COASTAL RECREATIONAL FISHING LICENSE

FINAL REPORT

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Abstract:

Salinity is the fundamental environmental parameter governing the distribution of estuarine species, and, importantly, the condition and resilience of habitat foundation species such as oysters and saltmarsh grasses. Consequently, in-depth knowledge of estuarine salinity regimes is critical for properly understanding estuarine community dynamics, siting expensive habitat restoration projects and aquaculture operations, modeling saltwater intrusion into low-lying coastal farmlands and bringing online state-of-the-art membrane technology to generate salinity gradient energy. In addition, the availability of complete and extensive salinity and water temperature (T) data would improve human health by better tracking/predicting risks related to microbial pathogen exposure, such as *Vibrio* spp. bacteria, in seafood and recreational waters. While past and on-going work by state and federal agencies and academic groups provide salinity records for various coastal regions of North Carolina, these data have not been integrated into a single, inclusive package that connects multiple regions over time and made available to any interested user. Since July 2013, a UNC-IMS team (N. Lindquist, S. Fegley, and R. Guajardo) with CRFL and NC Sea Grant support has worked to develop the inaugural version of a comprehensive salinity/T database for North Carolina's estuarine waters, referred to as *SalWise*, which presently has over 1,980,000 records ranging from 1945 to 2014. Contributions of salinity and other water quality parameters in the database come from: NCDMF programs – e.g., Shellfish Sanitation, Benthic Habitat Mapping, Fisheries Independent Assessments; academic-based programs – e.g., FerryMon, ModMon, DCERP; and the NC DEQ Division of Water Quality. Facile *SalWise* access to any interested party – government, academic or private – in a form that allows for searching and retrieval of data based on user-specified spatial and temporal parameters is being established through ECU's web-based North Carolina Coastal Atlas. Public access to *SalWise* through the Atlas is scheduled for spring 2016 once the structural alignment of the large SalWise database and the Atlas is finalized.

Situation and Need

Salinity is a primary driver of estuarine species distributions, including many foundation species such as oysters, submerged aquatic vegetation, and saltmarsh plants that promote fish production (e.g., Wells 1961, Crain et al. 2004). The critical importance of understanding salinity and other hydrographic features rigorously for the management of estuarine fisheries and habitat foundations species has long been recognized. For example, Williams and co-workers (1973) at the UNC Institute of Marine Sciences published "A Hydrographic Atlas of Larger North Carolina Sounds", that reported salinity and water temperature data recorded for 76 stations running from Bogue Sound to northern Pamlico Sound between 1948 and 1966. Despite this and other early efforts to amass salinity data in North Carolina and salinity's preeminence in estuarine ecology, it is surprising that there has been no modern attempt to develop a comprehensive salinity database for North Carolina with sufficiently high spatial and temporal resolution to identify major natural and anthropogenic drivers of salinity regime changes over time and the effects of changing salinity regimes on foundational estuarine species.

In response to the clear need for a contemporary comprehensive, state-wide salinity database, North Carolina's Coastal Recreational Fishing License (CRFL) Grant program and North Carolina Sea Grant program funded the "Salinity Wise" (*SalWise*) project at the UNC Chapel Hill Institute of Marine Sciences (UNC-IMS) lead by Prof. Niels Lindquist and Research Associate Prof. Stephen Fegley. The *SalWise* project has and is merging and integrating multiple short- and long-term salinity and water temperature records for North Carolina's estuarine waters into a single, inclusive digital platform that includes all estuarine waters over historic to present-day time scales and supports queries and analyses valuable for informing diverse management decisions and better guiding restoration of critical habitats that support recreationally and commercially important fish species as outlined in the North Carolina Coastal Habitat Protection Program (CHPP).

During Phase 1 development of *SalWise* covered by the CRFL and Sea Grant funding, the specific project objectives were –

1) to develop, using existing water quality records, a salinity database that broadly covers the estuarine waters of North Carolina over as long a timeframe as possible;
2) to develop for regions where data records are abundantly dense, high-resolution spatial and temporal views of salinity patterns that can be especially valuable for examining drivers of salinity regime changes over time and for building a baseline against which to detect future alterations to salinity regimes driven by human modifications to coastlines and watersheds, natural shoreline changes, climate change, and sea-level rise; and
3) to develop, for outside groups, a portal for database access that supports queries and analyses critical to multiple lines of research and species/habitat management efforts.

Methods

Acquisition of Datasets

For Phase 1 of the *SalWise* project, data acquisition was primarily directed toward large state government and academic monitoring programs, and programs of unique opportunity. Estuarine water monitoring programs run by State agencies included those housed within the North Carolina Department of Environment and Natural Resources (DENR; renamed the Department of Environmental Quality (DEQ) in 2015), including multiple biological programs of the Division of Marine Fisheries, estuarine waters monitoring by the Division of Water Quality (DWQ), and the Shellfish Sanitation (SS) and Recreational Water Quality (RWQ) Monitoring Program. Among the state-run monitoring programs, the SS program stood out for its coast-wide coverage, long time frame (since the 1960s, with data available in

electronic form from ~1989 to present), and relative consistency of sampling and water analysis methodologies.

Large academic water quality monitoring programs included in *SalWise* to date were provided by Prof. Hans Paerl's research group at the UNC Institute of Marine Sciences. Two Paerl-led programs in particular, the Neuse River Estuary MODeling and MONitoring (MODMON; www.unc.edu/ims/neuse/modmon) project and the FerryMon (www.ferrymon.org) project provided tremendous volumes of data due to their long-running status, and high frequency sampling rates.

A dataset of unique opportunity was an effort led by Mr. Hugh Porter, a former researcher at UNC Institute of Marine Sciences, to compile salinity and water temperature data collected by IMS researchers from multiple North Carolina water bodies from 1945 through 1967. The location, time of collection, and water parameter values were meticulously recorded on paper cards and archived at IMS. The *SalWise* project technician spent several months transcribing data from these cards to an electronic spreadsheet and verifying station locations. Included among these data were the nearly daily recording of salinity and water temperature taken in Bogue Sound from the IMS dock. This is the oldest record of high frequency sampling presently in *SalWise*. Although previous monitoring work conducted from Pivers Island-based marine labs in the early 1900s made daily records of salinity and water temperature, the original daily logs for these studies have not been located. The only available accounting of these data are published papers that provide monthly summary statistics of the data.

Data Integration, Access and Viewing

For the *SalWise* project, Microsoft's Access was chosen as the *SalWise* Database Management System (DMS). MS Access combines a relational Microsoft Jet Database Engine with a graphical user interface and software-development tools, including data query systems. An additional advantage of using MS Access as the data integration system is that Access readily allows the transfer of specified data to ESRI's ArcGIS platform. This capability allows *SalWise* salinity and water temperature data to be layered with other geospatially defined features.

Data Quality Assurance and Quality Control

Given that the data in *SalWise* has been aggregated from independent sources, the *SalWise* team cannot and does not certify the accuracy of the data beyond the quality assurance and quality control (QA/QC) efforts of the monitoring groups providing the data. In general, data from government agencies requires some degree of data quality assurance and validation; thus there is a reasonable level of confidence in the data quality. Water quality data generated through projects associated with Prof. Paerl's research group undergo a rigorous QA/QC process. The QA/QC statements for MODMON data can be viewed at www.unc.edu/ims/neuse/modmon/outreach.htm. By use of *SalWise* tools and extracted data, users acknowledge and accept these limitations.

Despite the QA/QC efforts of data source personnel, with the large volume of data in *SalWise* there were likely to be erroneous data entries that would become more obvious with examination of the integrated dataset. To provide even greater database QA/QC, the *SalWise* team conducted additional levels of data scrutiny. Prior to uploading salinity and water temperature data to the master *SalWise* Access file, the data were examined for location and parameter values that were outside the believable range for the parameter. For example, a sampling location for an estuarine monitoring program that had an ocean or terrestrial location was culled from the dataset. For culled data, the source program contact person was provided with the list and asked, if possible, to provide justifiable corrections. Corrected data were re-inserted in the dataset. Further culling of suspect data occurred once datasets were combined. If the preponderance of data clustered by reasonable spatial and temporal limits, pointed to a possible erroneous parameter value, a further examination of the suspect datum was

conducted. If there was no clear explanation for the out-of-range point and no possible corrective action, the data point was removed from *SalWise*.

To further enhance the reliability of *SalWise*, a response tool will be available through the public access portal to note suspect data that was not flagged by the *SalWise* team. Suspect datum/data may be examined in greater detail by the *SalWise* team and offered for possible correction to the source group. Again, if no justifiable correction can be made, and the datum/data are substantially beyond the expected range for the parameter, the datum/data may be removed from *SalWise* and a correction note logged for public viewing.

***SalWise* Overview**

Constituent Databases

An overview of the different programs contributing data to the integrated and searchable *SalWise* platform are provided in Appendix 1. As of June 2015, *SalWise* consisted of 1,980,813 salinity records aggregated from 27 different programs (Table 1). Each record identifies the water body, specific sample location (by latitude and longitude), sampling date, and source program and generally includes time of sampling, sampling depth, and water temperature. Spatial coverage extends over all North Carolina coastal waters. The earliest records are from 1940's and continue into 2015 for some programs (Fig. 1). Sampling frequencies among programs, years, and water bodies differ. The greatest number of records came from the FerryMon program, followed by pCO_2 and Shellfish Sanitation. With respect to temporal distribution, the majority of programs and the greatest number of records cover the past two decades. No records are present in *SalWise* from November 1967 through August 1970.

Table 1. Number of salinity records from each source program and the range in years over which the respective samples were taken. Brief descriptions of each program are presented in Appendix 1.

