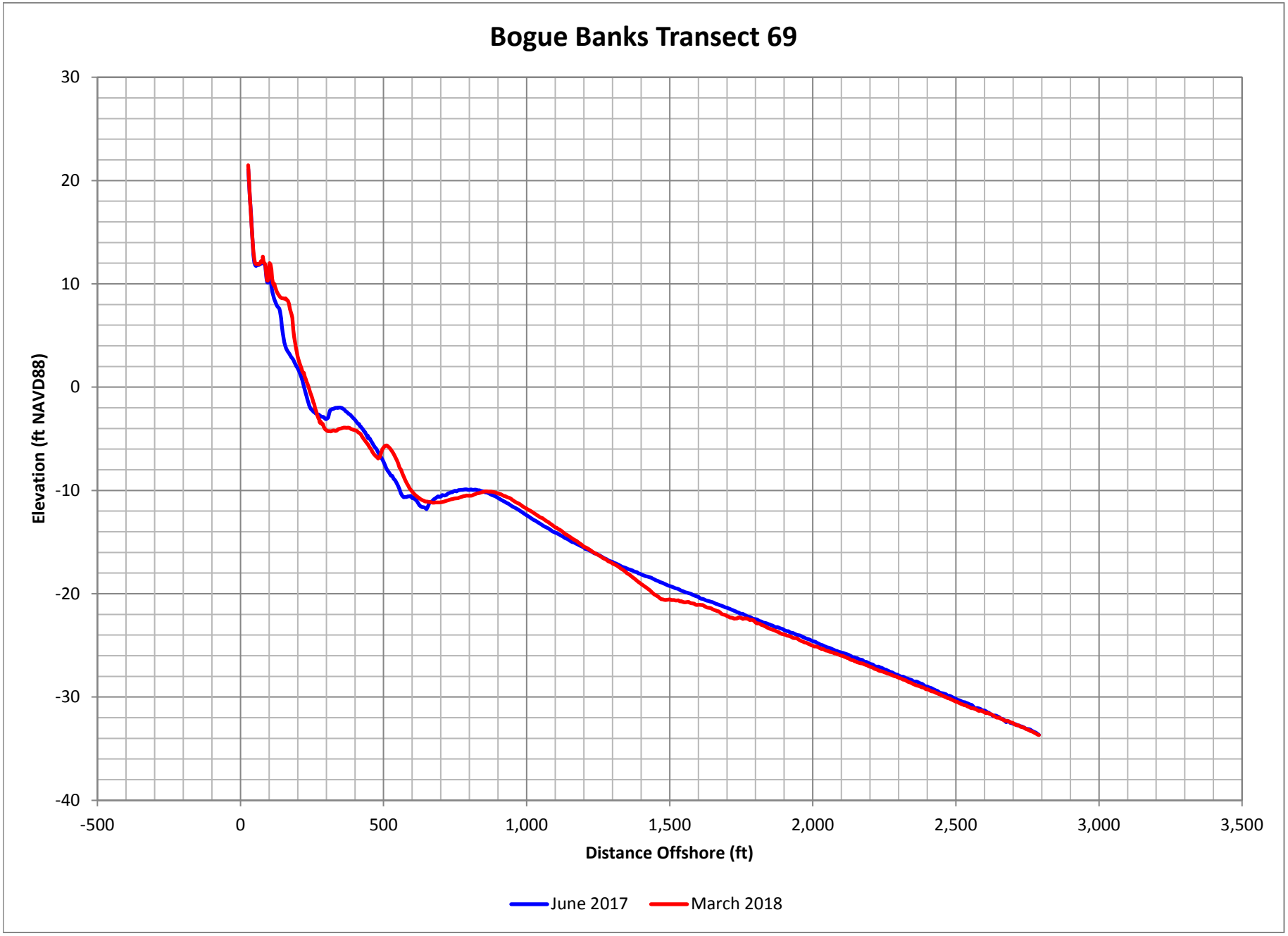


Figure D-137. Bogue Banks Profile Comparison Plot

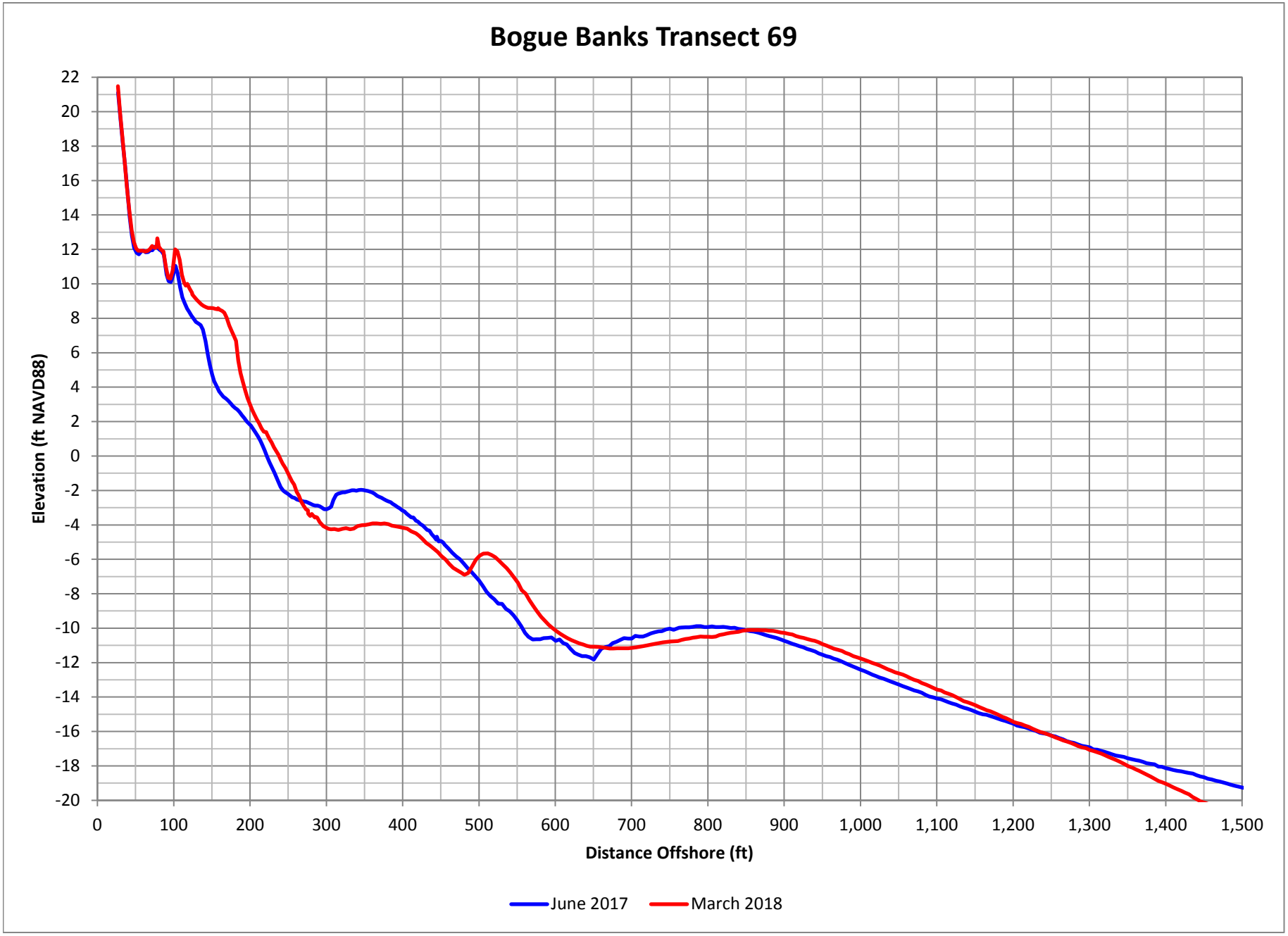


Figure D-138. Bogue Banks Profile Comparison Plot

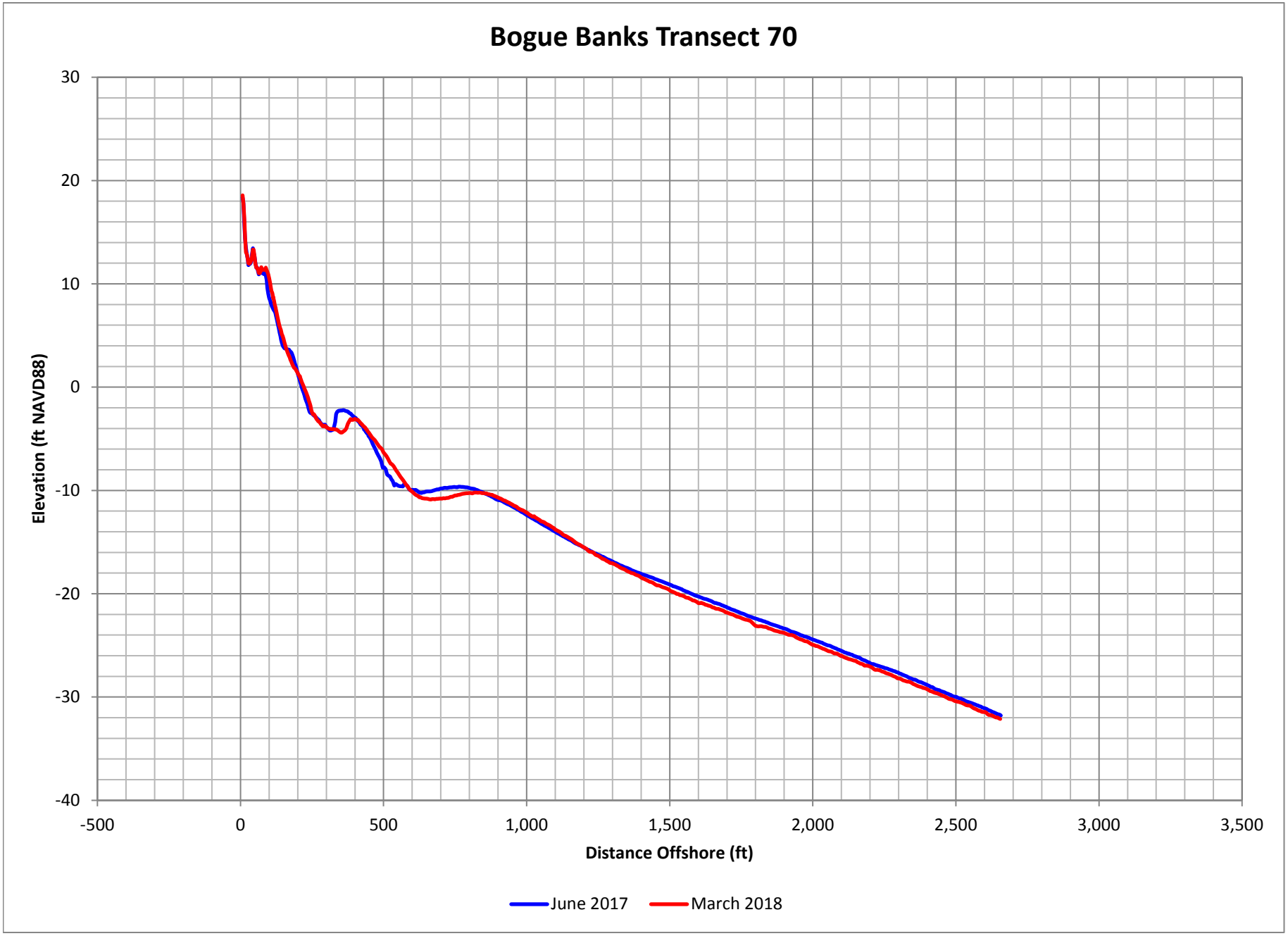


Figure D-139. Bogue Banks Profile Comparison Plot

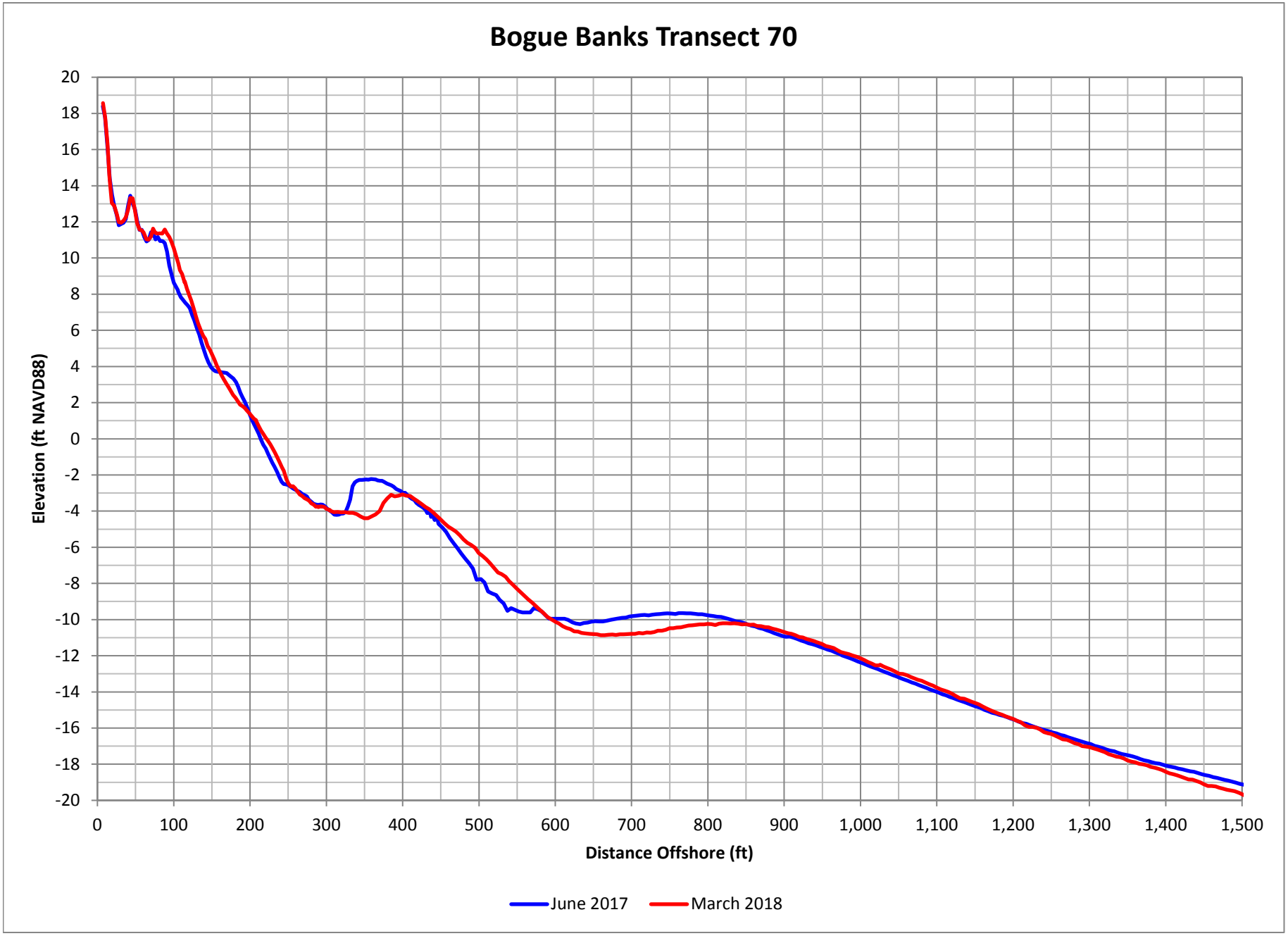


Figure D-140. Bogue Banks Profile Comparison Plot

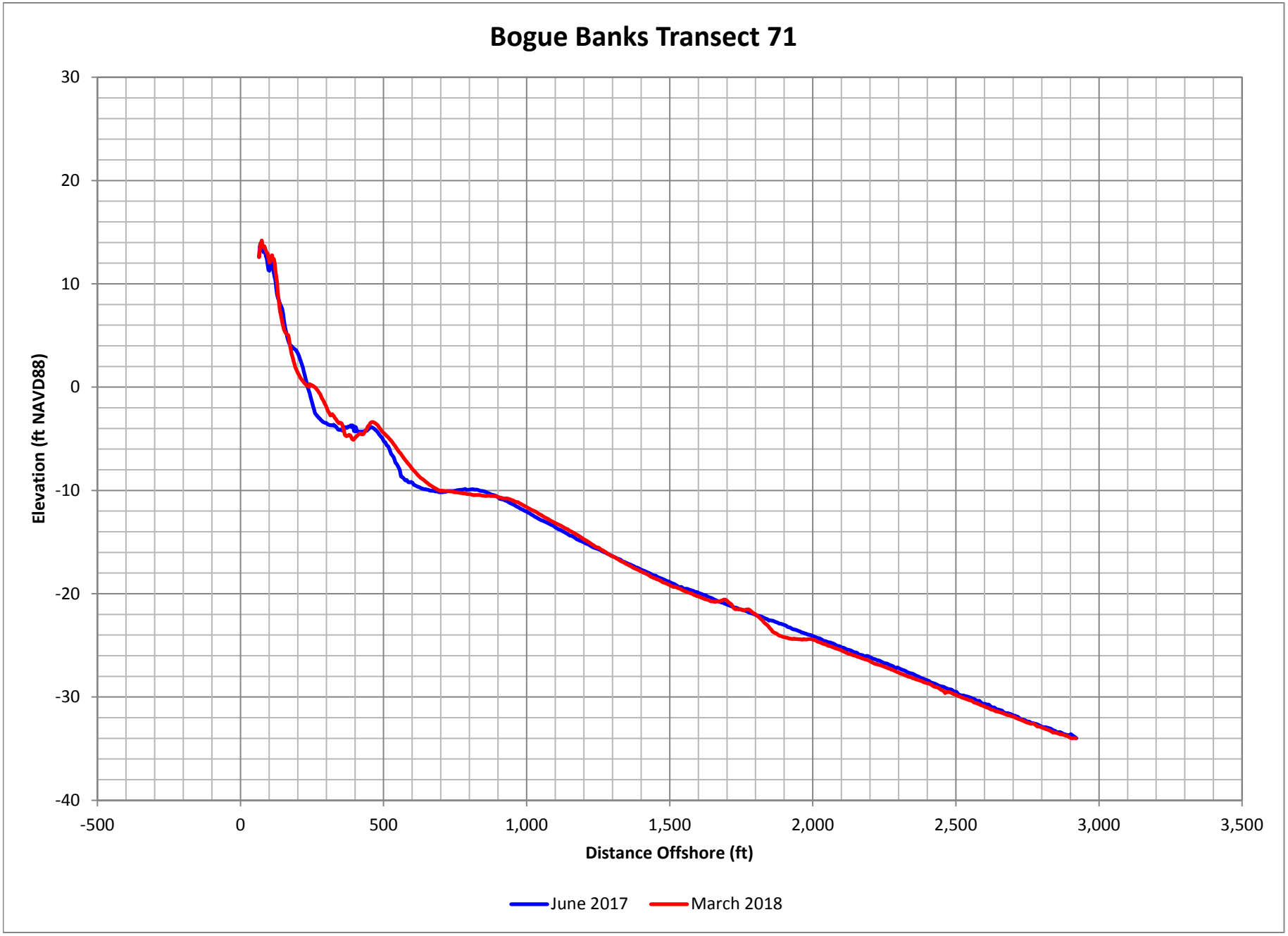


Figure D-141. Bogue Banks Profile Comparison Plot

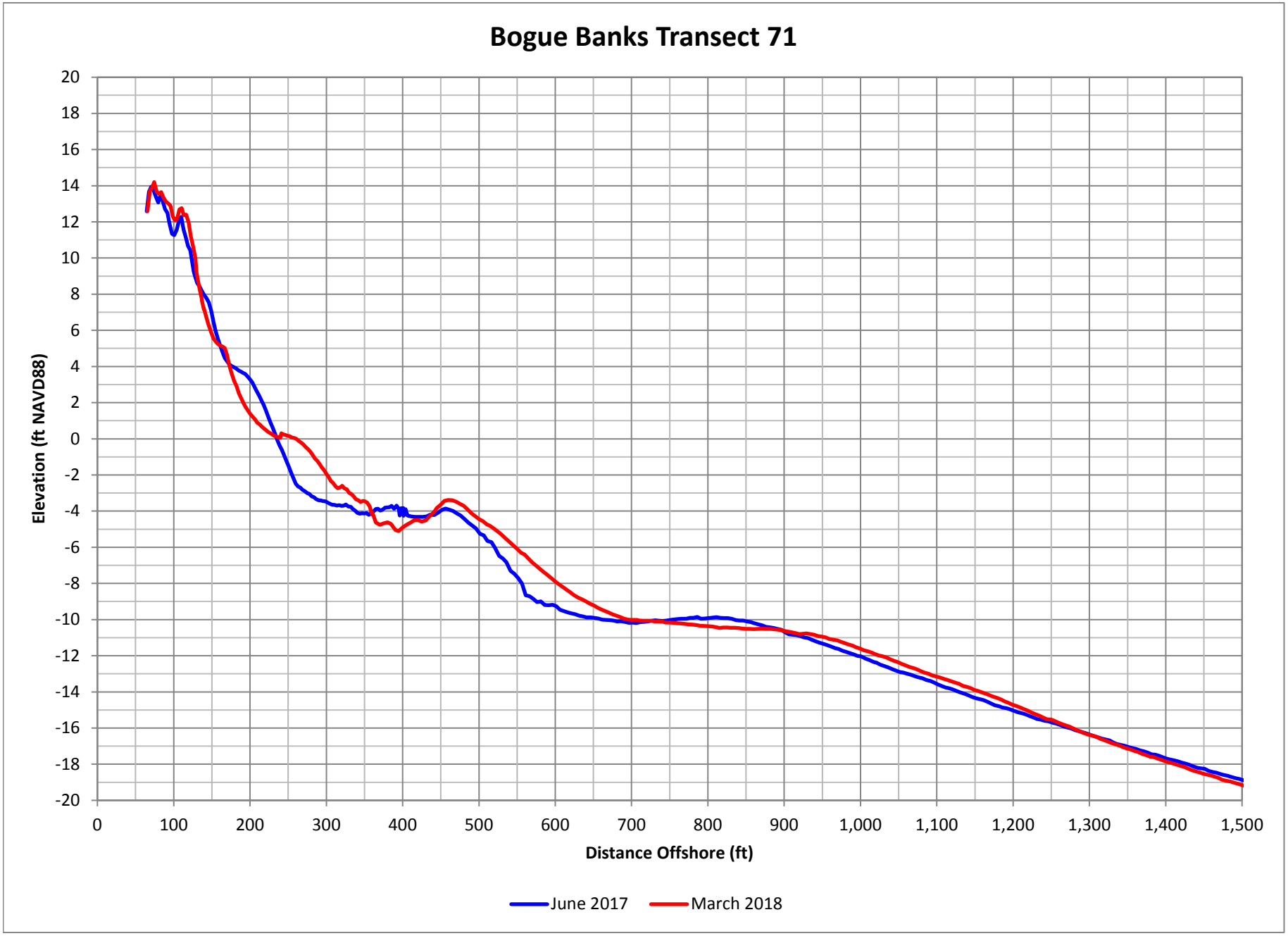


Figure D-142. Bogue Banks Profile Comparison Plot

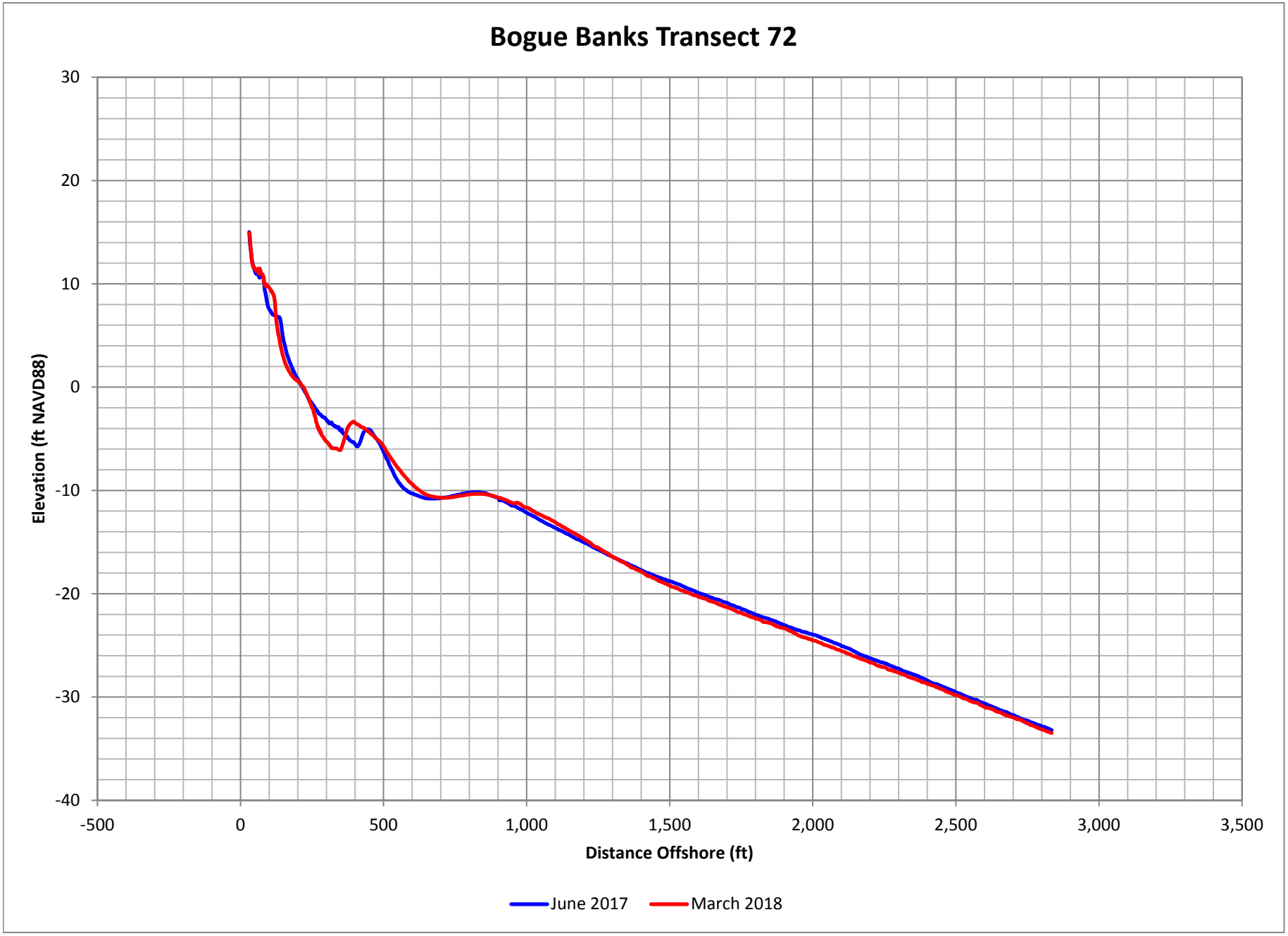


Figure D-143. Bogue Banks Profile Comparison Plot

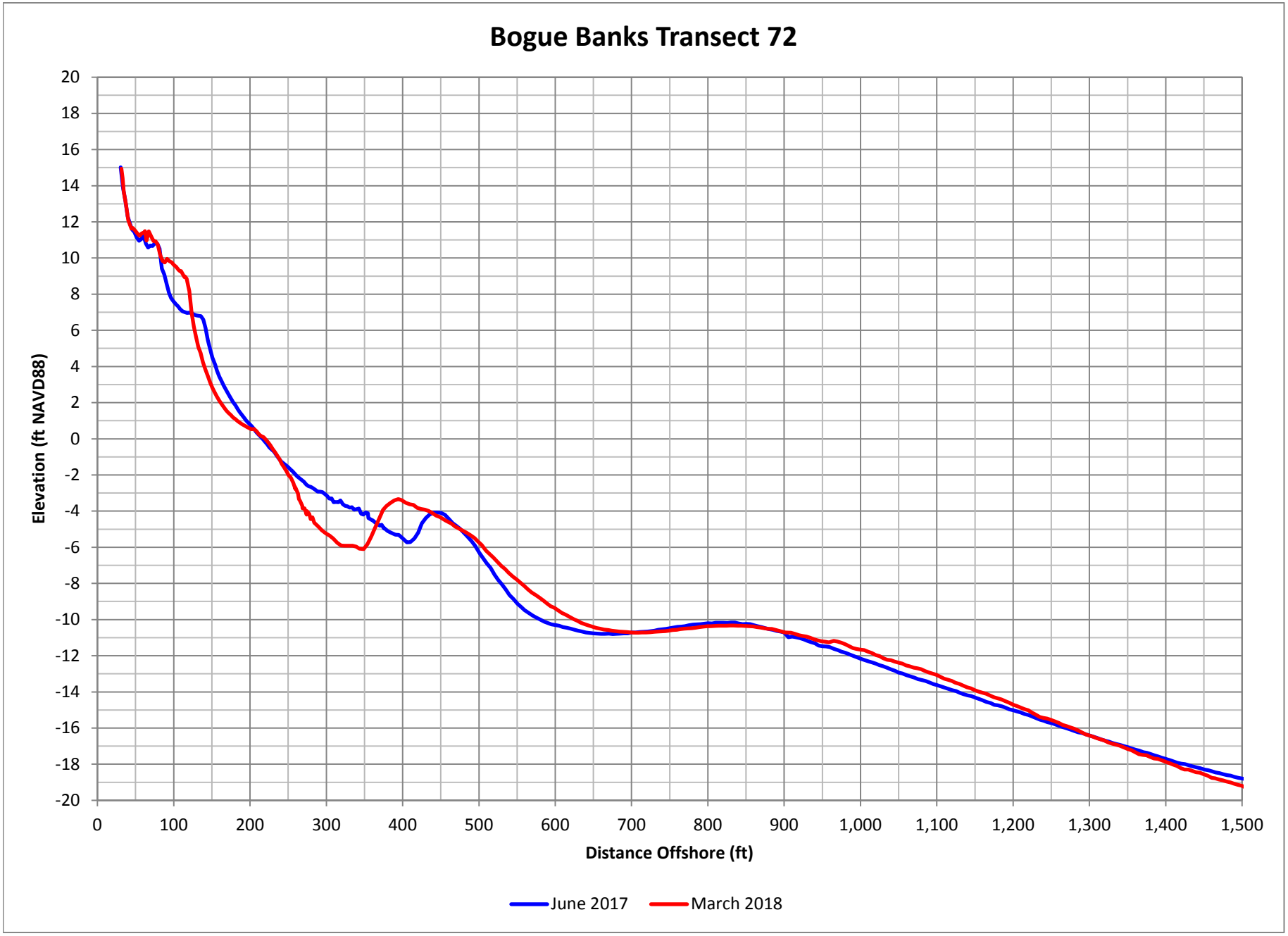


Figure D-144. Bogue Banks Profile Comparison Plot

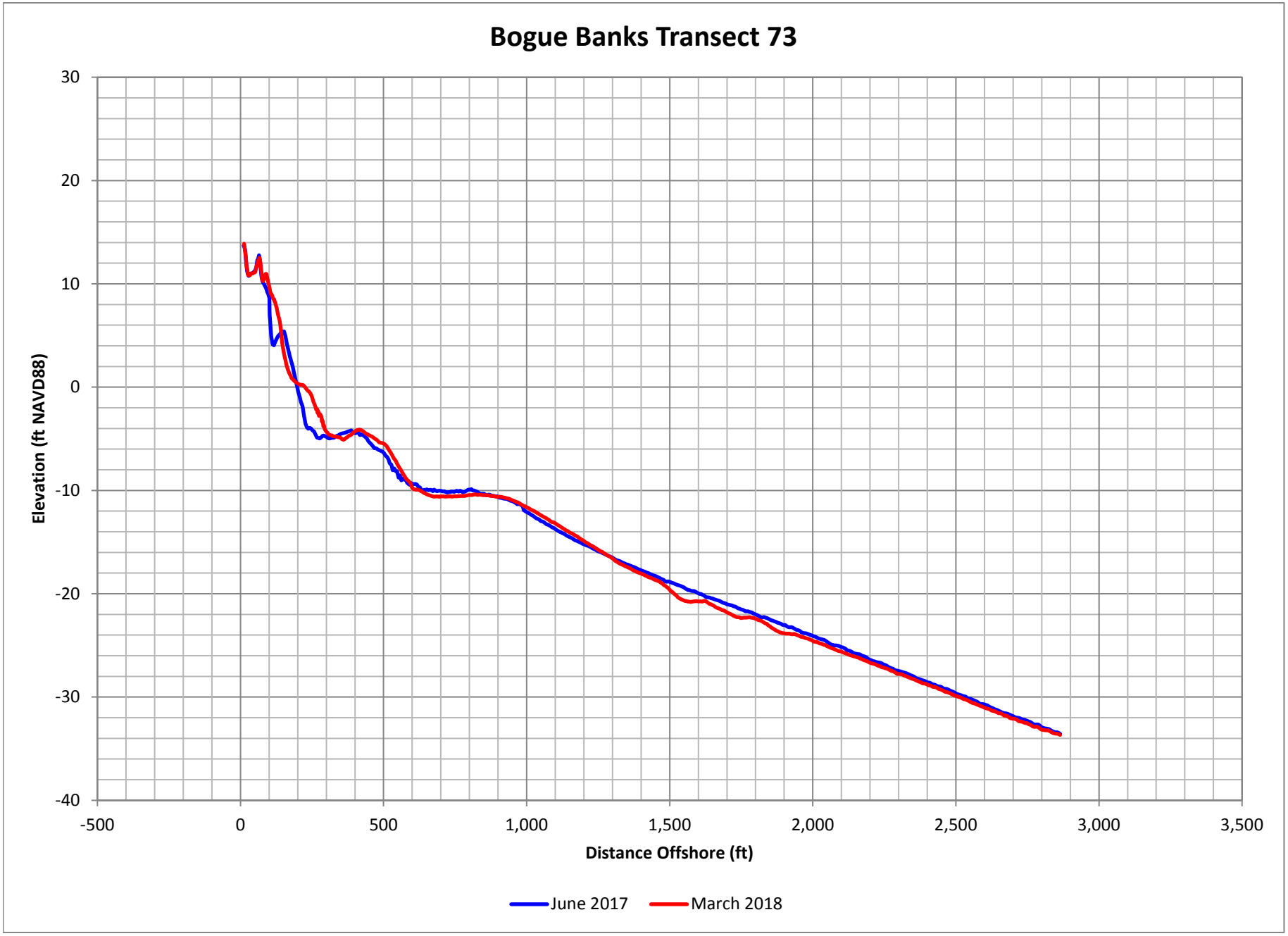


Figure D-145. Bogue Banks Profile Comparison Plot

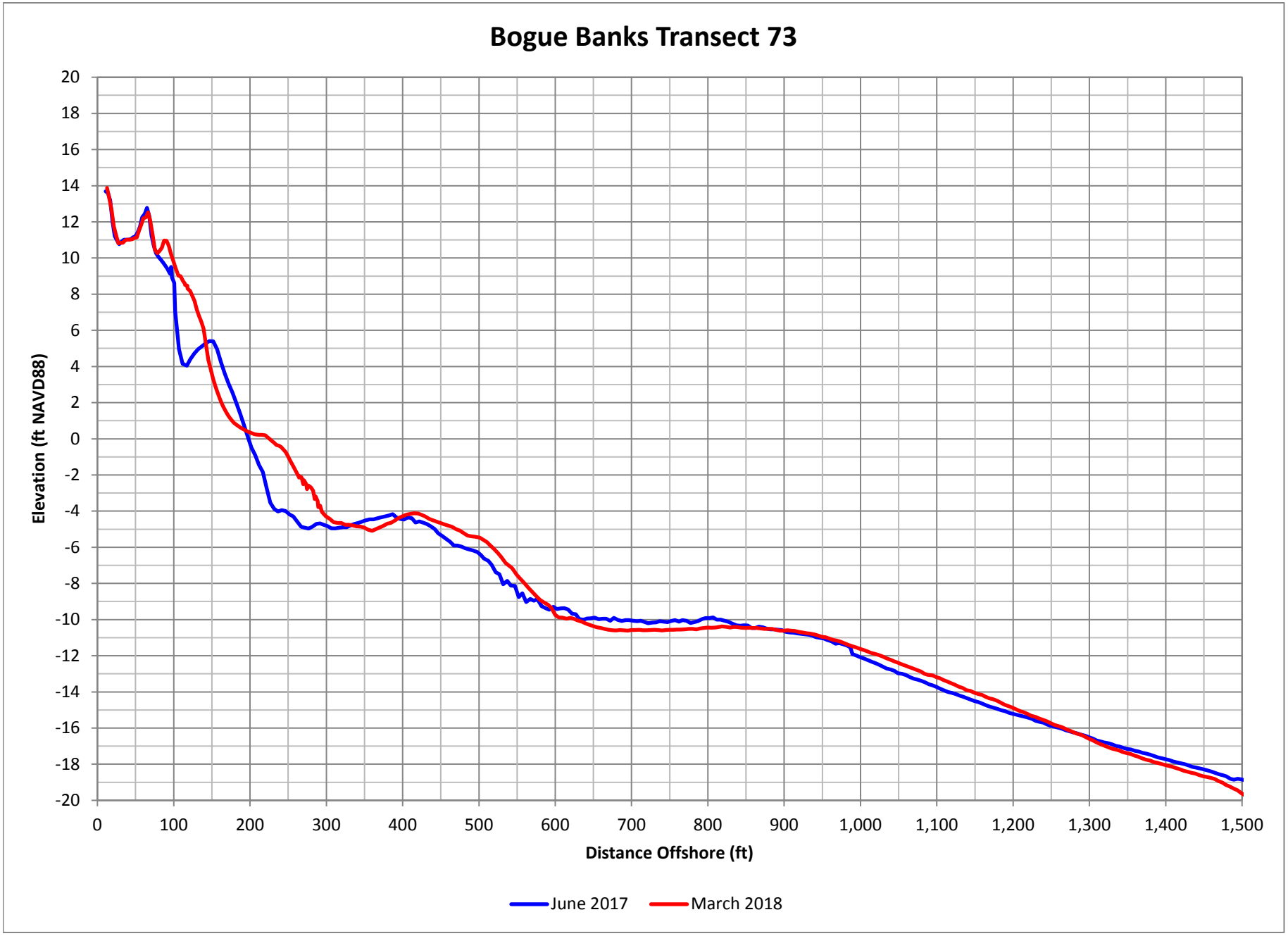


Figure D-146. Bogue Banks Profile Comparison Plot

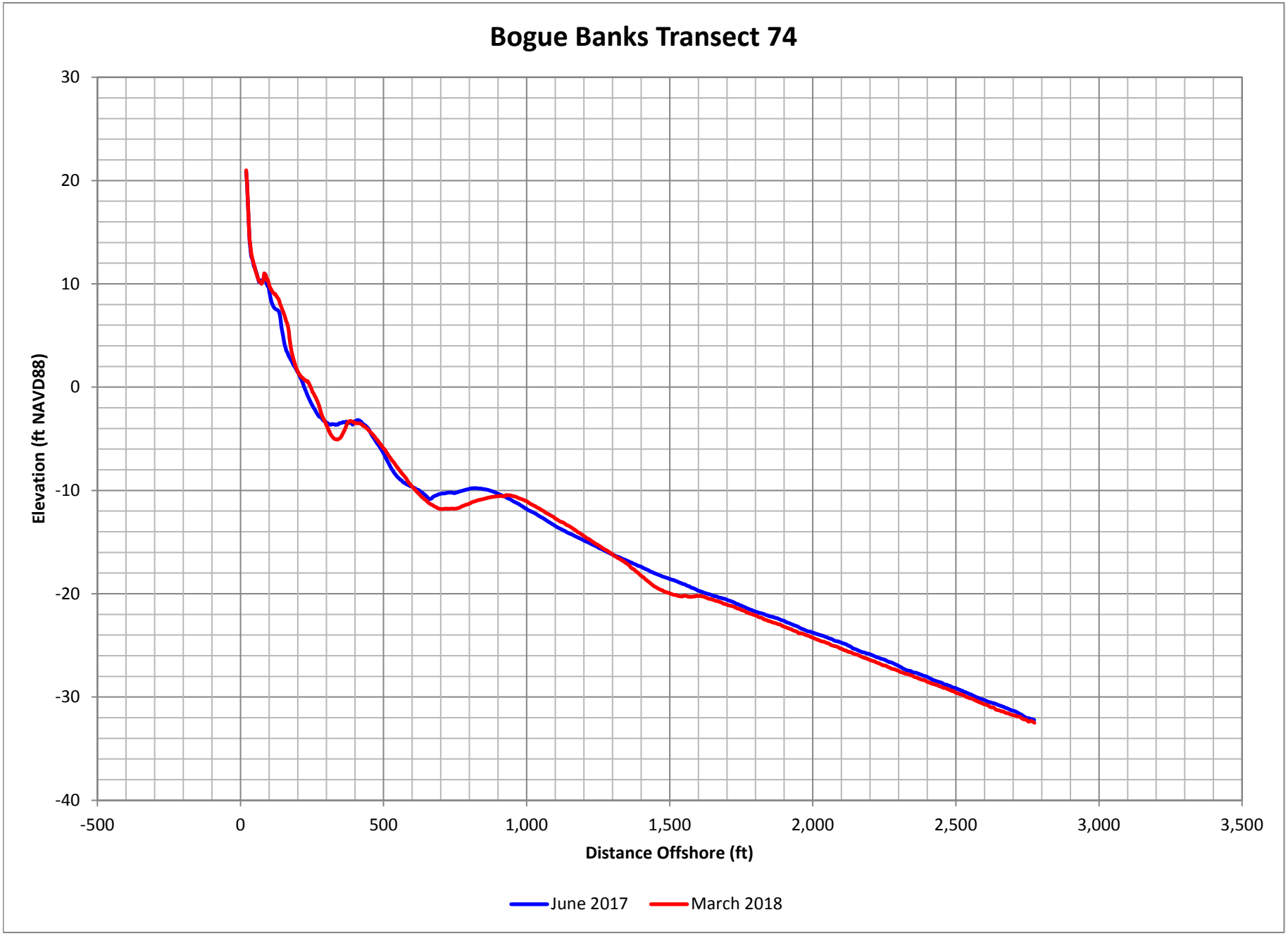


Figure D-147. Bogue Banks Profile Comparison Plot

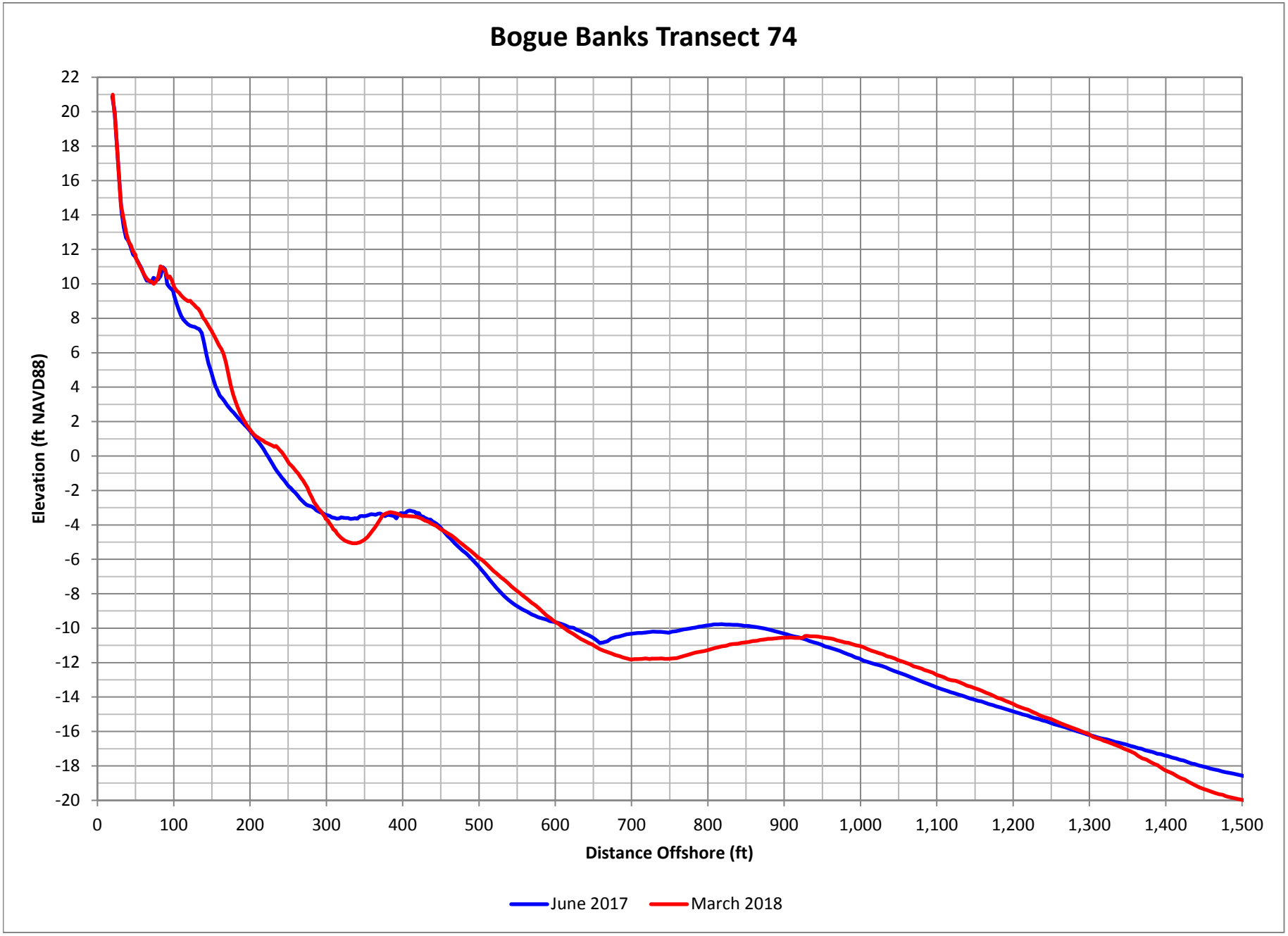


Figure D-148. Bogue Banks Profile Comparison Plot

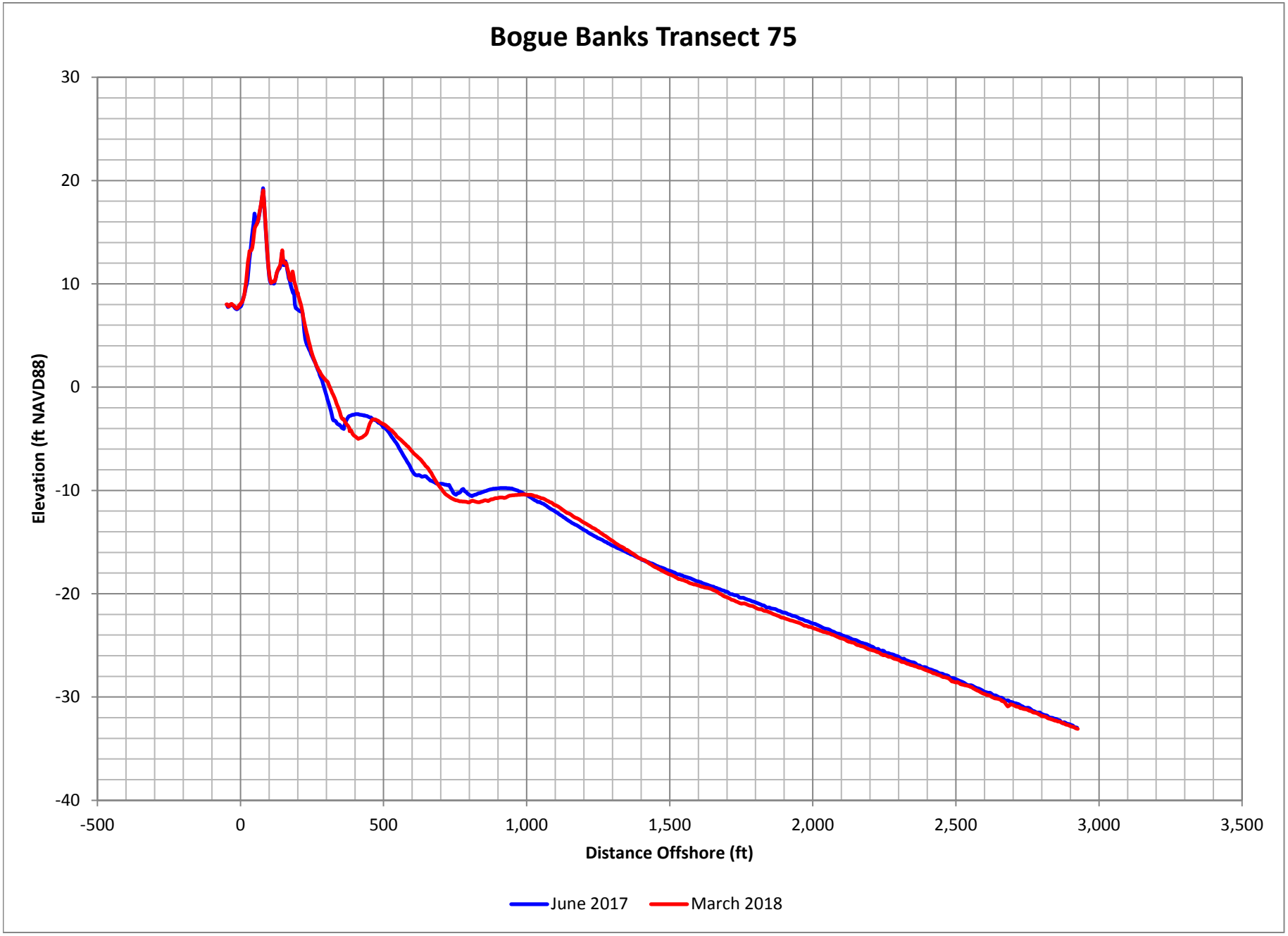


Figure D-149. Bogue Banks Profile Comparison Plot

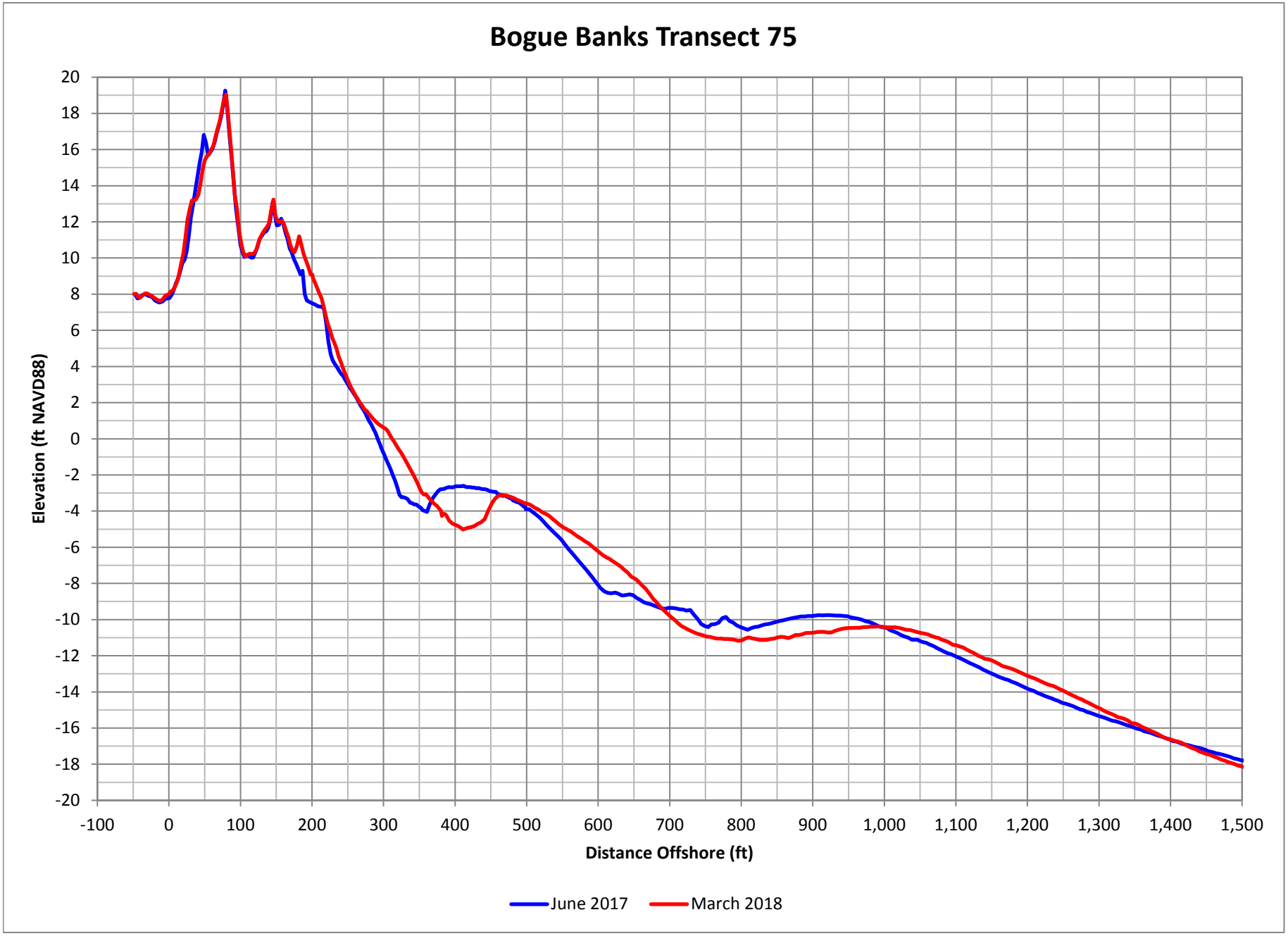


Figure D-150. Bogue Banks Profile Comparison Plot

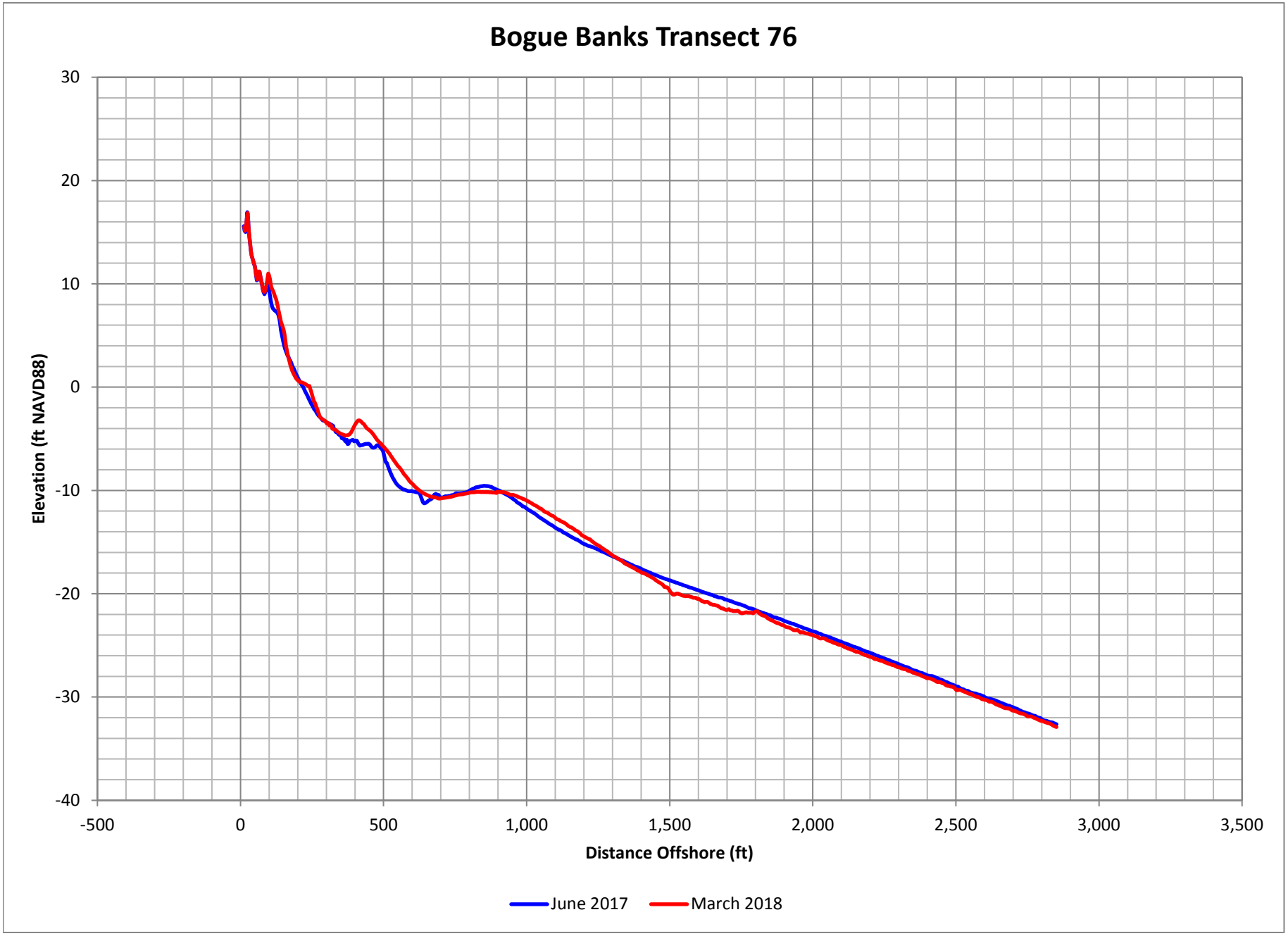


Figure D-151. Bogue Banks Profile Comparison Plot

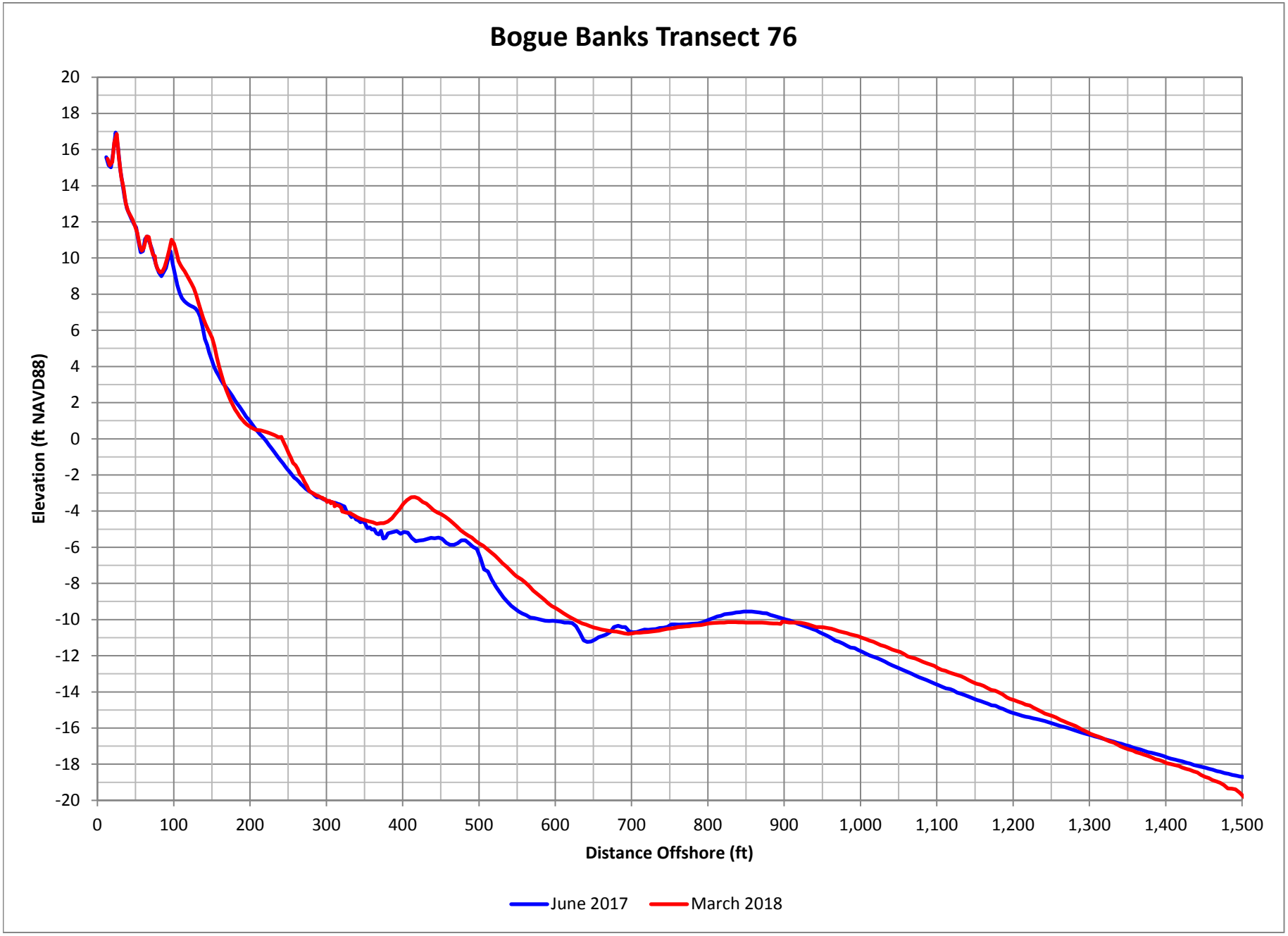


Figure D-152. Bogue Banks Profile Comparison Plot

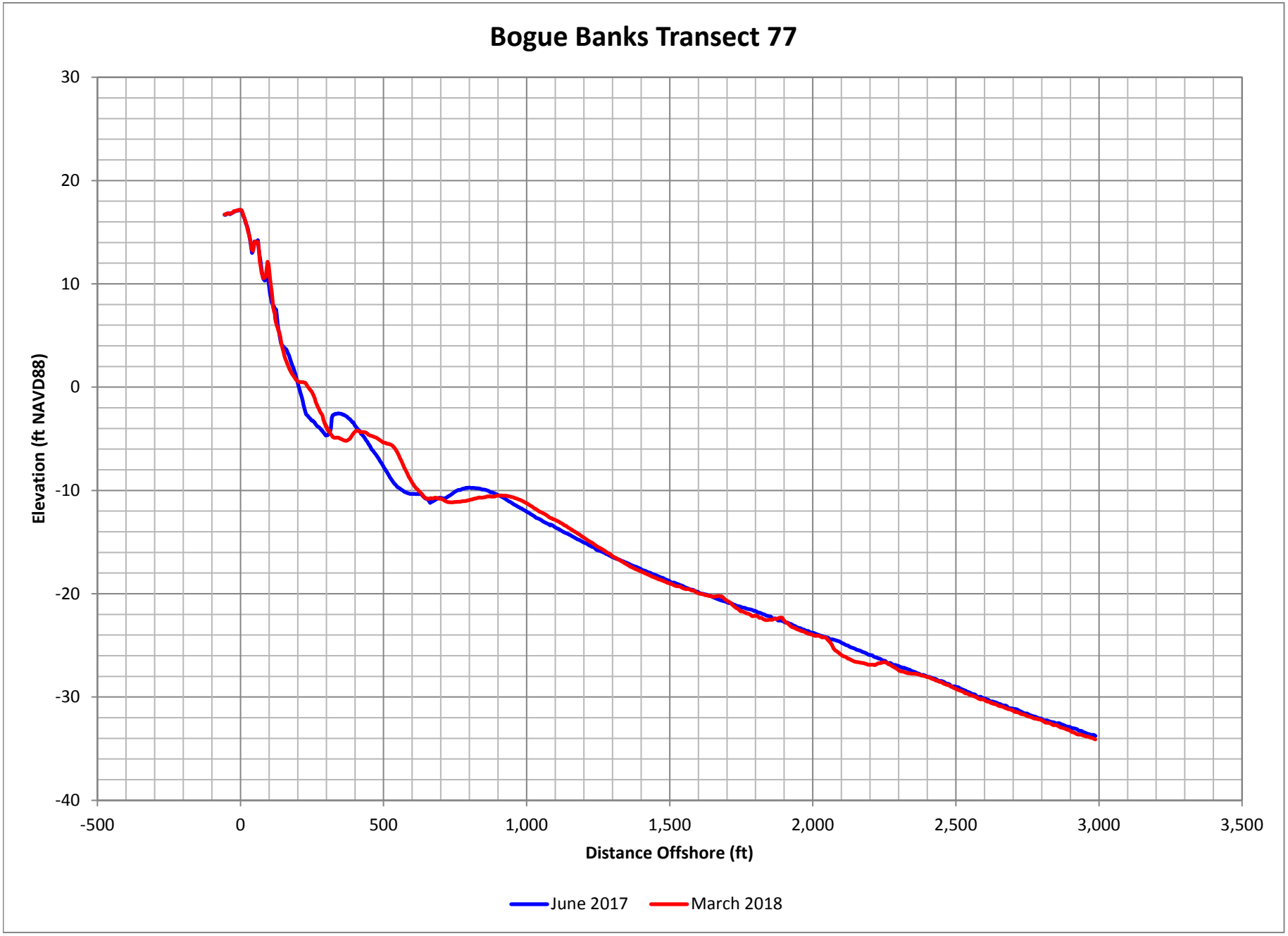


Figure D-153. Bogue Banks Profile Comparison Plot

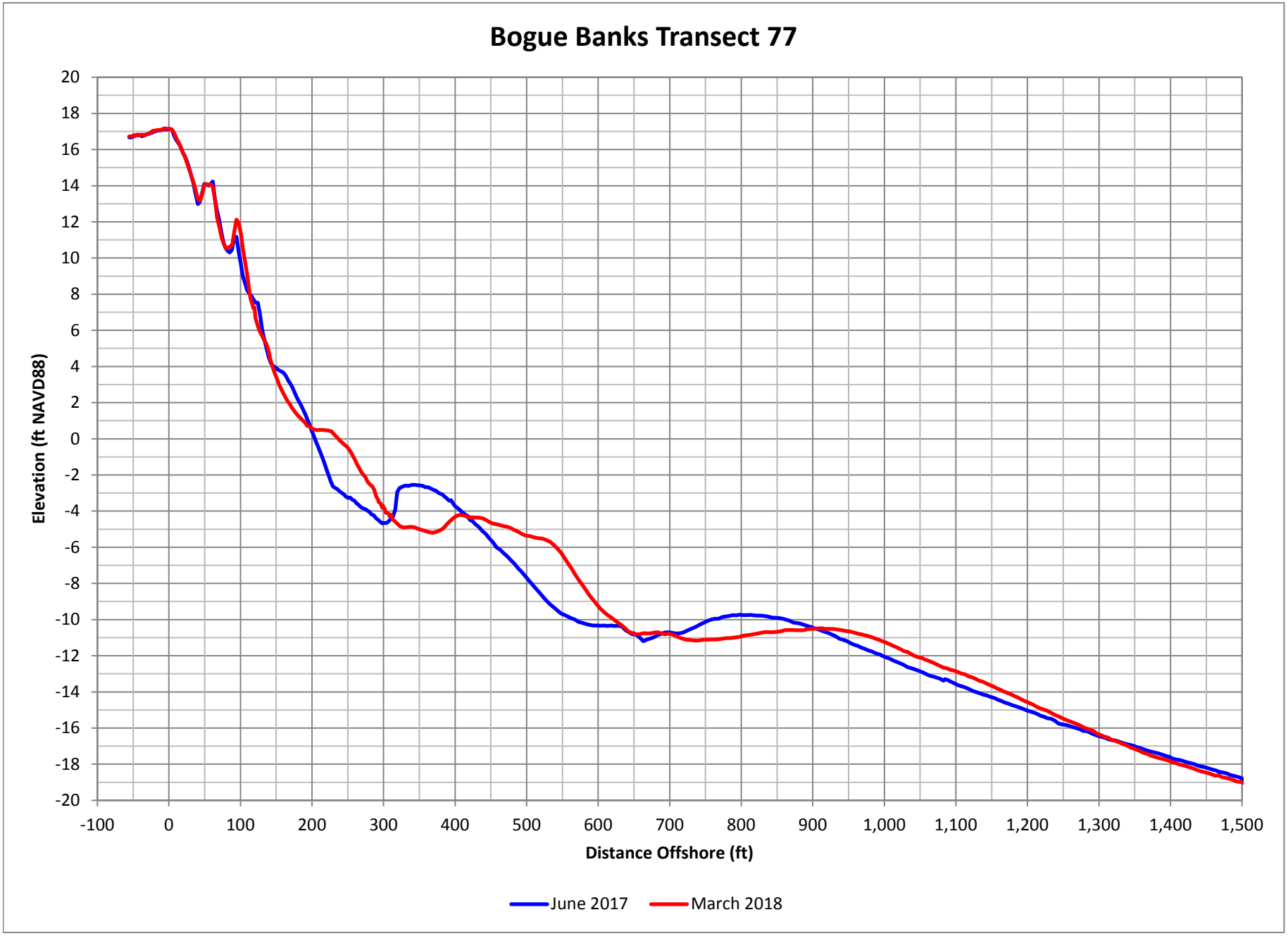


Figure D-154. Bogue Banks Profile Comparison Plot

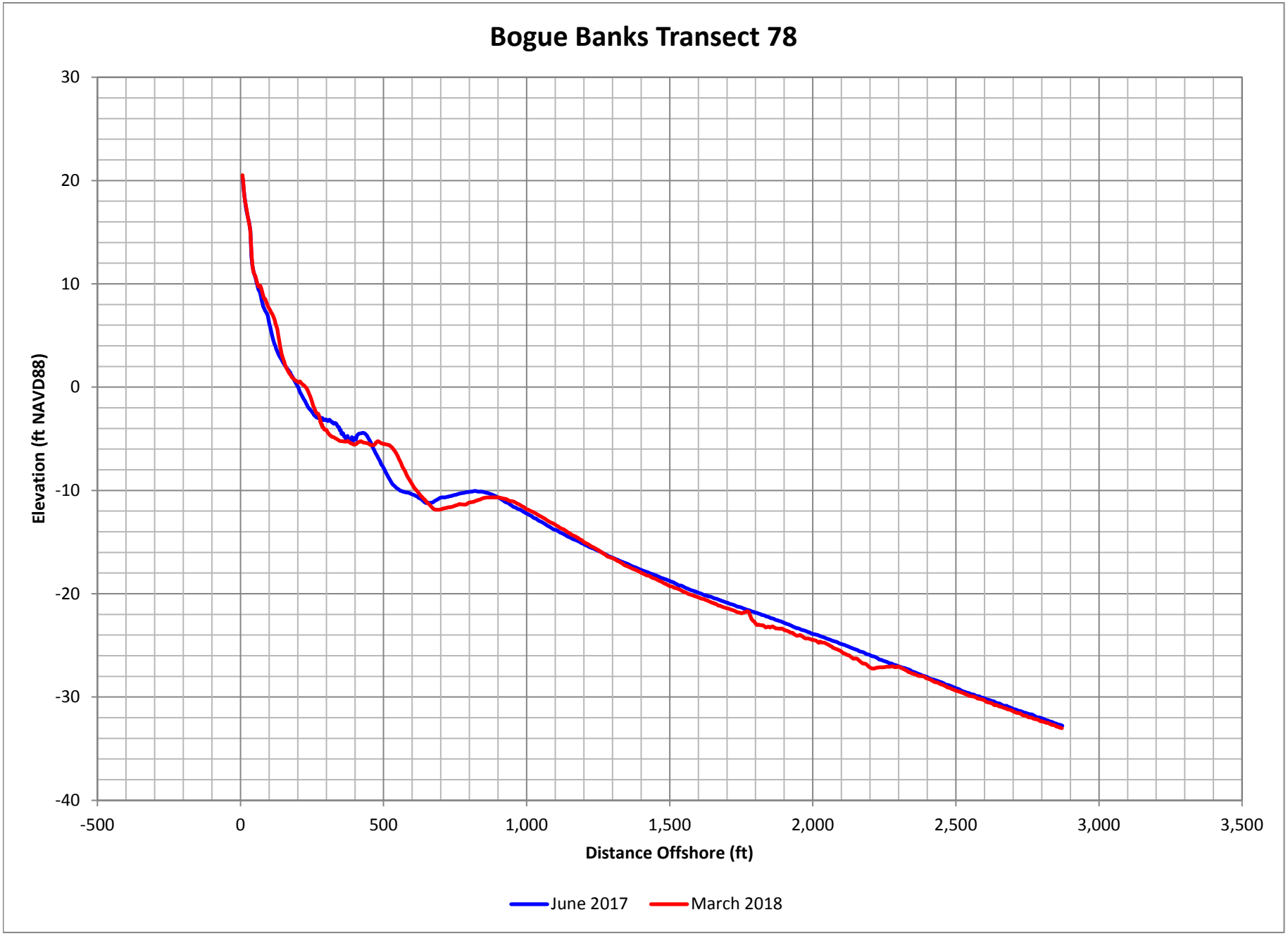


Figure D-155. Bogue Banks Profile Comparison Plot

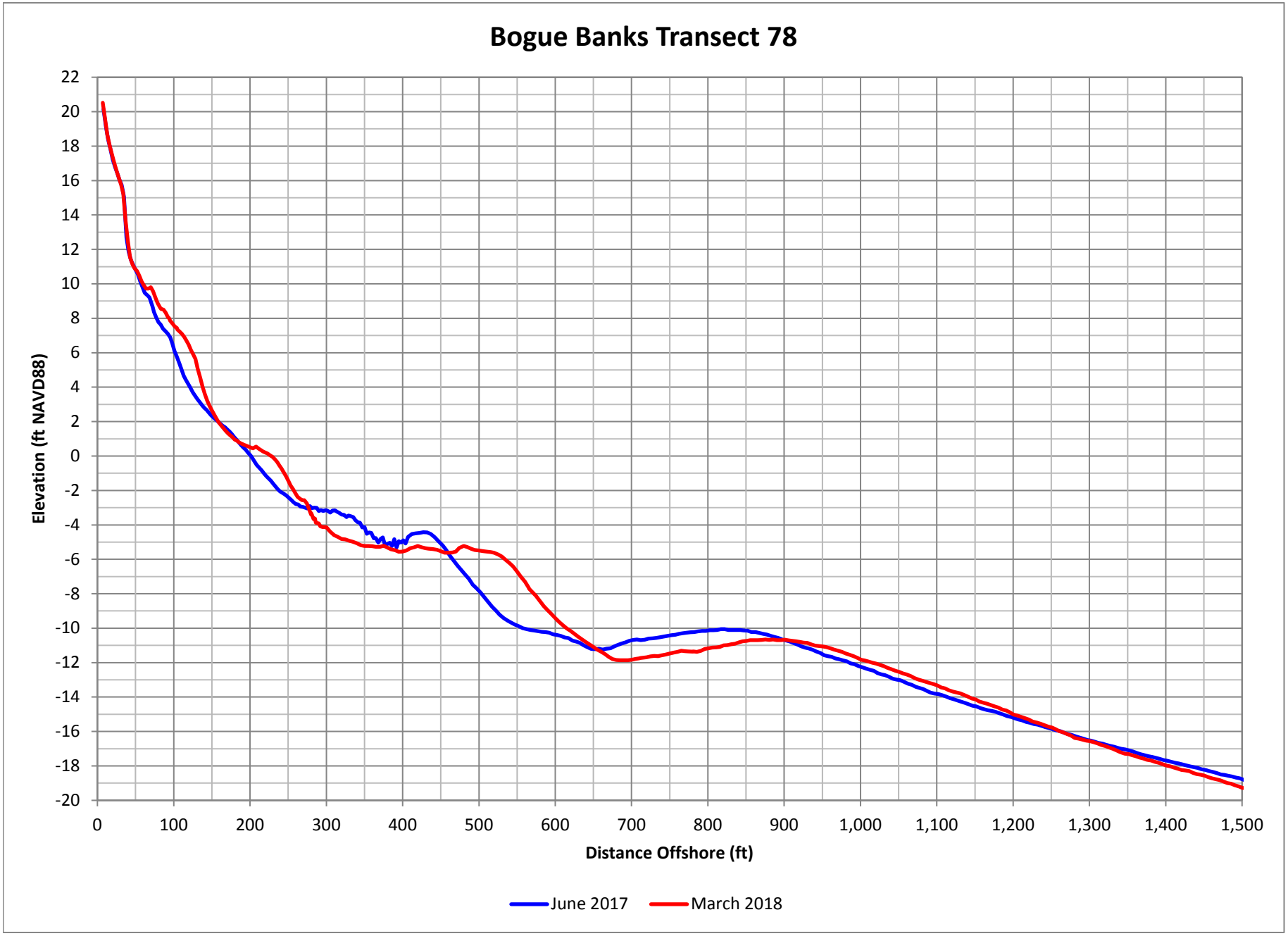


Figure D-156. Bogue Banks Profile Comparison Plot

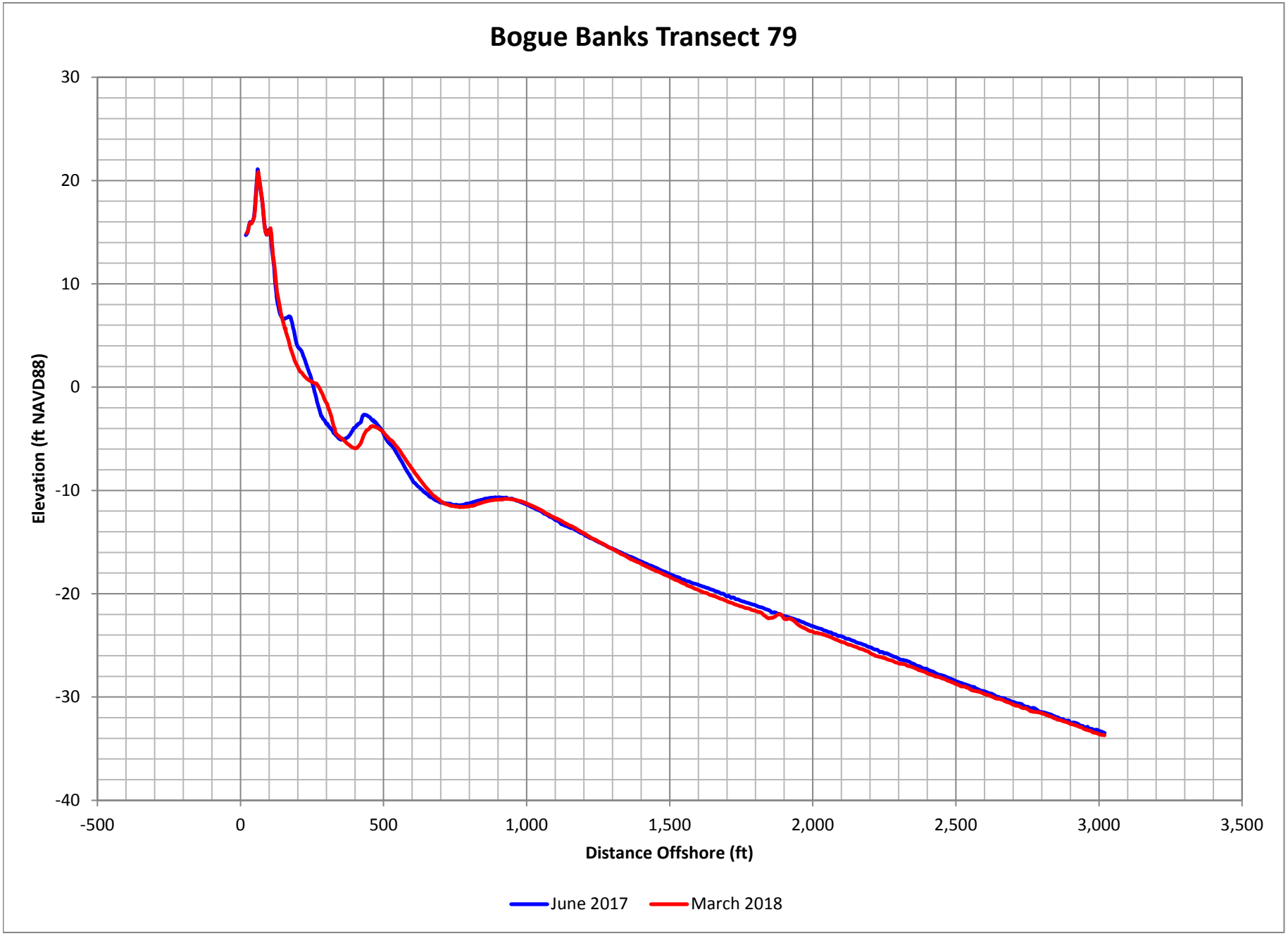


Figure D-157. Bogue Banks Profile Comparison Plot

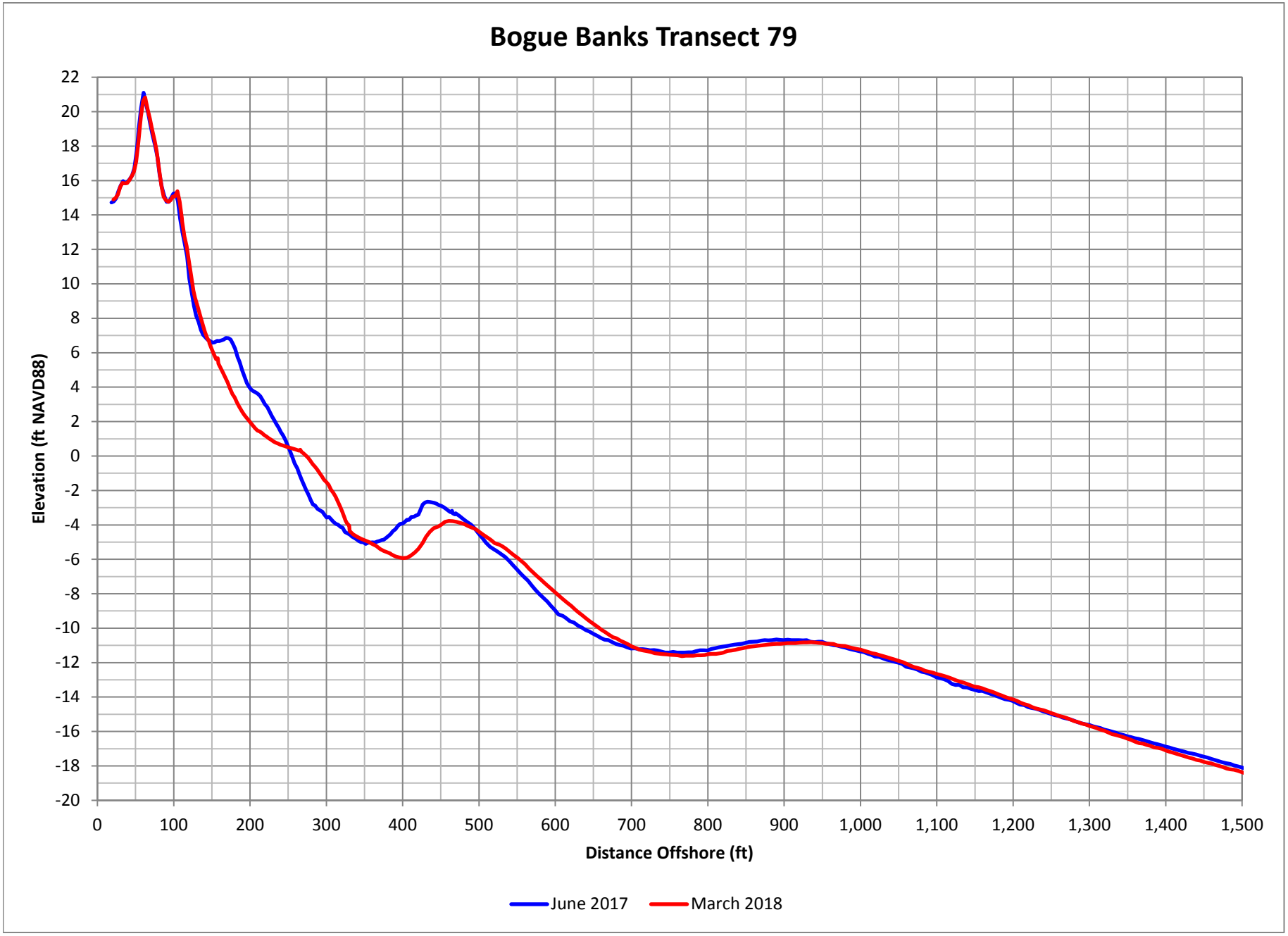


Figure D-158. Bogue Banks Profile Comparison Plot

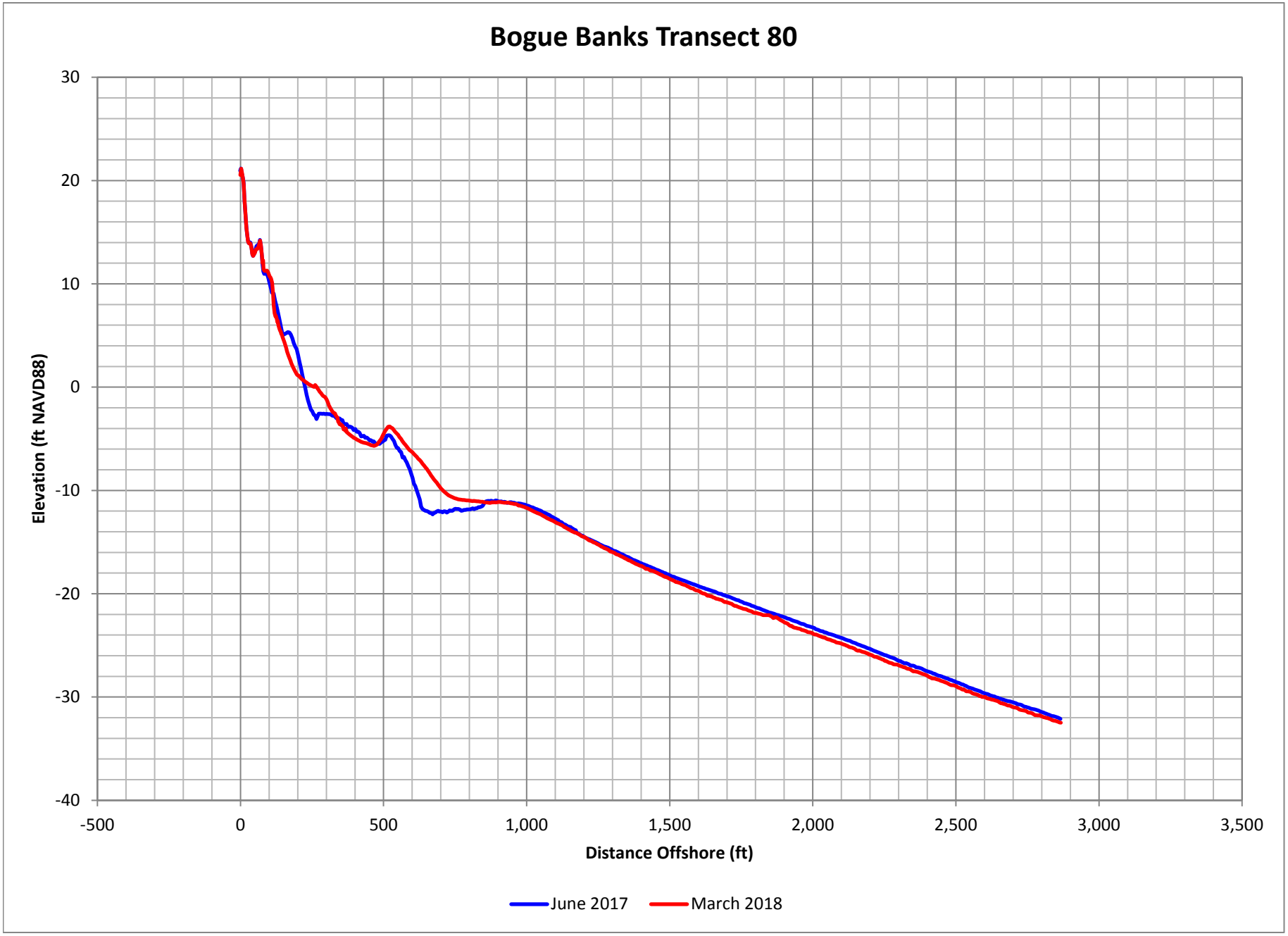


Figure D-159. Bogue Banks Profile Comparison Plot

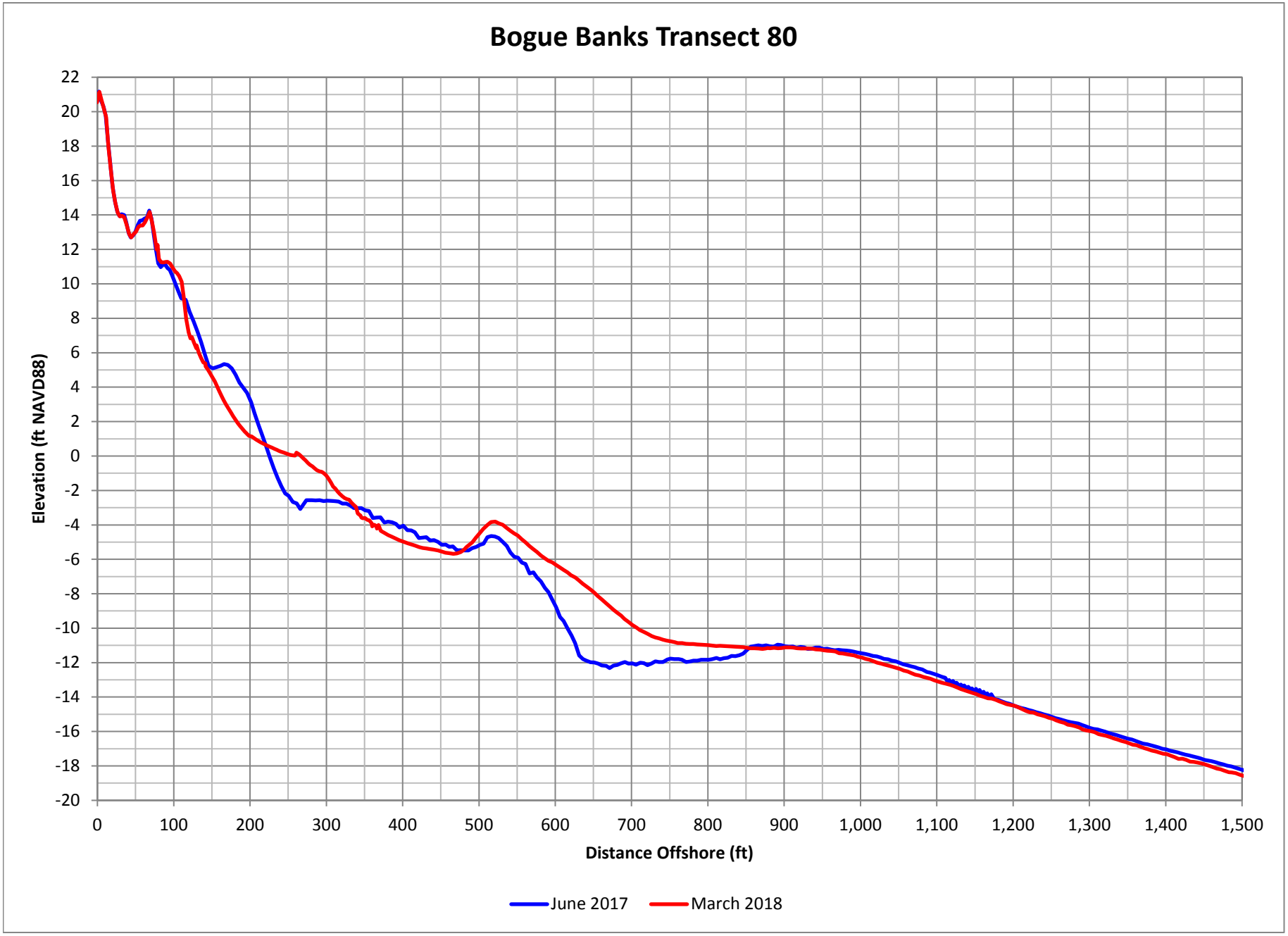


Figure D-160. Bogue Banks Profile Comparison Plot

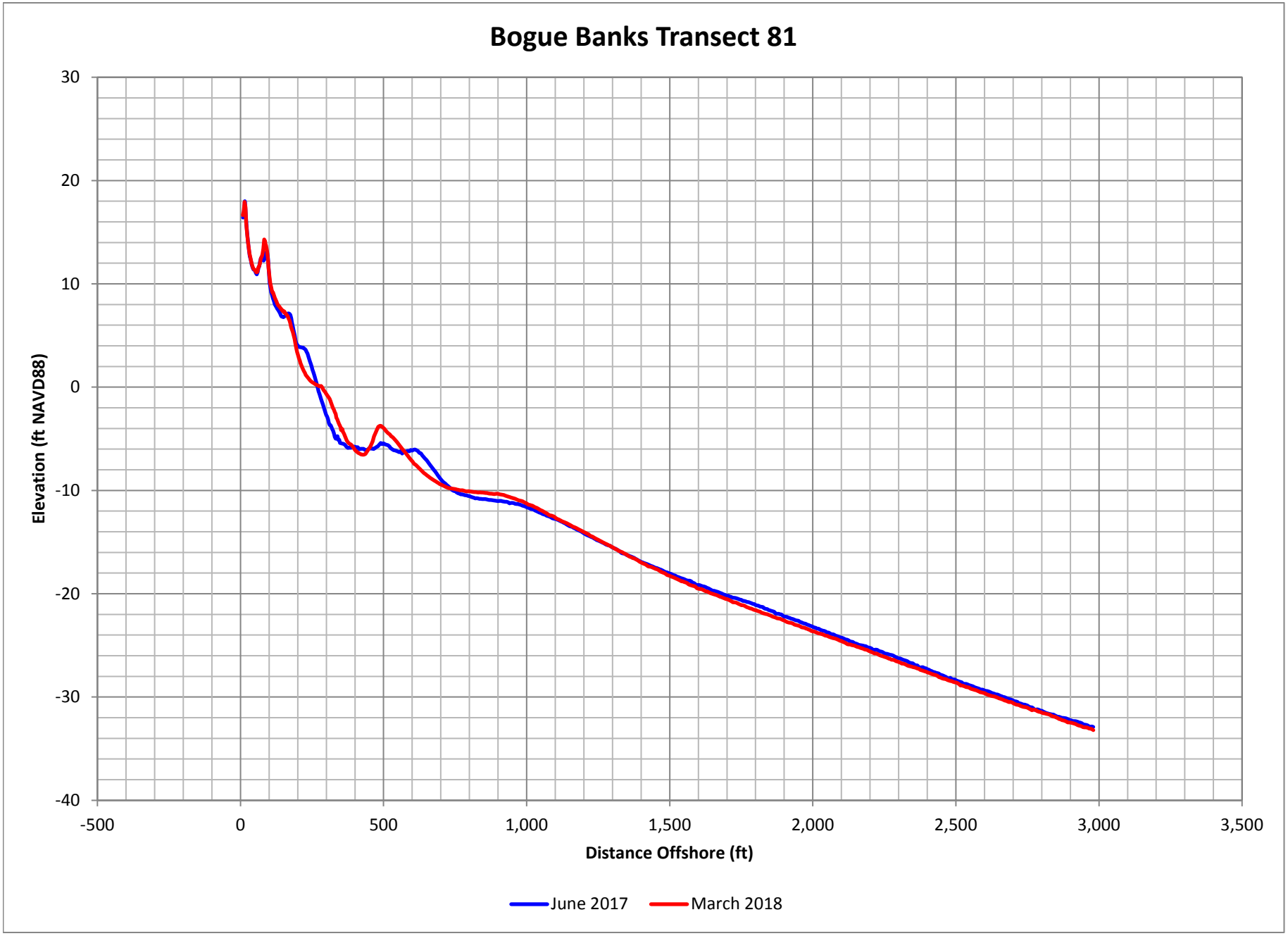


Figure D-161. Bogue Banks Profile Comparison Plot

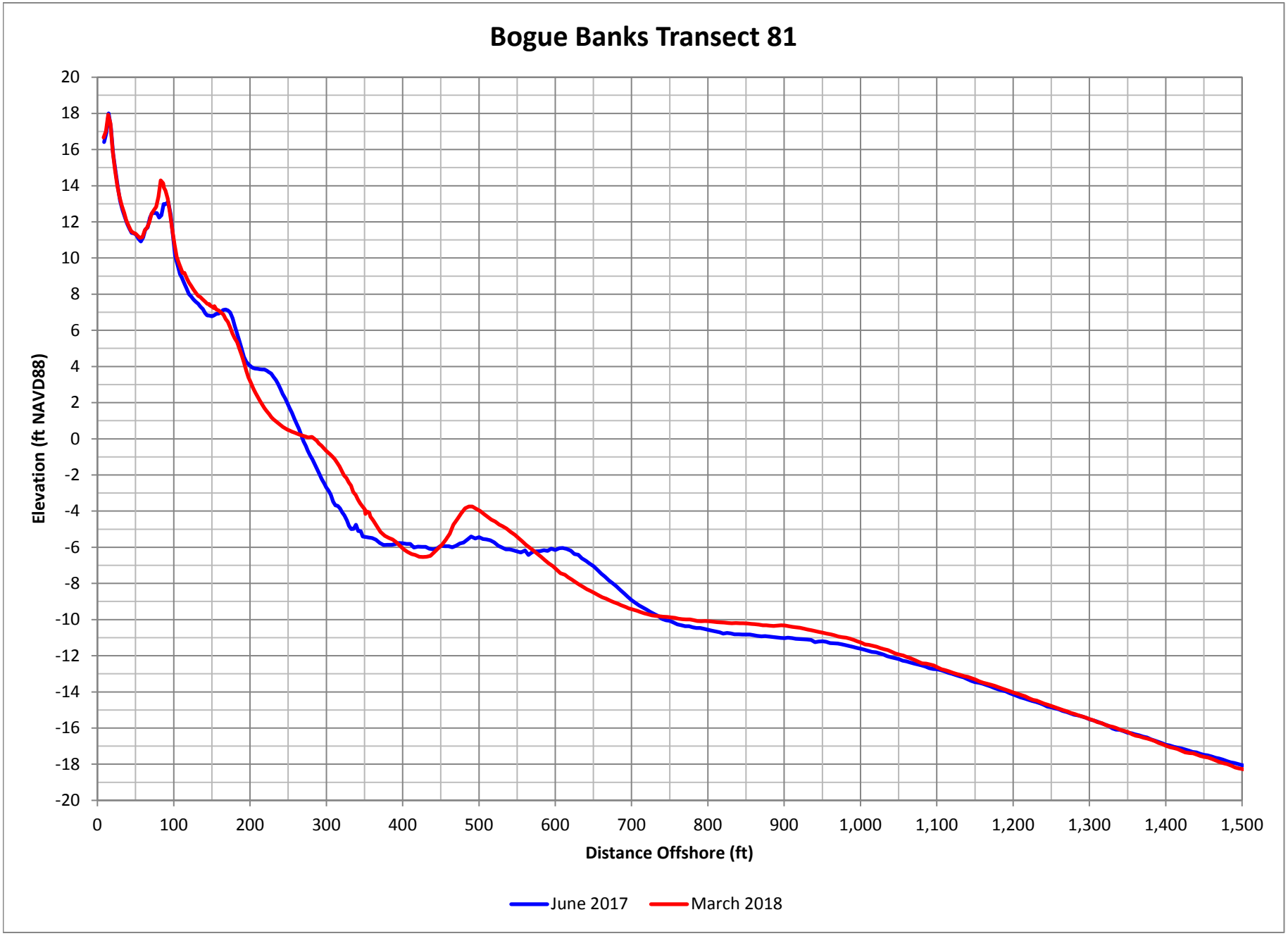


Figure D-162. Bogue Banks Profile Comparison Plot

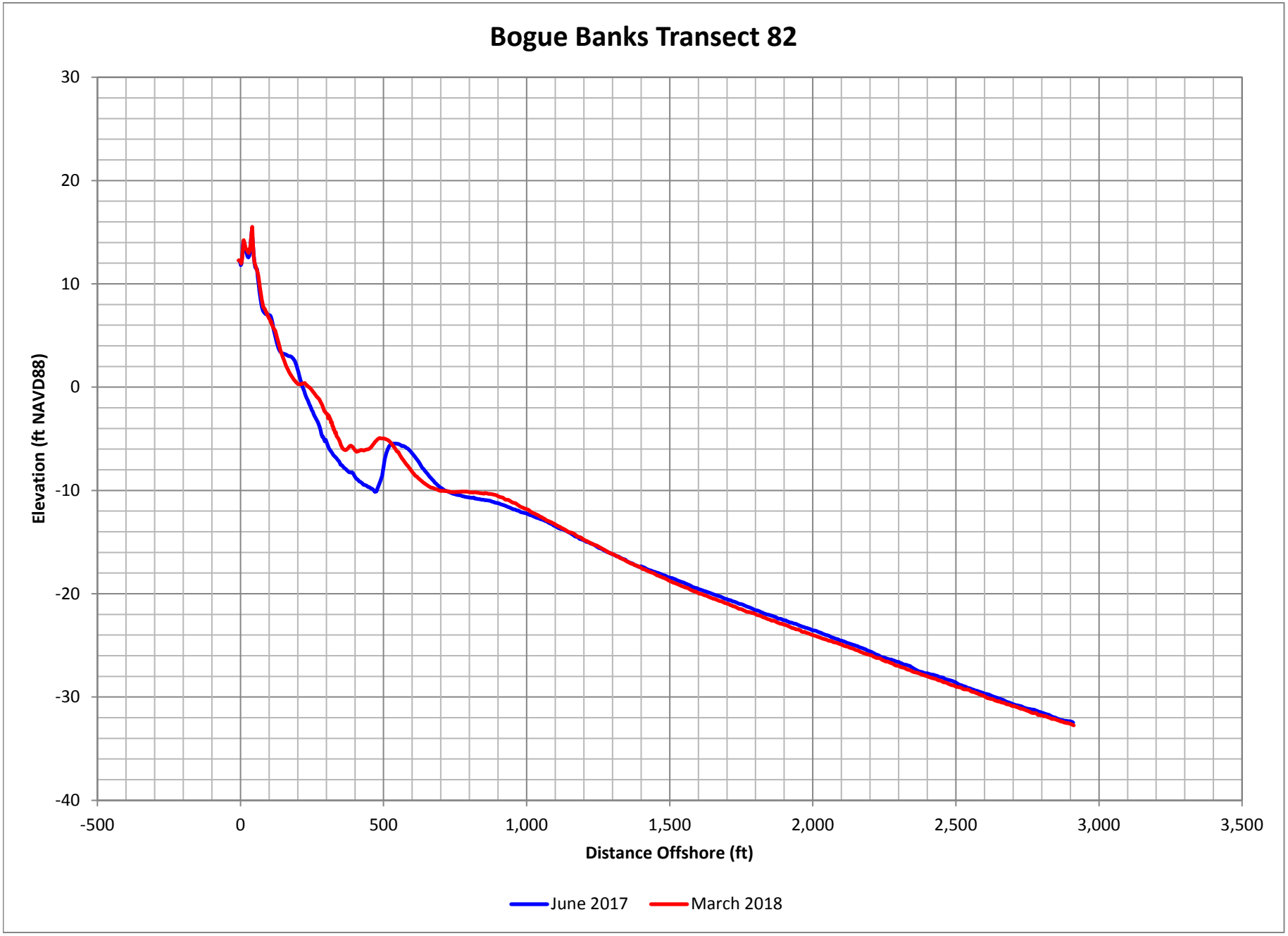


Figure D-163. Bogue Banks Profile Comparison Plot

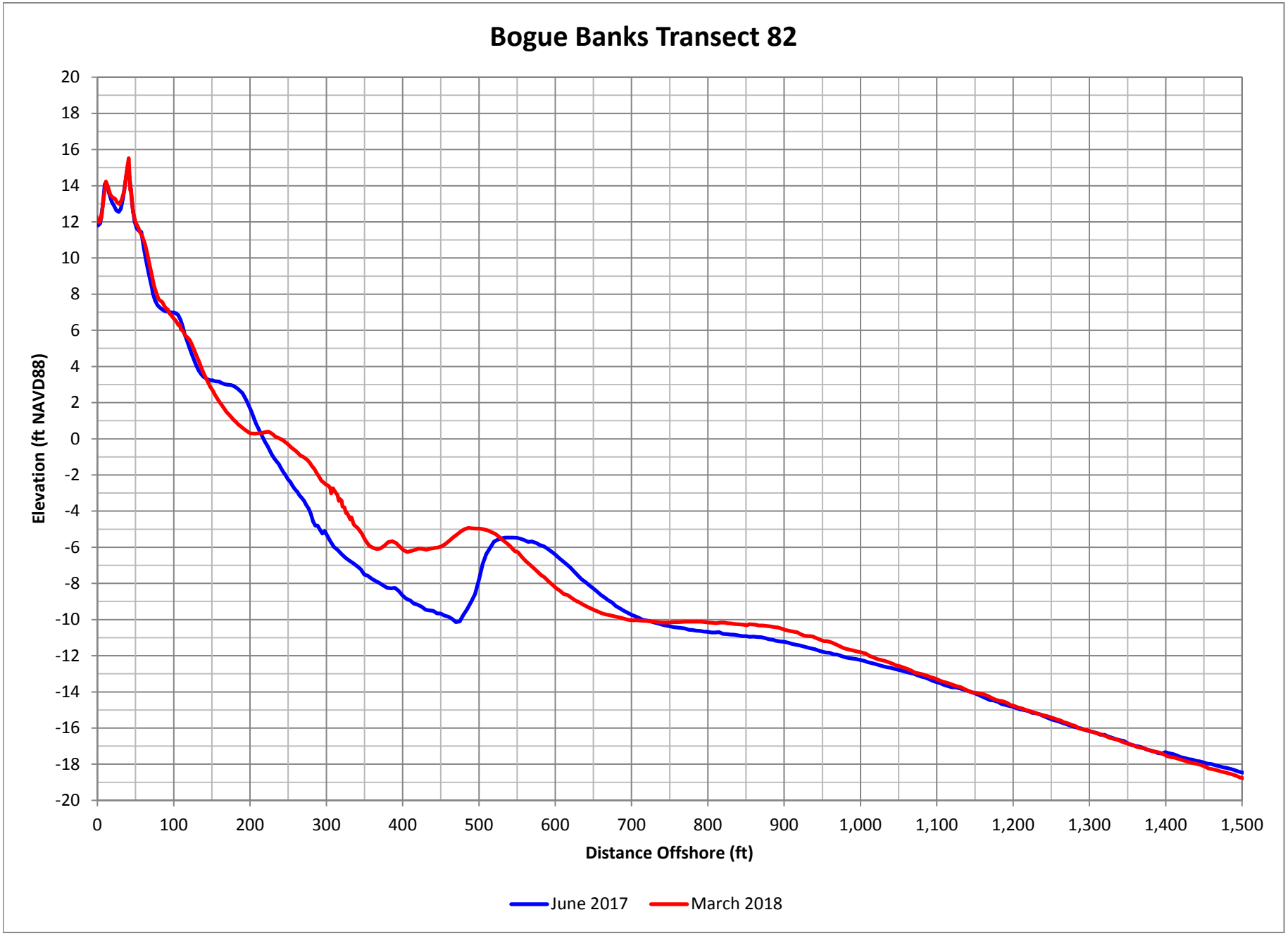


Figure D-164. Bogue Banks Profile Comparison Plot

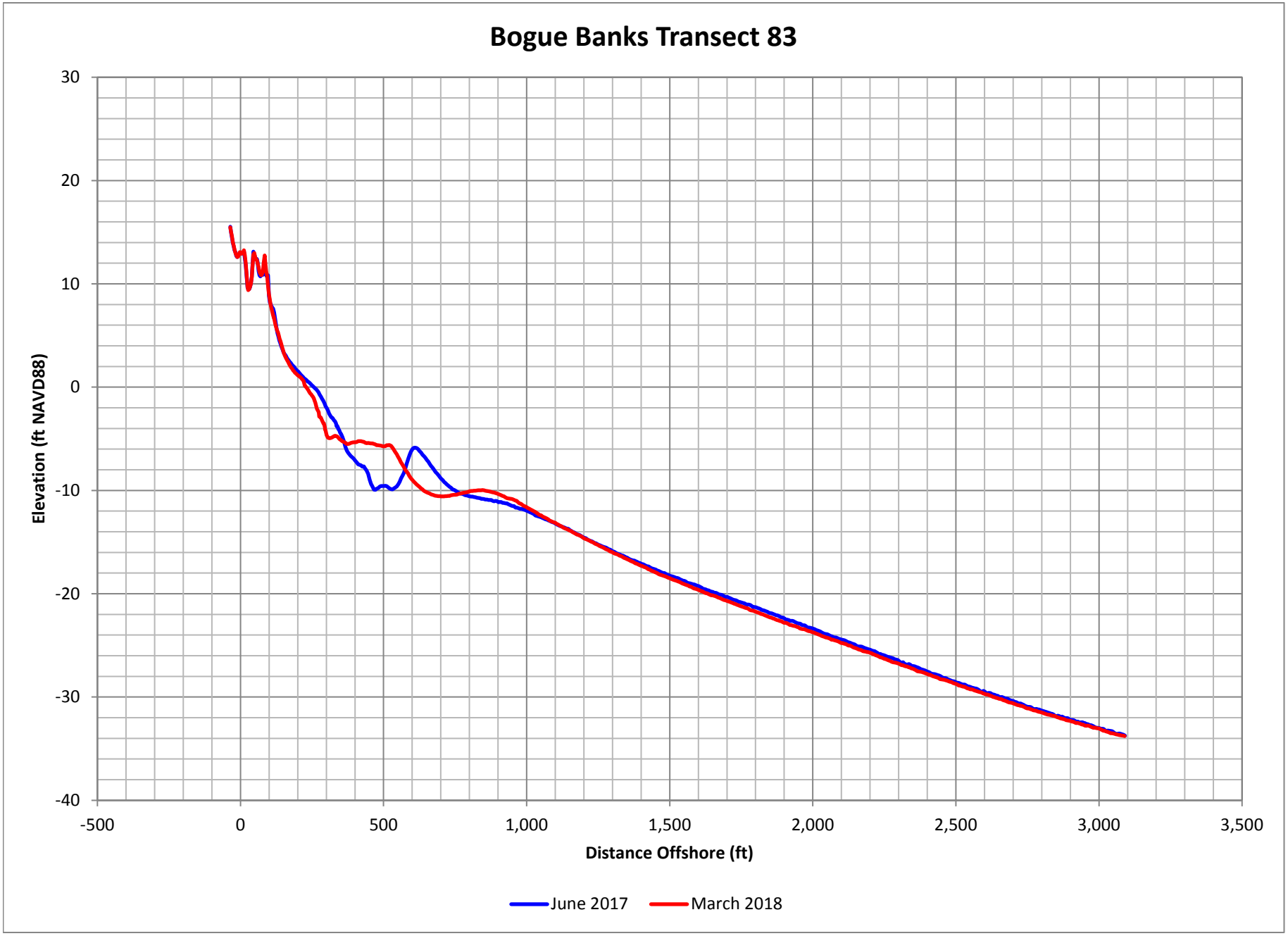


Figure D-165. Bogue Banks Profile Comparison Plot

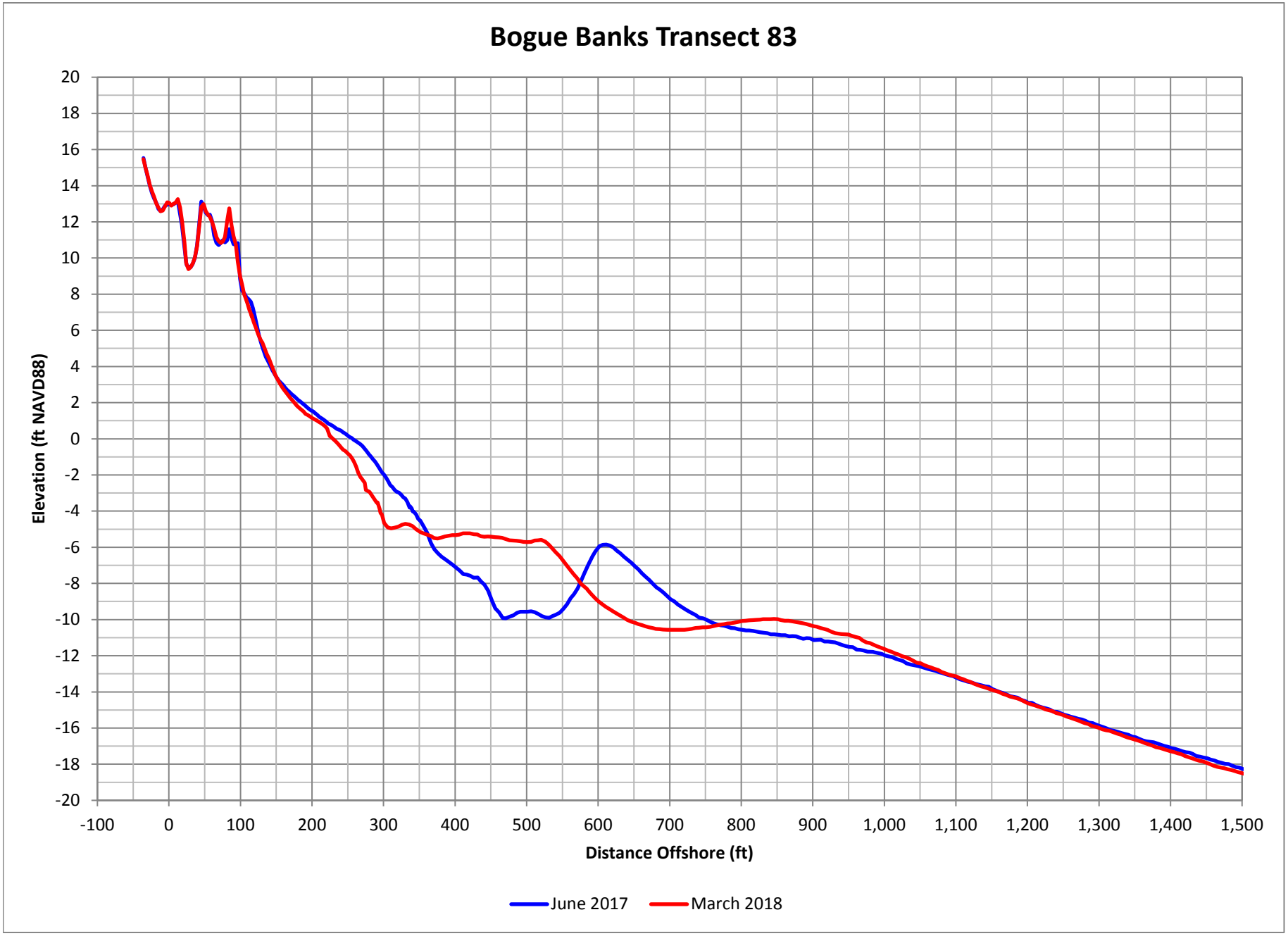


Figure D-166. Bogue Banks Profile Comparison Plot

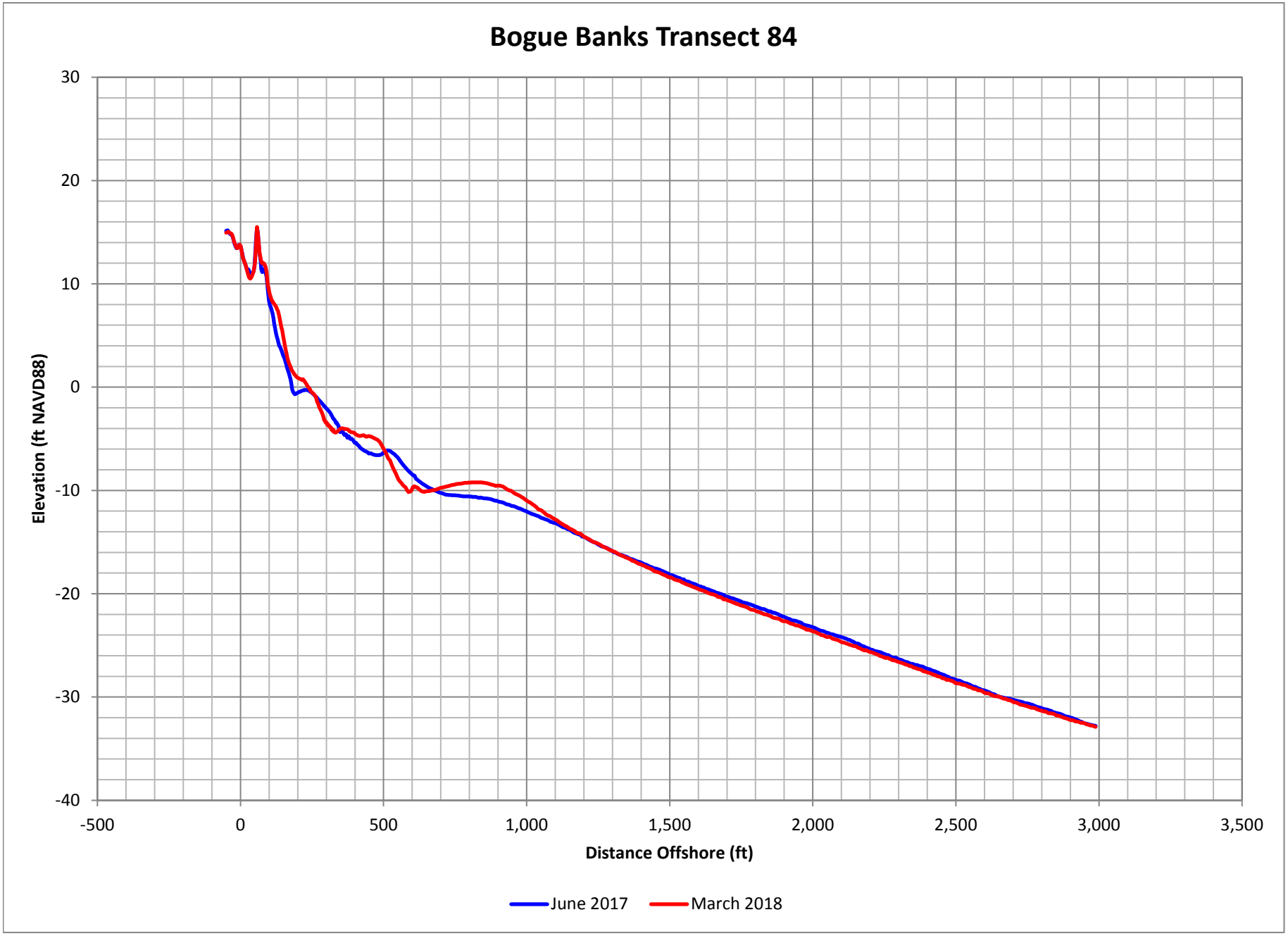


Figure D-167. Bogue Banks Profile Comparison Plot

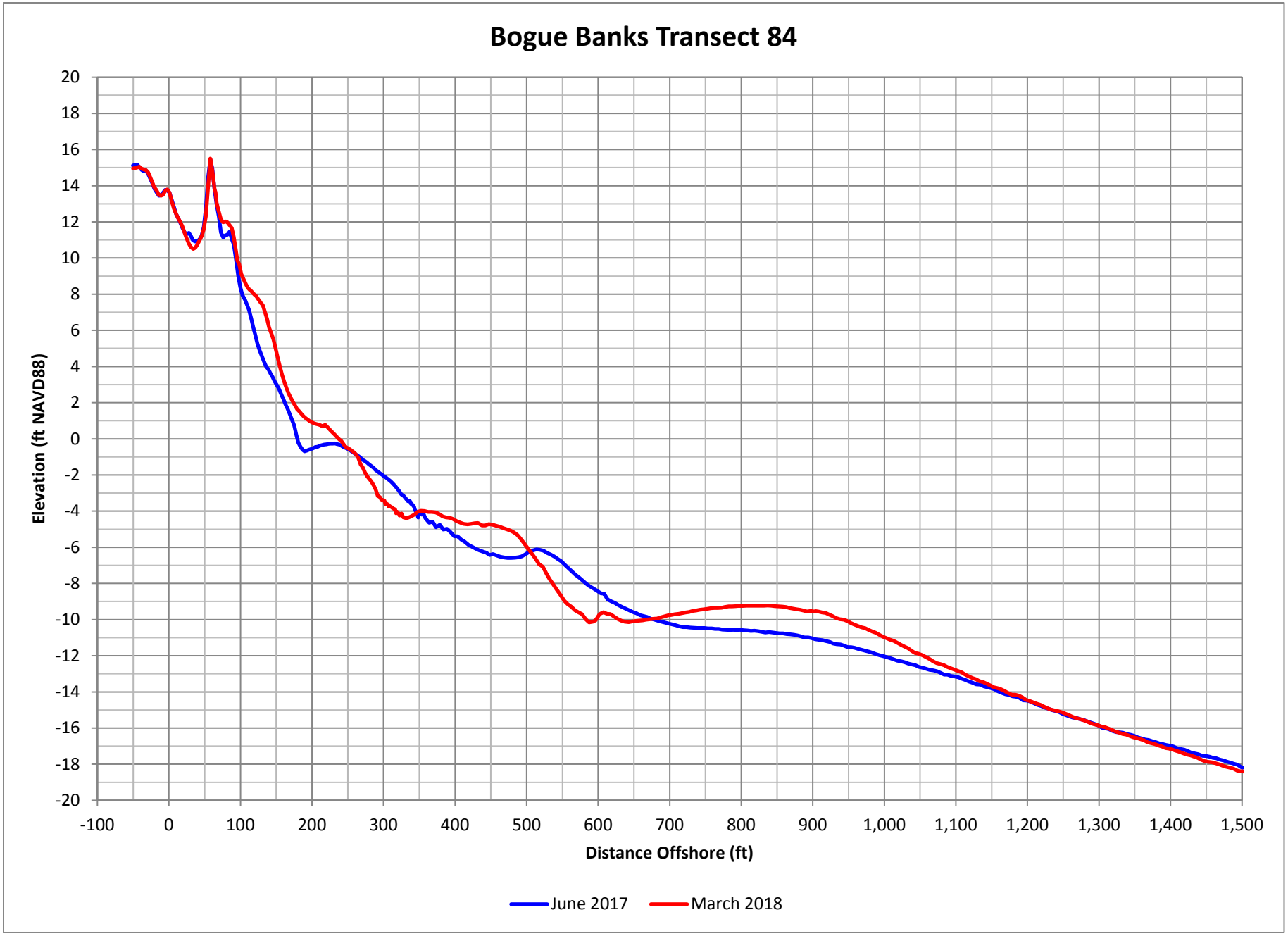


Figure D-168. Bogue Banks Profile Comparison Plot

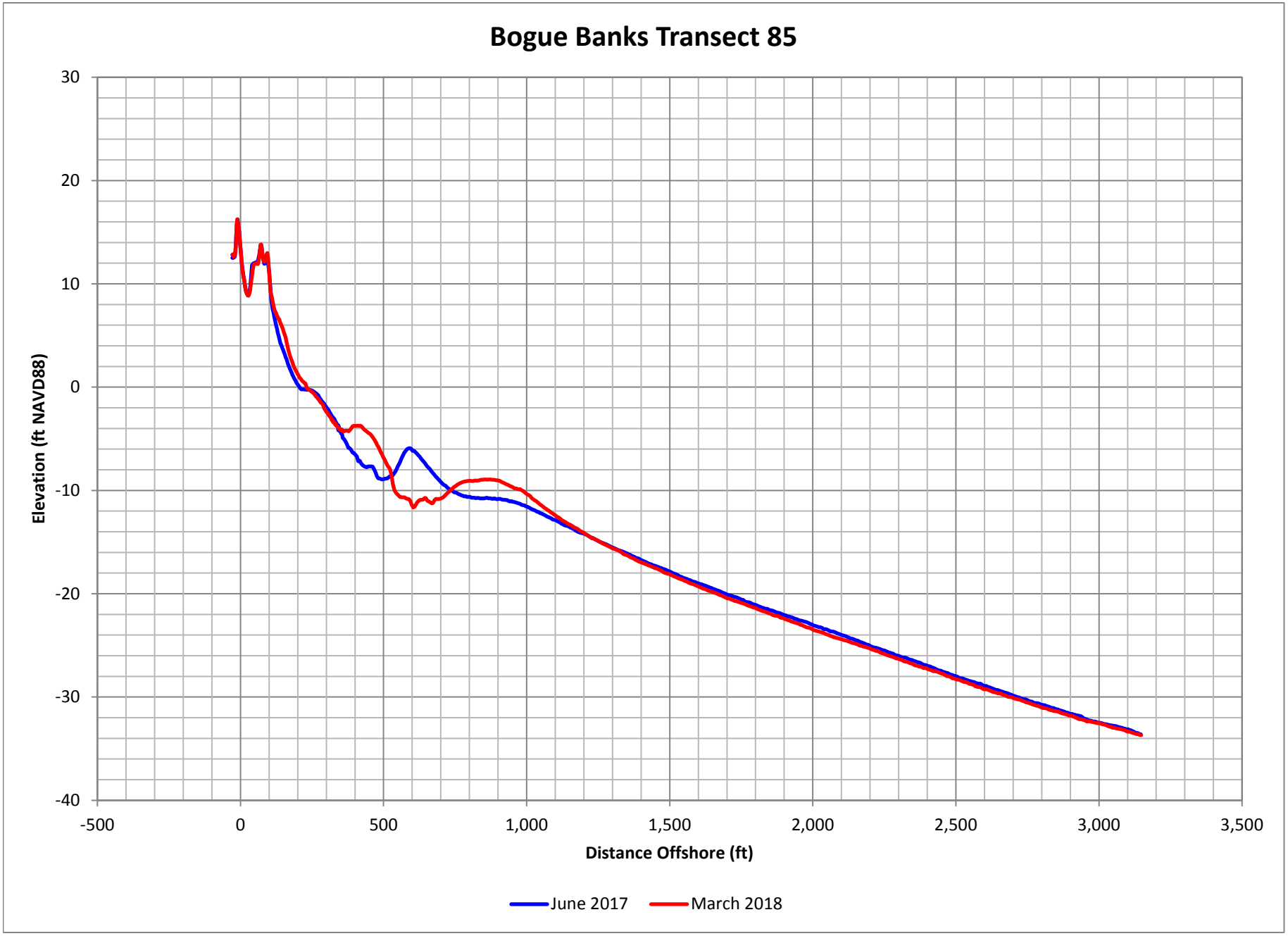


Figure D-169. Bogue Banks Profile Comparison Plot

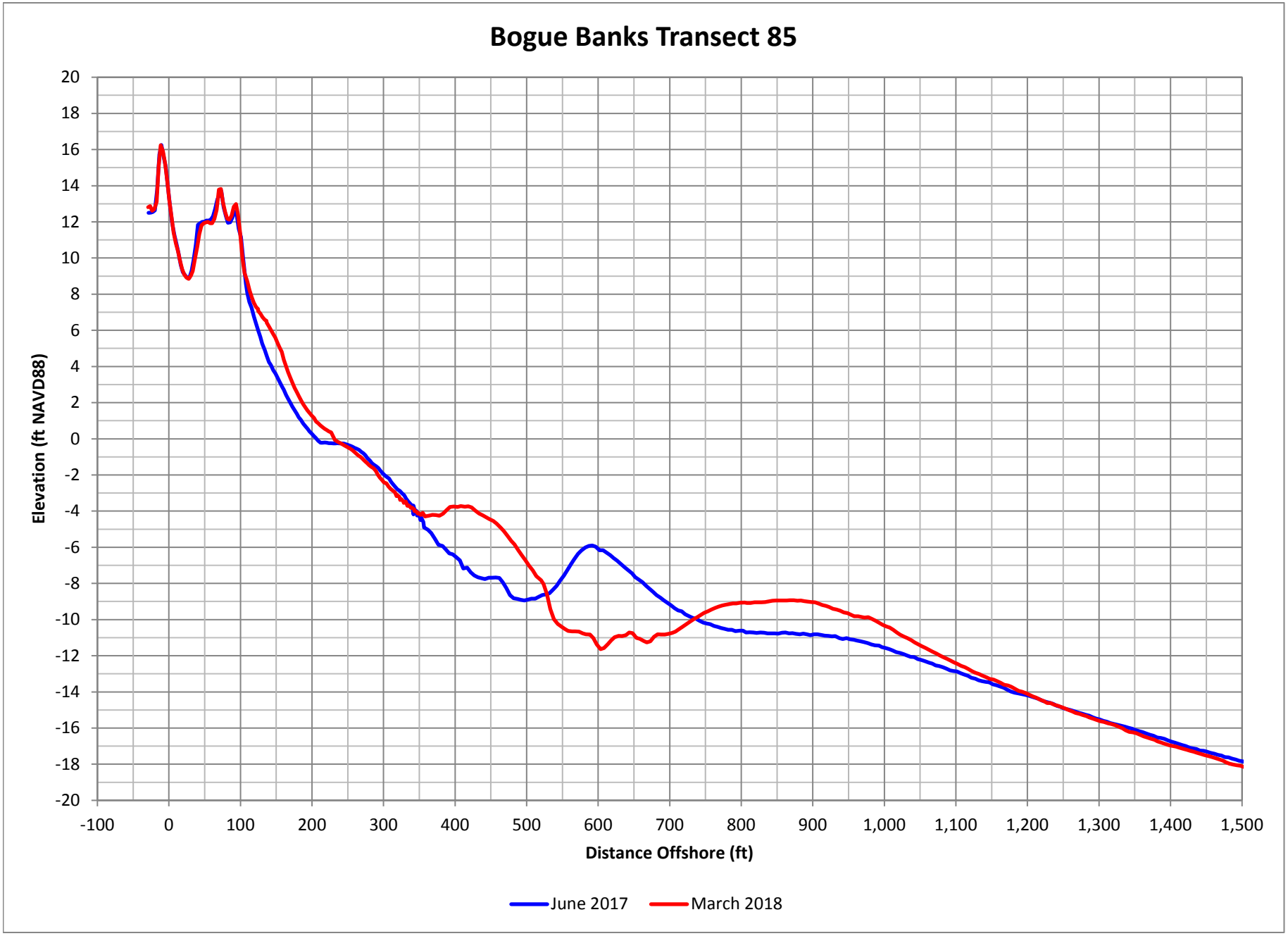


Figure D-170. Bogue Banks Profile Comparison Plot

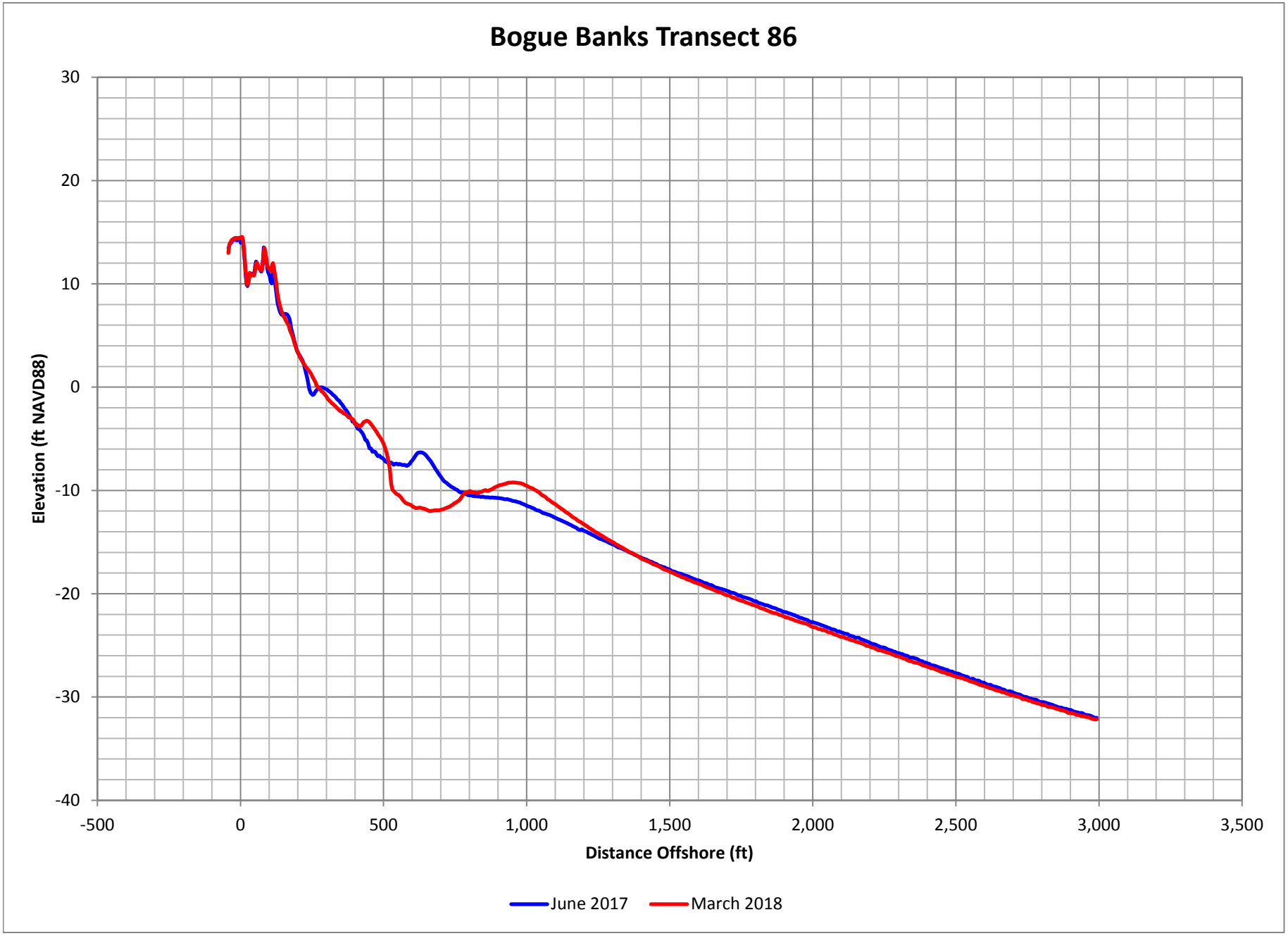


Figure D-171. Bogue Banks Profile Comparison Plot

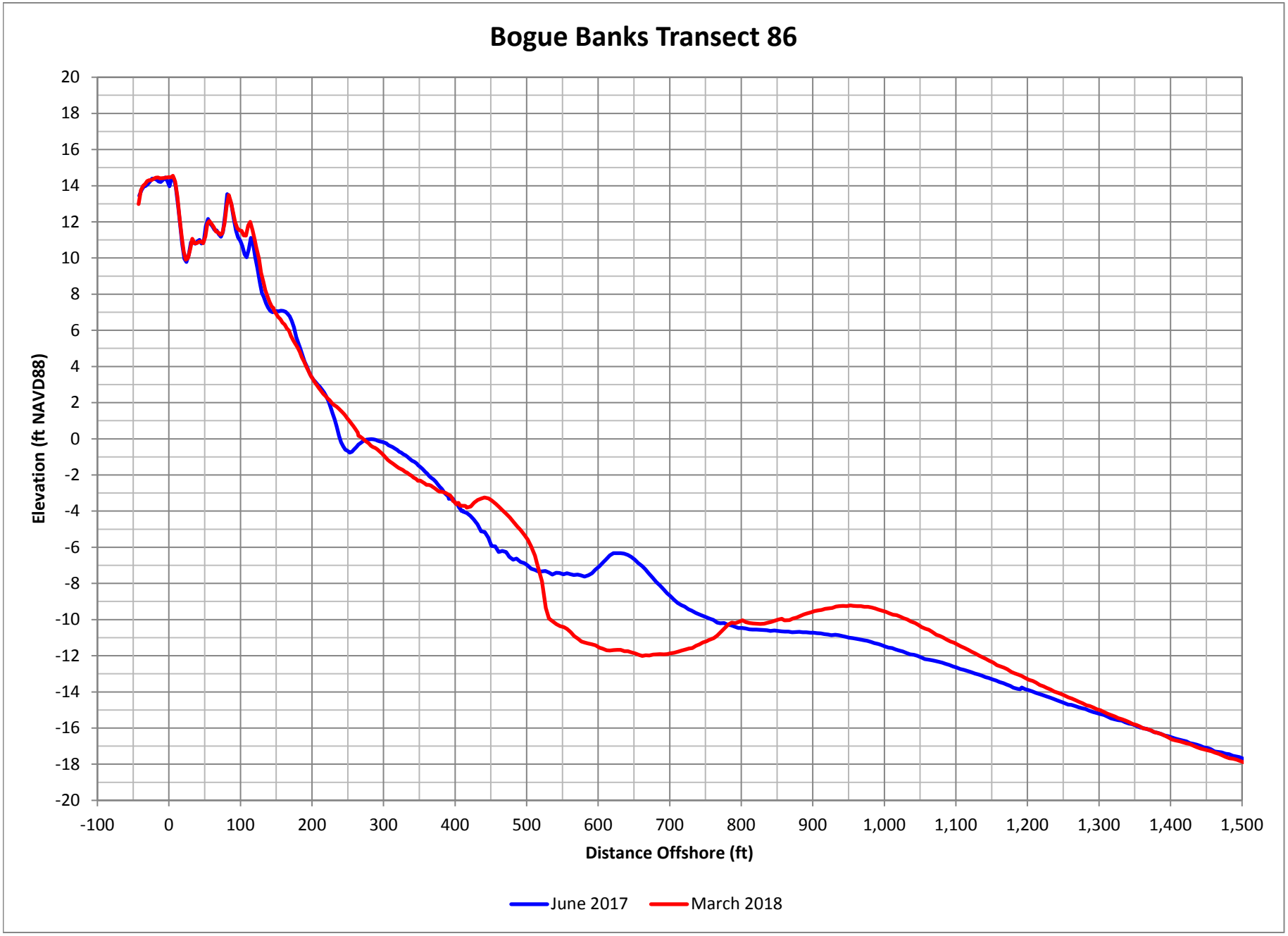


Figure D-172. Bogue Banks Profile Comparison Plot

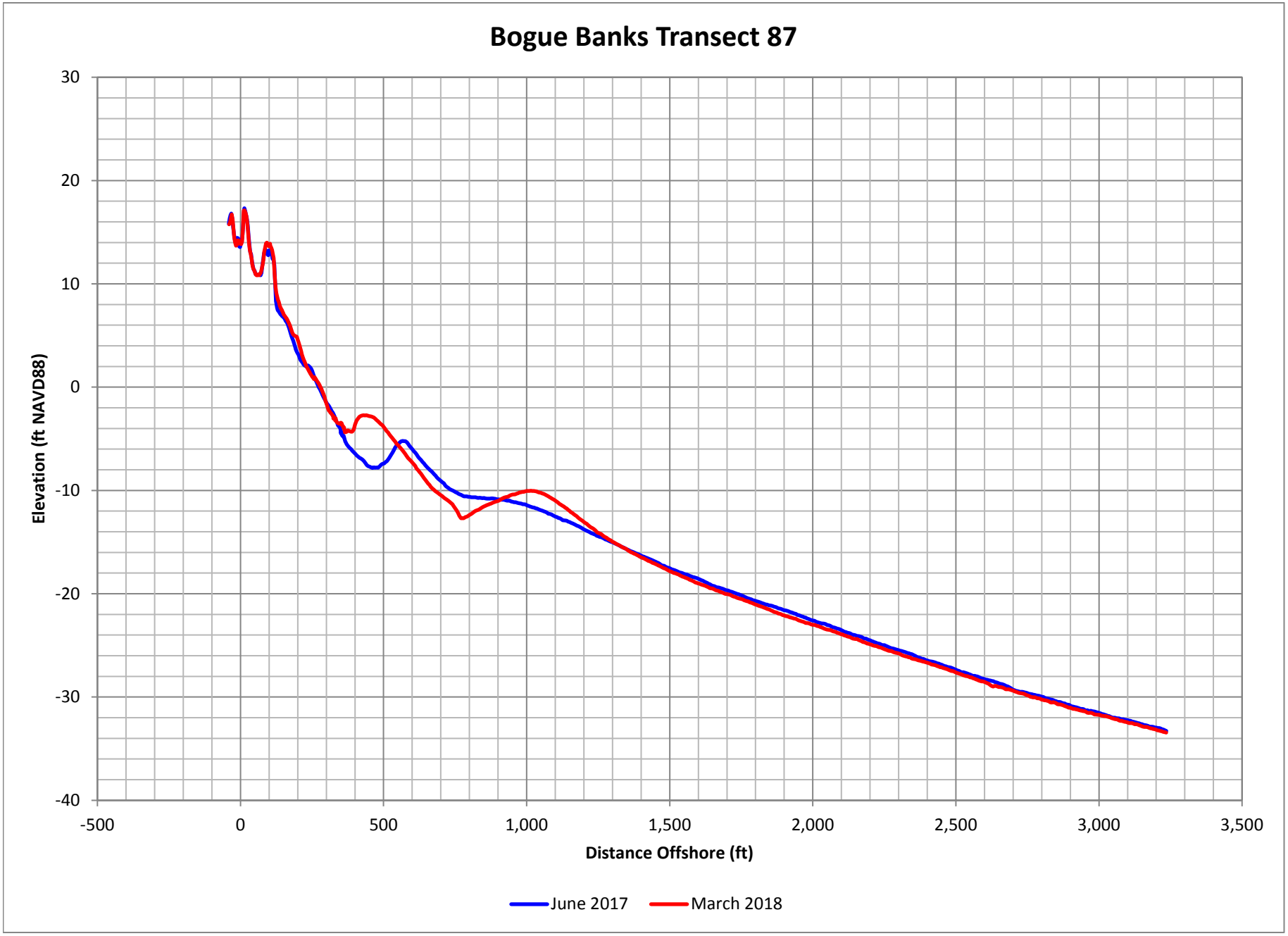


Figure D-173. Bogue Banks Profile Comparison Plot

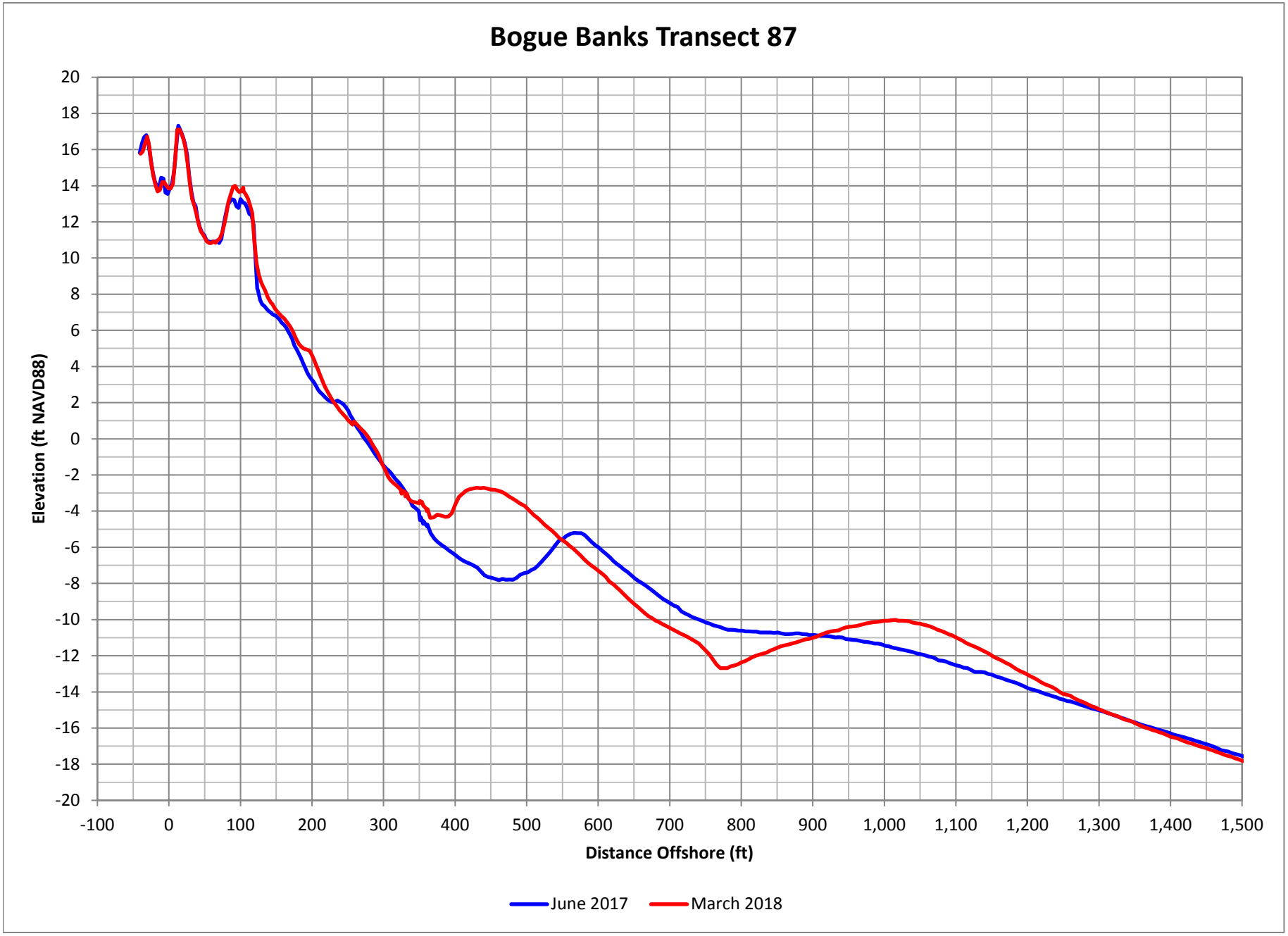


Figure D-174. Bogue Banks Profile Comparison Plot

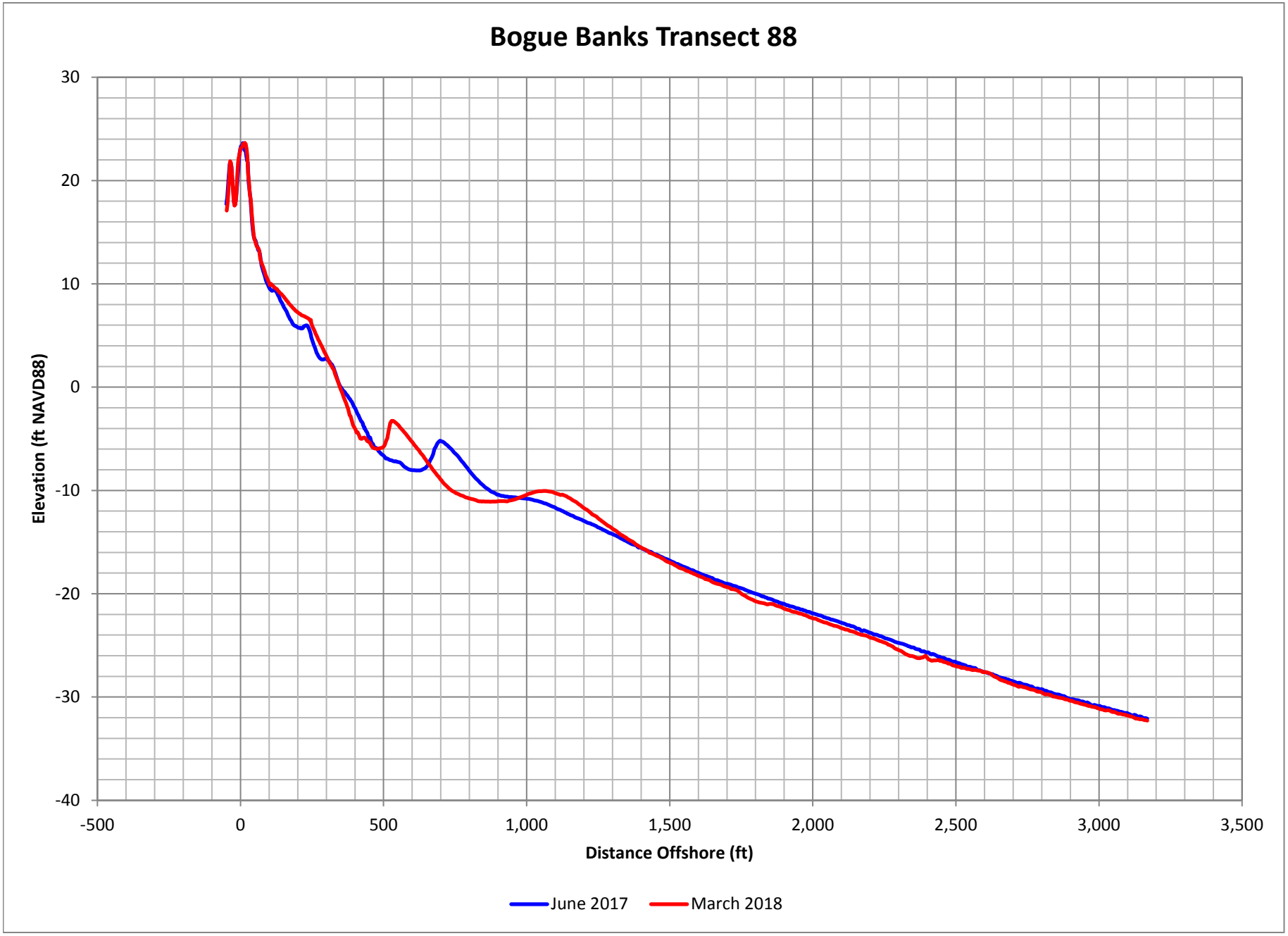


Figure D-175. Bogue Banks Profile Comparison Plot

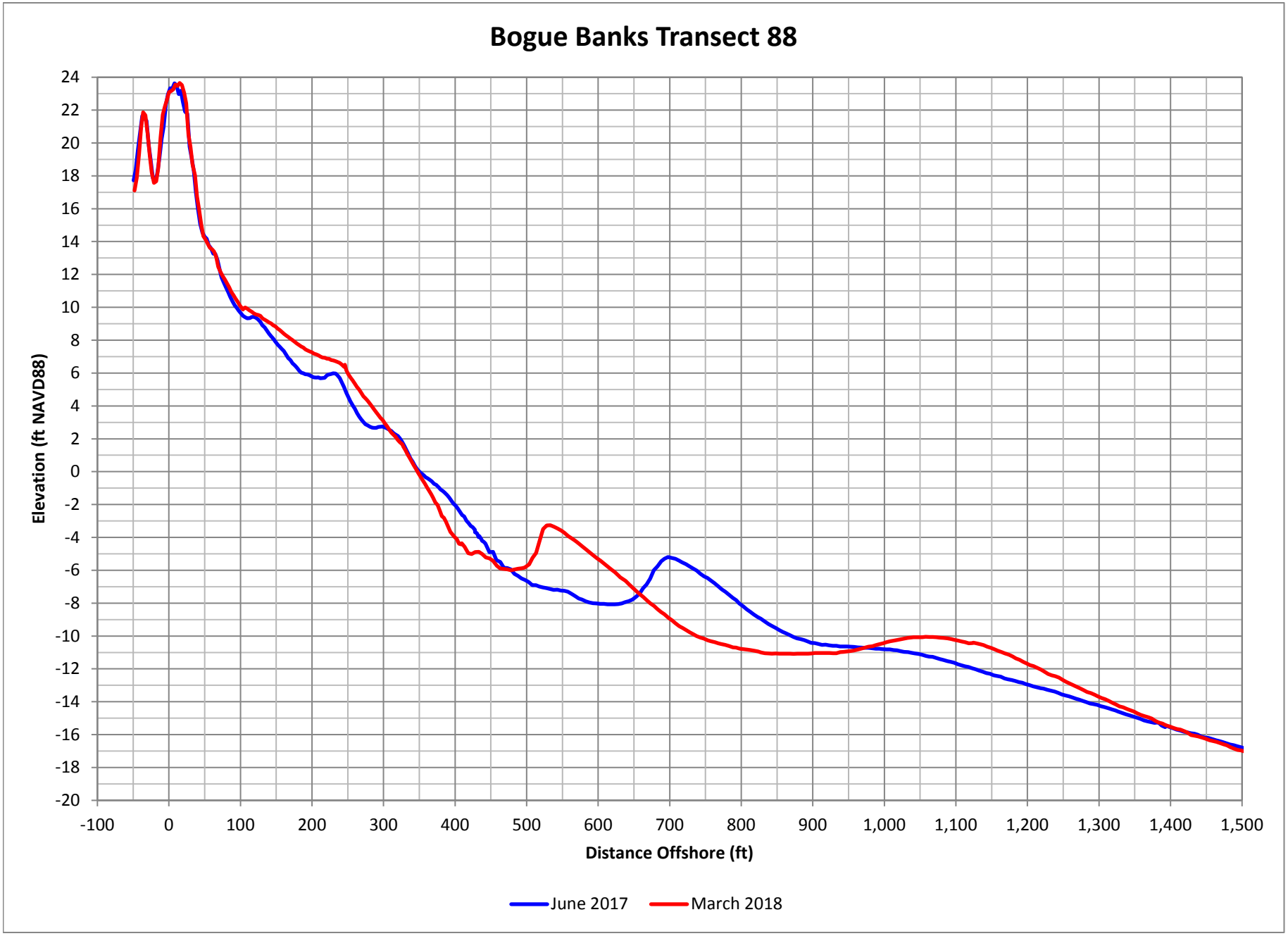


Figure D-176. Bogue Banks Profile Comparison Plot

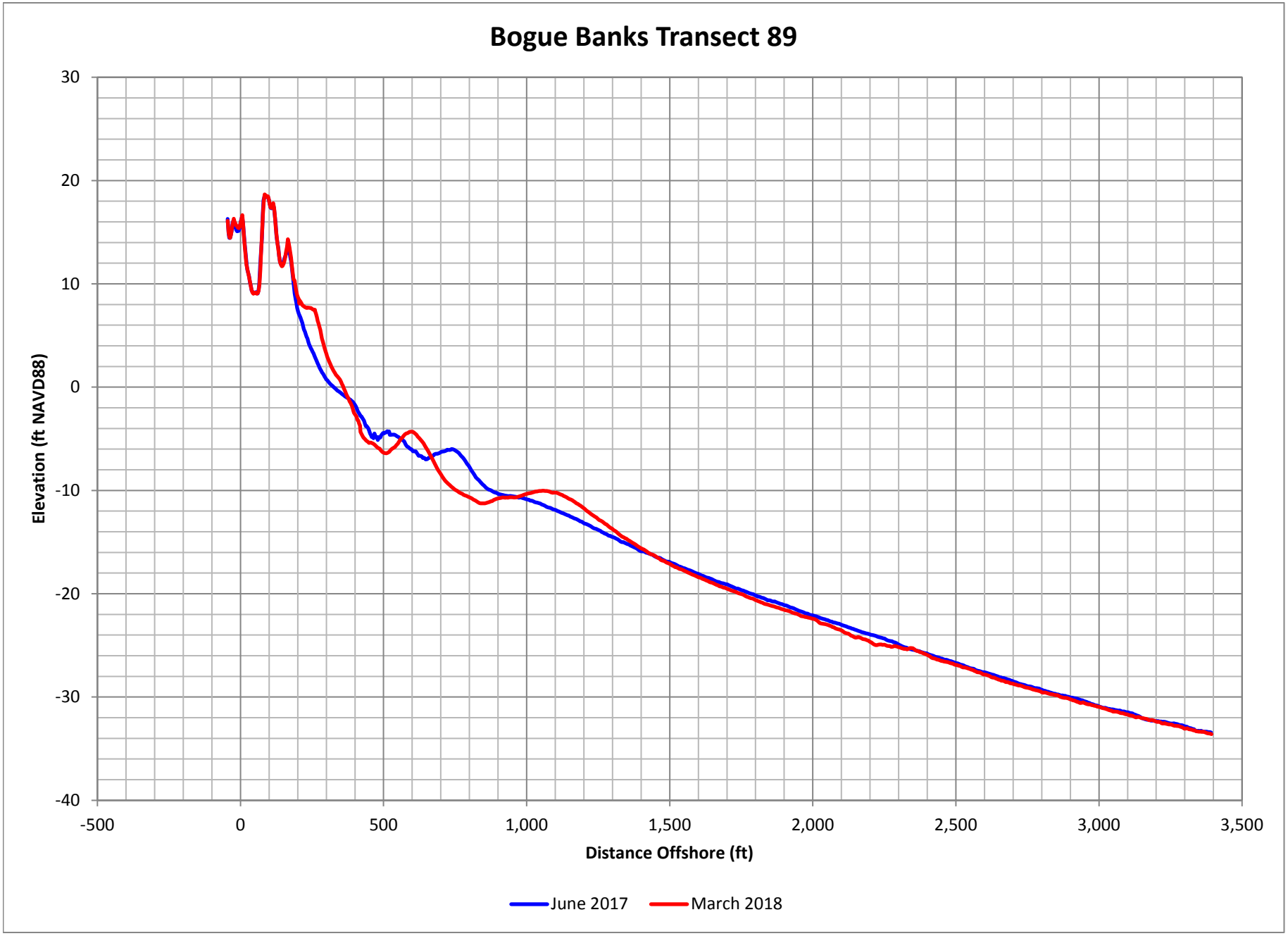


Figure D-177. Bogue Banks Profile Comparison Plot

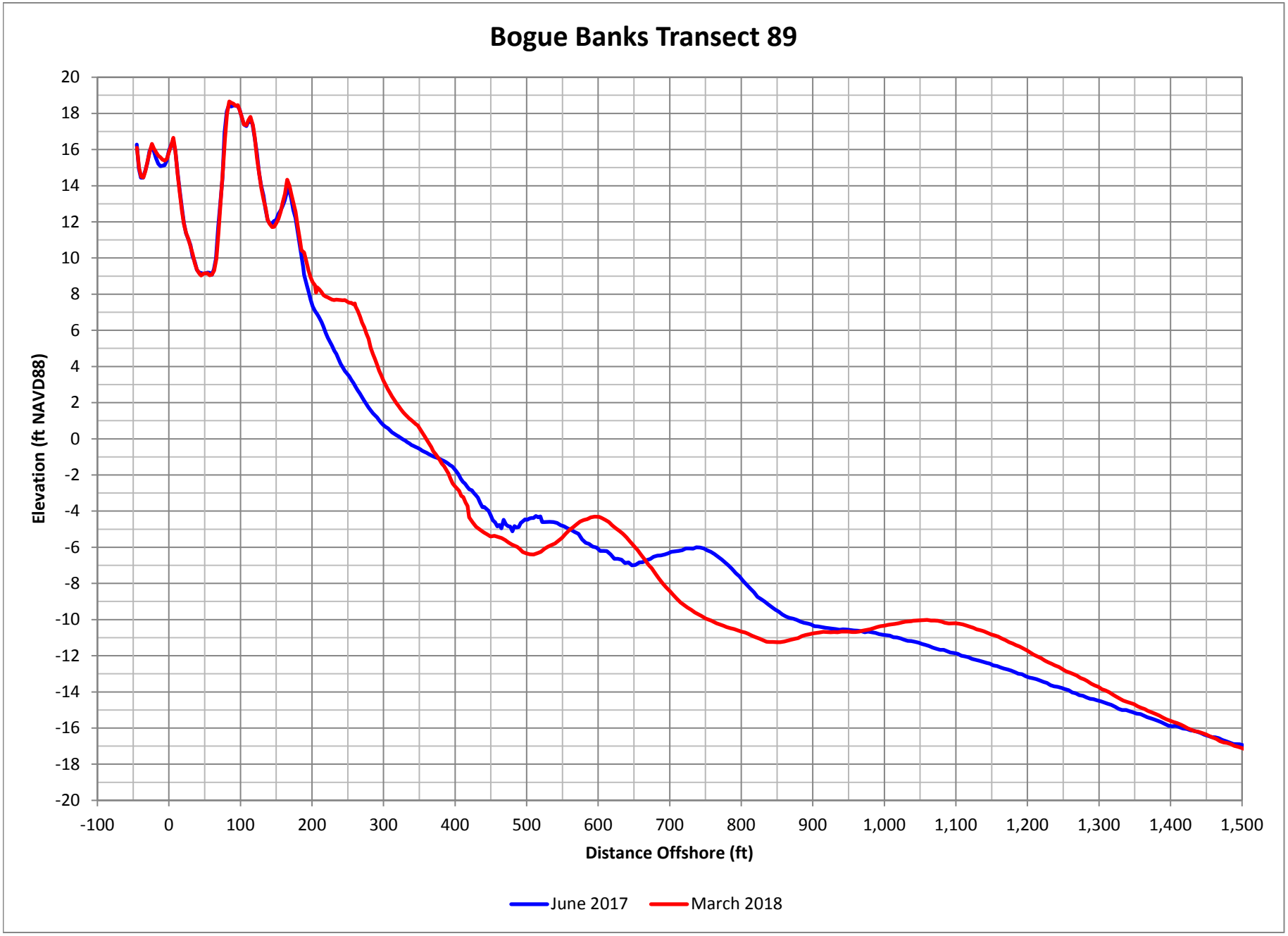


Figure D-178. Bogue Banks Profile Comparison Plot

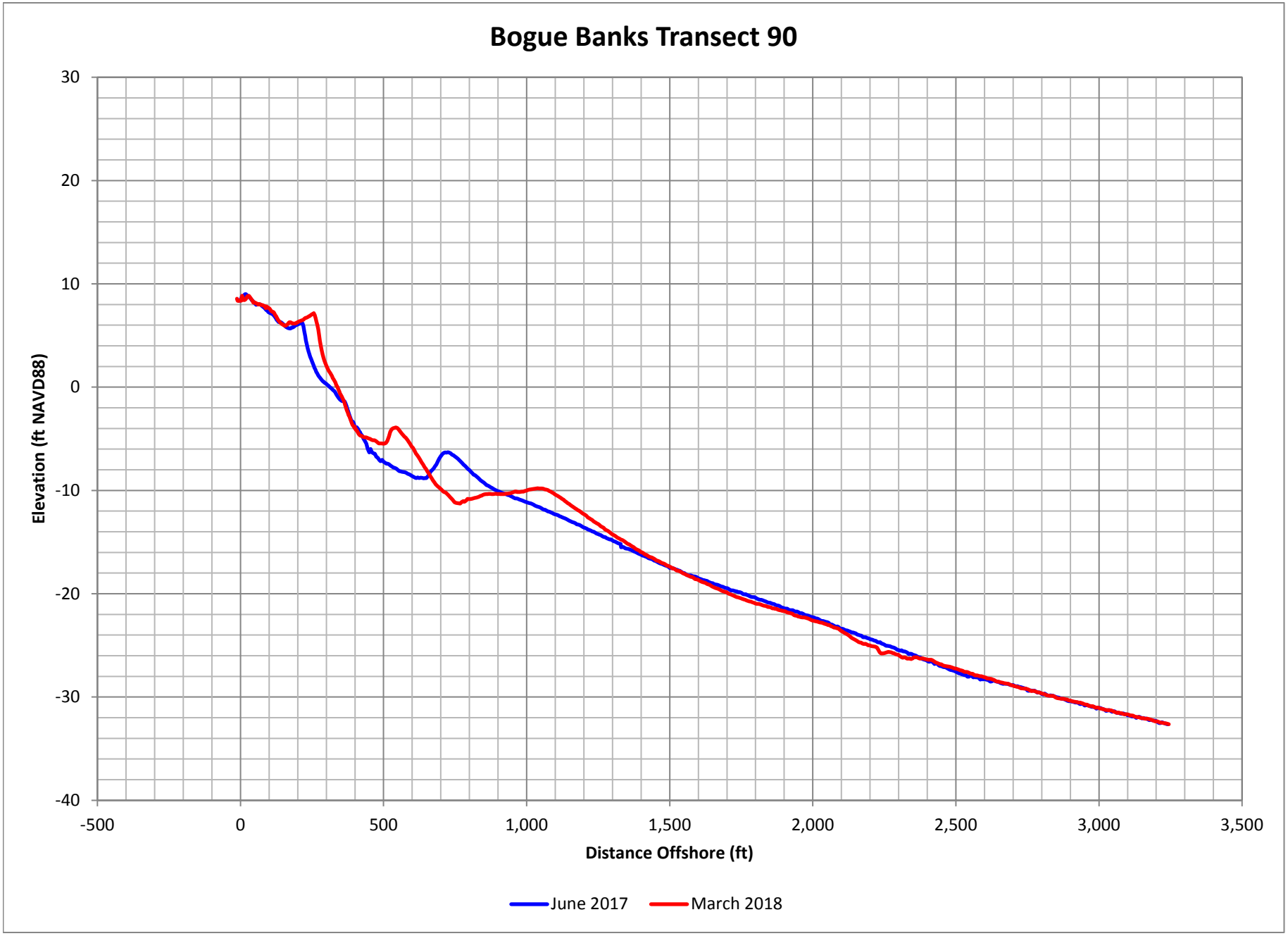


Figure D-179. Bogue Banks Profile Comparison Plot

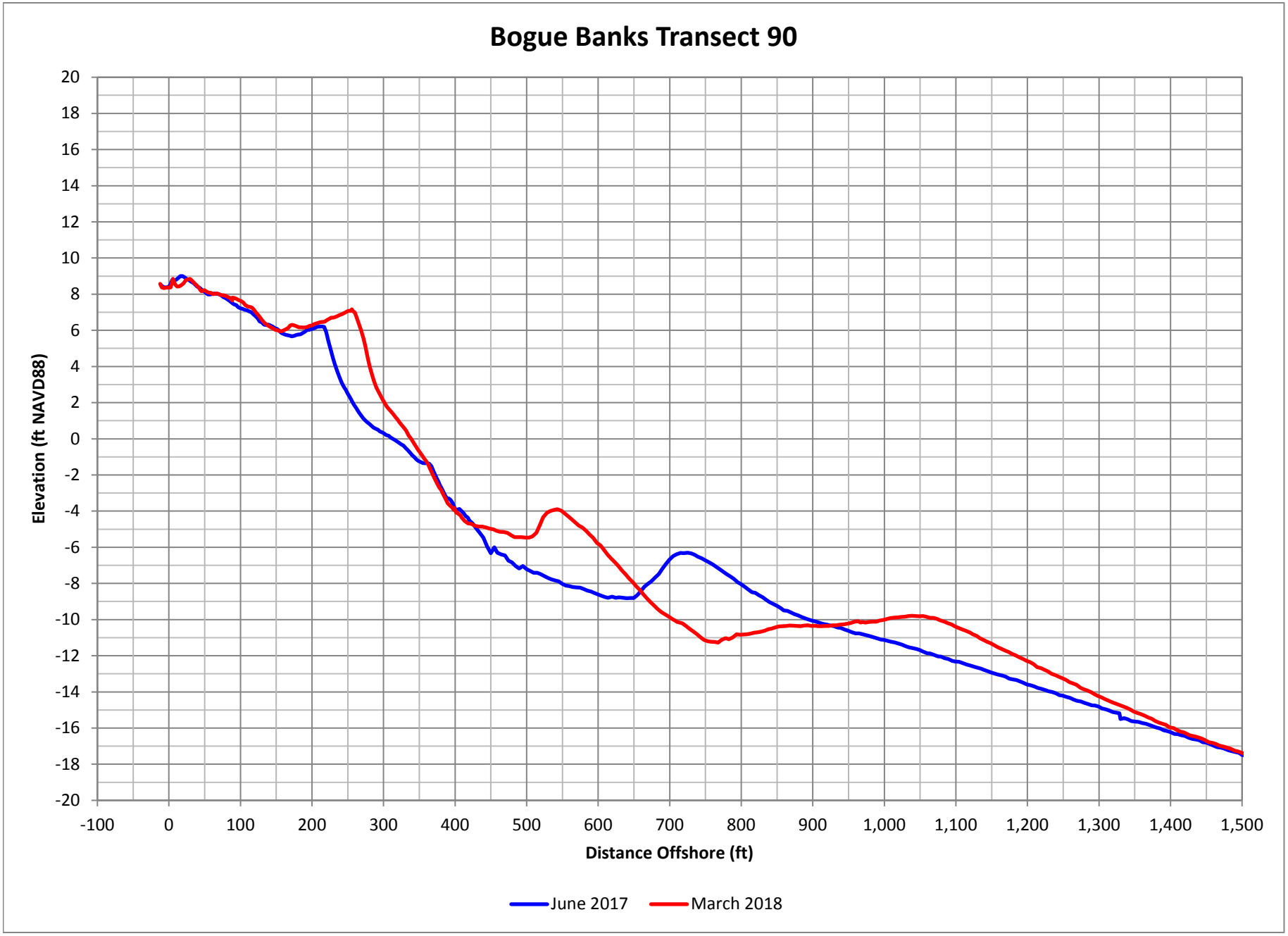


Figure D-180. Bogue Banks Profile Comparison Plot

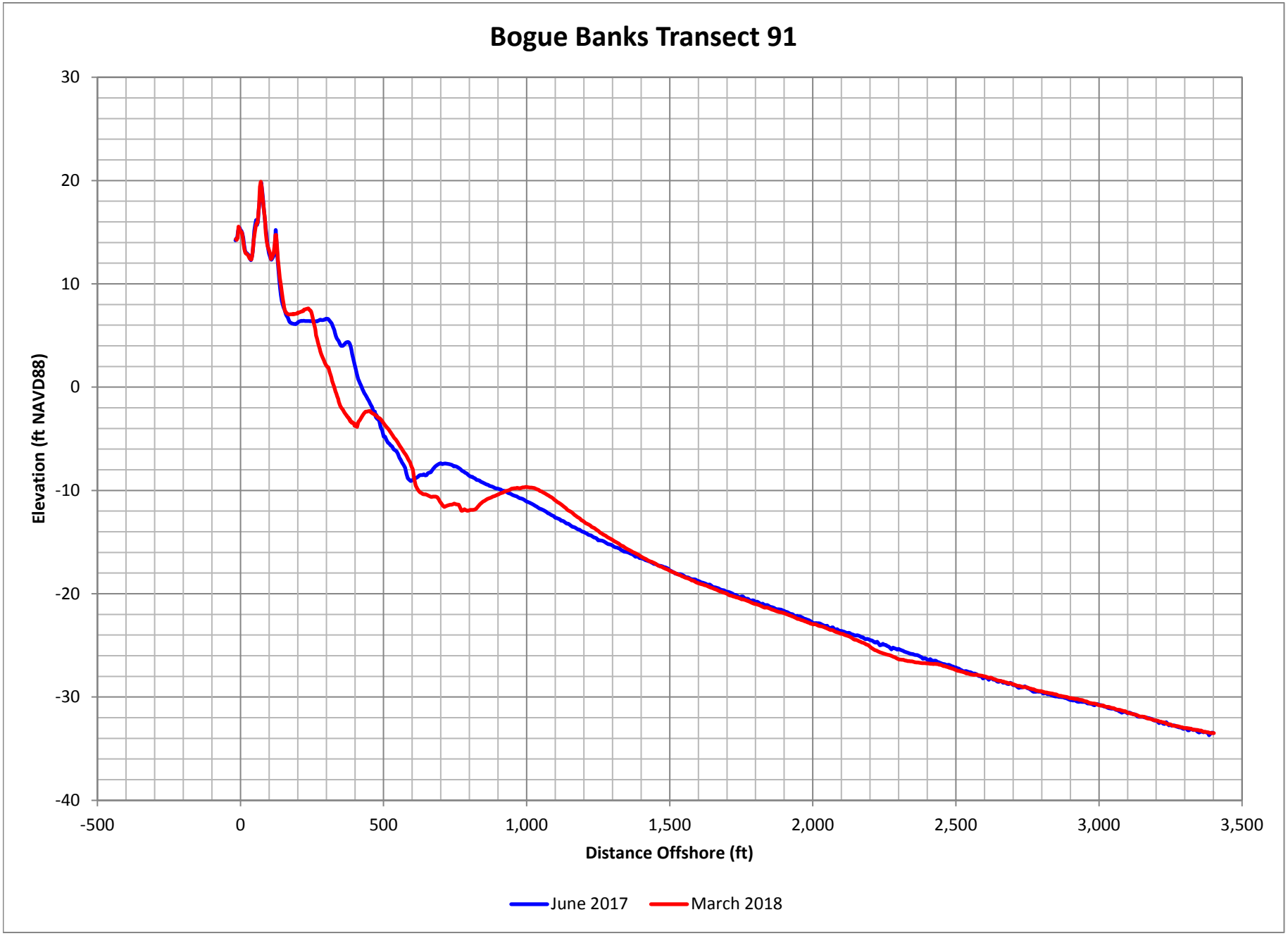


Figure D-181. Bogue Banks Profile Comparison Plot

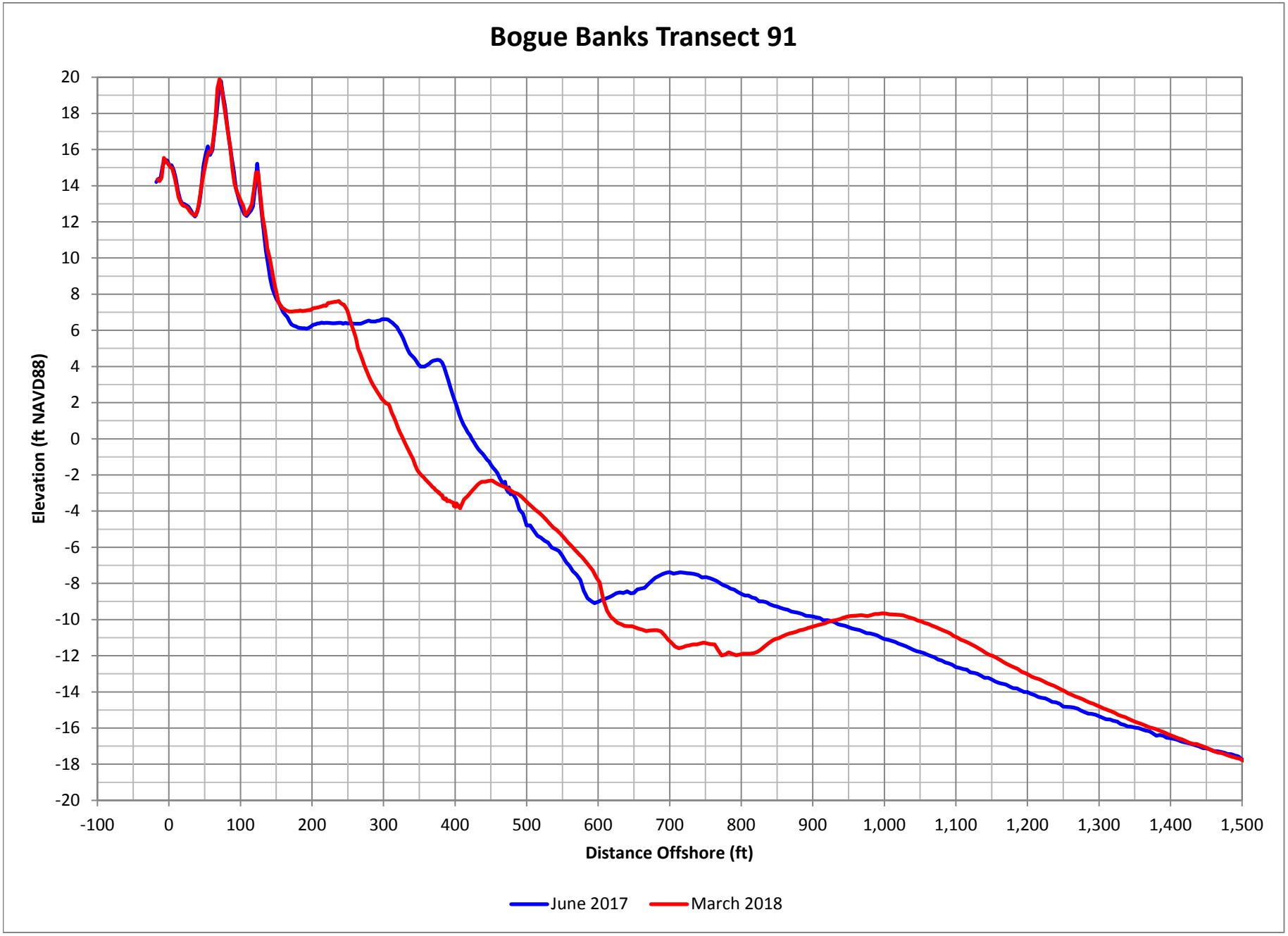


Figure D-182. Bogue Banks Profile Comparison Plot

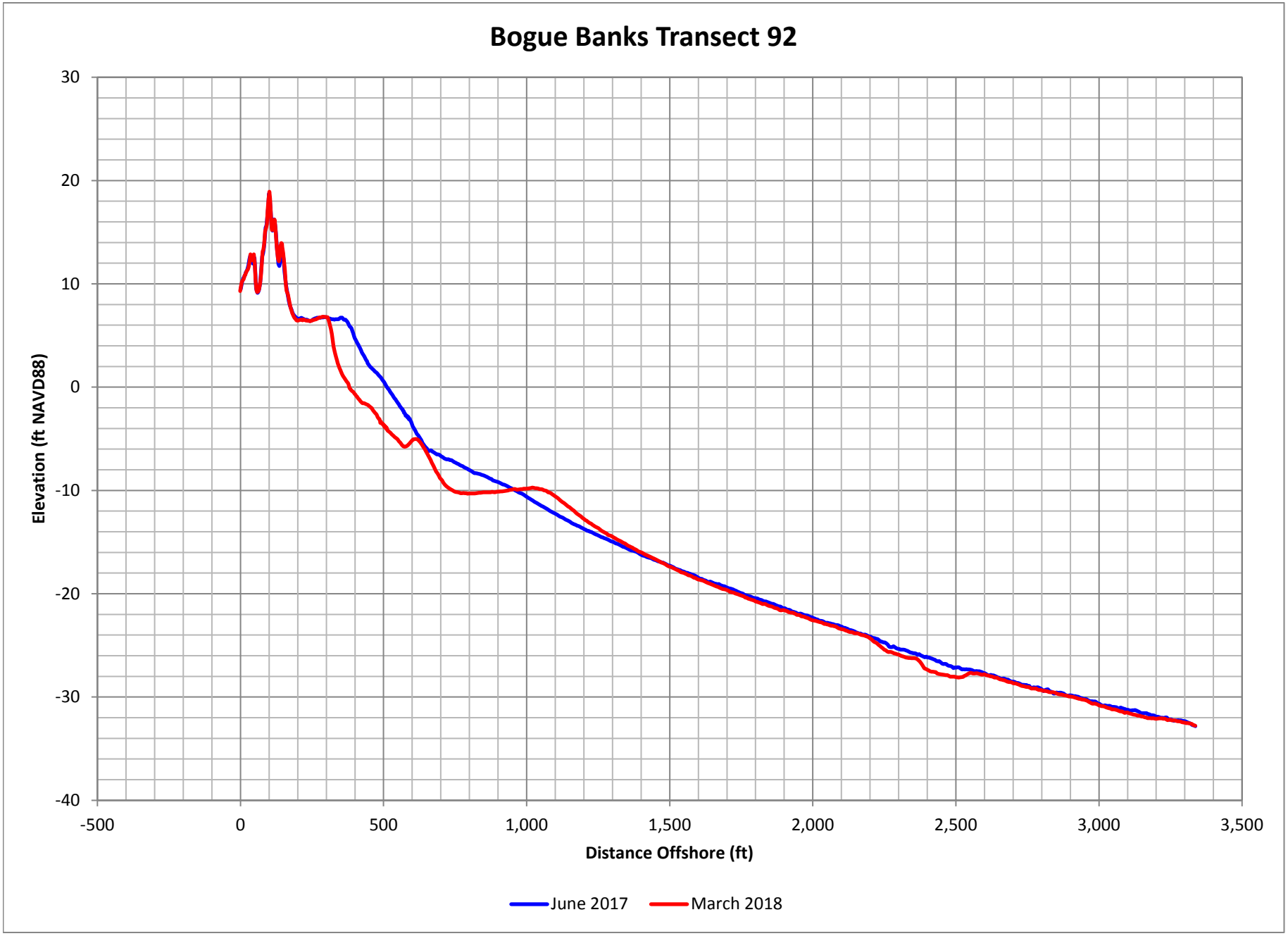


Figure D-183. Bogue Banks Profile Comparison Plot

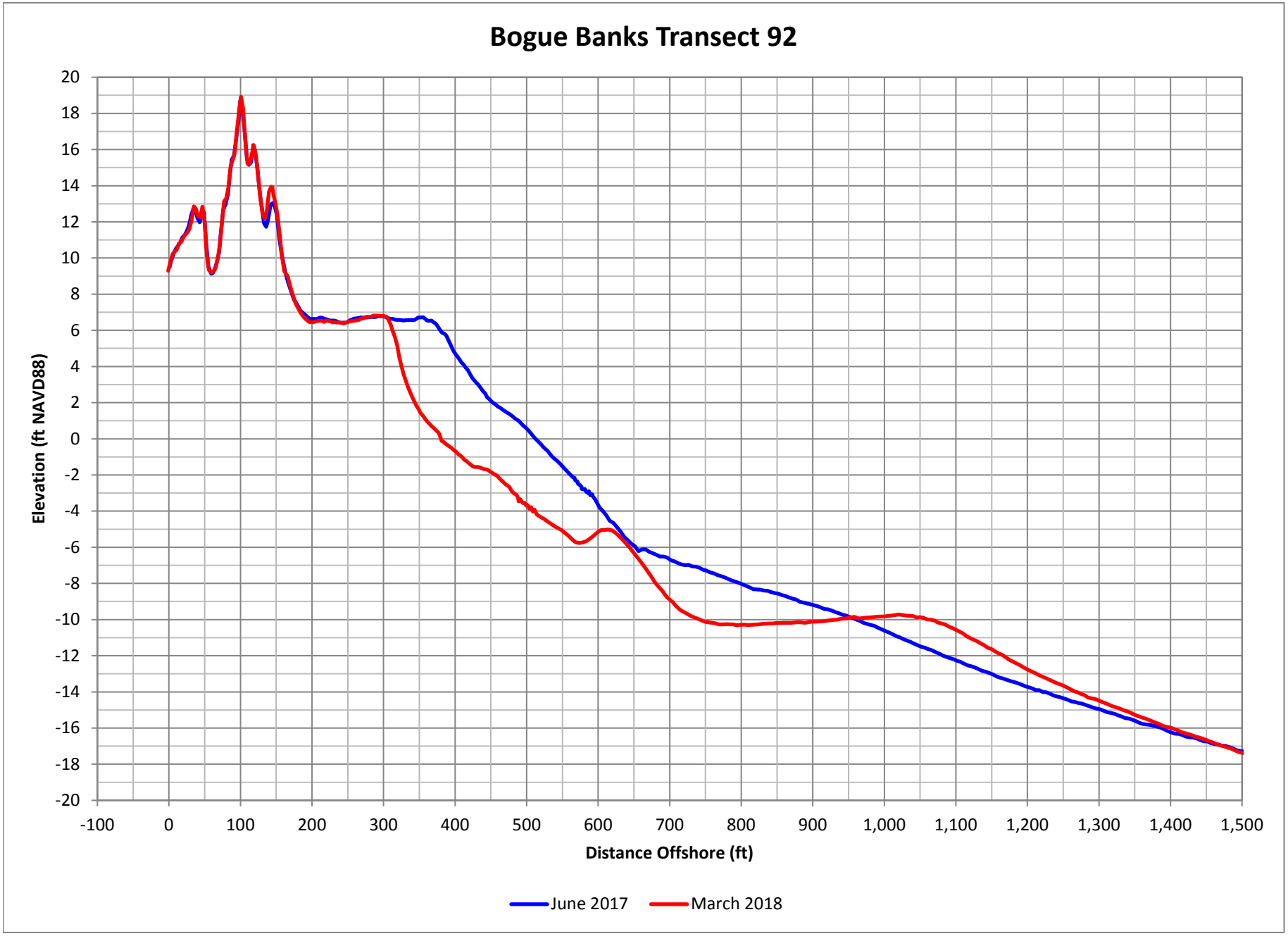


Figure D-184. Bogue Banks Profile Comparison Plot

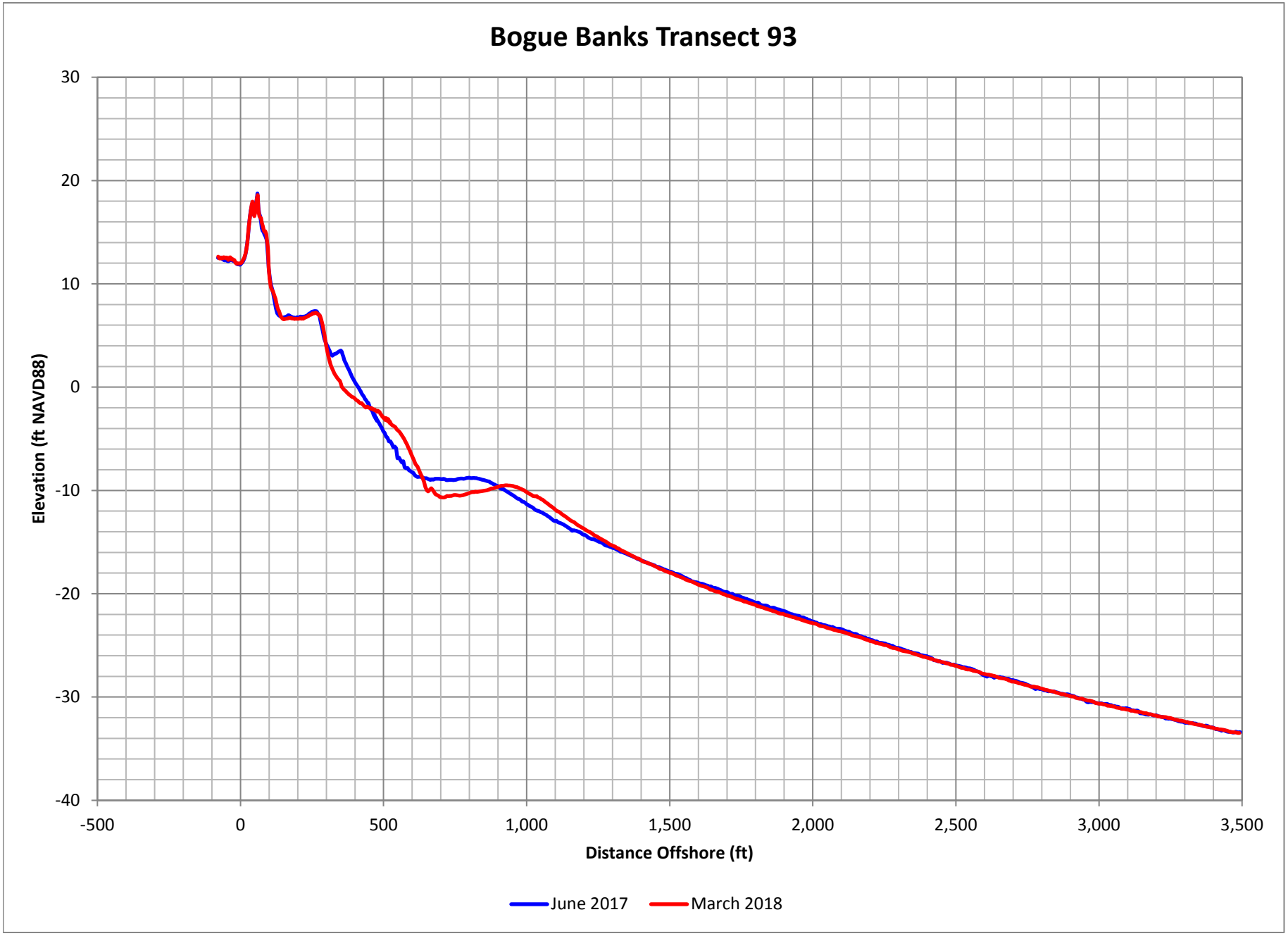


Figure D-185. Bogue Banks Profile Comparison Plot

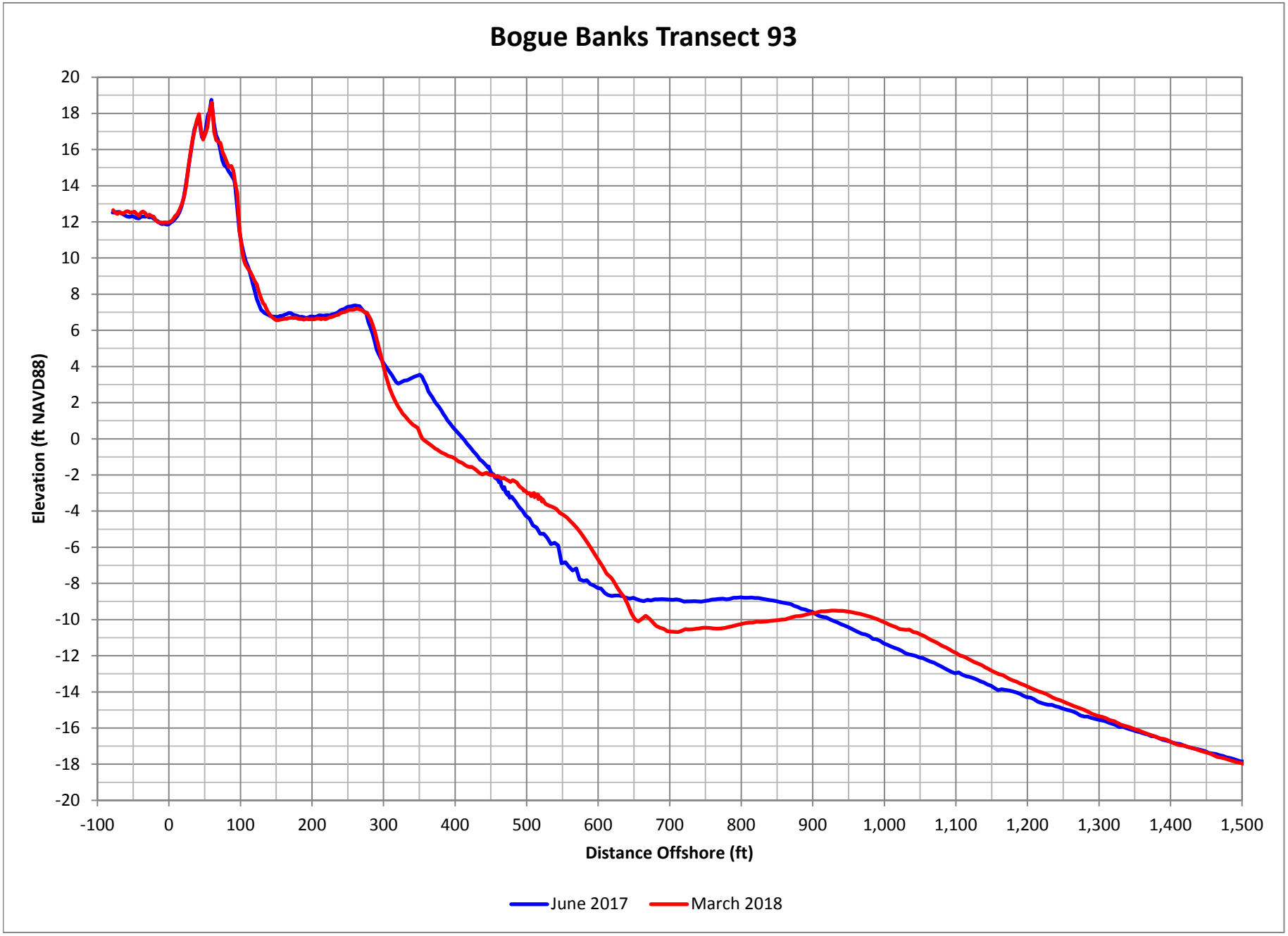


Figure D-186. Bogue Banks Profile Comparison Plot

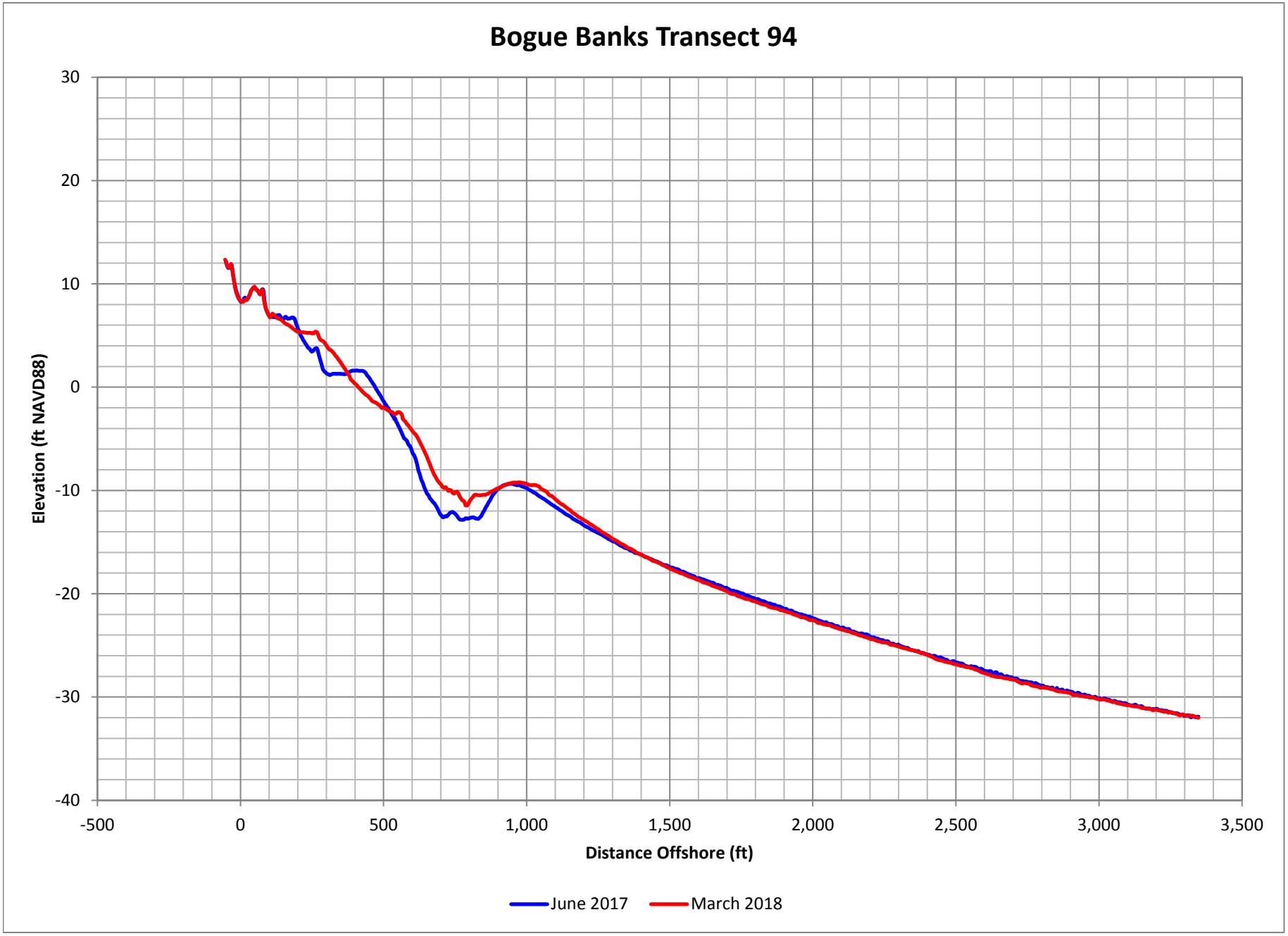


Figure D-187. Bogue Banks Profile Comparison Plot

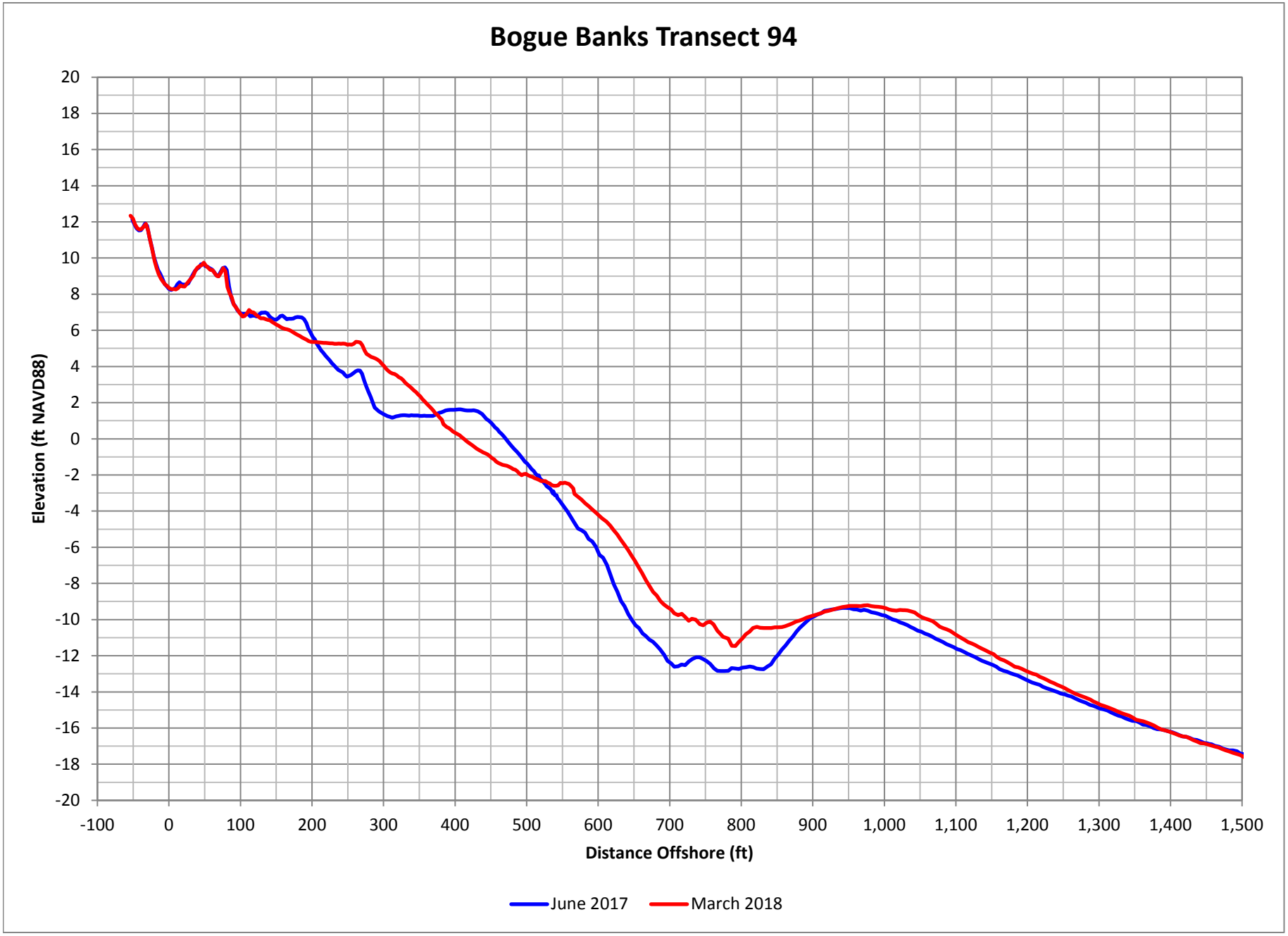


Figure D-188. Bogue Banks Profile Comparison Plot

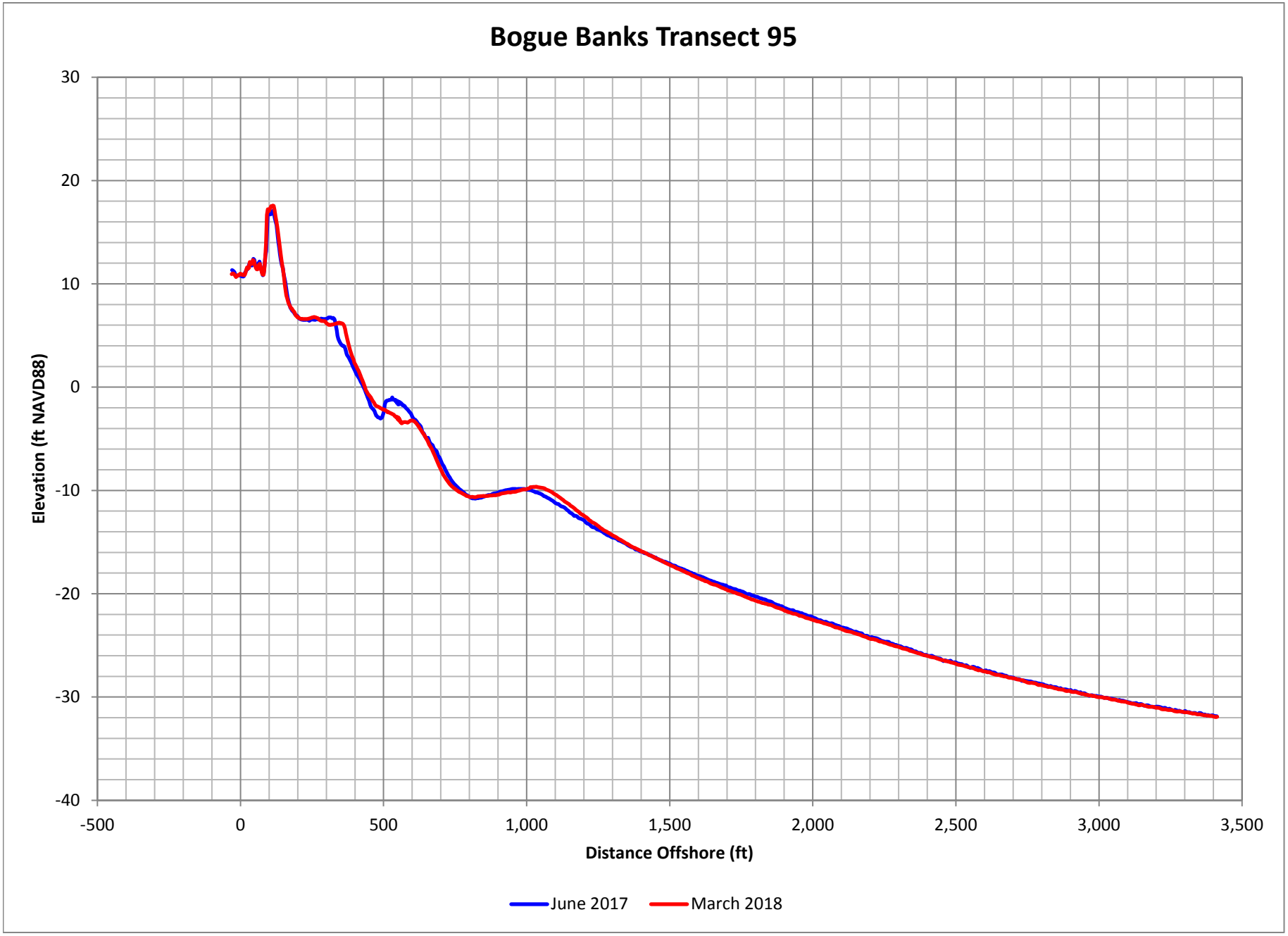


Figure D-189. Bogue Banks Profile Comparison Plot

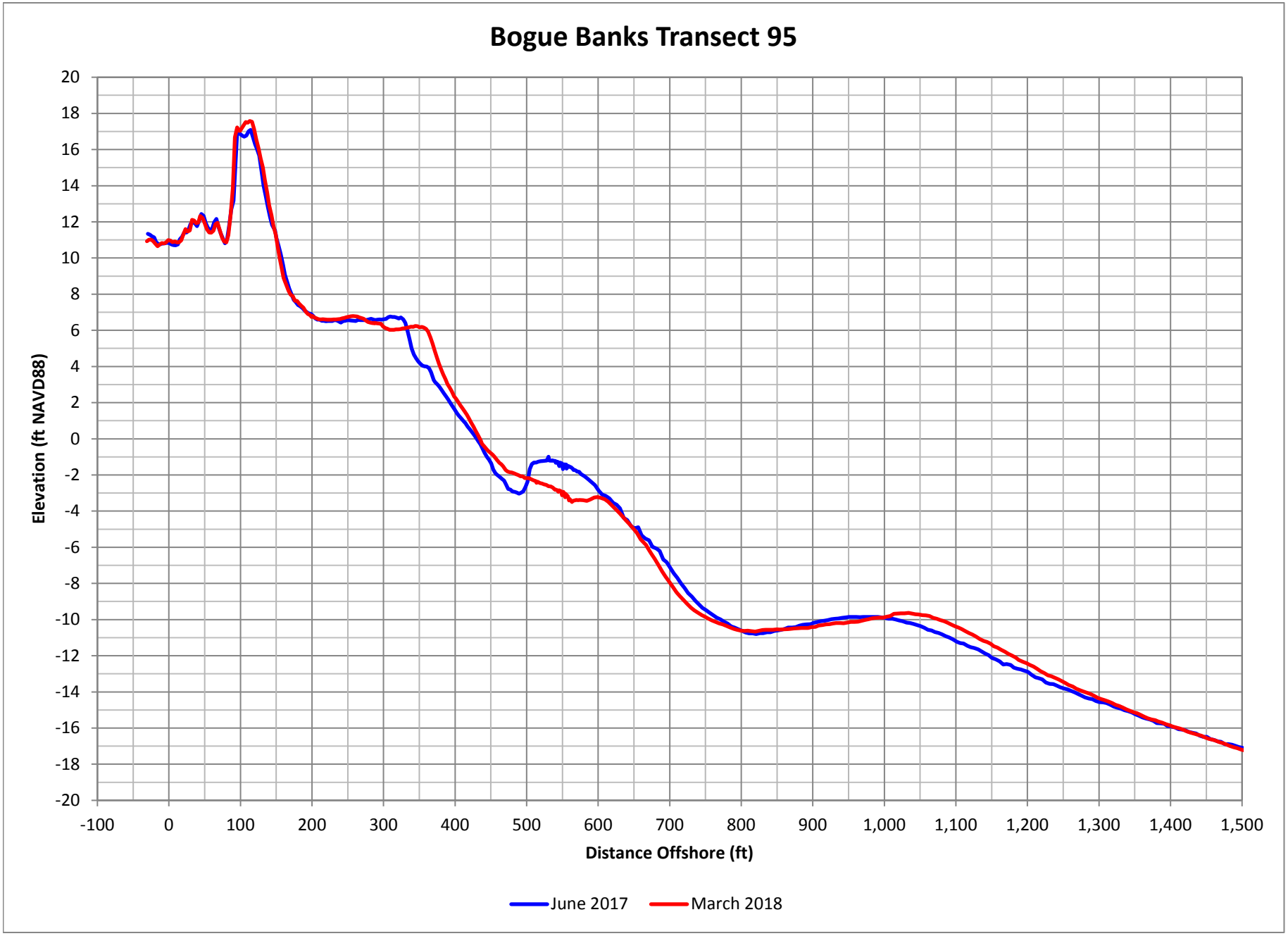


Figure D-190. Bogue Banks Profile Comparison Plot

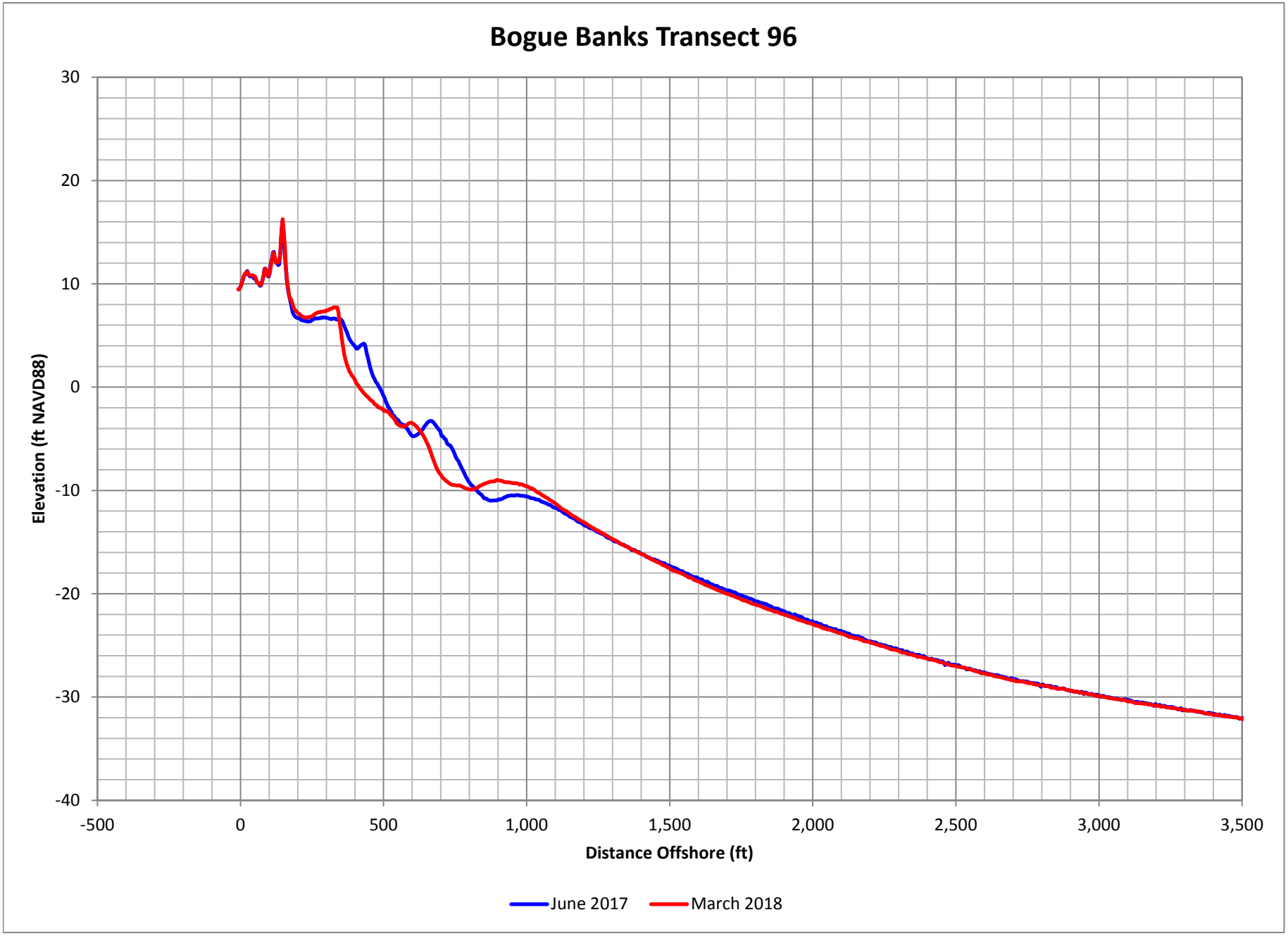


Figure D-191. Bogue Banks Profile Comparison Plot

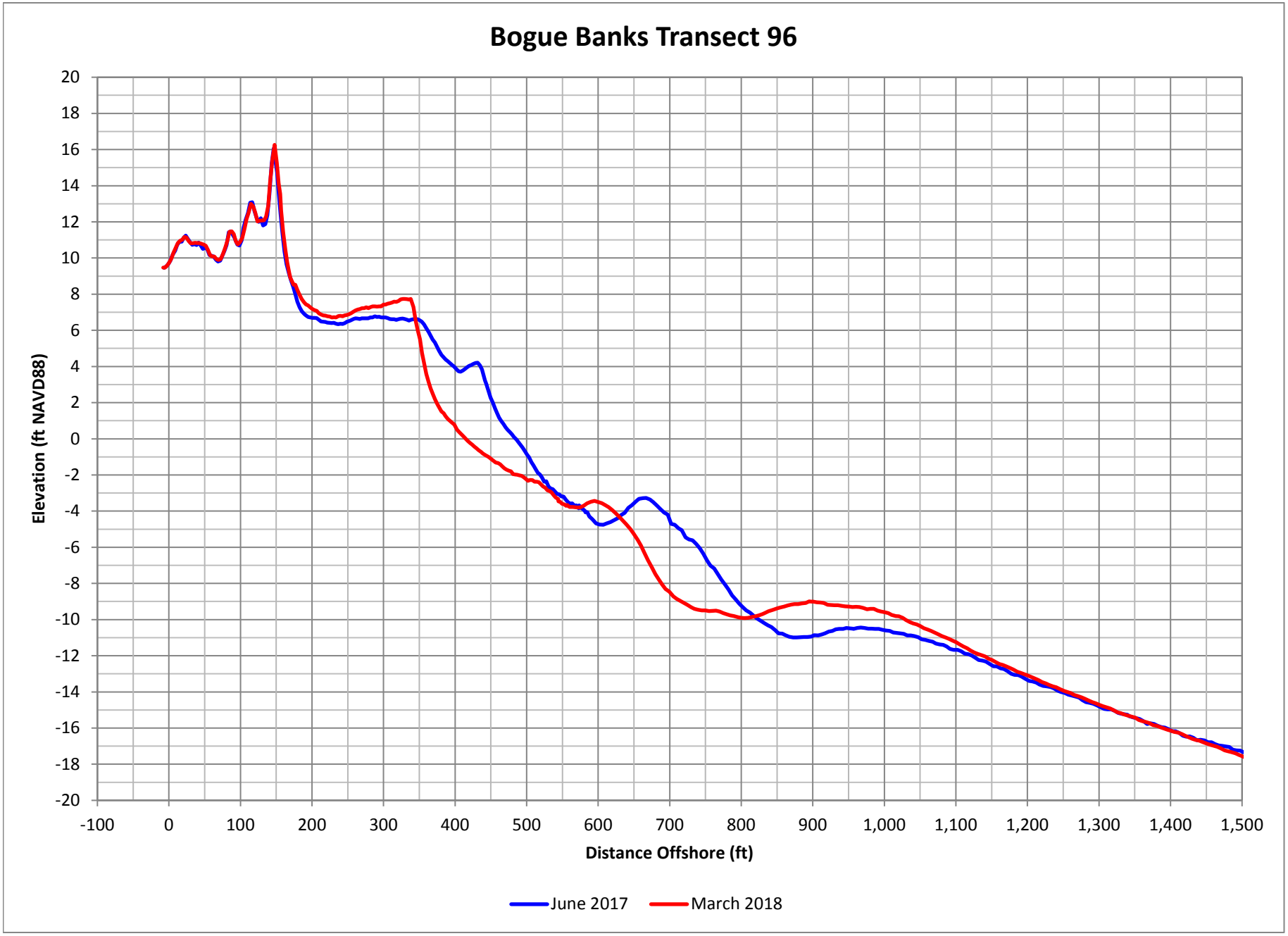


Figure D-192. Bogue Banks Profile Comparison Plot

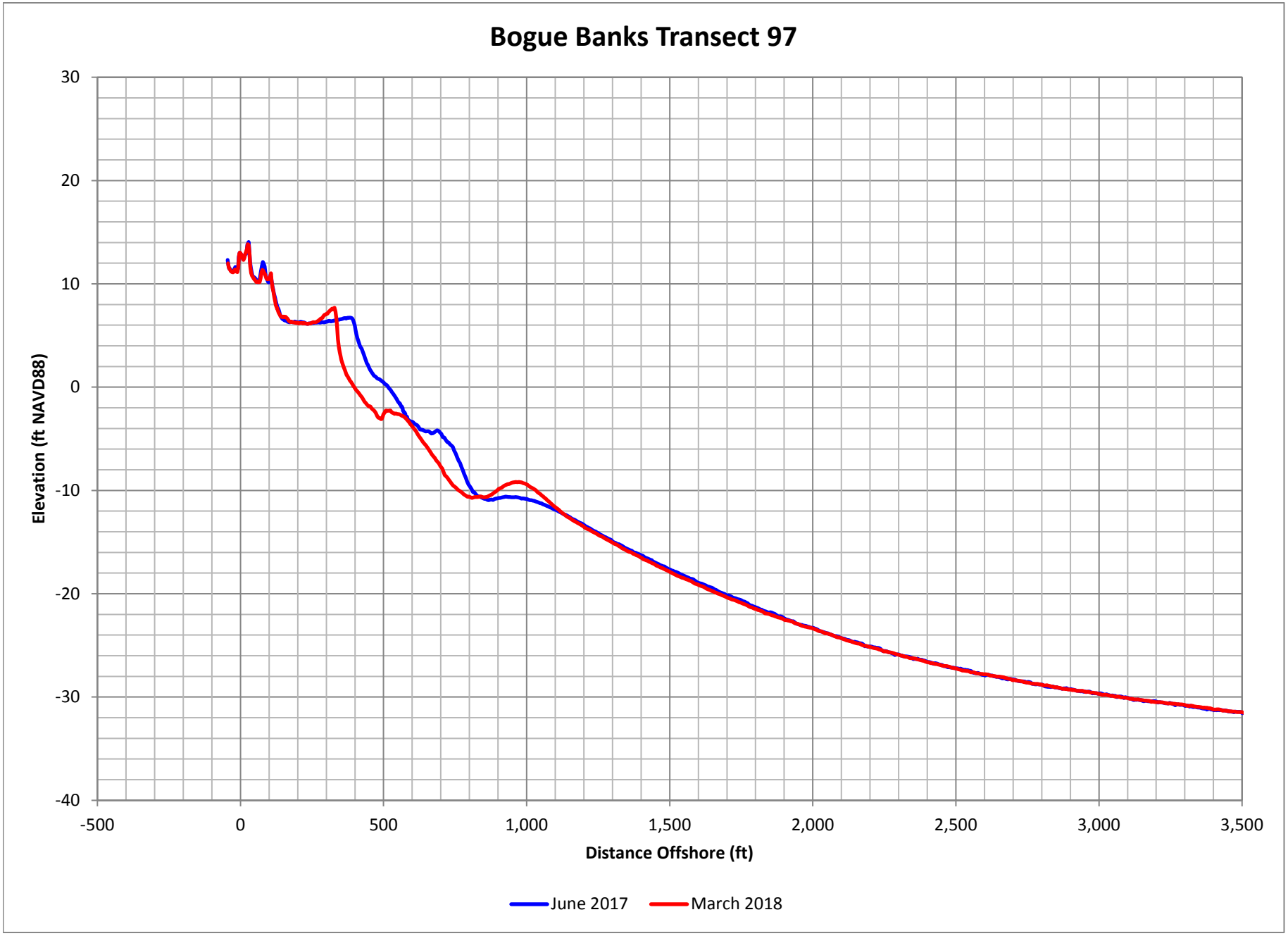


Figure D-193. Bogue Banks Profile Comparison Plot

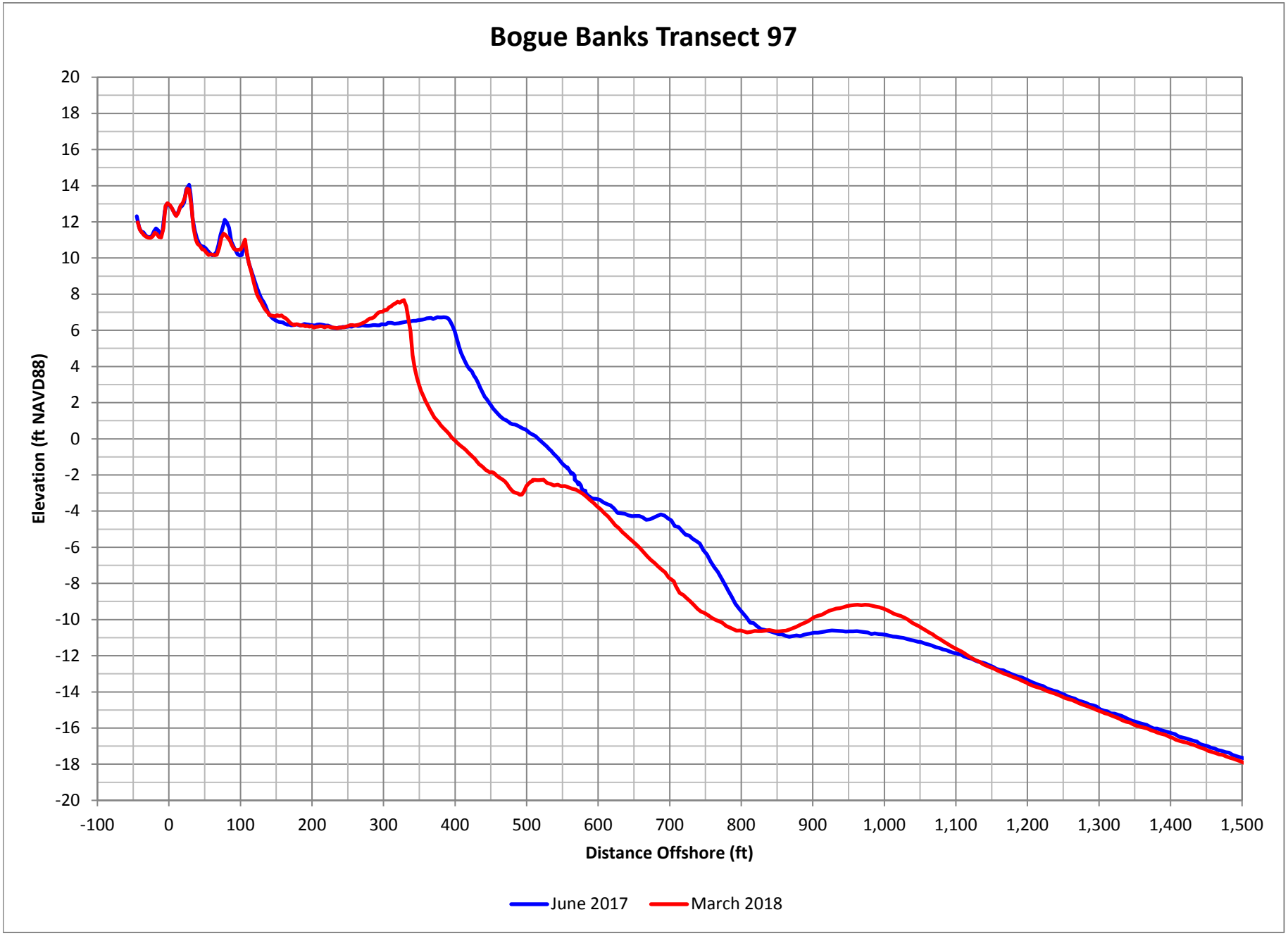


Figure D-194. Bogue Banks Profile Comparison Plot

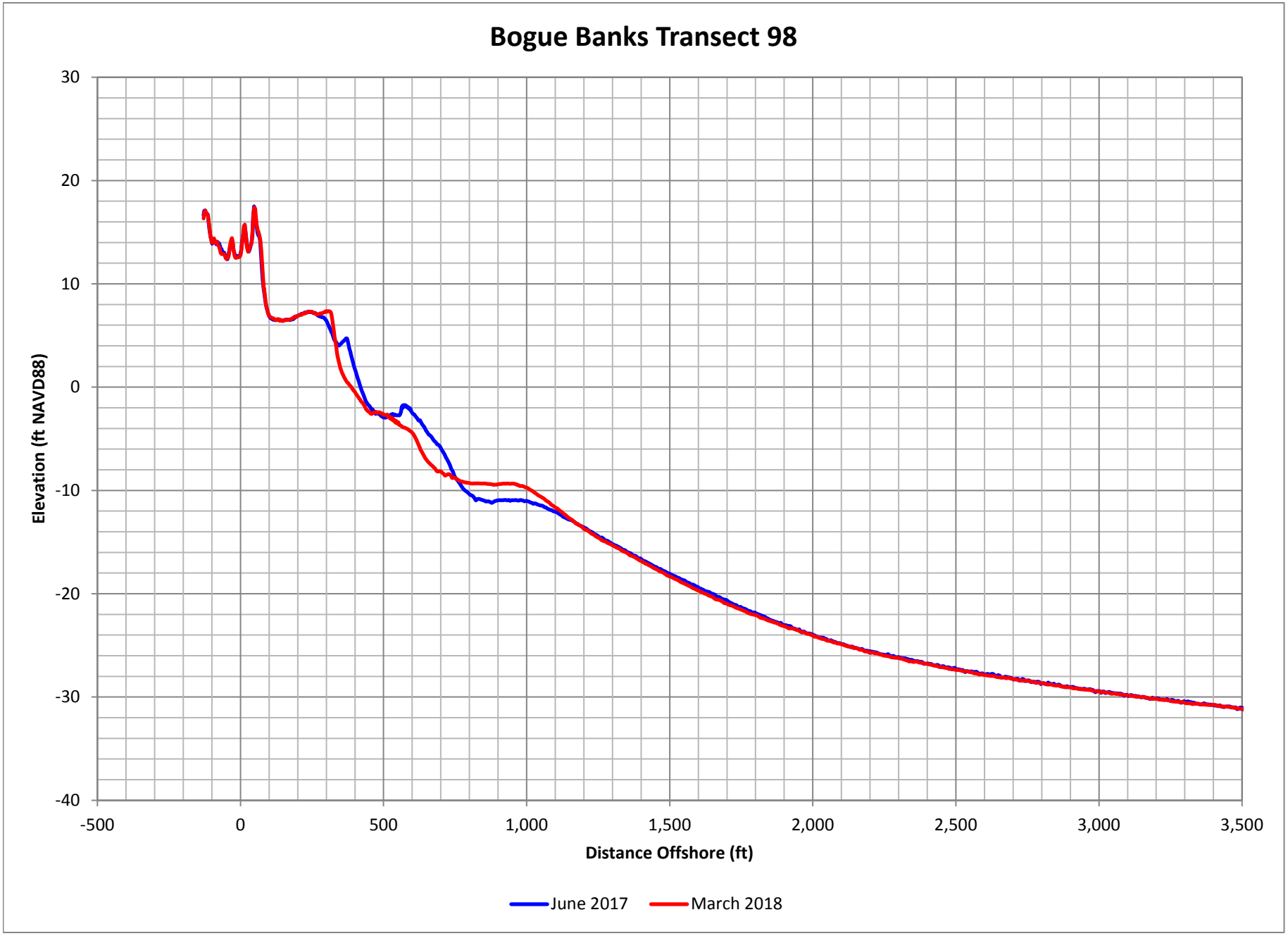


Figure D-195. Bogue Banks Profile Comparison Plot

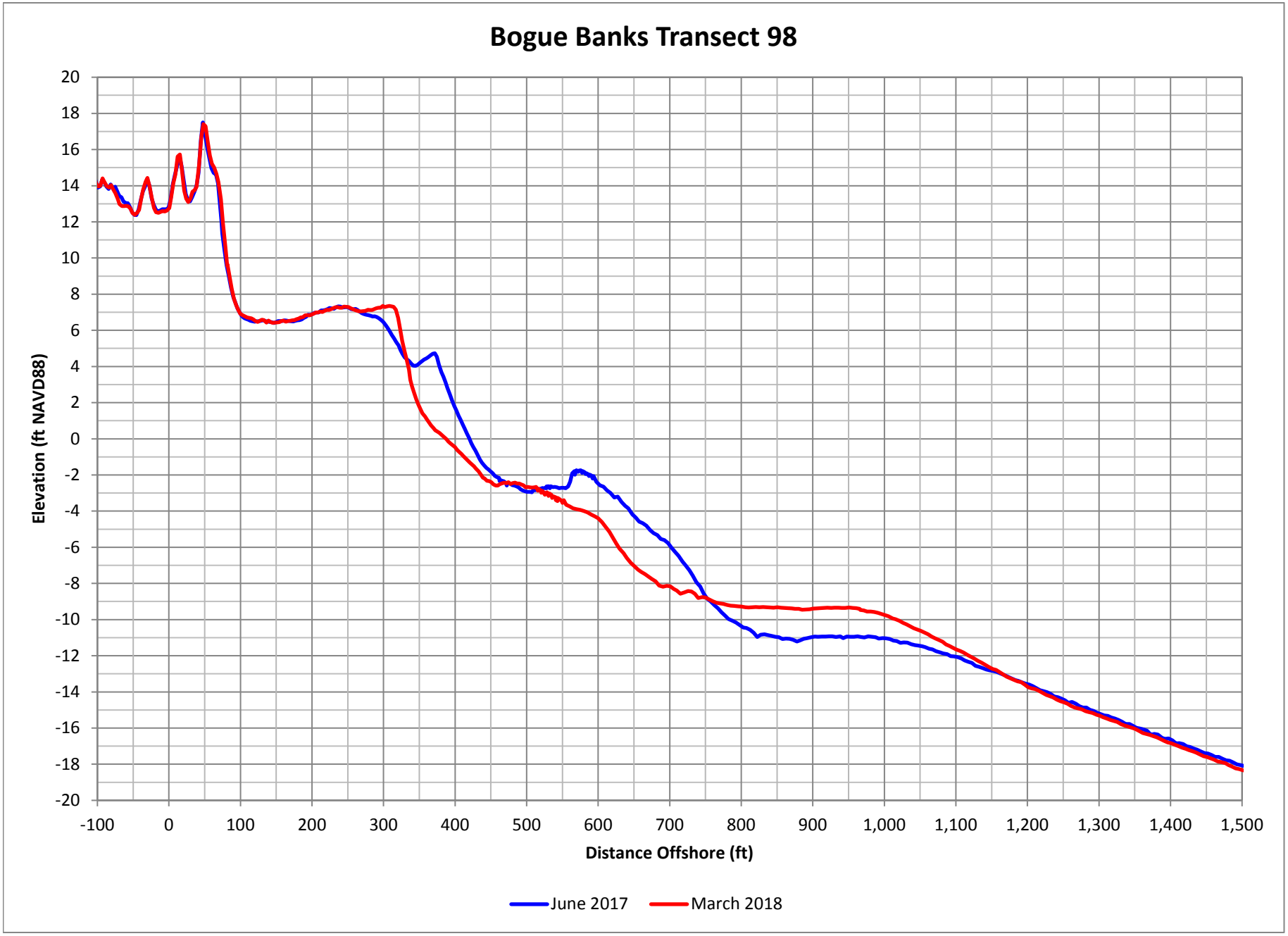


Figure D-196. Bogue Banks Profile Comparison Plot

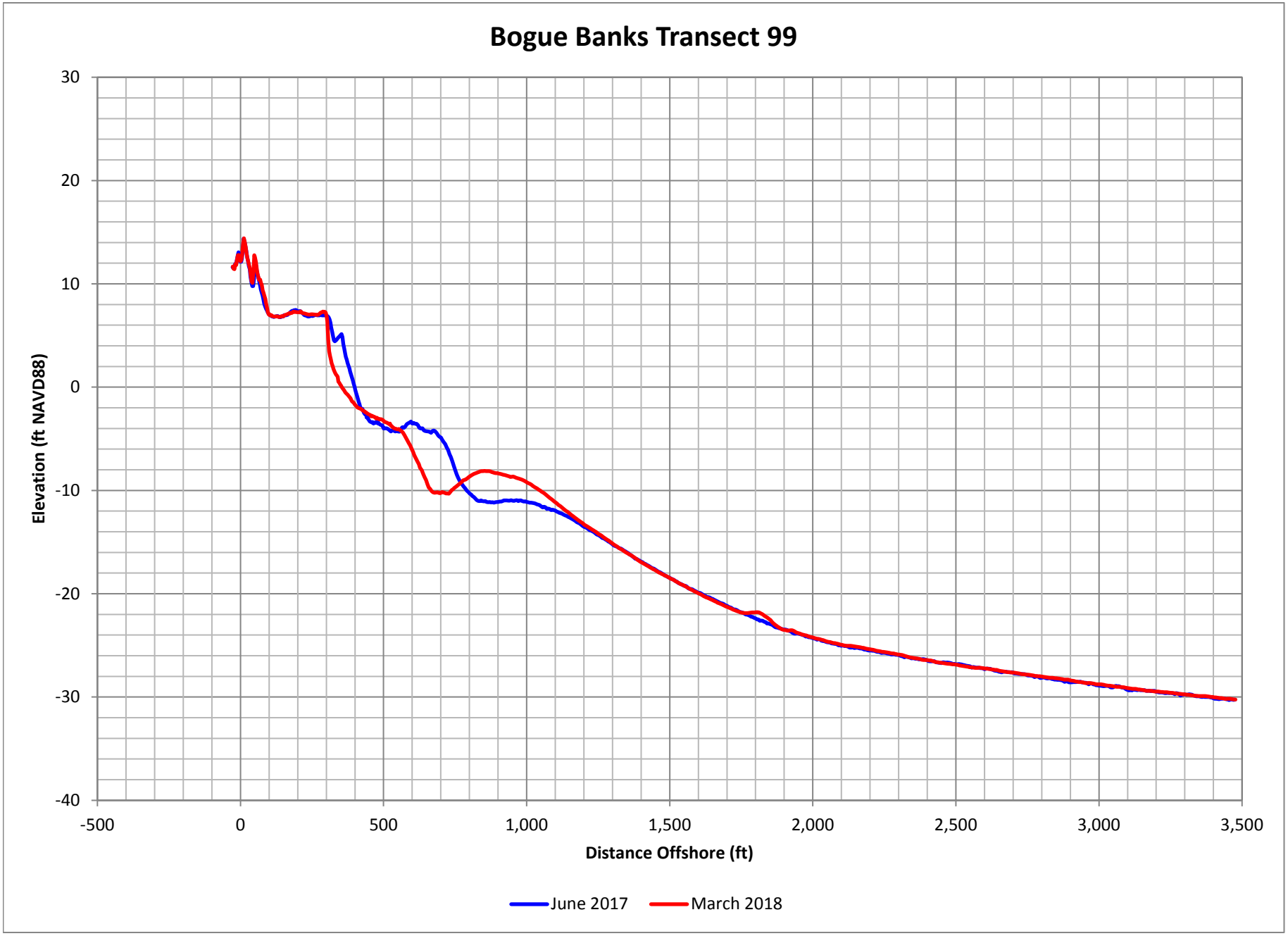


Figure D-197. Bogue Banks Profile Comparison Plot

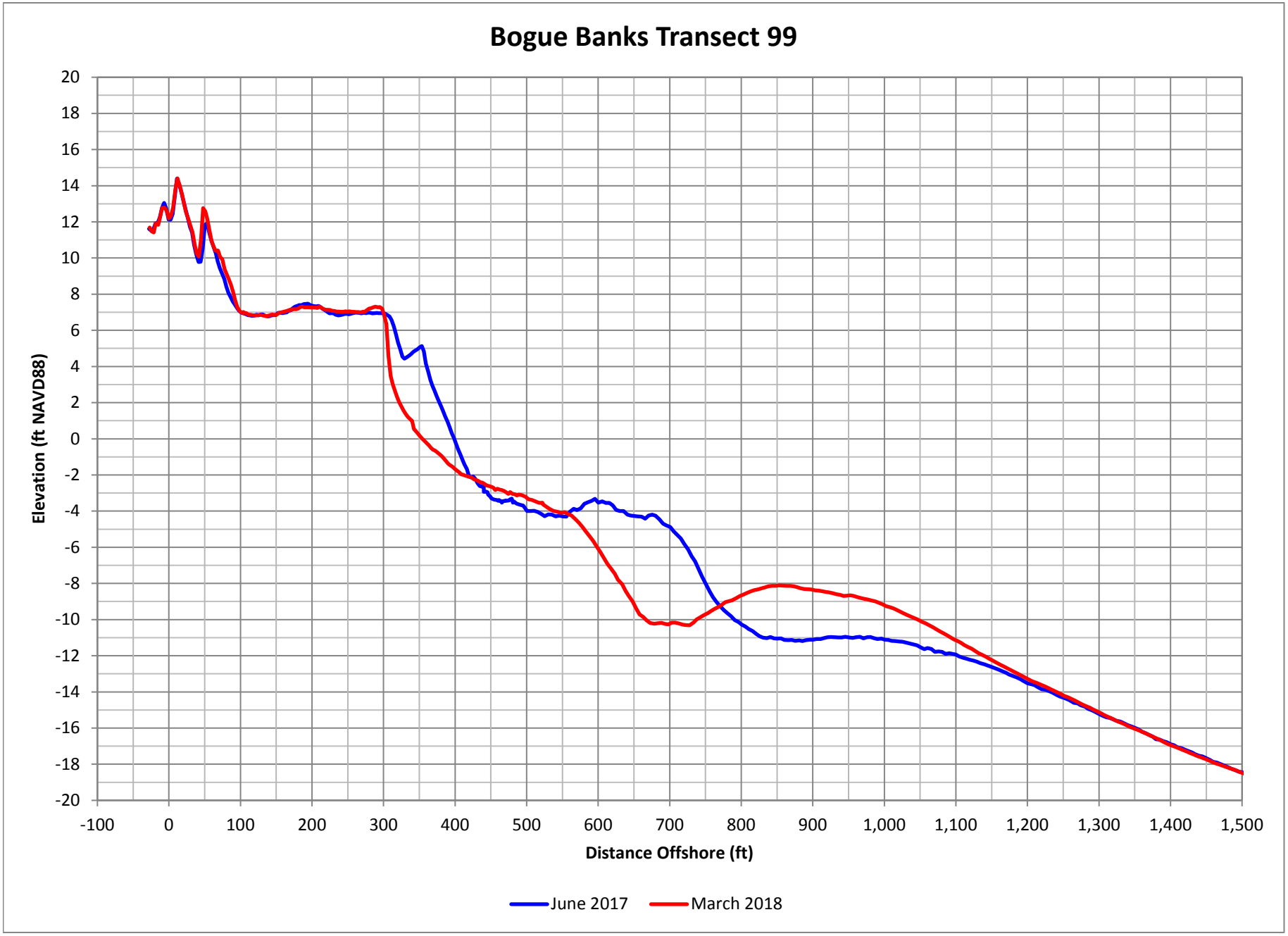


Figure D-198. Bogue Banks Profile Comparison Plot

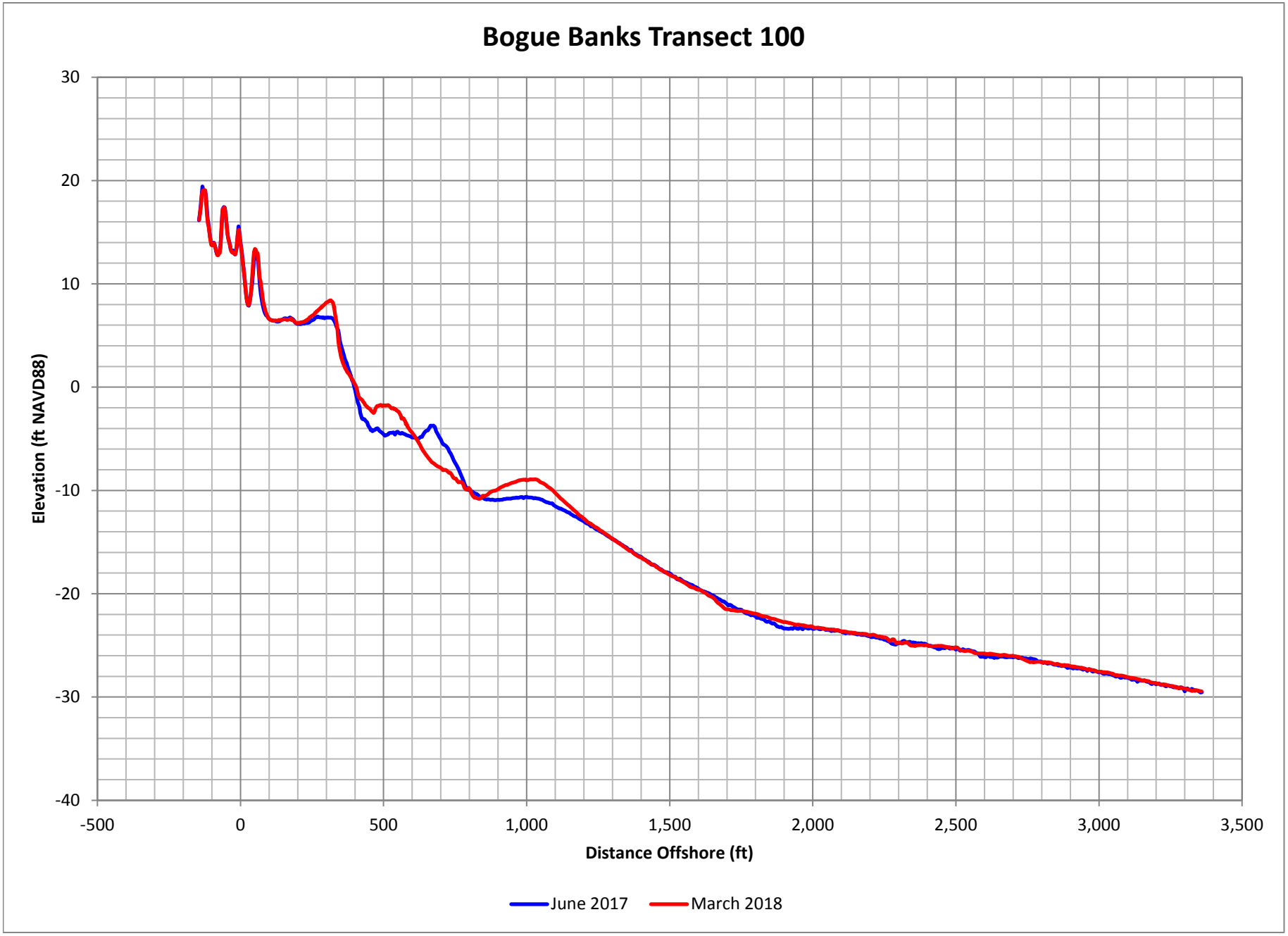


Figure D-199. Bogue Banks Profile Comparison Plot

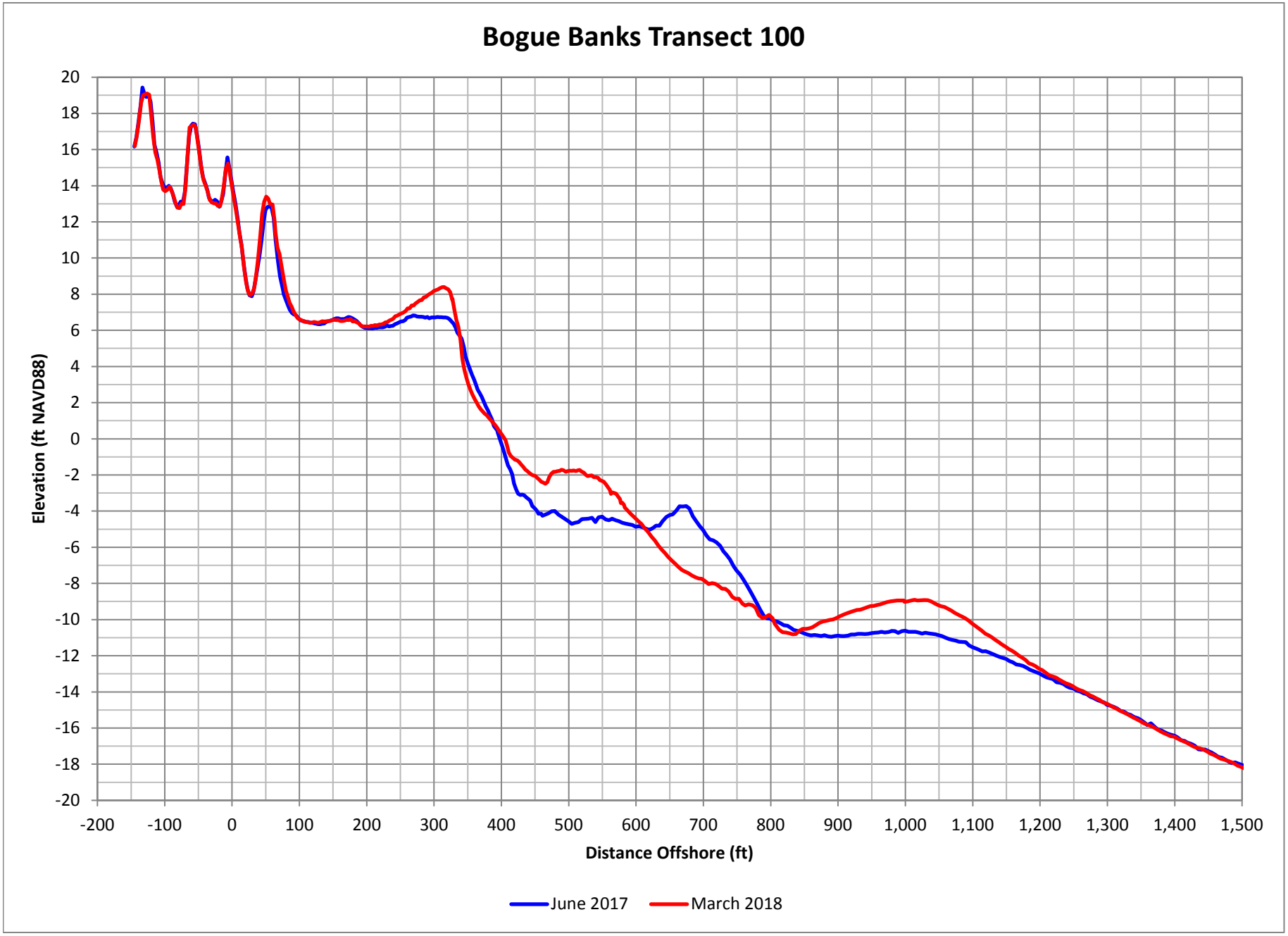


Figure D-200. Bogue Banks Profile Comparison Plot

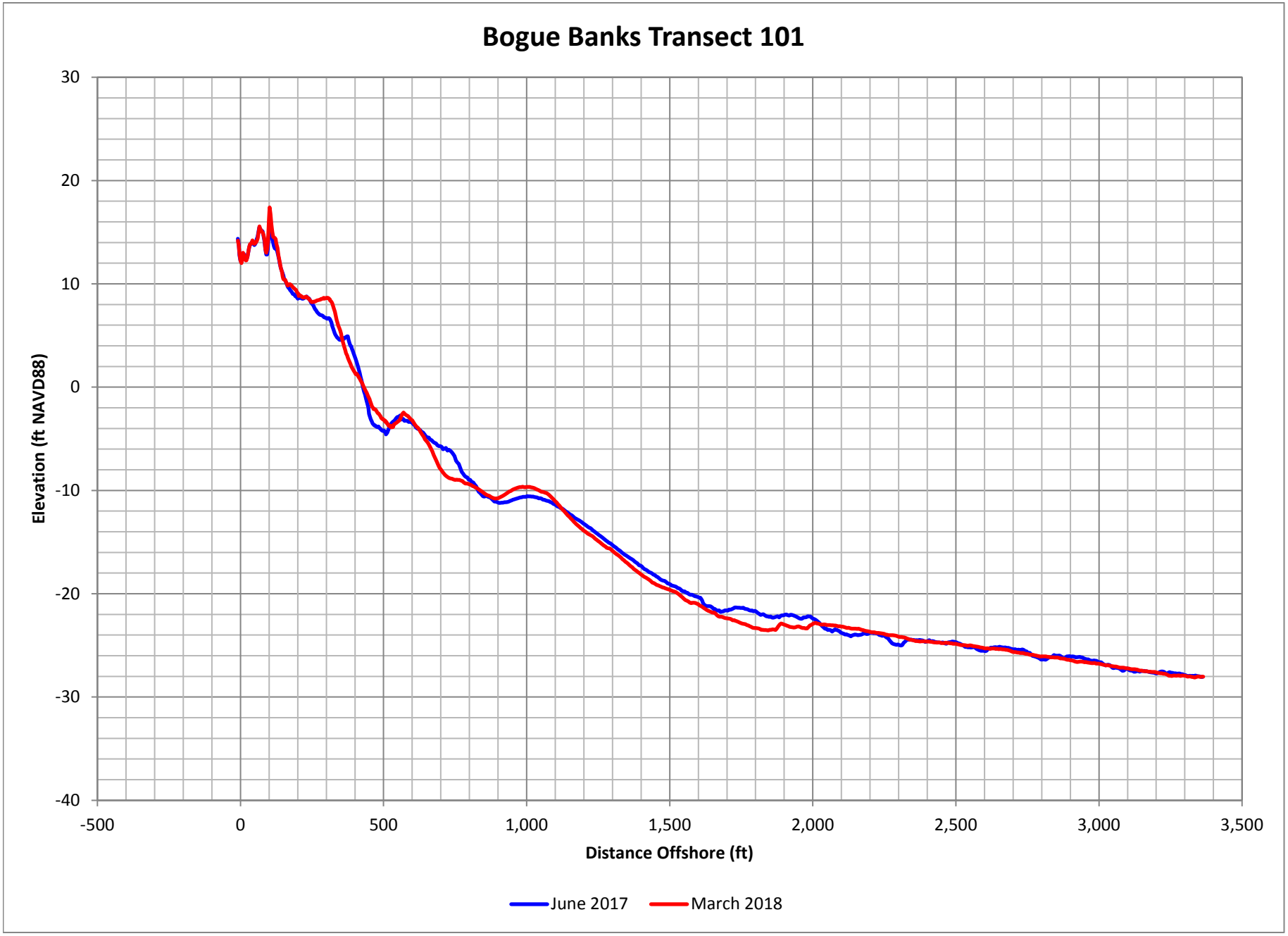


Figure D-201. Bogue Banks Profile Comparison Plot

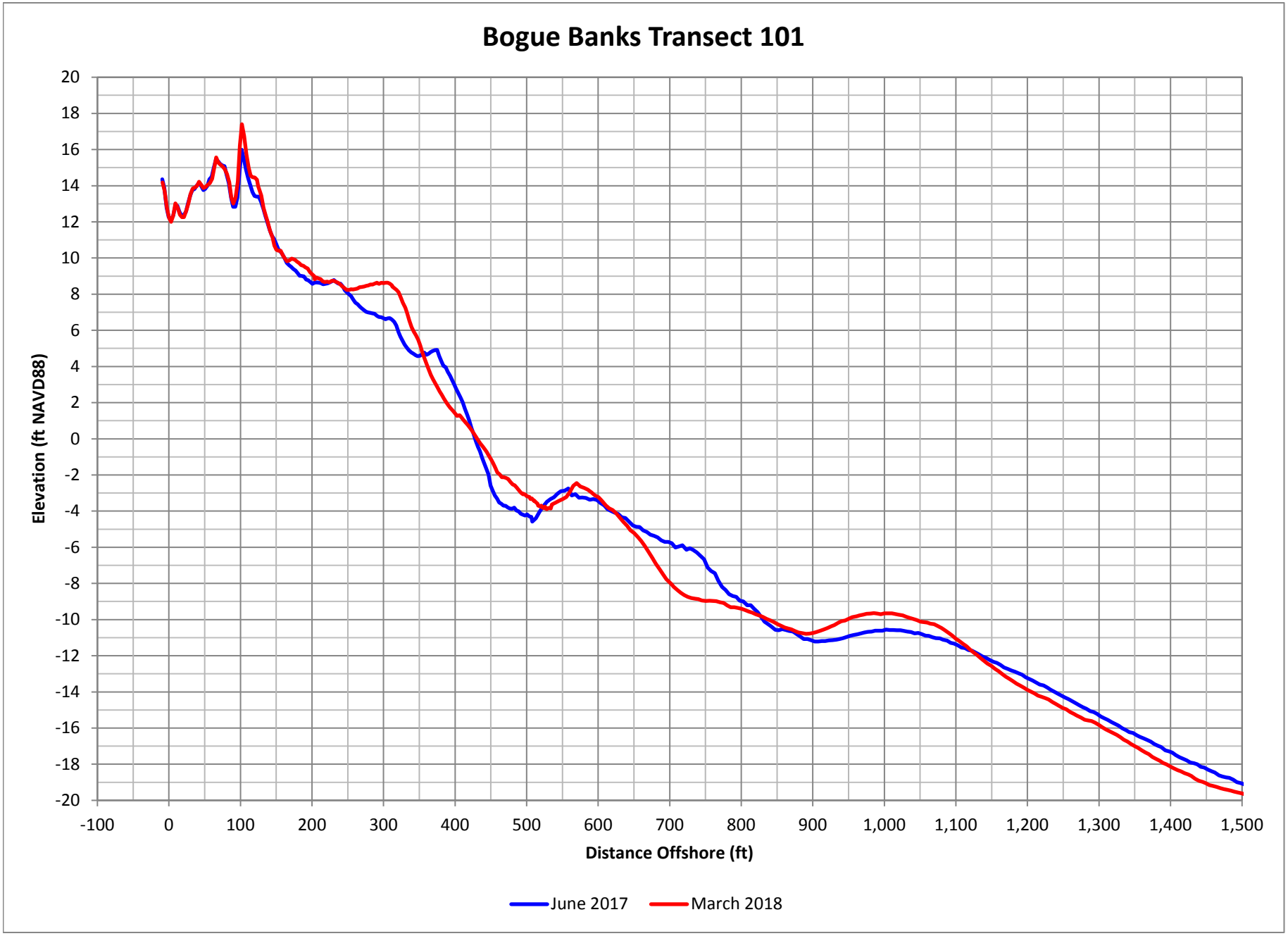


Figure D-202. Bogue Banks Profile Comparison Plot

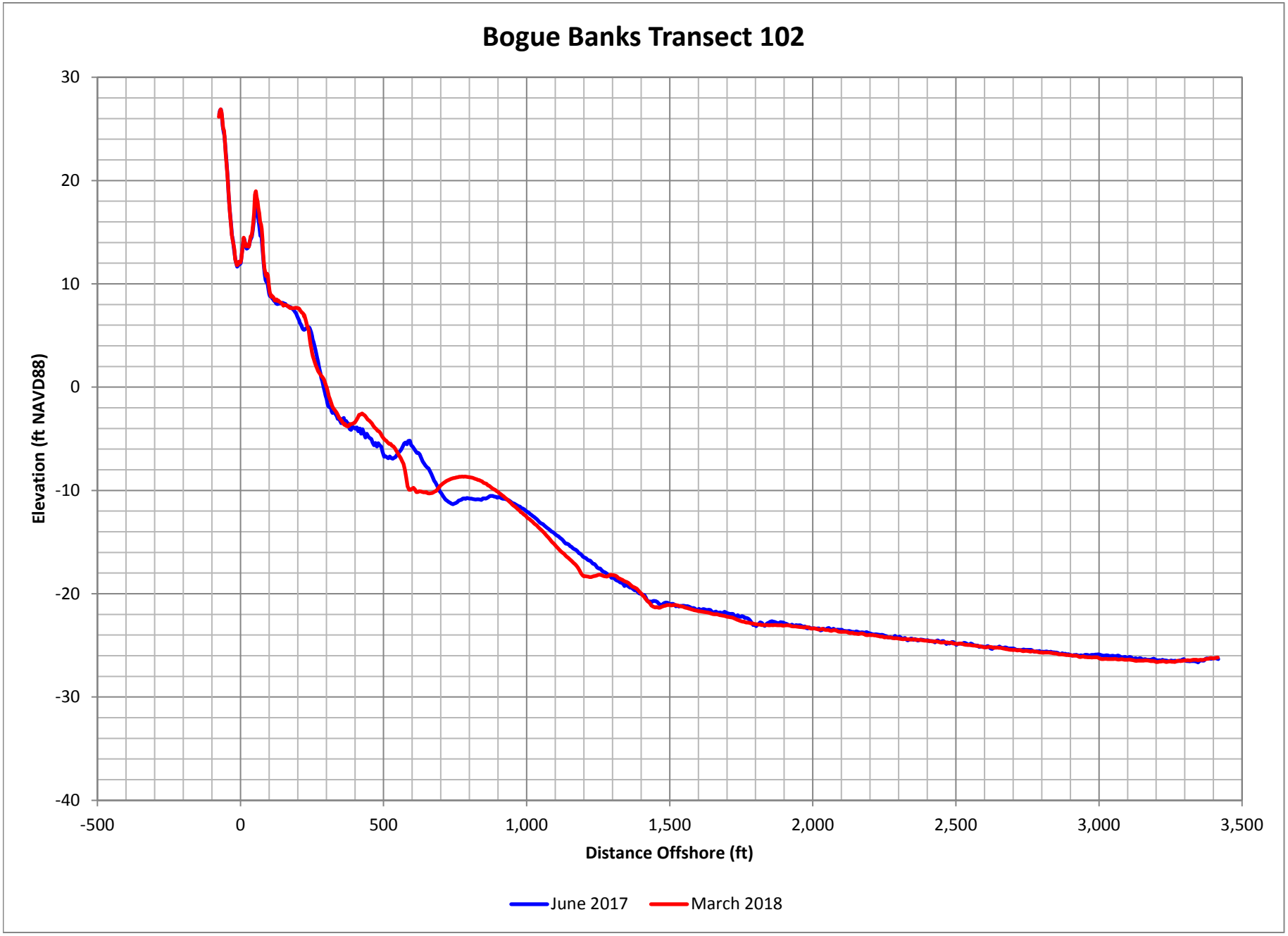


Figure D-203. Bogue Banks Profile Comparison Plot

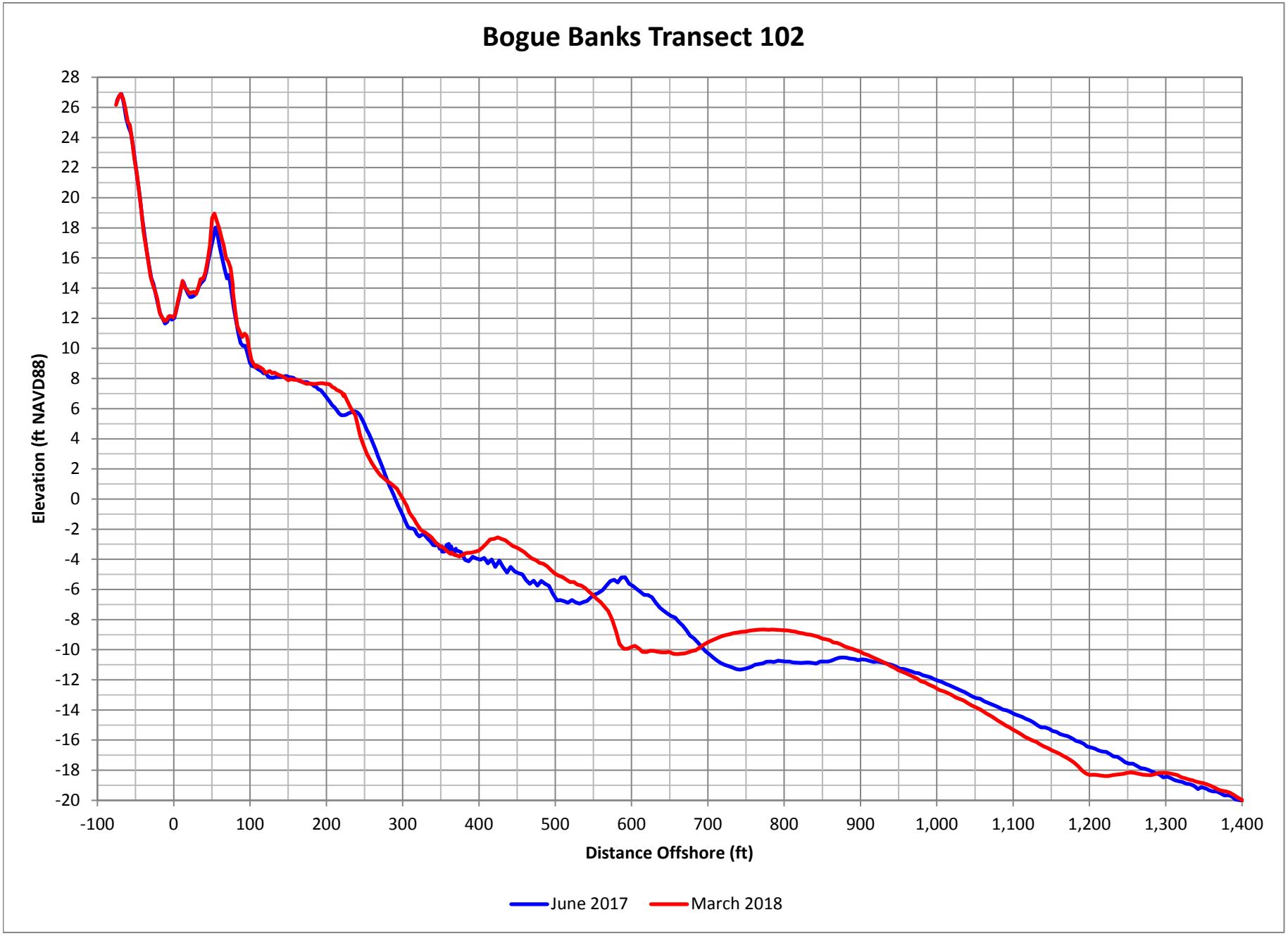


Figure D-204. Bogue Banks Profile Comparison Plot

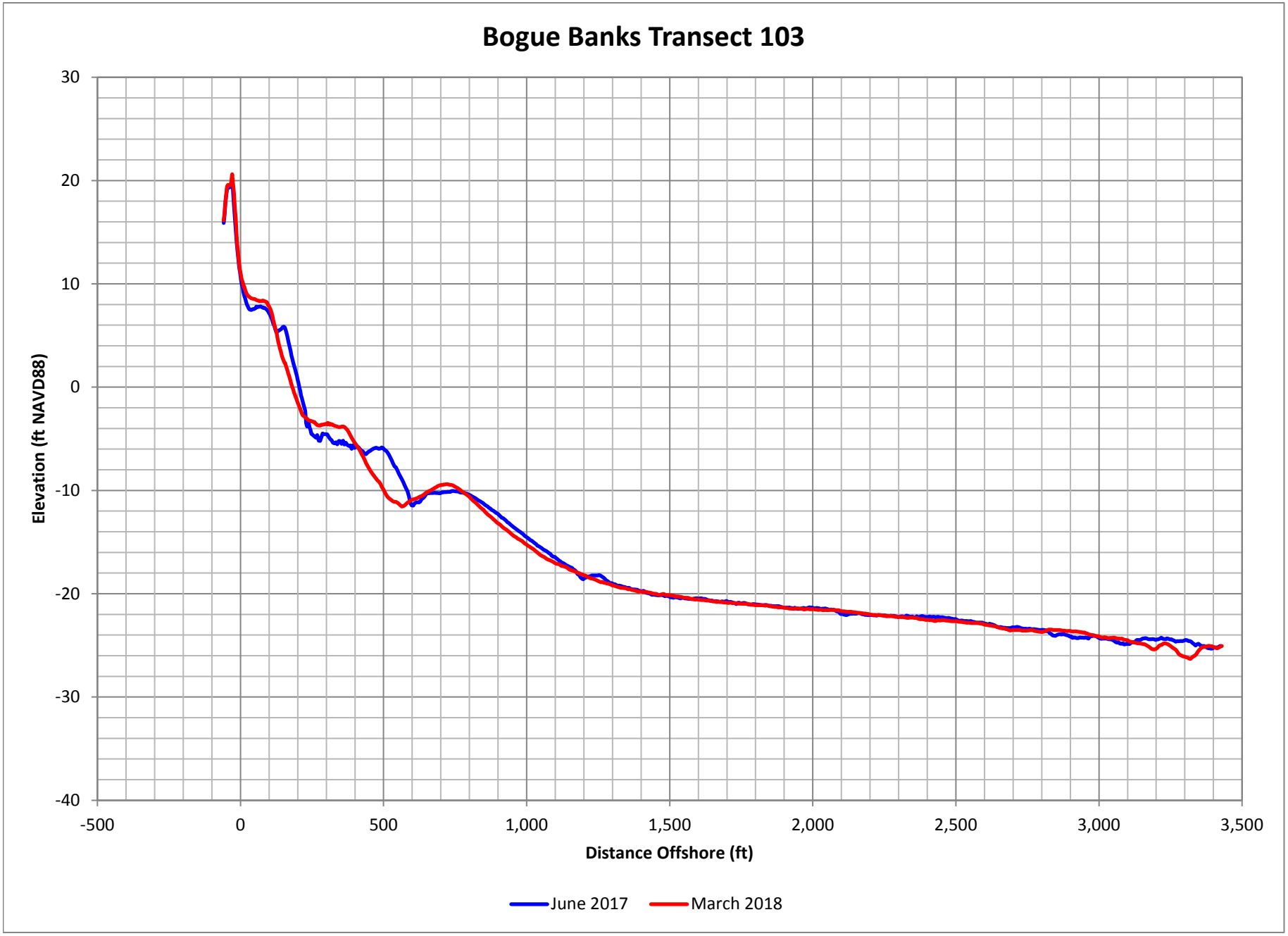


Figure D-205. Bogue Banks Profile Comparison Plot

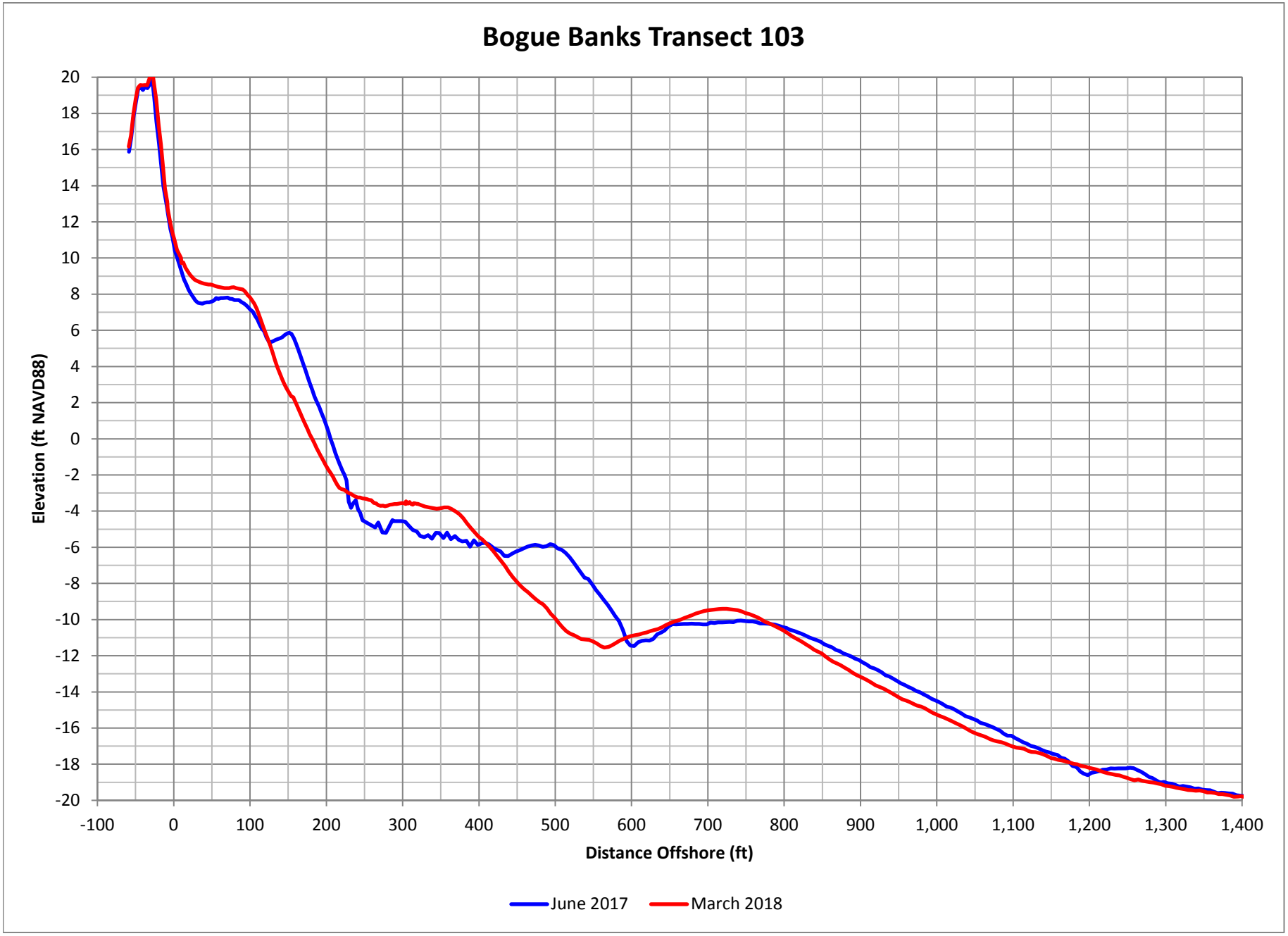


Figure D-206. Bogue Banks Profile Comparison Plot

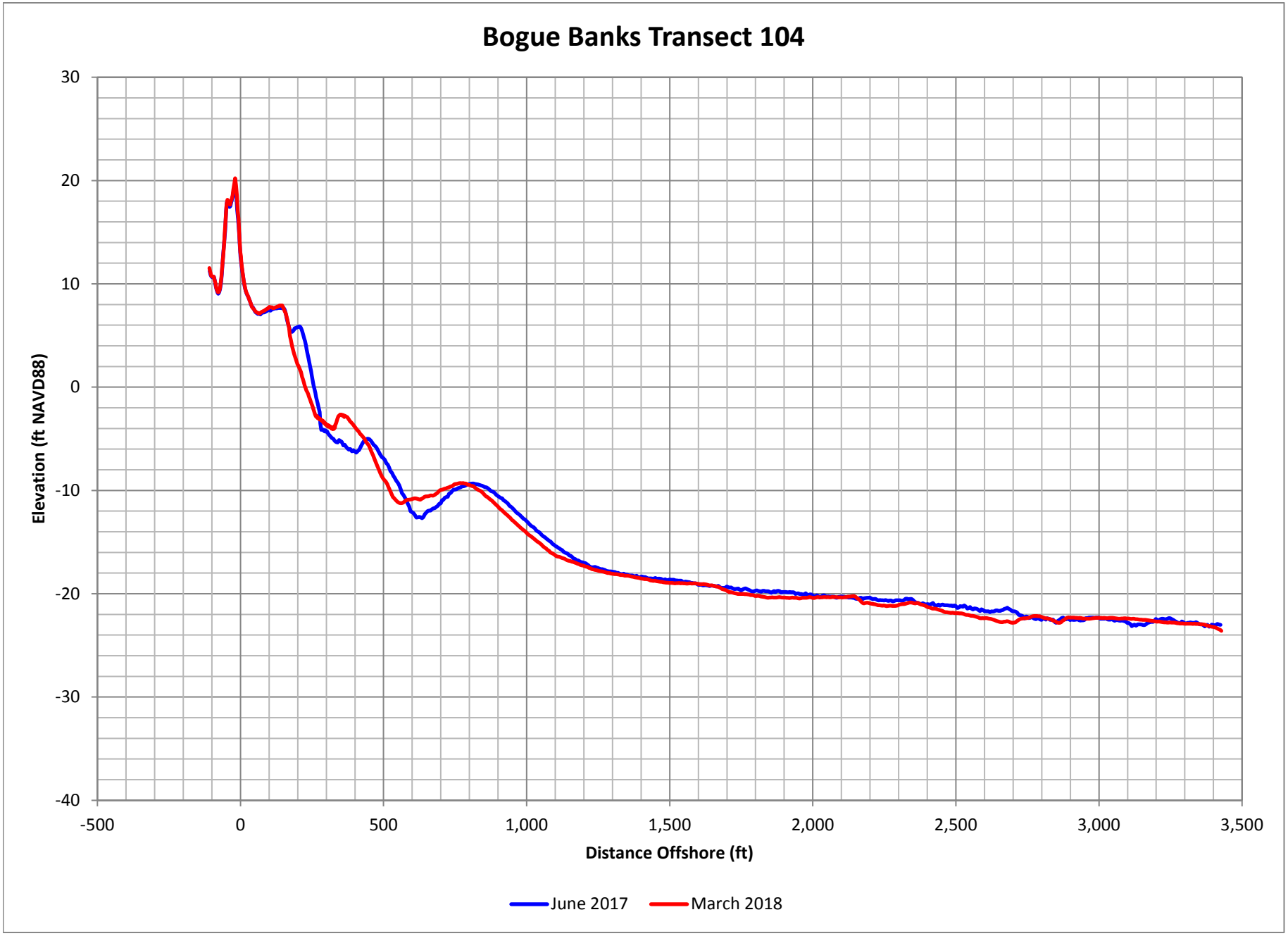


Figure D-207. Bogue Banks Profile Comparison Plot

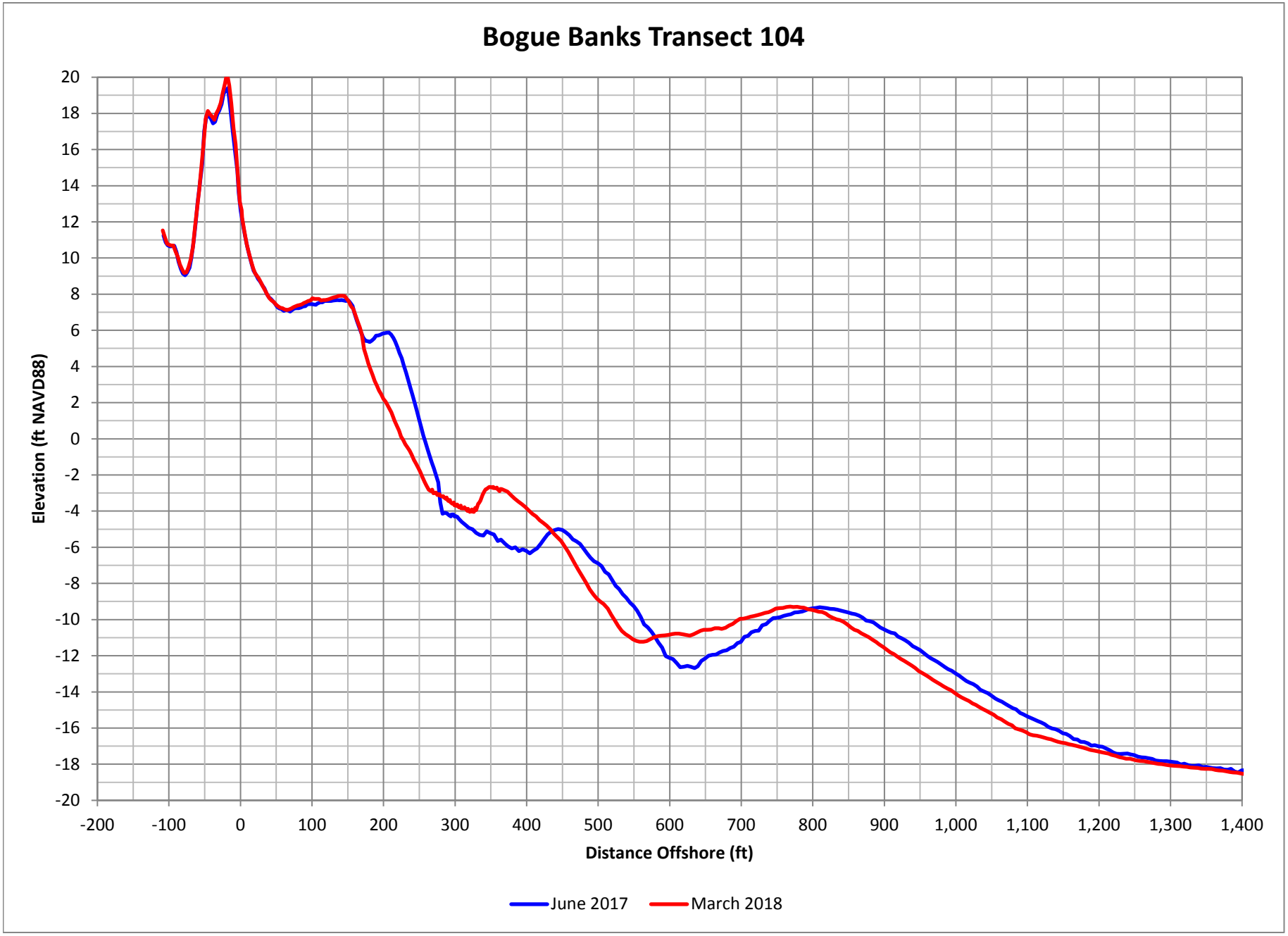


Figure D-208. Bogue Banks Profile Comparison Plot

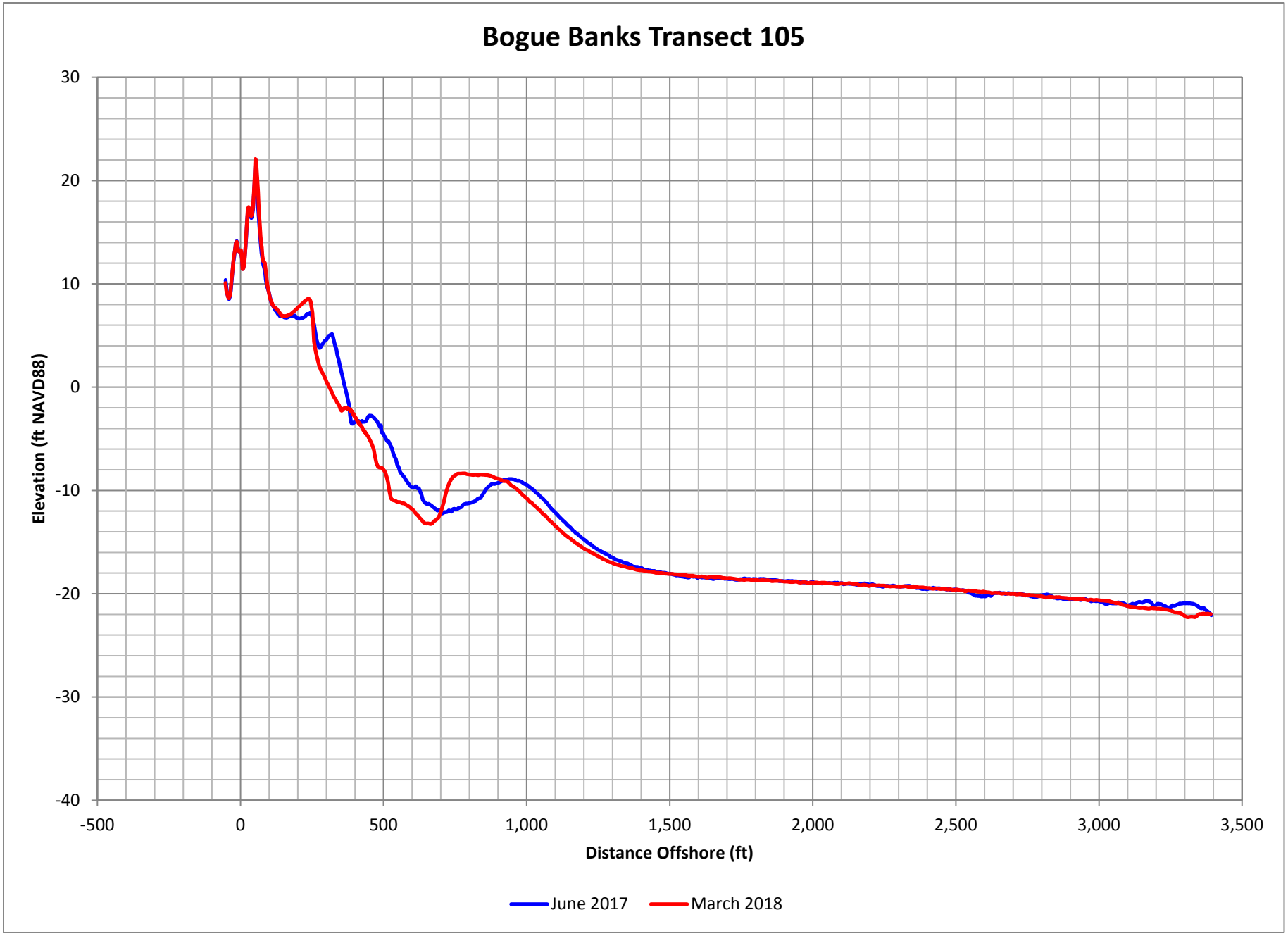


Figure D-209. Bogue Banks Profile Comparison Plot

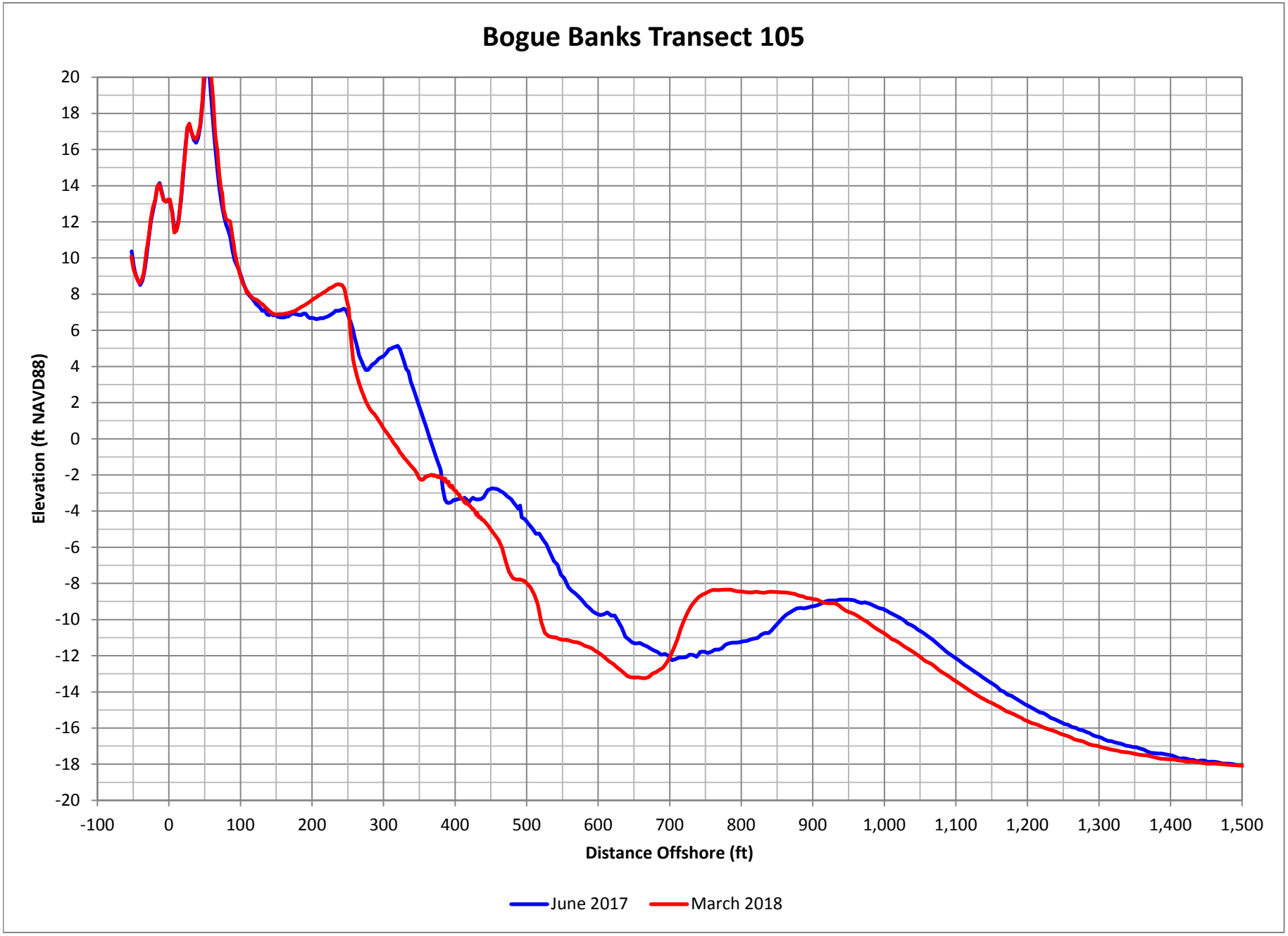


Figure D-210. Bogue Banks Profile Comparison Plot

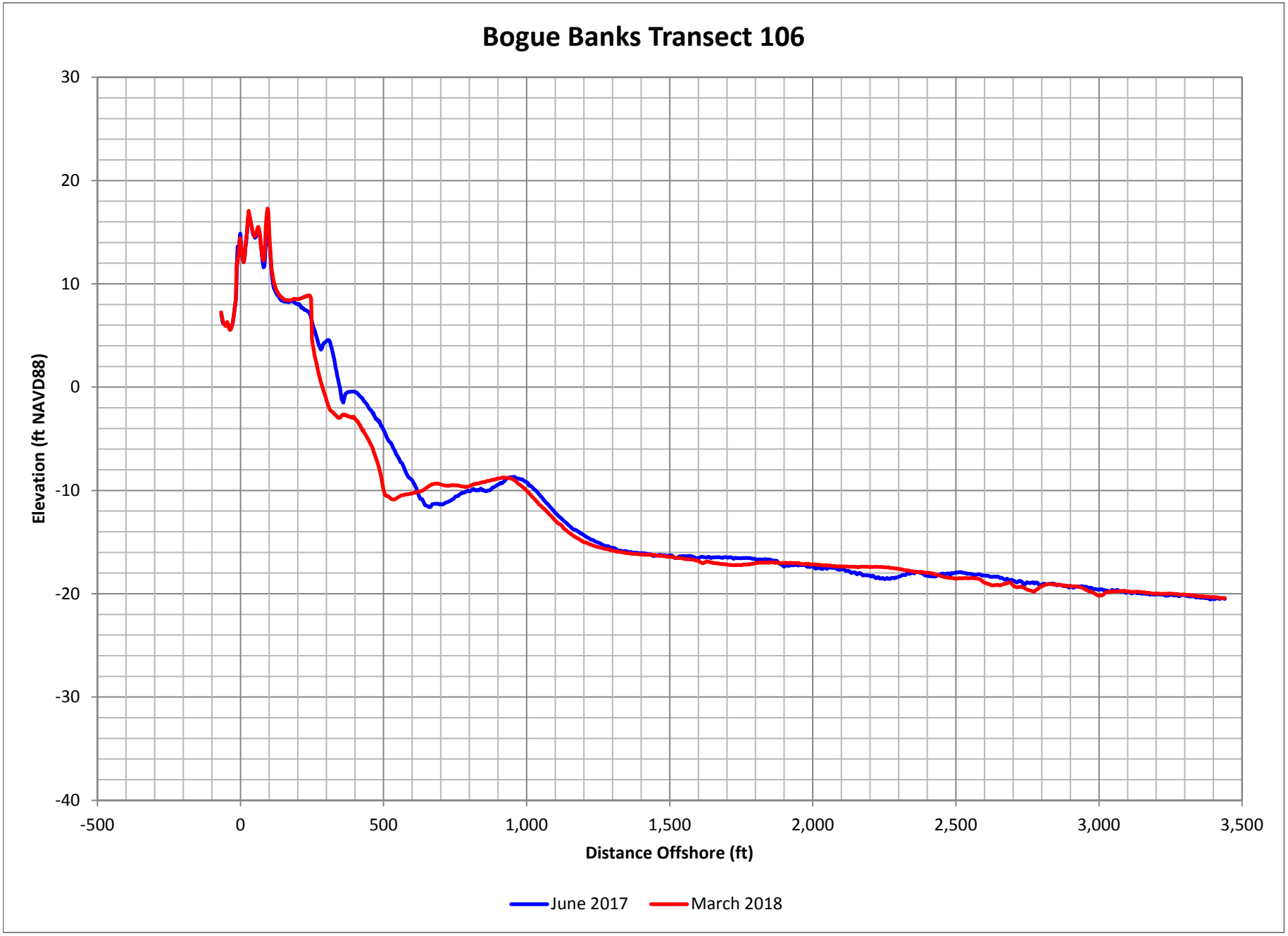


Figure D-211. Bogue Banks Profile Comparison Plot

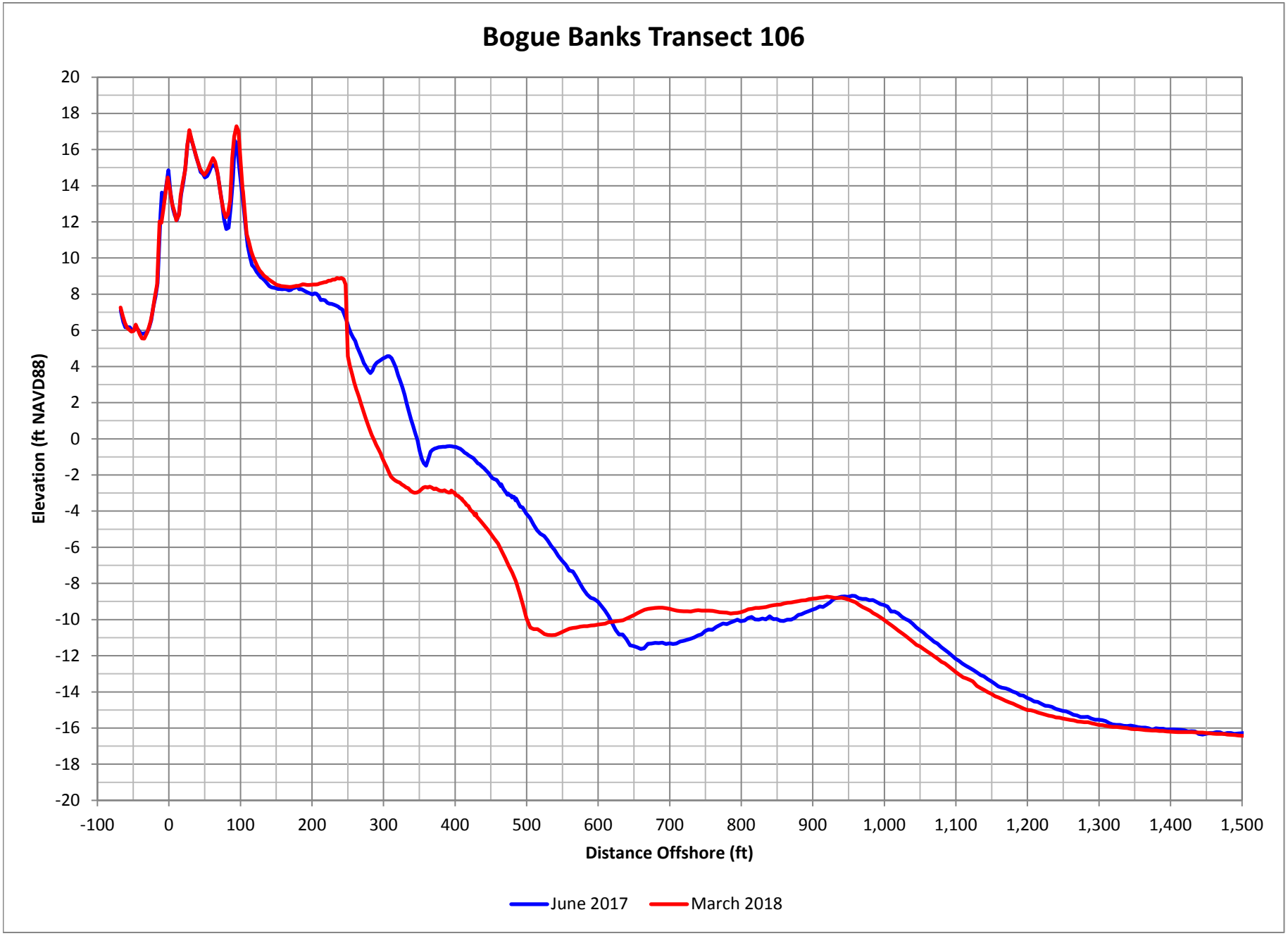


Figure D-212. Bogue Banks Profile Comparison Plot

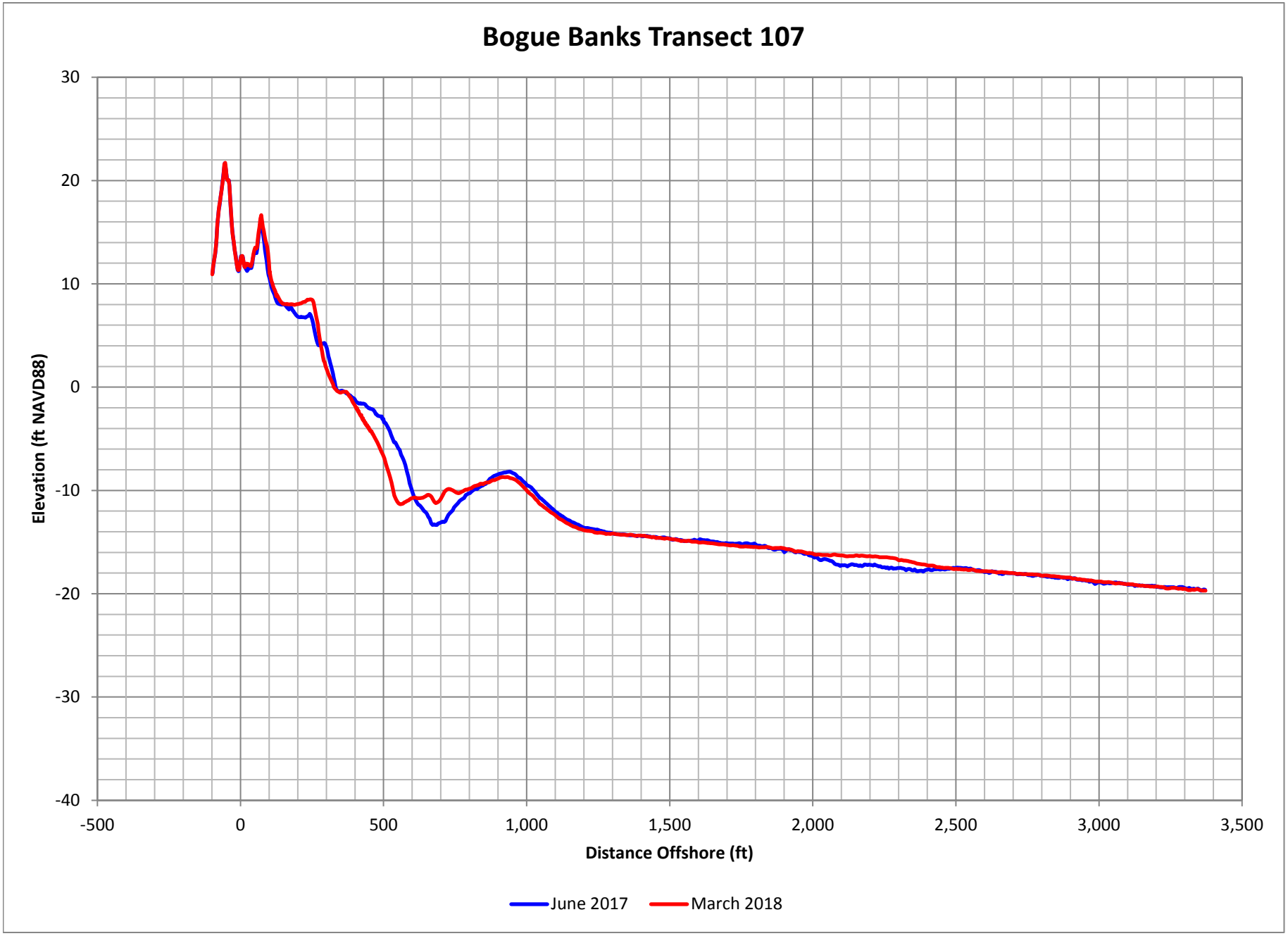


Figure D-213. Bogue Banks Profile Comparison Plot

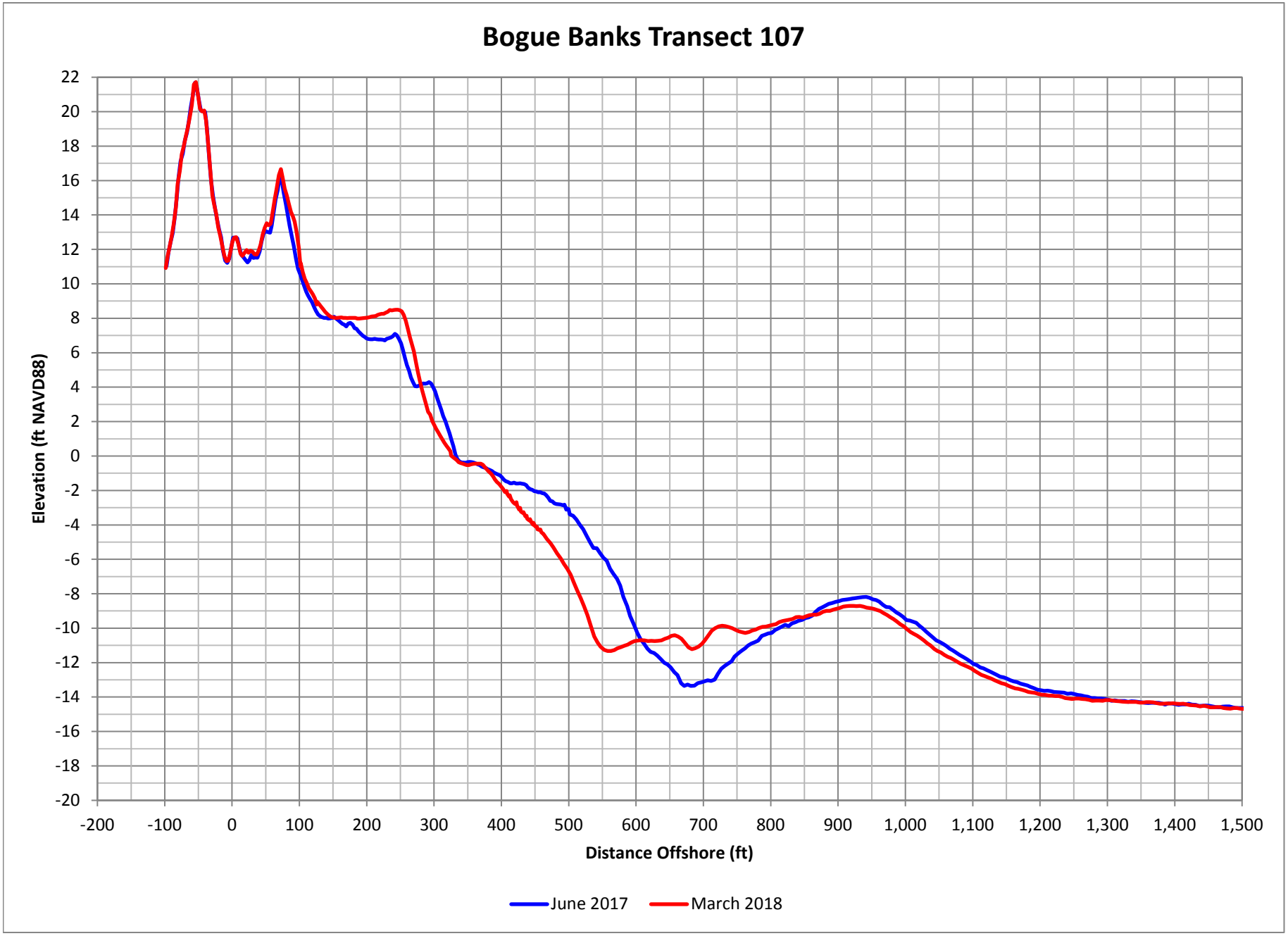


Figure D-214. Bogue Banks Profile Comparison Plot

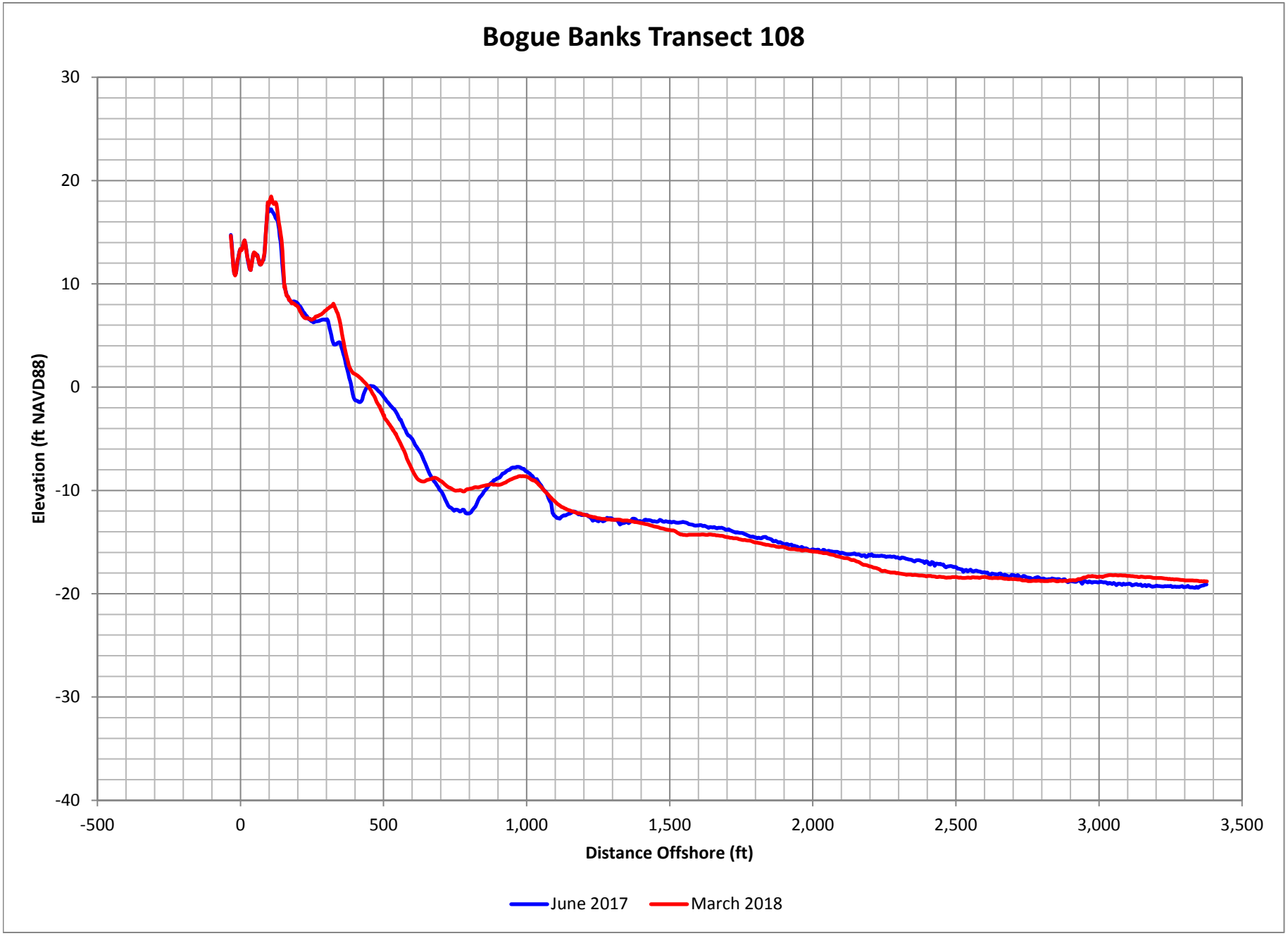


Figure D-215. Bogue Banks Profile Comparison Plot

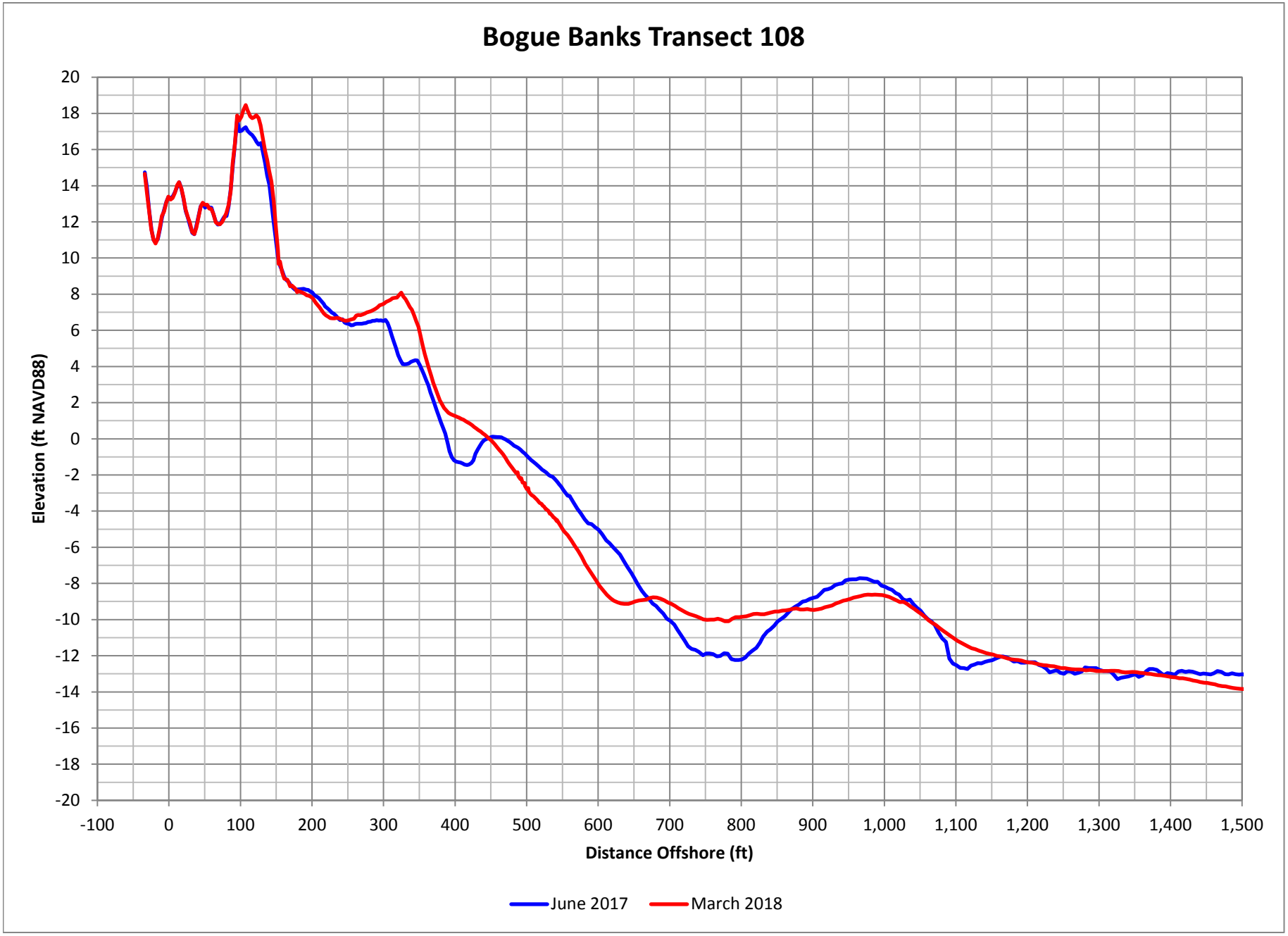


Figure D-216. Bogue Banks Profile Comparison Plot

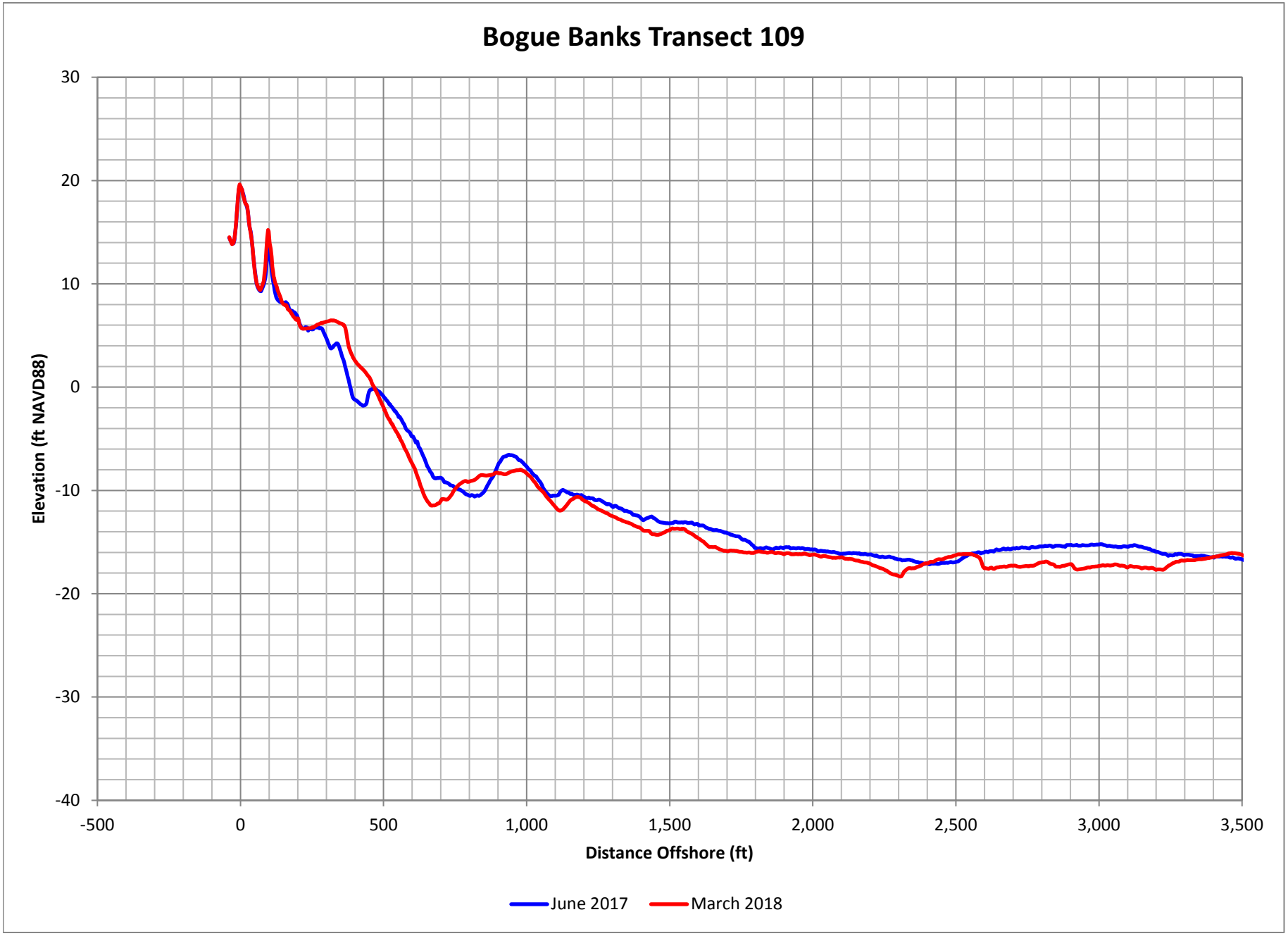


Figure D-217. Bogue Banks Profile Comparison Plot

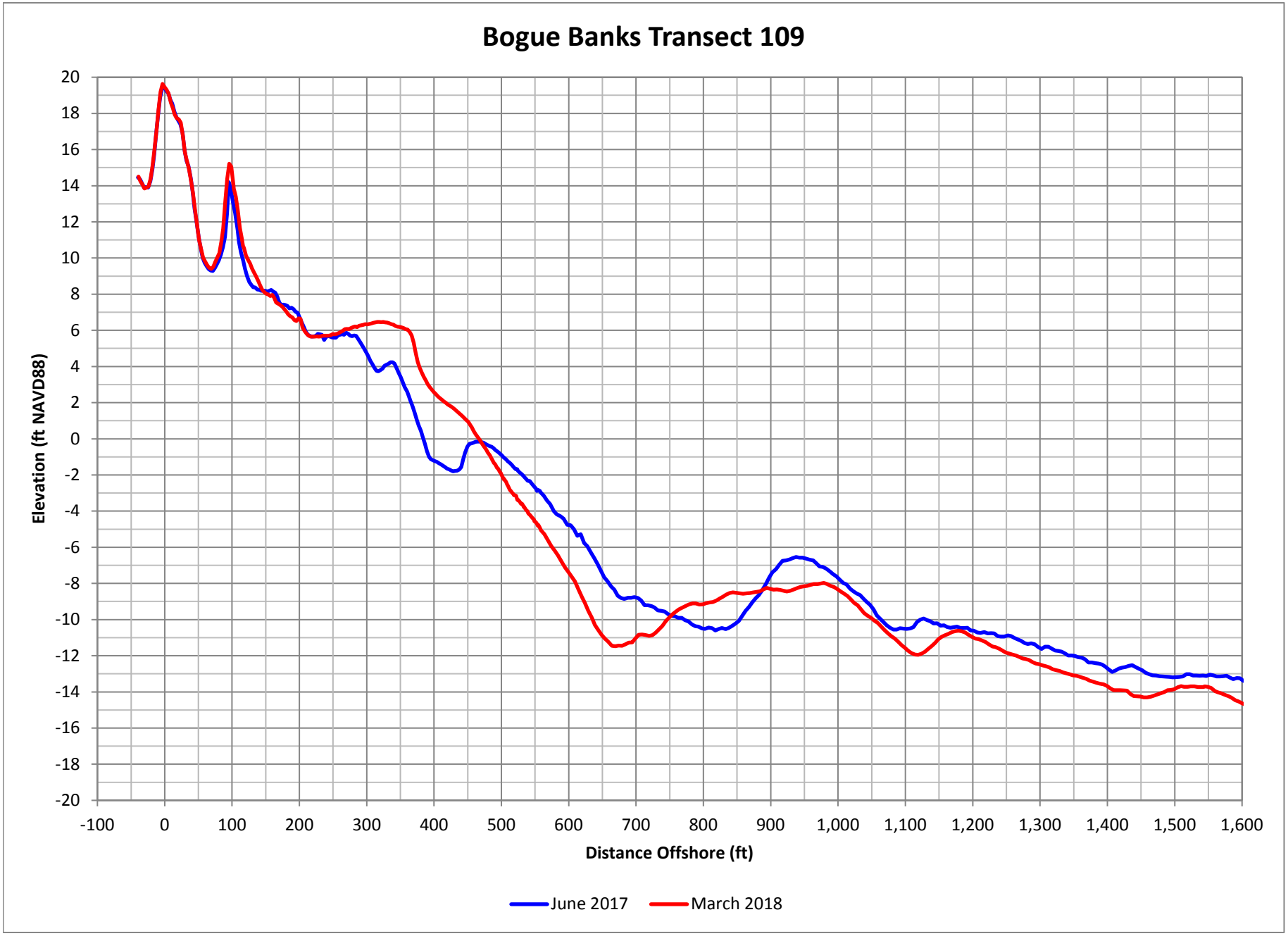


Figure D-218. Bogue Banks Profile Comparison Plot

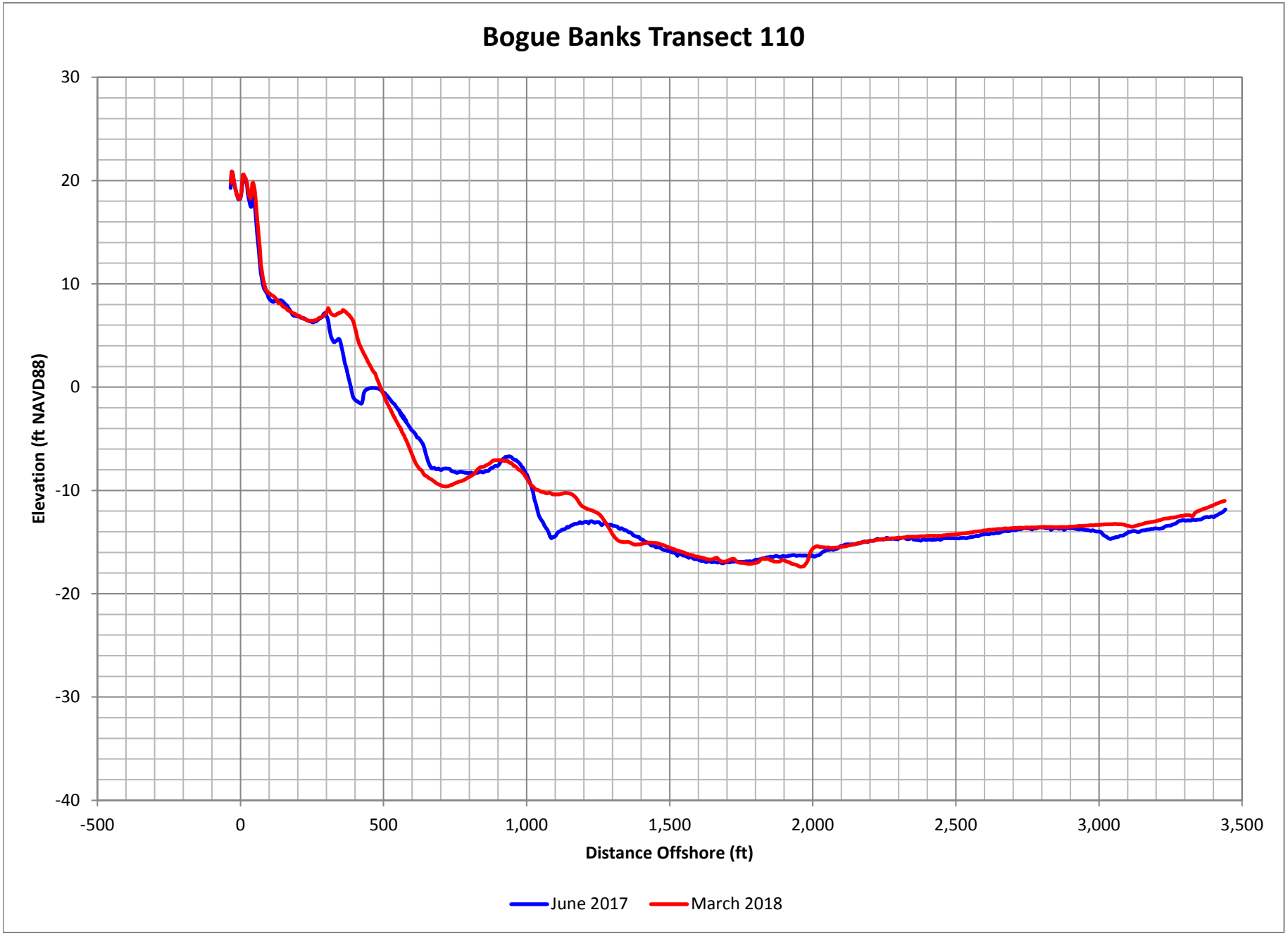


Figure D-219. Bogue Banks Profile Comparison Plot

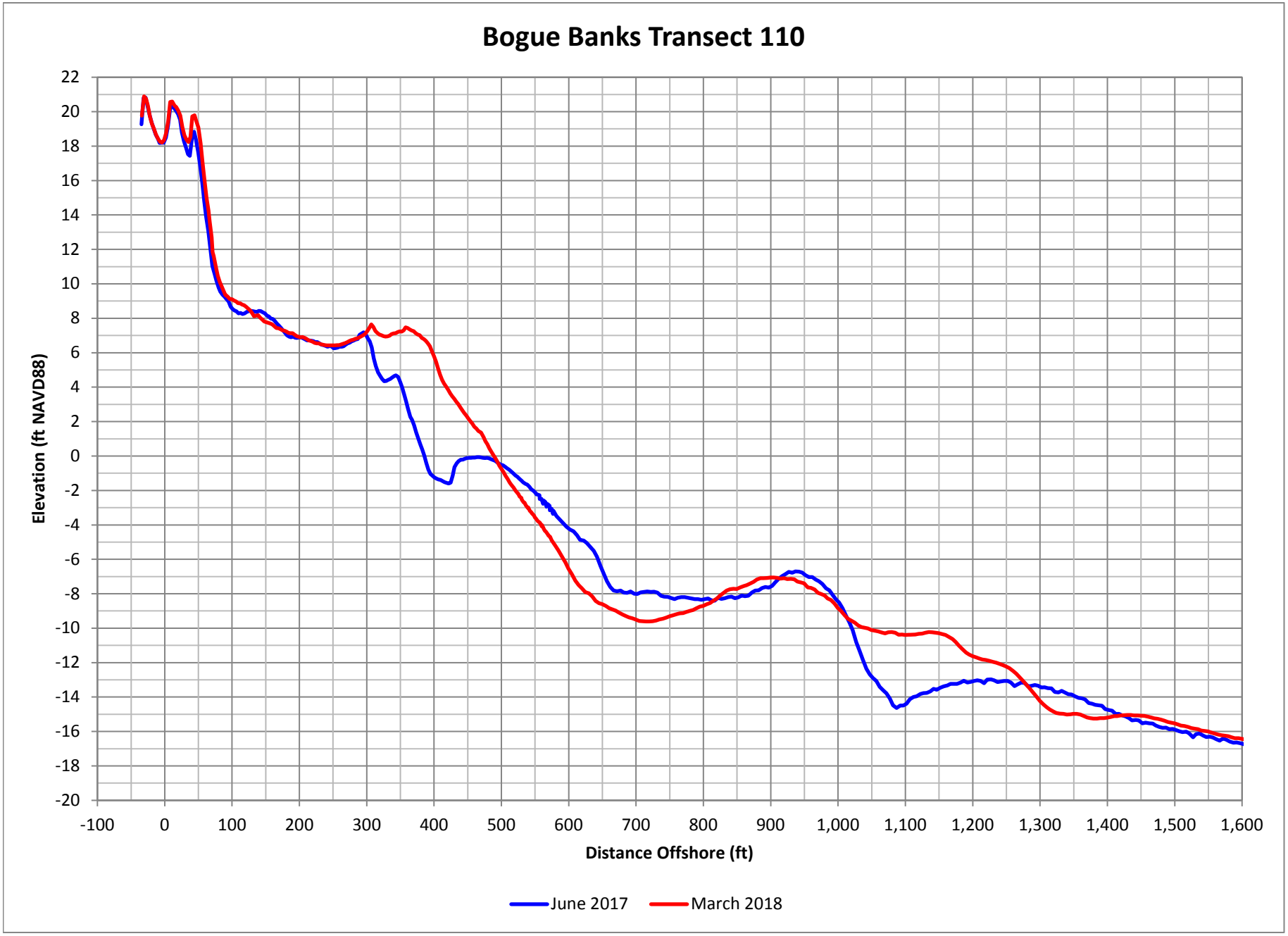


Figure D-220. Bogue Banks Profile Comparison Plot

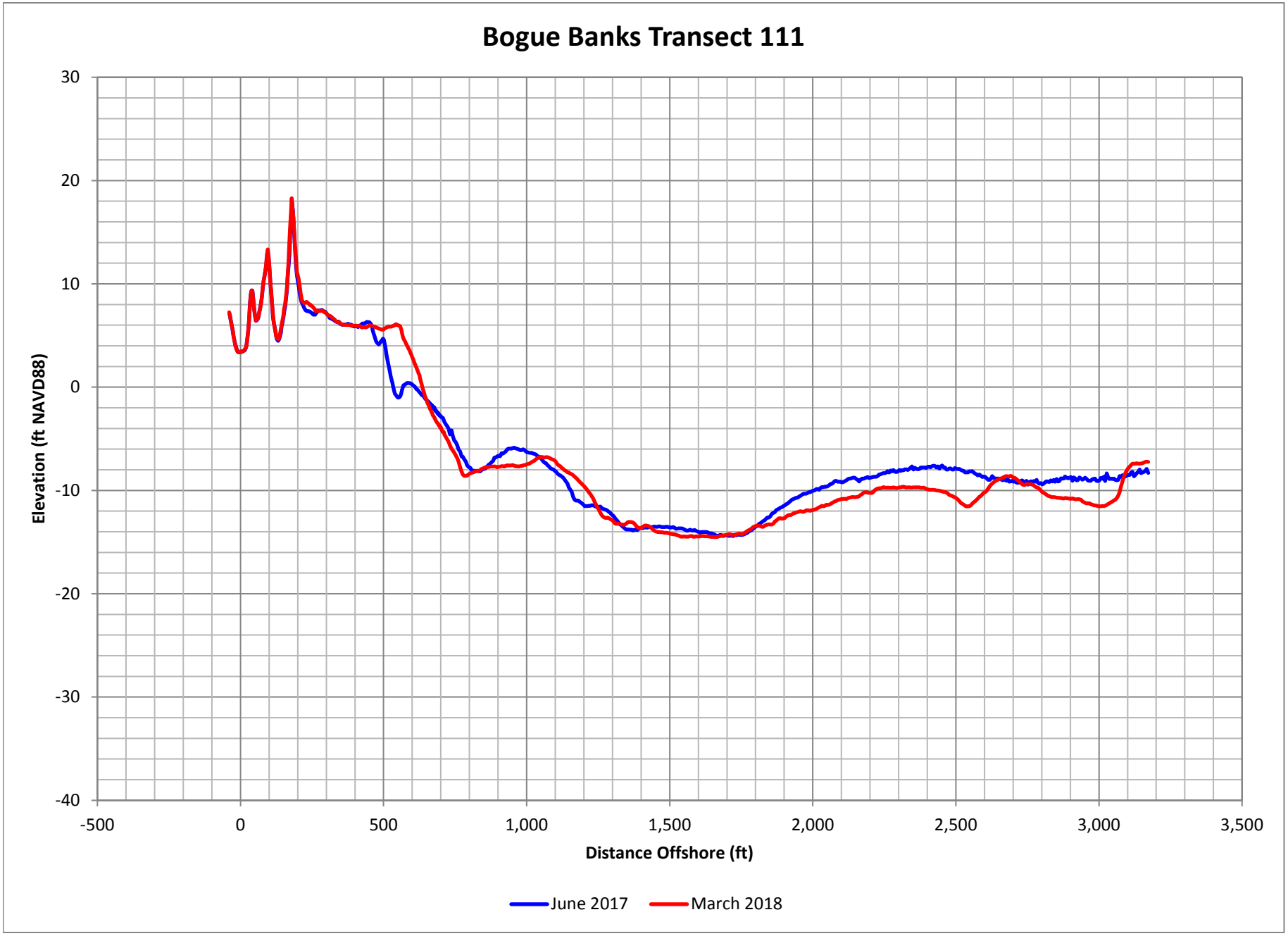


Figure D-221. Bogue Banks Profile Comparison Plot

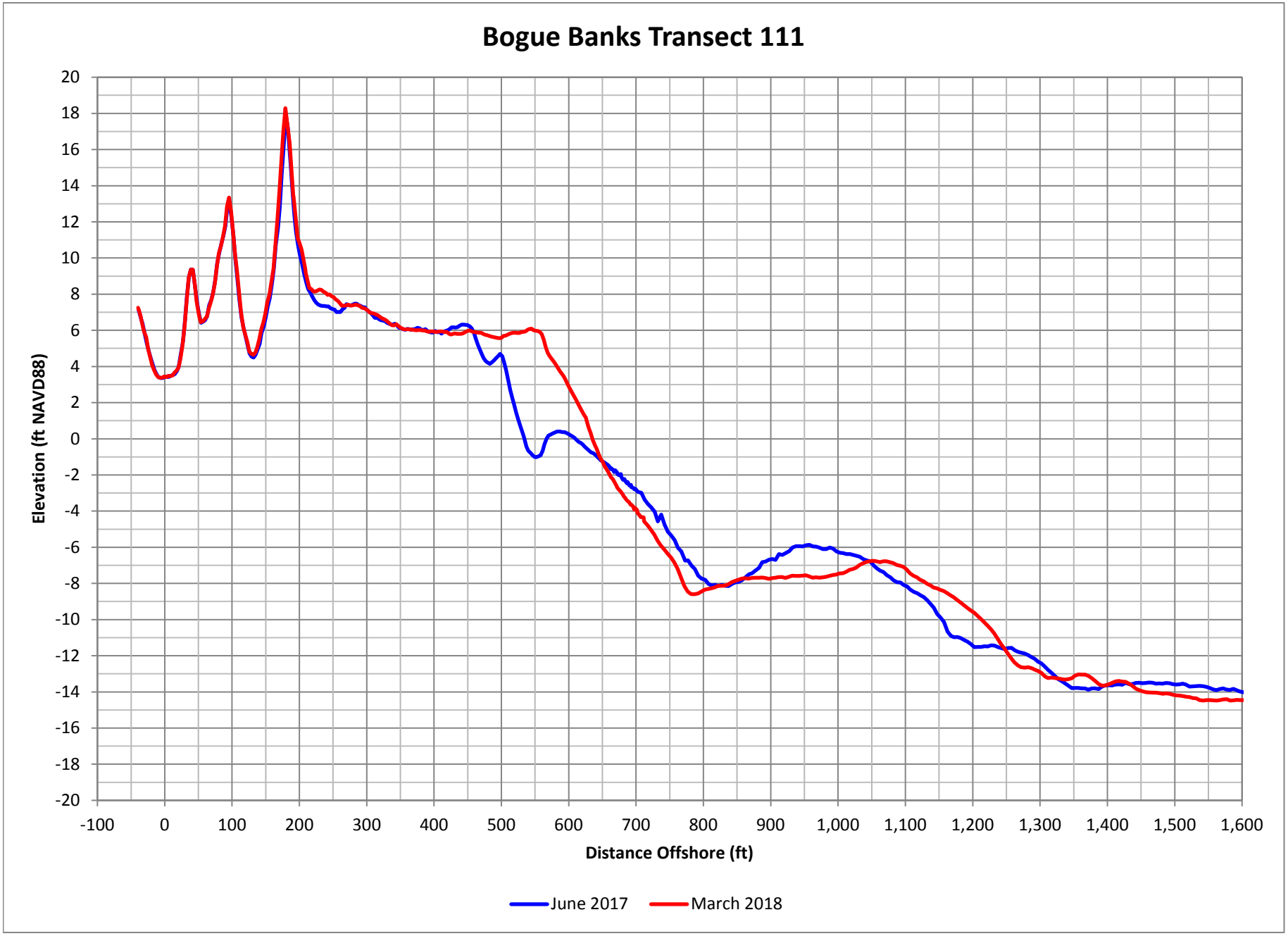


Figure D-222. Bogue Banks Profile Comparison Plot

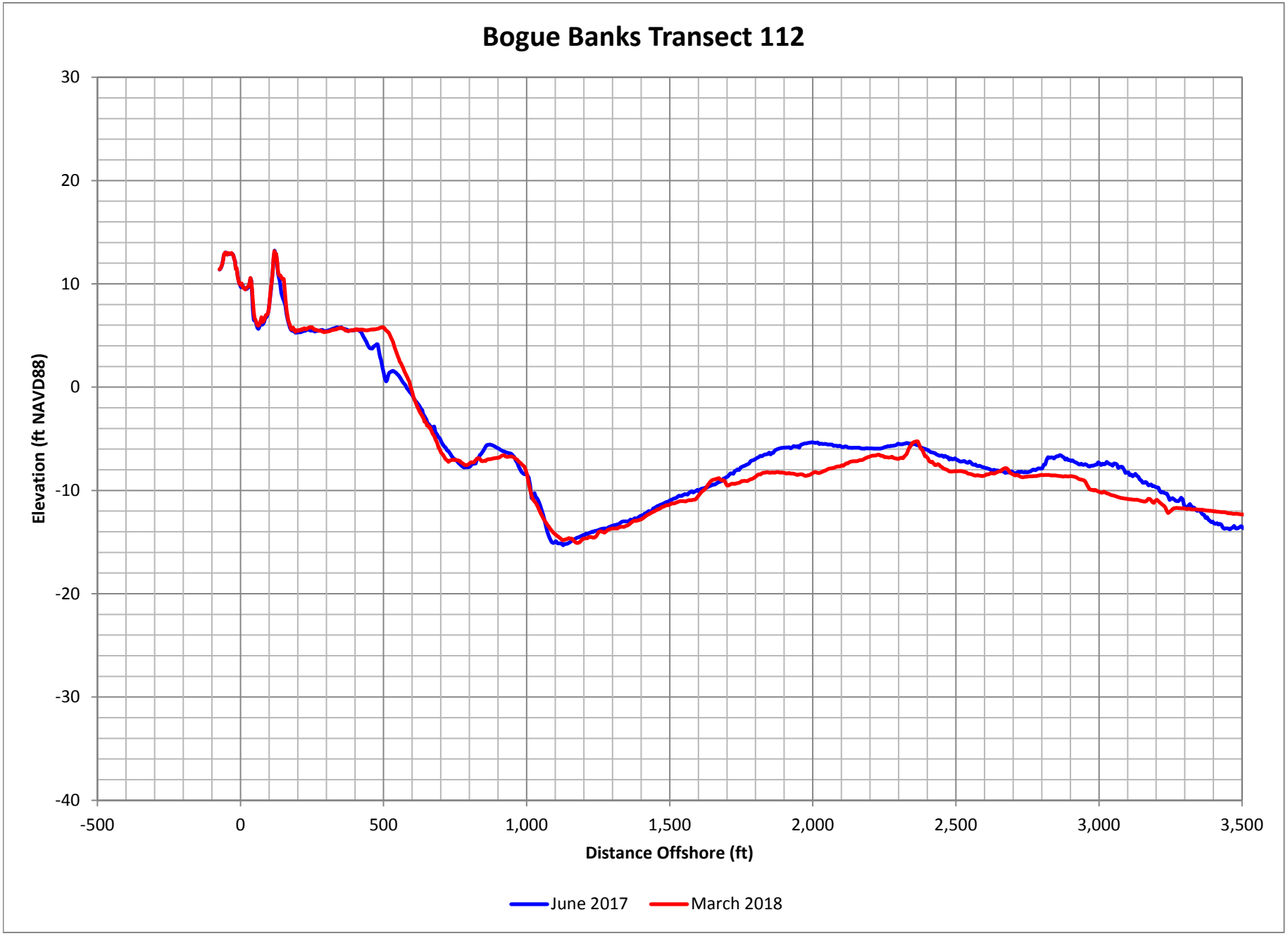


Figure D-223. Bogue Banks Profile Comparison Plot

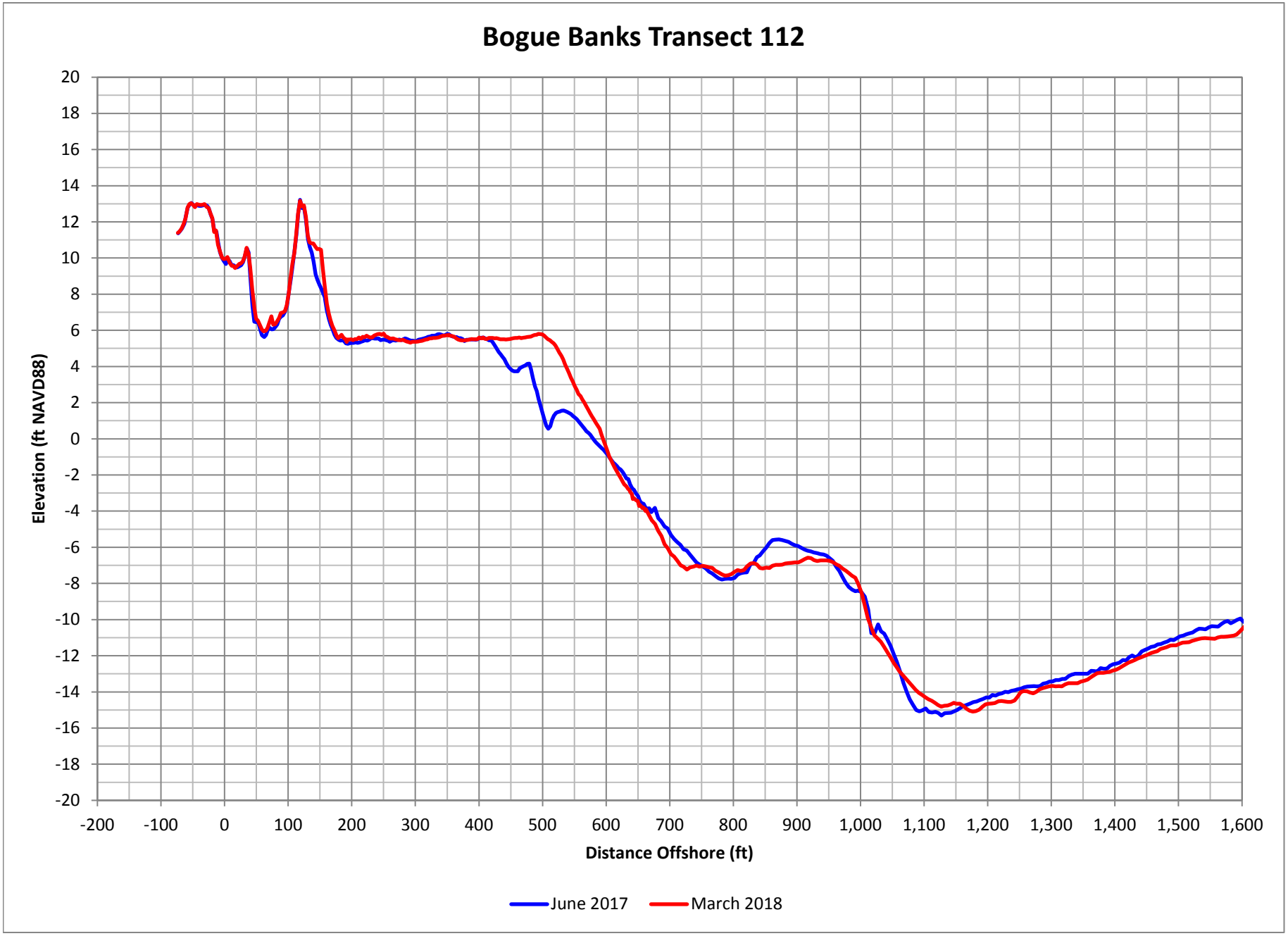


Figure D-224. Bogue Banks Profile Comparison Plot

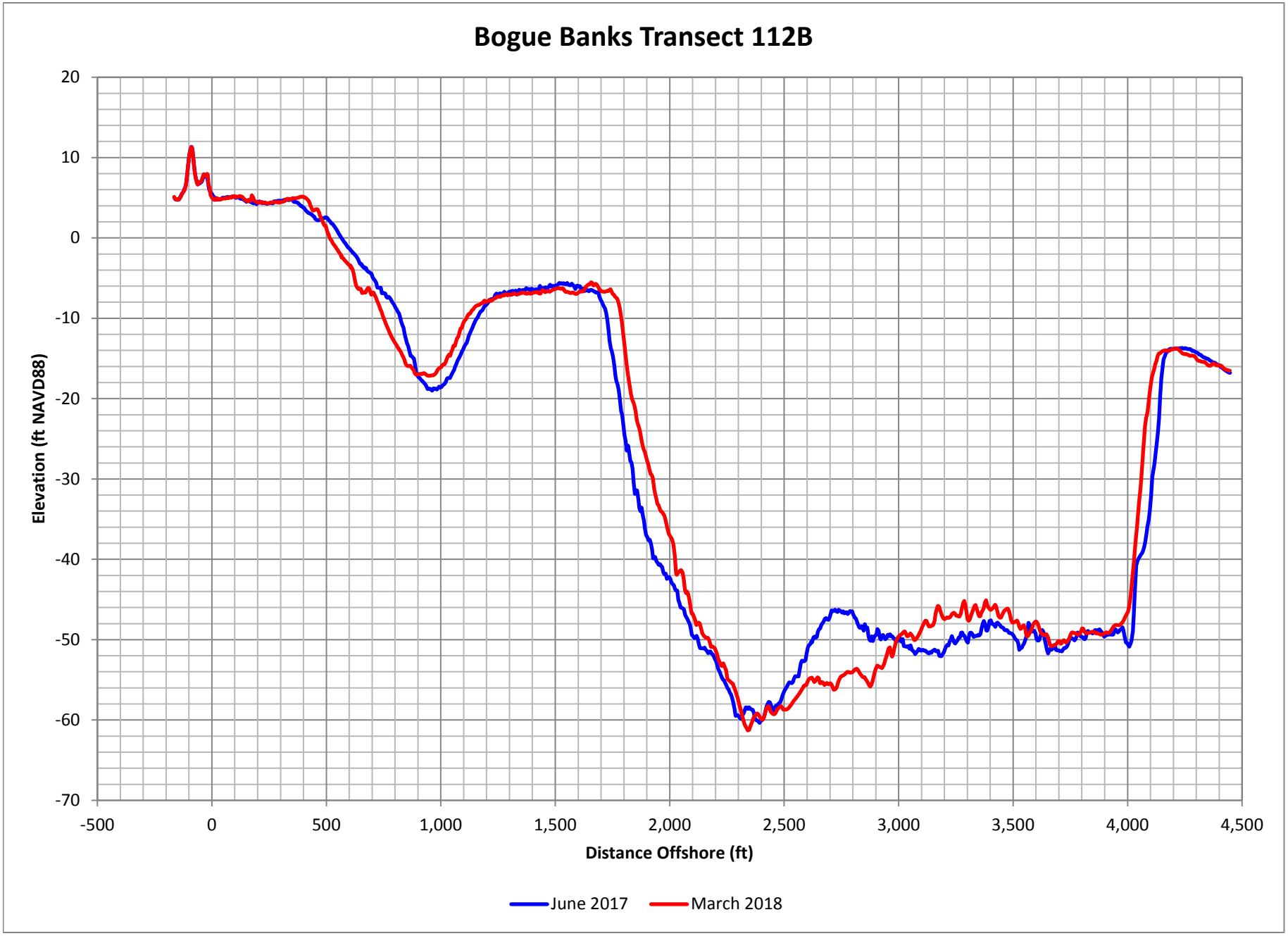


Figure D-225. Bogue Banks Profile Comparison Plot

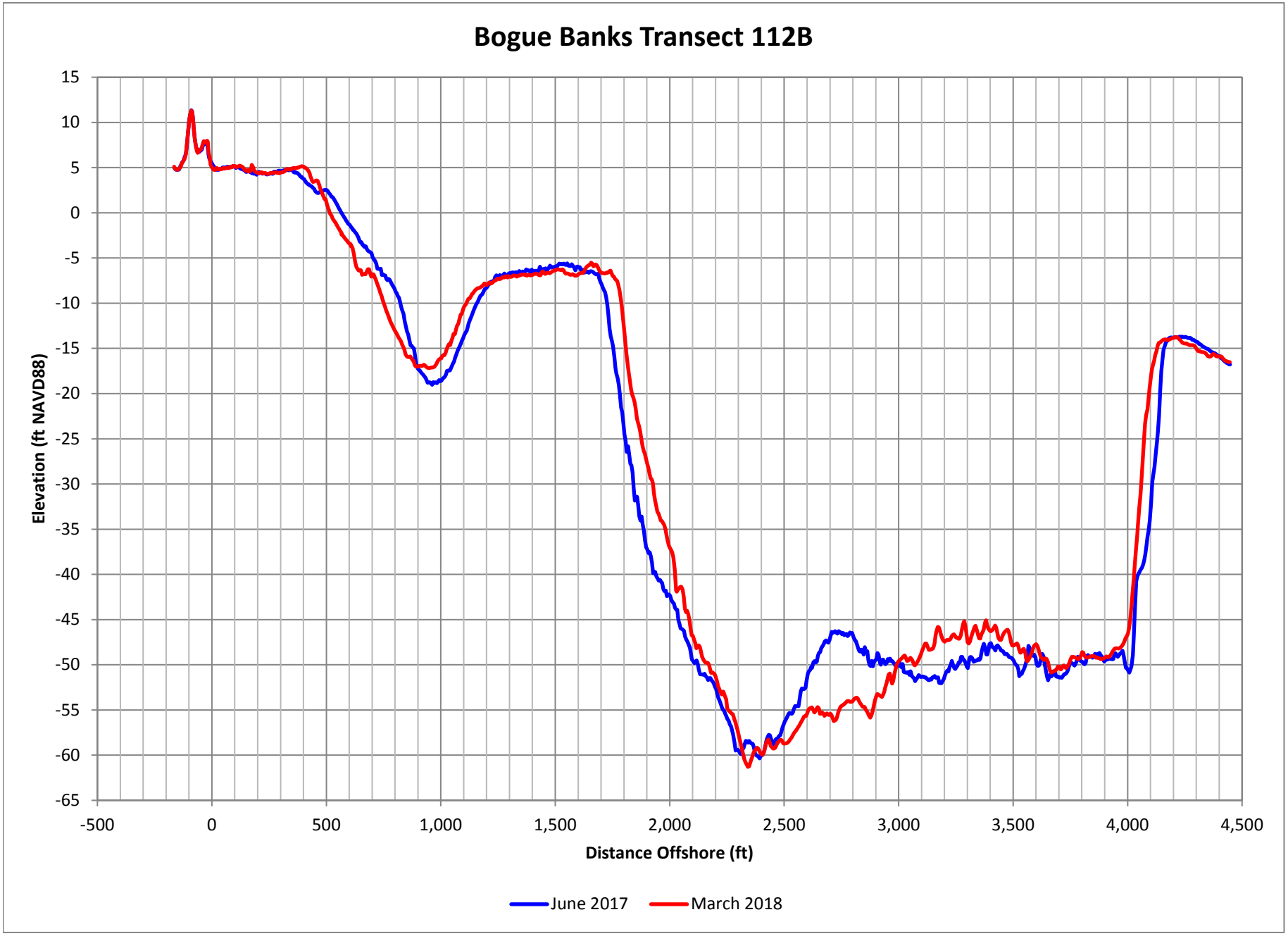


Figure D-226. Bogue Banks Profile Comparison Plot

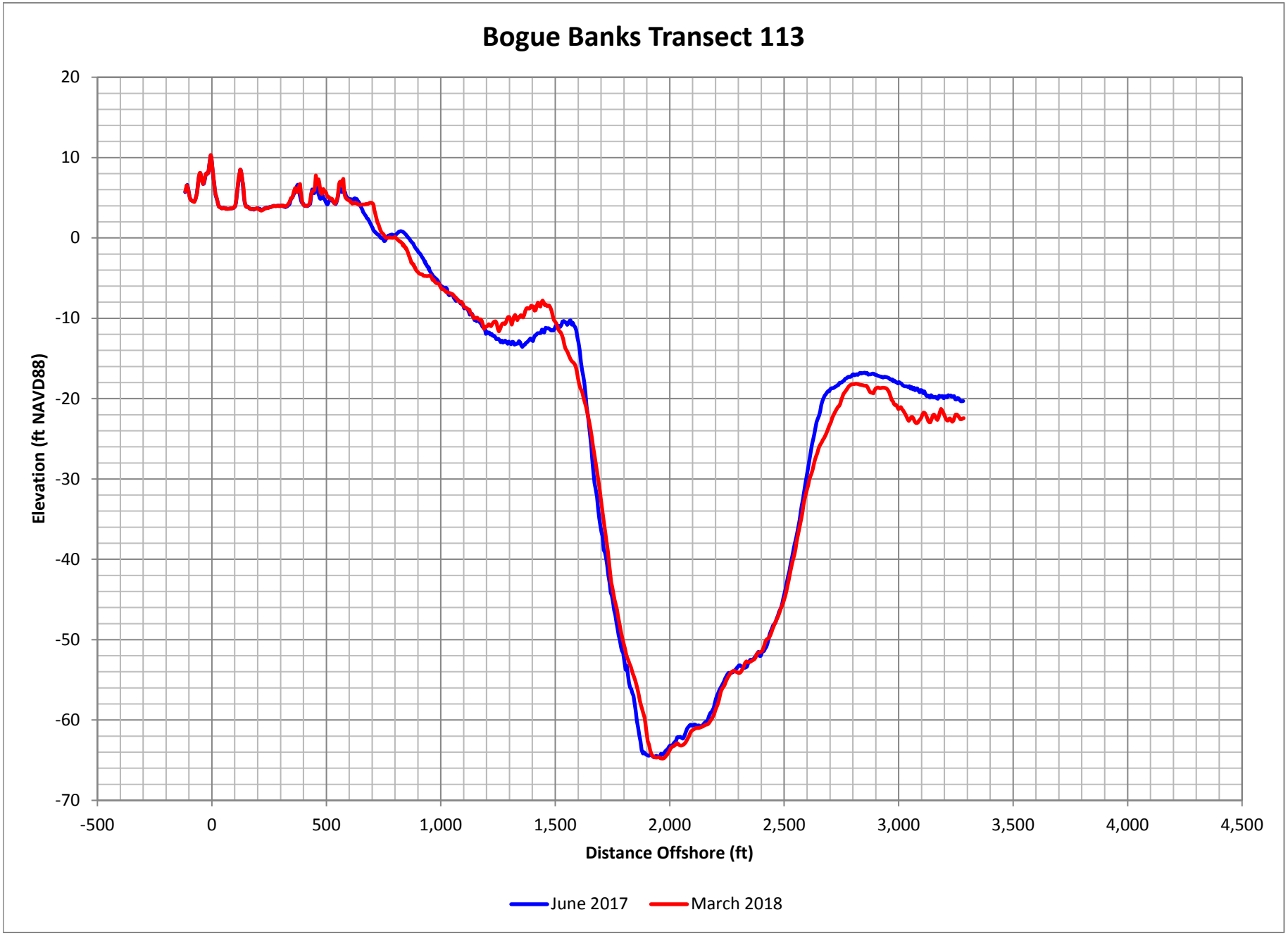


Figure D-227. Bogue Banks Profile Comparison Plot

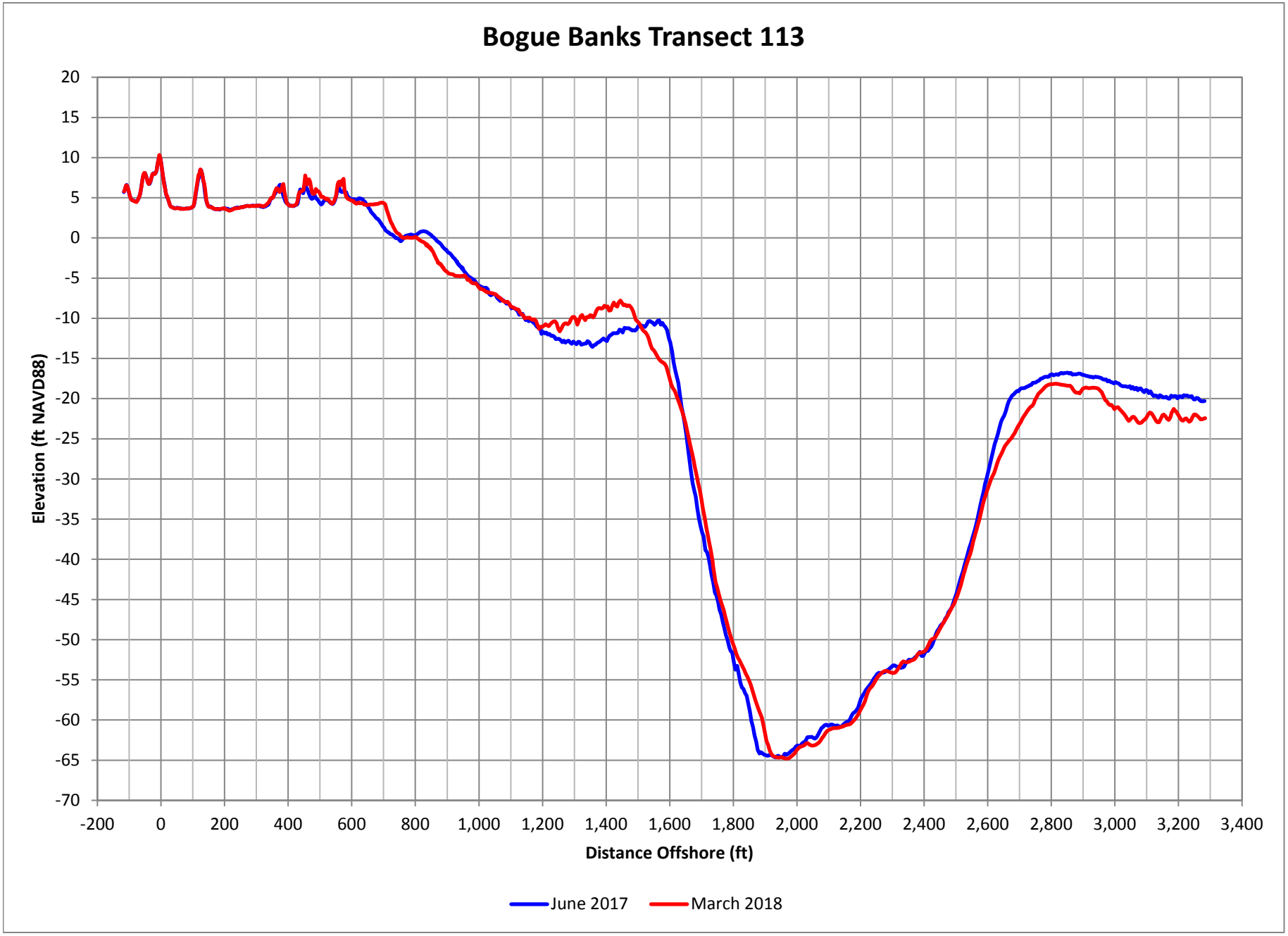


Figure D-228. Bogue Banks Profile Comparison Plot

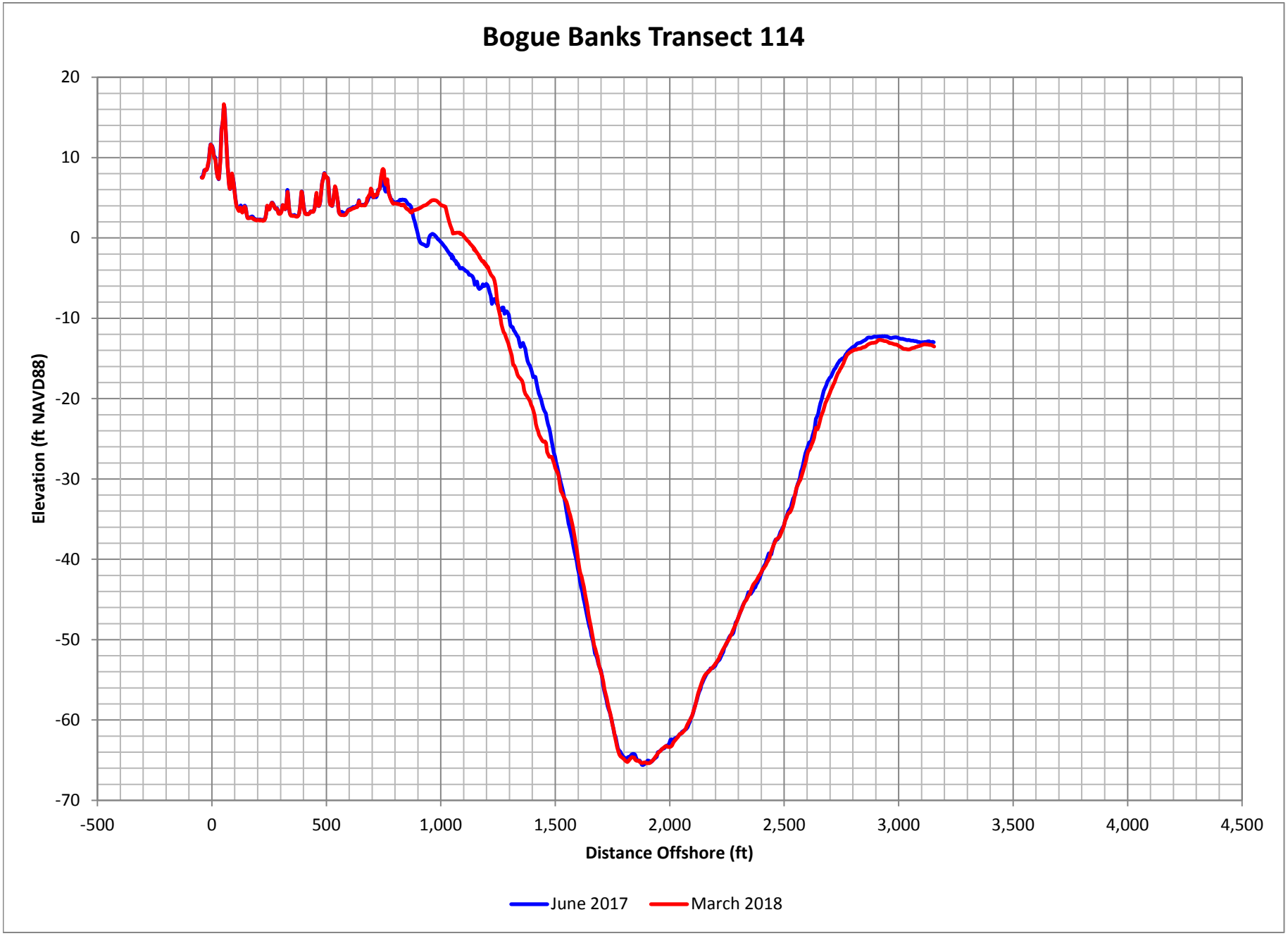


Figure D-229. Bogue Banks Profile Comparison Plot

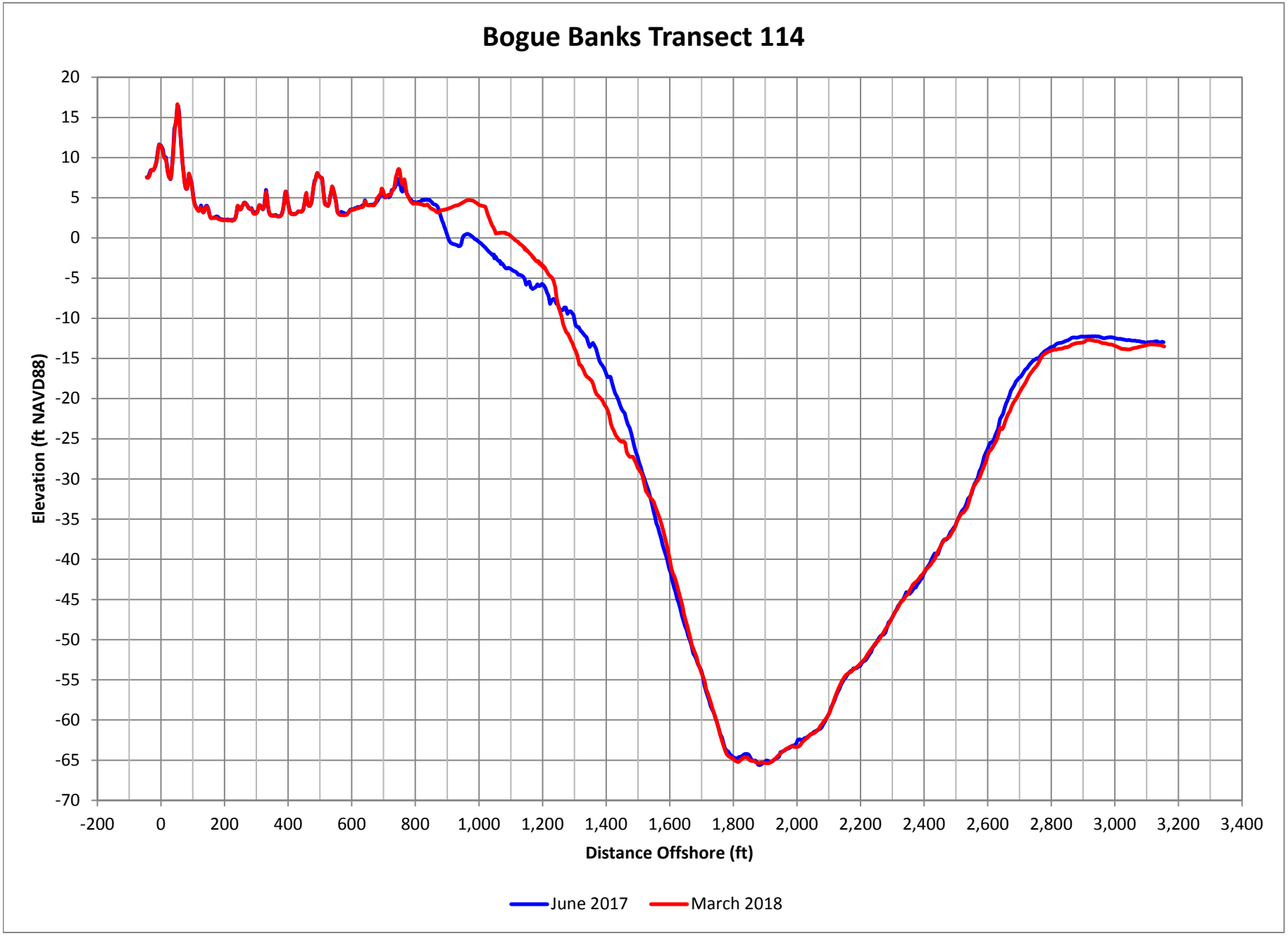


Figure D-230. Bogue Banks Profile Comparison Plot

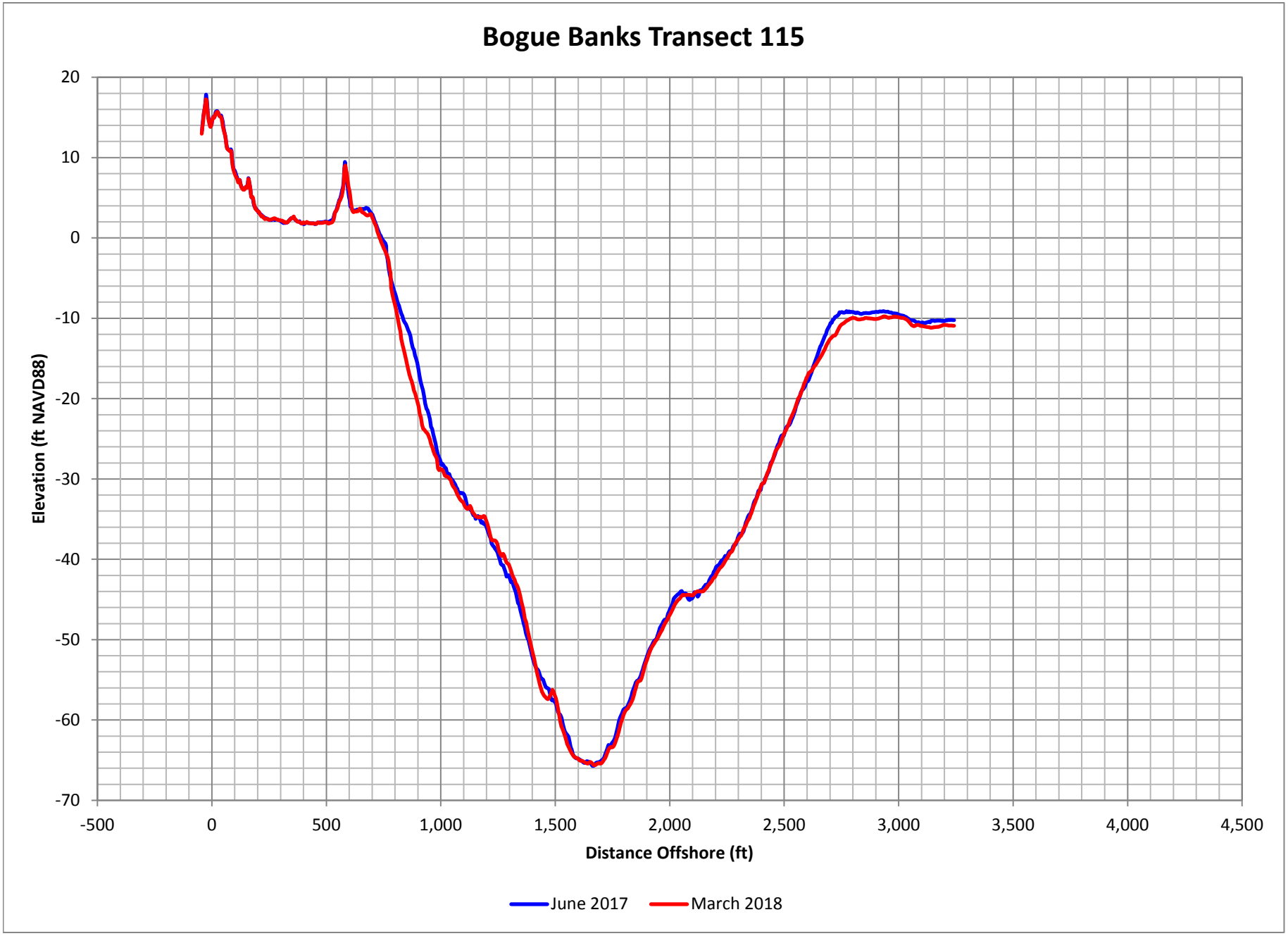


Figure D-231. Bogue Banks Profile Comparison Plot

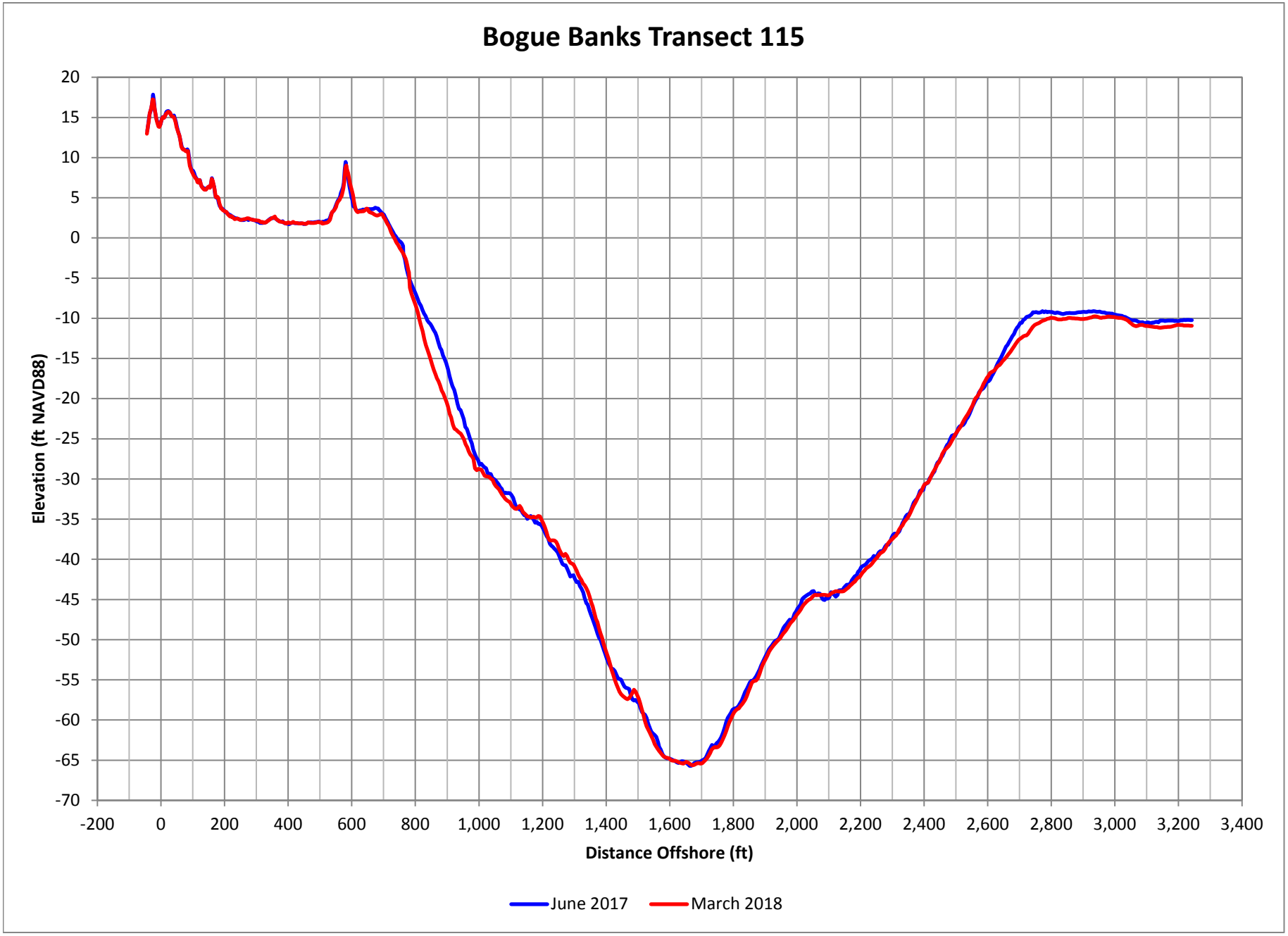


Figure D-232. Bogue Banks Profile Comparison Plot

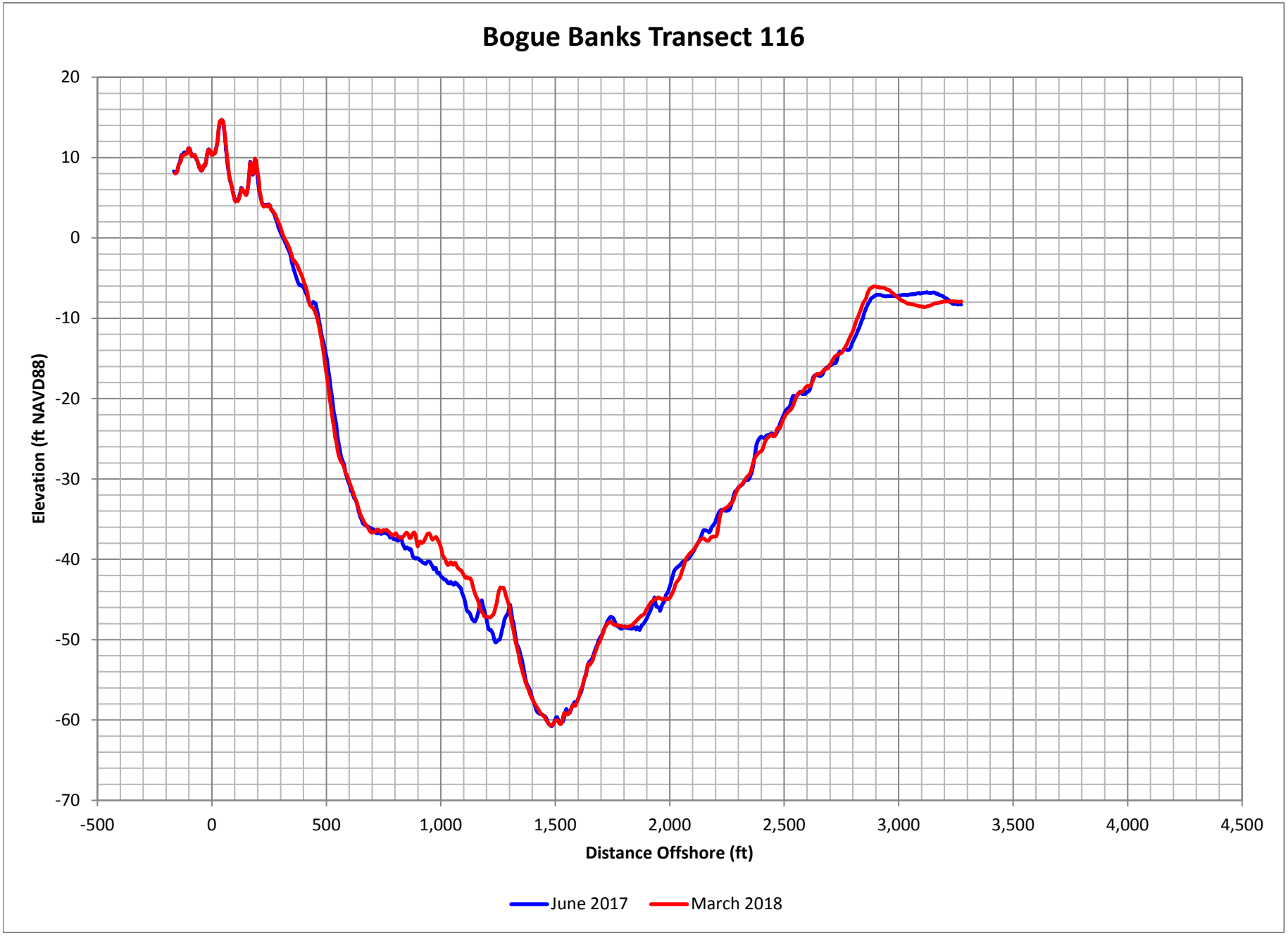


Figure D-233. Bogue Banks Profile Comparison Plot

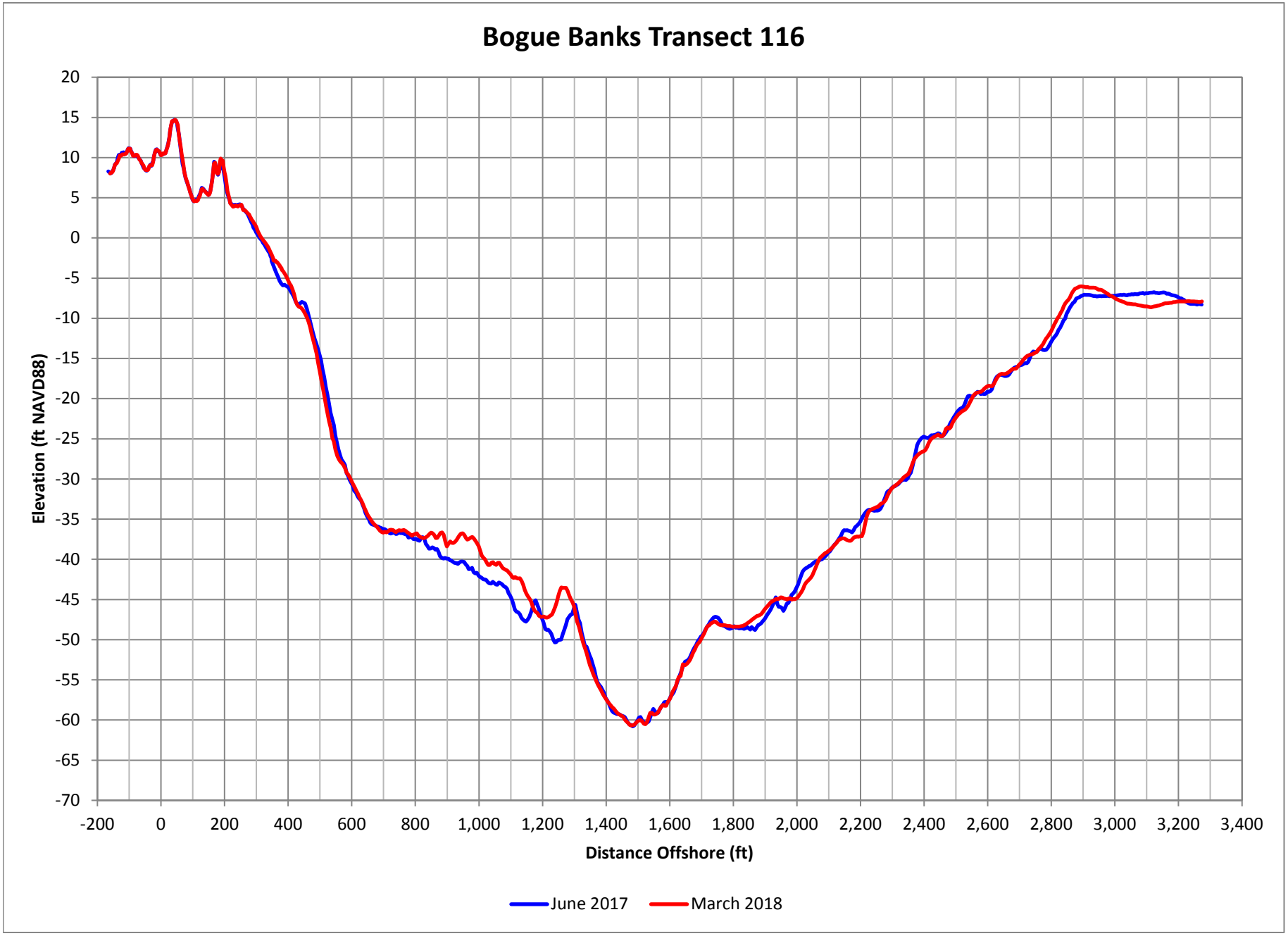


Figure D-234. Bogue Banks Profile Comparison Plot

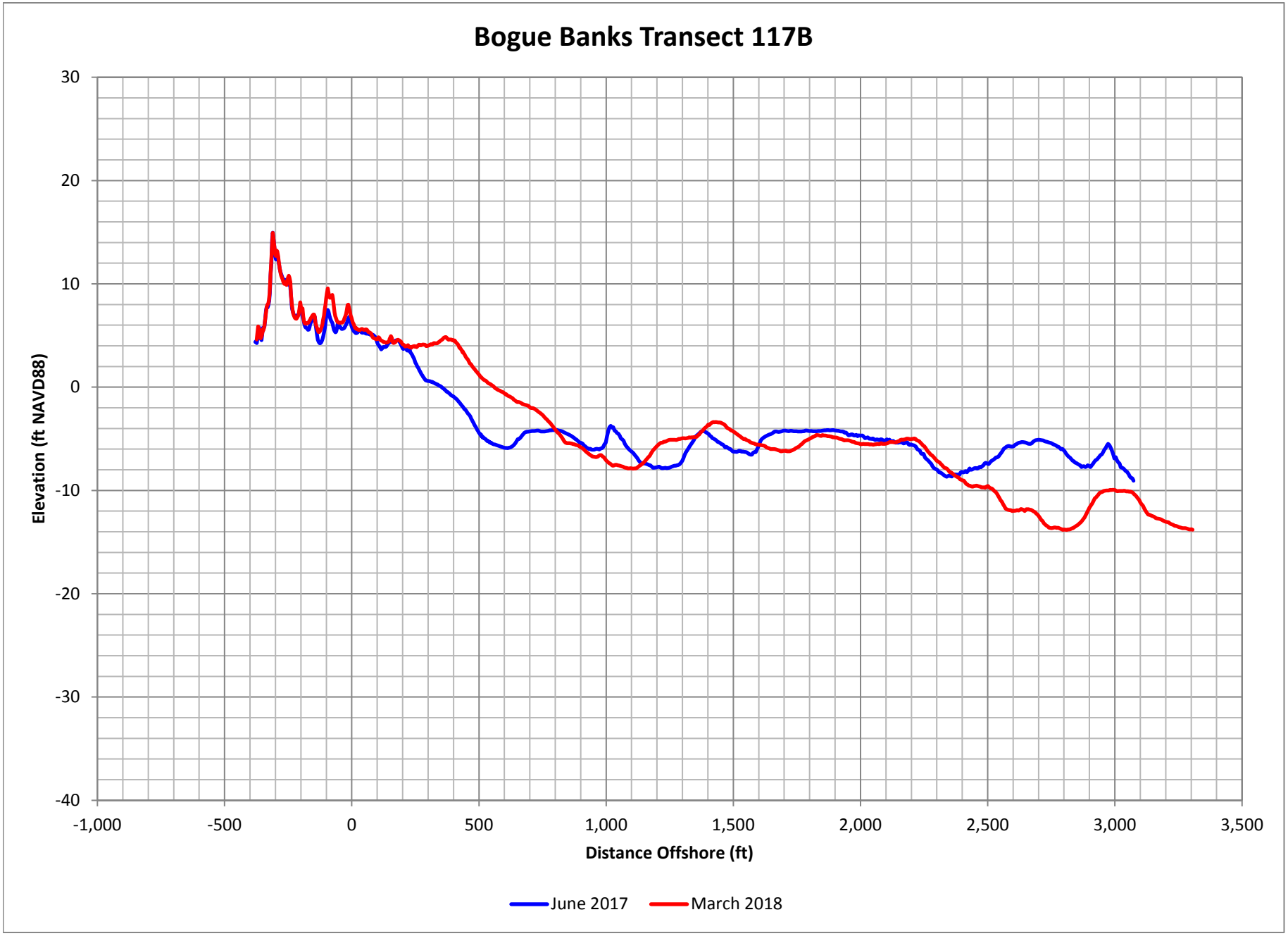


Figure D-235. Bogue Banks Profile Comparison Plot

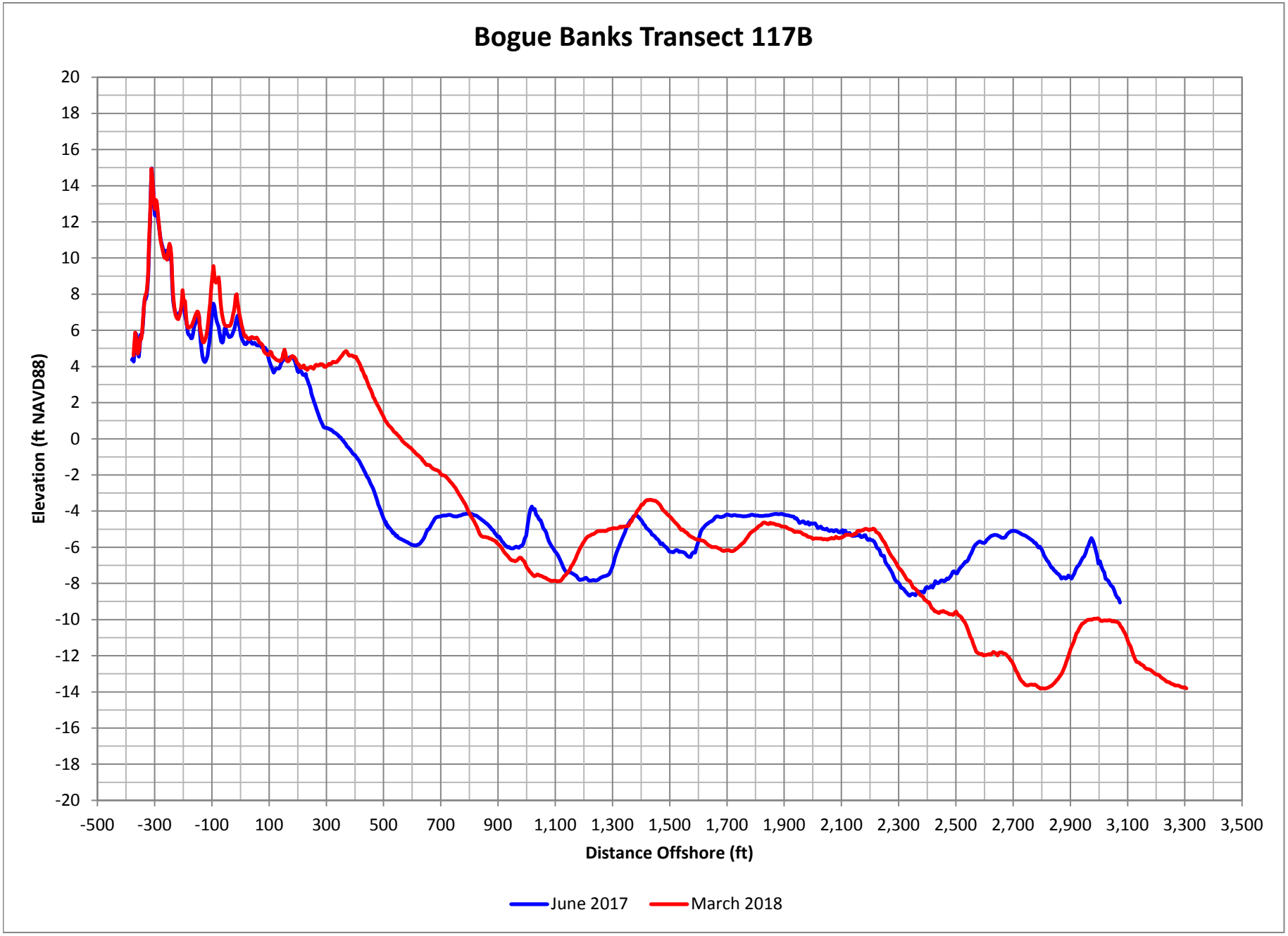


Figure D-236. Bogue Banks Profile Comparison Plot

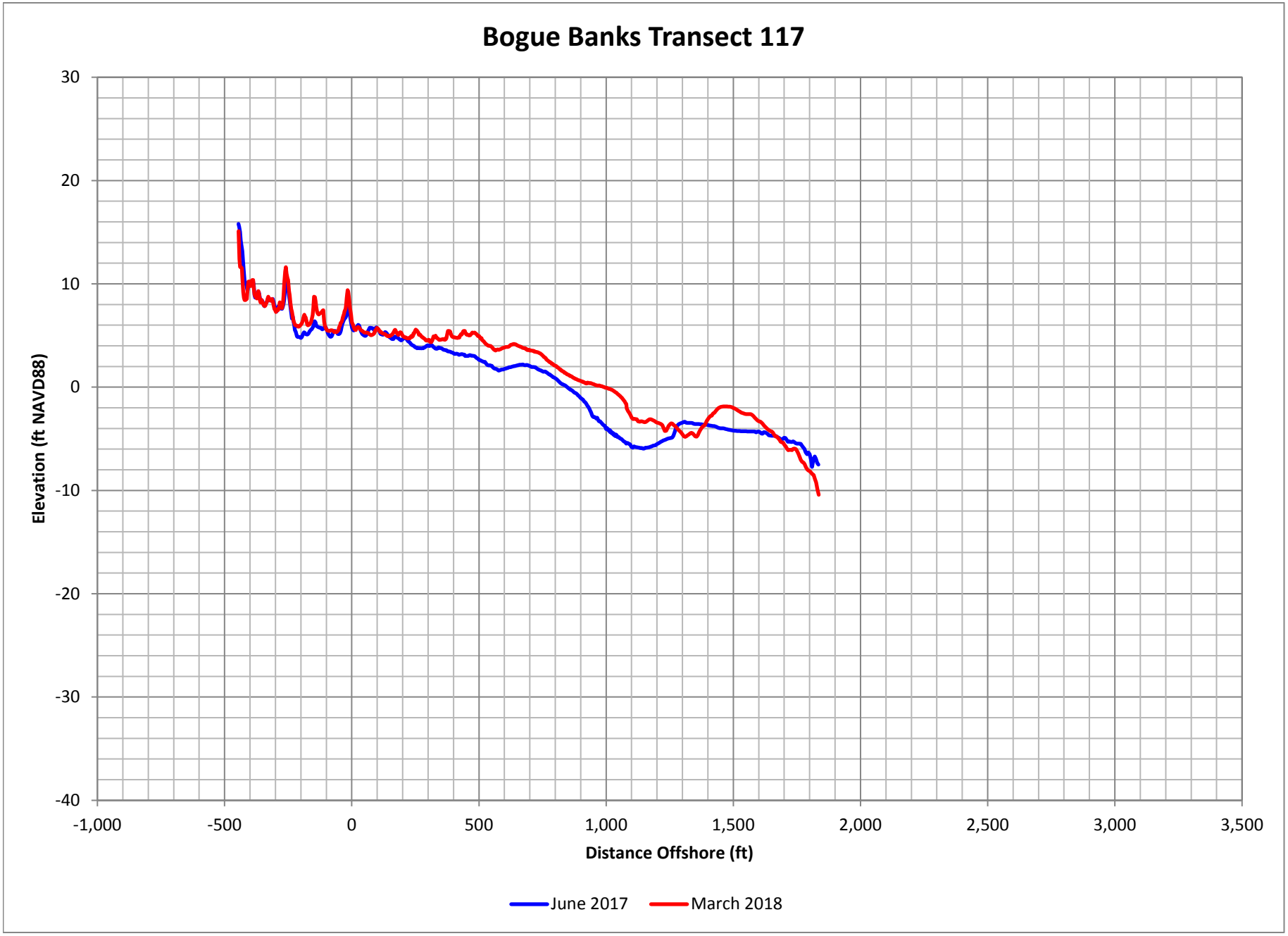


Figure D-237. Bogue Banks Profile Comparison Plot

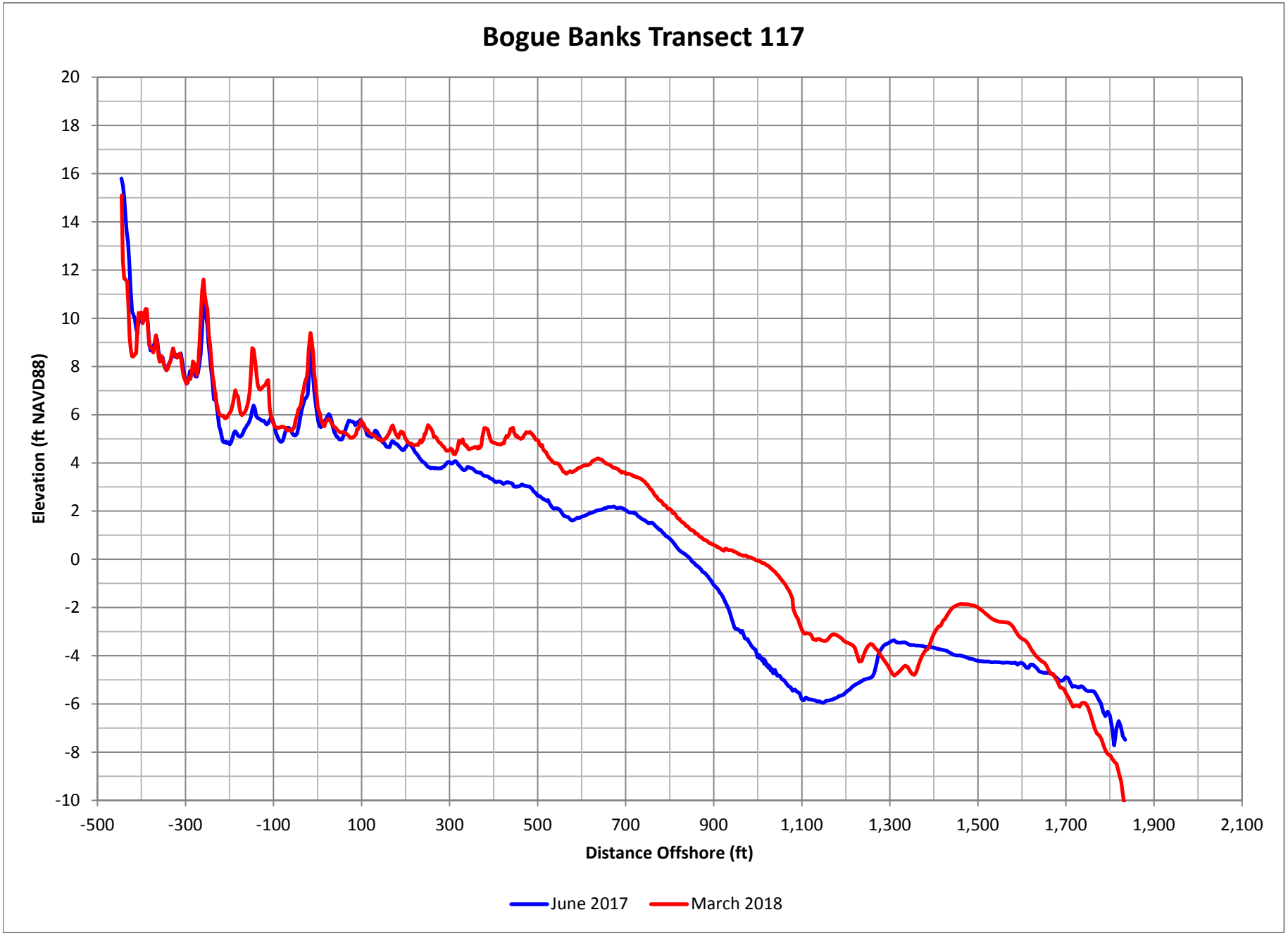


Figure D-238. Bogue Banks Profile Comparison Plot

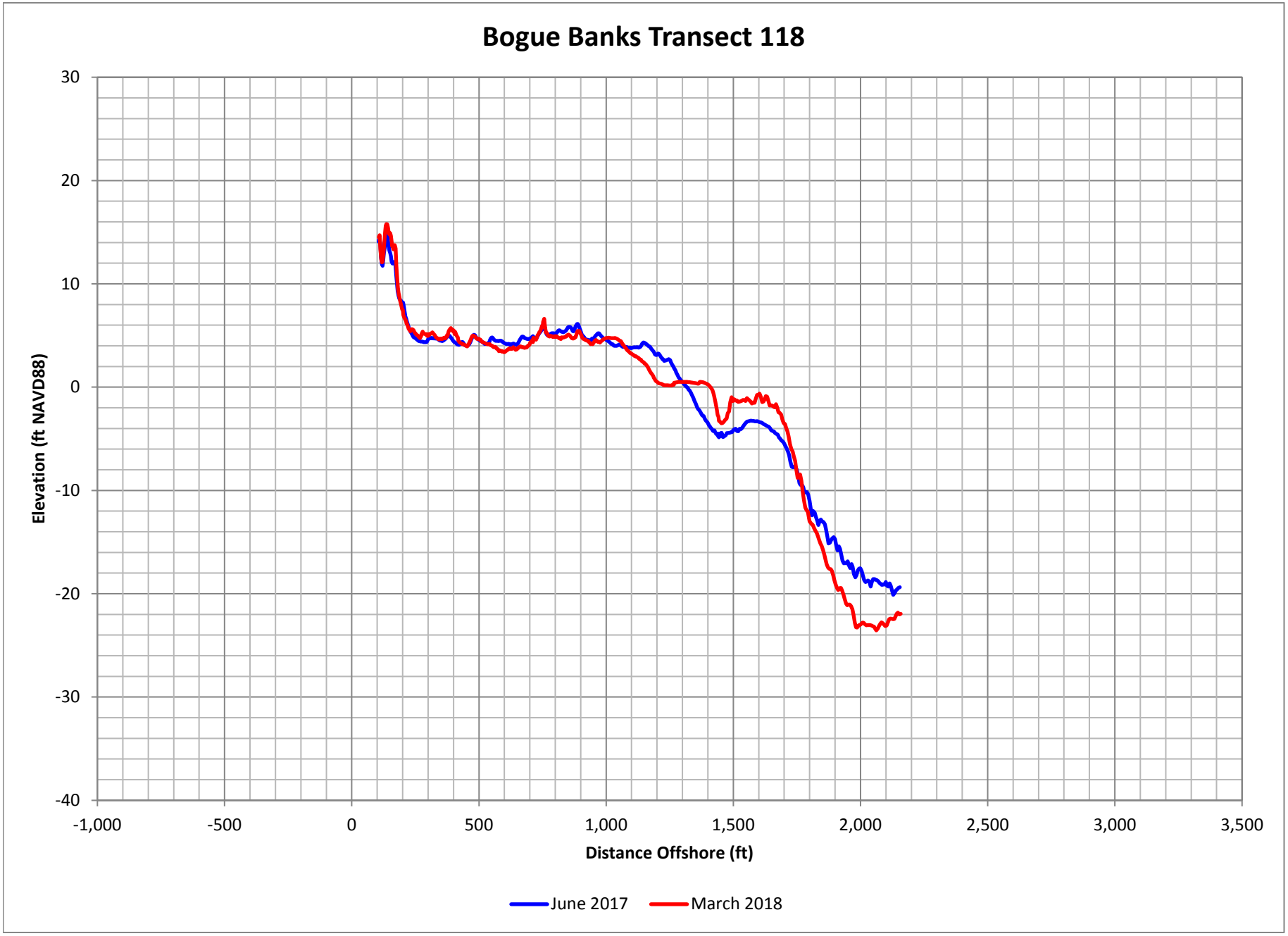


Figure D-239. Bogue Banks Profile Comparison Plot

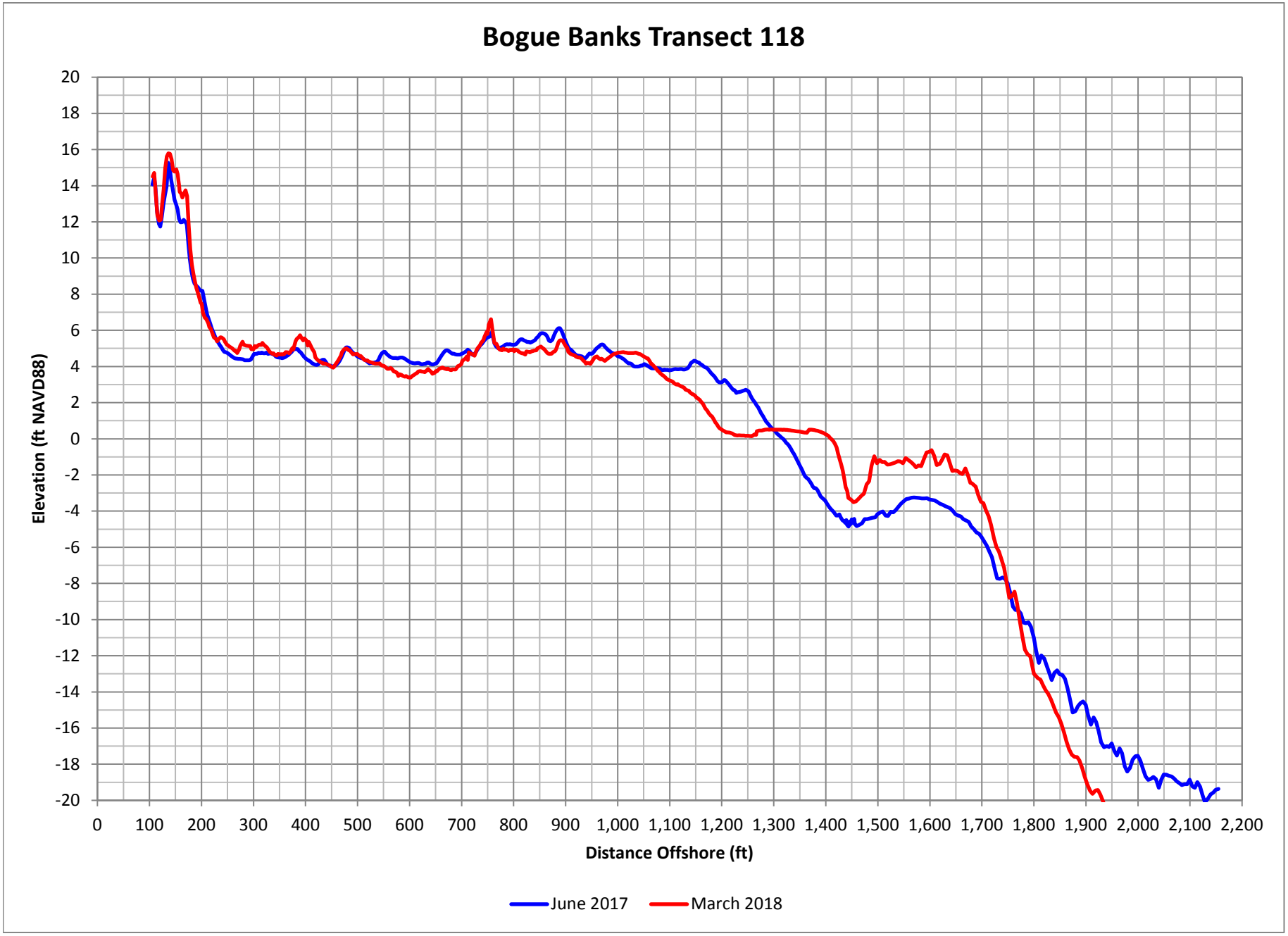


Figure D-240. Bogue Banks Profile Comparison Plot

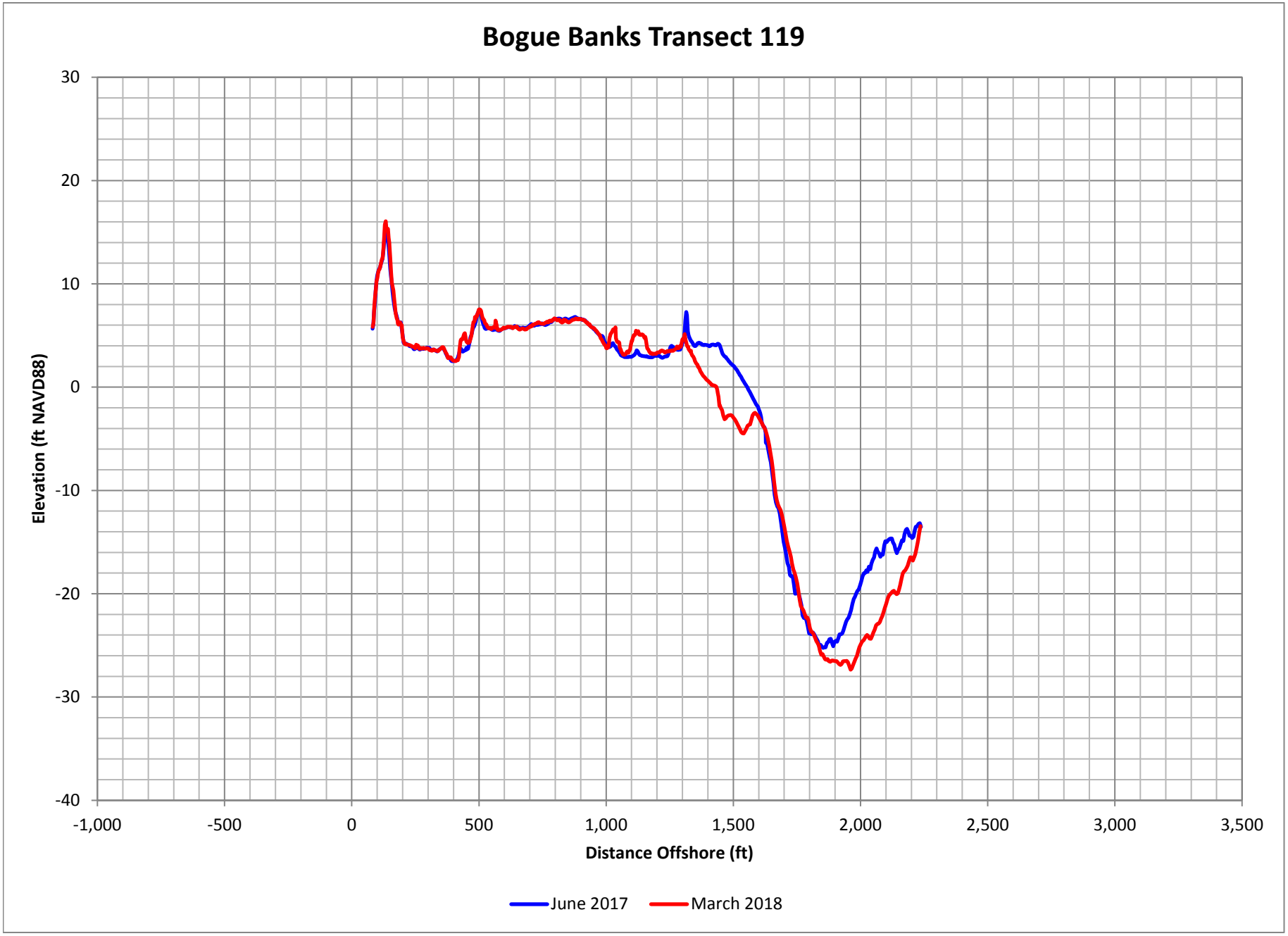


Figure D-241. Bogue Banks Profile Comparison Plot

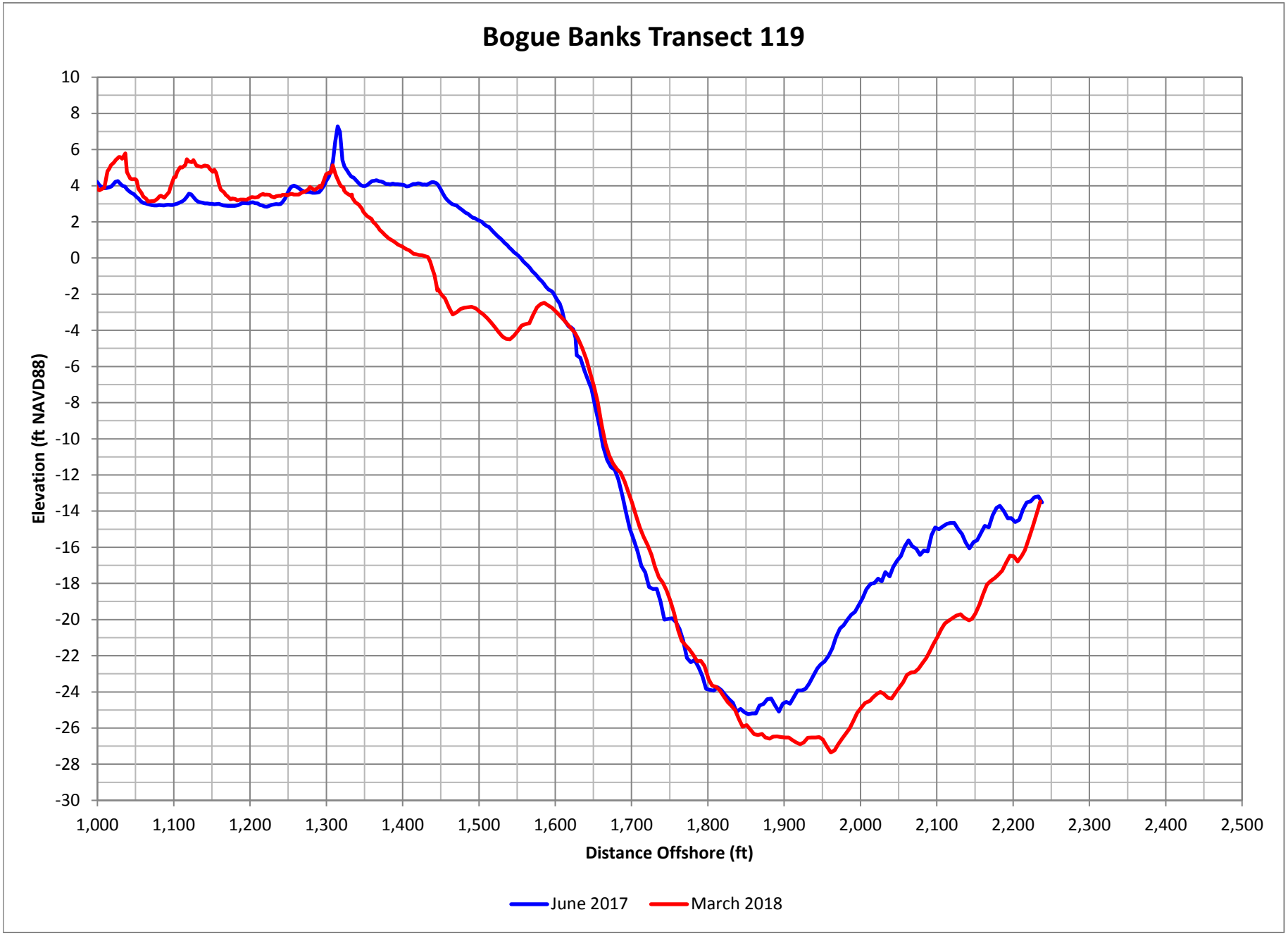


Figure D-242. Bogue Banks Profile Comparison Plot

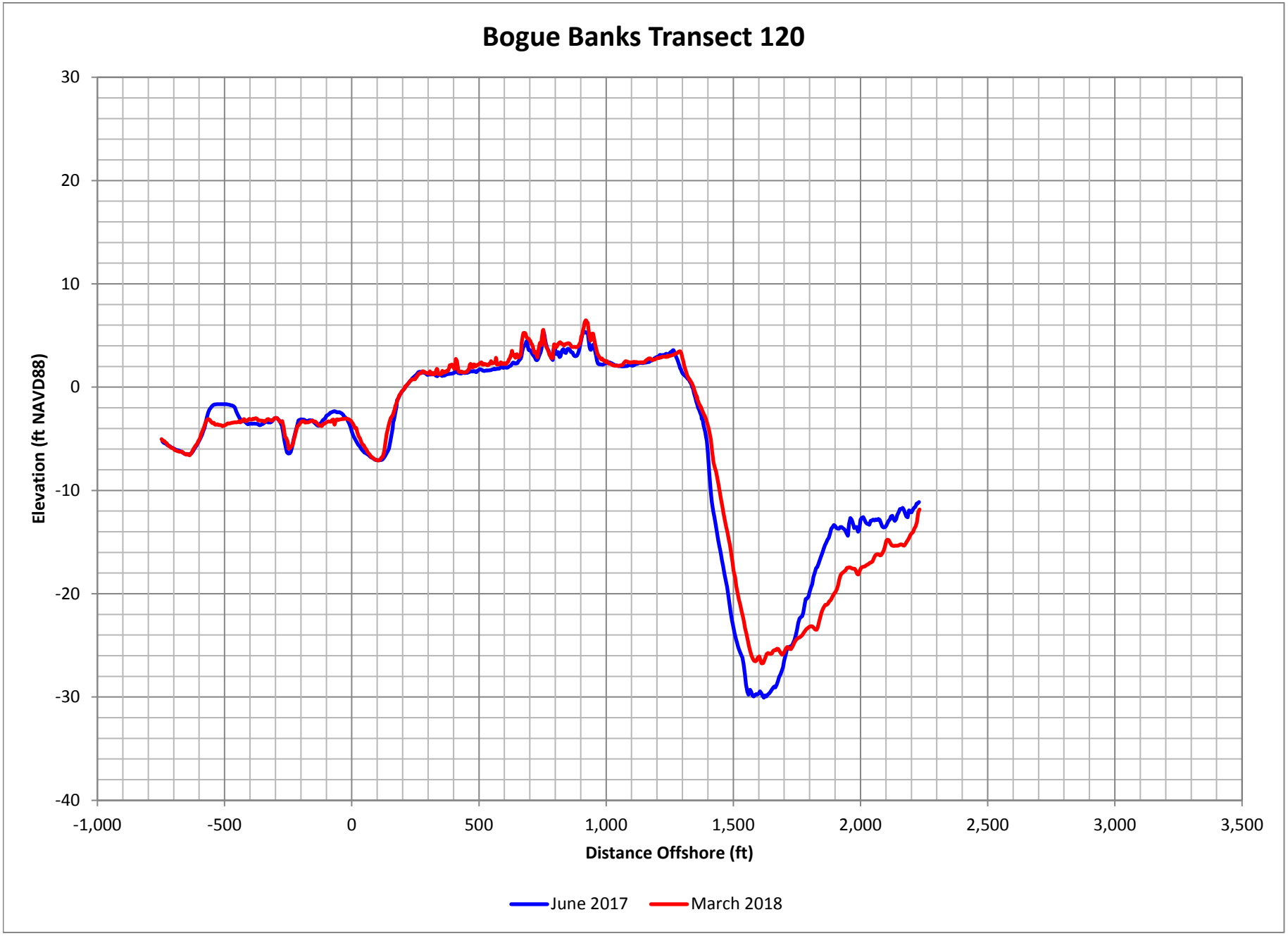


Figure D-243. Bogue Banks Profile Comparison Plot

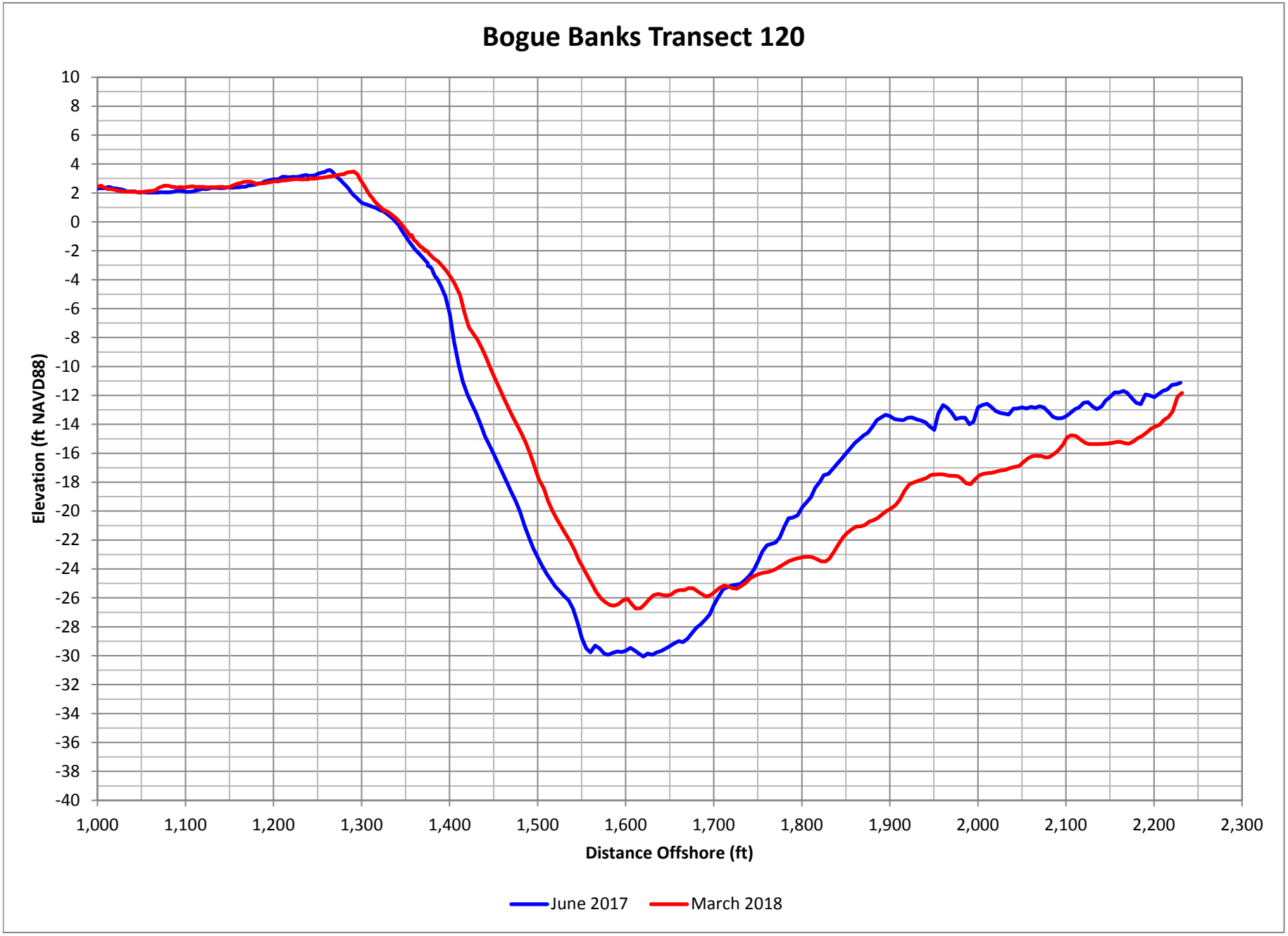


Figure D-244. Bogue Banks Profile Comparison Plot

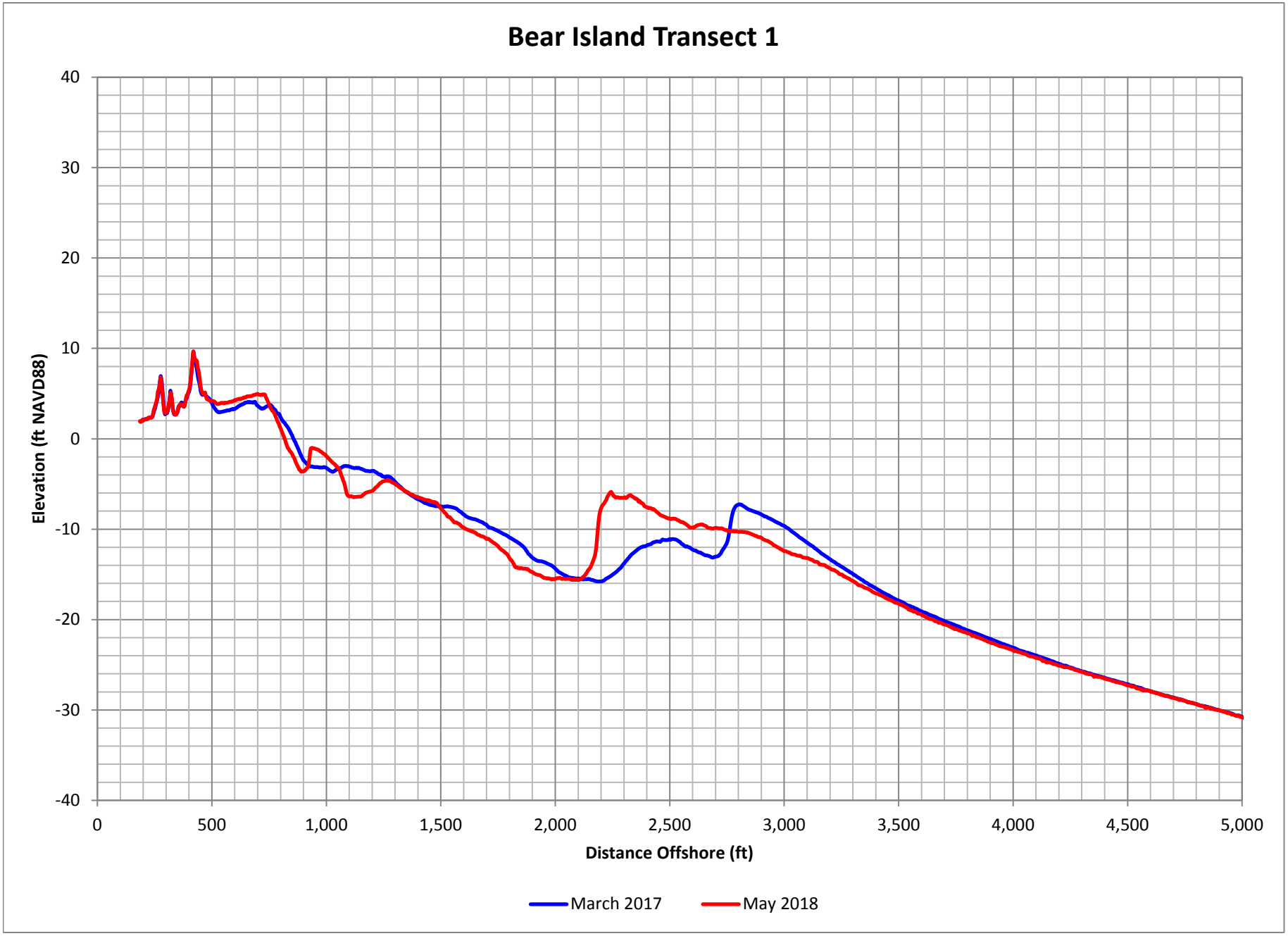


Figure D-245. Bear Island Profile Comparison Plot

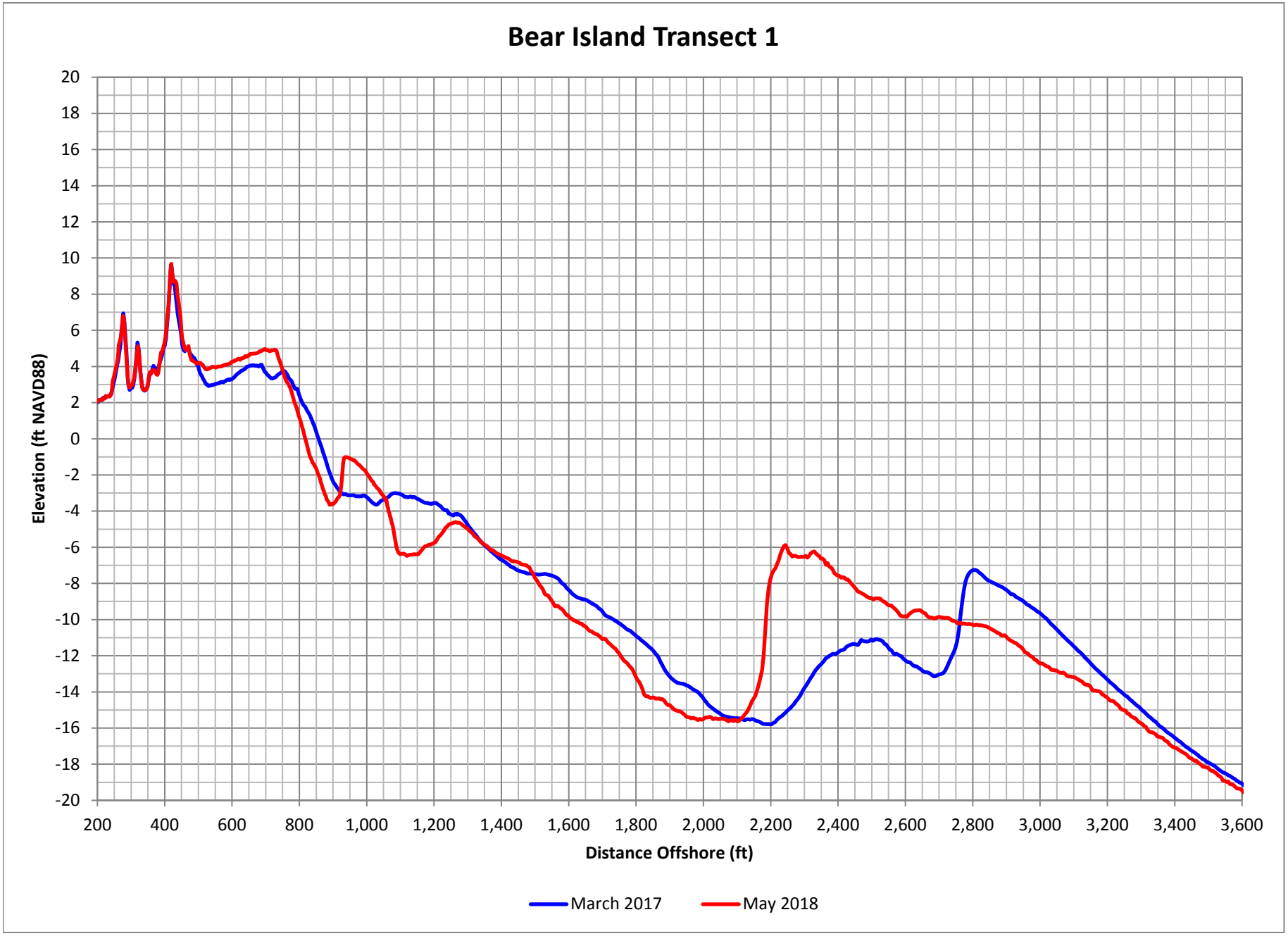


Figure D-246. Bear Island Profile Comparison Plot

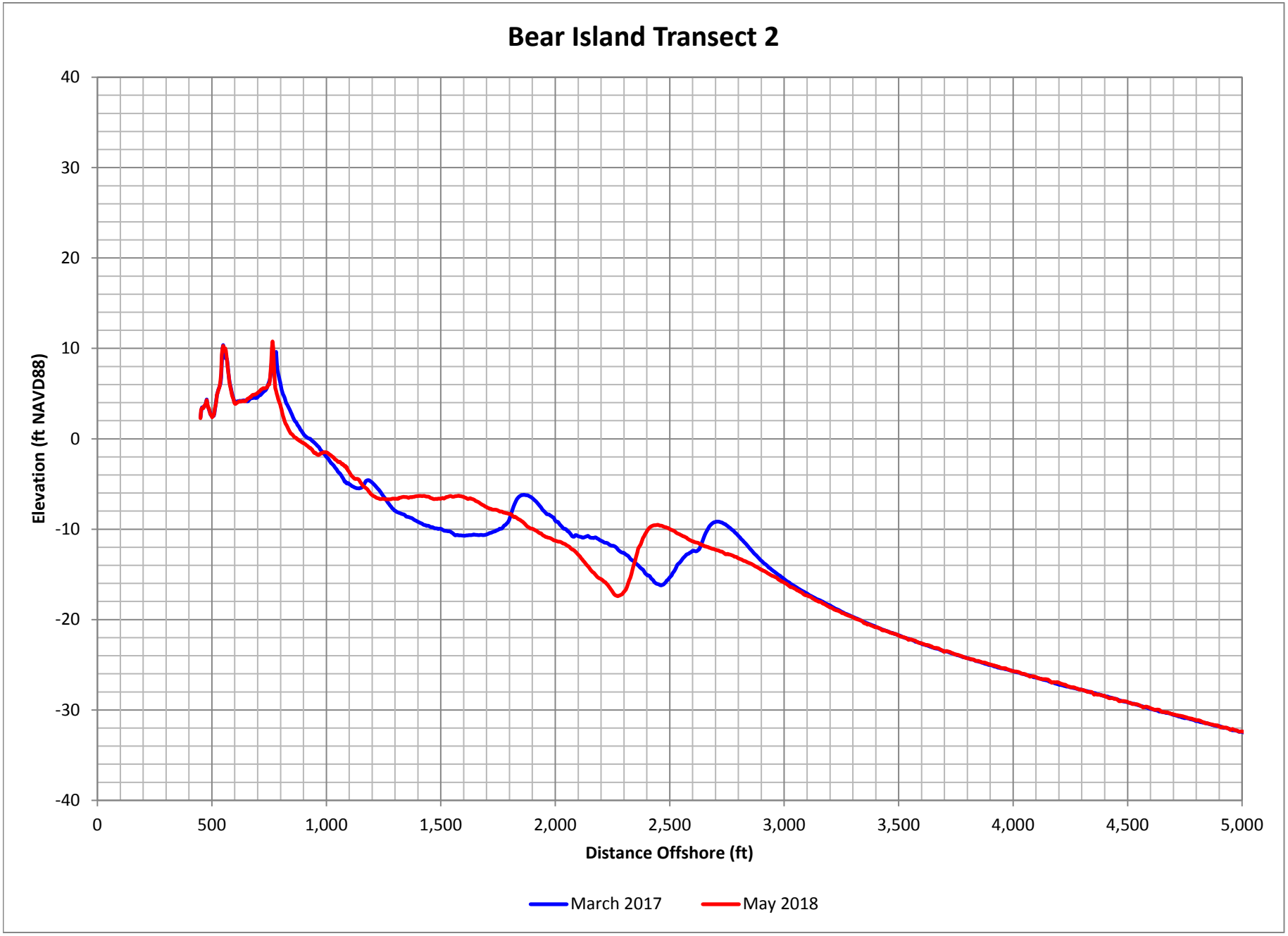


Figure D-247. Bear Island Profile Comparison Plot

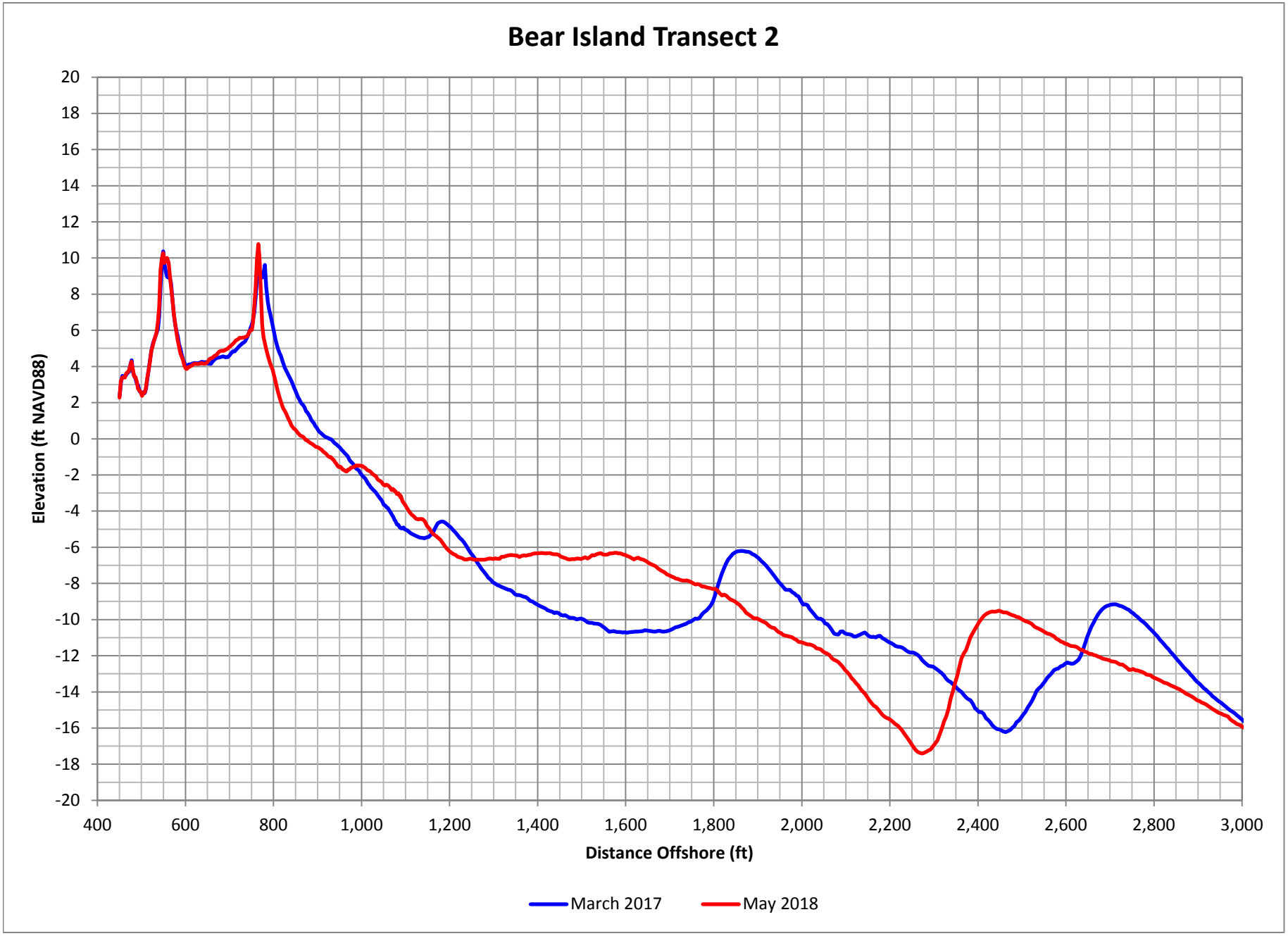


Figure D-248. Bear Island Profile Comparison Plot

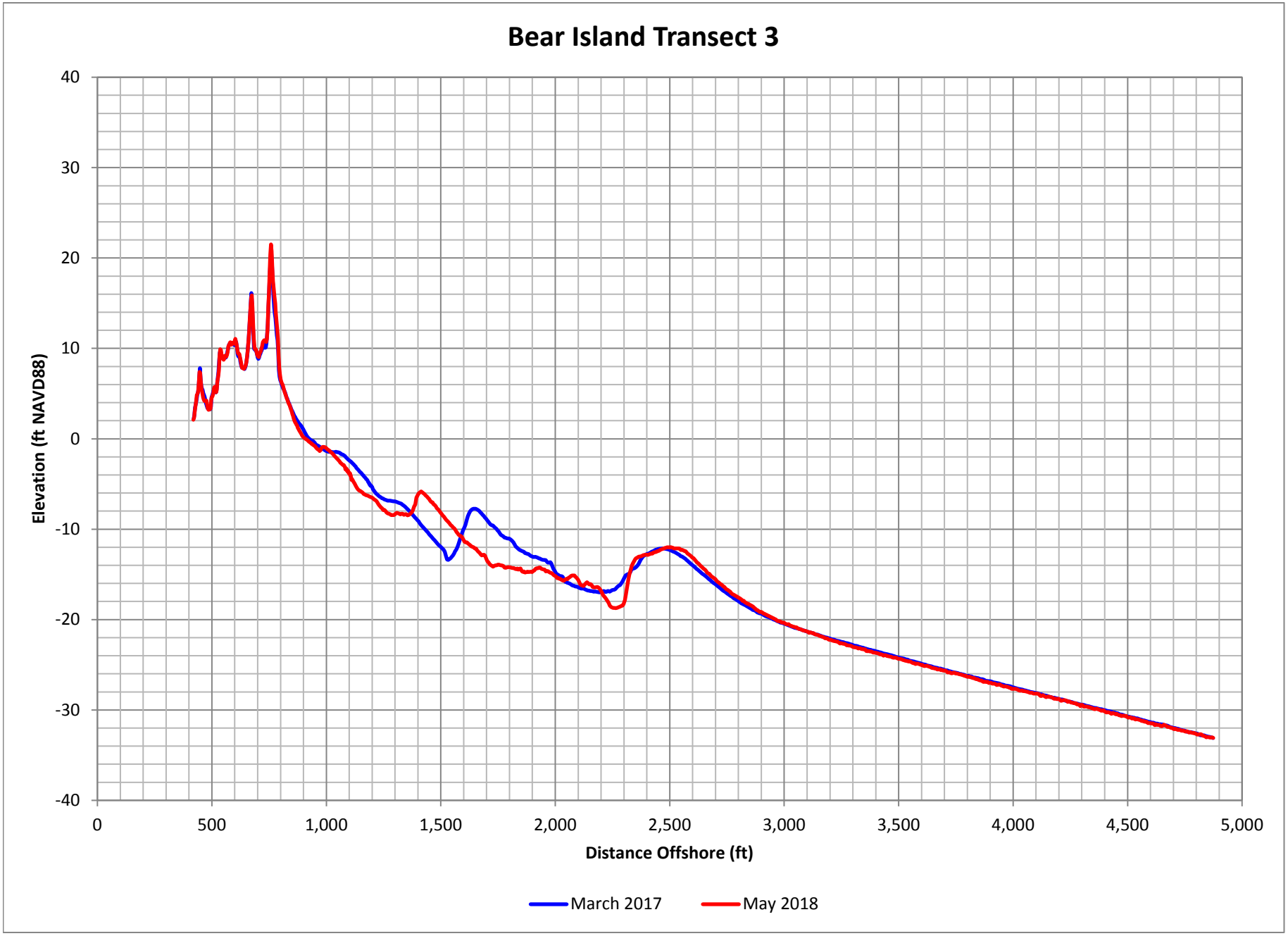


Figure D-249. Bear Island Profile Comparison Plot

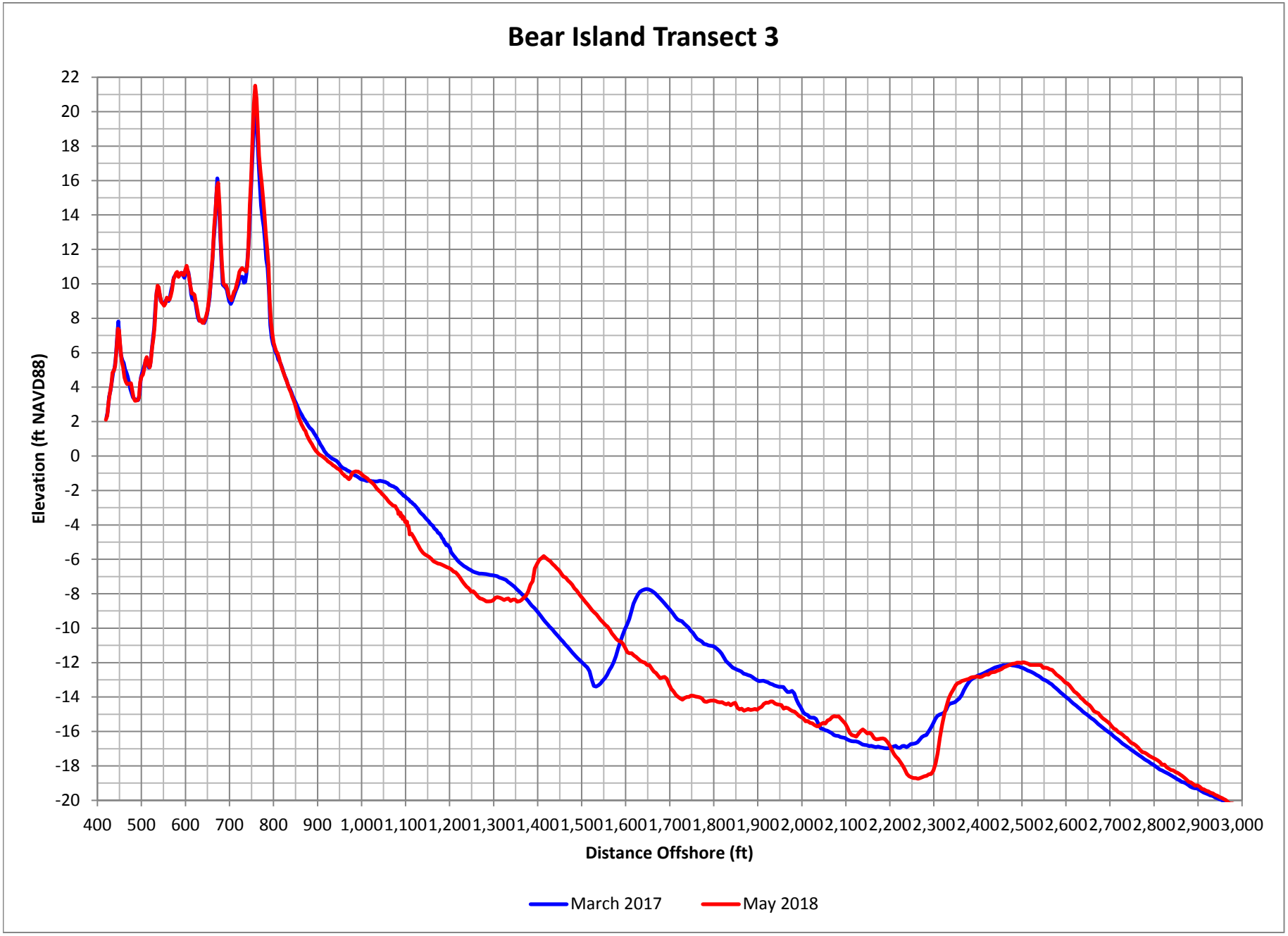


Figure D-250. Bear Island Profile Comparison Plot

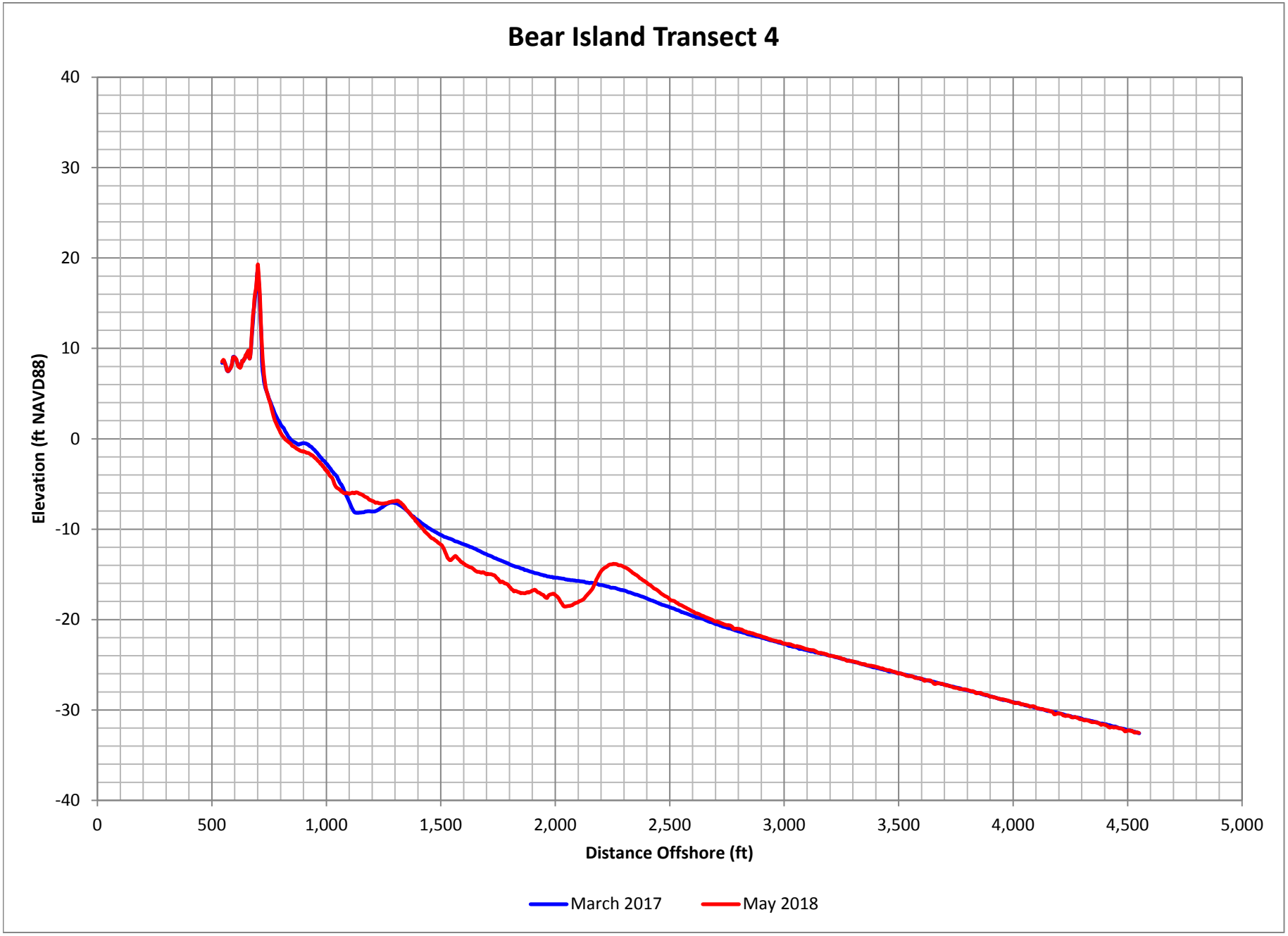


Figure D-251. Bear Island Profile Comparison Plot

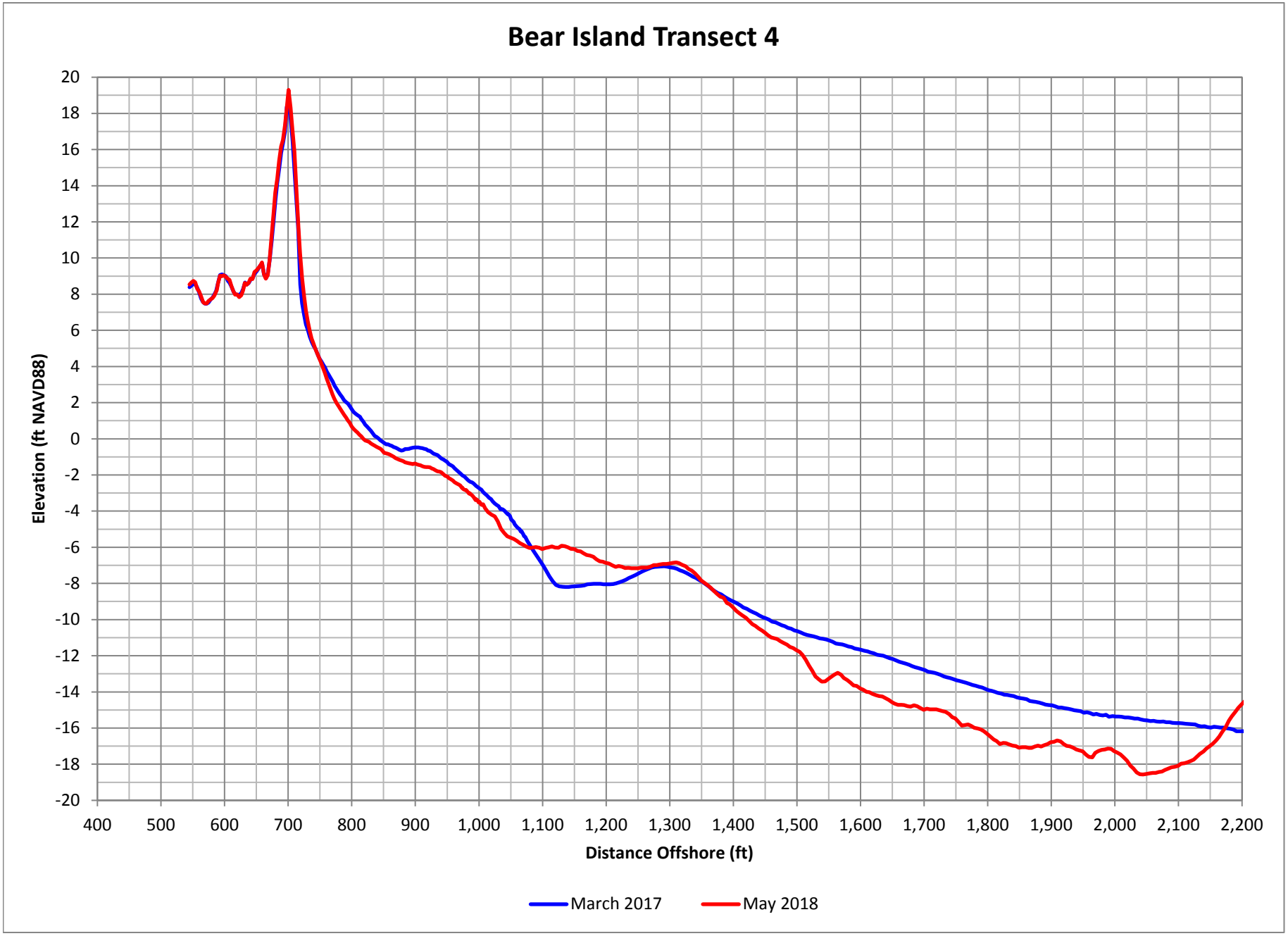


Figure D-252. Bear Island Profile Comparison Plot

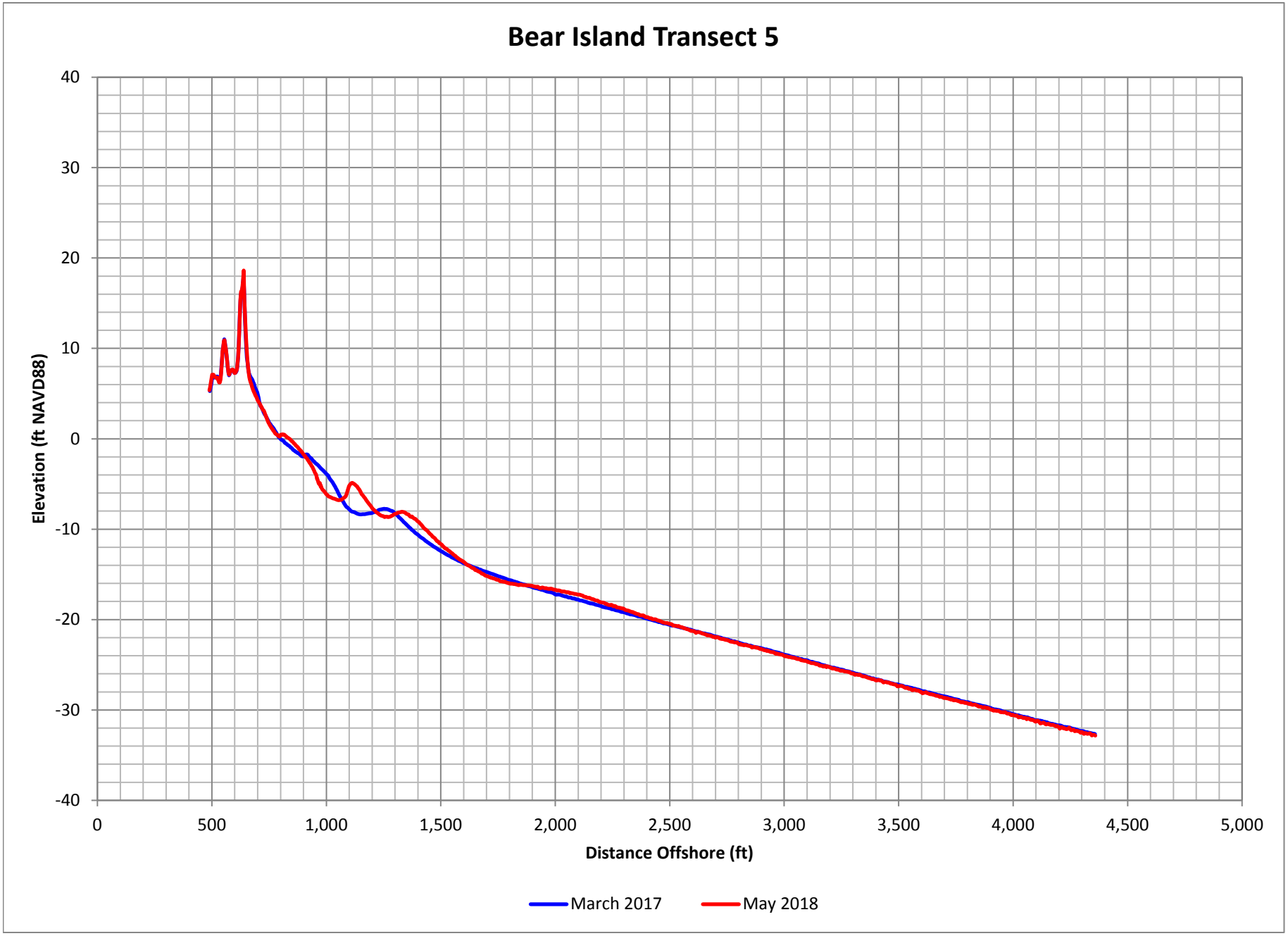


Figure D-253. Bear Island Profile Comparison Plot

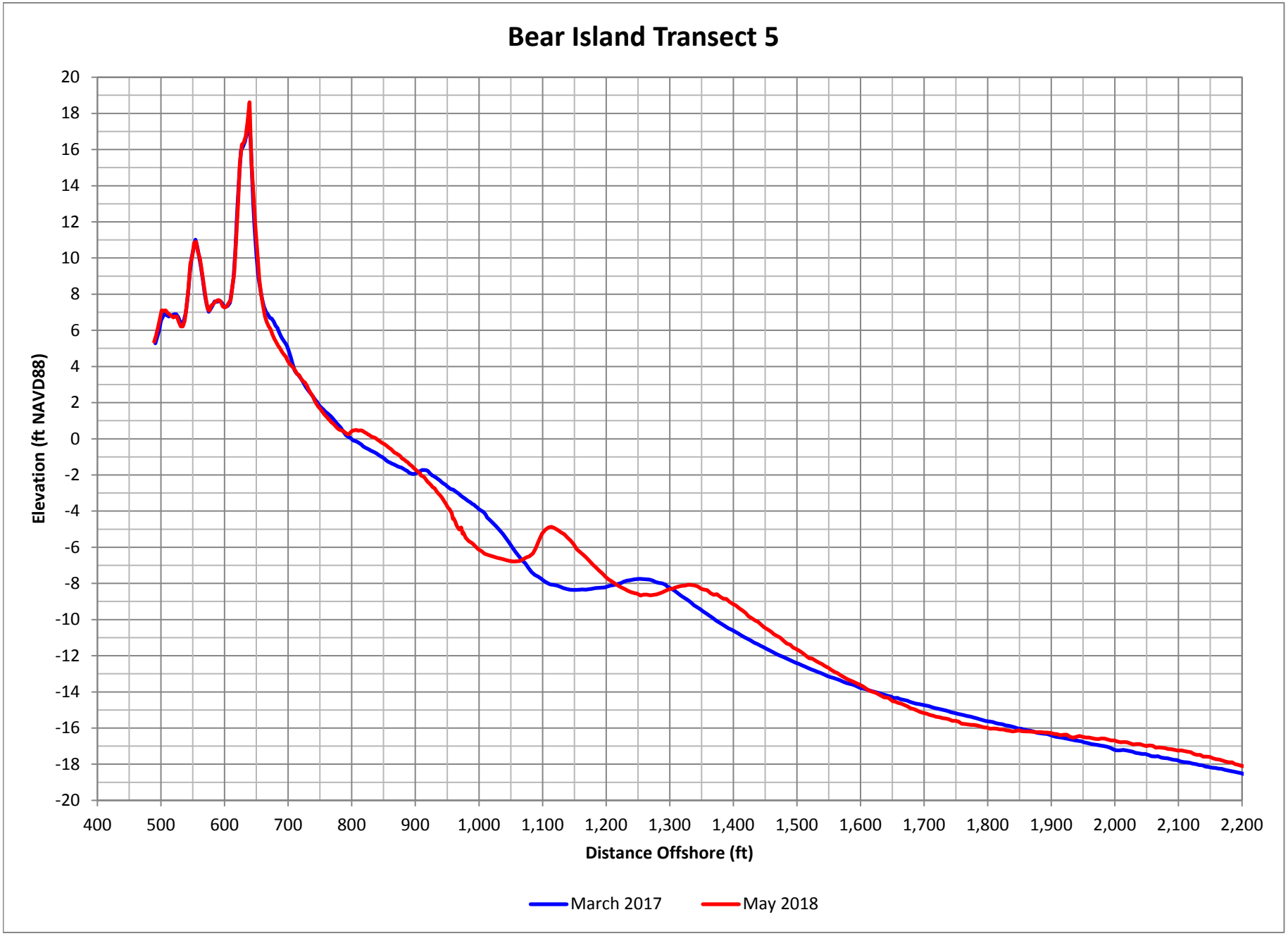


Figure D-254. Bear Island Profile Comparison Plot

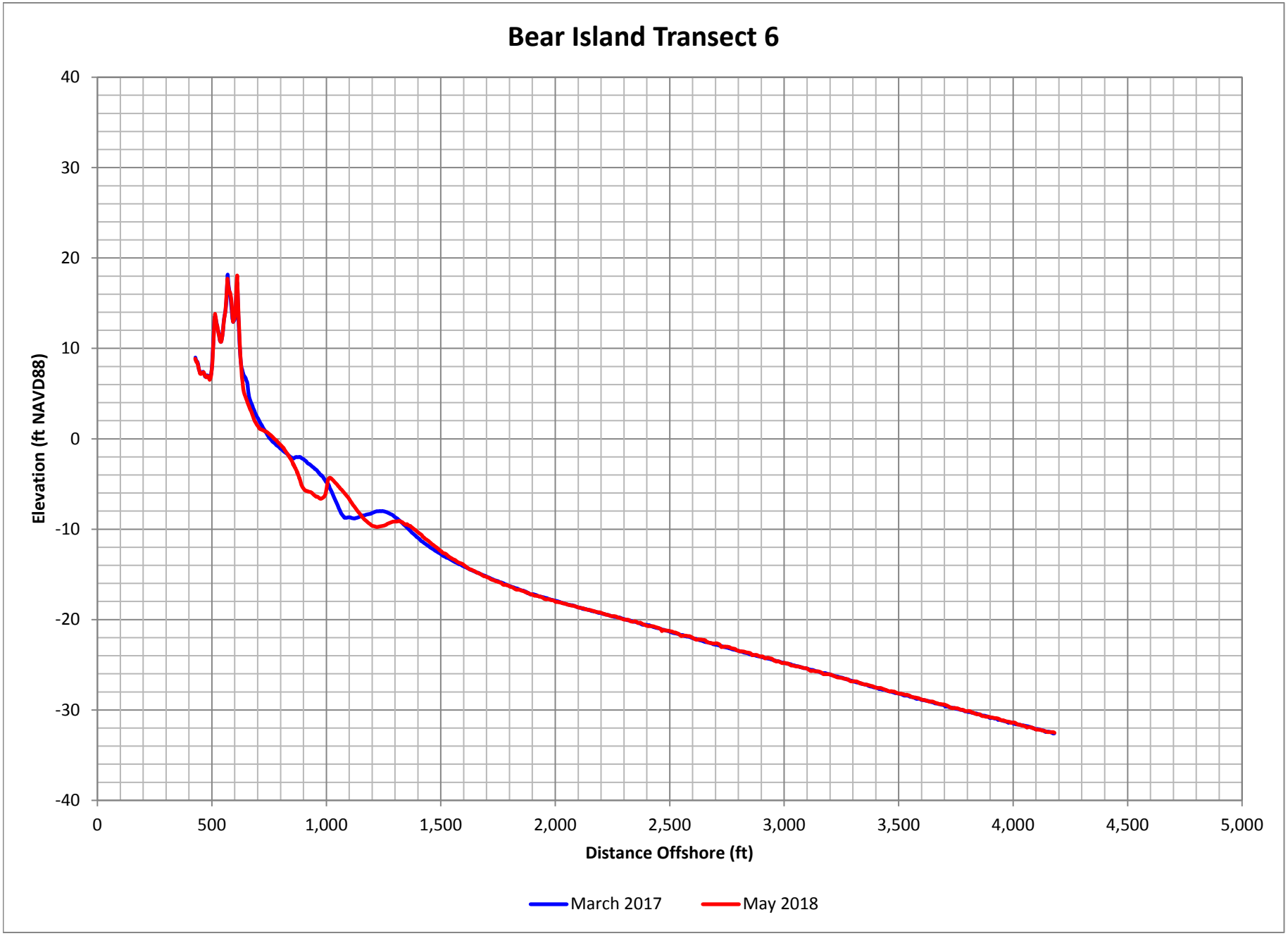


Figure D-255. Bear Island Profile Comparison Plot

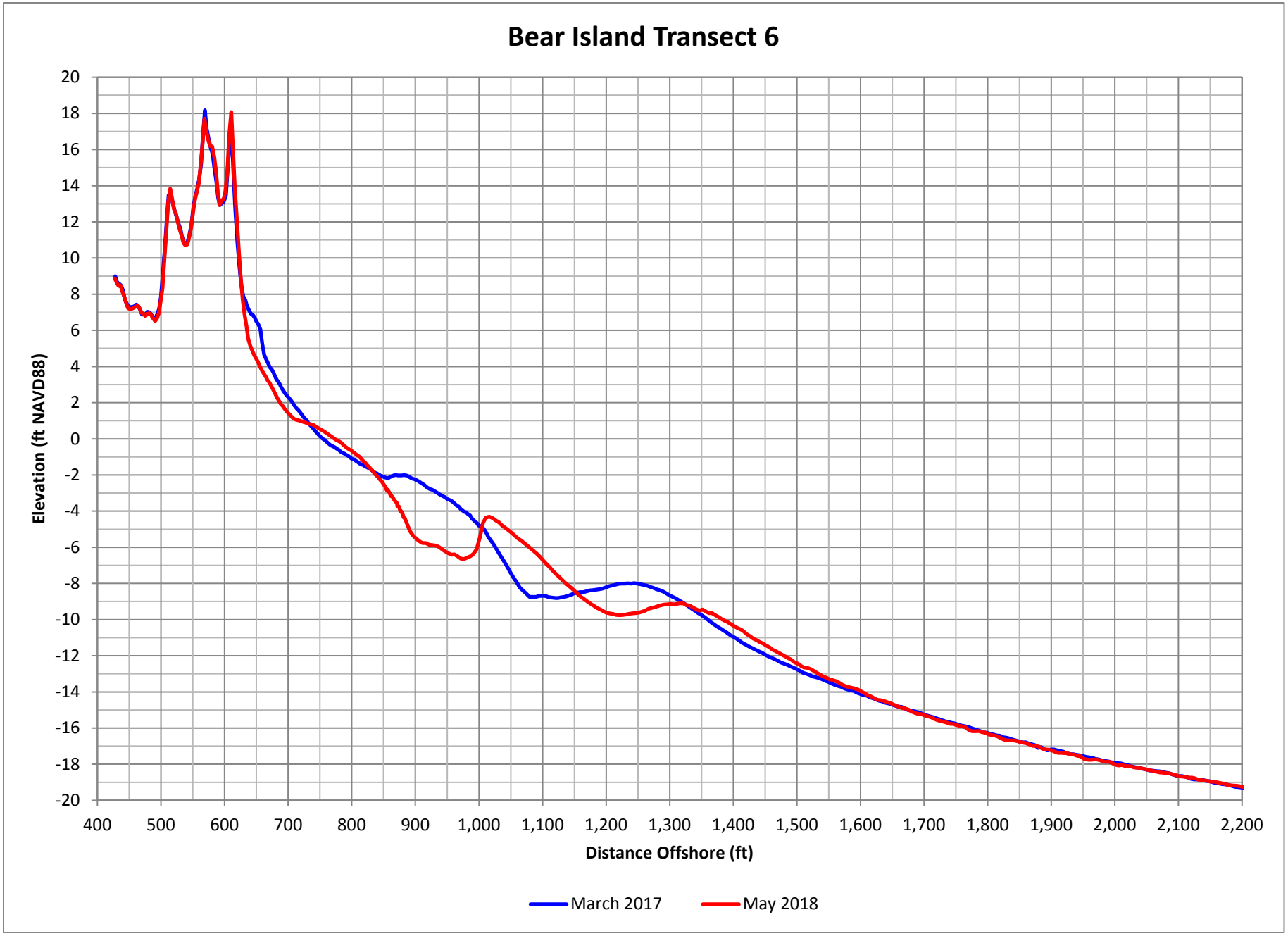


Figure D-256. Bear Island Profile Comparison Plot

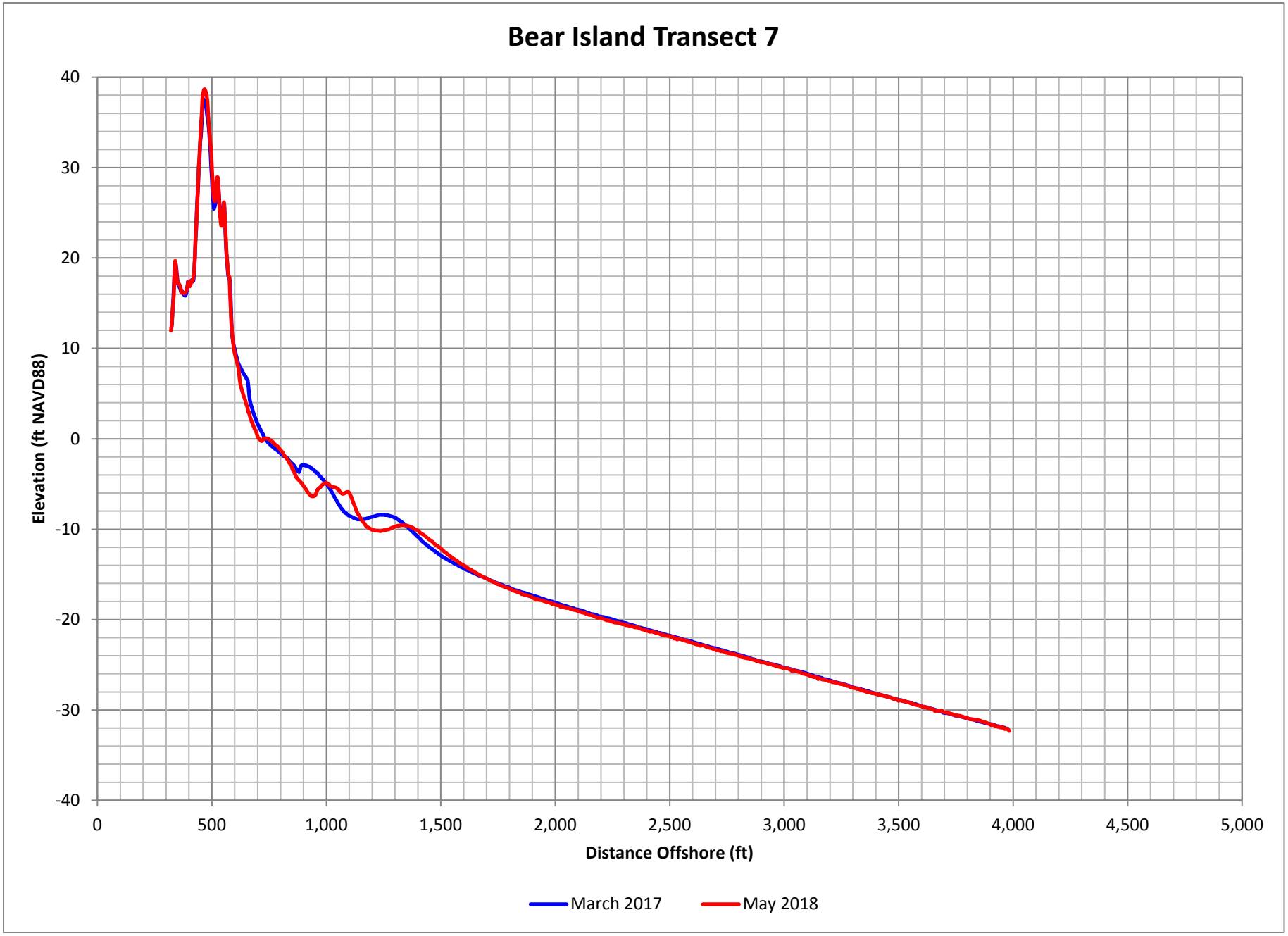


Figure D-257. Bear Island Profile Comparison Plot

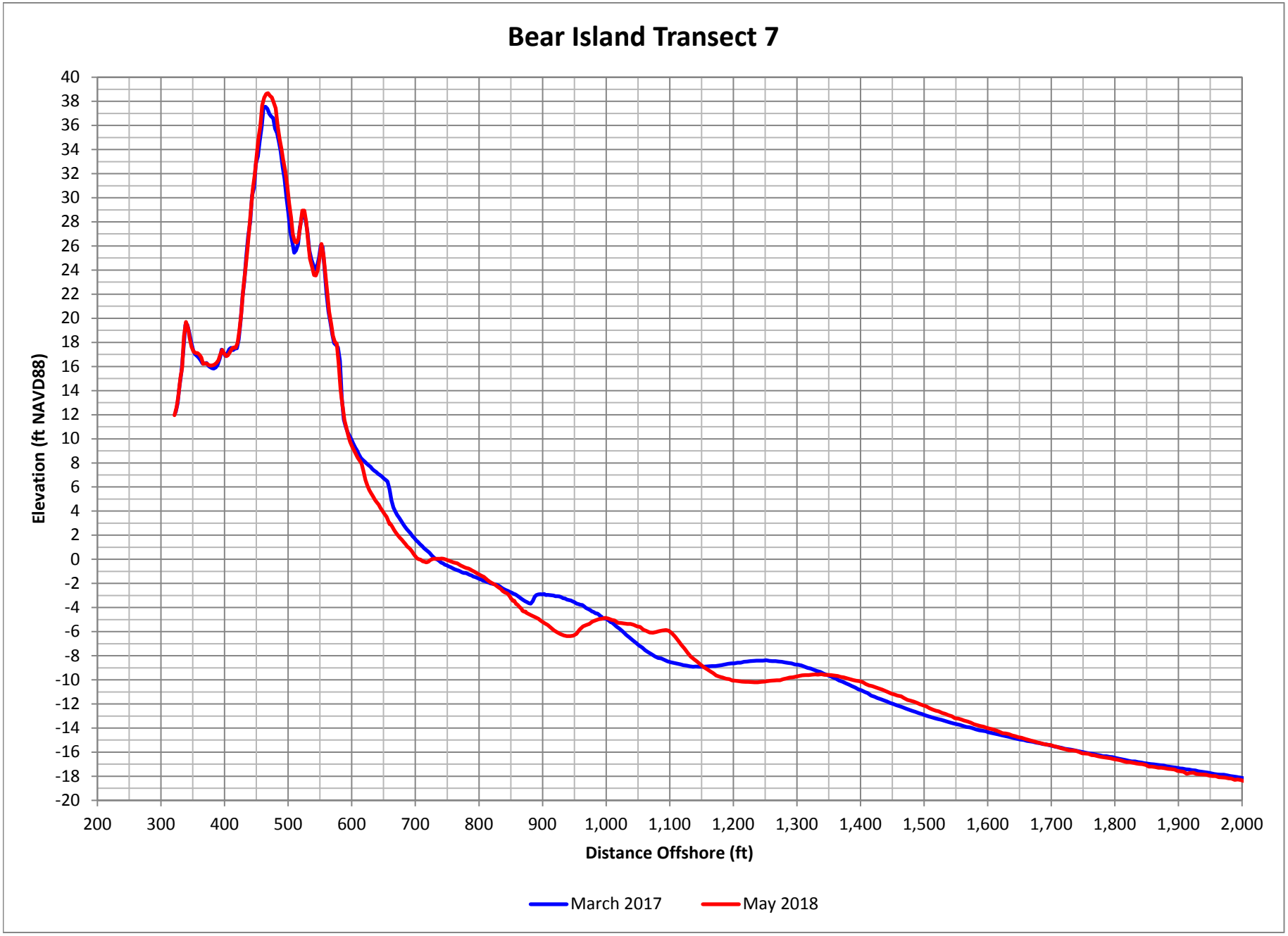


Figure D-258. Bear Island Profile Comparison Plot

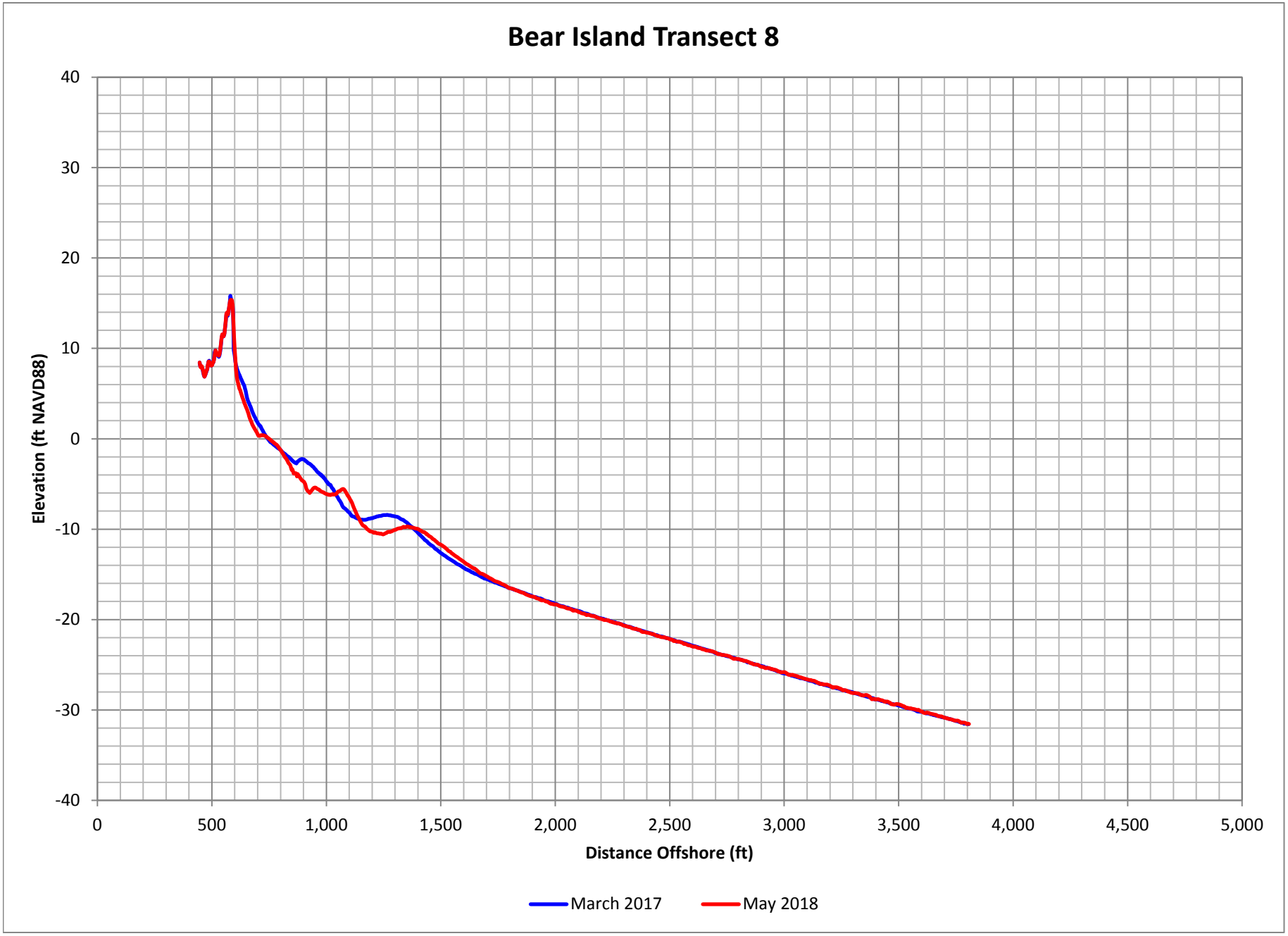


Figure D-259. Bear Island Profile Comparison Plot

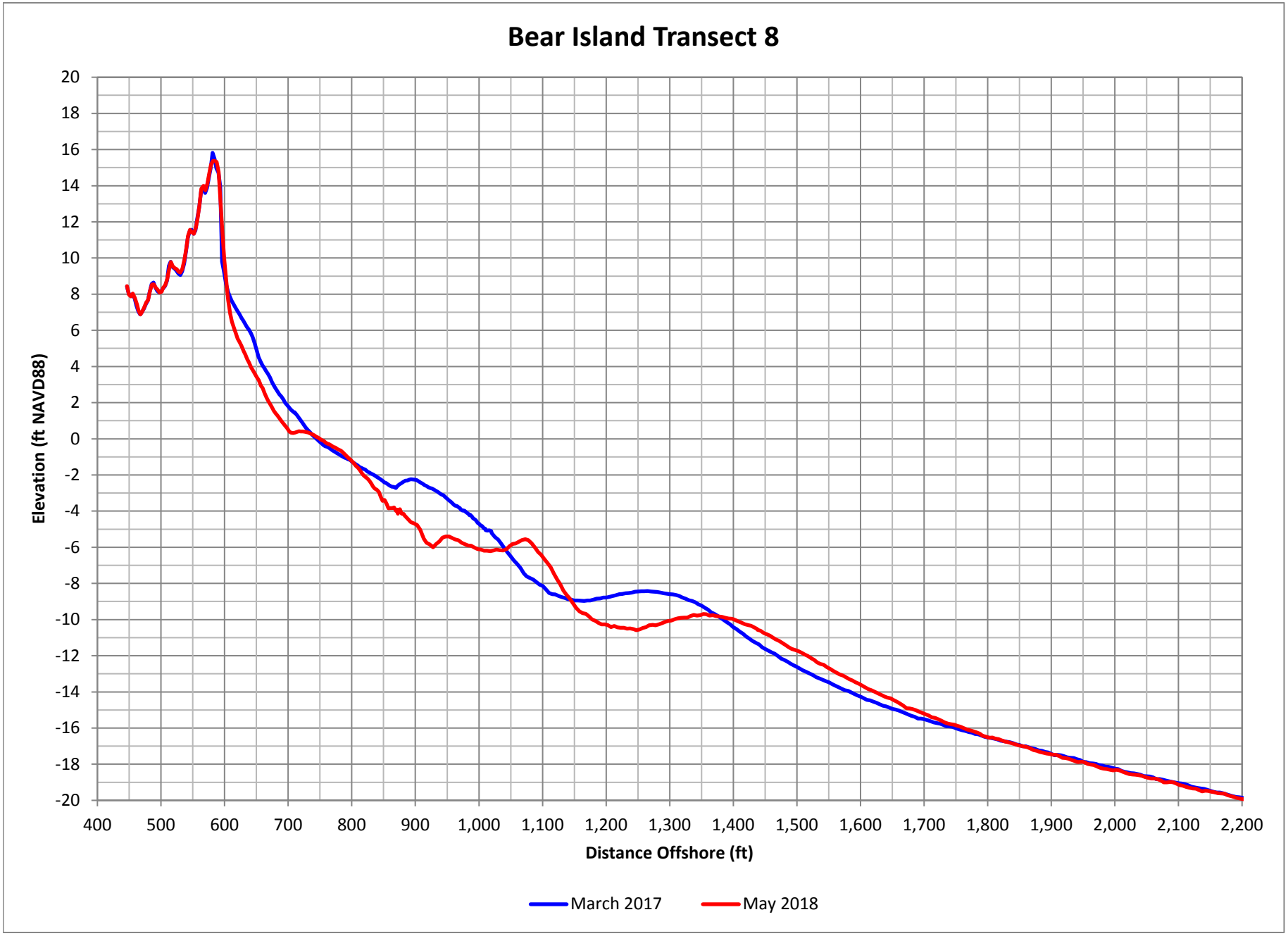


Figure D-260. Bear Island Profile Comparison Plot