Program	*SalWise* Program #	# of Records	Years
ModMon	5	57,689	1994-2014
FerryMon	10	1,169,131	2000-2011
pCO_2	12	217,699	2009-2011
Hugh Porter	15	14,523	1945-1967
Shellfish Sanitation	20	134,737	1989-2015
DENR DWQ	30	30,492	1962-1996
NCDENR-DWQ (2nd)	31	54,063	1997-2007
NCDENR-DWQ WQX	32	21,486	2007-2013
DCERP: Benthic Water Column	50	28,660	2007-2011
DCERP: Dataflow Mainstem	52	88,797	2009-2012
DCERP: Dataflow Shallow	54	80,024	2008-2011
DCERP: NRE Water Column	56	3,675	2007-2012
Estuarine Gag Trawl Survey	119	341	2010-2014
Estuarine Trawl Survey	120	202	1999-2014
Pamlico Sound Survey	195	11,009	1987-2014
Cold Stun Sampling	465	28	2010-2015
Sea Turtle Bycatch Monitoring	466	2,822	2004-2013
Alternative Platform Observations	467	64	2011-2013

Table 1 (cont.) Program	*SalWise* Program #	# of Records	Years
Pamlico River Blue Crab Fishery	471	4	1991
Fish Pot Study	517	79	2010-2011
Commercial Shrimp Trawl Fishery Characterization	570	38	2012
Oyster Sanctuary Evaluations	611	888	2007-2013
Shellfish Bottom Mapping	635	33,413	2007-2014
Hard Clam Survey	640	640	2006-2014
Bay Scallop Monitoring	697	1,448	2008-2015
Fisheries Independent Assessment (FIA)	915	28,559	1998-2015
Fisheries Independent Assessment Program/Ocean Gillnet	916	302	2008-2015
Grand Total		**1,980,813**	**1945-2015**

The highest numbers of records come from Pamlico Sound (822,256), Neuse River (726,753) and the New River (216,780). The Shellfish Sanitation program has the greatest spatial coverage, including all of the state's major estuarine waters (except central waters of Pamlico Sound) and is the longest running sampling program in the State. Data from the Shellfish Sanitation Program are available in electronic spreadsheets from ~1989 to present. Salinity records dating from the initiation of the Shellfish Sanitation Program's sampling campaigns beginning in the 1960 to ~1990 are in paper files. These have not yet been transcribed into electronic spreadsheet and added to *SalWise*.

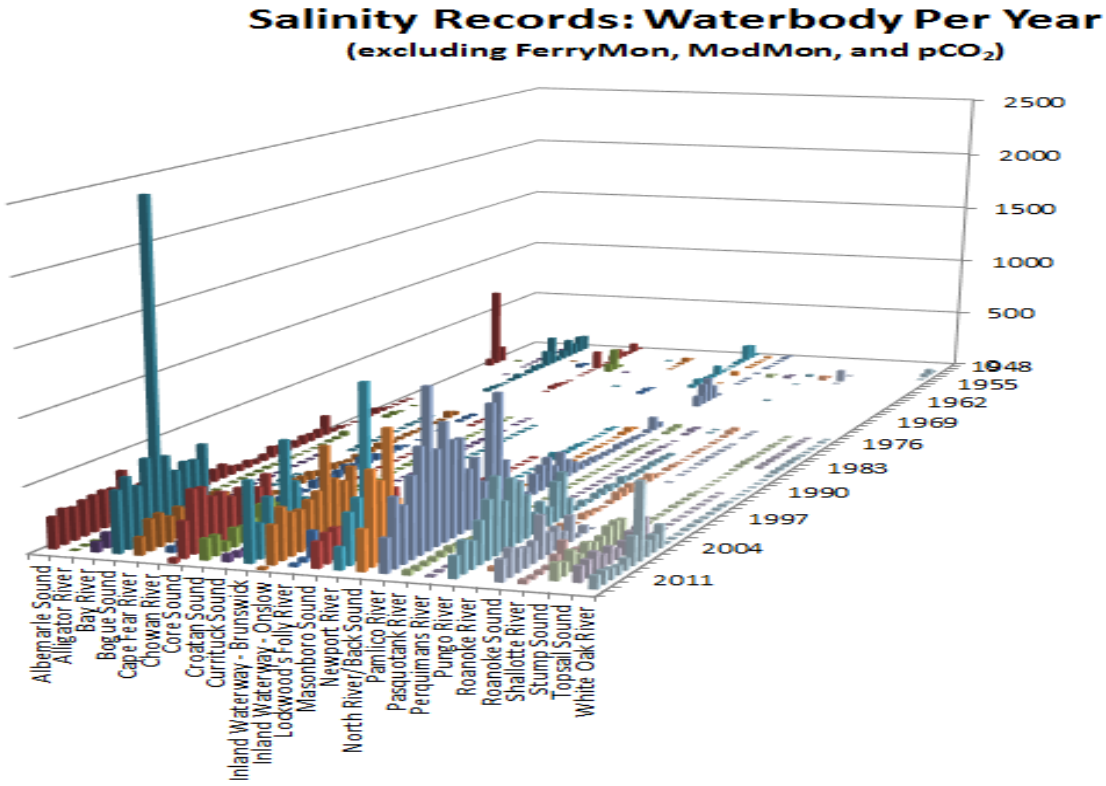


Figure 1. Number of salinity records in *SalWise* parsed by both water body (top) and year (bottom). The programs with the largest number of records are omitted from the bottom panel.

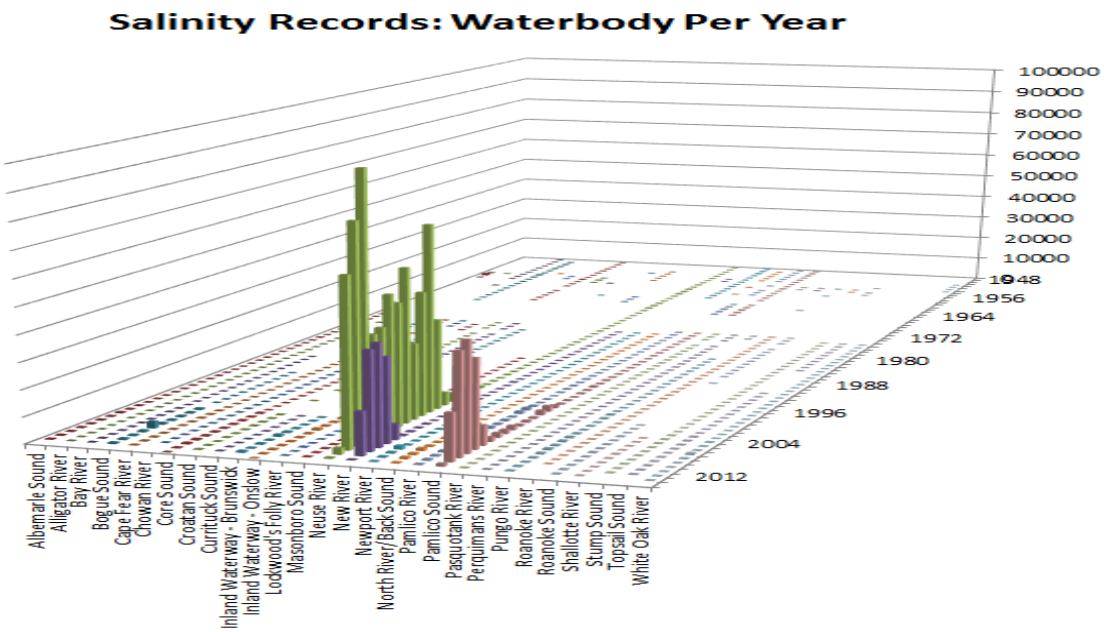


Figure 1 (cont.). Number of salinity records in *SalWise* parsed by both water body (top) and year (bottom). The programs with the largest number of records are omitted from the bottom panel.

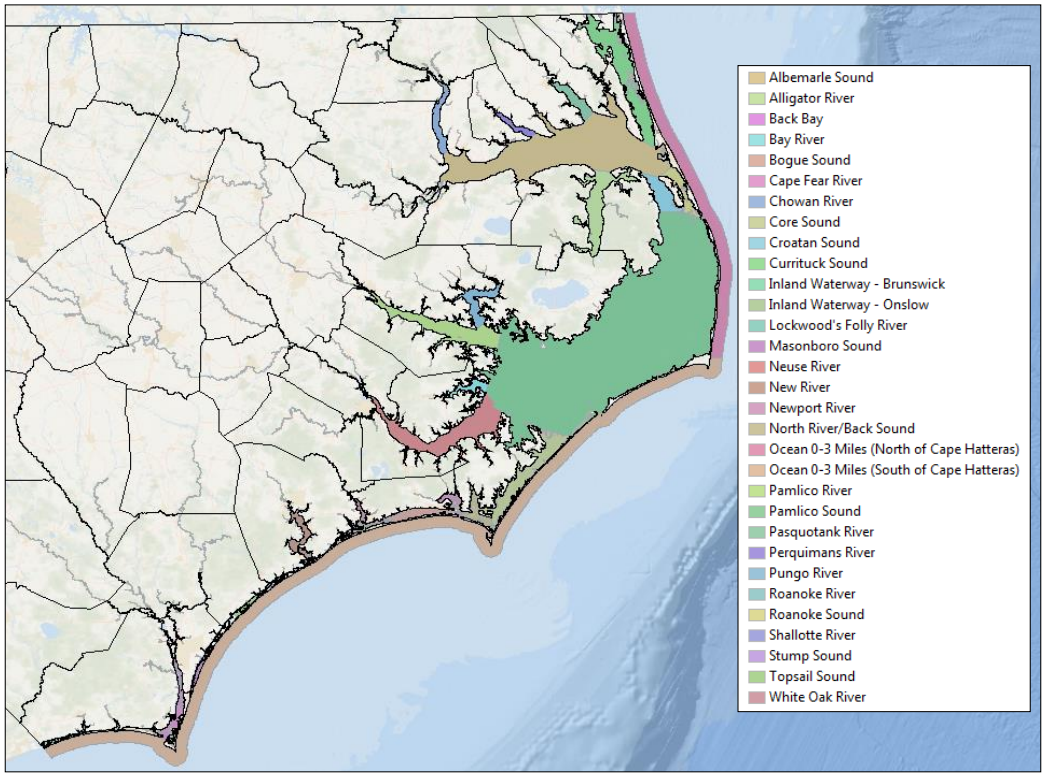


Figure 2. Map of the NC DMF trip ticket water bodies to which *SalWise* data are coded for a general location of data.

To aid user exploration of *SalWise*, all records are associated with the NC Division of Marine Fisheries trip ticket water body in which the sampling station is located (Fig. 2). The majority of source data programs do not extend across all of the water bodies (see Fig. 3 for examples) but all water bodies are represented by at least some sample stations.

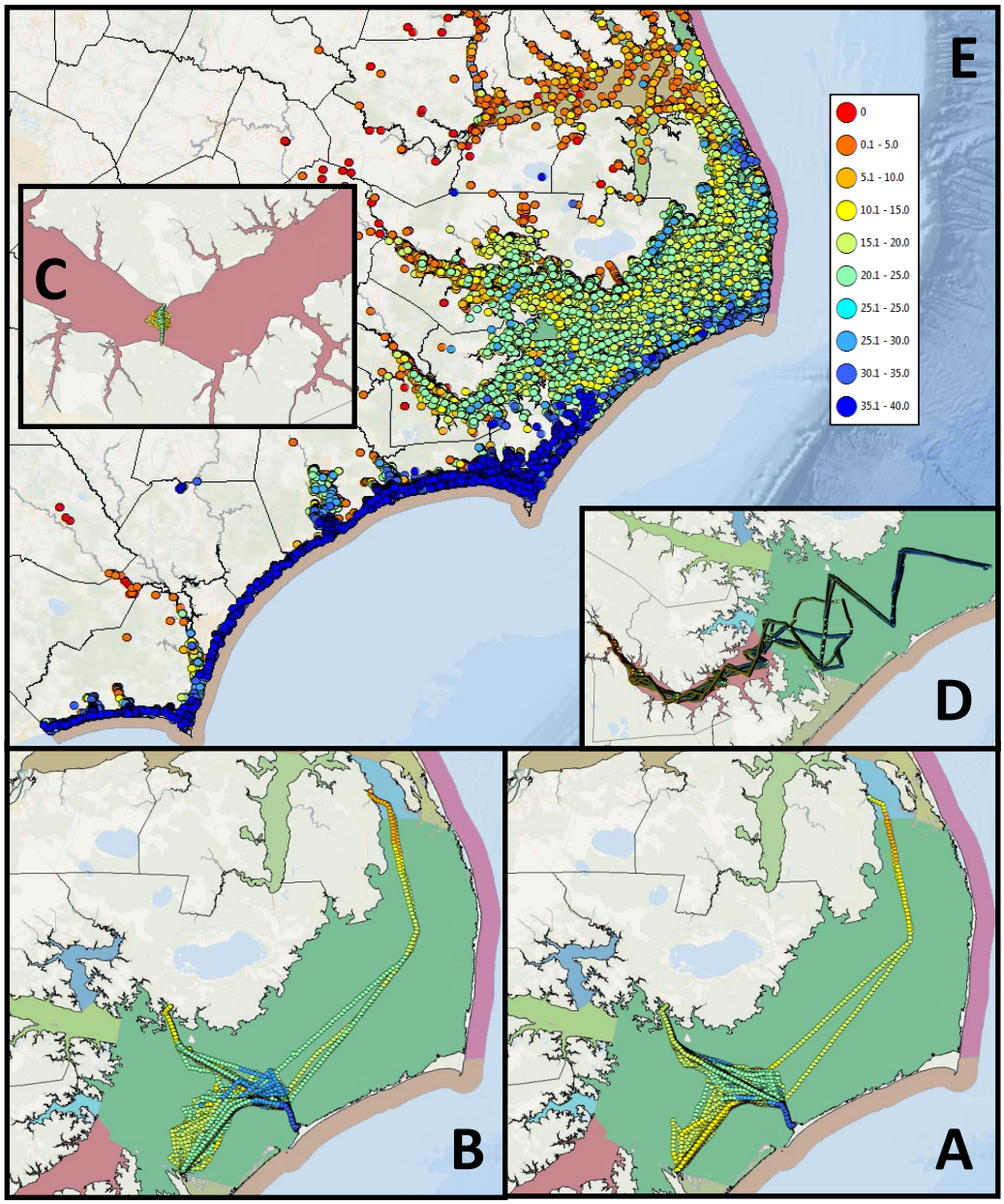


Figure 3. Views of the spatial coverage of SalWise components. At each station, data are stacked with only the most recent datum for the location visible. A – FerryMon: Swan Quarter-Ocracoke route (Program #10); B – FerryMon – Cedar Island-Ocracoke route (Program #10); C – FerryMon: Cherry Branch-Minnesott Beach route (Program #10); D – pCO_2 (Program #12) and E – all other Programs. The colored salinity scale, increasing in 5 ppt intervals from 0 ppt, for all panels is shown in the inset.

Among all programs contributing data to the *SalWise* database, those of the Shellfish Sanitation Program (SS) offers the longest-running (early 1960s to present) salinity and water temperature monitoring program in the State. The locations of the majority of its sampling stations, which cover

nearly all of the State estuarine waters (except those areas of Pamlico Sound well away from the coast) have remained unchanged since the program began. Stations are typically dropped from the program if the area becomes classified as permanently closed to shellfish harvesting. When this occurs, new stations are added typically in nearby waters open for shellfish harvest. The SS has two-types of sampling protocols: (1) "routine", which ideally obtains 6 samples per year (one sample every 2 months), for each station and (2) "conditional" sampling, which is triggered when a region receives an excessive level of rainfall, is conducted over a period of days after the rain event until the measured level of fecal coliform indicator bacteria falls below the water-closure standard. *SalWise* presently contains only routine SS data available in electronic spreadsheets, typically from ~1989 to present. Routine data collected prior to ~1998 and conditional data exist as paper records but have not been transcribed into spreadsheets and incorporated into *SalWise*.

The SS data offer many informative views of salinity regimes throughout the State's estuarine waters and that highlight the great variability of salinity in North Carolina, both spatially and temporally. For example, a plot of mean station salinity versus the standard deviation of the station mean salinity for SS stations having more than 30 observations between 2007 and 2011 shows that stations in areas at the extremes of the salinity range, the variation in the mean salinity value is low (Fig. 4). In contrast, for areas with mean salinities near the center of the salinity spectrum, there is high salinity variability, likely due to differences in the frequency and intensity of freshets.

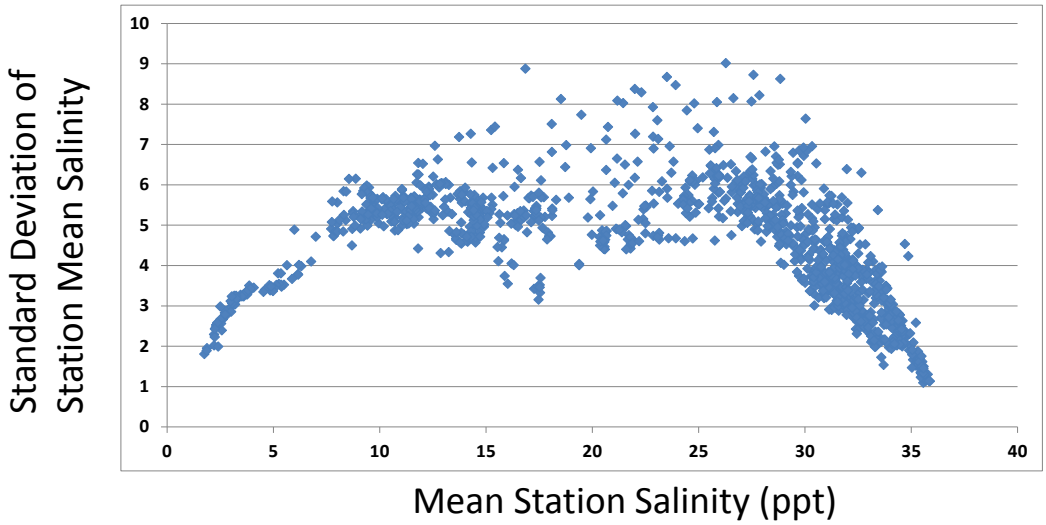


Figure 4. Plot of mean station salinity (ppt) vs. the standard deviation of the mean station salinity (ppt) for Shellfish Sanitation Program sampling stations have more than 30 observations between 2007 and 2011. N = 1239 stations.

When salinity is examined by water body, SS data are particularly useful for identifying water bodies most appropriate for particular habitat foundation species. As an example, consider the small coastal sounds and river estuaries from Carteret County to the South Carolina border (Fig. 5). In this figure, the data for the North River stations are designated by the large green circles. This highlighting of the North River stations was done to indicate a set of salinity regime characteristics for which recent survey data indicate that oyster habitats are struggling (Lindquist, unpub. data). Entirely subtidal oyster restoration efforts and cultch planting should not be conducted in water bodies with mean salinity values at or high than those of the North River. This figure also provide a view of salinity regimes averaged over a longer time period (~24 years) versus during a shorter 5-yr time frame characterized by persistent drought conditions. Note that during the drought period, salinities across all stations had higher mean values and lower variability.