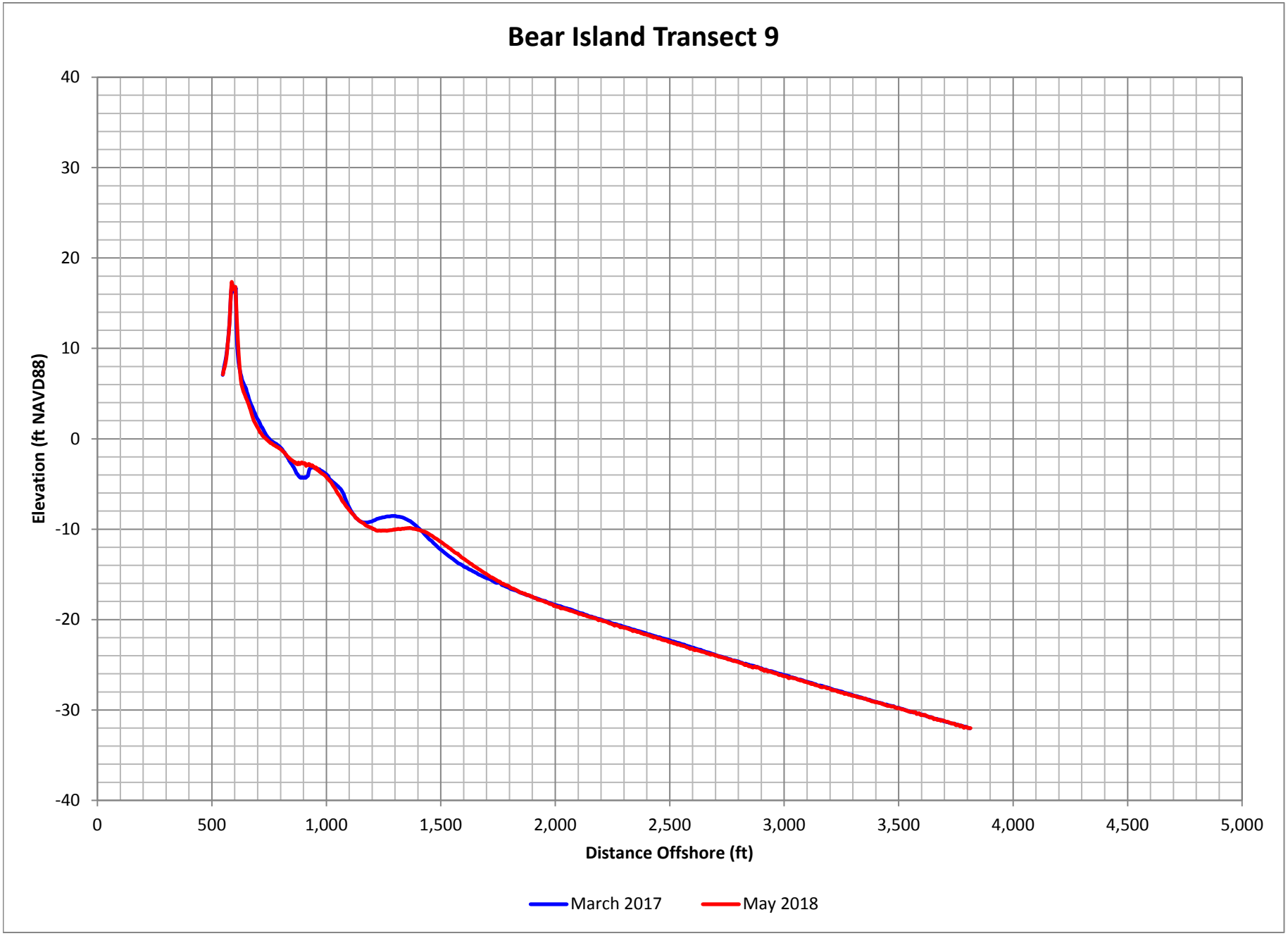


Figure D-261. Bear Island Profile Comparison Plot

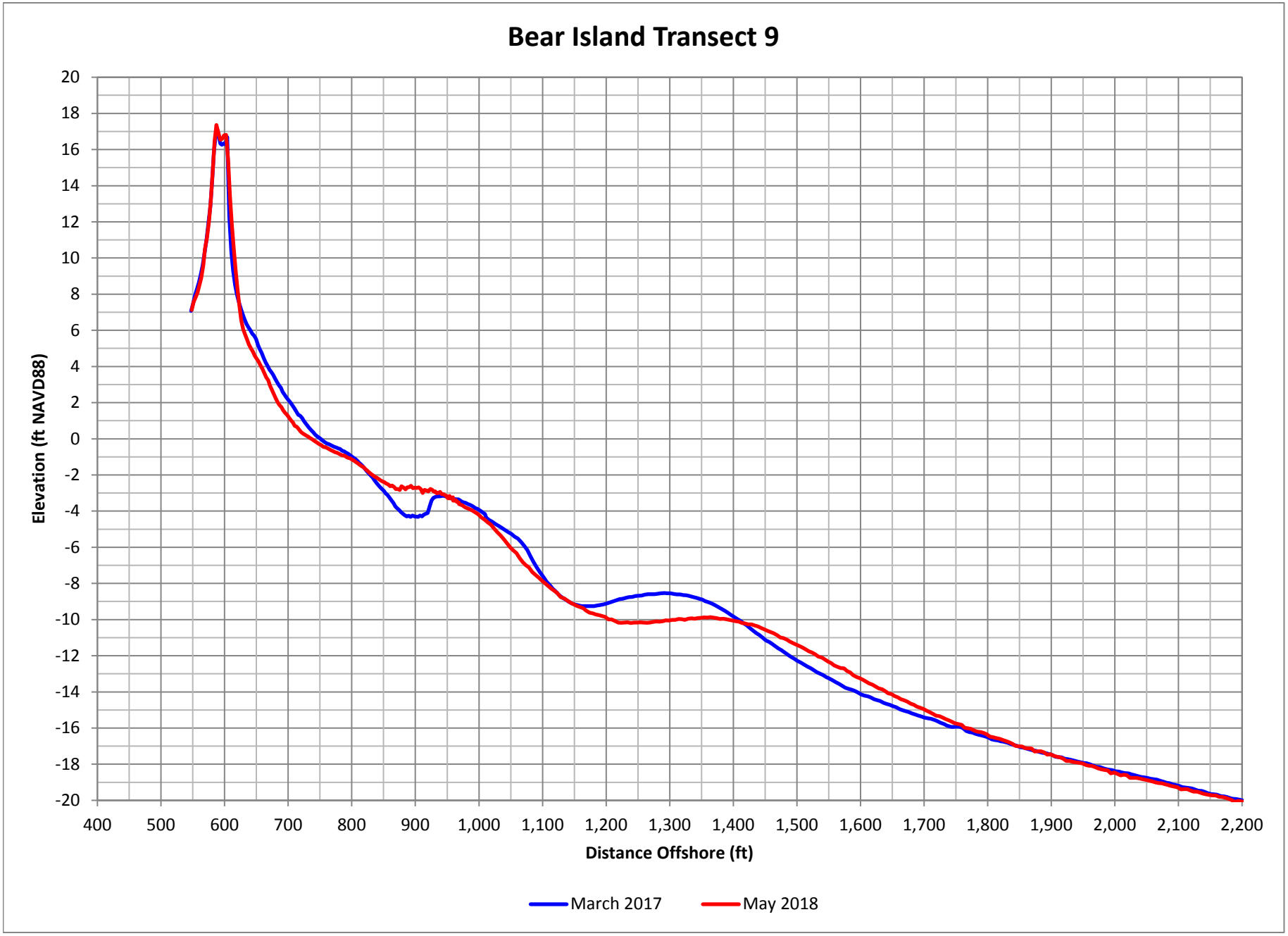


Figure D-262. Bear Island Profile Comparison Plot

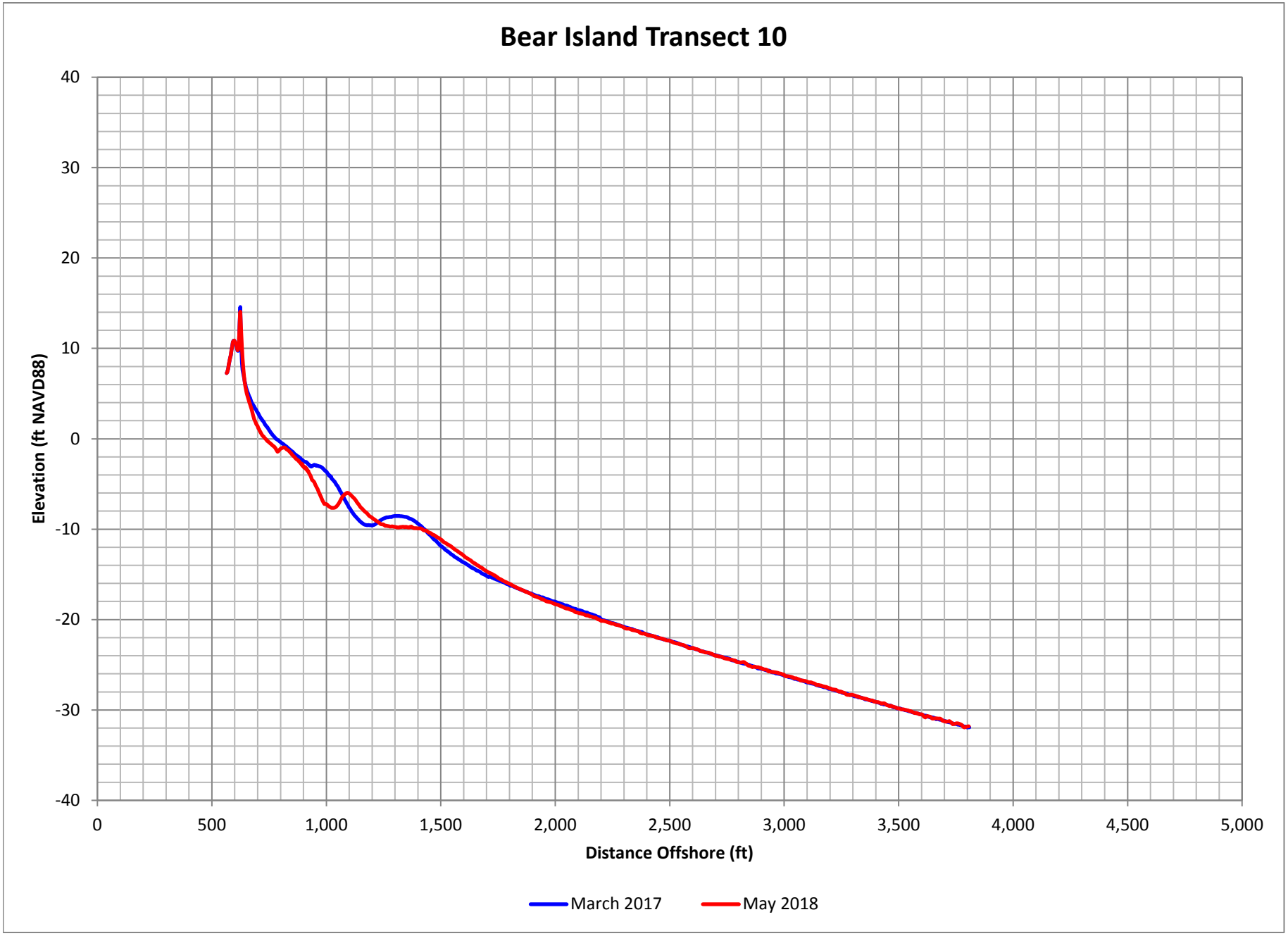


Figure D-263. Bear Island Profile Comparison Plot

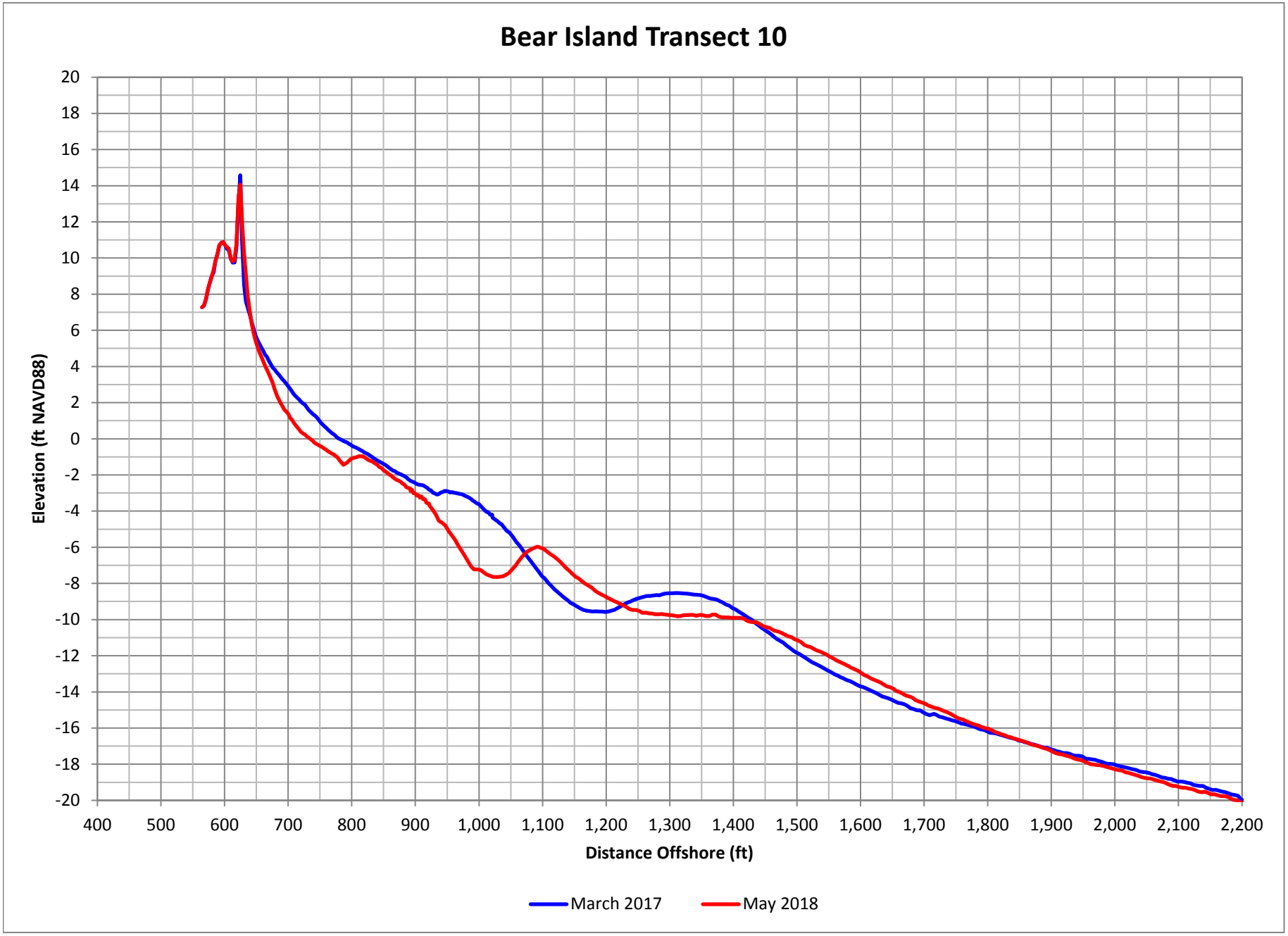


Figure D-264. Bear Island Profile Comparison Plot

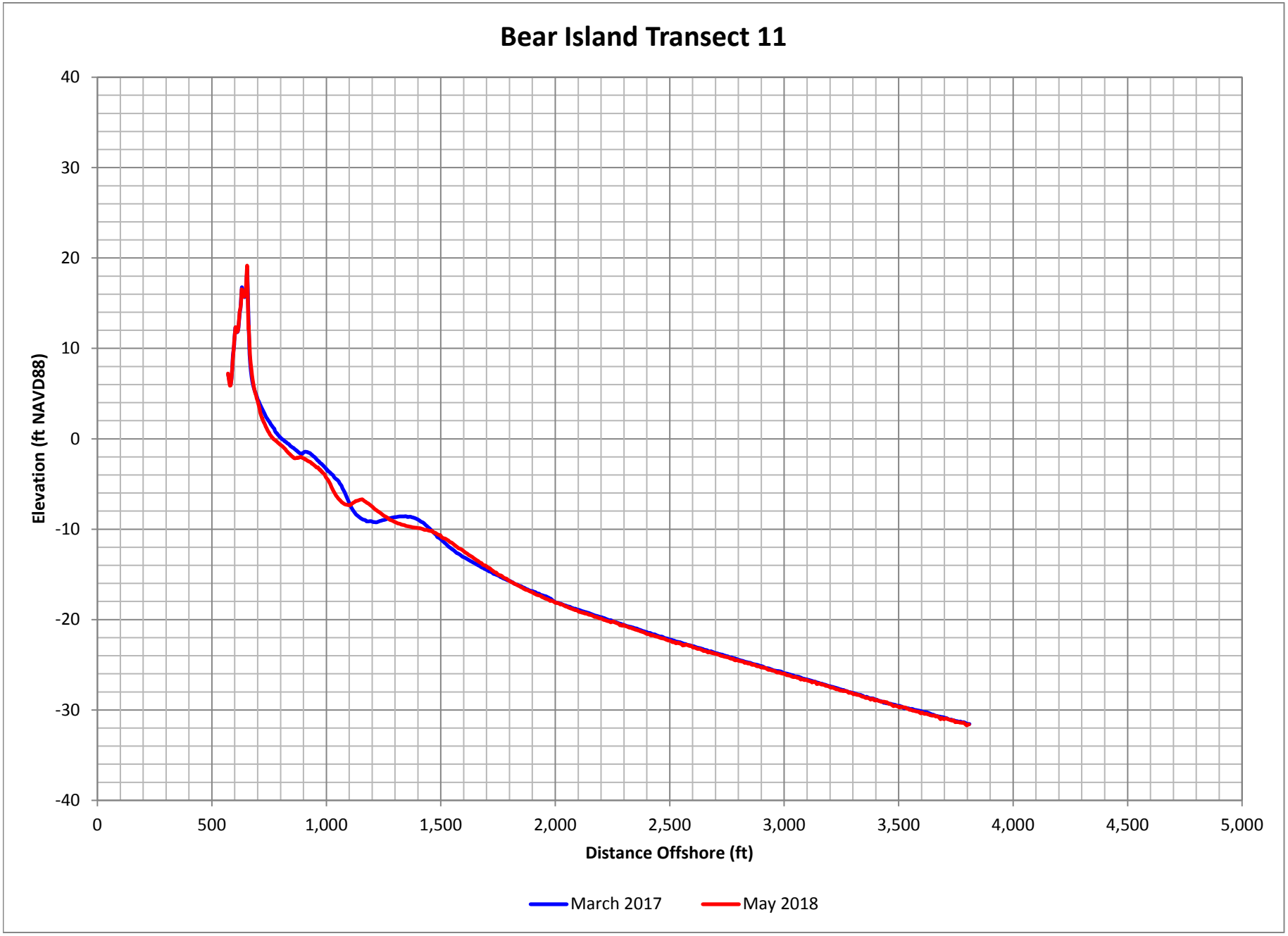


Figure D-265. Bear Island Profile Comparison Plot

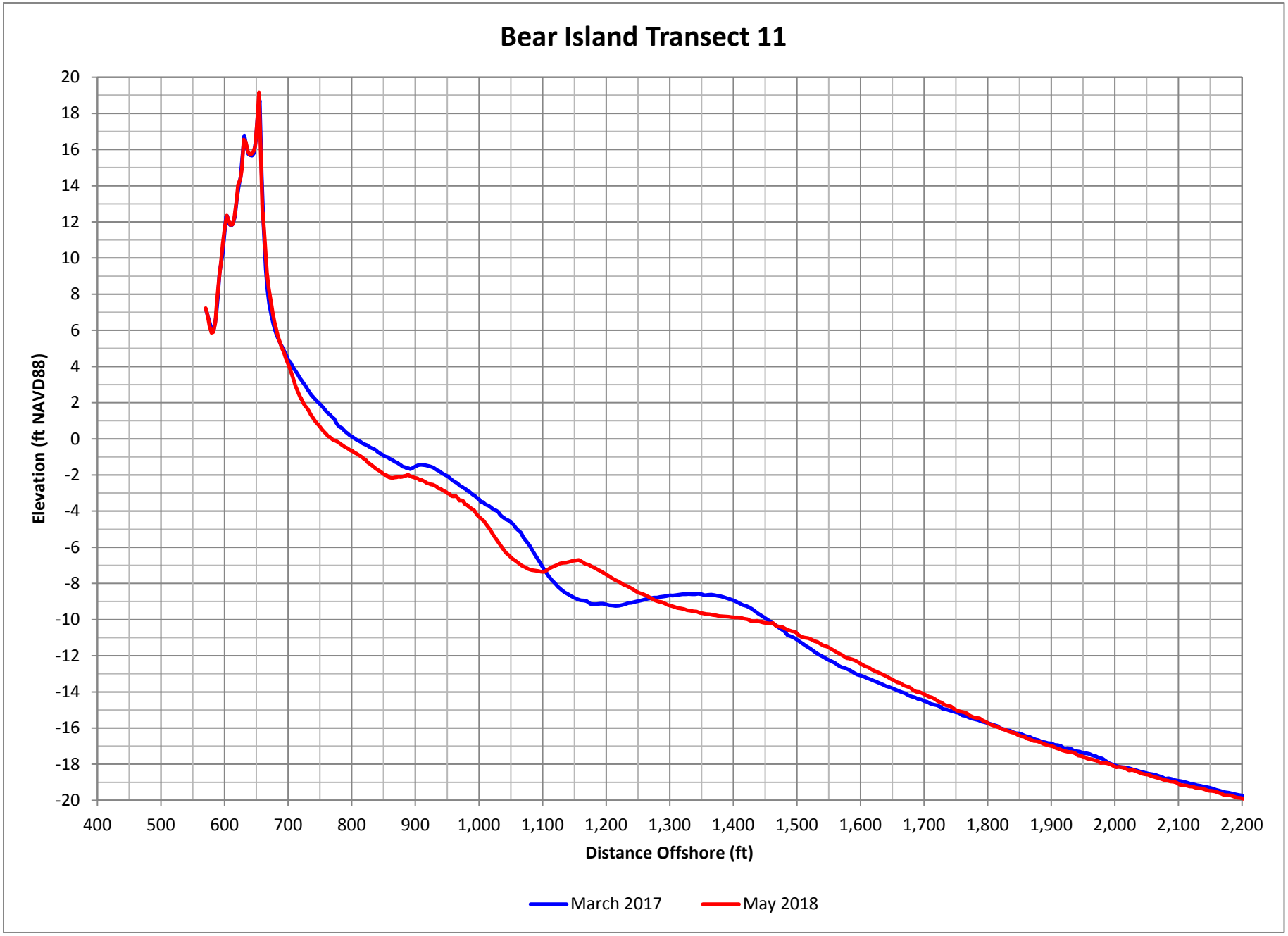


Figure D-266. Bear Island Profile Comparison Plot

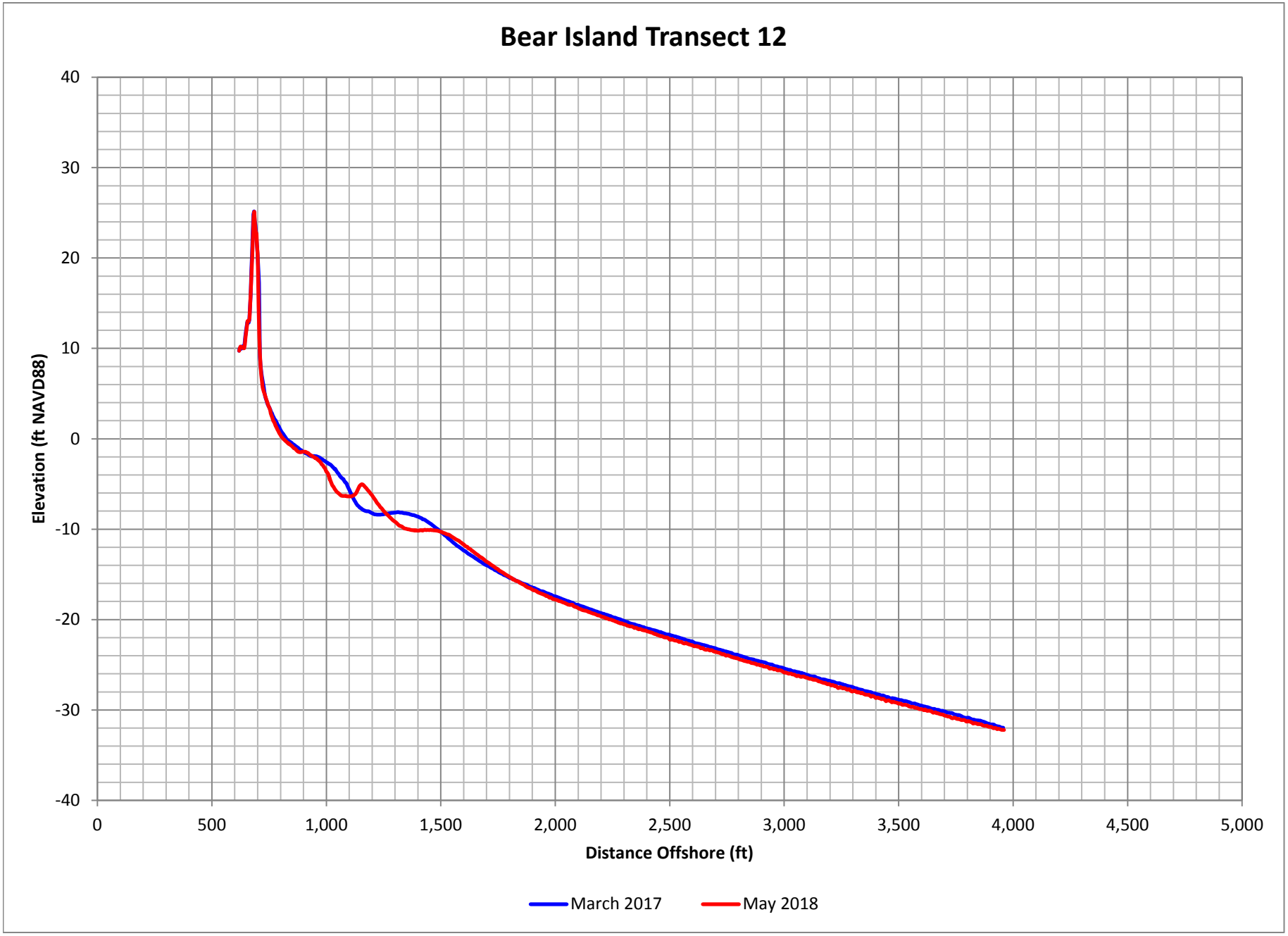


Figure D-267. Bear Island Profile Comparison Plot

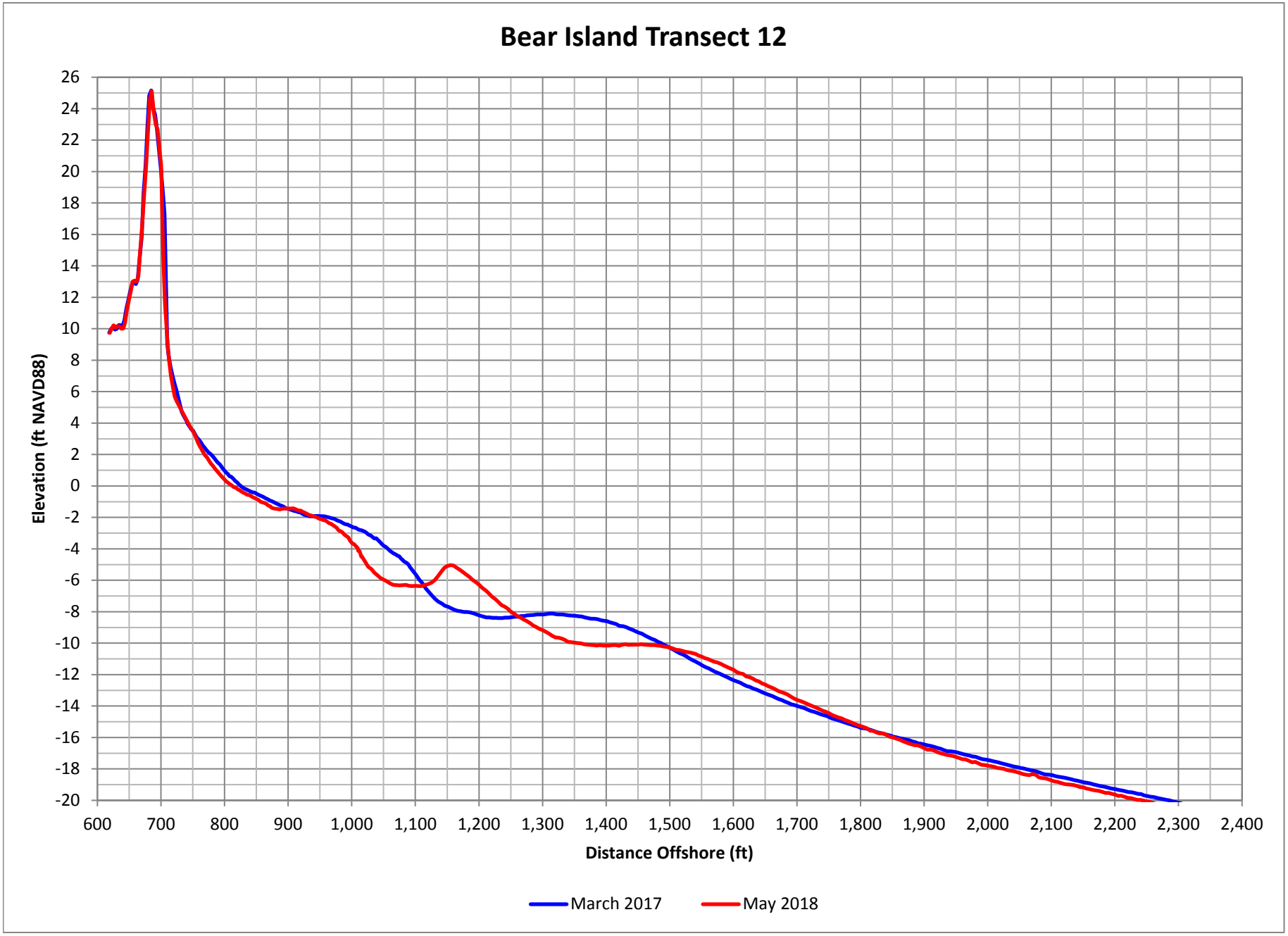


Figure D-268. Bear Island Profile Comparison Plot

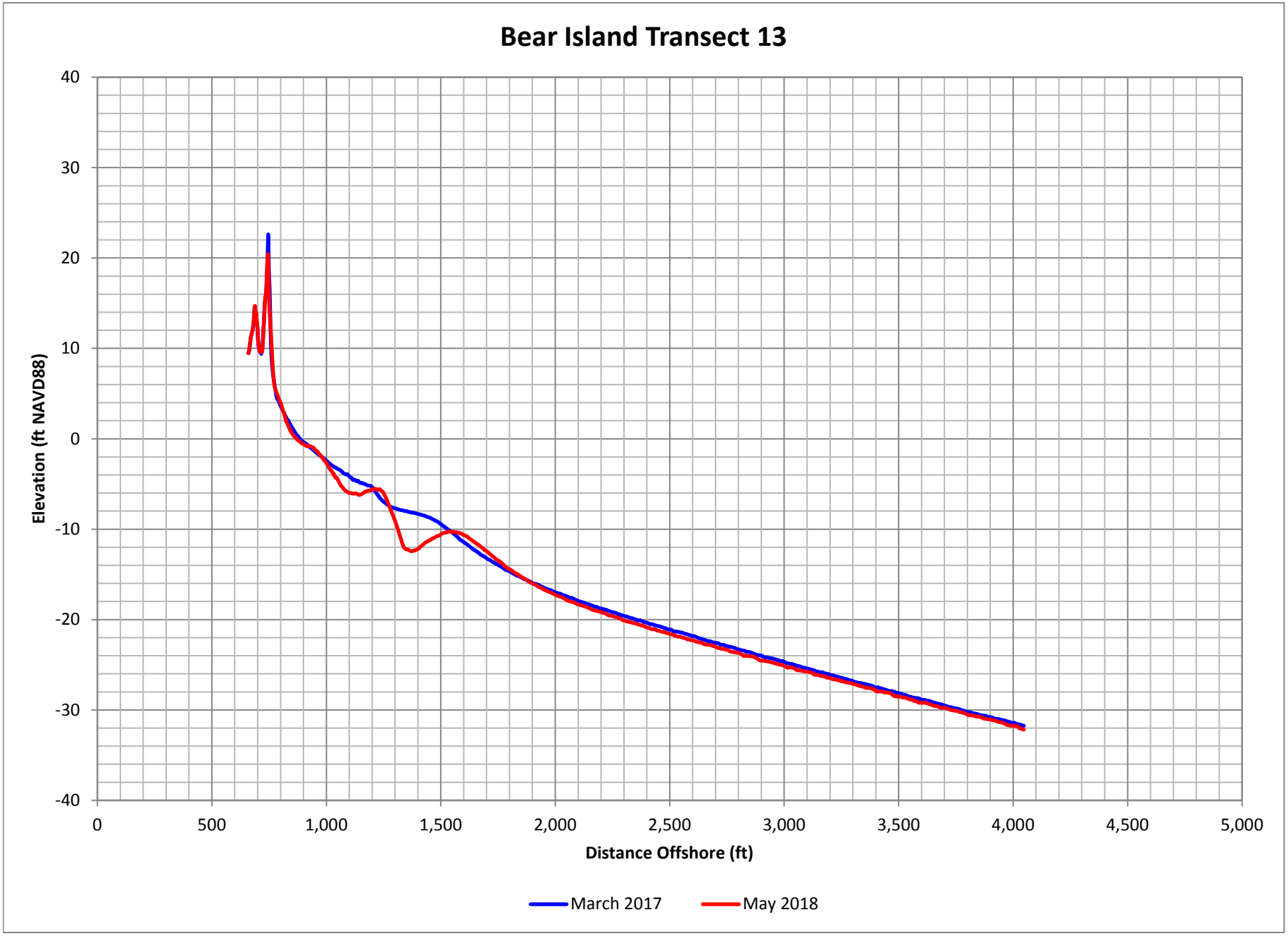


Figure D-269. Bear Island Profile Comparison Plot

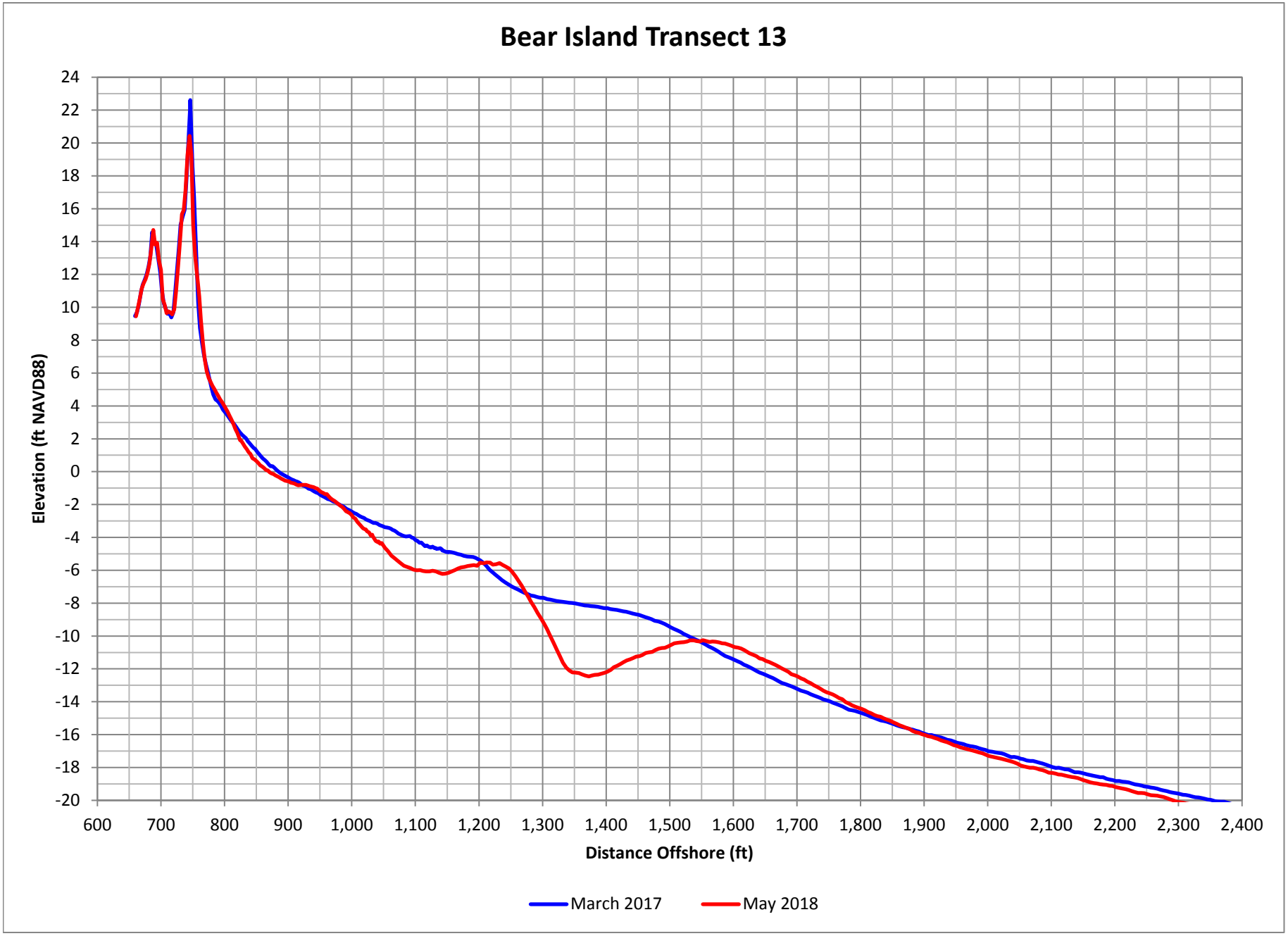


Figure D-270. Bear Island Profile Comparison Plot

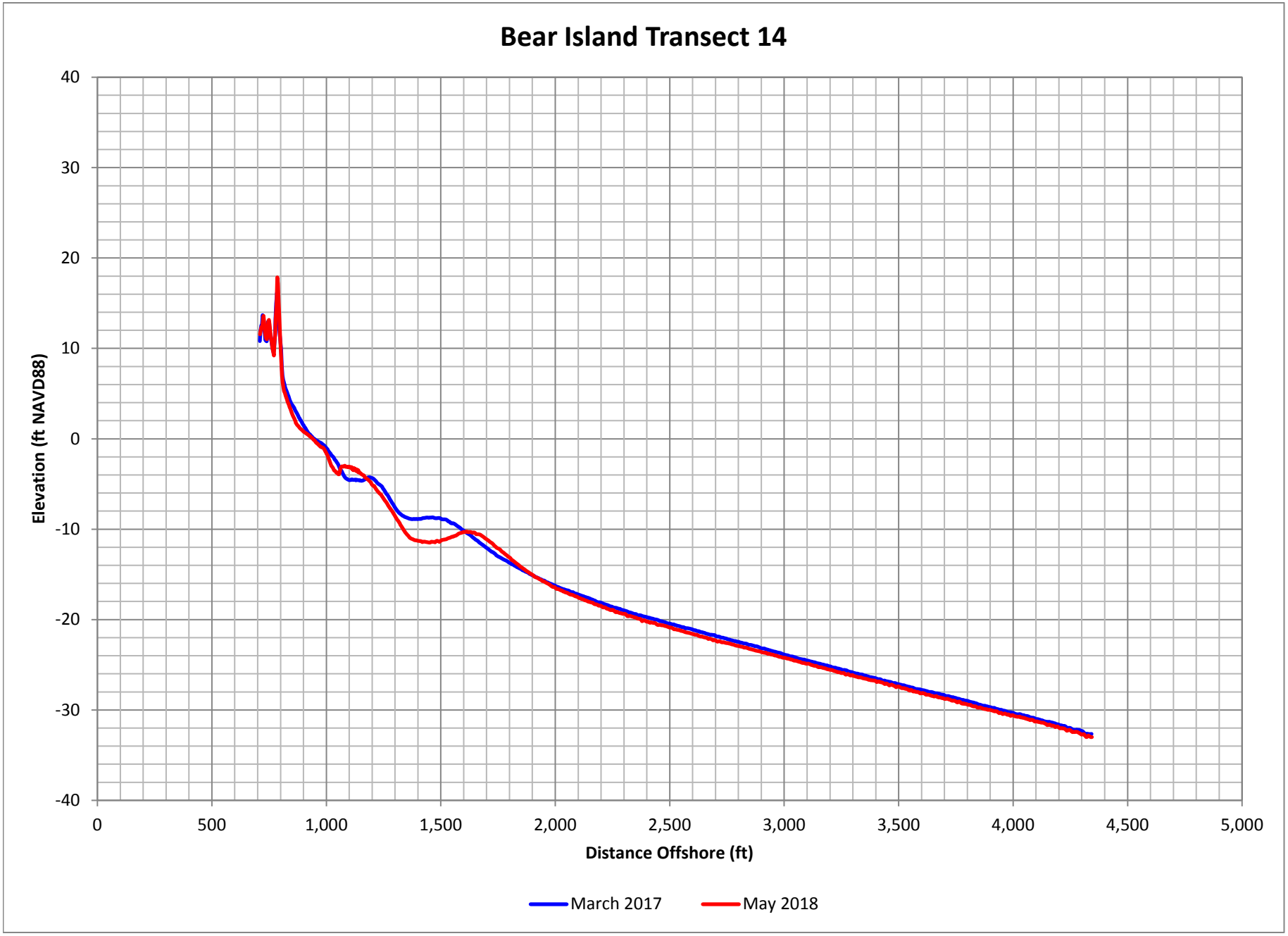


Figure D-271. Bear Island Profile Comparison Plot

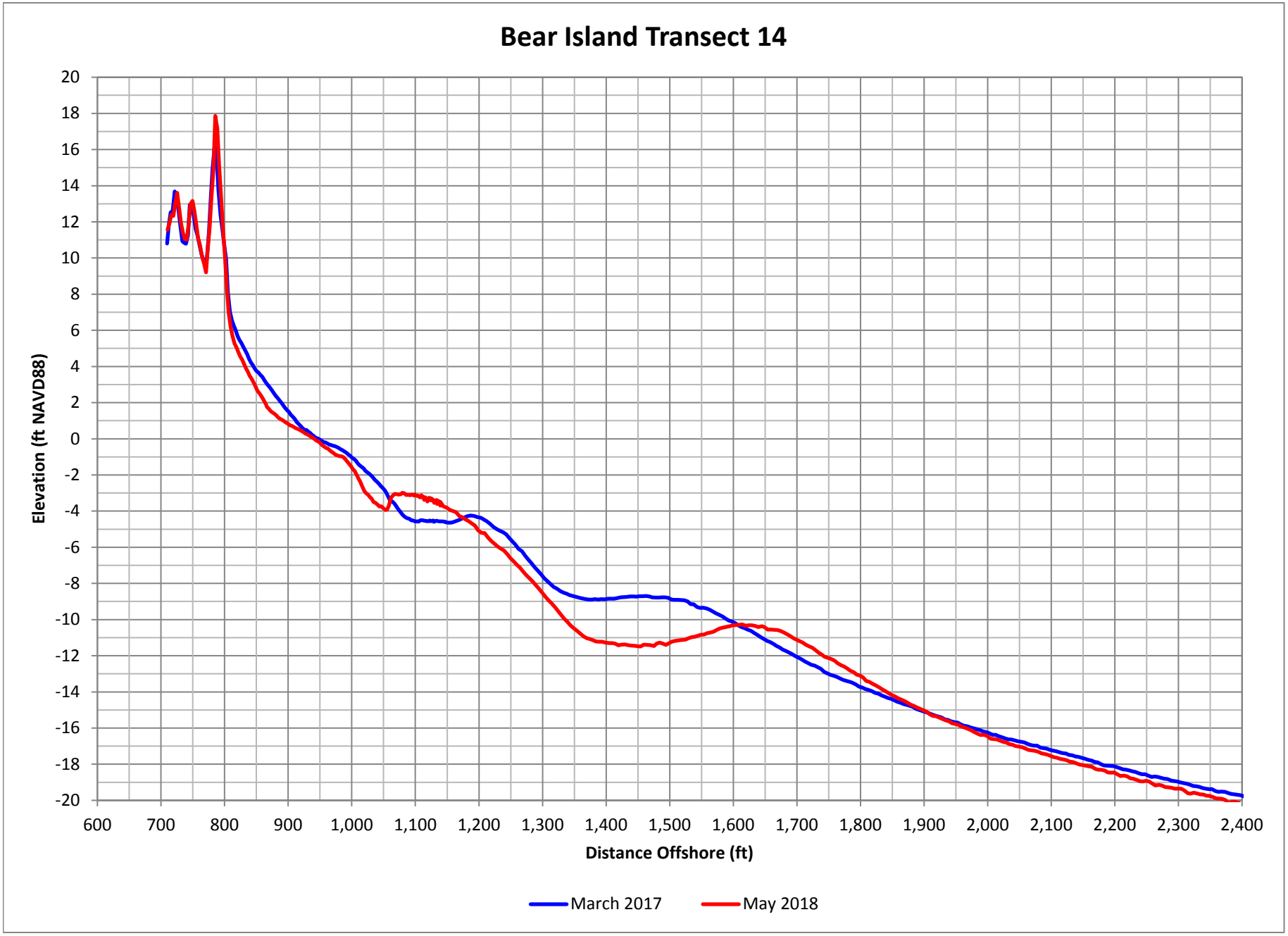


Figure D-272. Bear Island Profile Comparison Plot

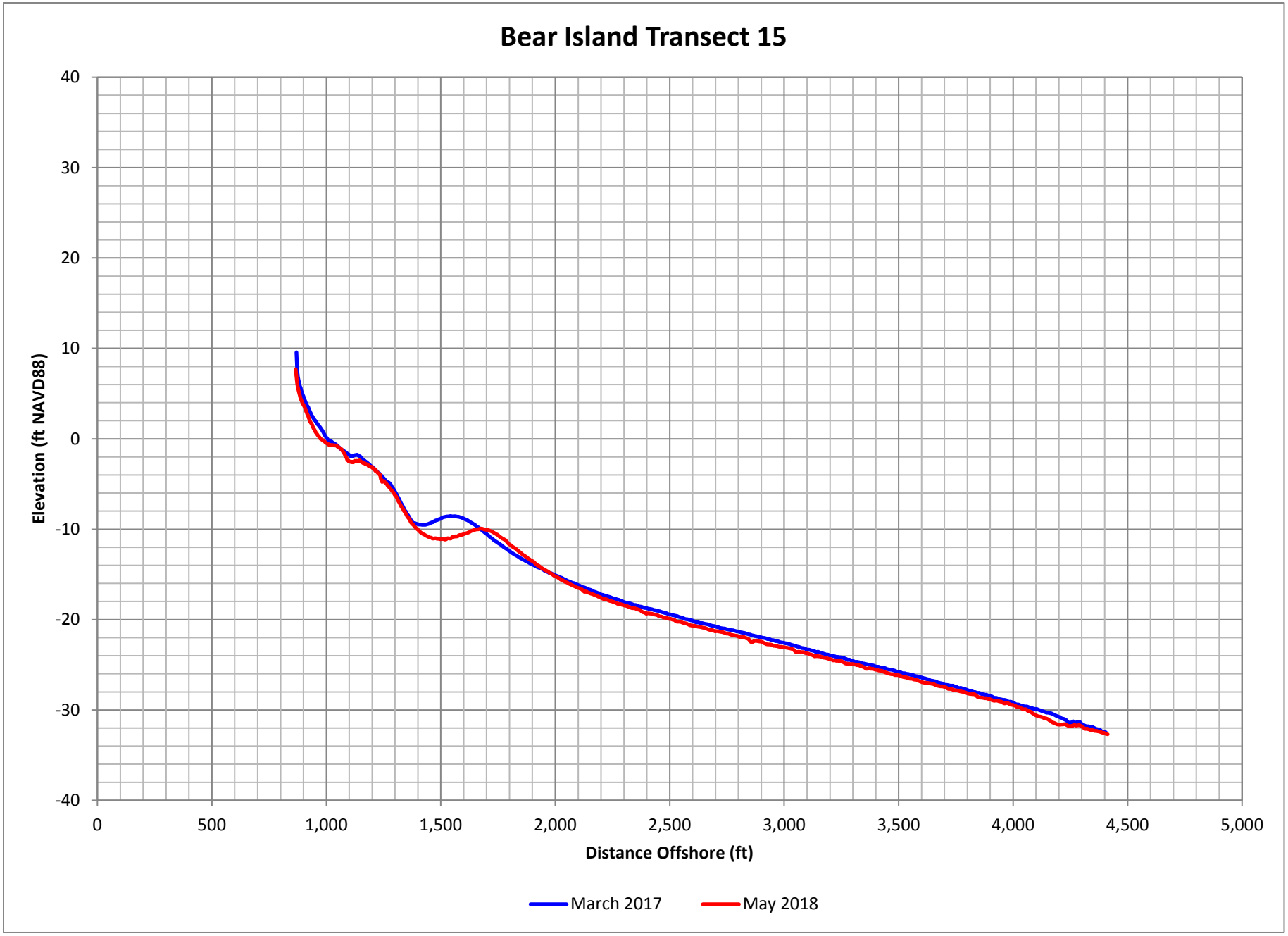


Figure D-273. Bear Island Profile Comparison Plot

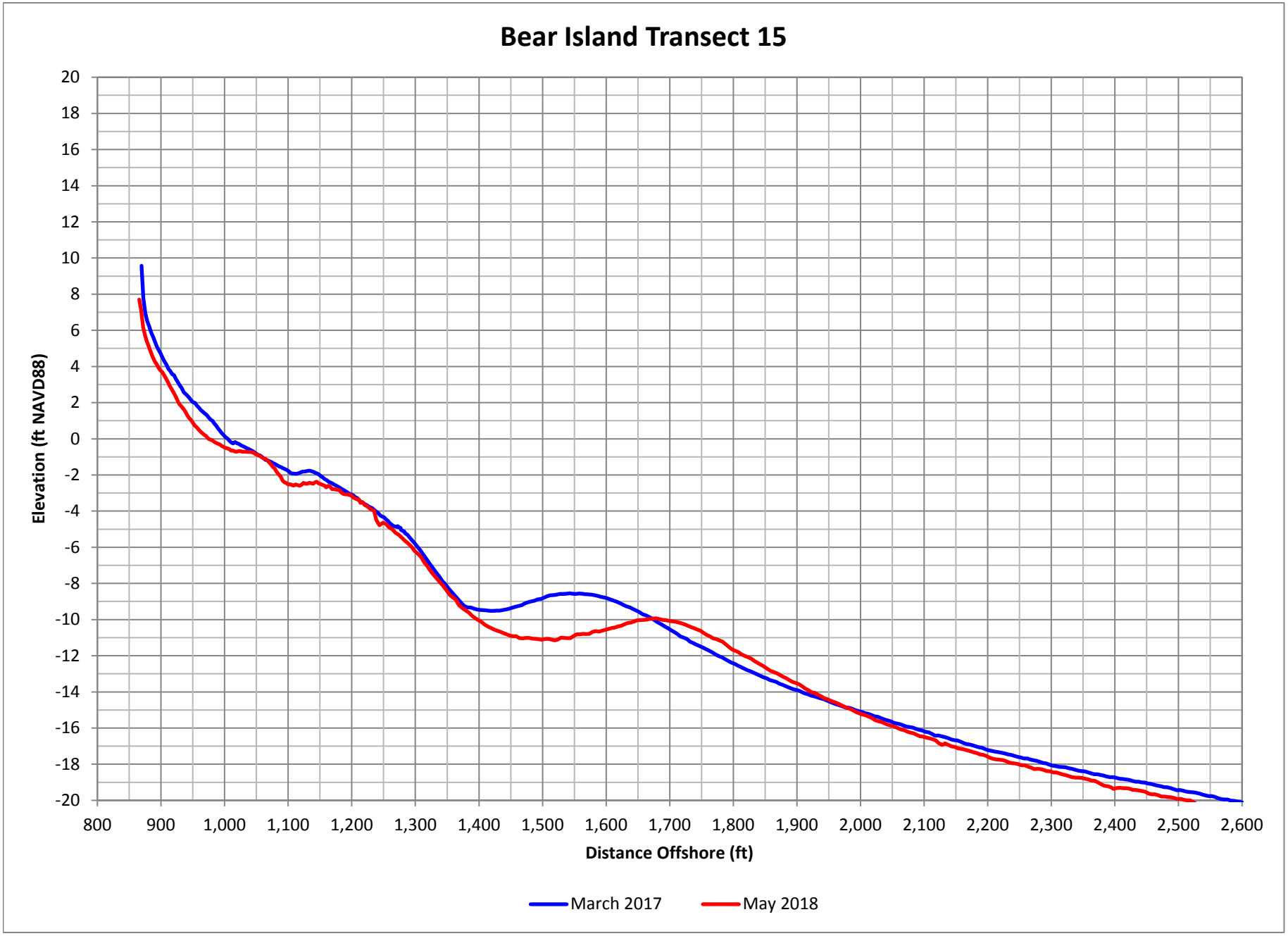


Figure D-274. Bear Island Profile Comparison Plot

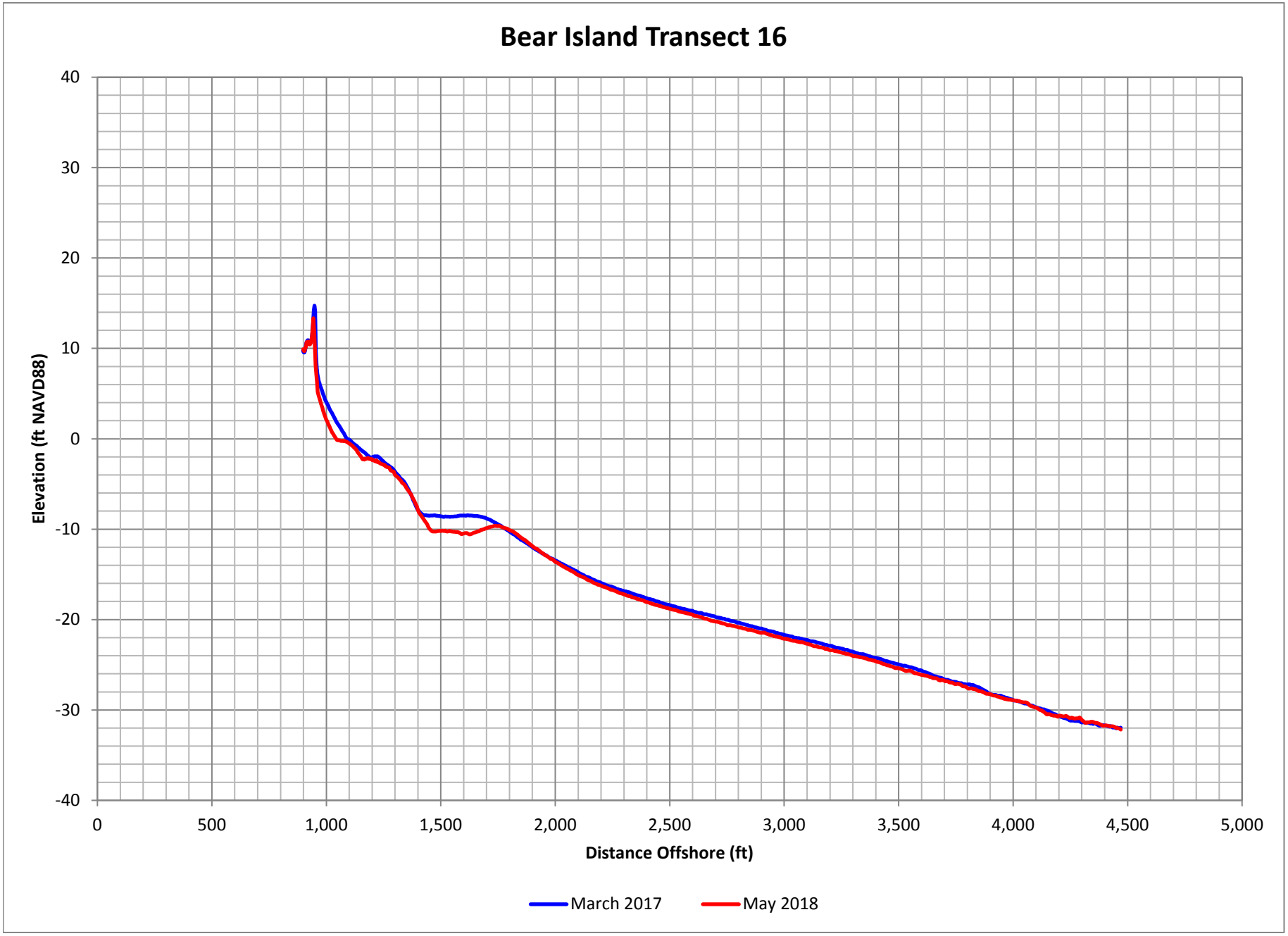


Figure D-275. Bear Island Profile Comparison Plot

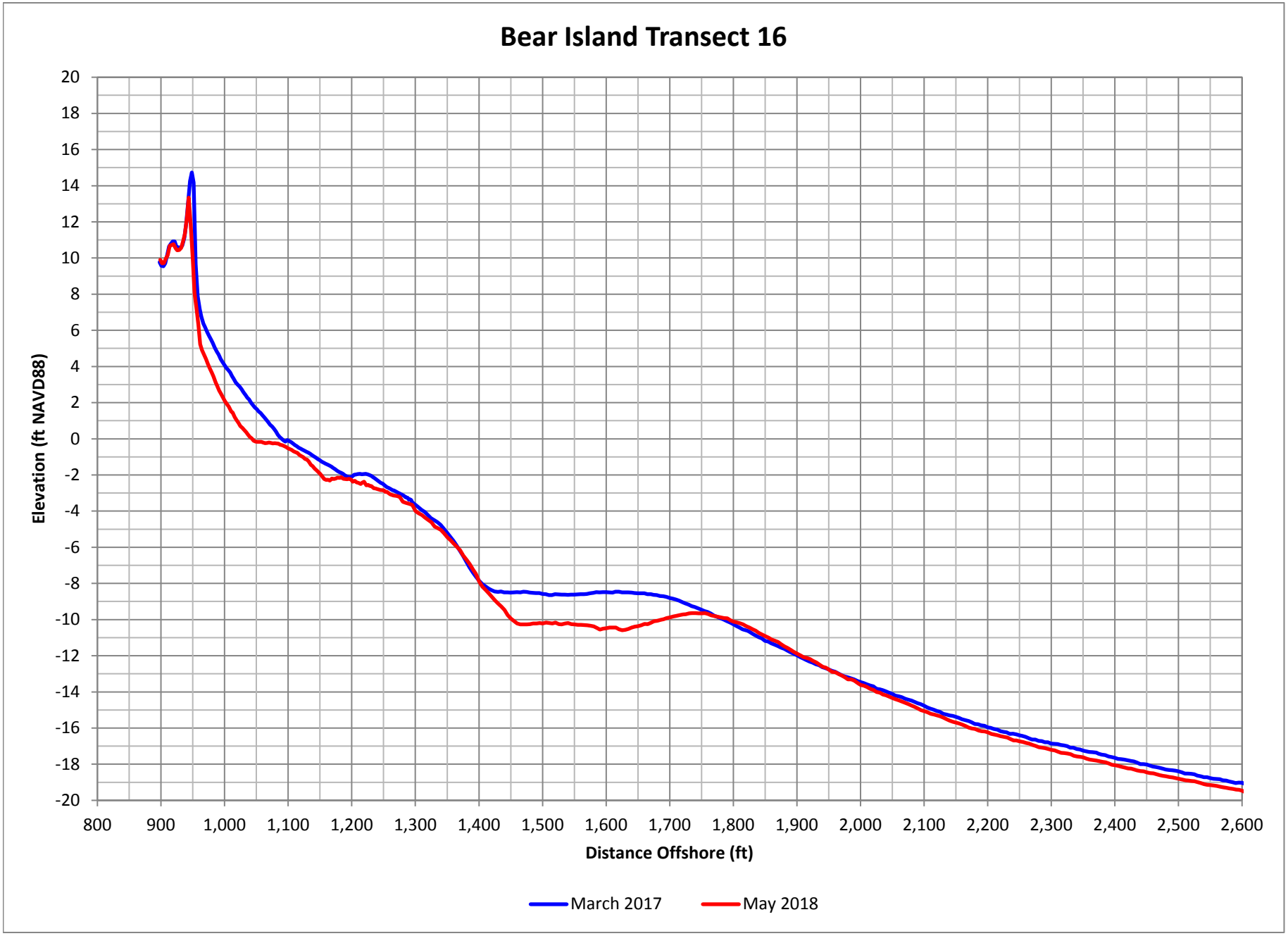


Figure D-276. Bear Island Profile Comparison Plot

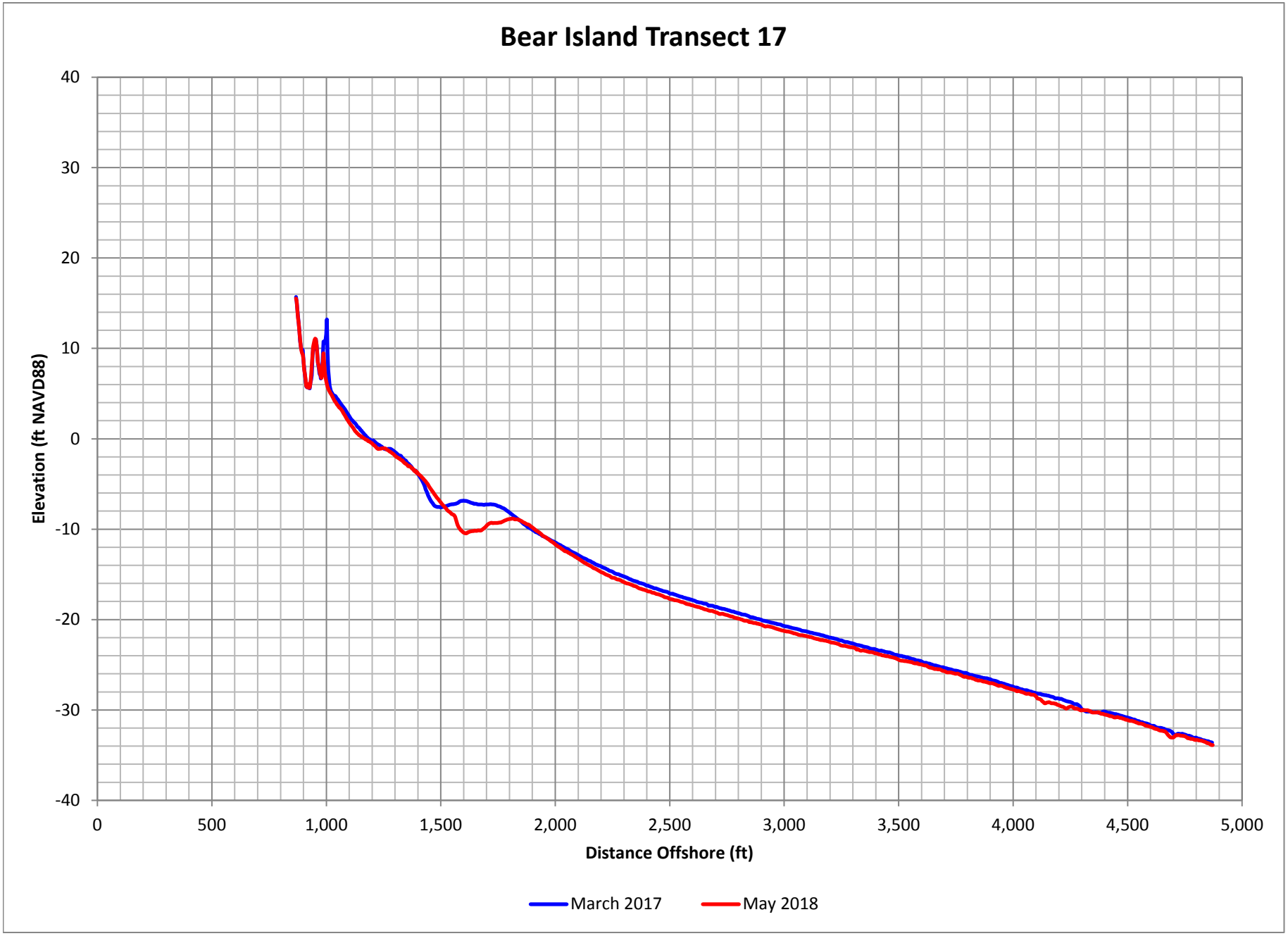


Figure D-277. Bear Island Profile Comparison Plot

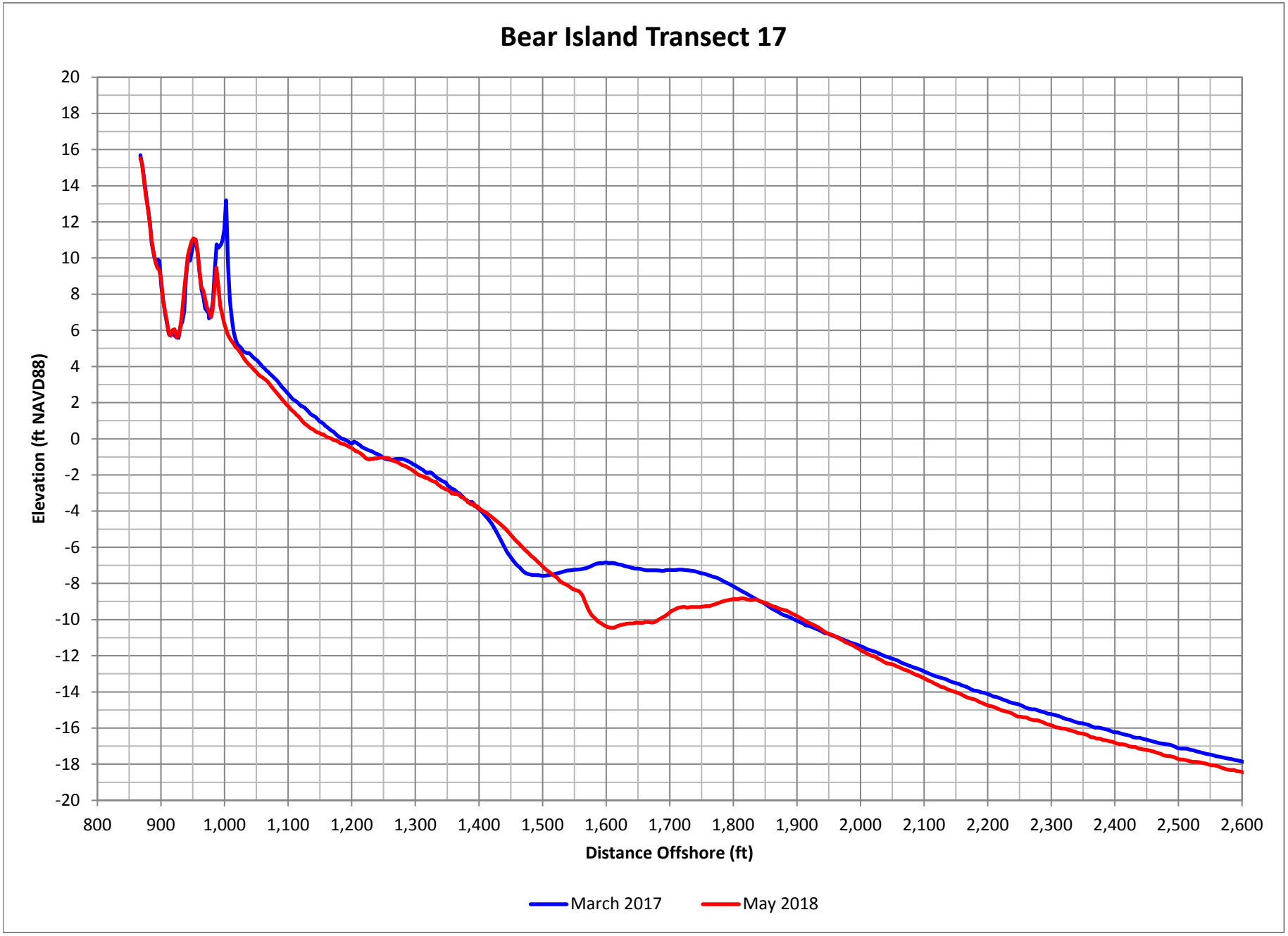


Figure D-278. Bear Island Profile Comparison Plot

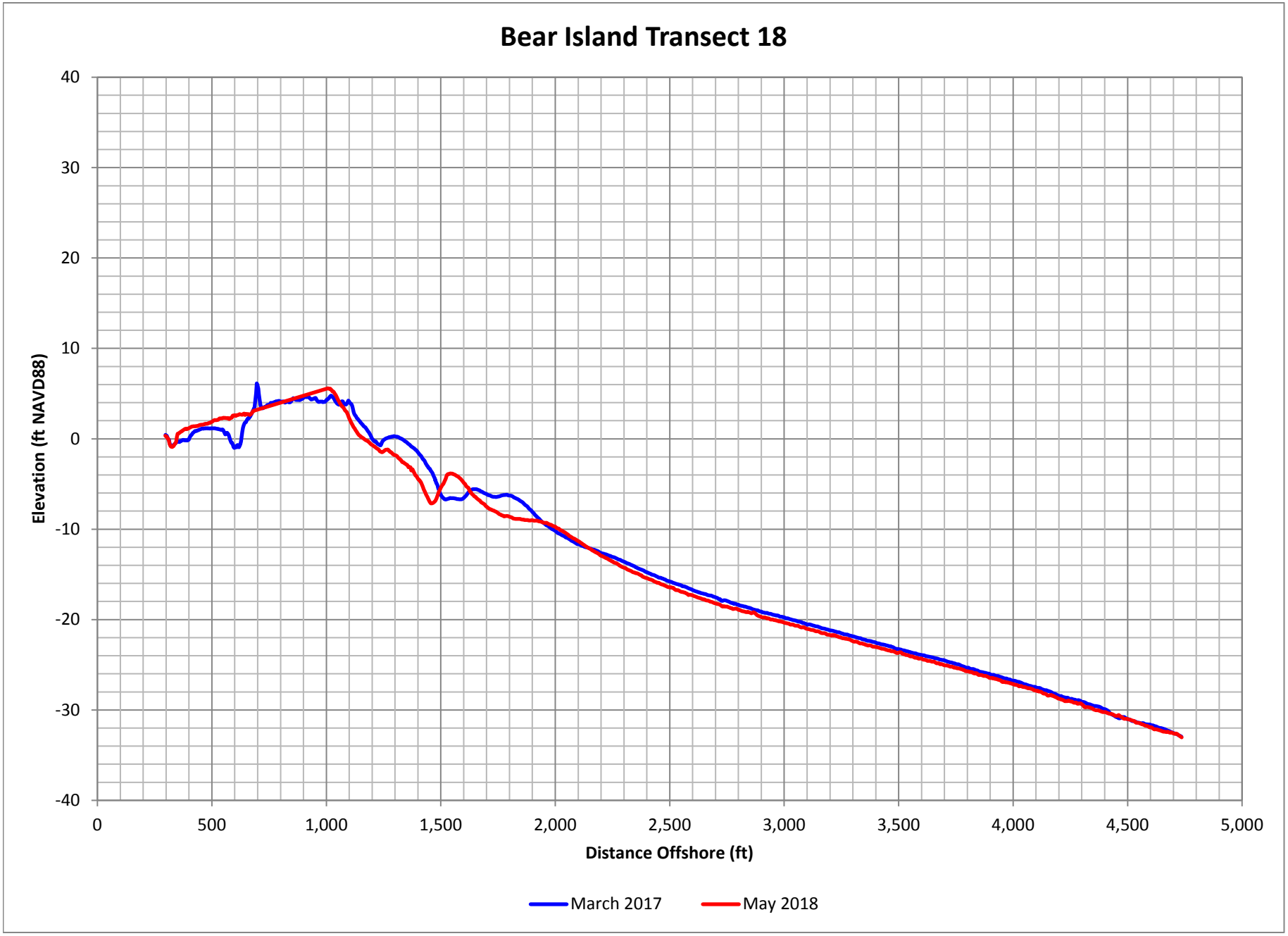


Figure D-279. Bear Island Profile Comparison Plot

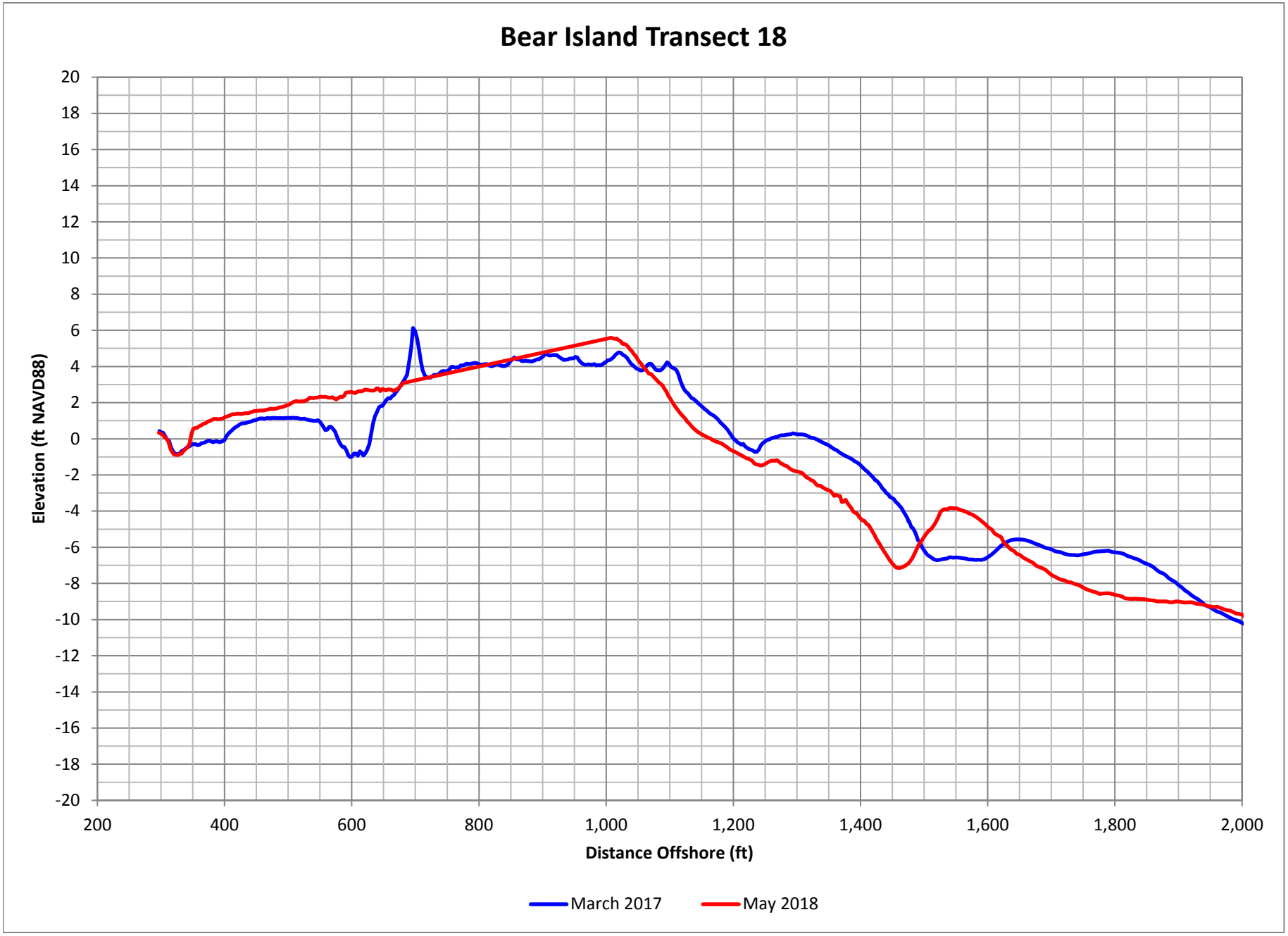


Figure D-280. Bear Island Profile Comparison Plot

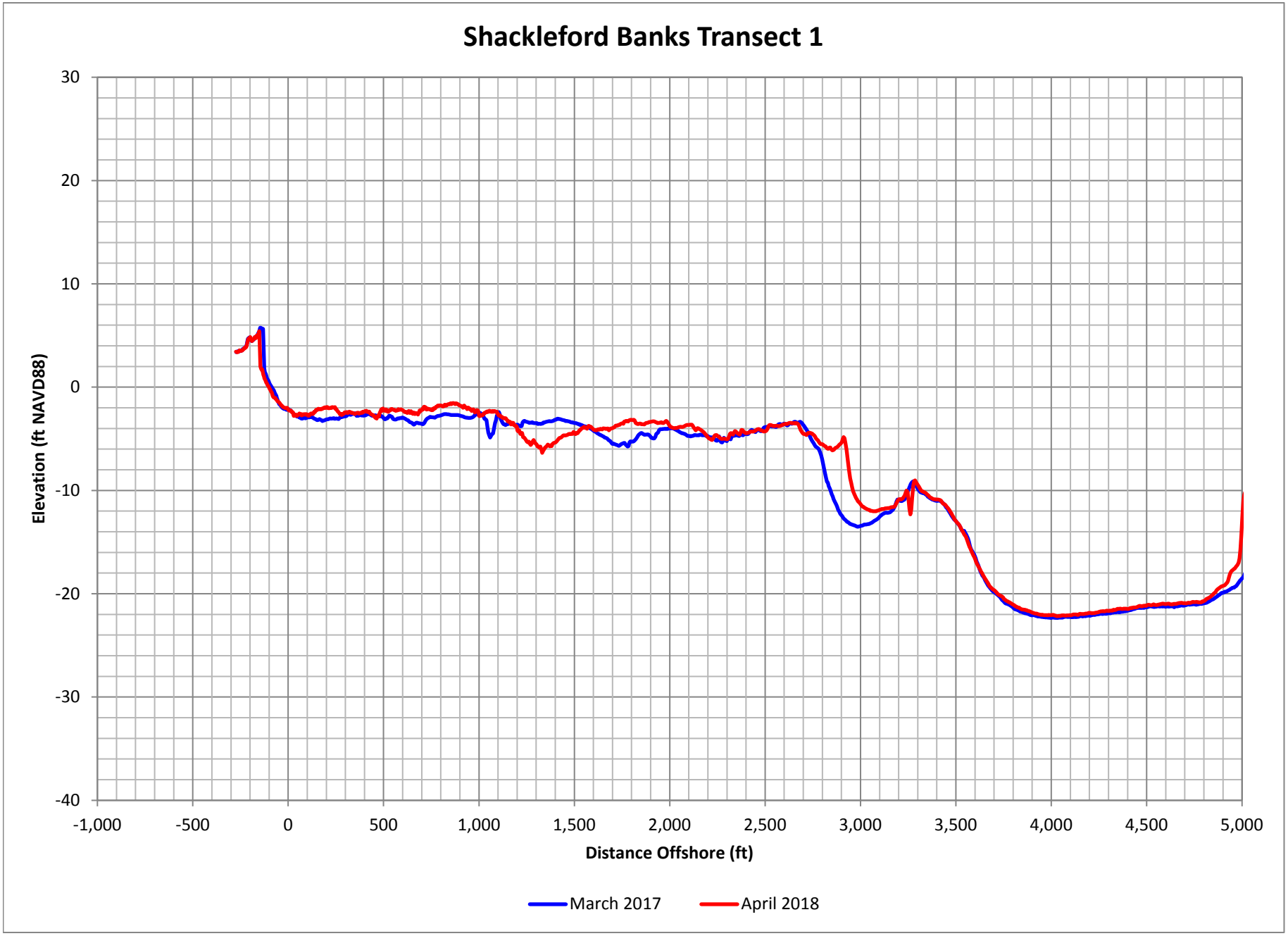


Figure D-281. Shackleford Banks Profile Comparison Plot

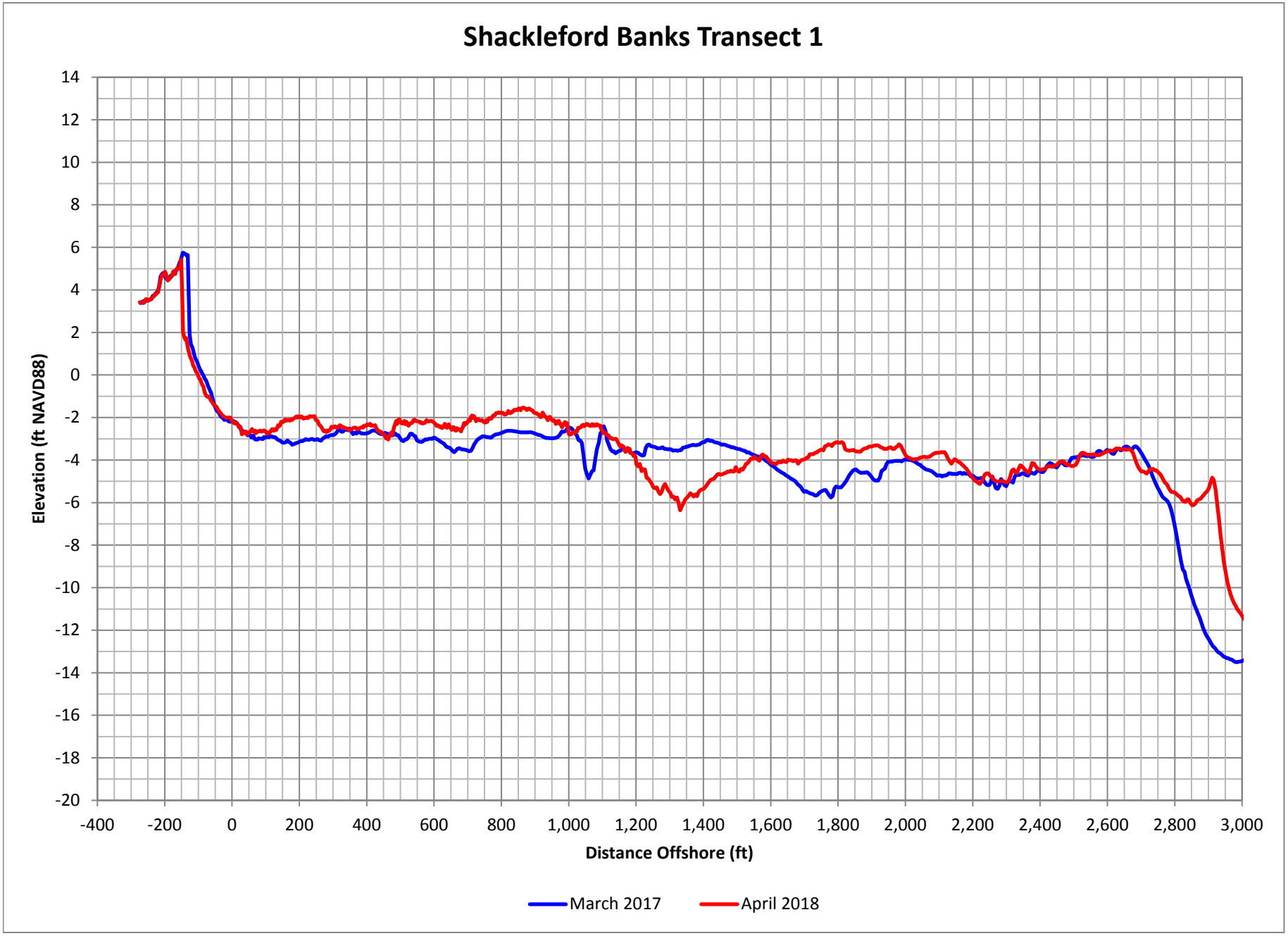


Figure D-282. Shackleford Banks Profile Comparison Plot

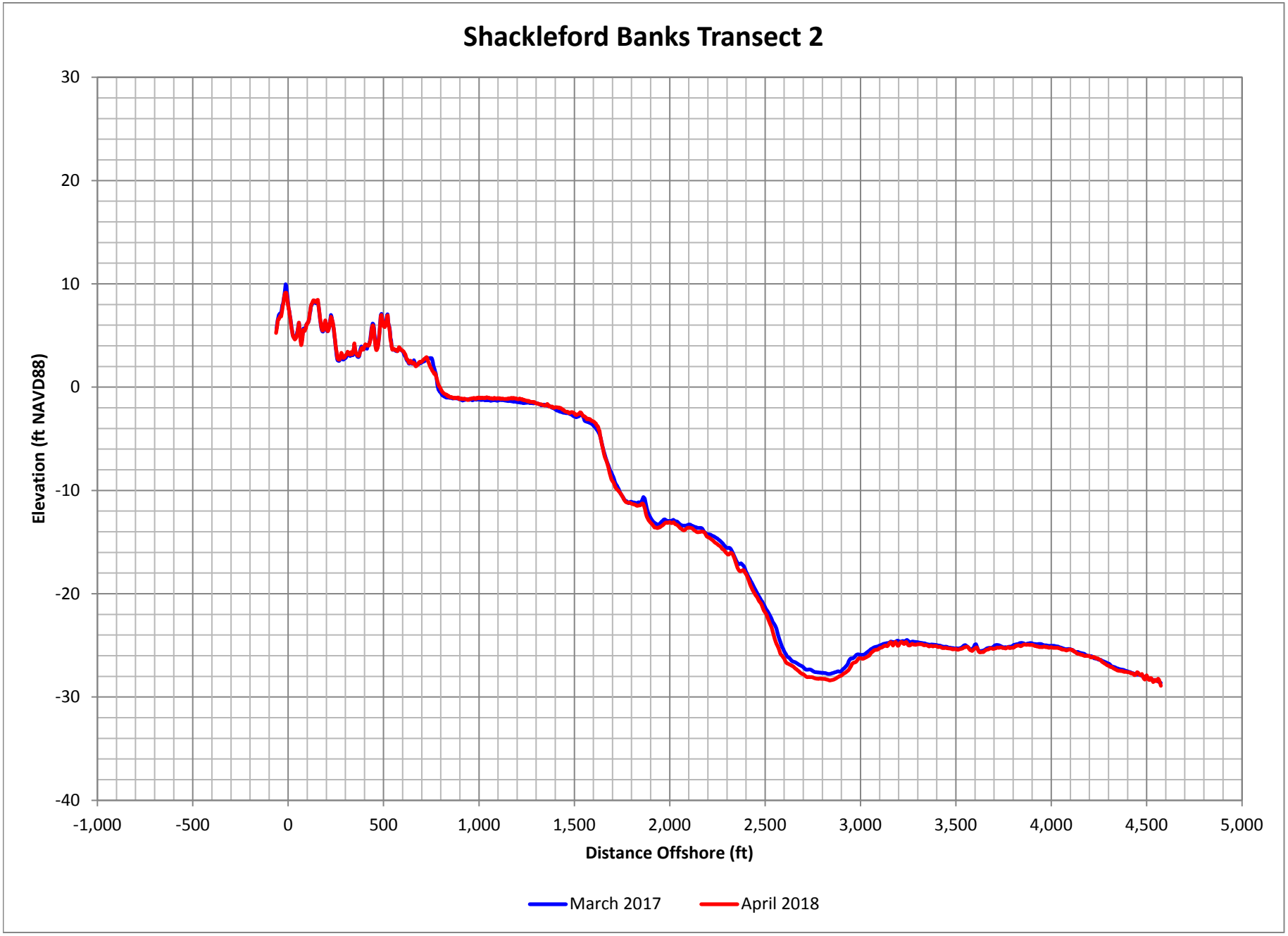


Figure D-283. Shackleford Banks Profile Comparison Plot

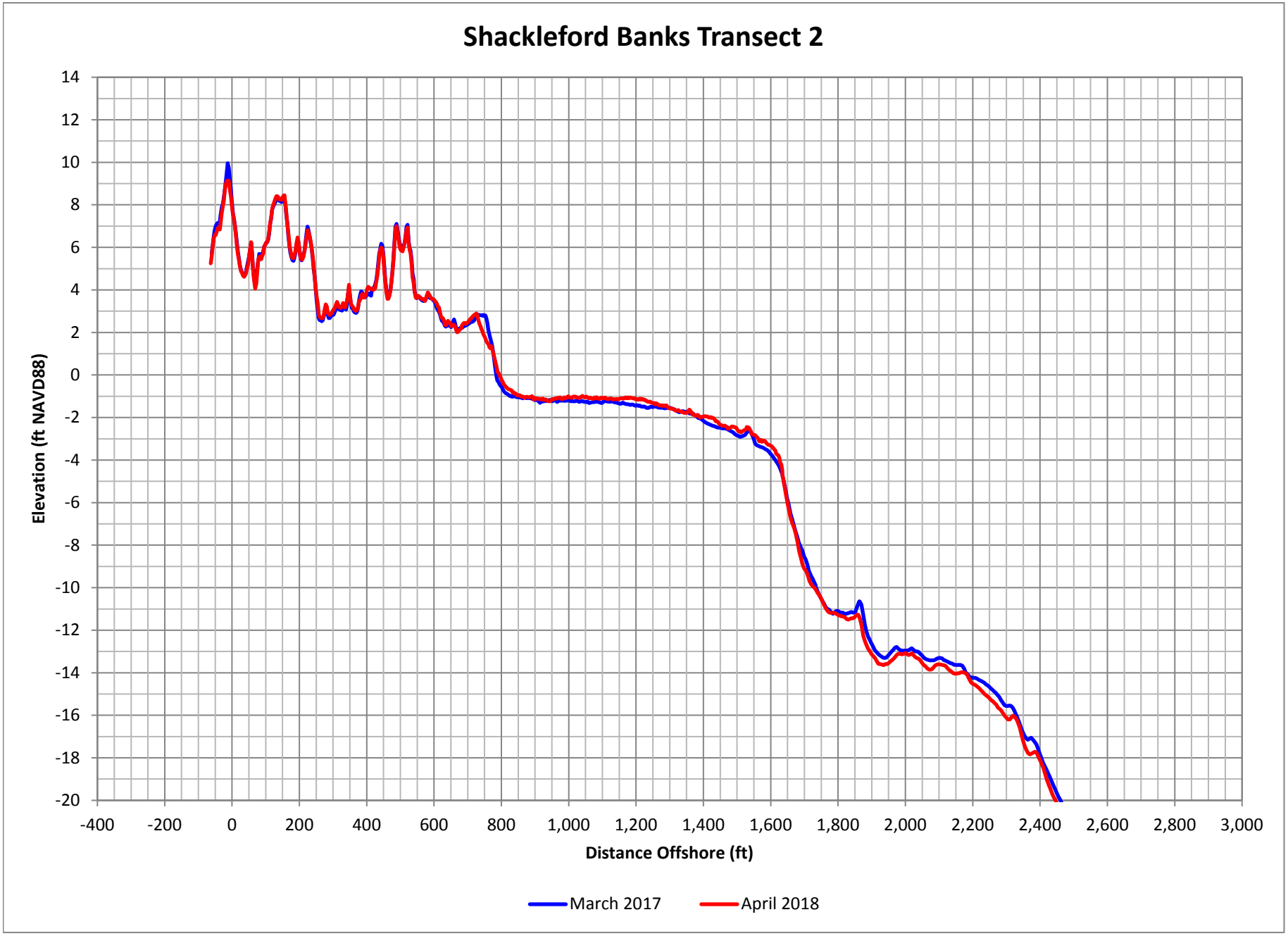


Figure D-284. Shackleford Banks Profile Comparison Plot

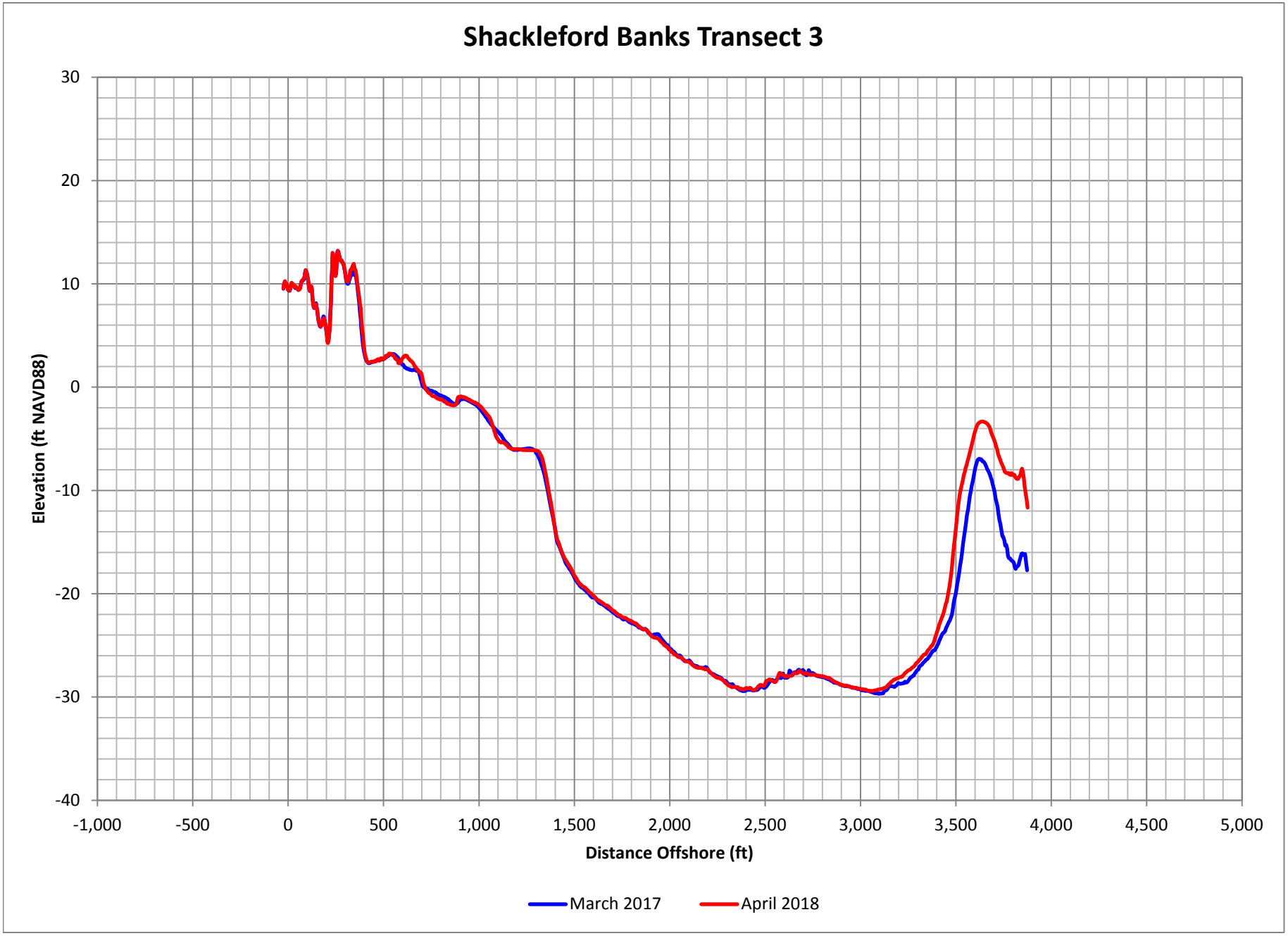


Figure D-285. Shackleford Banks Profile Comparison Plot

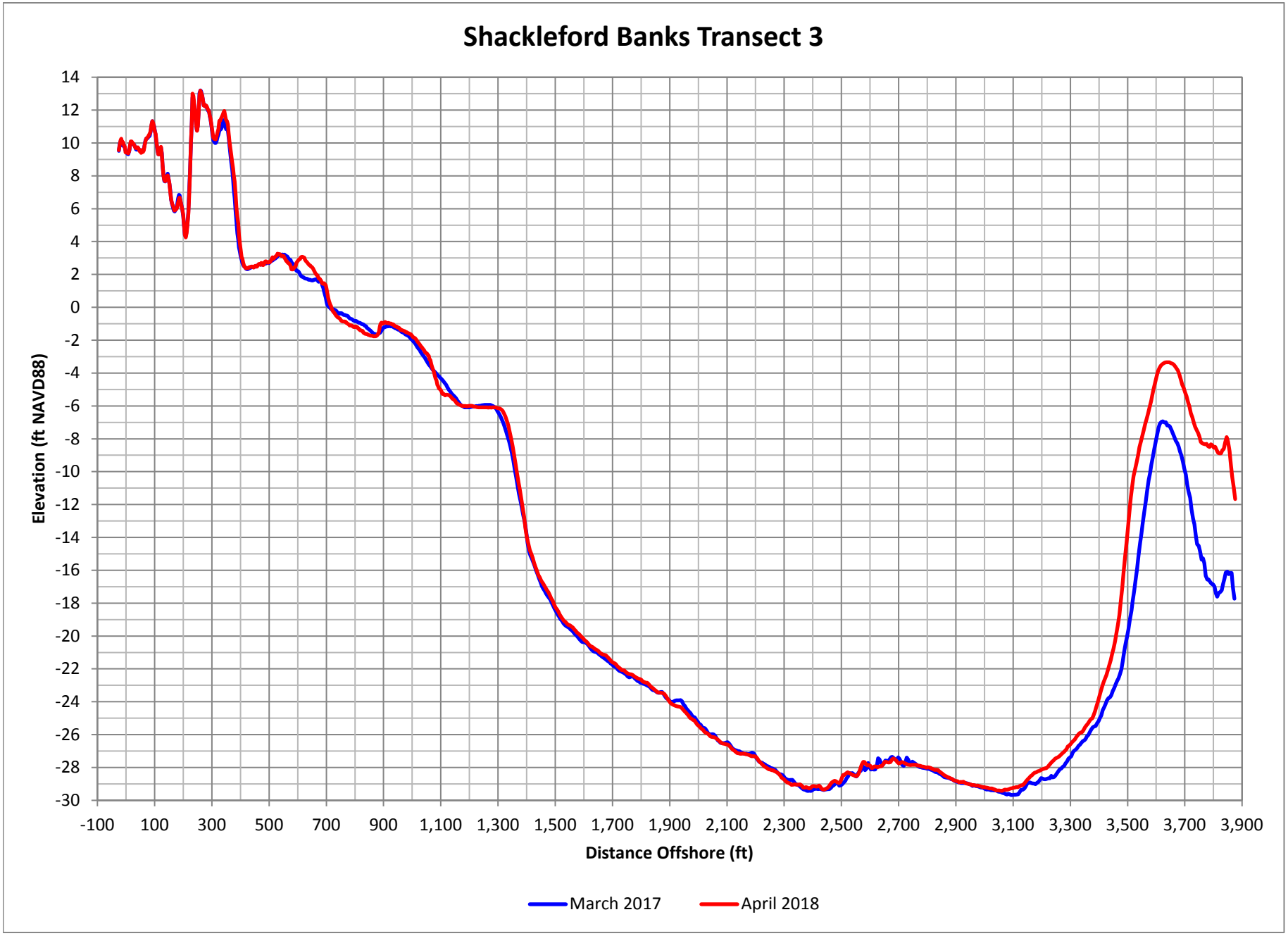


Figure D-286. Shackleford Banks Profile Comparison Plot

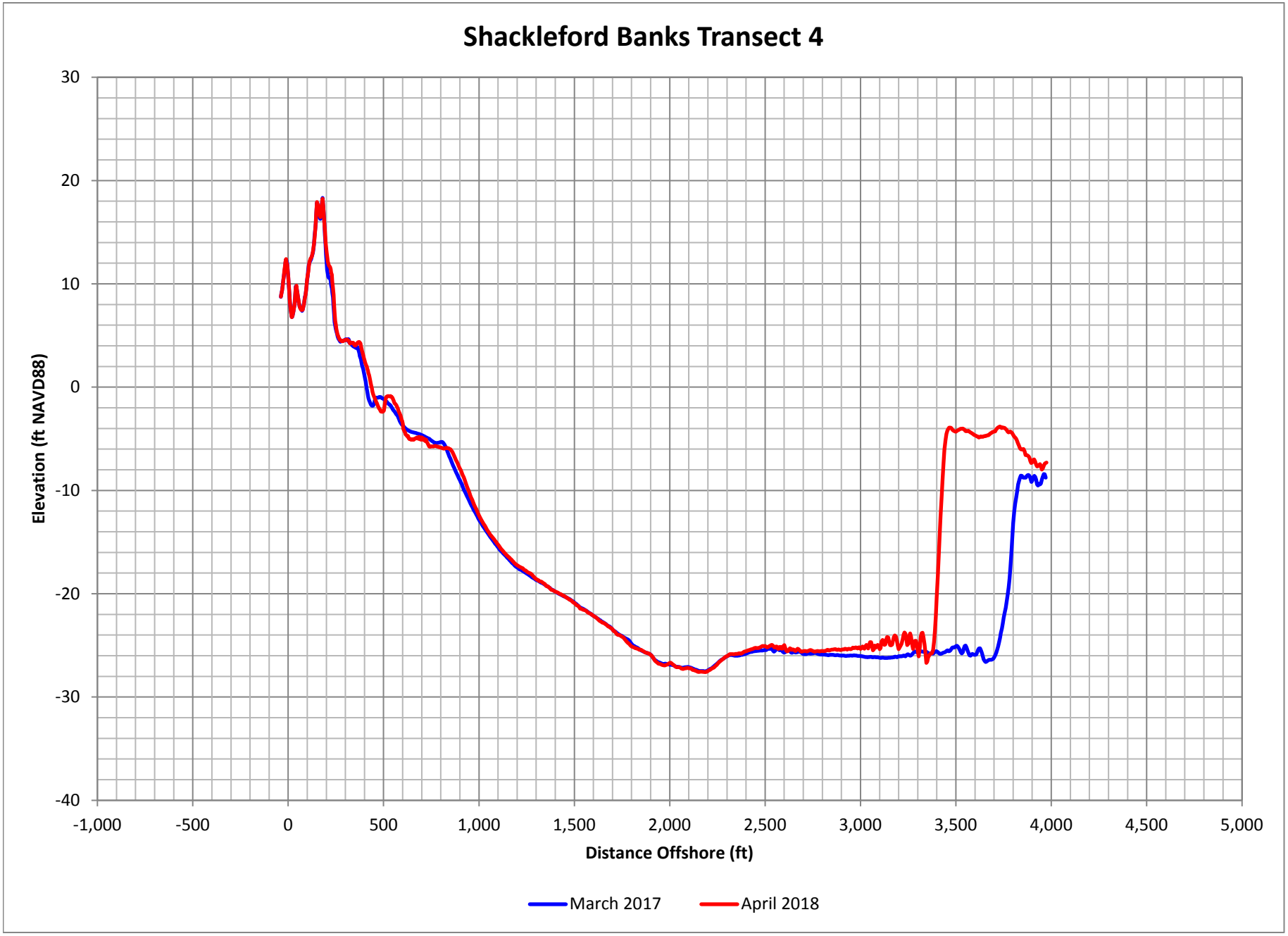


Figure D-287. Shackleford Banks Profile Comparison Plot

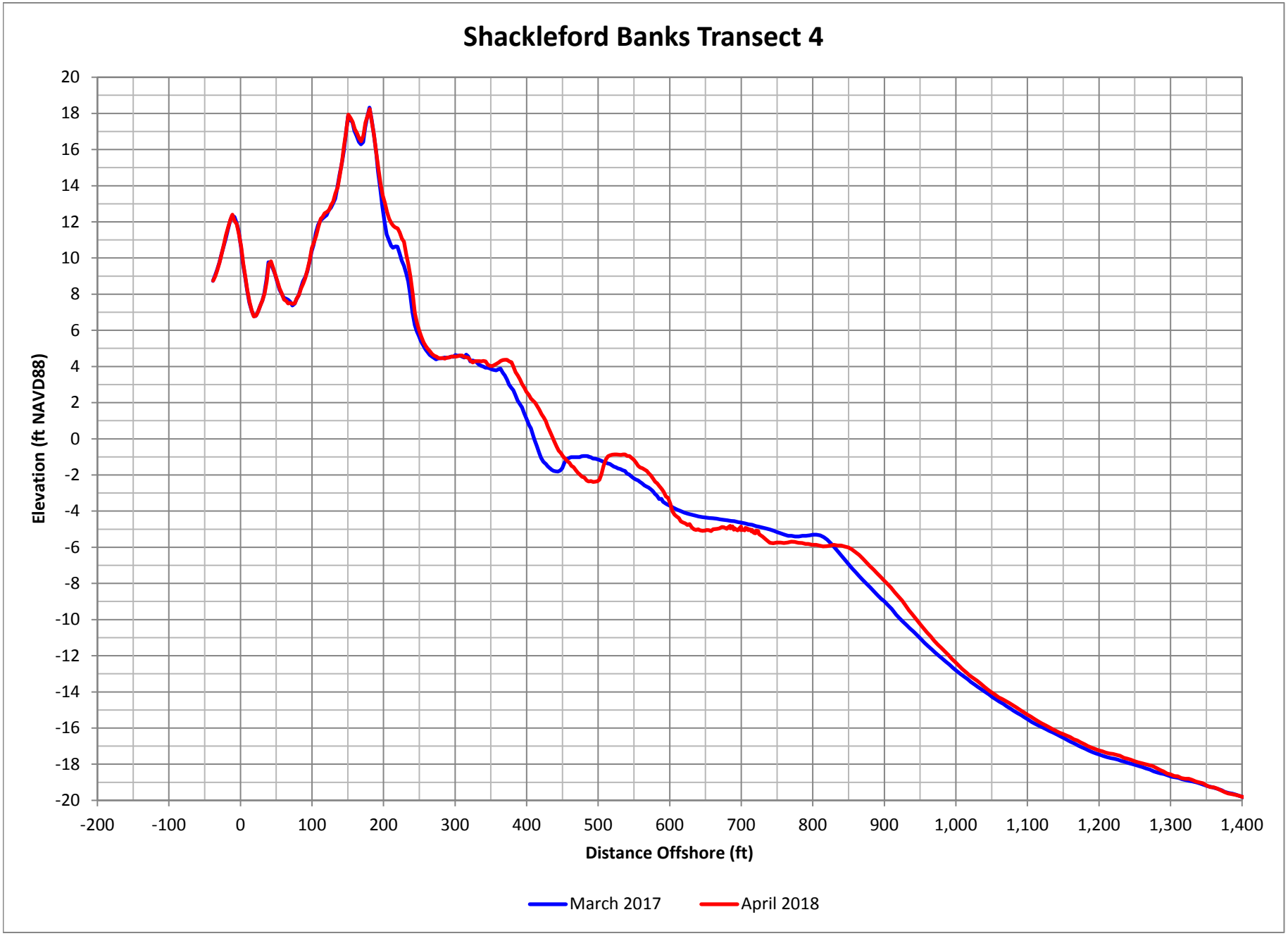


Figure D-288. Shackleford Banks Profile Comparison Plot

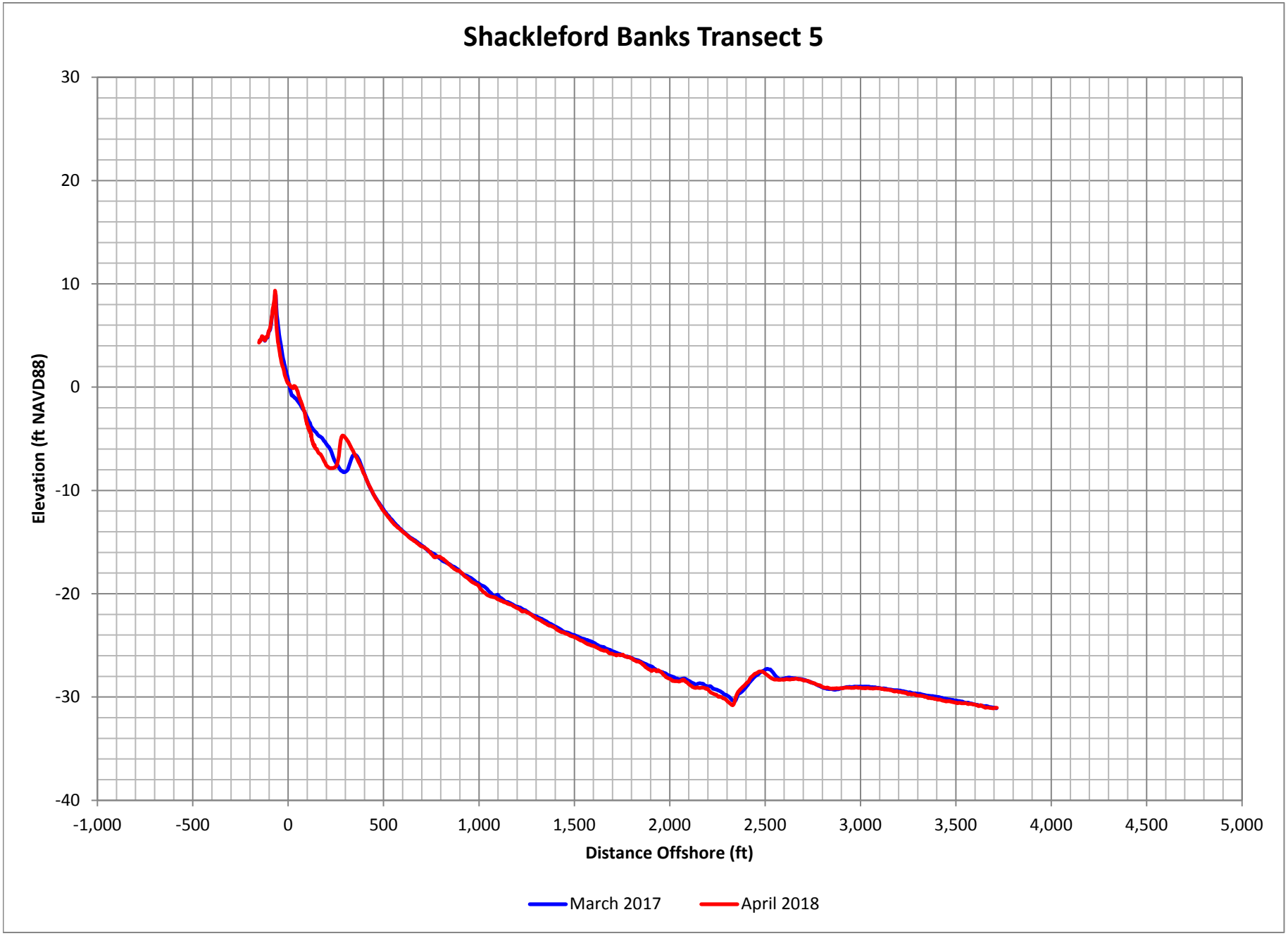


Figure D-289. Shackleford Banks Profile Comparison Plot

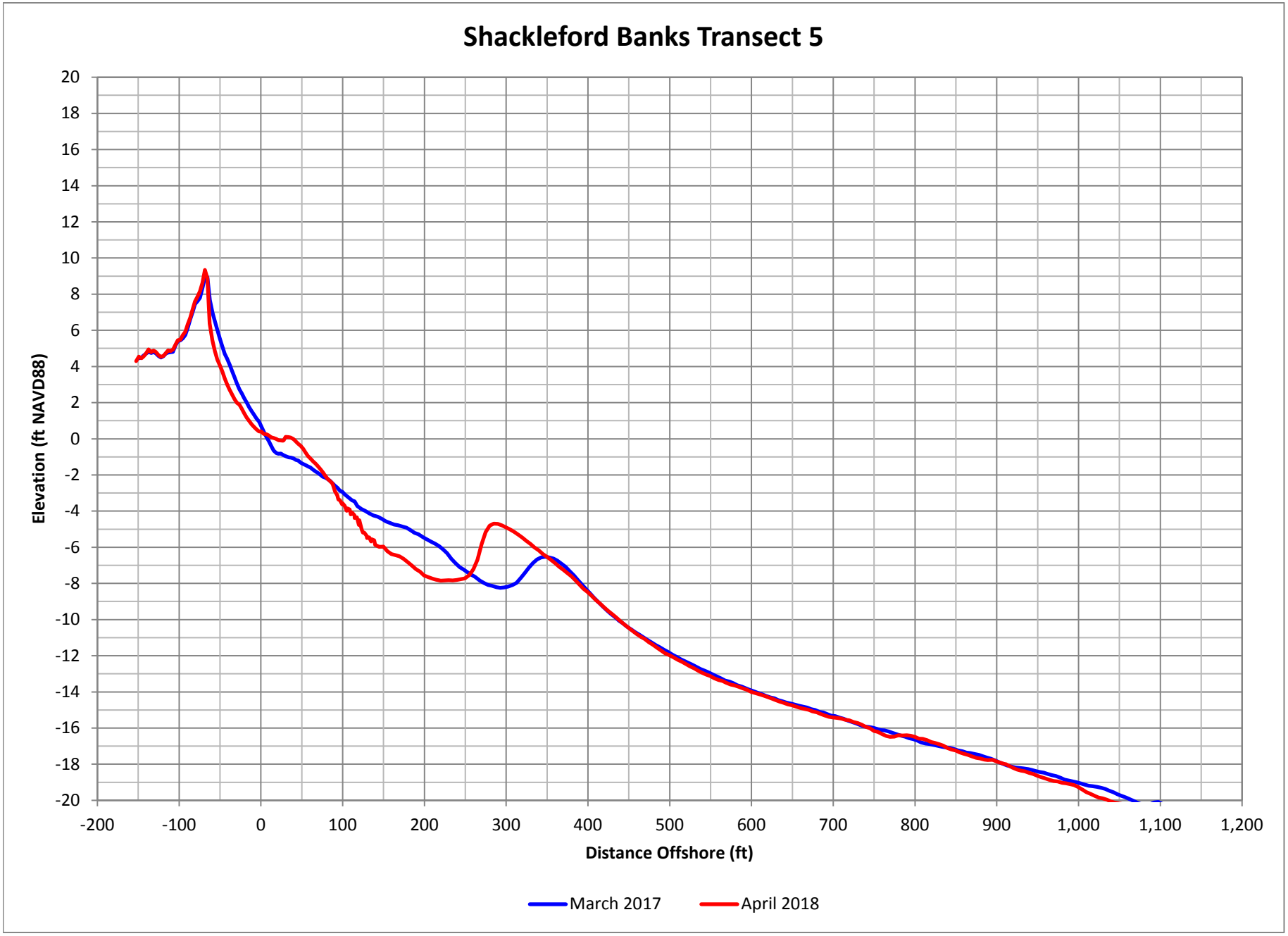


Figure D-290. Shackleford Banks Profile Comparison Plot

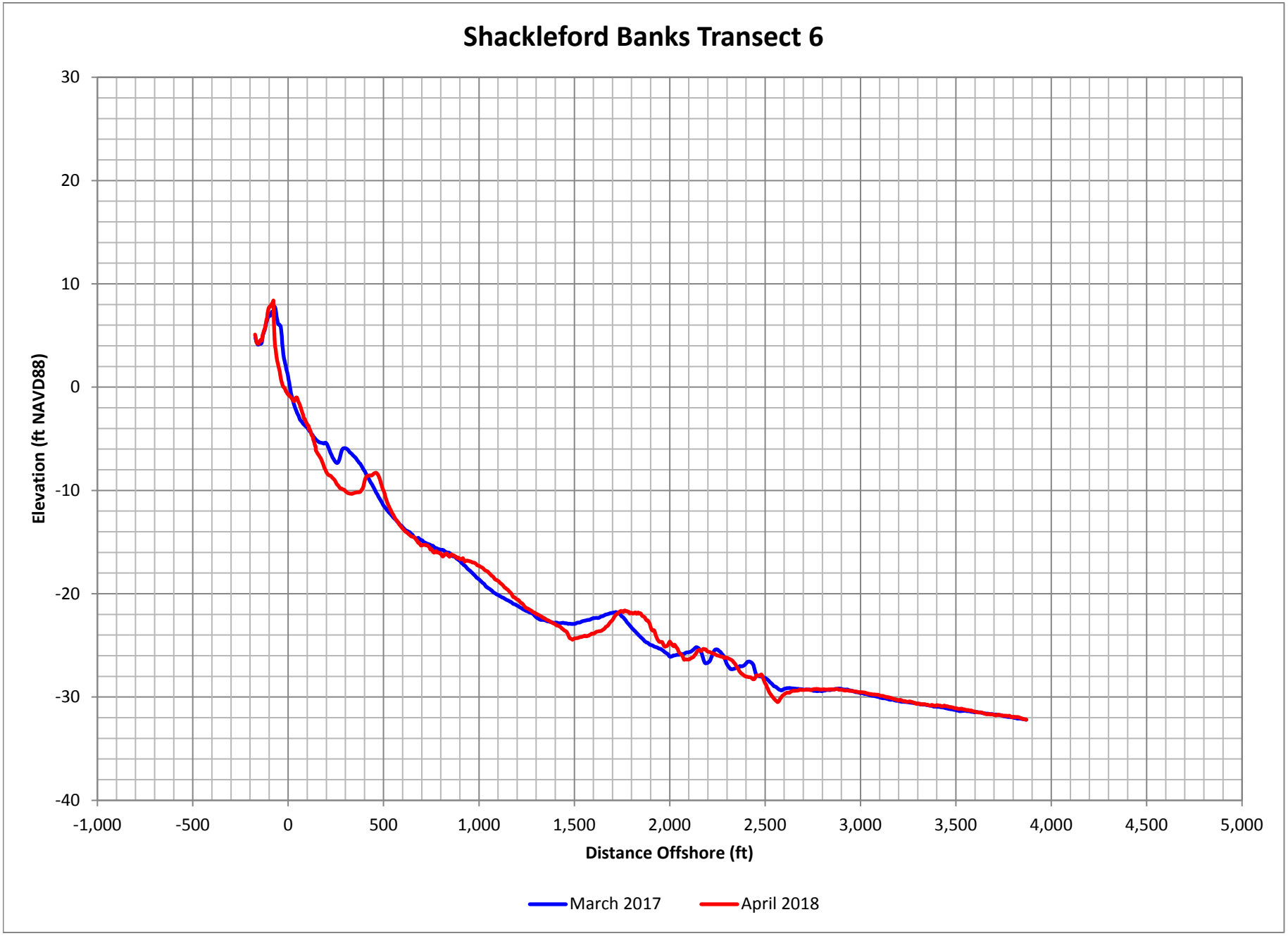


Figure D-291. Shackleford Banks Profile Comparison Plot

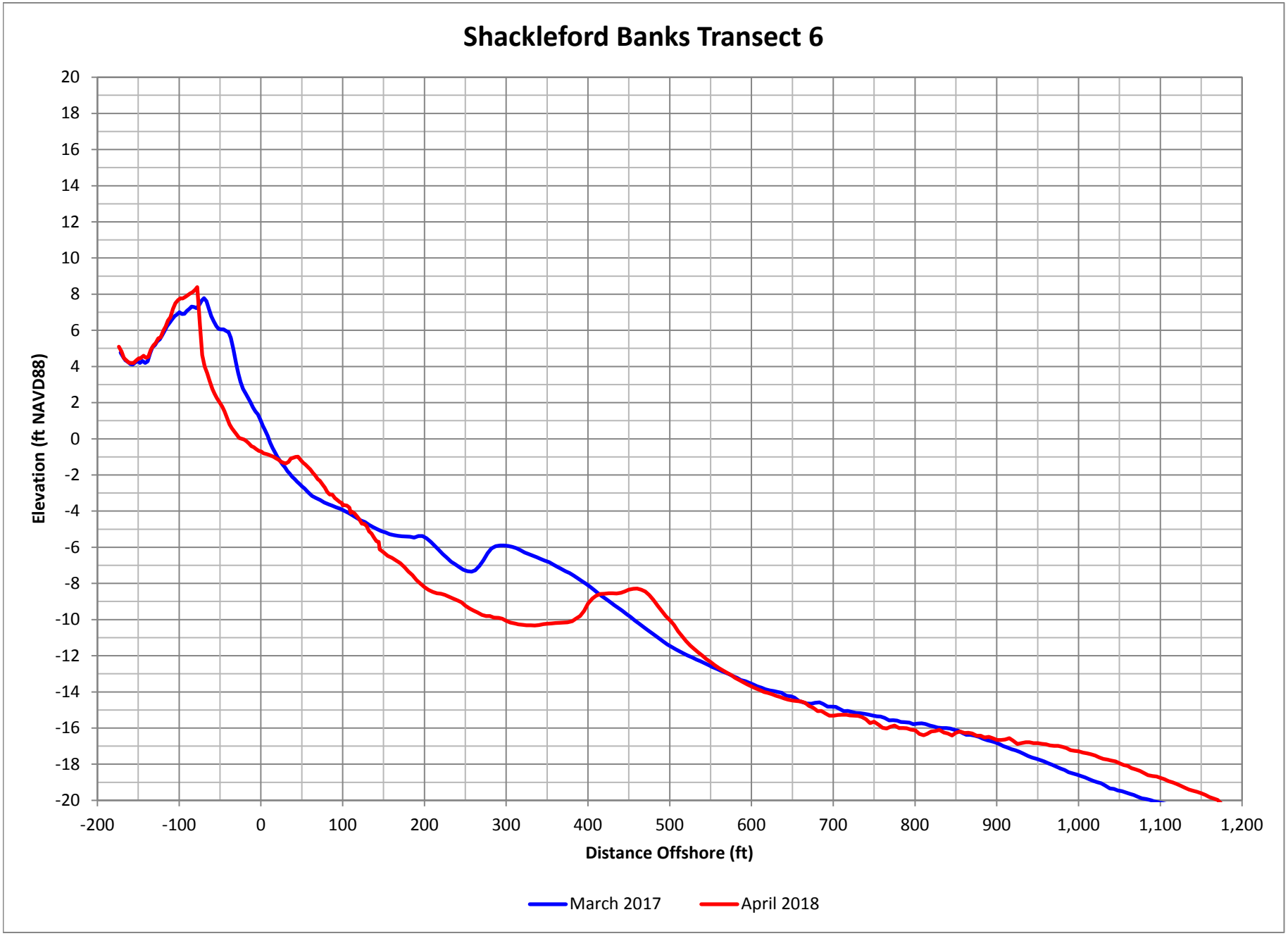


Figure D-292. Shackleford Banks Profile Comparison Plot

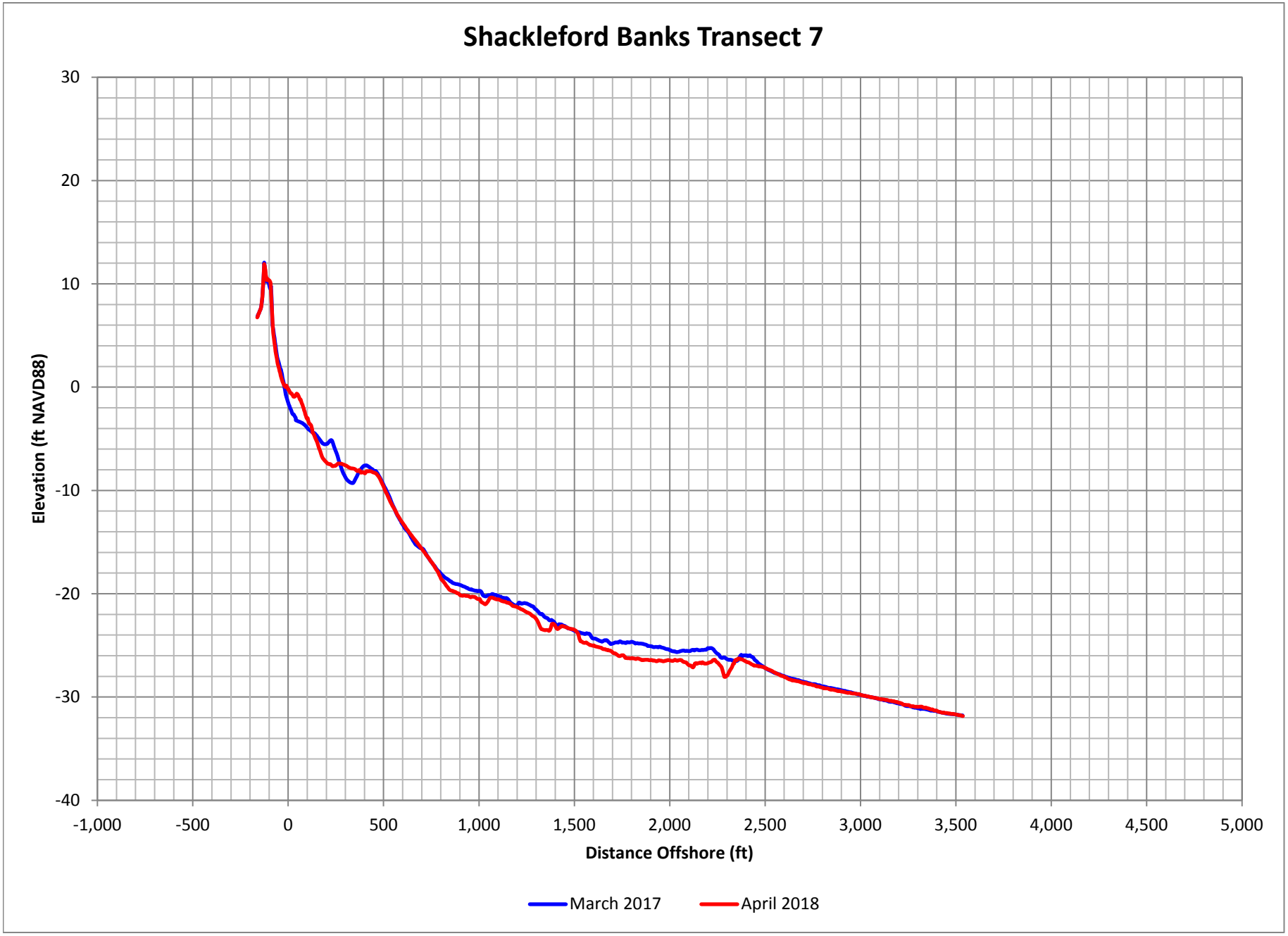


Figure D-293. Shackleford Banks Profile Comparison Plot

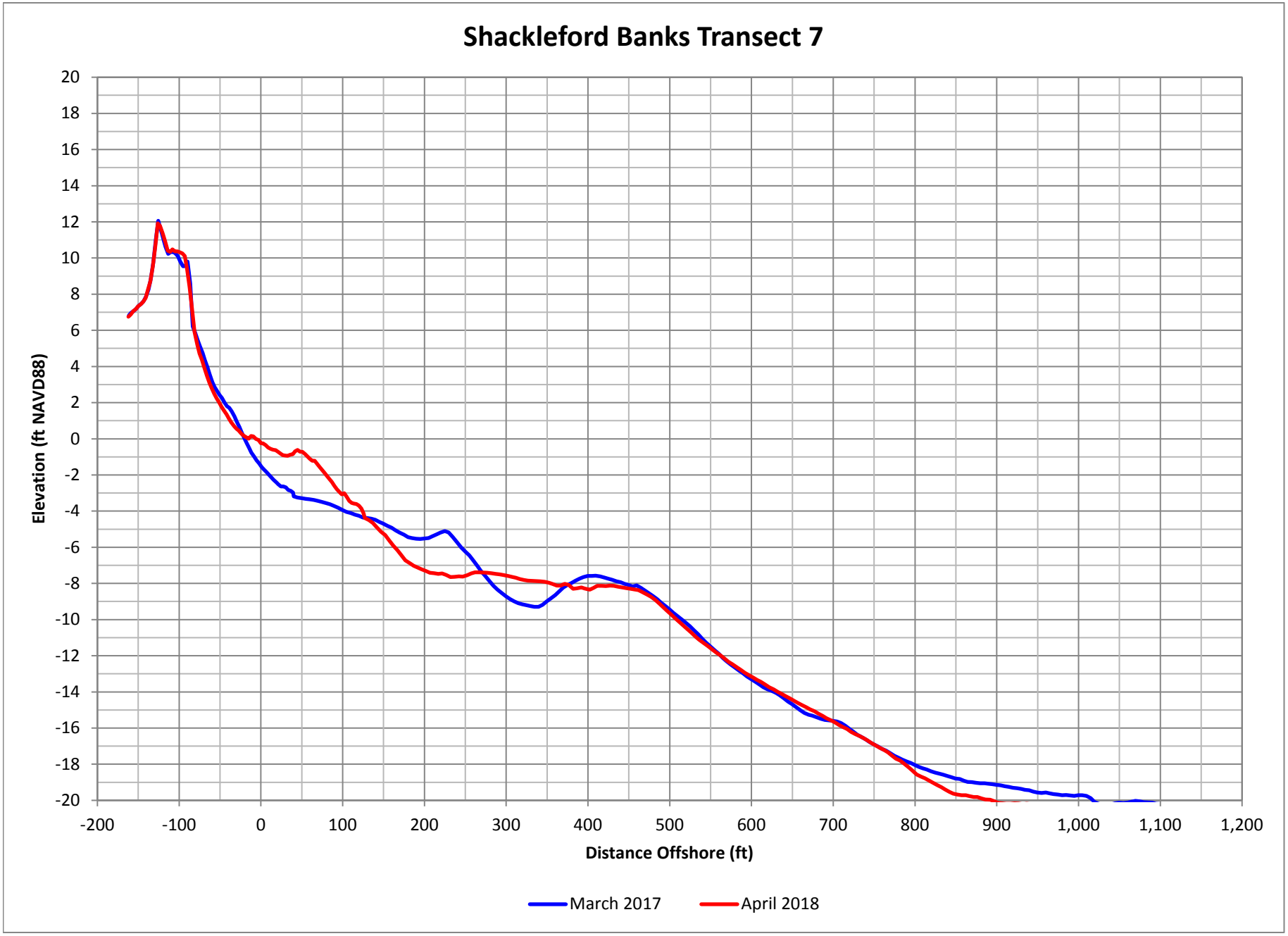


Figure D-294. Shackleford Banks Profile Comparison Plot

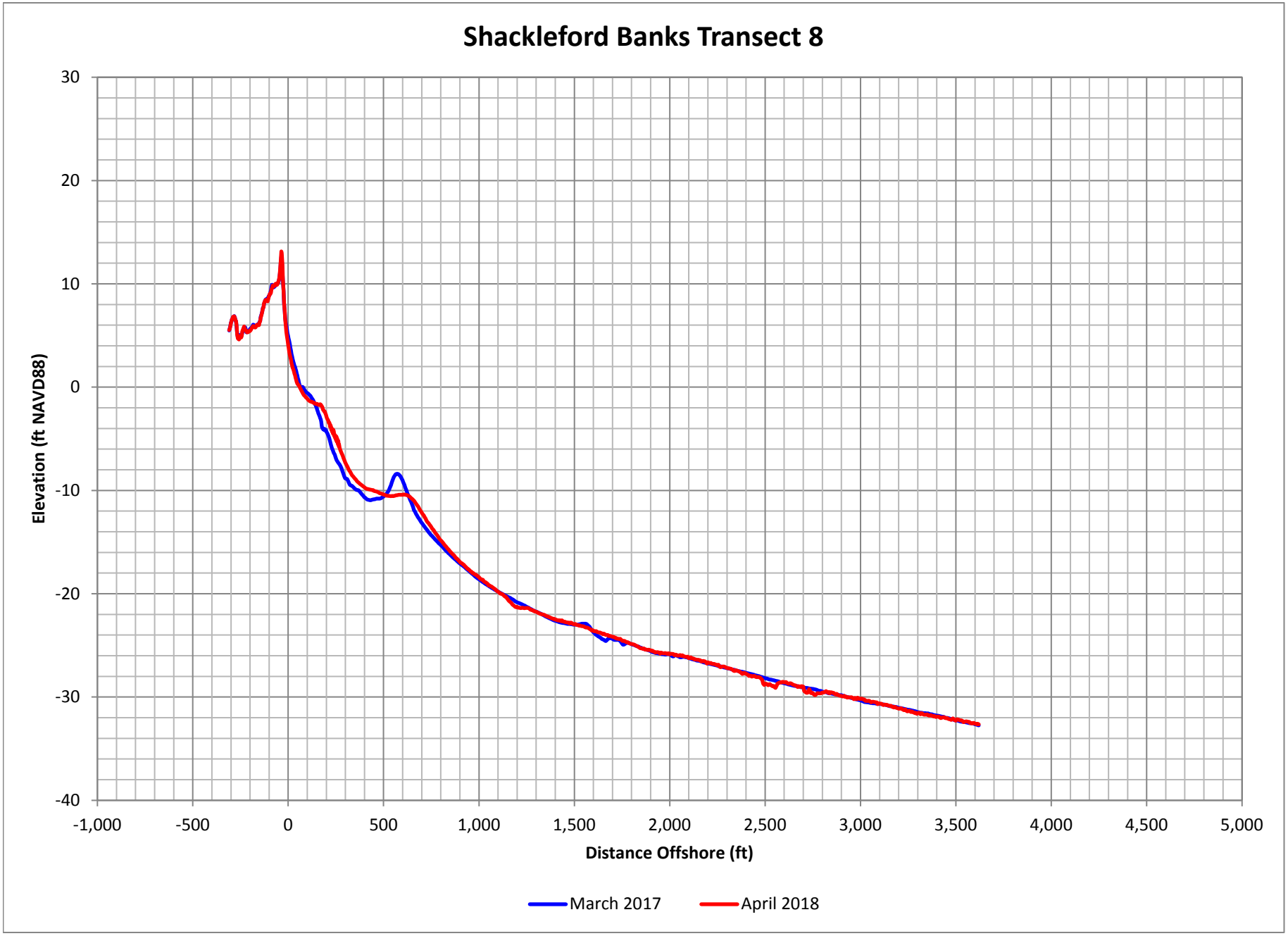


Figure D-295. Shackleford Banks Profile Comparison Plot

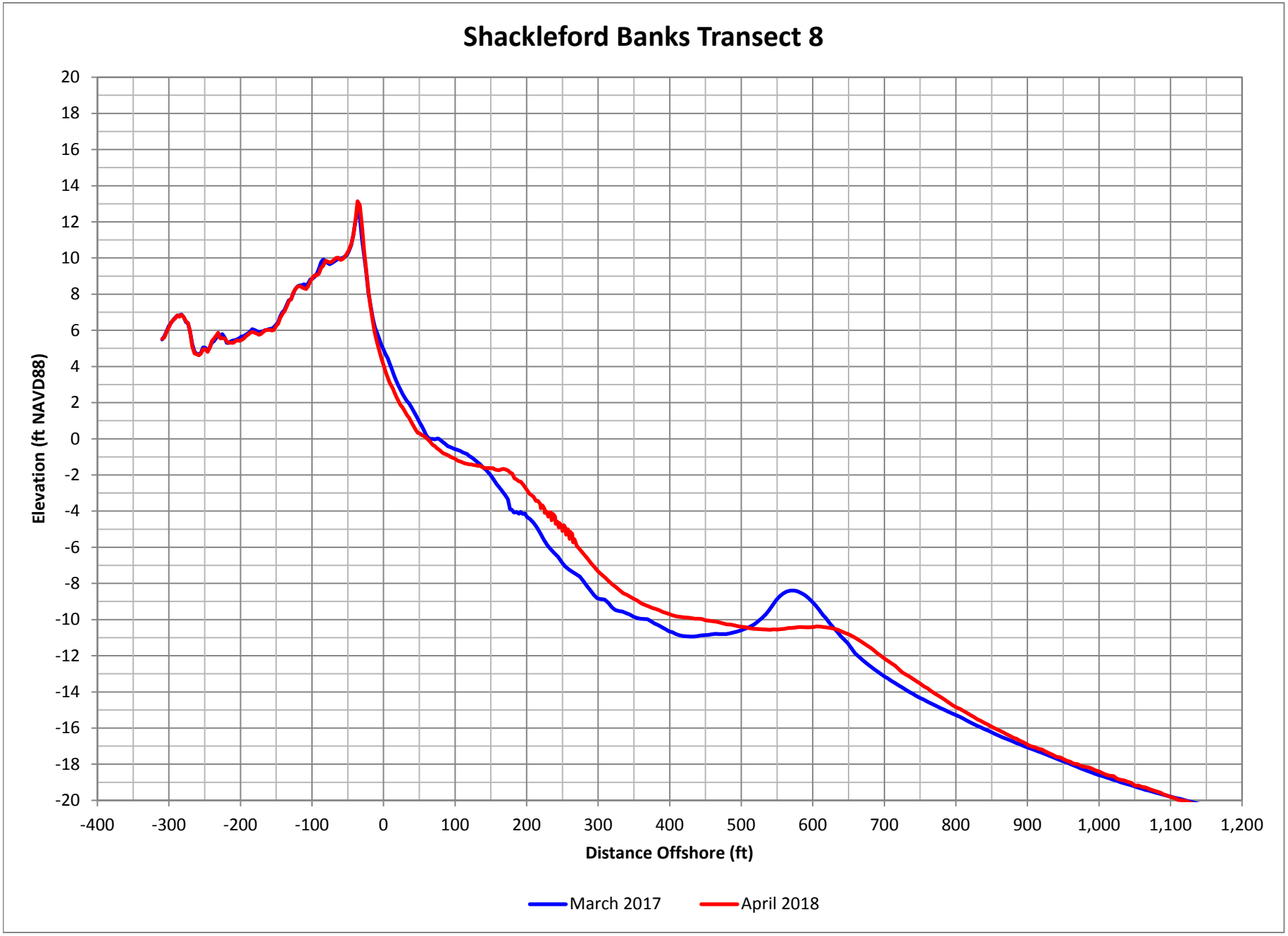


Figure D-296. Shackleford Banks Profile Comparison Plot

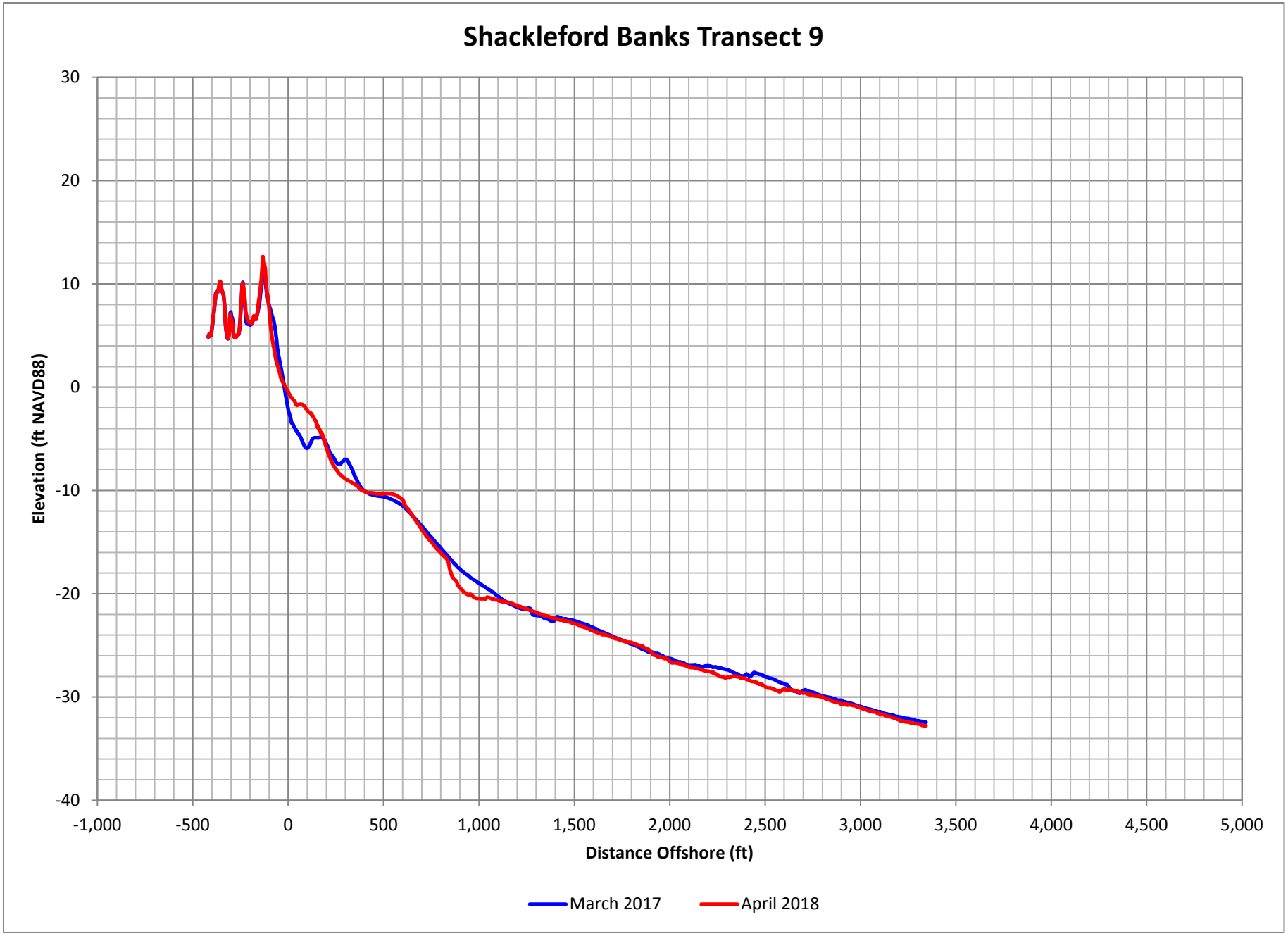


Figure D-297. Shackleford Banks Profile Comparison Plot

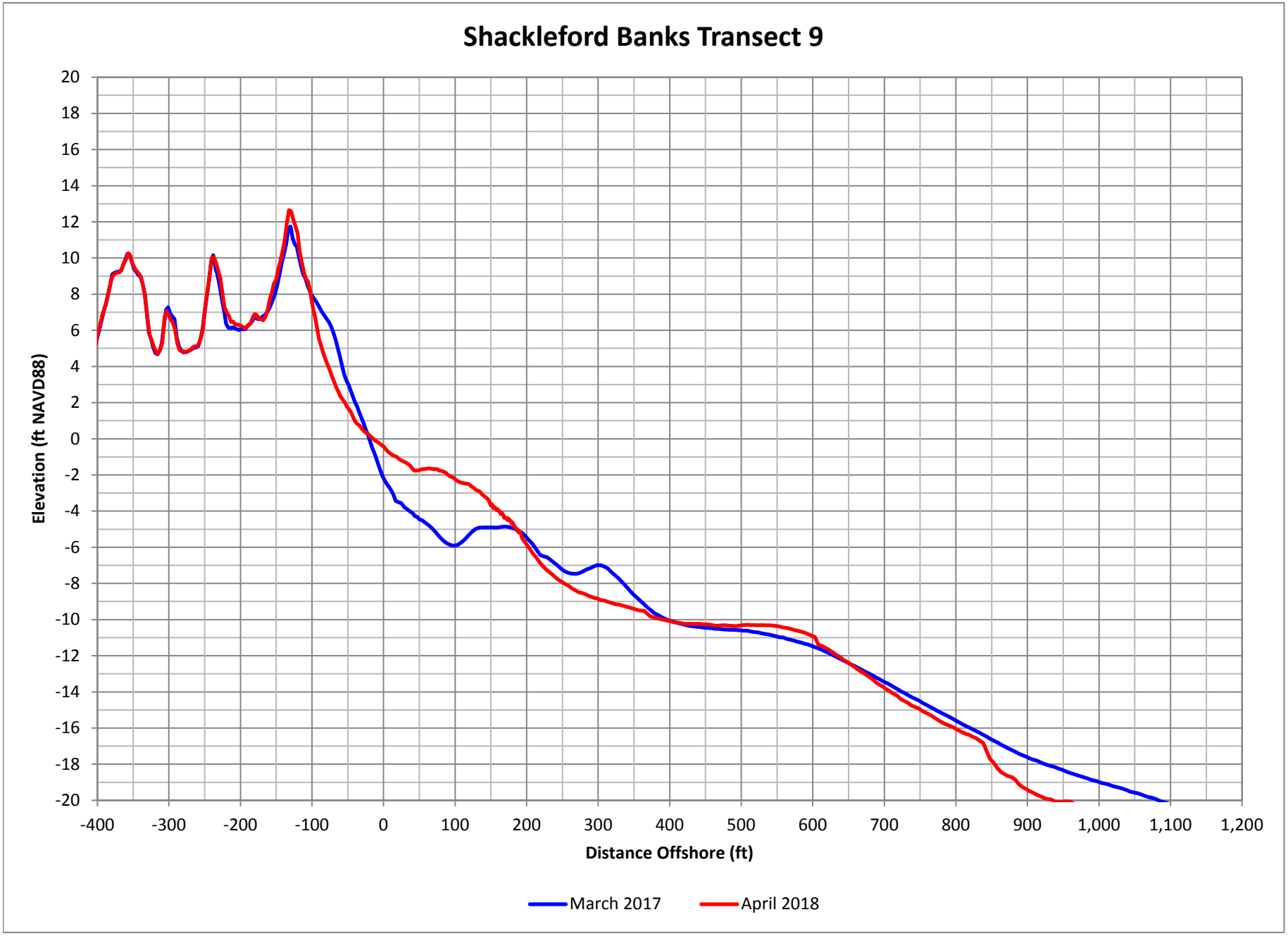


Figure D-298. Shackleford Banks Profile Comparison Plot

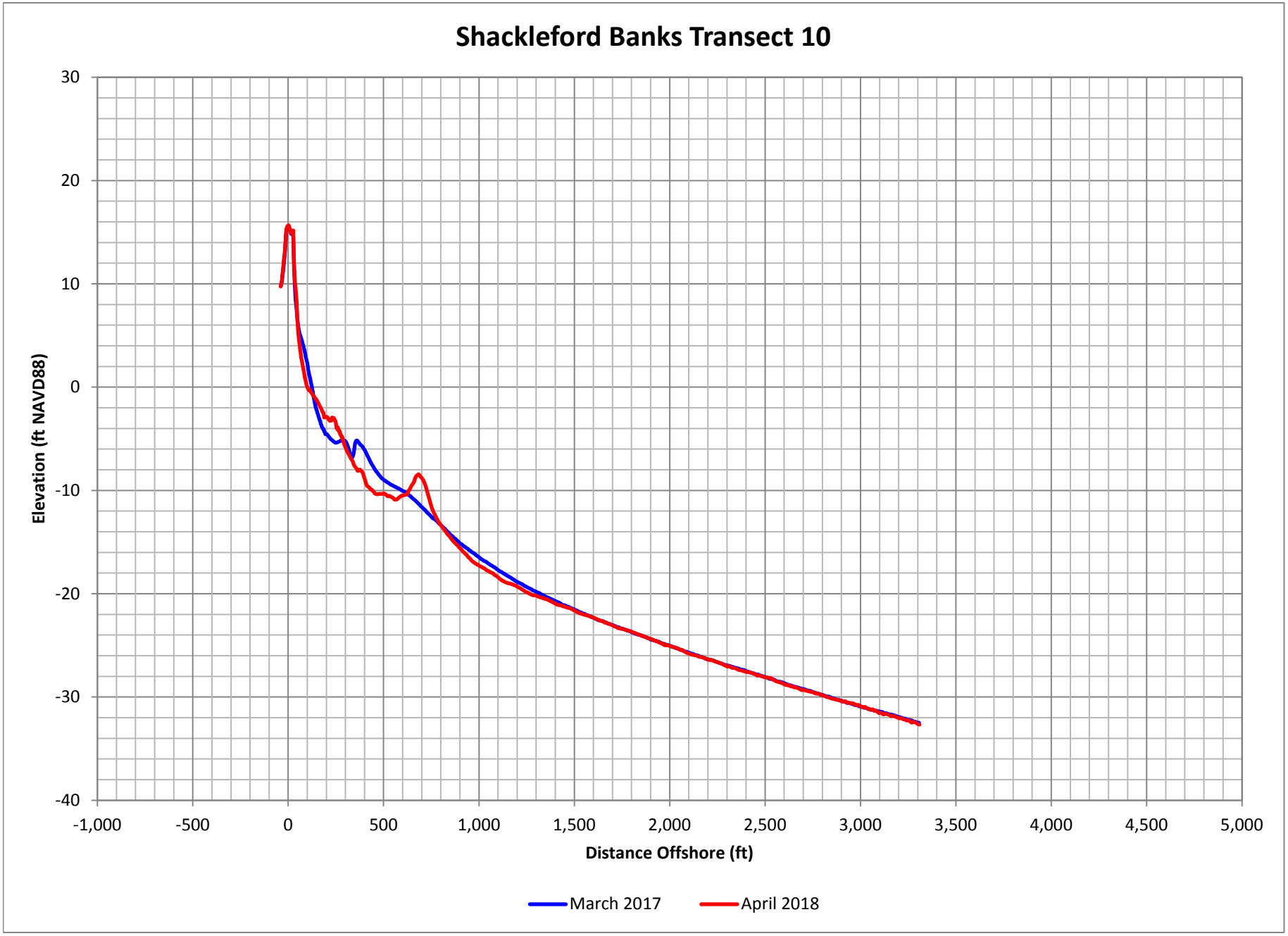


Figure D-299. Shackleford Banks Profile Comparison Plot

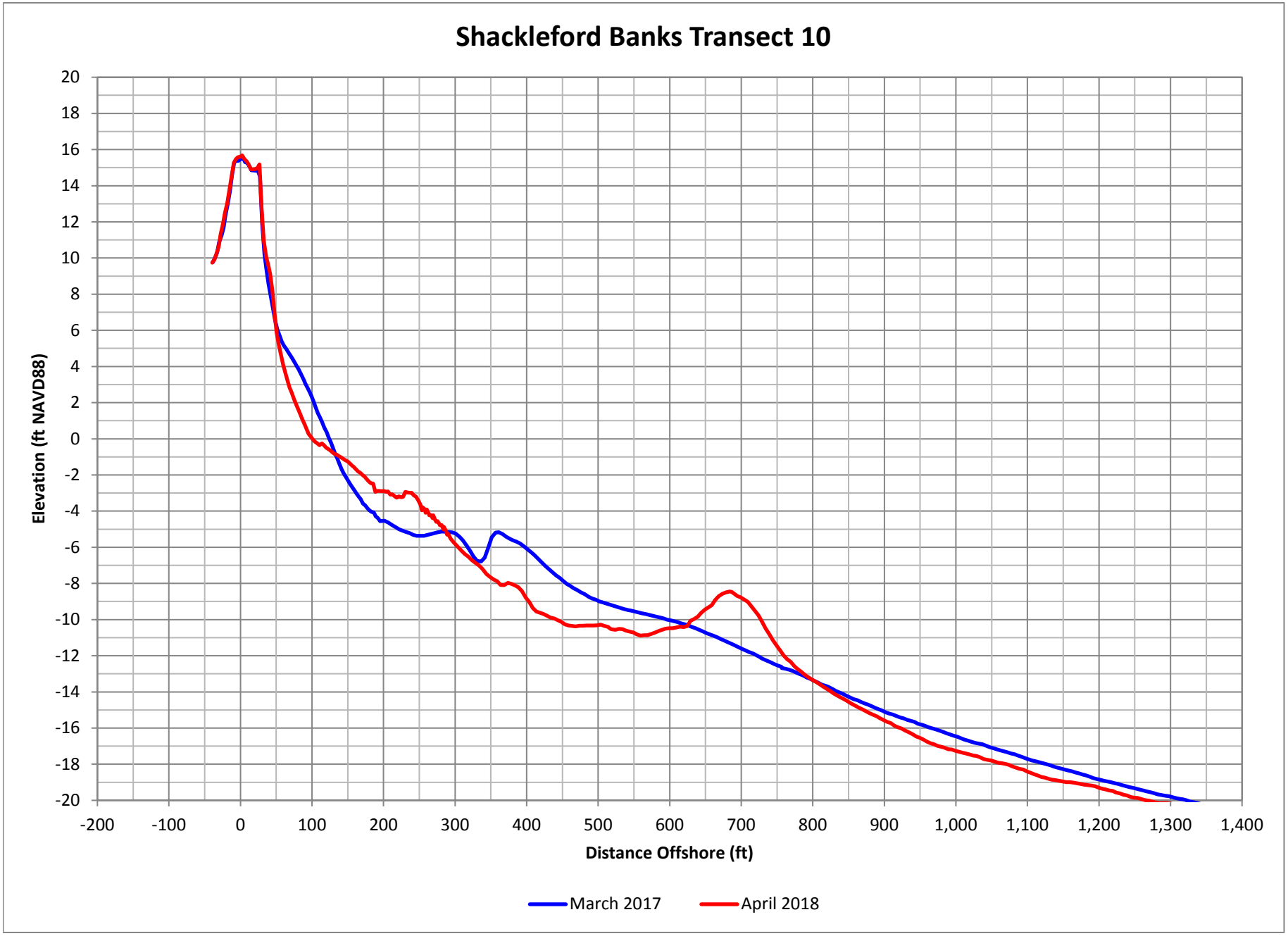


Figure D-300. Shackleford Banks Profile Comparison Plot

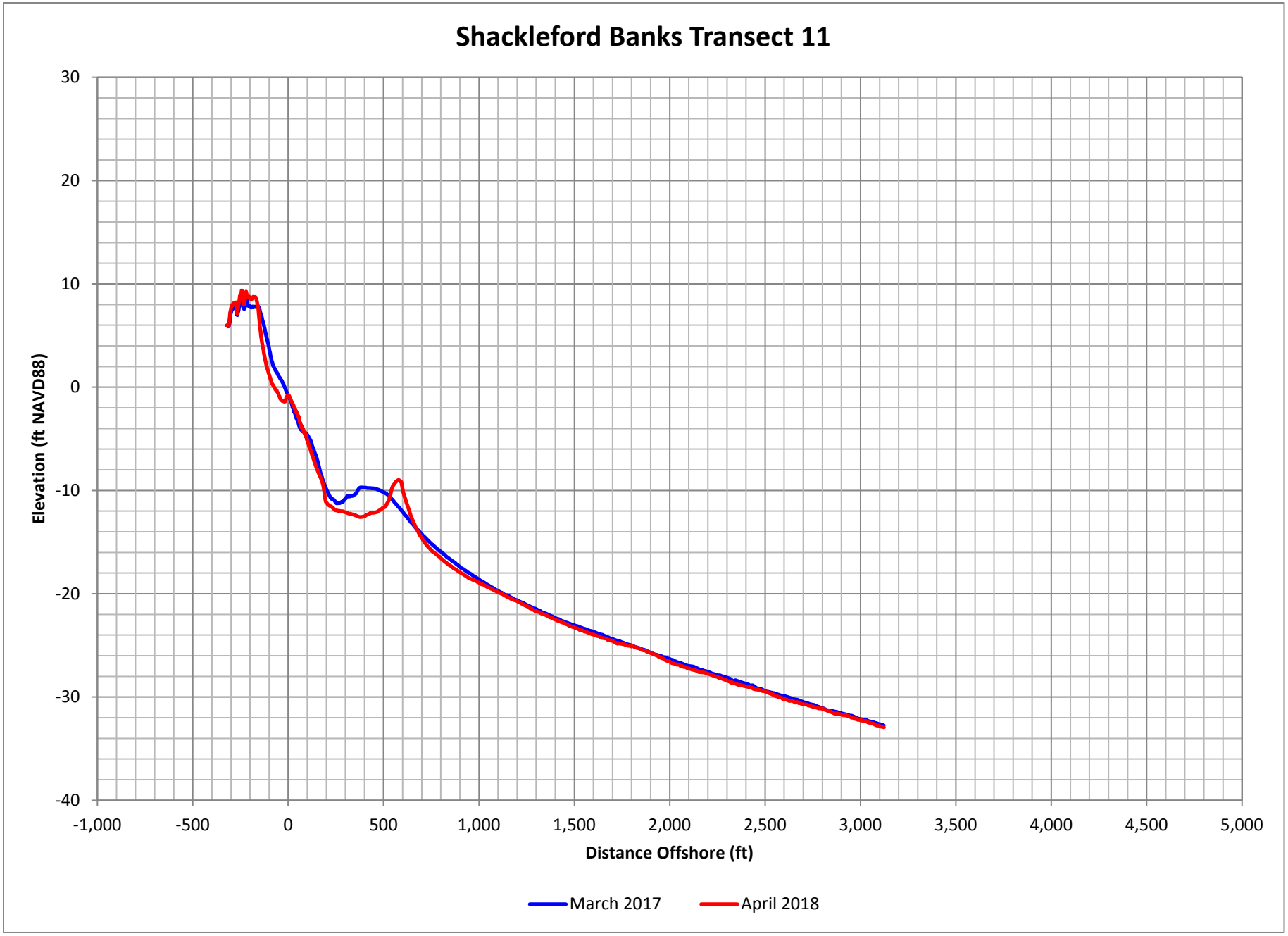


Figure D-301. Shackleford Banks Profile Comparison Plot

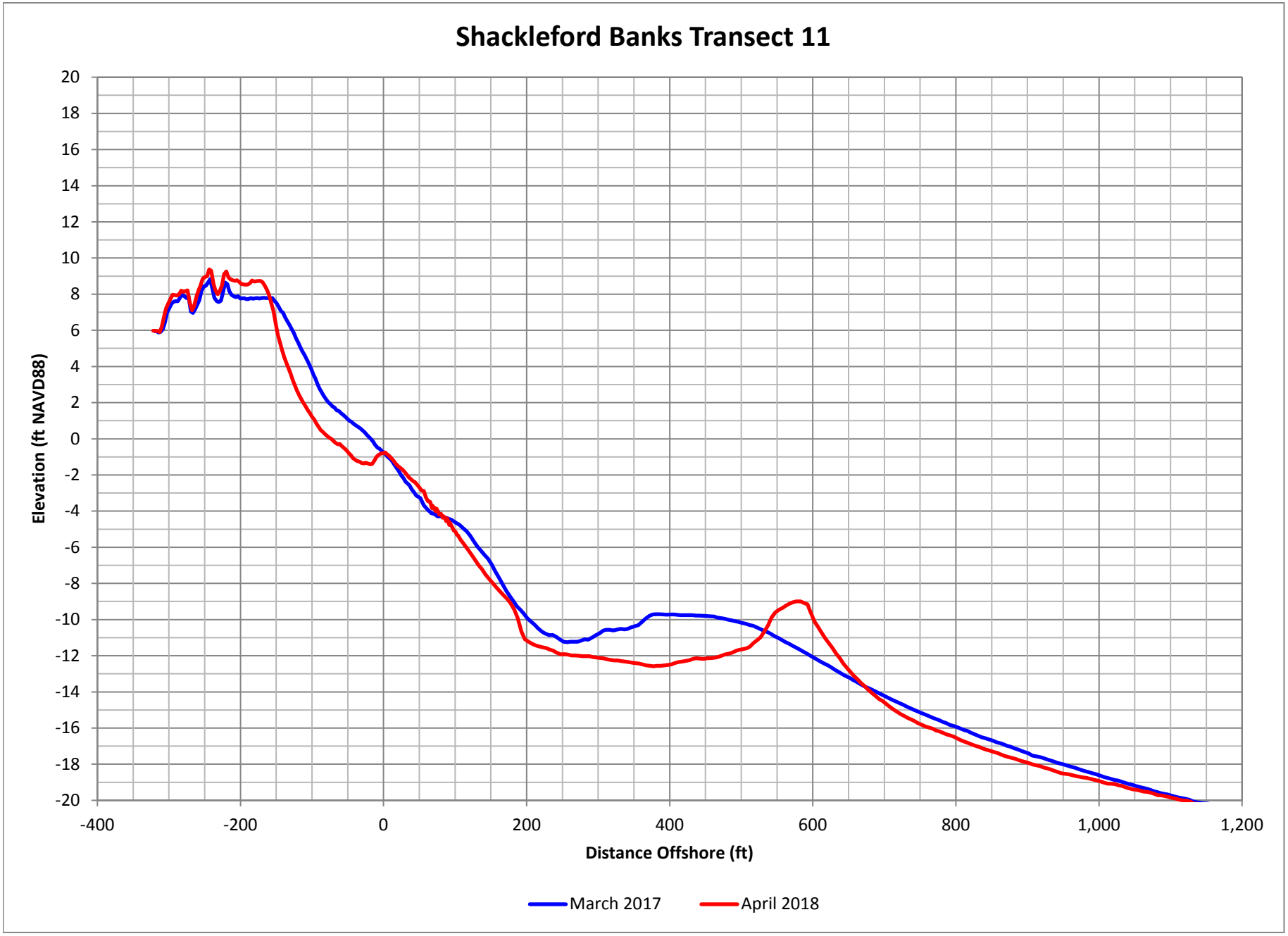


Figure D-302. Shackleford Banks Profile Comparison Plot

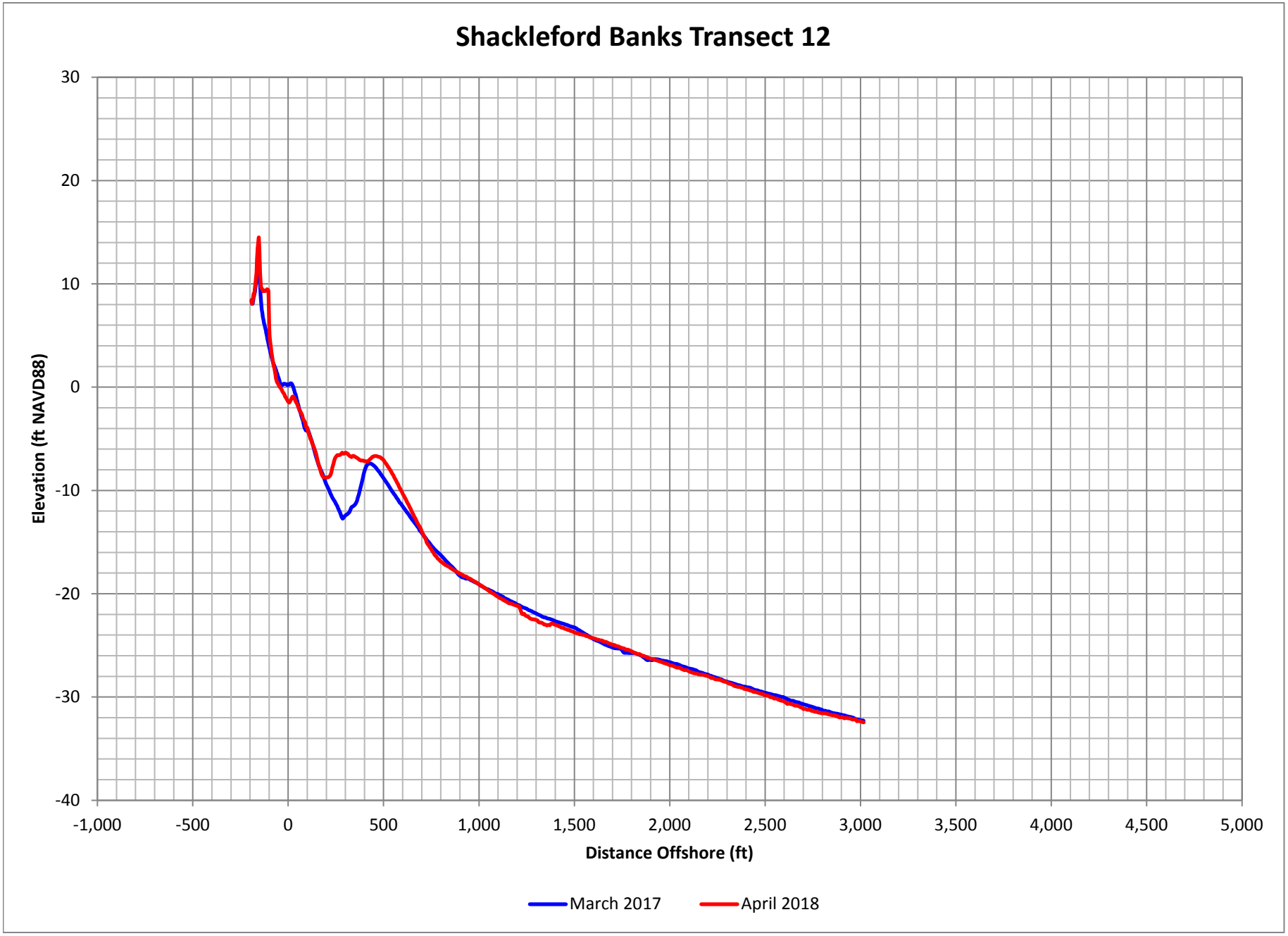


Figure D-303. Shackleford Banks Profile Comparison Plot

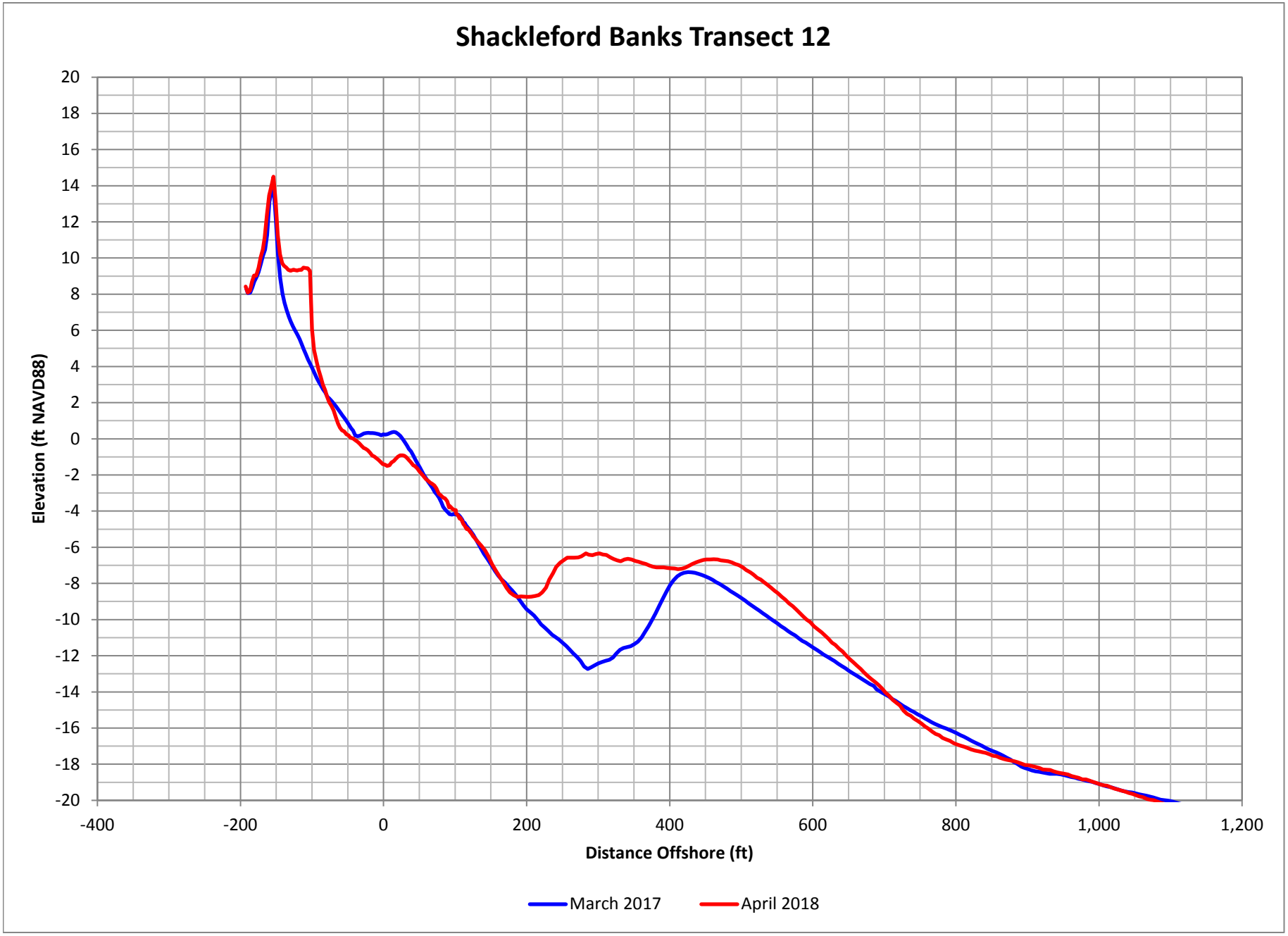


Figure D-304. Shackleford Banks Profile Comparison Plot

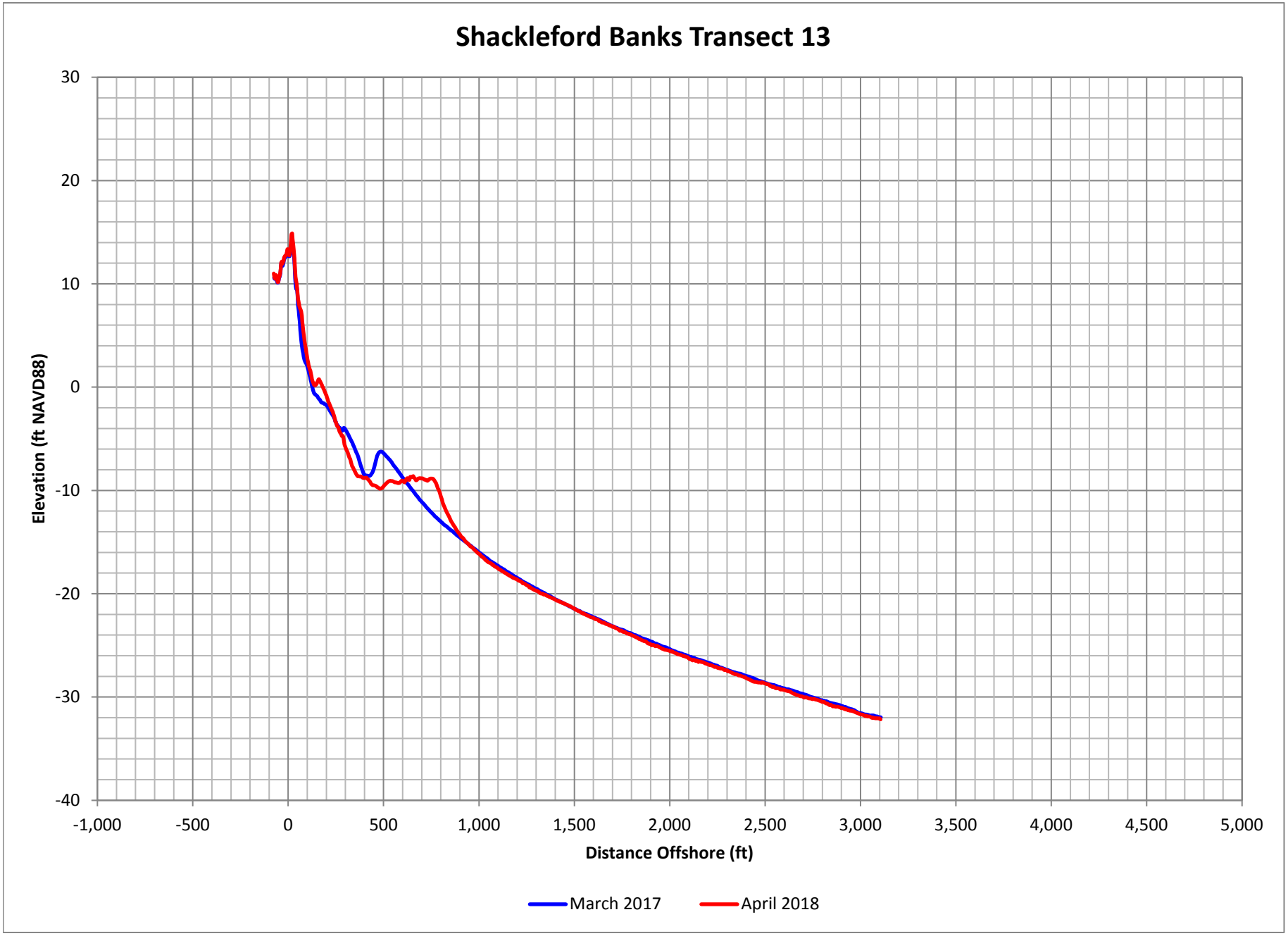


Figure D-305. Shackleford Banks Profile Comparison Plot

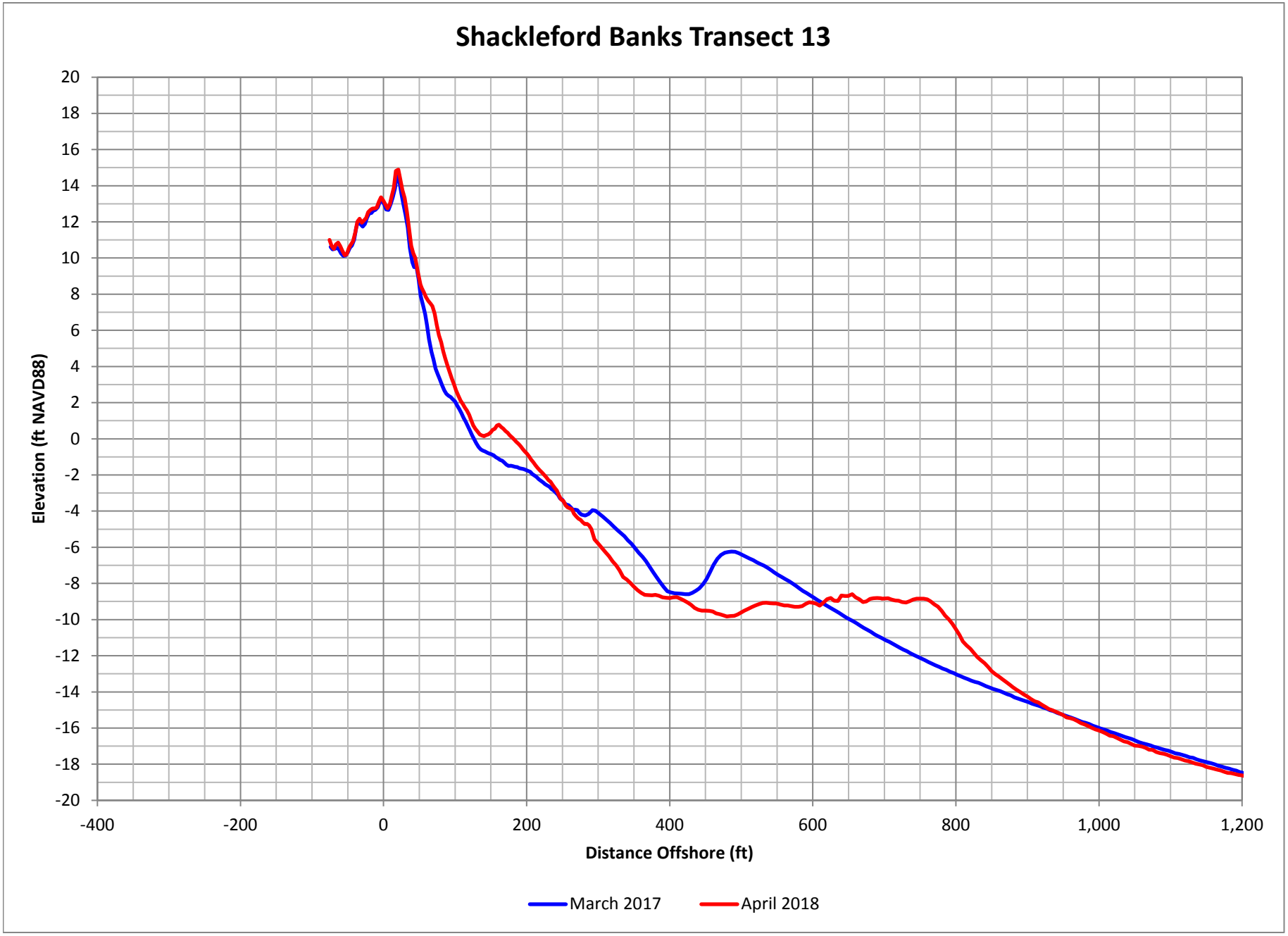


Figure D-306. Shackleford Banks Profile Comparison Plot

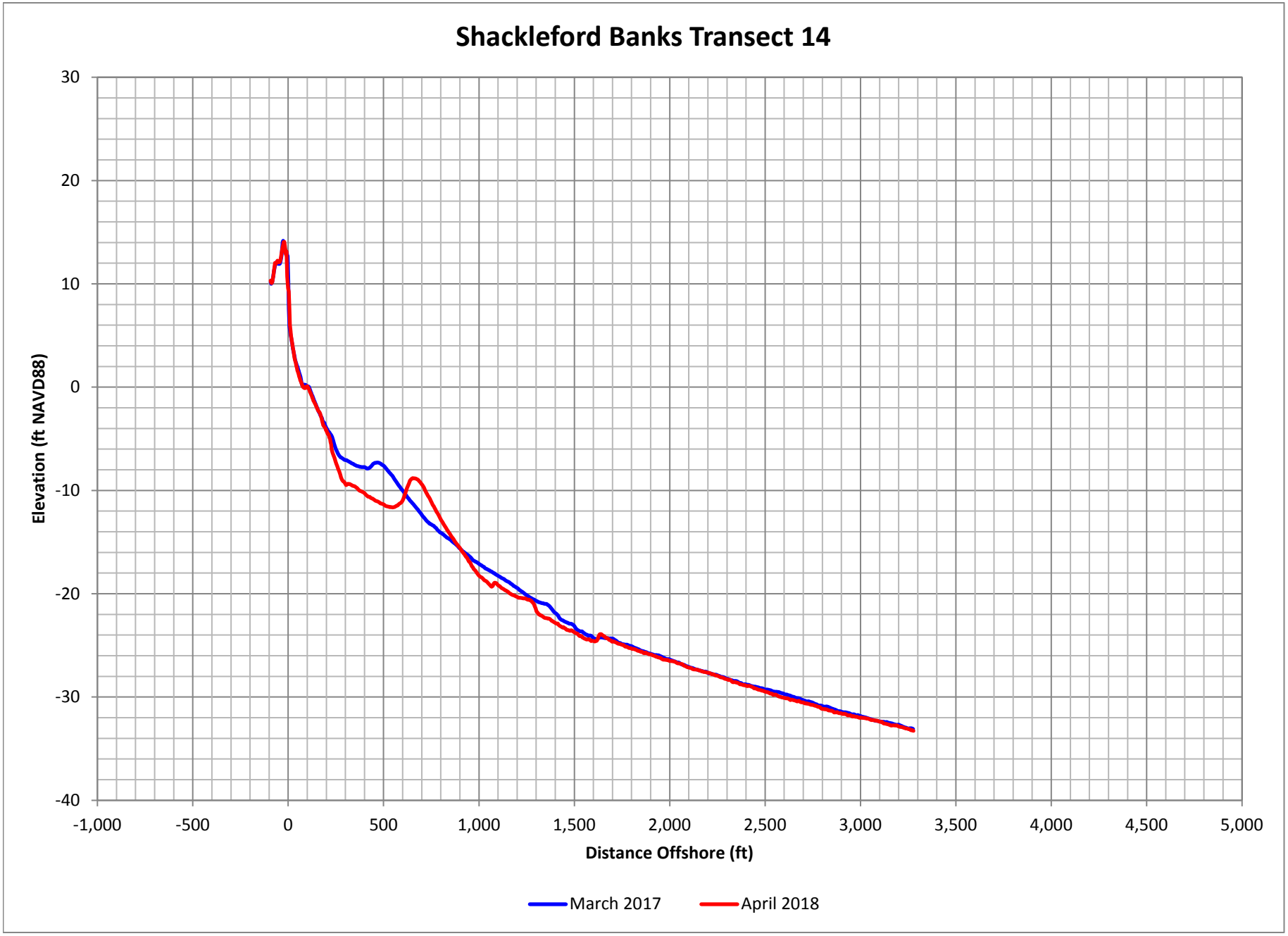


Figure D-307. Shackleford Banks Profile Comparison Plot

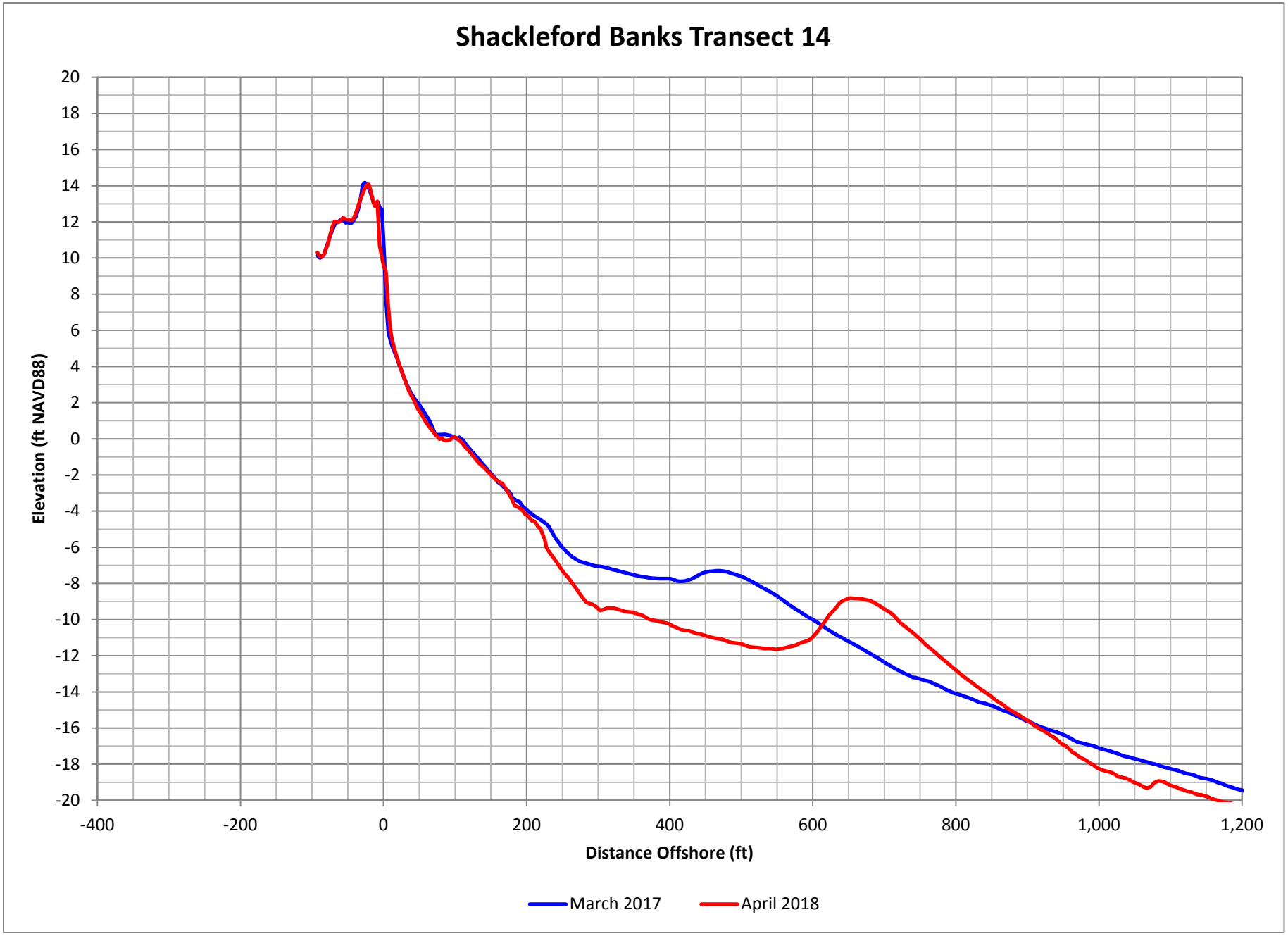


Figure D-308. Shackleford Banks Profile Comparison Plot

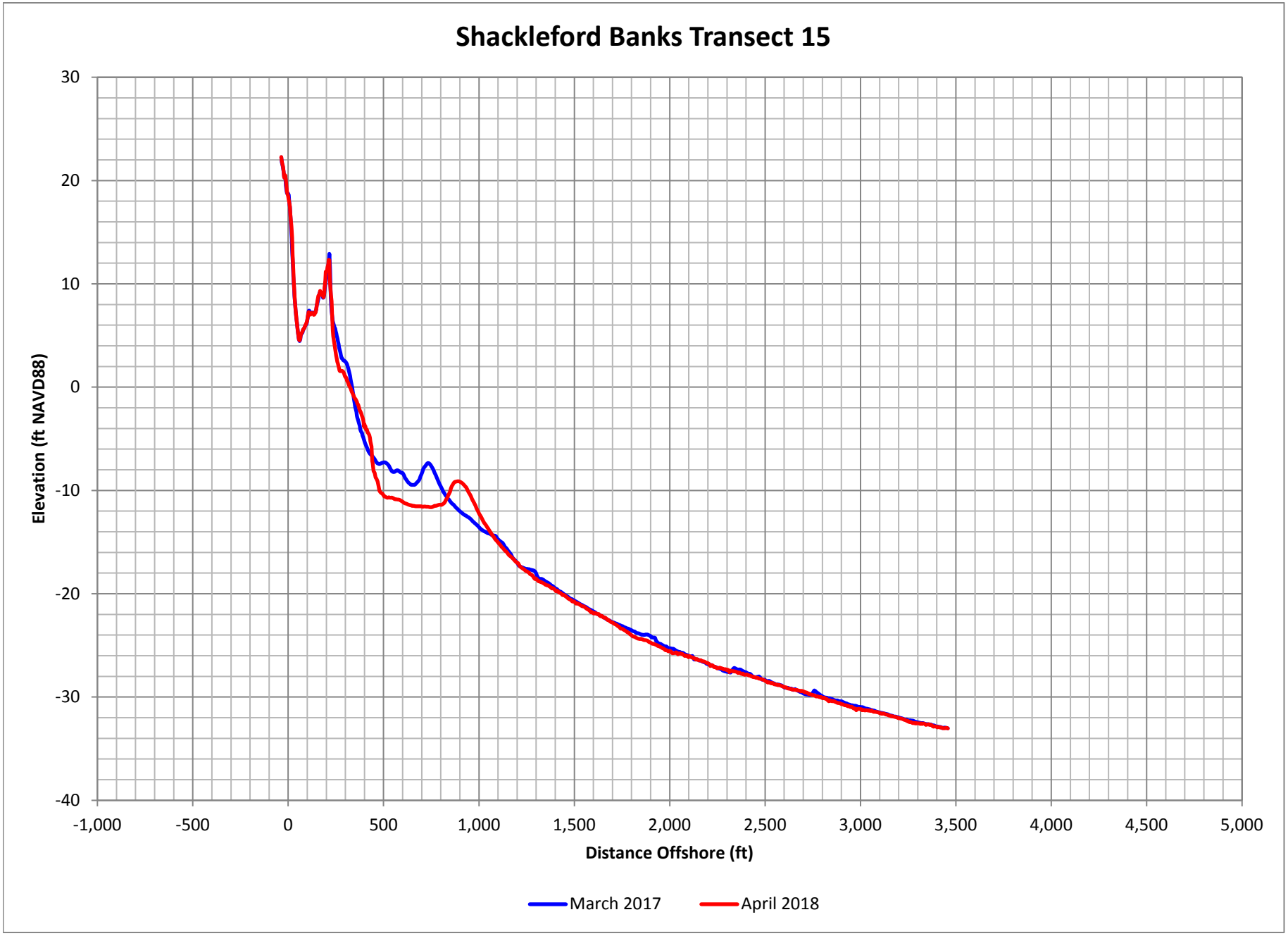


Figure D-309. Shackleford Banks Profile Comparison Plot

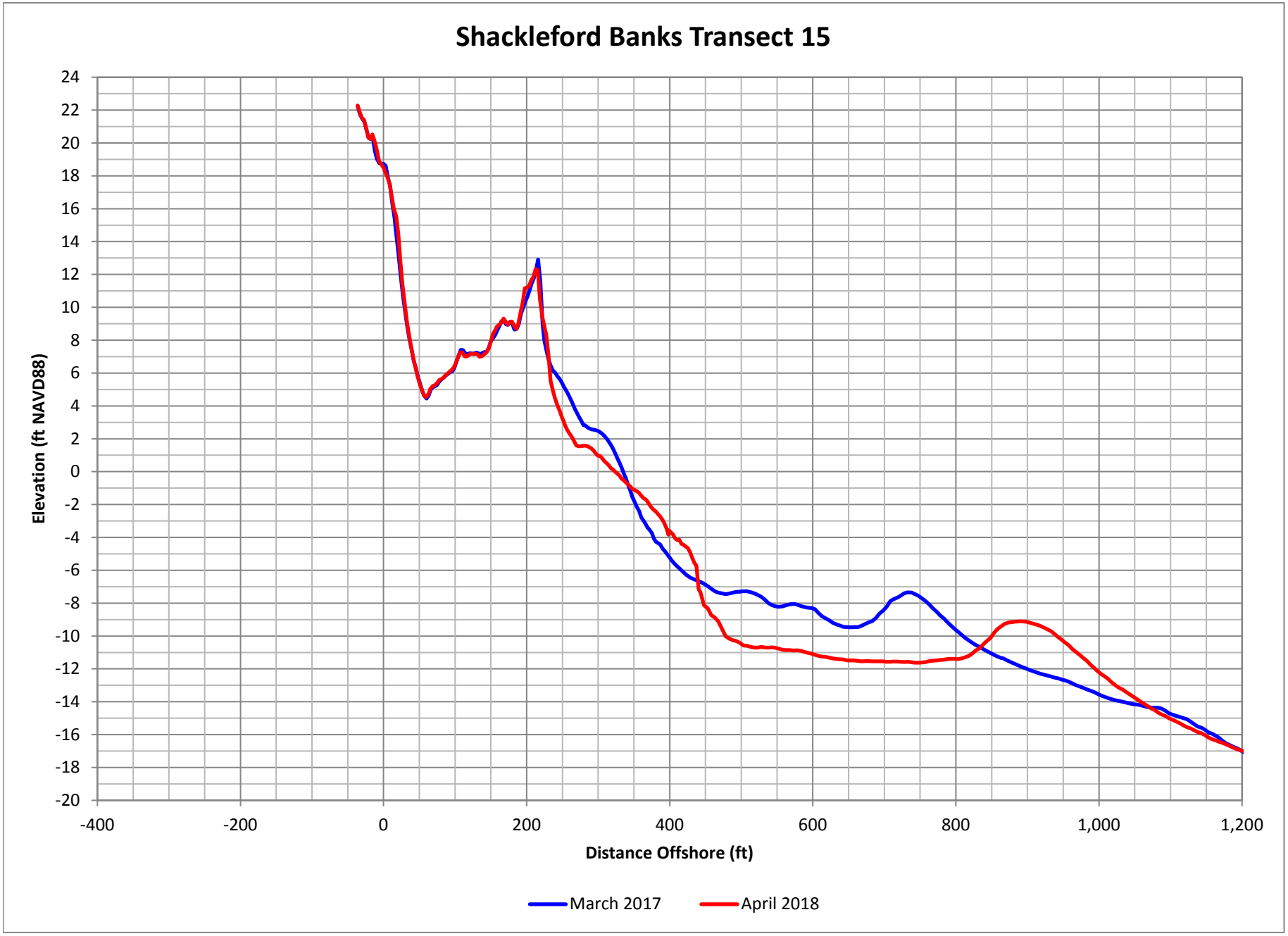


Figure D-310. Shackleford Banks Profile Comparison Plot

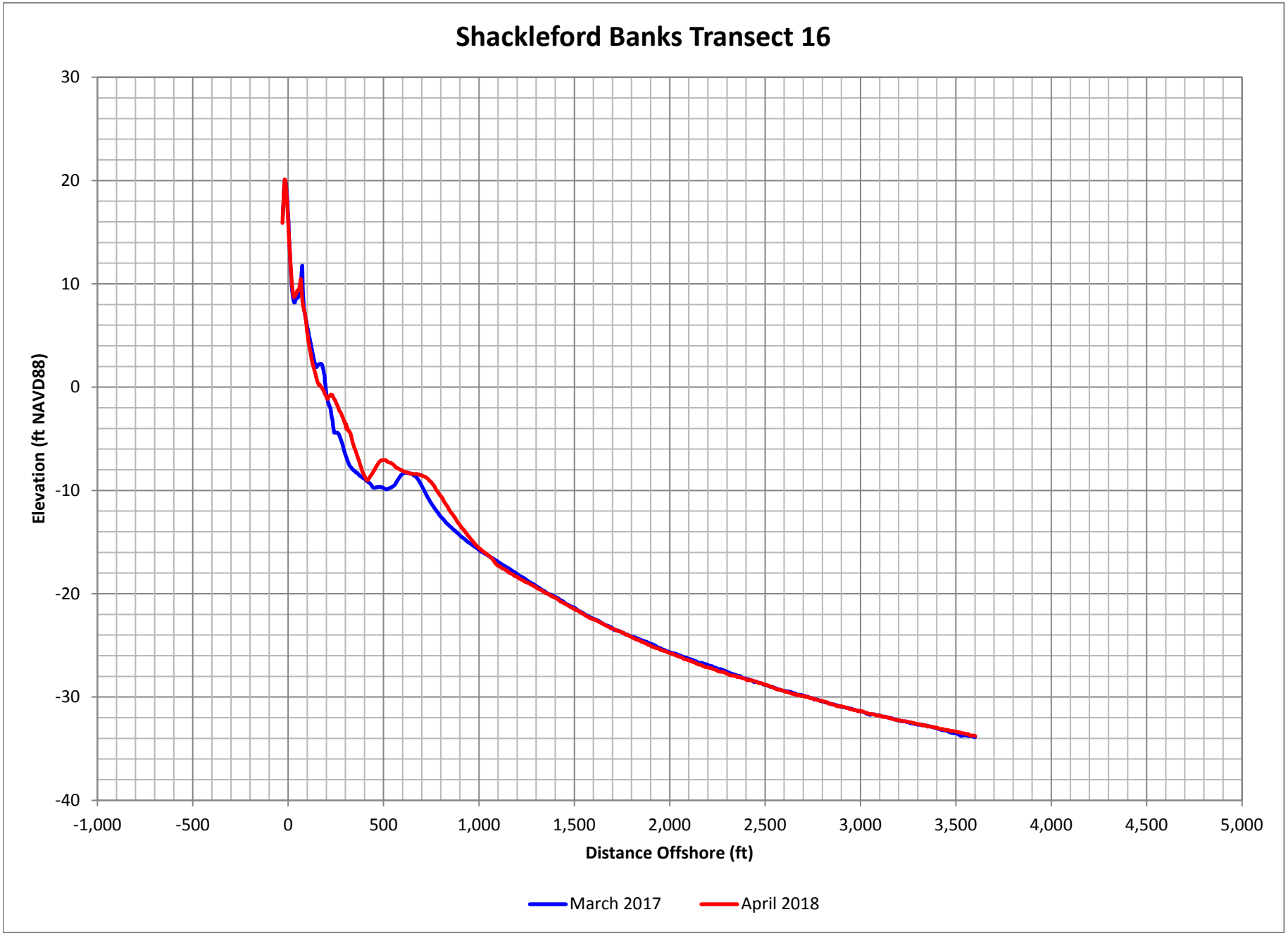


Figure D-311. Shackleford Banks Profile Comparison Plot

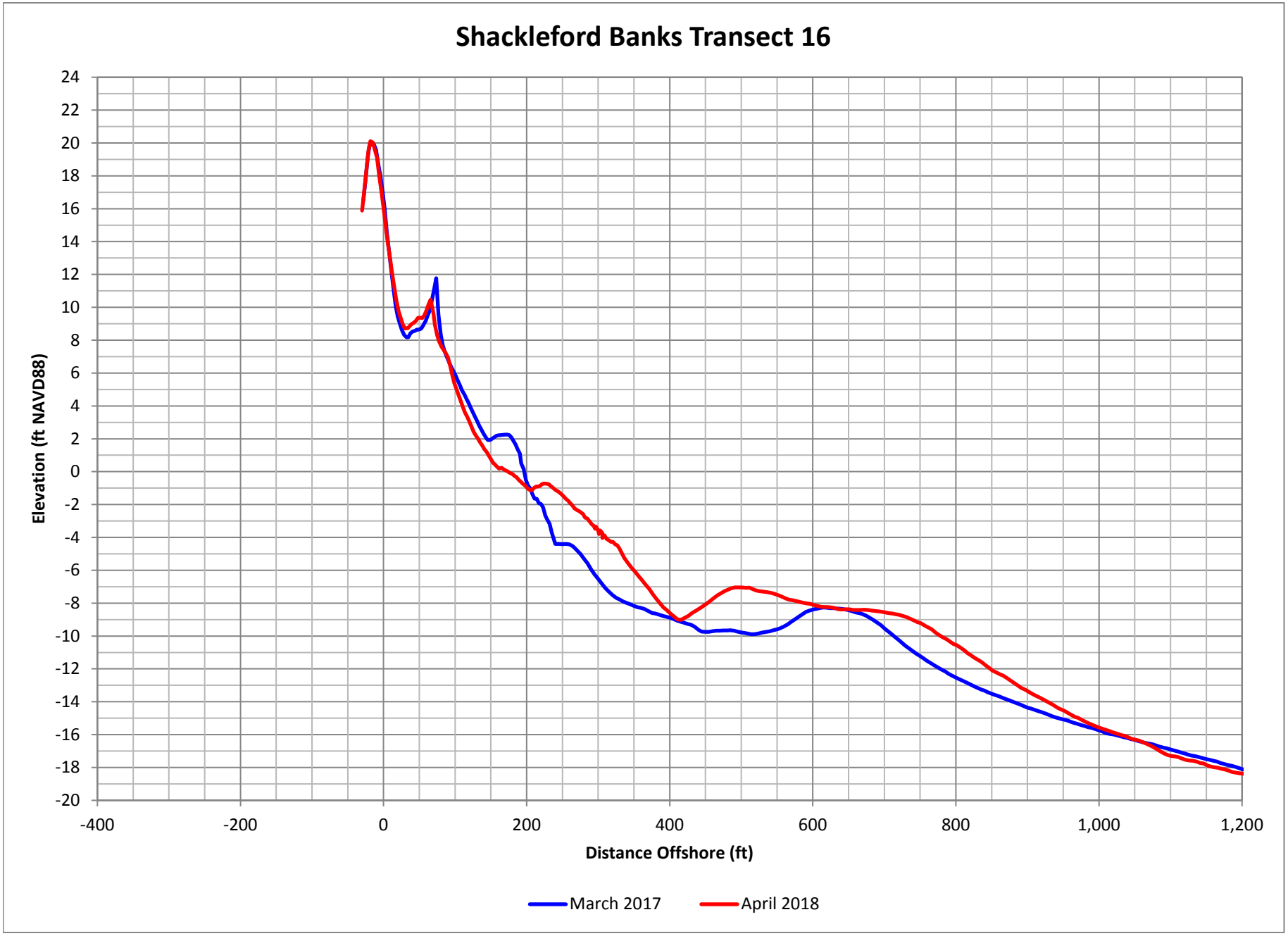


Figure D-312. Shackleford Banks Profile Comparison Plot

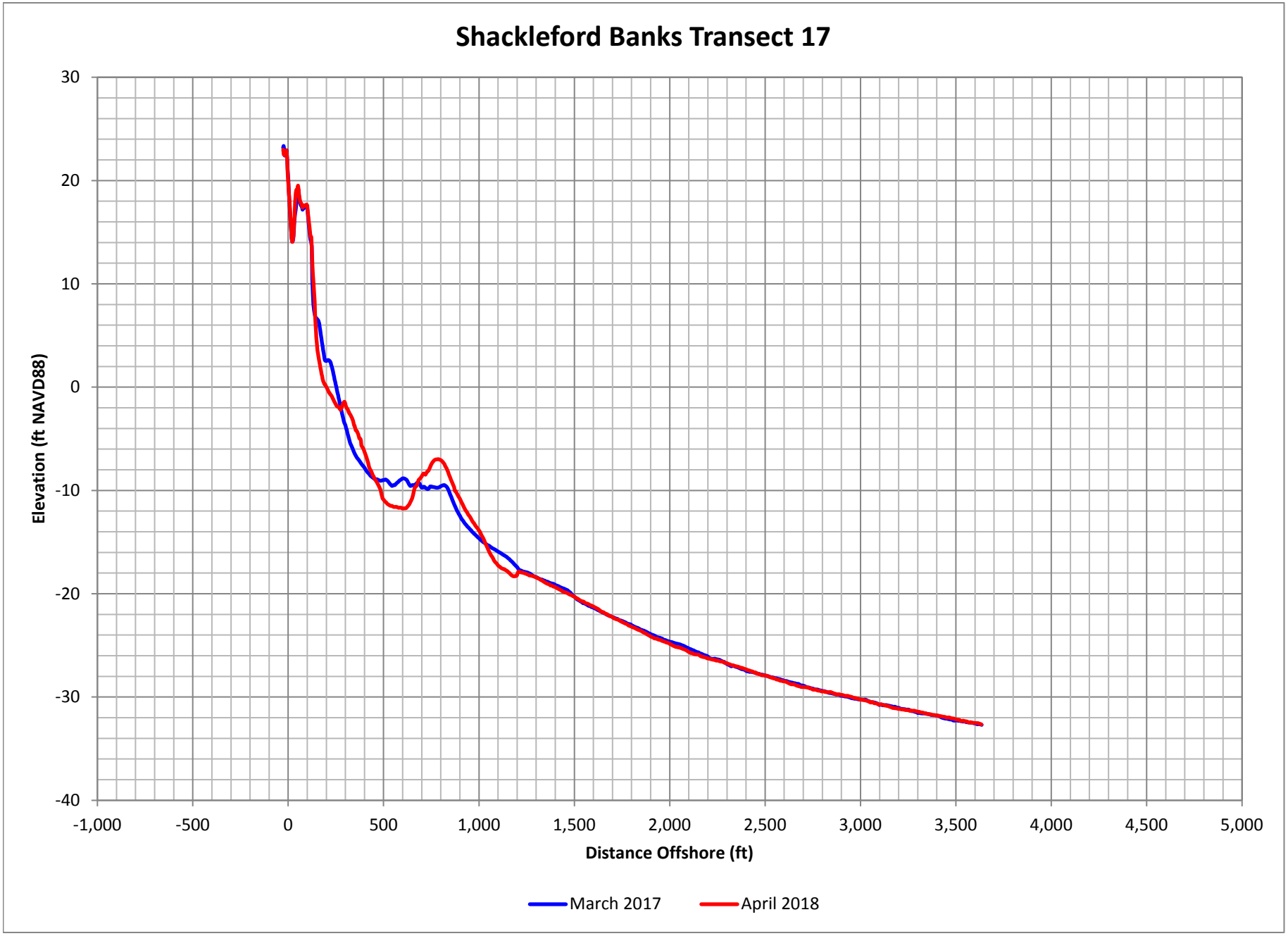


Figure D-313. Shackleford Banks Profile Comparison Plot

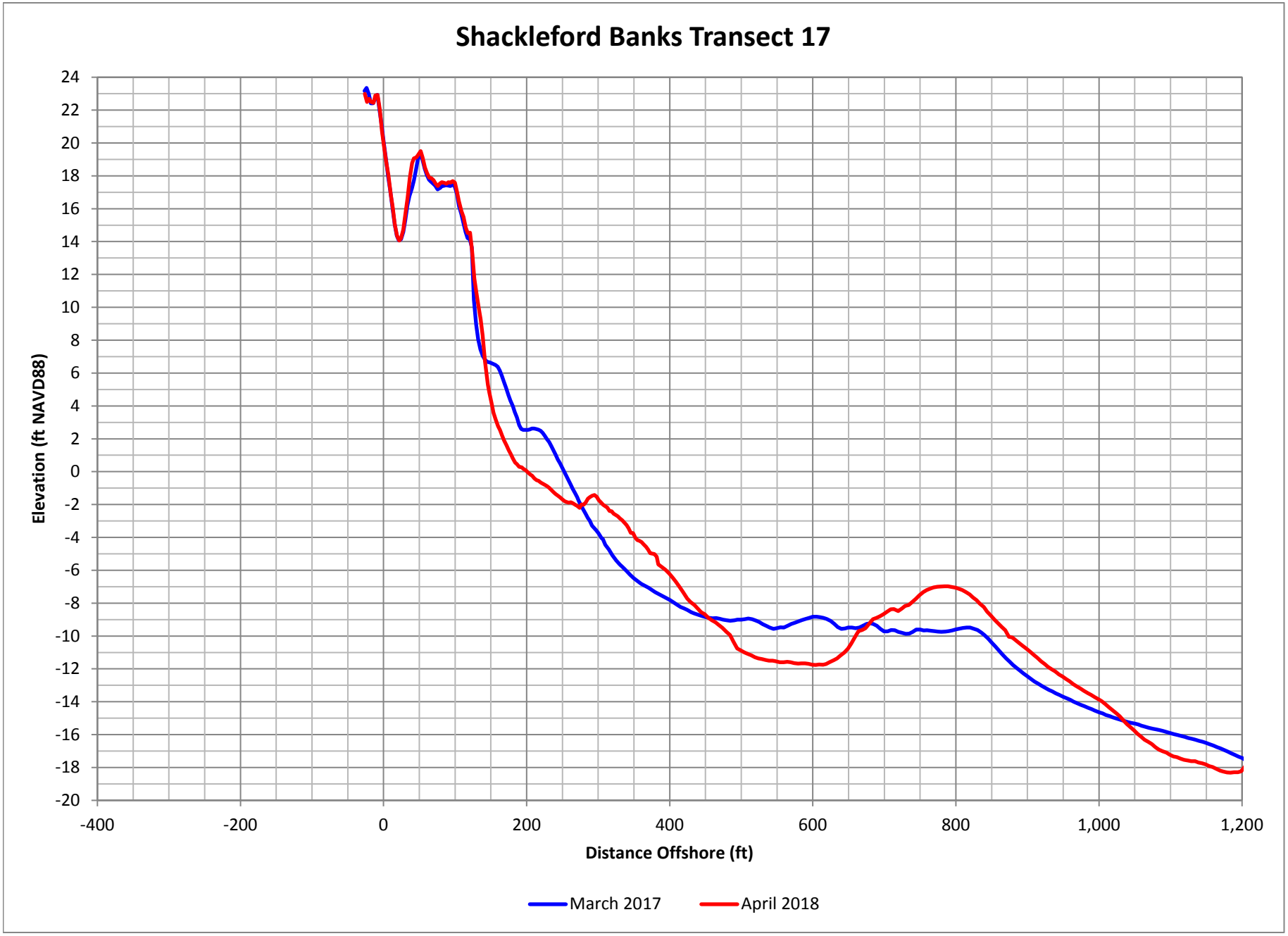


Figure D-314. Shackleford Banks Profile Comparison Plot

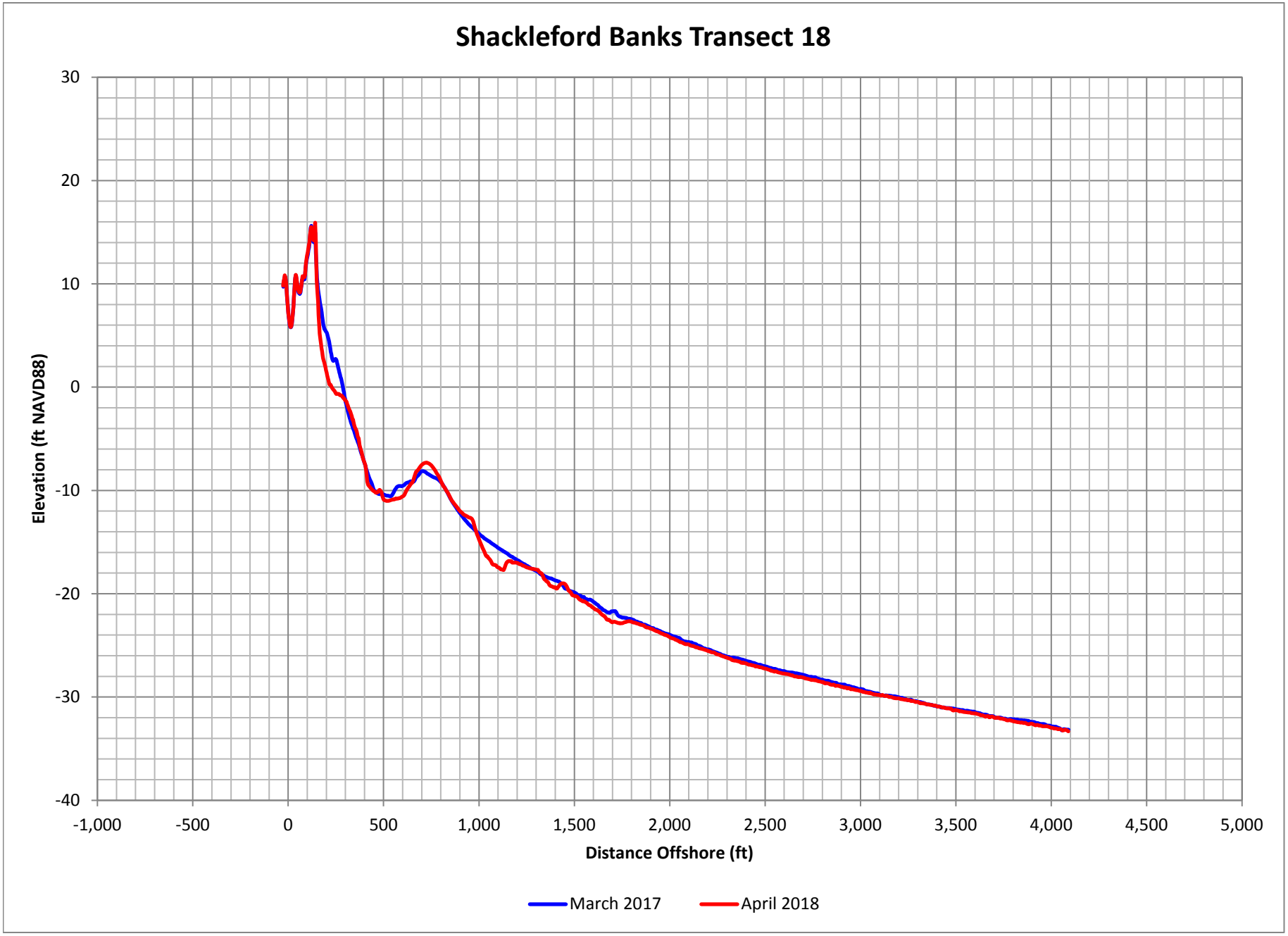


Figure D-315. Shackleford Banks Profile Comparison Plot

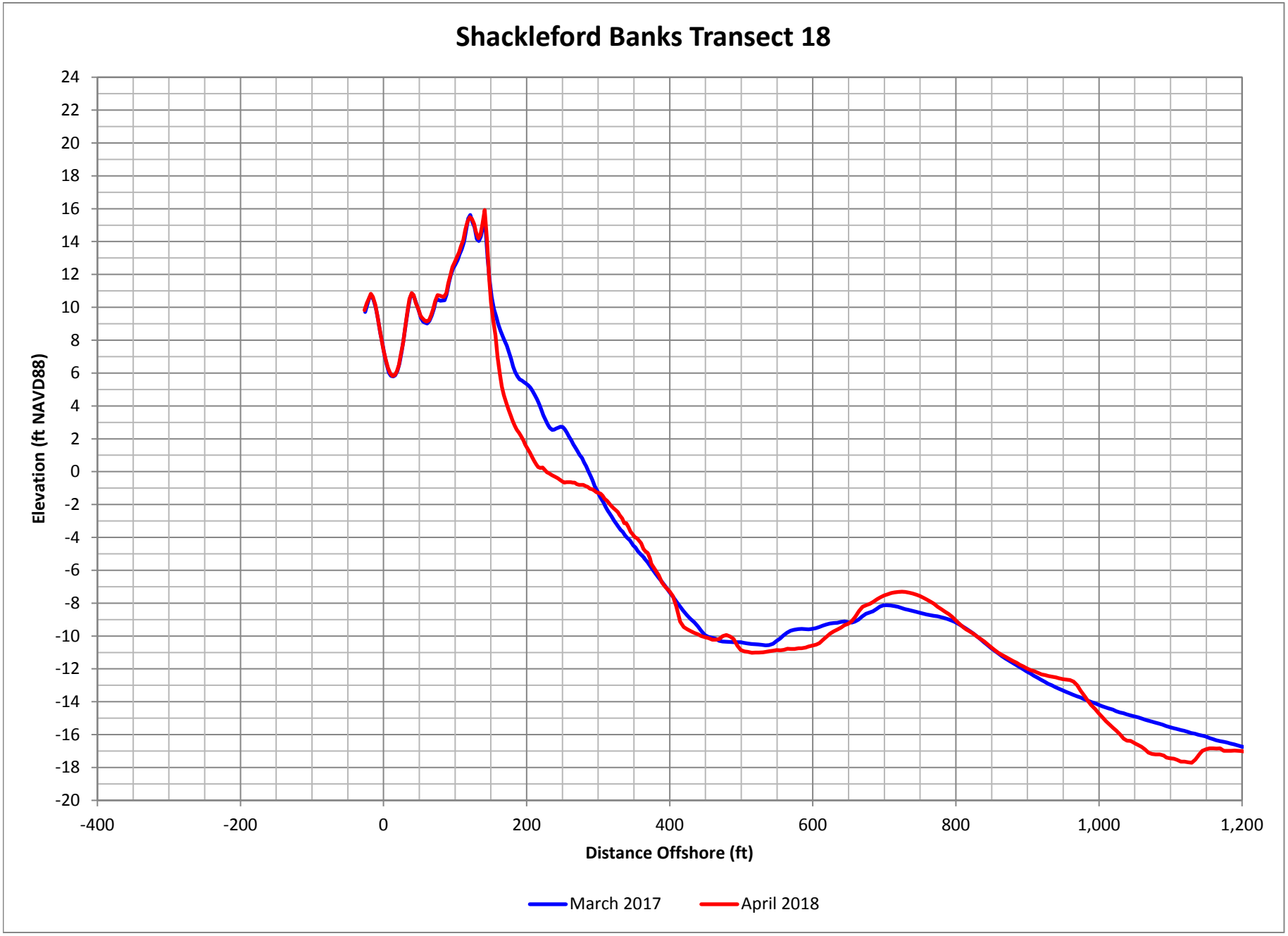


Figure D-316. Shackleford Banks Profile Comparison Plot

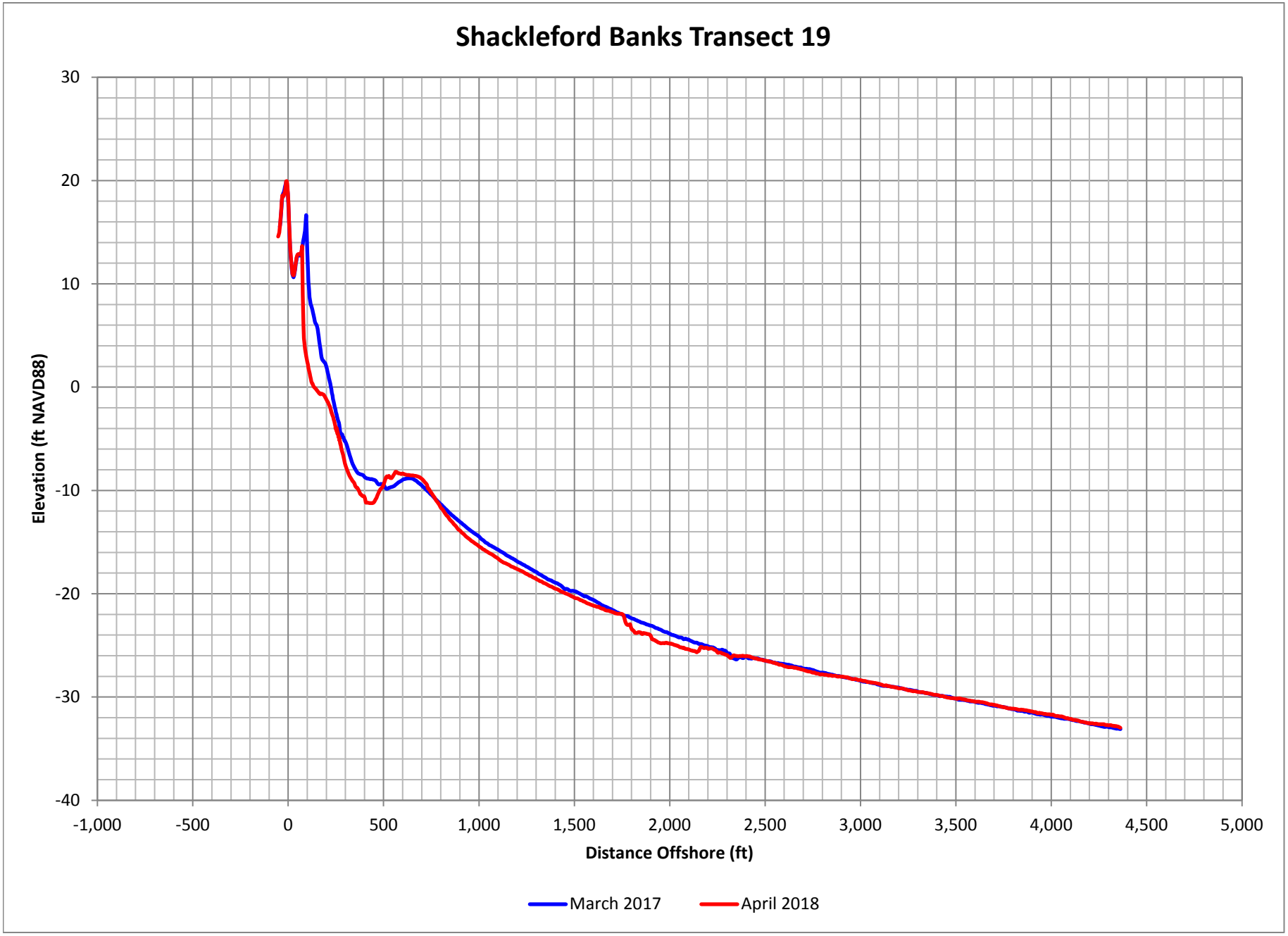


Figure D-317. Shackleford Banks Profile Comparison Plot

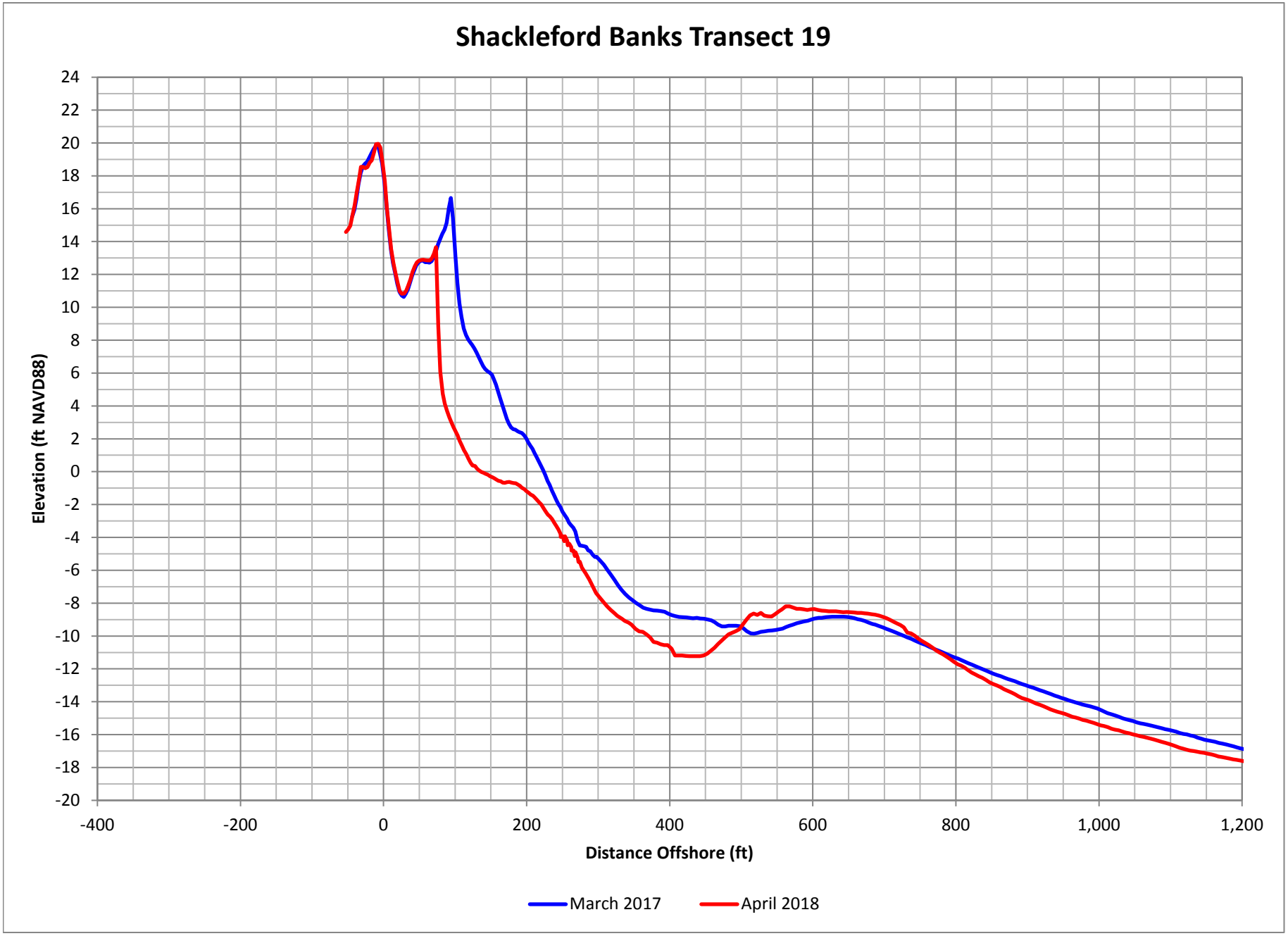


Figure D-318. Shackleford Banks Profile Comparison Plot

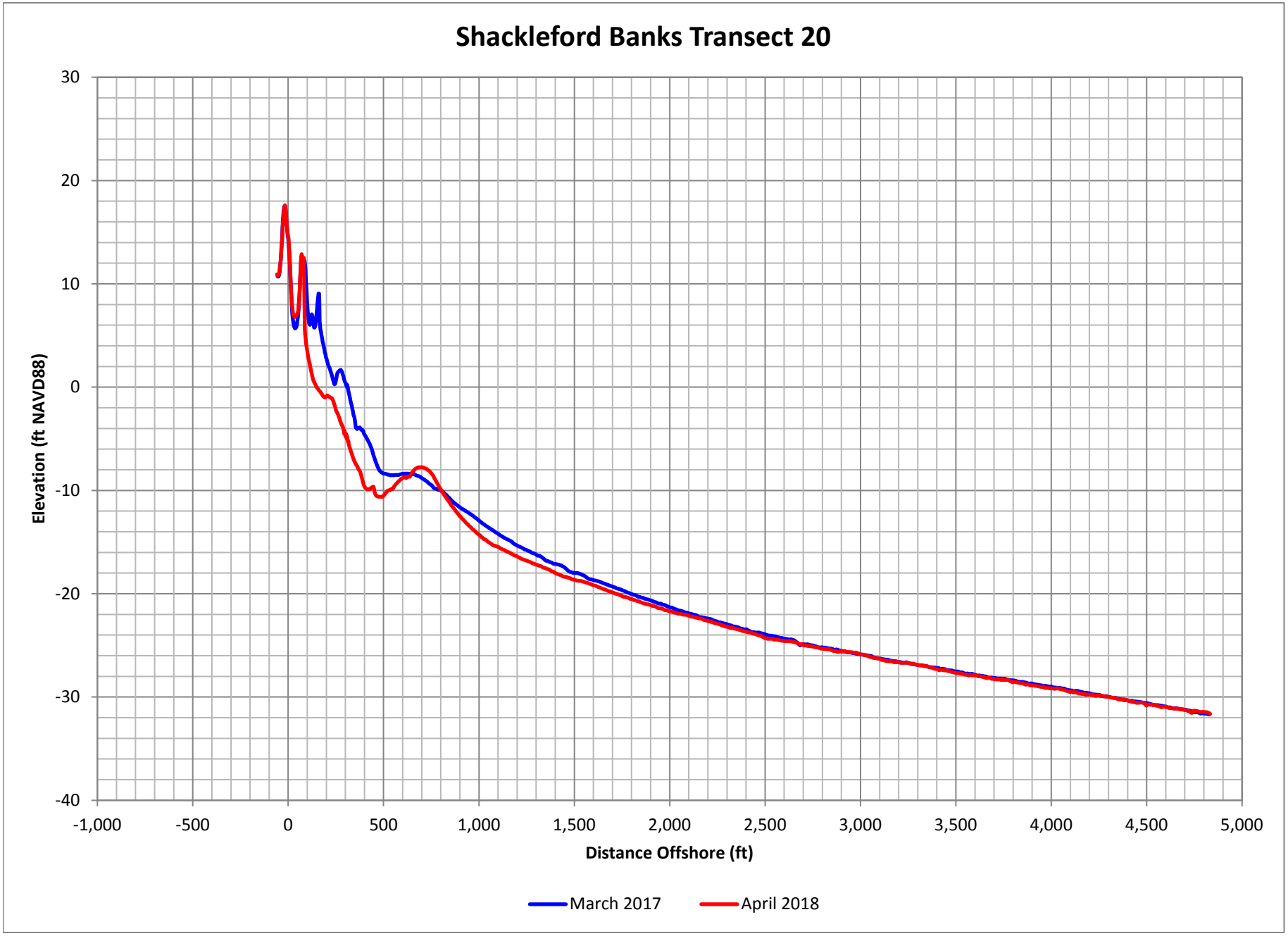


Figure D-319. Shackleford Banks Profile Comparison Plot

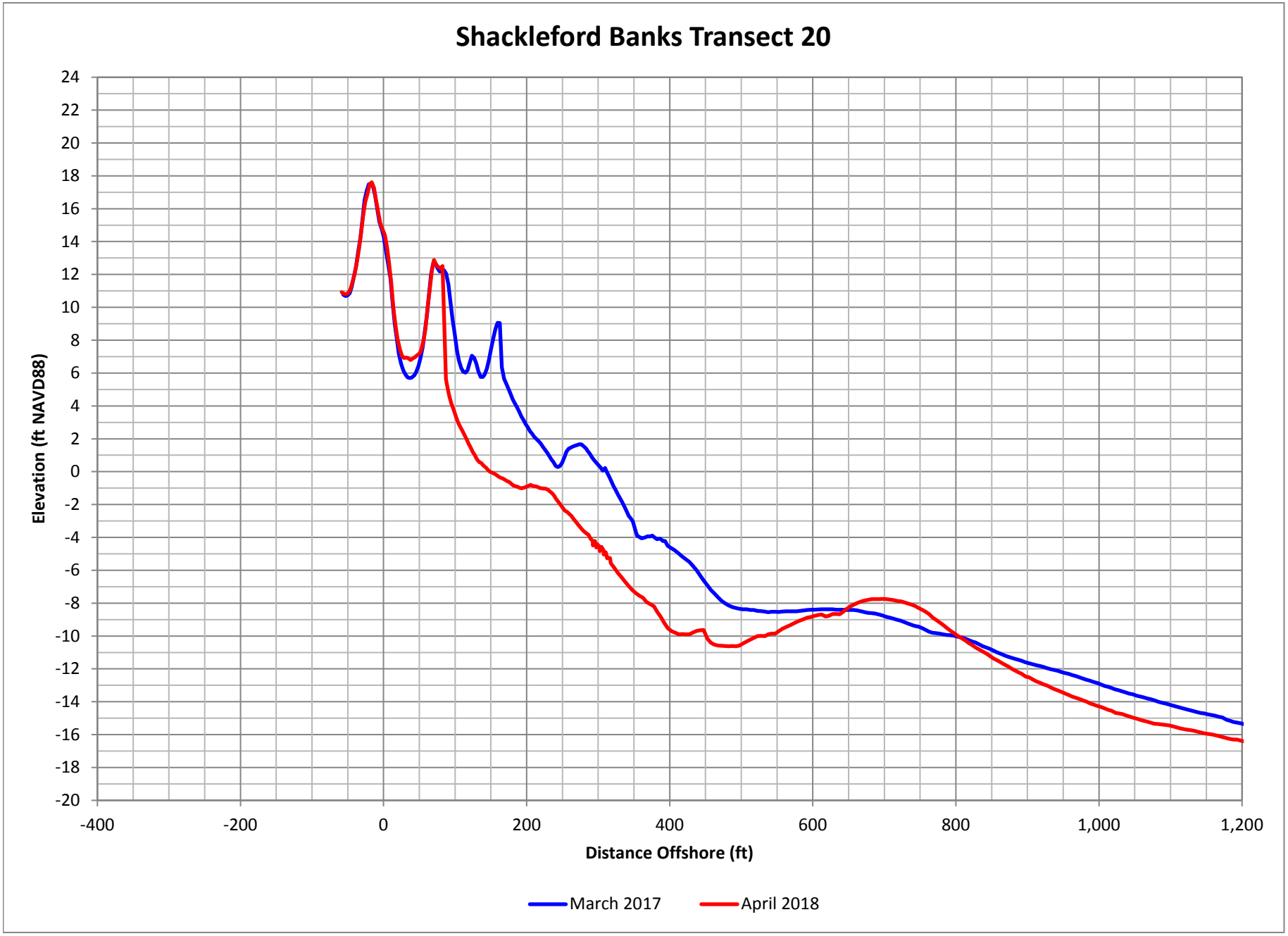