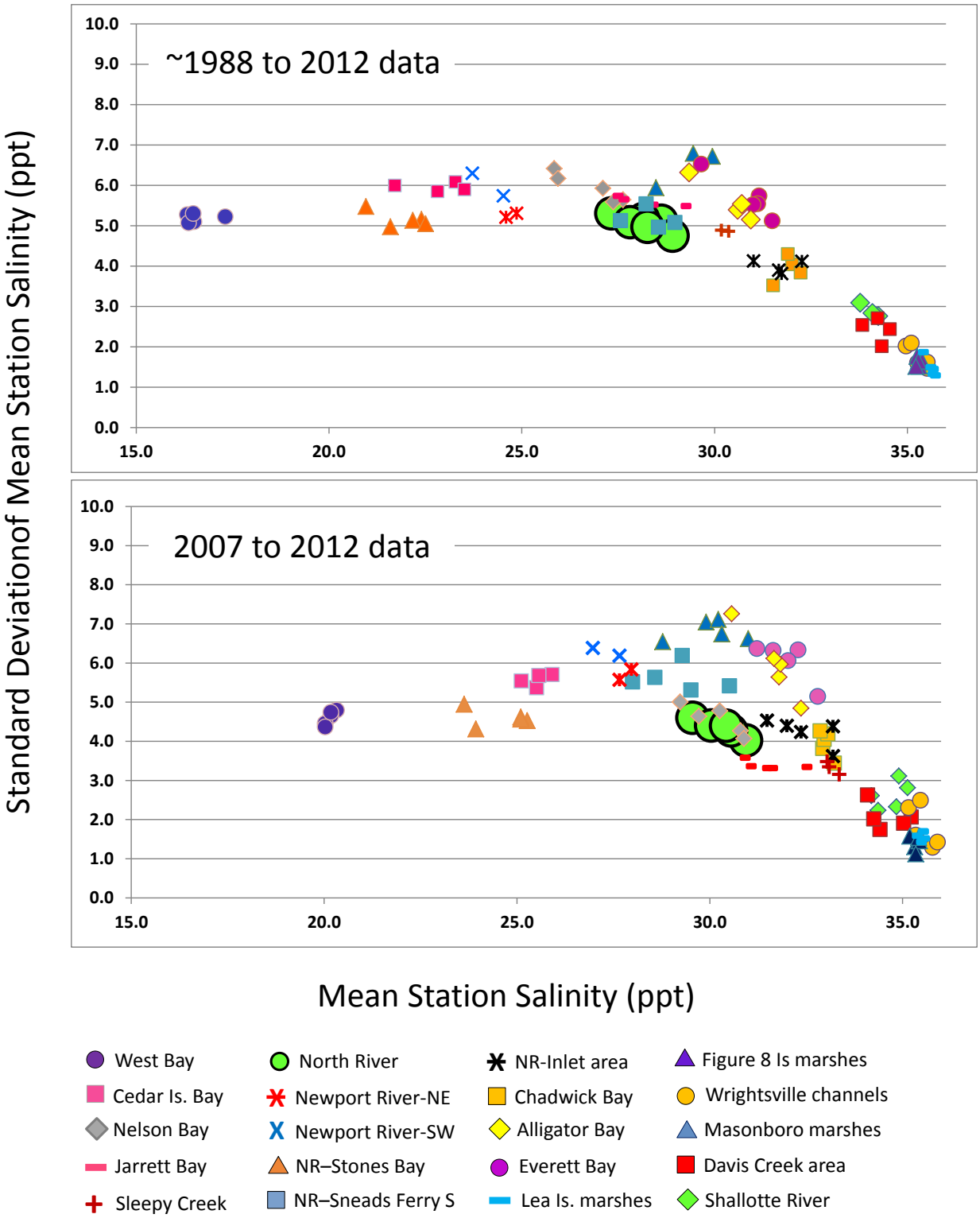


Figure 5. Plot of mean station salinity (ppt) vs. standard deviation of the mean station salinity for Shellfish Sanitation sampling stations within water bodies averaged over a 24-year period (top) vs. a 5-year period characterized by persistent drought conditions (bottom). The data for the North River are shown by the enlarged green dots to highlight the salinity characteristics of a water body that recent survey data show is unfavorable for the persistence of subtidal oyster reef habitat.

SS data are also useful for examining salinity characteristics in the areas surrounding Pamlico Sound oyster sanctuaries (Table 2). In this table, data for sanctuaries are grouped by sanctuaries and color coded by sanctuary conditions, where DMF survey data indicate that oysters are virtually absent from deployed foundation materials (red), potentially struggling to maintain oyster populations (gold), and maintaining substantial oyster populations over multiple years (green). These data strongly suggest what salinity regimes defined by SS data can be used to predict success in oyster habitat creation. Appropriately merging other data in *SalWise* with the SS data would further increase the value of these data as predictors of oyster habitat resilience and oyster habitat restoration success.

Table 2. Pamlico Sound Oyster Sanctuary Salinity Characteristics ~1990-2012.

Sanctuary	Mean Salinity	SD	Salinity Range	% obs < 10 ppt	% obs > 25 ppt
Croatan Sound	11.1	5.8	0-28	40	2
Neuse River	12.2	5.5	0-37	30	1
Deep Bay	13.4	5.9	0-28	27	4
Middle Bay	14.1	4.8	1-31	17	1
Crab Hole	14.4	5.4	0-30	14	5
Gibb Shoal	16.9	5.1	0-30	6	7
West Bluff	17.2	5.5	0-30	5	9
West Bay	17.6	6.2	2-37	10	12
Hatteras	21.7	4.8	10-35	0	31
Ocracoke	24.5	5.6	10-38	0	50

Interestingly, when SS station data are plotted over time for individual areas, swings in salinity levels emerge at multiple, different time frames (Fig. 6). From ~1989 to 2012 at three regions where oyster reef foundations have been deployed (the lower Neuse River south shore in Carteret County, behind Hatteras Island near the Clam Shoal sanctuary and near the Ocracoke reef complex), one obvious feature in each of the three locations is the steep upward trend in salinity values beginning around 2002 and lasting to the end of the record. This upward swing in salinity occurred during a decade of drought and near the time when reef foundation construction began at the Ocracoke and Hatteras sanctuary sites. The sustained rise in salinity in the eastern Pamlico Sound sanctuary sites likely contributed to the rather rapid demise of oysters at these locations.

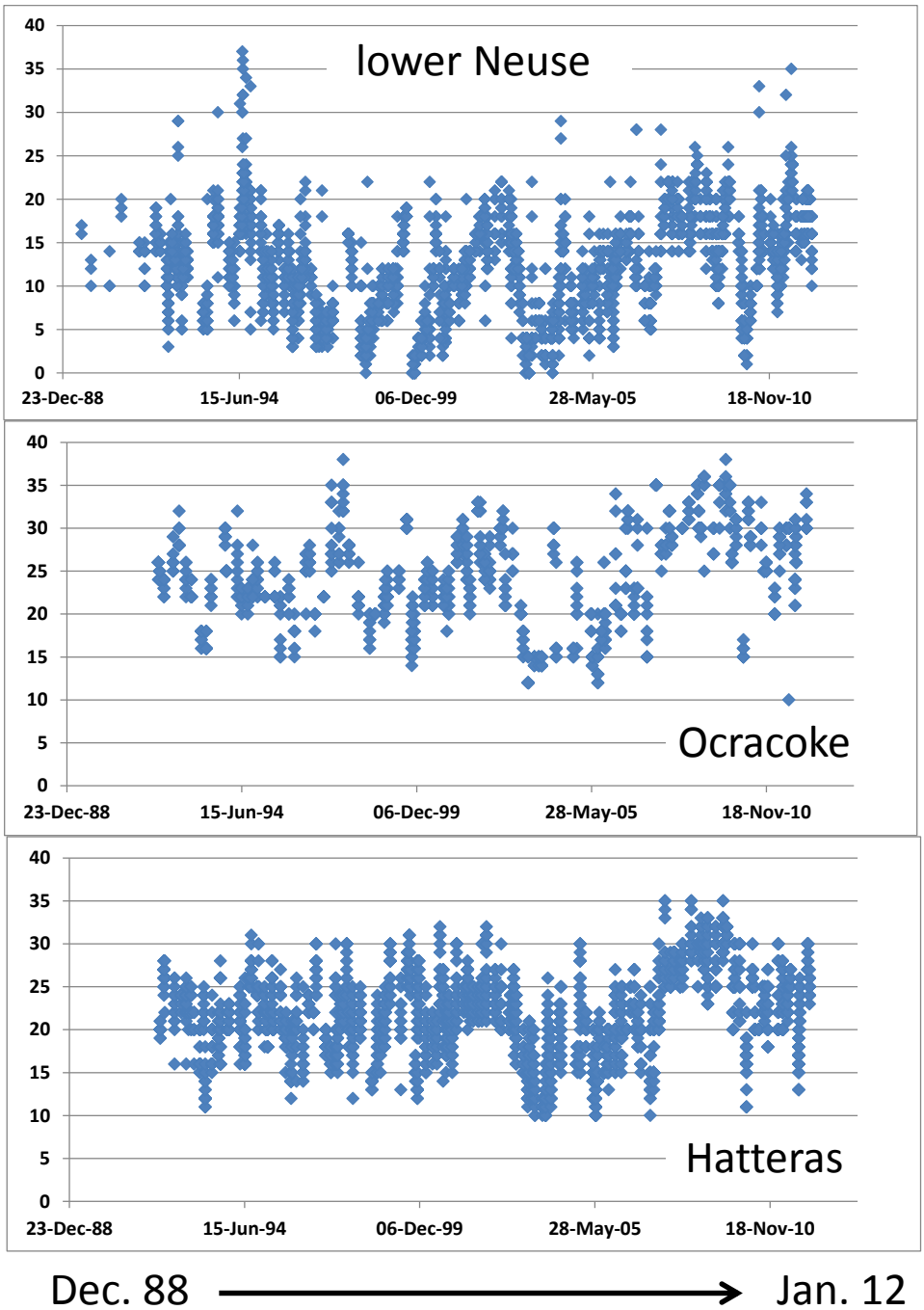


Figure 6. Plots of Shellfish Sanitation station salinity data between December 1988 and January 2012 for the lower Neuse River (top panel), the area near the Ocracoke reef complex (middle panel), and the area near the Clam Shoal reef site on the back side of Hatteras Island.

Deviations from Original Plan

The overarching goal for our proposed project was to begin developing a comprehensive, state-wide salinity database that enables government agencies, academic research groups, and other users to: (1) better understand salinity interactions with fish populations, essential fish habitats, and ecological and biogeochemical processes in estuarine waters; (2) rigorously examine drivers of past to present transitions in salinity regimes; and (3) establish a firm baseline for measuring salinity changes moving forward in a

coastal environment expected to change rapidly under multiple sea-level rise scenarios. Secondarily, we proposed integrating *SalWise* data with other environmental databases, such as precipitation, daily insolation and stream flows to explore and enhance our ability to predict future changes in salinity. The *SalWise* team achieved its primary objective by acquiring and integrating government and academic salinity and water T datasets detailed in Appendix 1.

The efforts of the *SalWise* team to date have met the project's stated objective to make substantial headway toward the creation of a comprehensive, state-wide salinity database for North Carolina that provides the foundation to address goals 1-3 listed above. The *SalWise* team also explored data integrity through an analysis of salinity trends over time for the region in Carteret County encompassing eastern Bogue Sound, Back Sound, southern Core Sound, North River estuary and Newport River estuary. This analysis, described in detail below, suggests that at least one set of data, namely the DENR DWQ (Program 30) data, needs to be removed from *SalWise* because of its large number of zero salinity values that are possibly derived from "no data" entries that were inappropriately assigned a "0" value while transforming the original source data set to the *SalWise* format.

The *SalWise* team also began explorations of environmental drivers of salinity and water temperature trends over time. We found, however, that a major hurdle for examining environmental drivers of salinity regime changes in North Carolina coastal waters was the time required to locate, acquire and sufficiently understand them to be confident in our ability to relate data on precipitation, stream flows, drought indices, storms, wind velocity/duration to salinity and water temperature data in *SalWise*. While we began exploring the availability and forms of data that address some of these factors (see section below related to inlet dredging), it became clear that appropriately examining any one of these factor's influence on salinity was going to be an effort beyond the support provided by the CRFL grant. Future *SalWise* work/research will focus on expanding the database and acquiring data on environmental/anthropogenic drivers possibly controlling salinity regimes and developing robust modeling tools for predicting salinity levels. Working toward this goal, we have established relationships with key people within various federal (e.g. NOAA's National Ocean Service and National Weather Service) and state (e.g. the State Climate Office of North Carolina) agencies that house and analyze data on various environmental factors that influence estuarine salinity regimes and water temperatures.

Historical Salinity Datasets (HSDs) and SalWise

Because of the long historical presence of academic, state and federal marine labs in the vicinity of Beaufort/Morehead City, multiple studies have been conducted since the early 1900s that involved the collection of salinity and water temperature data. Lindquist and Fegley initiated work to locate historical salinity datasets (HSDs) for the area around Pivers Island in Beaufort to compile a century-long record of salinity and water temperatures. Presently, the Pivers Island area study includes published data by Hoyt (1920), Gutsell (1930), and Wells (1961) and unpublished data from NOAA and Dr. Joel Fodrie (UNC-IMS). Additional data for Pivers Island (and other estuarine sites in North Carolina) exist in multiple theses and dissertations housed in the libraries of the Duke University Marine Lab, UNC-IMS, NOAA, NCSU, and other universities as well as in the undigitized files of the NC Shellfish Sanitation Program. Future work will focus on acquiring these studies and incorporating their data into *SalWise*, as well as HSDs for all regions of North Carolina.

With regards to HSDs, data from studies conducted in North Carolina in the late-19th (e.g. Winslow 1889) and early- and mid-20th (e.g. Grave 1904, Hoyt 1920, Gutsell 1930, Wells 1961, Williams et al. 1973) centuries, provide only statistical summaries of their data, such as monthly means and monthly minimum and maximum values. Because these records are not generally comparable to the point sampling of the more modern data in *SalWise*, the *SalWise* team did not add summarized historical salinity and water temperature data to *SalWise*. An important future effort for expanding the *SalWise* database will be attempting to track down and add to *SalWise*, if they still exist, records of the individual

samplings of the other summarized HSDs. However, the mid-20th century water sampling work of Mr. Hugh Porter, a researcher at the UNC Institute of Marine Sciences, was available as point sampling data. Mr. Porter frequently sampled waters off the IMS dock in Bogue Sound for salinity and water temperature between 1945 and 1967 and also on multiple sampling campaigns across the larger North Carolina sounds over the same time frame. Summaries of his sampling efforts and other IMS faculty were published by Williams and co-workers (1973). The individual records underpinning the Williams et al. summary were housed at IMS, and a significant portion of the first-year effort of the *SalWise* technician was devoted to transcribing these data from the individual sample record cards into an electronic spreadsheet for incorporation into *SalWise*. This "Porter" dataset added 14,523 records to *SalWise*.

Inclusion of summarized HSDs into SalWise will be a future feature of the database for examining long-term changes in salinity and water temperature (e.g. decadal- and centennial-scale) as an increasing number of water quality monitoring projects are deploying conductivity/T sensors that operate in a "continuous" mode with relative high rates of sampling, including for example FerryMon (included in *SalWise*) and automated vertical profiler (AVP) data being acquired by Dr. Rick Luettich's group (UNC-IMS) at two sites in the New River (not yet in *SalWise*). Importantly, these large, continuous datasets can be subsampled in ways that mimic sampling strategies of some HSDs. For example, Dr. Joel Fodrie (UNC-IMS) is leading a CRFL-funded project comparing past oyster communities in the Newport River estuary as reported by Wells (1959, 1961) with contemporary community compositions in reef habitat at the same locations studied by Wells. Dr. Fodrie's efforts include deploying sensors that are programmed to measure salinity and water temperature every 10 minutes. With these "continuous" data, it is possible to subsample them according to the standardized protocols of the historical studies to generate comparable summary statistics.

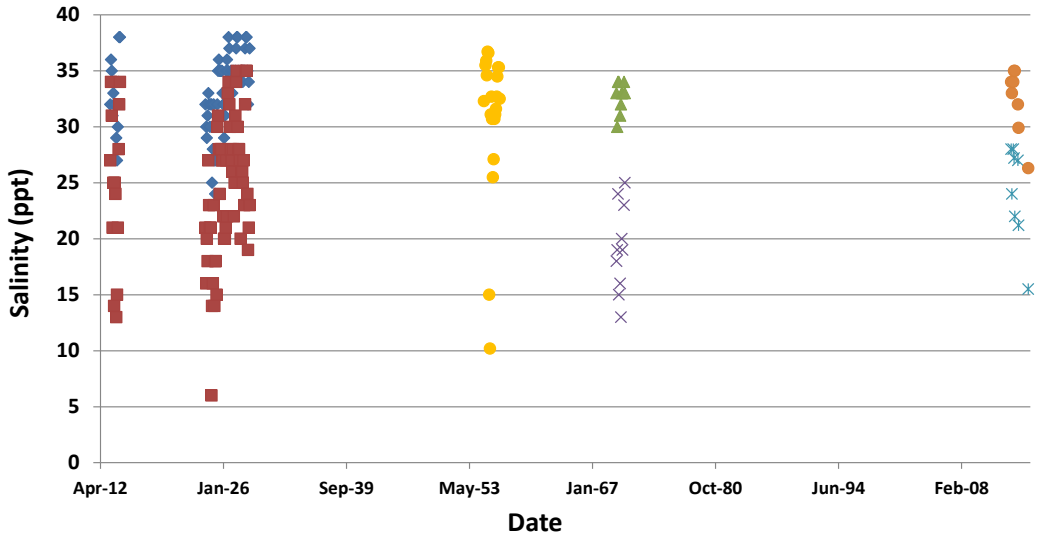


Figure 7. Monthly min-max salinity values in the vicinity of Pivers Island, Beaufort, North Carolina 1913-2014. Data clusters from oldest to newest were from Hoyt (1920) 1913-1914 daily 5 pm; Gutsell (1931) 1924-1928 daily time-of-day not specified, Wells (1961) 1955-1956 monthly targeting low tide and thus biased toward lower salinity values; Willis (NOAA, unpublished data) 1969-1970 monthly min-max extracted from ~hourly sampling sensor; and Fodrie (unpublished data) 2013-2014 monthly min-max extracted from ~10 minute sampling sensor. Note the general trends in these data of lower maximum and higher minimum values of the graphs time frame, suggesting that freshets of early 20th century magnitude do not occur later in the time period, possibly due to inlet dredging, which can increase the volume of higher salinity ocean waters entering nearby estuaries.

Figure 7 shows reported monthly minimum and maximum salinity values for the Pivers Island, Beaufort, North Carolina vicinity between 1913 and 2014. Data from continuously-sampling sensors,

like those deployed by Dr. Fodrie's team in the Newport River estuary, identify the absolute daily or tide-cycle minimum and maximum salinity and temperature values , which is not the case for the HSDs. Hoyt (1920) collected water samples daily at 5 pm over a nearly 5-year period, and during that time reported monthly minimums as low as 6 ppt. When Hoyt's 5-pm sampling protocol is compared to the Fodrie dataset for 2014, a year with an exceptional summer freshet, the lowest salinity obtained was 19 ppt – a value 4 ppt higher than the lowest value recorded by the sensor. Thus it is likely that the values reported by Hoyt did not always record the lowest and highest salinity values, suggesting that the waters near Pivers Island during ca. 1913-1918 were more extreme at both the low and high ends of the estuarine salinity spectrum. Further, great care needs to be taken in understanding the intended or unintended sampling biases in the study. For example, Wells (1959, 1961) sampled ~monthly with a bias toward low tides that would yield lower salinity values most pertinent to the distribution and abundance of carbonate eroding boring sponges and their interactions with oysters.

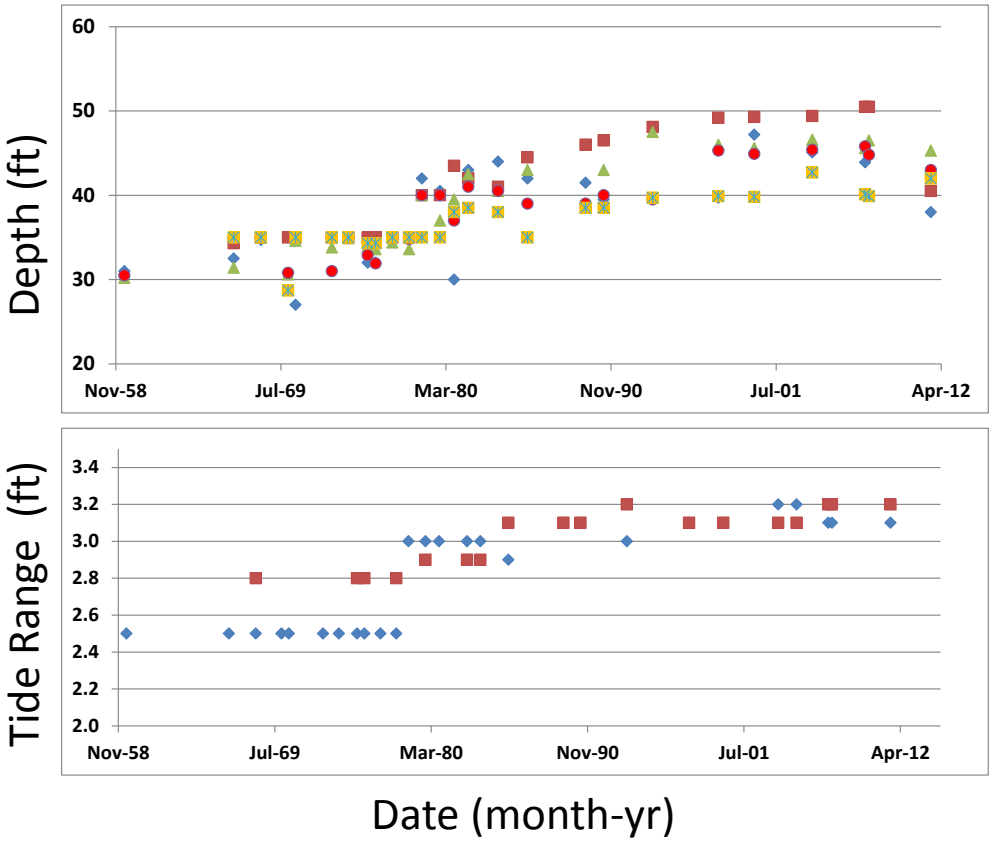
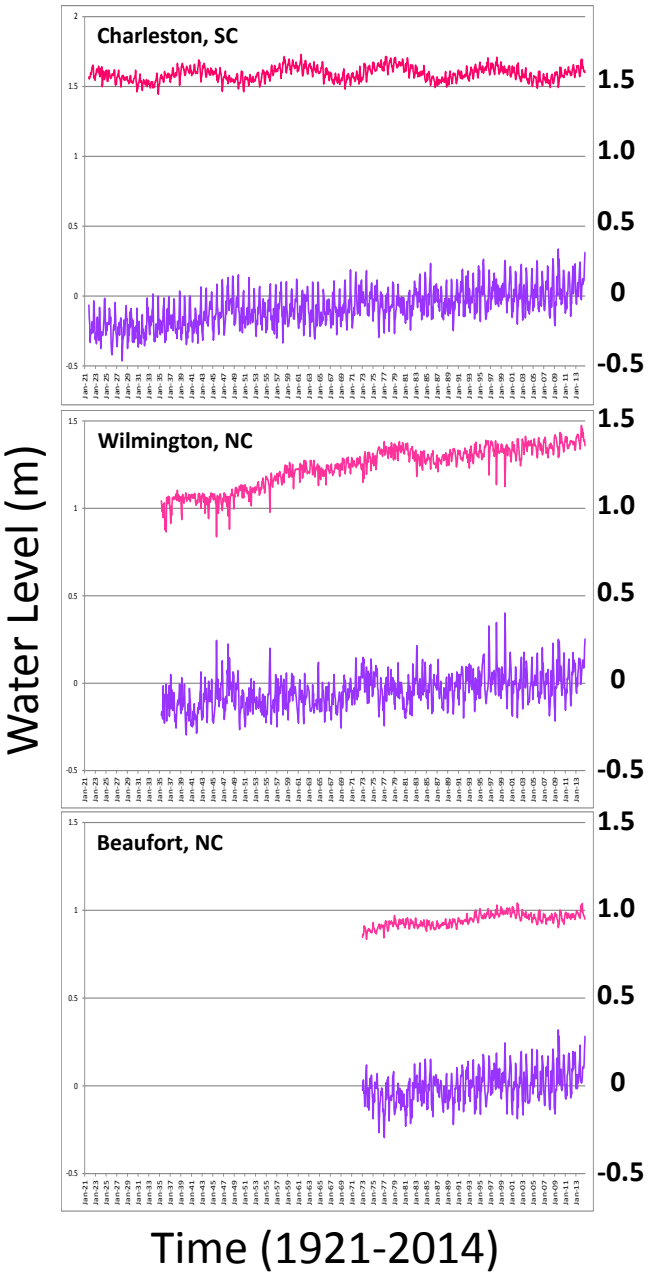