Figure D-320. Shackleford Banks Profile Comparison Plot

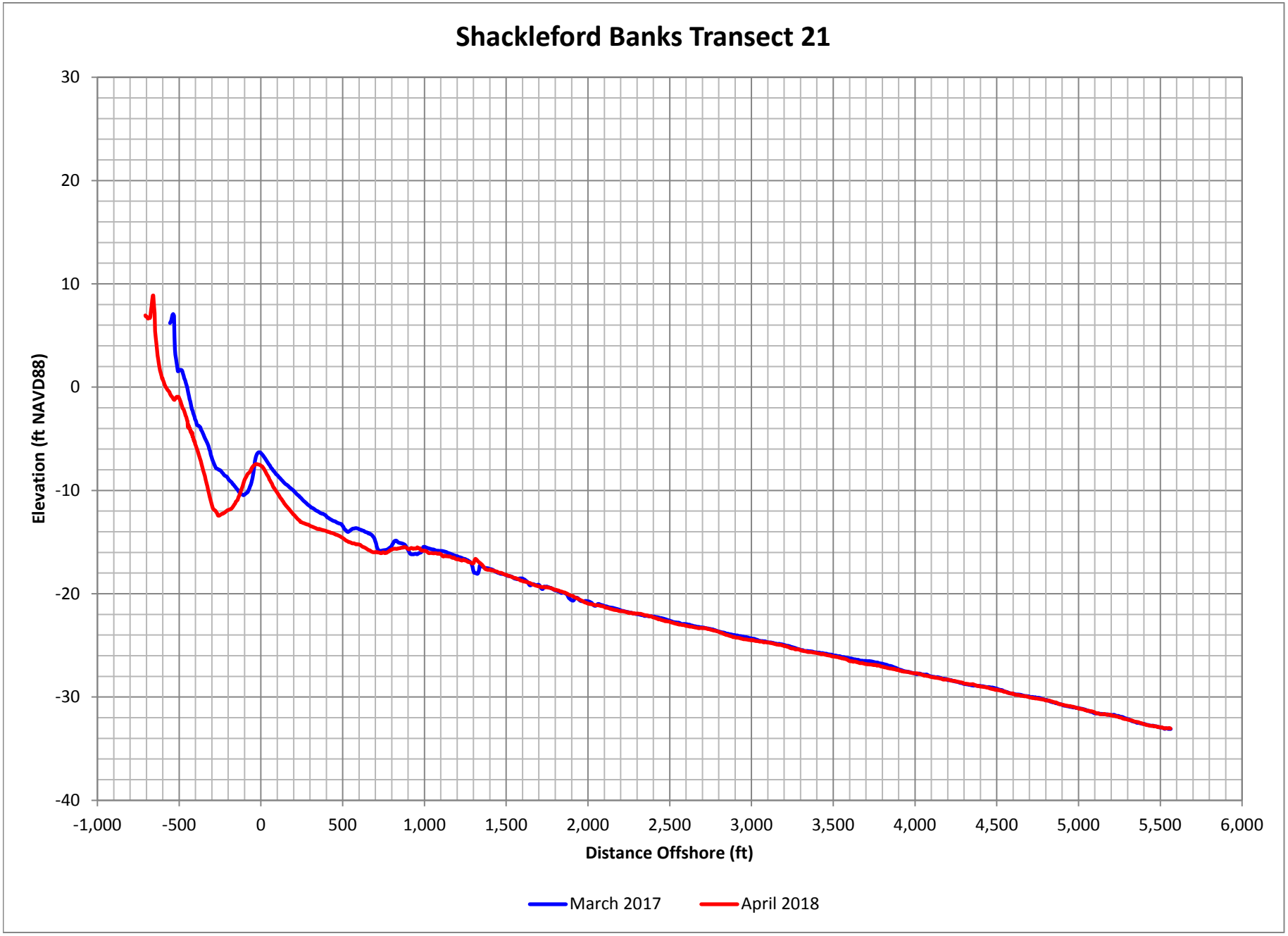


Figure D-321. Shackleford Banks Profile Comparison Plot

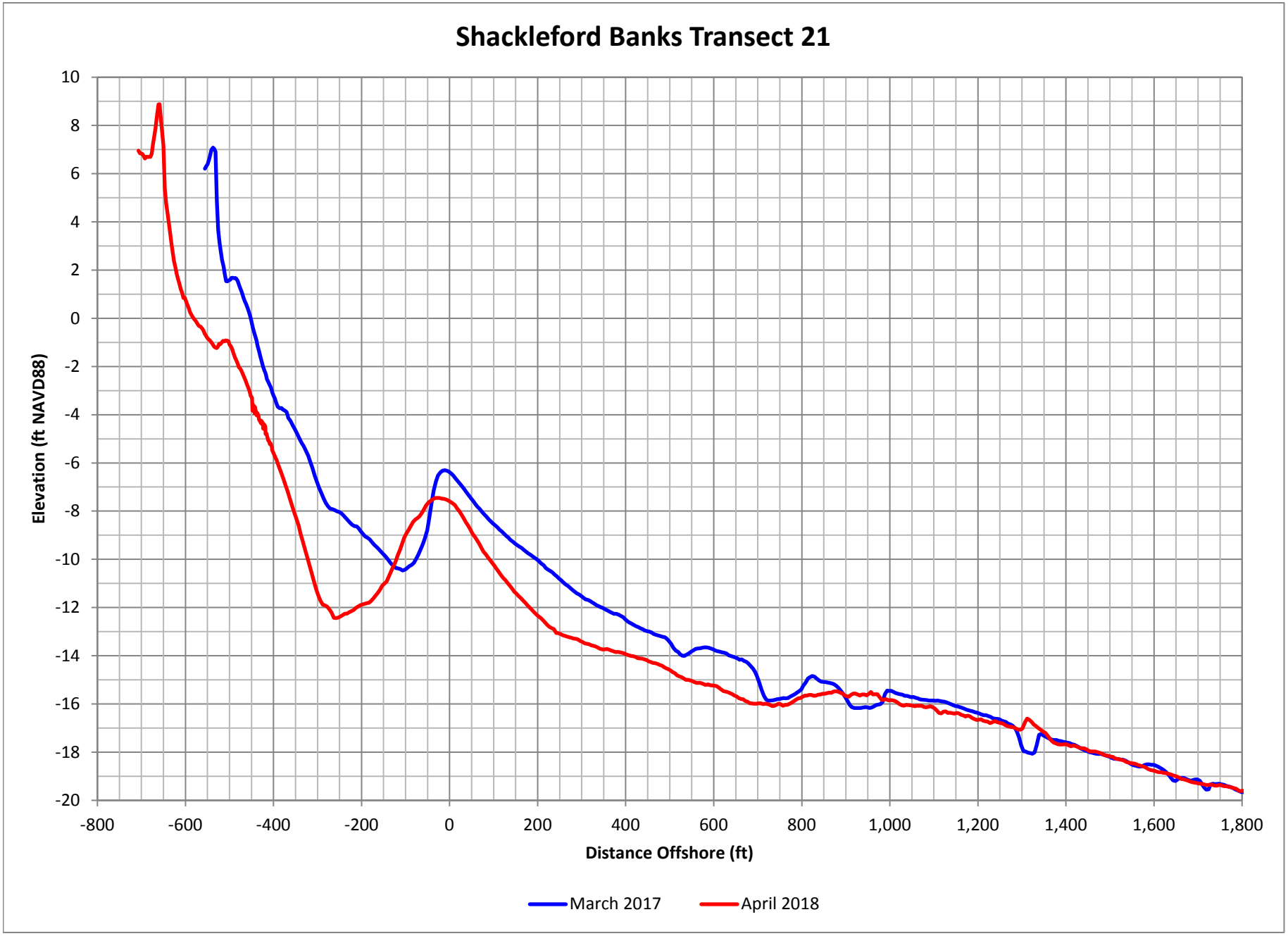


Figure D-322. Shackleford Banks Profile Comparison Plot

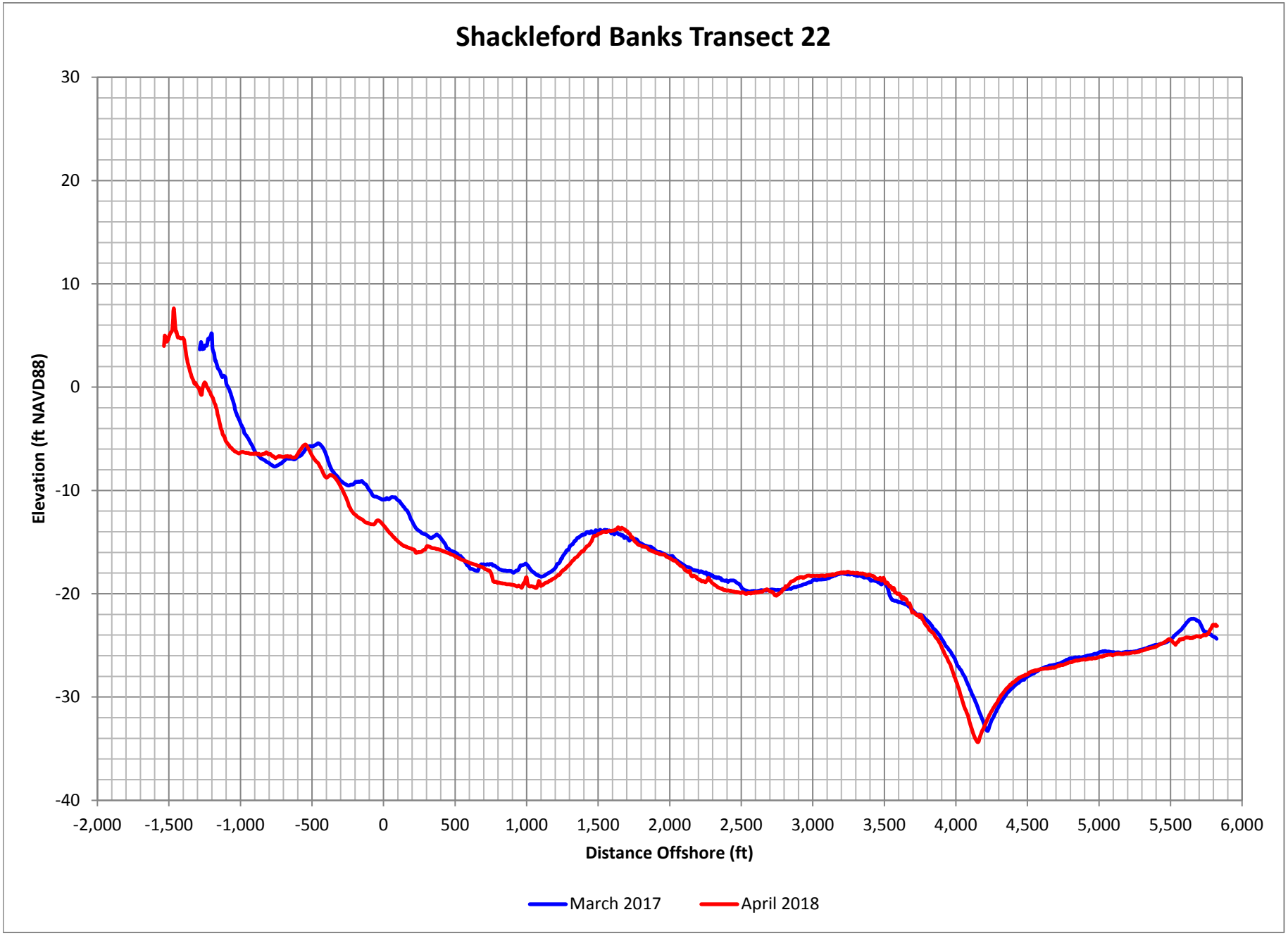


Figure D-323. Shackleford Banks Profile Comparison Plot

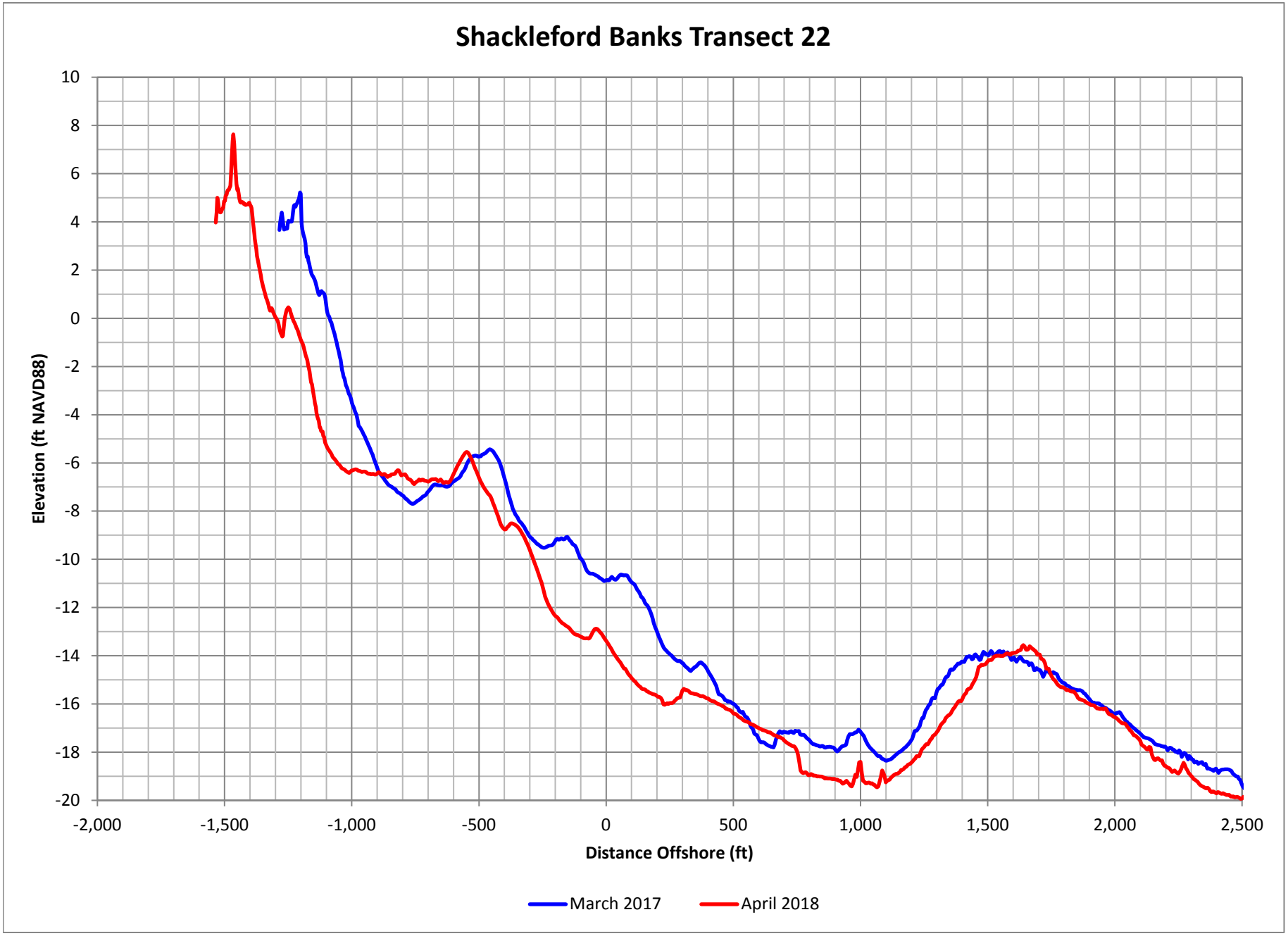


Figure D-324. Shackleford Banks Profile Comparison Plot

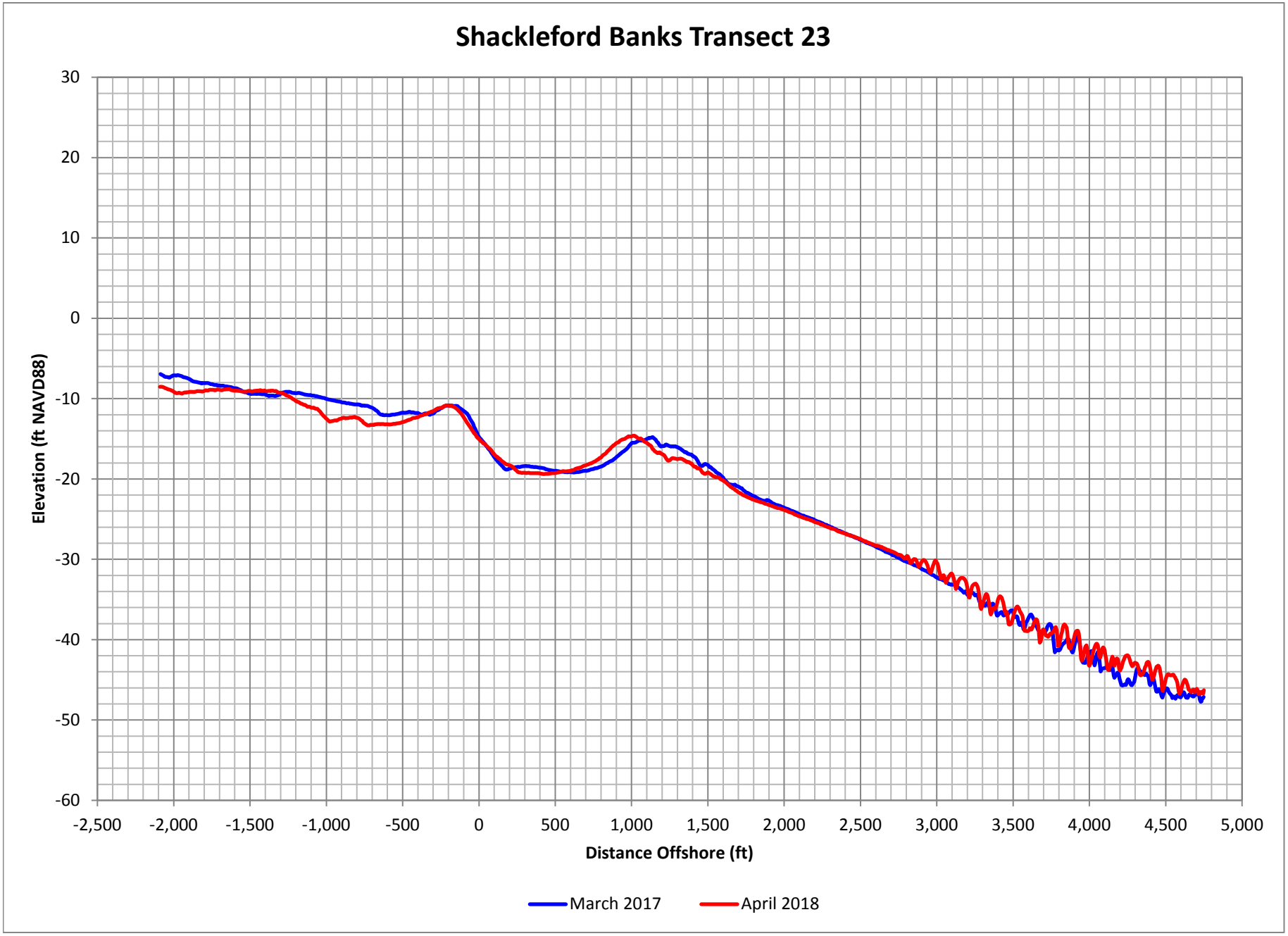


Figure D-325. Shackleford Banks Profile Comparison Plot

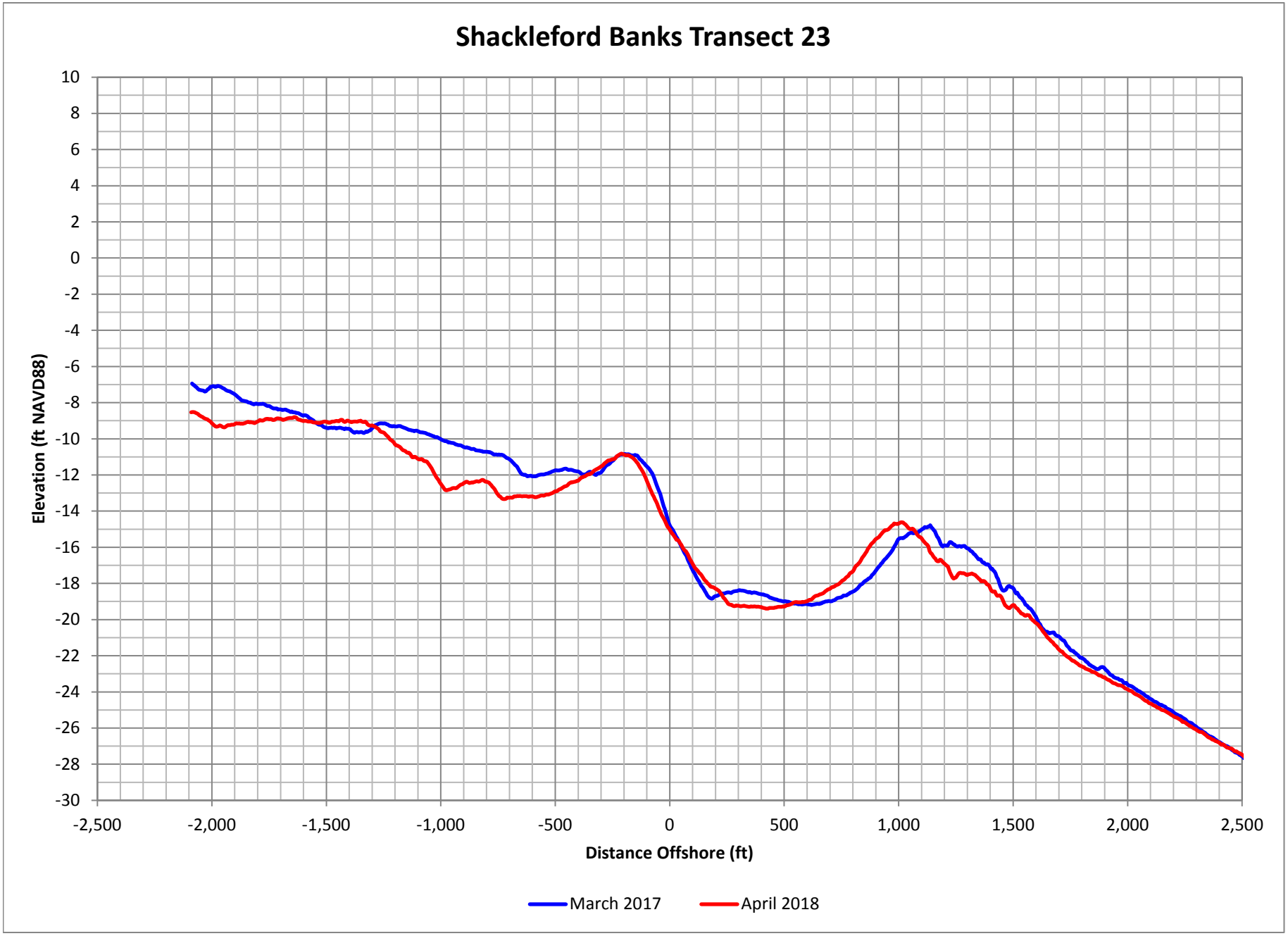


Figure D-326. Shackleford Banks Profile Comparison Plot

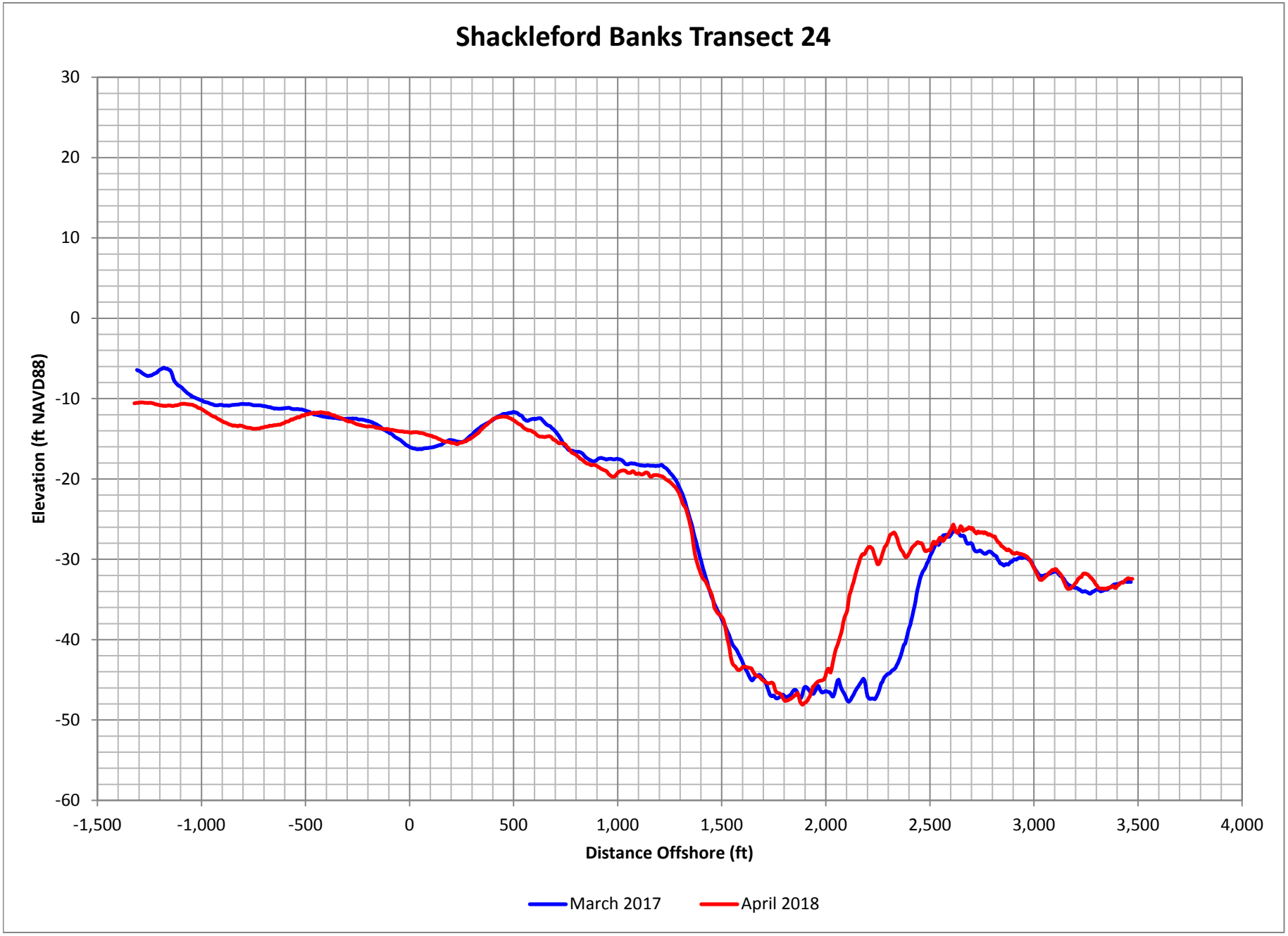


Figure D-327. Shackleford Banks Profile Comparison Plot

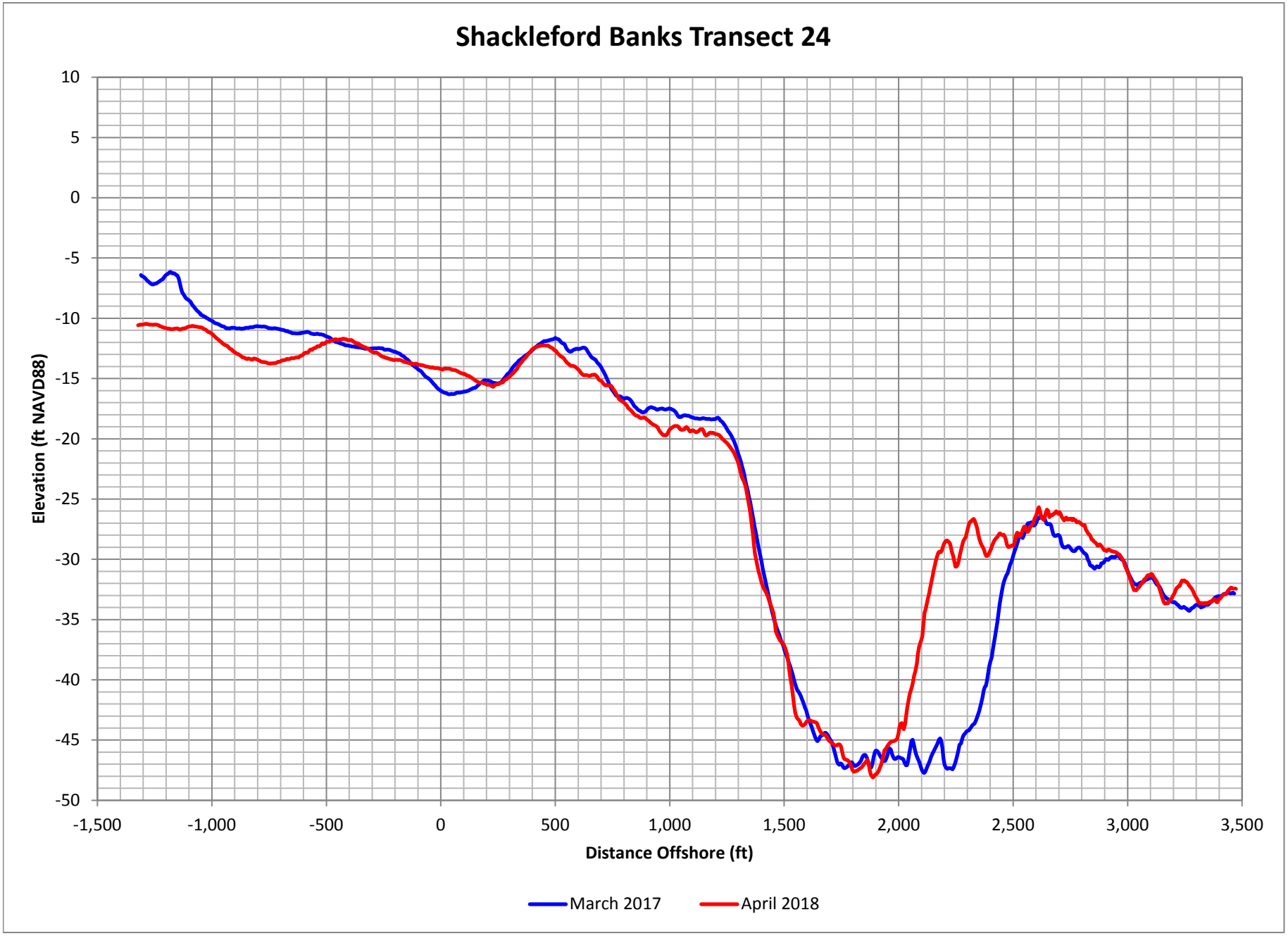


Figure D-328. Shackleford Banks Profile Comparison Plot

APPENDIX E

Results Tables

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (2017 to 2018)

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)
Bogue Inlet-Ocean/ Emerald Isle West	1	0+00	146.36	103.46	24.57	292.59	63.46	609.72	79.09	1305.61	85.52	2621.70	84.80
	2	5+59	127.16	108.63	21.99	289.81	47.52	568.34	37.36	1180.91	28.41	2414.34	26.60
	3	11+23	112.53	54.52	18.11	153.29	50.36	341.80	72.04	814.81	58.10	1824.73	56.28
	4	17+39	-19.62	17.83	-0.66	83.08	5.90	243.57	8.49	645.17	-7.75	1538.00	-6.78
	5	23+22	-2.47	34.91	4.35	103.49	10.28	263.82	5.90	627.12	-9.29	1465.90	-11.03
	6	36+28	22.14	30.47	4.51	85.56	2.41	228.91	-1.28	553.42	-8.20	1297.90	-9.90
	7	53+10	14.48	70.12	3.45	157.05	2.15	335.62	2.79	685.13	-8.86	1400.98	-14.55
	8	67+74	-17.45	68.73	-0.37	155.20	-7.12	342.73	2.03	691.60	-5.75	1373.70	-11.40
	9	80+91	-17.81	56.79	-1.44	140.92	-4.12	312.74	-6.75	653.27	-14.76	1315.39	-20.76
	10	93+40	-8.60	53.80	2.96	128.72	8.18	295.24	4.60	629.99	0.24	1274.20	-5.33
	11	108+58	26.23	48.29	5.24	126.83	12.61	295.88	8.47	628.49	2.30	1263.97	-2.23
Emerald Isle West	12	121+18	-3.03	90.21	-0.17	174.12	0.16	357.33	7.52	704.57	3.39	1349.68	-2.72
	13	134+61	5.63	64.71	4.54	137.04	-4.43	308.87	-4.36	648.37	-8.41	1280.98	-14.73
	14	146+67	-6.39	58.33	1.26	132.04	-6.69	303.50	-1.66	644.95	0.44	1276.92	-0.41
	15	160+16	1.35	54.10	6.01	126.71	4.54	296.41	10.93	624.86	5.67	1240.07	-2.06
	16	174+79	-10.21	59.54	11.20	136.66	10.48	302.72	14.41	632.12	14.85	1251.81	7.10
	17	189+23	-14.53	68.67	-3.75	154.34	-0.81	336.07	7.45	677.94	-1.23	1311.17	-11.27
	18	203+53	-10.34	71.26	-1.59	161.73	5.29	356.26	20.19	700.62	15.14	1334.67	5.62
	19	214+90	-5.29	62.00	2.71	132.15	5.90	302.45	12.61	631.22	9.13	1257.16	5.48
	20	230+02	-10.15	94.17	-0.66	183.44	13.32	359.81	14.85	705.62	9.60	1355.73	2.41
	21	241+15	4.03	64.79	-1.73	146.75	3.81	319.11	14.56	659.88	8.69	1304.25	-0.53
	22	252+19	8.40	72.61	-0.65	149.91	0.87	313.31	4.60	654.60	-1.13	1306.26	-8.44
	23	263+24	2.89	45.42	-0.89	110.23	-2.15	265.09	5.88	597.68	-0.54	1233.88	-7.18
	24	279+57	5.02	107.65	-1.37	185.18	-2.19	364.70	8.42	721.69	1.75	1389.95	-4.66
	25	290+77	13.45	62.06	5.30	137.98	16.09	314.08	26.00	662.15	18.53	1316.61	10.76

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from June 9, 2017 to March 23, 2018.

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (2017 to 2018) Cont.

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)
Emerald Isle Central	26	304+77	19.33	77.09	3.13	148.26	-2.10	327.13	11.27	684.05	3.54	1345.35	-6.21
	27	318+11	18.08	80.77	6.26	159.61	10.46	333.57	15.80	695.52	8.46	1355.70	-5.28
	28	329+10	-5.60	75.52	4.28	149.76	9.24	325.92	18.34	682.73	11.48	1338.05	2.12
	29	345+80	-36.65	47.38	-4.67	114.60	-1.75	288.17	9.97	637.04	6.40	1287.44	1.75
	30	362+22	-15.49	75.35	0.50	148.42	-0.31	326.15	10.70	685.94	10.55	1344.71	2.81
	31	378+80	15.91	60.95	5.95	124.09	3.55	289.30	15.22	637.26	12.08	1287.61	7.67
	32	395+22	36.48	86.50	10.67	164.35	12.32	330.89	17.38	685.36	11.87	1333.60	1.90
	33	408+86	-7.56	79.27	7.05	159.44	11.28	325.64	13.30	676.73	7.76	1322.54	-0.47
	34	422+83	-10.24	58.83	3.79	132.99	11.25	298.59	15.62	643.52	12.91	1283.34	2.17
	35	435+62	-23.81	44.66	0.29	105.49	6.45	268.84	16.61	596.50	6.19	1231.32	-1.74
	36	450+22	7.57	52.32	6.71	111.41	7.38	270.18	14.55	606.75	8.12	1249.24	0.87
Emerald Isle East	37	461+34	-5.77	34.05	0.62	87.97	-3.60	245.19	6.82	573.56	3.60	1197.90	-4.70
	38	472+44	-9.47	54.33	2.83	121.35	9.01	280.84	8.69	624.20	7.24	1265.38	0.78
	39	483+48	-9.62	58.81	3.38	121.14	0.12	294.25	13.03	641.64	10.18	1300.92	3.48
	40	494+44	-3.85	44.69	4.32	104.61	9.02	264.16	18.86	598.52	19.68	1226.28	18.44
	41	505+39	-16.56	55.90	-1.16	128.14	9.59	293.74	14.46	641.69	13.04	1287.10	8.08
	42	516+57	-33.60	27.34	-7.04	75.58	-6.90	222.33	-5.47	546.79	-9.54	1164.11	-18.61
	43	527+37	-47.15	36.82	-6.31	91.89	-8.93	252.37	-7.48	587.33	-9.68	1218.57	-18.57
	44	538+39	-22.18	63.06	1.68	131.17	6.69	299.24	12.82	652.34	13.41	1299.47	6.79
	45	549+45	2.28	56.04	2.52	132.25	18.97	294.47	20.88	645.42	19.99	1292.83	11.66
	46	560+42	30.93	59.83	6.50	134.09	13.35	293.81	12.72	644.13	10.95	1293.42	1.93
	47	571+43	-3.28	55.99	2.28	124.26	7.70	286.15	11.63	633.20	9.32	1280.28	0.44
	48	580+13	-35.92	50.27	-1.28	118.95	8.55	290.70	21.09	641.75	22.05	1294.08	13.47

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from June 9, 2017 to March 23, 2018.

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (2017 to 2018) Cont.

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)
Indian Beach/Salter Path	49	595+84	-31.73	60.07	-0.93	128.34	-1.03	299.44	12.18	650.51	11.70	1309.52	1.40
	50	608+06	-30.39	74.66	-0.30	149.55	2.43	317.66	4.39	674.60	4.73	1344.13	-6.30
	51	620+90	1.11	54.87	2.68	113.90	0.16	268.74	5.33	606.70	-0.33	1266.20	-7.75
	52	633+31	5.81	18.63	-1.65	67.47	0.27	203.09	0.72	522.94	-2.73	1154.32	-15.17
	53	648+17	5.70	86.30	3.20	174.83	10.36	348.34	13.42	711.76	7.59	1405.22	-1.32
	54	660+65	-6.52	116.94	4.98	216.03	7.94	401.45	-0.12	785.67	0.42	1498.88	-9.87
	55	672+30	-14.96	53.82	4.74	118.26	10.40	273.11	7.32	617.43	0.67	1293.77	-7.79
	56	683+24	8.60	43.71	3.98	110.08	11.69	265.43	11.42	609.67	8.05	1280.09	-3.47
	57	693+79	4.73	57.87	4.61	119.51	3.93	283.13	14.16	633.37	12.88	1309.87	3.55
	58	709+05	18.75	51.96	4.29	117.00	12.36	275.46	17.75	621.25	13.93	1299.46	6.35
Pine Knoll Shores	59	723+93	-5.21	47.09	2.87	111.61	11.80	263.49	11.82	613.13	13.35	1297.67	7.15
	60	736+01	-40.34	32.79	-8.12	95.75	0.86	251.59	0.92	592.20	-1.66	1274.17	-12.11
	61	748+06	-53.66	47.96	-11.69	116.30	-7.33	285.56	-3.54	645.50	-3.20	1359.47	-4.35
	62	761+80	18.21	44.23	4.13	102.74	5.33	256.11	14.59	610.07	17.98	1315.29	16.15
	63	774+77	36.35	45.81	7.08	101.48	4.14	253.98	15.83	606.56	17.33	1313.96	13.92
	64	787+61	14.26	53.99	10.95	124.35	14.07	283.66	17.94	640.79	18.30	1351.01	4.71
	65	800+91	2.70	47.46	2.86	110.32	13.48	270.38	20.39	624.44	20.00	1341.60	14.07
	66	813+33	-40.67	37.04	-2.61	97.01	-1.94	251.29	7.93	601.39	6.05	1314.00	-11.11
	67	825+53	-25.35	27.40	-6.69	71.05	-17.68	219.81	-1.14	557.87	-16.33	1265.75	-30.41
	68	840+55	-2.08	50.01	5.98	106.86	-4.59	256.61	-0.68	617.22	0.46	1344.56	-8.66
	69	850+84	11.54	56.62	10.54	116.69	4.50	271.98	10.89	630.14	7.90	1357.65	-8.15
	70	863+28	-1.18	50.55	1.82	115.51	-0.41	274.96	-0.62	640.62	-3.36	1379.26	-19.92
	71	882+23	-23.13	30.92	-2.77	87.88	1.74	246.57	8.17	605.25	8.37	1336.24	-5.39
	72	896+24	-15.56	34.57	-0.69	89.12	-4.00	245.10	0.67	616.13	1.50	1363.03	-12.87
	73	910+53	-17.57	43.15	2.12	103.28	10.21	267.20	10.51	640.10	9.38	1386.90	-8.81
	74	922+70	1.12	49.78	5.14	114.90	5.02	270.03	-1.14	644.24	-5.82	1402.50	-23.14
	75	937+70	3.92	54.28	2.72	122.05	2.55	290.06	2.28	674.29	3.82	1444.23	-9.13
	76	948+81	-8.45	41.77	1.83	103.97	6.99	268.54	15.83	643.45	16.73	1405.70	0.02

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from June 9, 2017 to March 23, 2018.

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (2017 to 2018) Cont.

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)
Atlantic Beach	77	961+72	-13.09	54.59	-0.97	119.18	0.36	287.05	10.78	670.19	14.42	1440.83	3.20
	78	971+20	-3.99	44.41	5.14	103.37	4.16	260.76	9.42	636.12	9.67	1393.78	-9.56
	79	985+64	-29.86	42.54	-6.66	101.07	-7.36	253.35	-6.37	628.87	-10.10	1396.19	-26.08
	80	994+64	-22.24	60.32	-5.37	135.08	0.13	314.43	19.93	702.88	13.57	1485.06	-5.13
	81	1005+61	-31.83	57.81	-1.51	130.90	5.19	310.03	8.29	702.80	7.08	1490.12	-5.86
	82	1012+68	-32.80	37.84	-1.67	101.05	5.15	270.69	24.42	651.29	22.88	1426.08	8.43
	83	1022+69	-13.81	30.96	1.07	83.43	-5.88	243.26	7.53	618.97	5.38	1390.62	-4.80
	84	1032+70	14.93	29.07	5.43	82.75	7.10	244.92	19.57	619.57	18.92	1390.19	6.73
	85	1042+73	18.06	56.54	4.32	130.92	8.55	305.22	13.95	706.68	12.65	1513.27	0.33
	86	1052+75	13.68	59.10	-9.77	141.30	-12.93	305.44	-32.57	712.51	-36.46	1521.80	-58.78
	87	1062+69	-10.95	61.94	2.43	141.61	11.49	317.80	17.12	723.37	16.85	1539.67	2.76
	88	1072+62	-1.91	90.06	7.50	180.18	5.42	375.82	1.85	803.19	3.50	1645.68	-14.35
	89	1082+69	43.32	74.44	12.60	147.95	12.57	327.55	1.15	730.43	5.47	1544.16	-8.41
	90	1093+69	45.81	53.12	9.41	137.25	12.54	327.48	17.19	741.19	23.25	1564.65	13.18
	91	1102+82	-93.56	61.90	-11.16	139.58	-25.47	300.80	-40.98	691.91	-32.88	1493.25	-42.79
	92	1112+81	-119.66	60.30	-16.93	142.16	-44.48	321.97	-57.36	711.33	-52.08	1509.25	-67.35
	93	1122+81	-56.86	73.01	-3.58	169.20	-5.09	349.11	-4.75	740.72	-0.43	1564.99	-6.05
	94	1131+73	-61.88	70.99	6.69	197.77	3.81	411.58	28.98	837.30	32.58	1699.18	23.49
	95	1141+97	12.19	73.78	3.83	173.21	1.03	358.58	1.50	752.65	1.63	1571.50	-4.87
	96	1151+92	-42.89	78.94	10.22	154.47	-16.42	338.11	-18.93	718.39	-20.85	1517.48	-28.39
	97	1161+91	-90.66	87.11	-13.28	203.77	-33.37	412.54	-39.28	819.96	-43.57	1651.03	-46.34
	98	1171+91	-49.20	82.89	-2.83	190.58	-14.30	397.81	-7.28	793.80	-10.21	1605.16	-15.41
	99	1182+17	-54.36	73.25	-6.14	173.98	-13.91	380.27	-11.16	778.37	-10.09	1611.69	-6.25
	100	1191+90	-8.27	146.47	2.42	295.34	13.72	545.44	17.06	993.16	17.04	1946.72	21.34
	101	1201+93	-17.32	105.63	4.70	214.66	8.15	415.22	5.59	789.77	-4.19	1695.18	-18.65
	102	1211+94	-5.48	123.64	0.83	226.20	6.51	424.07	8.75	786.09	-1.69	1750.59	-11.20

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from June 9, 2017 to March 23, 2018.

Table E-1. Summary of Shoreline Change and Volume Change Along Bogue Banks (2017 to 2018) Cont.

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)
Fort Macon	103	1222+11	-28.00	59.27	-0.82	126.44	2.09	276.91	-11.04	606.44	-19.34	1692.92	-25.98
	104	1231+86	-36.40	70.90	-4.90	150.24	-1.75	312.92	-3.07	674.98	-15.33	1853.69	-29.07
	105	1241+79	-68.51	73.57	-3.64	153.54	-14.10	310.44	-23.67	716.46	-35.22	1936.51	-40.63
	106	1251+79	-63.52	78.79	-2.58	153.21	-23.85	317.76	-33.76	818.39	-43.33	2080.23	-42.13
	107	1257+09	-17.02	117.74	5.34	224.63	-3.73	409.82	-13.88	1031.38	-2.55	2299.73	-3.03
	108	1261+80	14.27	77.76	8.55	170.57	5.07	347.94	4.61	942.48	-19.41	2157.49	-18.26
	109	1267+13	64.14	106.22	12.23	226.66	13.76	433.46	-9.84	1115.79	-91.17	2415.87	-91.36
	110	1271+73	92.24	113.65	19.65	235.89	22.65	458.05	22.37	1266.29	49.53	2536.02	49.41
	111	1278+93	98.35	81.92	16.14	198.26	19.92	418.94	17.46	1343.87	-58.32	2452.29	-58.13
	112	1283+93	35.56	72.72	13.46	193.88	14.33	401.48	9.55	1620.50	-68.72	2910.64	-68.62
Beaufort Inlet	112B	0+00	-37.92	75.84	3.86	231.79	-9.78	566.49	-14.08	1092.83	11.73	1821.57	36.93
	113	5+00	32.14	98.03	7.61	312.24	-1.72	636.66	19.58	1119.36	14.72	1752.43	16.85
	114	10+00	152.29	103.28	14.02	367.29	46.23	678.46	47.30	1056.32	29.57	1573.08	17.78
	115	15+00	-3.35	97.29	-1.16	285.28	-1.53	499.81	-5.92	761.37	-17.91	1123.01	-26.92
	116	20+00	9.24	48.75	1.25	123.42	4.18	227.84	4.34	364.48	1.84	553.68	-0.92
Bogue Inlet	117B	0+00	-	-	-	-	-	-	-	-	-	-	-
	117	5+00	-	-	-	-	-	-	-	-	-	-	-