Figure 8. Depth of various sections of the Beaufort Inlet-Morehead City Port shipping lane (top) and tide ranges (bottom) for the Morehead City State Port (red squares) and Beaufort harbor (blue diamonds) as reported on NOAA nautical charts between 1958 and 2011.

It appears that over the past century there has been a narrowing of the salinity range at Pivers Island (Fig. 7). We hypothesize that this range narrowing likely occurred due to both natural and anthropogenic factors. Natural factors include the opening of Barden Inlet at Cape Lookout and Drum Inlet on Core Banks during the passage of the 1933 Outer Banks Hurricane. Anthropogenic factors include dredging of Beaufort Inlet and local ICW channels. Dredging of ocean inlets likely increases the saltwater influx and brackish water efflux of estuarine systems (e.g., Flick et al. 2003). Depending on the local coastal bathymetry, inlet dredging may also increase the estuarine tide range (Flick et al. 2003, Zervas 2003), a highly visible manifestation of the dredging activity, which likely further increases water exchanges between the connected ocean-estuarine systems. The increased levels of ocean-estuarine water

exchanges in some coastal areas likely narrows both salinity and temperature ranges, bringing their mean values closer to that of coastal ocean waters. Although Beaufort Inlet has been dredged since the early 1900s, with the development of the state port at Morehead City, more extensive deep dredging of Beaufort Inlet began in the mid-1970s. Figure 8 shows the depths of various sections of the channel leading to the post at Morehead City over time and the tide ranges over the same time period for the Morehead City port and the town of Beaufort. These data were taken from NOAA nautical charts published between 1958 and 2011.

Figure 9. Tide range (fuchsia line) and mean sea level (purple line) relative to mean sea level (1983-2001 epoch) at Charleston, SC, Wilmington, NC and Beaufort, NC. The time axis for all graphs runs from 1921 to 2014.



We presently have relatively little salinity and water temperature data for Pivers Island between ~1970 and 2000 with which to examine correlations between inlet dredging activity (Fig. 8) and estuarine tide, salinity and water temperature ranges. Navigation channel deepening has been proposed to alter tidal characteristics, include tide ranges (Flick et al. 2003, Zervas 2003) and, in some estuarine systems, salinity regime by increasing saltwater intrusion (Hackney and Yelverton 1990). The hypothesis that inlet dredging can increase tidal ranges within some estuaries is further supported by water-level data for at least one other U.S. location, namely the Cape Fear River estuary. This is a system that also experienced extensive dredging of the ocean inlet and Cape Fear River navigation channels leading up to the port at Wilmington, North Carolina. Figure 9 shows tide range and mean water level for 3 stations: Charleston, South Carolina; Wilmington, North Carolina; and Beaufort, North Carolina. At Charleston, the station with the longest record among the three locations, mean sea level has increased by ~20 cm, while the mean tide range has not changed. The ~18.6 year cycle in tidal range amplitude modulation, evident in the record, is due to the lunar-nodal cycle, which globally modulates the gravitational pull of the moon on the Earth's oceans and seas (Flick et al. 2003, Haigh et al. 2011). At Wilmington, mean sea level has increased slightly less than in Charleston, but the tide range began increasing in the late 1940's and is today 50% greater than at earlier times (Flick et al. 2003, Zervas 2003). The late 1940s was when extensive deep channel

dredging began in the Lower Cape Fear River in association with the development of the state port at Wilmington. In the lower Cape Fear River estuary, saltwater intrusion associated with the increased tide range and rising sea levels have led to increasing levels of nuisance flooding and substantial vegetative changes in the tidal marshlands of the lower estuary (Hackney and Yelverton 1990). Although, the official water-level record for Beaufort is not as long as those of Charleston and Wilmington, like at Wilmington, both tidal range and sea level have increased in recent decades. In the Beaufort record, the 18.6 year lunar-nodal cycle is clearly seen in the tide range data. The amplitude of the lunar-nodal cycle is in Wilmington and Beaufort is ~10 cm and ~5 cm, respectively. Among all of the NOAA water level stations, there are only 4 stations that show an increase in tide range; the other two are Philadelphia, Pennsylvania and Anchorage, Alaska (Zervas 2003). The increase in the tide range at Anchorage was likely due to the 1964, magnitude 9.2, megathrust earthquake that altered the harbor's bathymetry. This "Good Friday" earthquake was the most powerful recorded in North American history, and the second most powerful recorded in world history. We have not yet searched for the hypothesized cause of the Philadelphia tide range increase.

An important feature to note in Figure 9 is that the lunar-nodal cycle's influence on the North Carolina coastal tide ranges, and likely estuarine salinity and water temperature regimes in the vicinity of ocean inlets, will peak in 2016, after which the lunar nodal effect will run counter to increasing sea-level rise trends and effects. However, beginning in ~2025, the lunar-nodal cycle will switch to reinforce sea-level rise such that many regions of the North Carolina coast will experience a rapid rise in nuisance flooding and increasing saltwater intrusion into the State's estuaries that will likely have substantial and sustained impacts on all estuarine ecosystems.

While global atmospheric warming is generally also warming coastal marine and estuarine waters, this trend may not represent the direction of temperature changes in the estuarine waters along some areas of the North Carolina coast. For the smaller coastal sounds and small river estuaries from Carteret County to the South Carolina border, rising sea levels and tide ranges may be reducing levels of thermal and pH stresses on estuarine organisms by increasing ocean water (more constant T and pH) influx and brackish water (large T and pH ranges) efflux in many estuarine systems. In North Carolina, from Carteret County to the South Carolina border, there is only one inlet that has not been dredged – Rich Inlet (personal communication, ACE-Wilmington).

Salinity over time in Carteret County estuarine waters (excluding Pamlico Sound)

With reasonable evidence for increasing sea level and tidal range in the vicinity of Beaufort Inlet (Figure 9), we began an analysis using *SalWise* data to test for salinity regime changes in the estuarine waters connected to Beaufort Inlet, namely those of eastern Bogue Sound, Back Sound and Core Sound and the Newport and North River estuaries. For this analysis, the Porter salinity dataset was exceptionally important, as many of the records in the Porter dataset were collected during the period preceding the extensive deep dredging of Beaufort Inlet. However, the individual data sets merged into *SalWise* originate from an array of governmental and research sampling programs. Although all of these programs measured salinity, the sampling designs of the programs, reflecting program-specific goals, often differed. Given these programmatic differences, there is a potential that naïve interpretation of patterns drawn from *SalWise* will not truly represent water body conditions at the time of sampling. Our examination of salinity over time in Carteret County waters also permitted an examination of whether *SalWise* could be burdened by programmatic issues (beyond simple sampling intensity and frequency).

Sampling efforts by the 13 different programs providing data for this analysis were not uniformly distributed across the different water bodies (Table 3). About half of the programs had at least some samples in all four water body regions. Core Sound is the only water body in which every program contributed samples. The greatest number of samples in the record subset were collected in Bogue Sound, the least in the Newport River. The largest single source of samples (66.4% of all records) is the

Shellfish Sanitation program. Sampling effort across time is not consistent either (Fig. 10). We currently have no salinity records for any of these water bodies from 1968 to 1974. Also, in two time intervals, all records derive from a single program. For the years from 1945 to 1967 all records come from the Hugh Porter data set. From 1975 through 1989 all of the records come from the DENR DWQ program. Since 1990, 12 programs provide salinity data from all four water bodies. No single program provides data over the entire time interval.

Table 3. Number of SalWise salinity records from each sampling program among four water body regions from 1945 through the first half of 2015. Gray cells indicate that no samples were taken in the respective water body by that program in any year.