	118	10+00	-	-	-	-	-	-	-	-	-	-	-
	119	15+00	-	-	-	-	-	-	-	-	-	-	-
	120	20+00	-	-	-	-	-	-	-	-	-	-	-

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from June 9, 2017 to March 23, 2018.

Table E-2. Summary of Shoreline Change and Volume Change Along Bear Island (2017 to 2018)

Reach	Transect Number	Station	Shoreline Change @ MHW +1.7 ft NAVD	Above MHW +1.7 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)
Bear Island	1	0+00	-27.65	39.38	7.08	164.07	-5.34	535.34	19.12	1352.70	8.46	2761.10	-0.01
	2	10+00	-49.36	36.70	-5.63	144.21	-6.40	459.34	19.71	1153.98	1.57	2405.09	2.63
	3	20+00	-14.25	24.70	2.03	85.34	-5.95	256.14	-12.56	752.22	-26.17	1811.85	-30.95
	4	30+00	-17.56	15.92	0.28	67.91	-7.38	229.67	-5.41	629.53	-29.91	1619.21	-26.02
	5	40+00	-3.63	15.87	-1.51	76.16	-3.96	244.30	8.04	618.75	13.94	1551.49	8.89
	6	50+00	-19.38	12.27	-2.85	63.75	-10.78	218.89	-10.42	574.81	-9.48	1473.70	-7.76
	7	60+00	-22.06	124.01	-13.46	204.84	-22.73	395.58	-24.80	785.88	-26.82	1702.40	-33.85
	8	70+00	-27.17	16.00	-4.32	69.64	-15.47	228.00	-22.67	588.49	-18.10	1441.33	-17.77
	9	80+00	-19.39	21.89	-0.32	84.54	1.61	244.16	-7.13	604.07	-1.09	1438.85	-4.79
	10	90+00	-37.45	8.95	-1.92	58.90	-14.32	213.59	-19.85	568.28	-16.92	1391.95	-16.83
	11	100+00	-25.97	11.79	-0.55	63.98	-10.63	223.54	-9.38	576.64	-7.34	1396.54	-11.97
	12	110+00	-10.71	24.53	-2.12	79.75	-8.62	242.51	-10.94	596.98	-12.95	1418.79	-32.80
	13	120+00	-10.77	14.63	0.47	65.44	-4.78	211.85	-28.04	562.46	-30.31	1394.56	-51.27
	14	130+00	-26.90	13.29	-2.76	69.92	-3.72	216.32	-25.67	575.91	-28.50	1441.20	-50.75
	15	140+00	-25.90	5.65	-2.29	60.87	-6.77	206.58	-20.57	570.69	-24.97	1471.80	-48.25
	16	150+00	-41.05	7.56	-3.93	61.75	-9.73	211.17	-25.75	588.96	-33.60	1510.19	-49.50
	17	160+00	-23.92	10.50	-5.45	81.82	-8.66	257.39	-28.68	661.85	-45.69	1620.88	-70.24
	18	170+00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

NOTES:

1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from March 17, 2017 to May 1, 2018.

Table E-3. Summary of Shoreline Change and Volume Change Along Shackleford Banks (2017 to 2018)

Reach	Transect Number	Station	Shoreline Change @ MHW +1.5 ft NAVD	Above MHW +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
				2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)	2018 Measured Volume (cy/ft)	2017-2018 Volume Change (cy/ft)
Shackleford Banks	1	0+00	-11.08	0.61	-2.21	191.71	29.00	1004.48	60.93	2111.91	71.35	3788.01	79.62
	2	20+51	-11.66	19.18	-0.76	197.13	4.94	513.35	2.59	1032.05	-5.68	2078.06	-27.13
	3	40+80	0.89	57.72	4.25	218.80	8.42	489.25	4.82	842.46	6.28	1520.30	7.43
	4	58+81	23.44	60.26	4.56	149.82	6.18	343.64	9.45	642.48	12.39	1465.99	-21.22
	5	77+99	-10.71	4.31	-2.19	36.22	-2.47	147.26	-2.46	391.38	-4.94	1059.68	-17.59
	6	96+76	-37.81	2.43	-5.37	31.64	-3.81	129.91	-22.52	399.31	-12.37	1159.00	-10.22
	7	113+28	-8.98	16.68	-0.23	60.87	7.26	189.96	2.59	438.18	-1.45	1164.74	-50.01
	8	130+01	-12.23	9.98	-1.29	52.97	1.43	166.83	8.36	436.07	14.07	1149.48	12.60
	9	152+46	-11.72	15.15	-3.70	63.12	11.42	186.95	8.45	459.02	-5.03	1183.47	-22.30
	10	170+79	-25.16	27.89	-1.90	71.44	3.74	194.17	-5.68	479.12	-15.08	1227.94	-17.84
	11	190+43	-42.89	40.16	-2.60	111.82	-6.32	239.03	-21.47	562.32	-29.03	1334.42	-38.42
	12	210+07	-8.03	18.56	6.42	62.36	2.82	217.24	43.46	500.57	43.67	1197.62	33.51
	13	229+21	9.60	21.59	4.81	68.46	8.65	199.70	4.17	497.22	6.48	1217.87	-0.49
	14	248+63	-5.74	14.73	-1.54	53.79	-3.43	157.76	-28.81	439.30	-33.07	1109.93	-48.83
	15	272+15	-32.52	8.43	-3.13	44.45	-0.08	130.57	-25.15	413.26	-23.12	1076.67	-28.95
	16	293+38	-46.92	43.35	-3.26	105.89	2.25	265.51	30.20	582.95	33.95	1310.49	28.76
	17	322+18	-62.05	49.48	-4.90	102.68	-5.36	241.03	1.17	555.27	-3.08	1308.08	-7.09
	18	343+08	-67.49	19.65	-9.16	61.26	-12.70	176.30	-13.15	474.13	-23.07	1233.34	-39.12
	19	363+54	-96.03	39.26	-24.97	88.67	-36.20	213.48	-45.24	535.46	-63.38	1369.86	-84.07
	20	383+92	-159.36	37.11	-18.96	94.56	-45.53	239.80	-68.28	602.26	-97.87	1656.49	-112.95
	21	405+26	-134.70	0.00	-6.20	14.73	-24.04	102.37	-69.21	547.88	-97.16	1937.67	-106.01
	22	423+85	-209.48	0.00	-10.98	21.98	-47.00	226.11	-85.99	936.00	-166.14	2843.24	-178.46
	23	444+92	-	-	-	-	-	-	-	-	-	-	-
	24	460+01	-	-	-	-	-	-	-	-	-	-	-

NOTES:
1. Positive changes indicate accretion or gain in volume along the profile and negative changes indicate erosion or loss of volume along the profile.
2. Shoreline Change and Volume Change is calculated for the period between surveys from March 7, 2017 to April 21, 2018.

APPENDIX F

Statistics Tables

Table F-1. Summary of Average Annual Volume Change Statistics Along Bogue Banks (2008 to 2018)

Average Annual Volume Change (2008-2018)												
			Above +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
Reach	Transect Number	Station	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation
Bogue Inlet-Ocean	1	0+00	9.68	15.48	16.98	52.48	-1.59	70.65	-26.41	77.13	-26.72	83.46
	2	5+59	7.37	11.92	11.76	21.51	-2.58	30.48	-27.69	31.32	-33.63	32.82
	3	11+23	0.95	11.53	2.29	28.73	-11.28	42.79	-29.61	50.08	-36.24	55.64
	4	17+39	-0.95	6.17	-0.68	17.71	-5.17	35.37	-16.90	37.14	-17.62	42.92
	5	23+22	0.37	8.25	-1.04	16.07	-2.34	21.77	-12.08	20.67	-13.33	22.58
	6	36+28	0.25	4.45	-0.46	8.25	0.51	21.01	-5.49	20.60	-6.46	23.98
	7	53+10	0.16	5.43	0.98	12.13	1.74	13.89	-2.17	14.75	-5.10	15.46
	8	67+74	0.43	5.11	0.92	8.34	3.81	18.75	3.22	14.32	1.13	13.12
	9	80+91	1.13	5.79	2.42	5.72	2.95	16.95	1.88	21.66	-0.24	23.29
	10	93+40	-0.51	7.21	-0.63	9.77	0.06	11.52	0.26	10.64	-0.71	7.90
	11	108+58	-0.14	5.56	1.86	10.78	4.04	18.80	4.23	16.20	3.03	13.91
Emerald Isle West	12	121+18	-0.65	3.40	-0.32	3.54	1.10	12.73	2.16	13.59	1.66	14.80
	13	134+61	-1.24	5.46	-2.07	6.74	0.38	6.59	1.06	10.72	0.24	13.66
	14	146+67	-0.98	5.47	-2.39	7.70	-1.19	14.15	-0.04	14.20	-0.34	16.61
	15	160+16	-0.15	4.80	0.07	5.24	1.17	9.56	2.23	10.79	1.56	11.08
	16	174+79	0.47	5.80	1.27	6.74	1.86	11.28	2.57	11.87	2.01	8.72
	17	189+23	-0.12	6.09	-0.15	8.58	0.90	14.27	0.94	15.46	-1.17	15.66
	18	203+53	1.16	5.58	0.98	8.95	3.03	16.09	3.63	15.17	1.77	12.13
	19	214+90	1.53	5.67	2.29	5.34	3.27	9.44	3.90	11.46	2.76	11.56
	20	230+02	0.68	6.22	3.25	4.67	3.87	9.45	4.70	9.96	3.79	8.03
	21	241+15	0.95	3.96	2.38	6.47	3.55	9.89	3.95	10.70	3.22	16.88
	22	252+19	1.14	4.37	2.17	4.01	2.12	8.97	2.73	11.07	1.81	9.30
	23	263+24	0.10	4.94	0.59	3.55	1.10	10.87	1.98	15.45	1.12	12.78
	24	279+57	0.09	6.86	0.29	5.81	0.22	15.02	0.45	18.94	-0.50	15.68
	25	290+77	0.22	6.67	1.50	9.12	2.65	12.76	2.38	13.67	0.84	9.27

Table F-1. Summary of Average Annual Volume Change Statistics Along Bogue Banks (2008 to 2018) Cont.

Average Annual Volume Change (2008-2018)												
Reach	Transect Number	Station	Above +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
			Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation
Emerald Isle Central	26	304+77	0.52	5.50	1.30	7.97	3.28	12.91	3.39	15.59	2.23	12.35
	27	318+11	0.40	4.94	1.15	7.25	2.75	10.28	2.30	13.80	0.41	11.23
	28	329+10	0.44	4.32	0.18	9.08	0.56	22.07	0.21	16.18	-1.31	14.14
	29	345+80	-0.54	6.84	0.12	6.29	3.57	20.34	3.48	26.11	1.97	24.78
	30	362+22	0.37	5.06	0.48	10.91	2.40	13.91	3.78	18.57	3.02	15.58
	31	378+80	0.89	4.07	1.28	8.43	3.31	16.24	4.20	21.56	6.14	18.59
	32	395+22	0.55	5.05	0.09	10.84	-1.91	24.21	-1.69	25.04	-3.91	24.50
	33	408+86	0.59	5.58	1.39	9.57	1.89	15.99	2.62	16.18	0.57	13.67
	34	422+83	-0.26	8.03	0.33	6.43	0.60	13.89	0.99	12.81	-1.39	10.80
	35	435+62	-2.25	4.39	-4.29	5.67	-3.91	12.48	-5.09	8.08	-7.20	7.44
	36	450+22	-1.35	4.62	-3.21	7.86	-2.57	16.64	-2.04	14.00	-4.02	10.88
Emerald Isle East	37	461+34	-2.01	6.42	-2.88	10.53	-1.87	24.37	-0.89	22.56	-2.80	22.90
	38	472+44	-0.88	3.97	-2.35	5.35	-2.90	10.00	-2.16	6.37	-3.08	8.10
	39	483+48	-1.93	4.55	-3.66	5.14	-1.41	11.25	-0.67	13.52	-1.55	12.03
	40	494+44	-1.25	6.86	-2.79	8.92	-2.21	16.03	-0.77	16.26	-1.85	17.31
	41	505+39	-1.93	5.20	-2.49	10.56	-3.03	18.60	-1.49	21.01	-2.37	18.93
	42	516+57	-3.41	6.59	-5.64	12.74	-7.24	20.30	-5.71	23.63	-7.26	24.40
	43	527+37	-1.99	6.38	-3.38	7.22	-2.94	17.30	-1.47	20.73	-2.66	20.06
	44	538+39	-1.07	5.78	-2.15	7.28	-0.20	9.74	1.47	11.07	0.49	12.06
	45	549+45	-1.45	5.20	-2.27	9.62	-1.96	12.16	-0.44	13.36	-1.32	10.77
	46	560+42	1.37	3.54	2.32	5.94	3.51	7.41	4.58	7.02	3.54	13.83
	47	571+43	0.79	6.03	1.09	10.93	2.22	11.89	2.59	15.04	2.31	19.71
	48	580+13	-0.10	5.71	-0.02	10.60	0.64	27.65	1.33	30.30	0.79	27.58

Table F-1. Summary of Average Annual Volume Change Statistics Along Bogue Banks (2008 to 2018) Cont.

Average Annual Volume Change (2008-2018)												
Reach	Transect Number	Station	Above +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
			Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation
Indian Beach/Salter Path	49	595+84	-0.20	4.51	-0.59	5.48	-0.36	12.31	0.54	16.56	0.04	13.48
	50	608+06	-0.44	6.23	-0.30	9.62	-0.54	12.86	0.23	12.21	-1.50	8.66
	51	620+90	-0.60	5.32	-1.28	6.77	-1.90	16.44	-1.86	19.49	-2.85	17.40
	52	633+31	-0.98	4.18	-1.44	6.22	-1.30	10.58	-1.20	14.36	-2.90	12.53
	53	648+17	0.61	3.28	0.70	8.00	0.55	12.02	0.77	12.53	0.03	12.44
	54	660+65	1.13	5.54	1.31	9.99	1.29	15.73	2.53	17.11	2.07	17.33
	55	672+30	-0.09	5.92	-0.29	10.93	-0.61	14.24	-0.24	11.90	-0.92	14.77
	56	683+24	-0.58	4.88	-0.54	6.62	-0.40	14.42	0.55	13.57	-0.03	12.25
	57	693+79	-0.21	5.40	-0.78	6.70	-0.11	13.45	0.85	14.66	0.29	14.01
	58	709+05	-0.33	5.96	-0.80	9.77	-1.23	18.16	-0.52	18.75	-0.53	19.49
Pine Knoll Shores	59	723+93	0.11	3.00	-0.69	7.78	-0.70	13.05	0.47	19.96	-0.27	15.78
	60	736+01	-0.29	4.63	0.57	8.03	1.01	11.14	2.48	13.72	1.94	14.21
	61	748+06	-0.96	6.29	-0.58	9.15	0.16	18.89	2.12	20.19	2.38	18.48
	62	761+80	-0.60	5.18	-1.03	8.43	-1.32	8.24	-0.42	15.17	-2.07	16.26
	63	774+77	-1.79	7.15	-3.89	10.00	-4.94	29.51	-3.95	27.08	-5.25	33.50
	64	787+61	-1.08	6.30	-2.41	9.47	-4.07	16.84	-2.50	19.16	-3.61	19.45
	65	800+91	-1.90	7.07	-3.63	7.94	-4.06	17.60	-1.78	21.59	-2.21	19.70
	66	813+33	-2.30	5.03	-3.83	9.53	-5.04	12.58	-4.00	15.69	-6.38	14.18
	67	825+53	-1.64	4.86	-3.78	10.35	-2.30	10.06	-1.82	13.61	-3.44	15.39
	68	840+55	-0.08	4.85	-1.87	8.96	-2.71	10.50	-1.26	10.62	-2.53	10.07
	69	850+84	-0.42	6.63	-0.97	7.73	-0.21	10.80	0.71	14.00	-0.89	12.98
	70	863+28	-1.29	6.79	-2.21	8.64	-1.68	13.07	-0.46	15.82	-1.54	16.52
	71	882+23	-1.23	5.33	-2.03	6.54	-0.95	14.20	-0.43	22.53	-3.03	23.31
	72	896+24	-0.73	4.54	-1.47	8.23	-1.59	14.21	-0.53	18.50	-1.21	19.57
	73	910+53	0.33	4.18	0.38	9.85	2.52	15.33	3.24	23.13	1.32	21.30
	74	922+70	-0.24	5.13	-0.47	9.03	-0.74	13.00	1.14	15.42	1.61	19.78
	75	937+70	0.47	4.89	0.22	10.50	2.68	10.20	2.38	15.90	0.93	16.06
	76	948+81	-0.87	6.63	-1.76	6.21	-1.49	12.17	-1.42	17.28	-3.20	16.02

Table F-1. Summary of Average Annual Volume Change Statistics Along Bogue Banks (2008 to 2018) Cont.

Average Annual Volume Change (2008-2018)												
Reach	Transect Number	Station	Above +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
			Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation
Atlantic Beach	77	961+72	-0.97	3.47	-1.73	4.46	-3.00	13.42	-2.49	17.19	-4.08	18.71
	78	971+20	-0.99	4.33	-1.87	9.88	-2.75	11.90	-2.59	20.31	-5.54	21.99
	79	985+64	-0.27	4.93	-0.16	7.69	-0.71	12.24	-0.57	16.80	-2.51	21.75
	80	994+64	0.58	4.38	1.17	8.87	0.66	12.02	0.71	11.74	-0.86	12.88
	81	1005+61	0.98	3.93	1.52	4.83	2.43	12.44	2.44	16.81	0.69	20.09
	82	1012+68	0.69	5.30	0.89	8.60	2.15	15.63	1.75	23.02	-0.02	24.64
	83	1022+69	0.17	4.36	0.42	8.09	1.60	16.19	0.87	17.99	-0.72	21.62
	84	1032+70	-0.13	3.37	0.33	9.75	1.23	16.46	1.12	17.75	-0.27	23.63
	85	1042+73	-0.84	2.76	-1.82	7.56	-3.60	14.66	-3.04	15.53	-3.76	17.73
	86	1052+75	-1.47	4.57	-1.75	10.60	-4.53	17.67	-5.22	18.81	-7.51	26.76