Program	Bogue Sound	Core Sound	Newport River	North River/Back Sound	Grand Total
Alternative Platform Observations	6	14		3	**23**
Bay Scallop Monitoring	326	238		212	**776**
Commercial Shrimp Trawl Fishery Characterization		1			**1**
DENR DWQ	221	194	404	351	**1170**
Estuarine Gag Trawl Survey	75	110		79	**264**
Fish Pot Study	15	27	3	11	**56**
Hard Clam Survey		502		10	**512**
Hugh Porter	1977	767	752	100	**3596**
NCDENR-DWQ (2nd)	207	357	572	611	**1747**
NCDENR-DWQ WQX		65	279	71	**415**
Sea Turtle Bycatch Monitoring		85	23	7	**115**
Shellfish Bottom Mapping	4006	362	2934	2033	**9335**
Shellfish Sanitation:	13445	9030	4848	8304	**35627**
Grand Total	**20278**	**11752**	**9815**	**11792**	**53637**

Perusal of the distribution of salinity over time (Fig. 10) suggests that Carteret County estuarine waters may have been fresher during the interval from 1975 through 1990, a pattern that is more apparent in the annual means (Fig. 11). A two-way ANOVA, followed by Tukey's unplanned comparisons, reveals **a** significant two-way interaction for time interval (1945-1970, 1975-1989, and 1990-2015, Porter data, DENR DWQ data, and multiple data sets, respectively) and water body. The post hoc tests reveal that recorded salinities are lowest in each water basin from 1975-1989. Salinities are highest in each water basin from 1990-2015, with salinities in the oldest interval, 1945-1970, either intermediate in salinity (Newport River and Core Sound) or not differing from the most recent decades (Bogue Sound and North River/Back Sound; Fig. 12).

Examination of water temperatures taken simultaneously with the salinity samples do not show the same patterns (Fig. 13). However, a two-way ANOVA of temperature data comparing water basin and time interval did indicate a highly significant interaction term. Tukey unplanned comparisons revealed a more complex pattern than that observed for salinity in these locations during these time intervals (Fig. 14). In general, water temperatures have been cooler in the last 25 to 40 years, except in in the Newport River, which was coolest in the interval from 1975 – 1989 and no different in mean water temperature between the interval of 1945 – 1970 and the past 25 years.

Before concluding that environmental changes affected mean salinity and temperature of estuarine waters in these intervals we must be assured that programmatic eccentricities do not contribute to the observed temporal patterns. All measurements in the oldest interval (prior to 1970) come from the Hugh Porter dataset. All measurements from the 1970's and 1980's come from the DENR DWQ dataset. At IMS, we have written records of the intent for sampling water salinity and temperature by this former IMS faculty member, Hugh Porter, and his colleagues. Almost without exception, sampling was conducted, without bias, to reveal spatial and temporal variation in salinity and temperature in many locations throughout the North Carolina's coastal waters. We have not yet been able to find comparable written or oral histories about the DENR DWQ dataset during the time interval from 1975 - 1989. Because of the significantly lower salinities recorded in that data set, we must consider the possibility that

all, or some portion, of these data may have been "conditional" samples, samples taken when storms or spring freshets were likely to alter background estuarine water quality conditions.

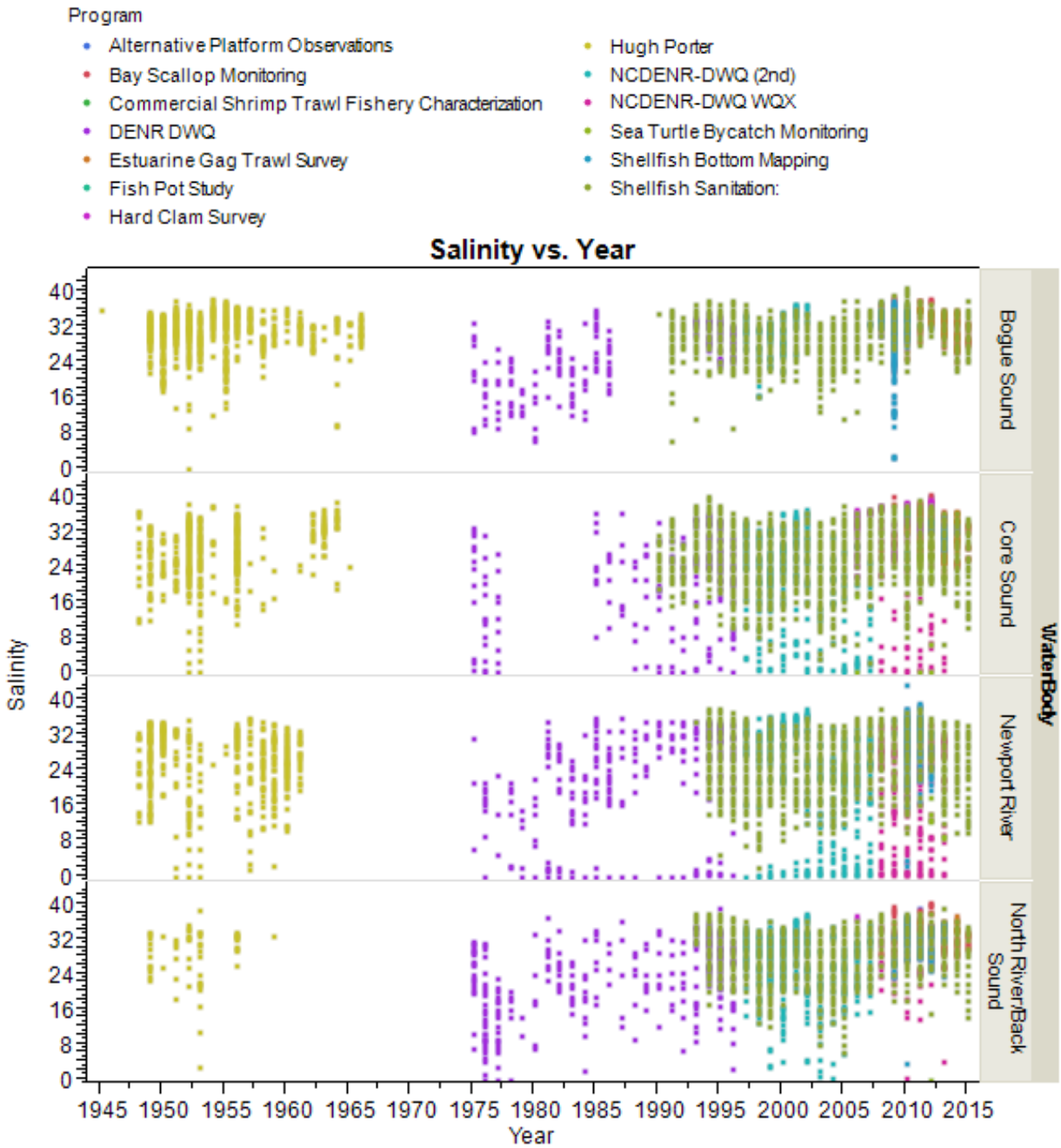


Figure 10. Each salinity sample (in ppt) by program, year, and water body.

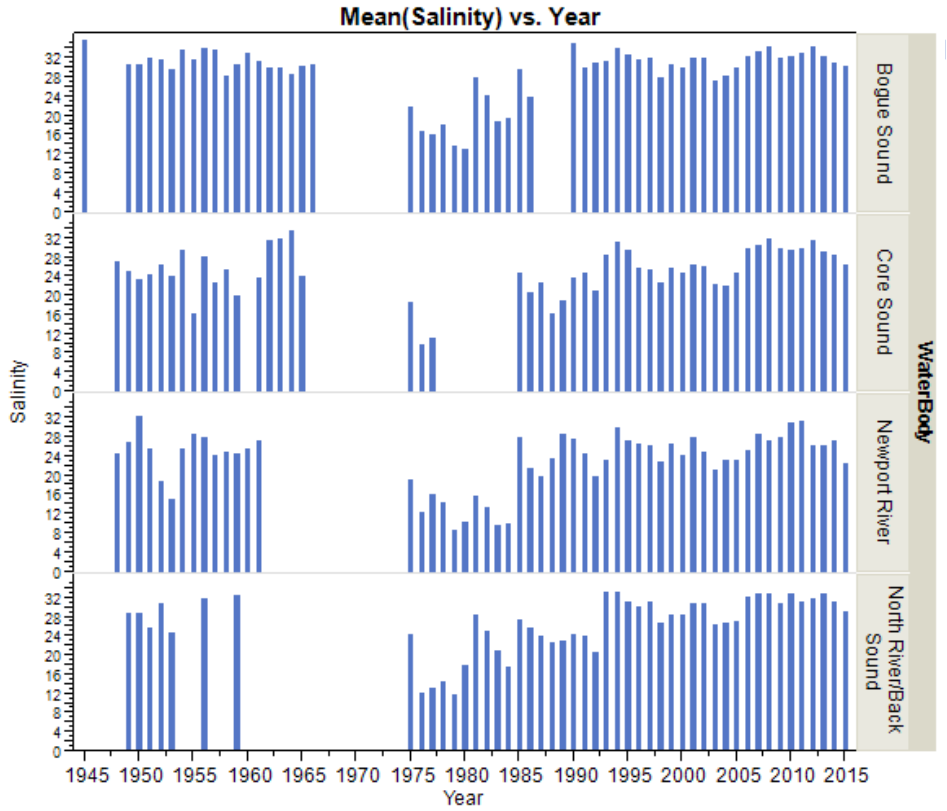


Figure 11. Annual mean salinity (in ppt) by water body.

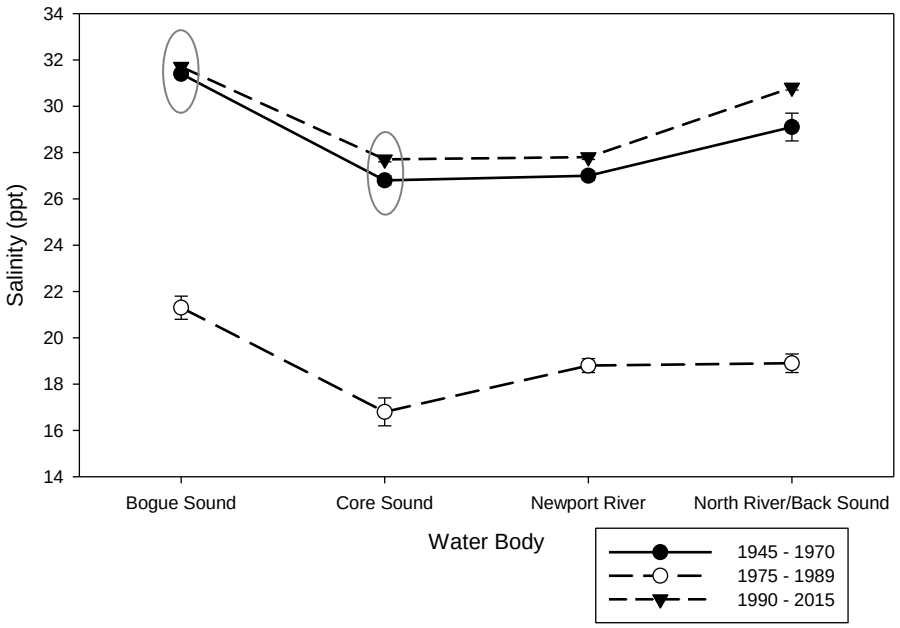


Figure 12. Mean salinity (±1 SE) for three time intervals (1945-1970, 1975-1989, and 1990-2015), determined by the temporal pattern of records in *SalWise*, for each of four water basins in Carteret County. Means, within a water body, not enclosed within an ellipse are significantly different as determined by Tukey unplanned comparisons after ANOVA indicated a significant time interval x water body interaction ($P < 0.0001$).