	87	1062+69	-0.38	4.30	-0.61	7.03	-1.86	9.93	-1.66	10.51	-2.67	10.17
	88	1072+62	-0.08	5.29	-0.41	4.04	-1.05	8.12	-0.75	11.15	-2.91	16.14
	89	1082+69	1.37	6.05	1.40	6.92	2.52	7.73	2.48	9.93	0.41	16.34
	90	1093+69	-1.39	8.39	-4.01	15.50	-3.08	19.76	-2.54	25.24	-5.19	31.22
	91	1102+82	-3.63	8.24	-8.22	14.18	-11.13	25.24	-11.42	29.73	-15.39	36.64
	92	1112+81	-3.07	9.73	-6.15	21.05	-7.30	29.47	-7.44	32.40	-11.14	37.53
	93	1122+81	-2.96	6.36	-5.42	10.51	-8.73	12.09	-10.37	13.24	-13.95	14.23
	94	1131+73	2.10	4.76	5.04	12.23	6.73	10.93	5.37	11.88	0.90	11.50
	95	1141+97	1.86	3.92	2.33	9.26	2.11	11.77	1.90	14.27	-1.75	20.17
	96	1151+92	-0.38	5.98	-3.65	11.64	-3.72	16.14	-4.45	15.99	-9.35	18.09
	97	1161+91	-1.77	6.28	-3.35	15.31	-4.03	17.90	-4.47	20.59	-7.99	22.36
	98	1171+91	-4.69	12.74	-9.05	23.53	-11.31	31.40	-11.20	32.78	-15.03	40.65
	99	1182+17	-4.62	15.78	-9.75	26.59	-11.11	39.68	-10.37	41.17	-13.88	47.64
	100	1191+90	-0.68	8.96	-2.45	16.91	-3.44	22.91	-3.39	23.81	-6.18	27.95
	101	1201+93	-0.93	5.18	-3.96	6.28	-5.74	11.18	-7.07	13.23	-14.04	25.82
	102	1211+94	-1.66	6.15	-5.66	11.38	-7.58	18.10	-9.34	18.43	-13.77	26.69

Table F-1. Summary of Average Annual Volume Change Statistics Along Bogue Banks (2008 to 2018) Cont.

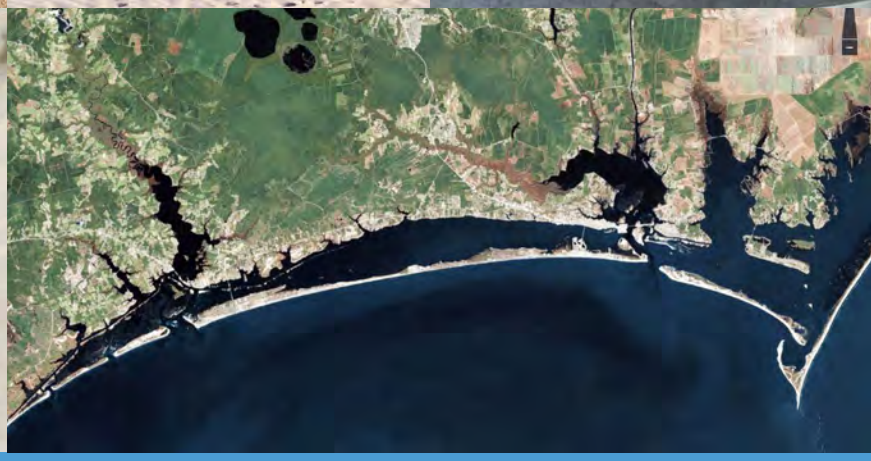
Average Annual Volume Change (2008-2018)												
Reach	Transect Number	Station	Above +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
			Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation
Fort Macon	103	1222+11	-4.21	6.05	-11.00	13.08	-15.36	13.56	-19.18	19.28	-25.23	39.08
	104	1231+86	-2.57	6.75	-7.99	17.34	-12.93	28.14	-16.42	30.11	-19.69	35.26
	105	1241+79	-5.34	11.93	-13.85	27.61	-19.52	46.55	-18.95	51.93	-21.25	52.77
	106	1251+79	-6.08	8.37	-16.76	17.84	-26.47	25.58	-26.56	26.92	-27.55	32.12
	107	1257+09	-3.71	9.72	-9.35	17.17	-14.09	28.87	-11.05	22.33	-11.64	22.68
	108	1261+80	1.01	6.92	1.85	20.89	4.51	26.33	1.81	35.21	2.39	34.63
	109	1267+13	1.14	8.59	2.30	17.70	5.70	29.35	5.55	53.71	5.58	53.74
	110	1271+73	2.45	12.63	4.16	24.35	10.40	39.78	18.03	54.73	18.01	55.12
	111	1278+93	2.69	9.85	4.63	19.75	11.65	30.45	15.65	74.38	27.44	67.79
	112	1283+93	3.36	7.74	4.20	16.51	8.04	21.31	24.25	88.65	25.48	90.94

Table F-2. Summary of Average Annual Volume Change Statistics Along Bear Island (2008 to 2018)

Average Annual Volume Change (2008-2018)												
Reach	Transect Number	Station	Above +1.7 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
			Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation
Bear Island	1	0+00	-0.42	11.75	-2.21	36.62	2.08	77.20	16.11	126.50	15.36	130.57
	2	10+00	-0.45	4.44	-1.32	20.59	5.19	60.52	20.37	77.64	21.11	82.52
	3	20+00	0.68	5.50	1.27	13.57	1.72	27.12	9.50	39.21	9.77	41.67
	4	30+00	-0.56	4.74	-0.46	12.25	-0.96	10.64	-1.12	15.10	-1.14	15.20
	5	40+00	-1.46	4.64	-1.38	10.56	-0.65	11.35	-2.21	13.53	-2.48	17.40
	6	50+00	-1.52	5.41	-1.87	10.34	-1.96	16.75	-4.47	17.51	-4.33	21.16
	7	60+00	-2.87	13.10	-3.37	14.35	-4.10	15.03	-6.67	20.80	-7.31	28.60
	8	70+00	-0.15	4.19	-1.05	7.20	-1.60	10.30	-3.57	11.34	-4.22	17.62
	9	80+00	-0.95	4.24	-1.19	7.10	-2.09	11.38	-4.40	8.35	-5.68	13.39
	10	90+00	-1.63	3.36	-2.36	10.59	-3.66	14.62	-6.03	12.90	-7.19	16.42
	11	100+00	-1.40	3.94	-2.45	8.76	-3.60	9.90	-6.13	7.00	-8.19	8.19
	12	110+00	-0.80	4.08	-1.71	7.50	-2.99	6.50	-6.05	7.47	-9.60	15.52
	13	120+00	-2.13	4.79	-3.42	8.71	-5.87	12.83	-9.27	10.83	-13.20	21.00
	14	130+00	-2.07	4.59	-3.75	10.17	-6.42	17.20	-10.09	17.25	-14.82	23.83
	15	140+00	-3.17	5.26	-4.32	9.62	-6.98	12.64	-10.75	10.65	-15.67	19.20
	16	150+00	-2.73	8.12	-4.79	17.80	-8.32	26.26	-11.51	32.53	-15.87	40.60
	17	160+00	-2.56	7.57	-4.67	17.43	-8.13	35.04	-13.91	32.83	-19.01	35.54
	18	170+00	-	-	-	-	-	-	-	-	-	-

Table F-3. Summary of Average Annual Volume Change Statistics Along Shackleford Banks (2008 to 2018)

Average Annual Volume Change (2008-2018)												
Reach	Transect Number	Station	Above +1.5 ft NAVD		Above -5 ft NAVD		Above -12 ft NAVD		Above -20 ft NAVD		Above -30 ft NAVD	
			Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation	Mean Volume Change (cy/ft)	Standard Deviation
Shackleford Banks	1	0+00	-1.18	1.20	5.65	24.62	13.66	33.98	14.92	37.65	23.98	42.70
	2	20+51	0.78	1.47	3.27	4.41	-0.80	8.25	-8.00	11.38	-11.11	22.01
	3	40+80	3.15	3.42	6.60	6.59	8.01	8.12	8.01	9.06	-0.61	15.79
	4	58+81	2.71	2.70	5.40	4.30	9.34	5.78	9.60	7.57	17.72	30.07
	5	77+99	-0.58	2.45	-1.24	4.84	-2.17	10.49	-5.65	17.52	-15.14	19.89
	6	96+76	-0.86	3.28	-1.91	5.50	-3.66	16.63	-3.85	19.55	-5.19	18.46
	7	113+28	-0.79	2.88	-0.81	7.50	0.47	15.13	-3.61	14.99	-9.81	23.18
	8	130+01	-0.16	2.32	-0.79	4.86	-1.51	7.48	-4.78	8.79	-8.70	19.64
	9	152+46	-0.36	3.83	-0.98	7.75	-1.89	13.60	-5.27	17.71	-10.66	23.69
	10	170+79	-0.35	3.09	-1.59	7.26	-0.23	10.95	-3.95	12.31	-4.40	16.75
	11	190+43	-1.38	2.74	-2.63	8.76	-4.80	17.38	-7.32	21.85	-9.94	28.63
	12	210+07	-2.13	9.80	-2.90	12.29	0.59	24.01	-1.15	23.11	-3.96	27.78
	13	229+21	-1.23	6.20	-1.58	10.65	-0.47	12.78	-1.87	16.66	-3.83	21.91
	14	248+63	-2.32	6.39	-4.46	7.71	-7.30	15.64	-11.25	18.09	-14.32	23.77
	15	272+15	-0.36	4.74	-0.63	6.30	-1.33	9.37	-2.86	10.77	-2.56	12.49
	16	293+38	-1.30	4.37	-1.99	9.03	1.72	17.48	-0.64	17.77	-0.67	20.31
	17	322+18	-1.56	4.41	-2.31	6.67	-0.55	9.71	-4.68	12.84	-8.12	19.09
	18	343+08	-1.85	5.63	-2.75	10.11	-2.65	19.51	-8.32	17.33	-11.06	22.76
	19	363+54	-4.92	11.43	-7.54	16.61	-8.48	27.32	-14.38	25.97	-22.49	31.71
	20	383+92	-10.69	10.83	-18.07	15.29	-24.46	31.14	-33.56	33.60	-41.51	35.27
	21	405+26	-12.27	11.96	-28.81	26.95	-46.84	38.57	-64.16	47.89	-65.69	56.15
	22	423+85	-13.86	14.00	-39.45	32.57	-58.02	51.18	-89.92	89.84	-100.30	150.42
	23	444+92	-18.82	14.38	-70.92	81.21	-121.35	119.08	-137.07	134.46	-139.95	142.30
	24	460+01	-23.50	26.13	-55.19	43.83	-100.00	74.10	-108.55	92.16	-91.31	104.36



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