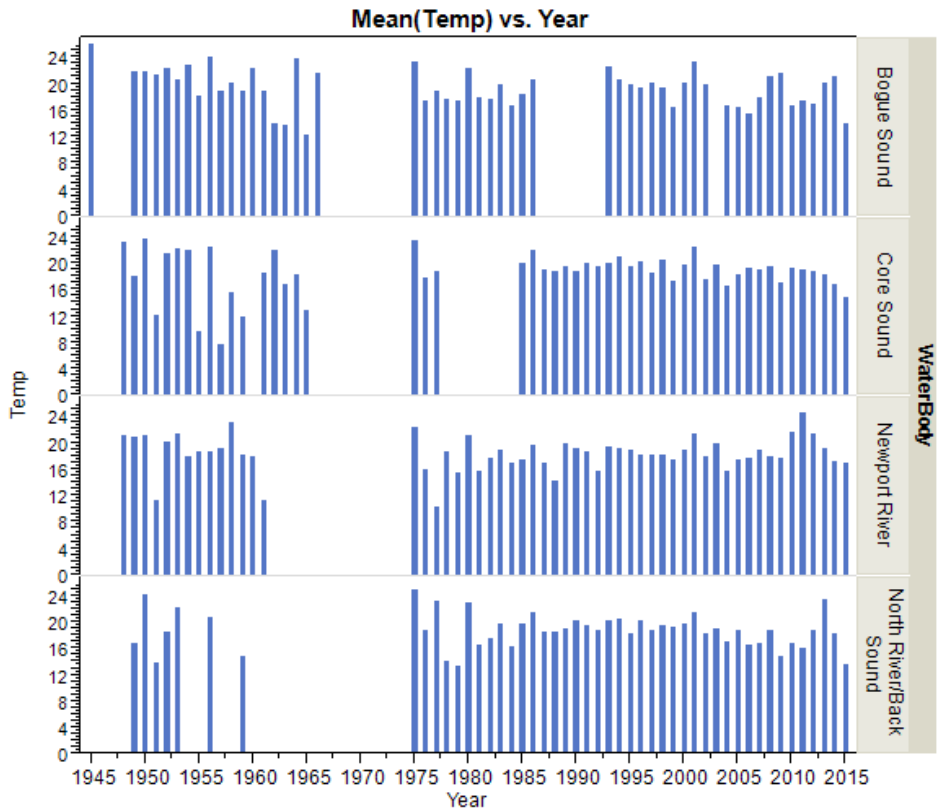


Figure 13. Annual mean temperature (in °C) by water body.

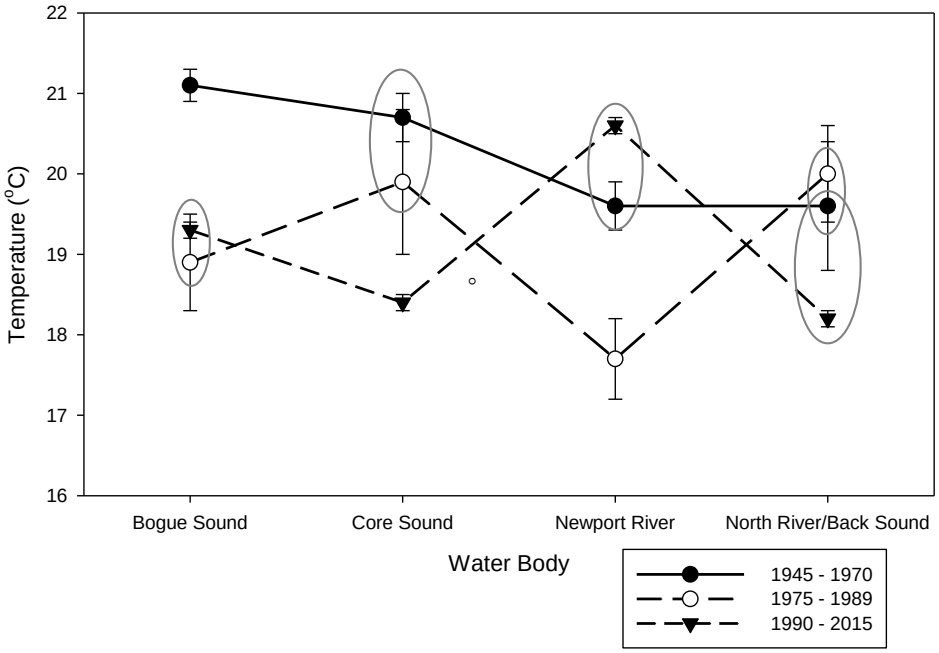


Figure 14. Mean temperature (±1 SE) for three time intervals (1945-1970, 1975-1989, and 1990-2015), determined by the temporal pattern of records in SalWise, for each of four water basins in Carteret County. Means, within a water body, not enclosed within an ellipse are significantly different as determined by Tukey unplanned comparisons after ANOVA indicated a significant time interval x water body interaction ($P < 0.003$).

To determine whether the DENR DWQ sampling program, during its early years, indicates background salinity conditions, we obtained historical data collected from eastern Bogue Sound from two sources, which had not yet been digitized, for the interval from 1969–2013. The first data set consists of Shellfish Sanitation standard and conditional water sampling records. In this data set, each sample is clearly designated as taken under either a standard sampling regime, to reveal natural patterns of salinity, or conditionally in response to storms that could affect water quality. The second data set, from the Atlantic Estuaries Fisheries Center, has daily minimum and maximum salinities sampled from a fixed location on Piver's Island for one year starting in October 1969 and extending through October 1970.

Inspection of the new Shellfish Sanitation data reveals differences between standard and conditional sampling data and, independently, a difference in standard sampling values over time (Fig. 15). From 1987–2013 the conditional observations range over salinity values characteristic of fresh water to full seawater although a large proportion of salinity measurements are less than 28 ppt. Standard sampling values tend to be more restricted to values between 29 and 36 ppt (the mean salinities between the two sampling regimes over this time interval are significantly different, $P < 0.001$, with the standard sampling mean salinity higher than the conditional sampling mean). With respect to just the standard sampling data, from 1971–1986 the observed values extend over a substantially greater range of salinities compared to the values recorded from 1987 – 2013, even though sampling frequency is less frequent in the earlier interval. Parsing the records into these two time intervals reveals that mean salinity is significantly lower in the earlier interval ($P < 0.001$).

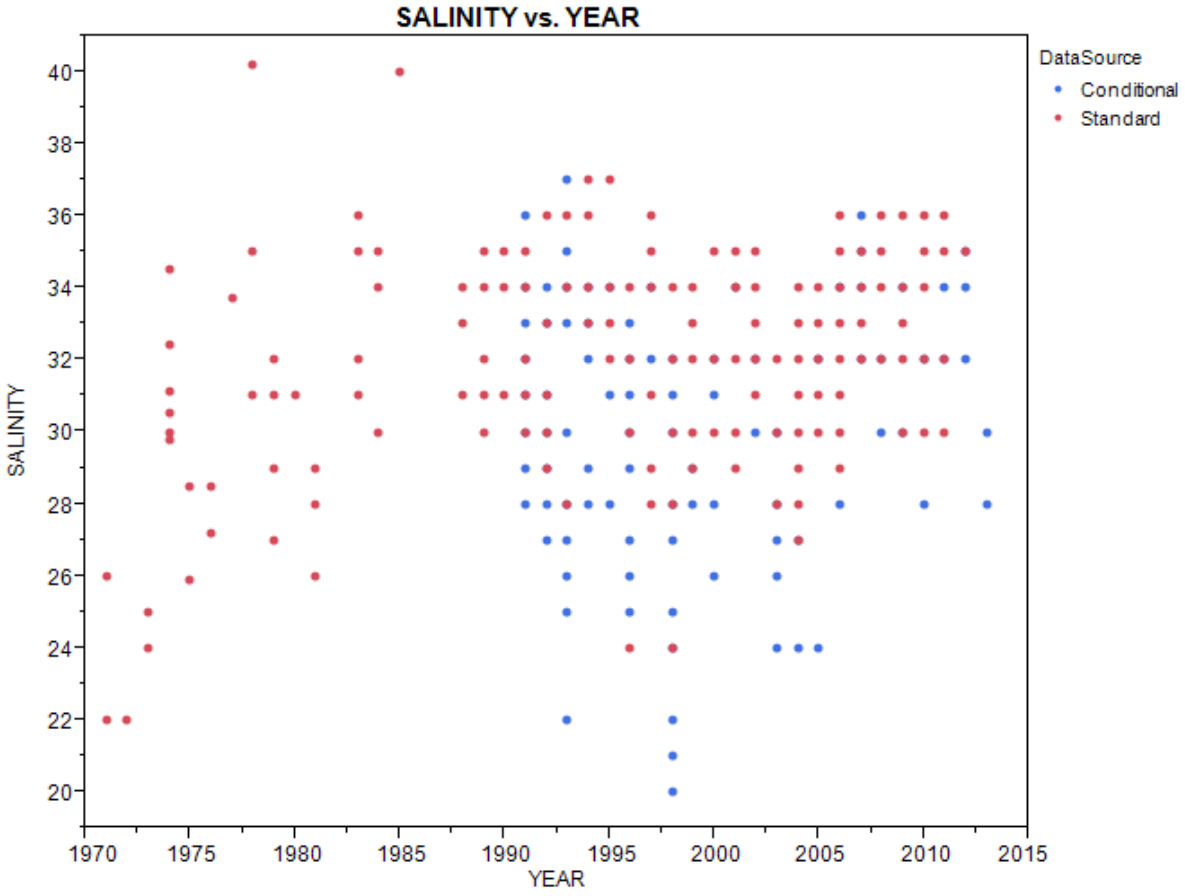


Figure 15. Salinity (in ppt) measured in eastern Bogue Sound from 1971 to 2013 under both standard and conditional SSP sampling regimes.

Examination of daily minima and maxima at Piver's Island recorded over part of 1969 and much of 1970 demonstrates that salinities were well below full seawater values for much of this year interval (Fig. 16).

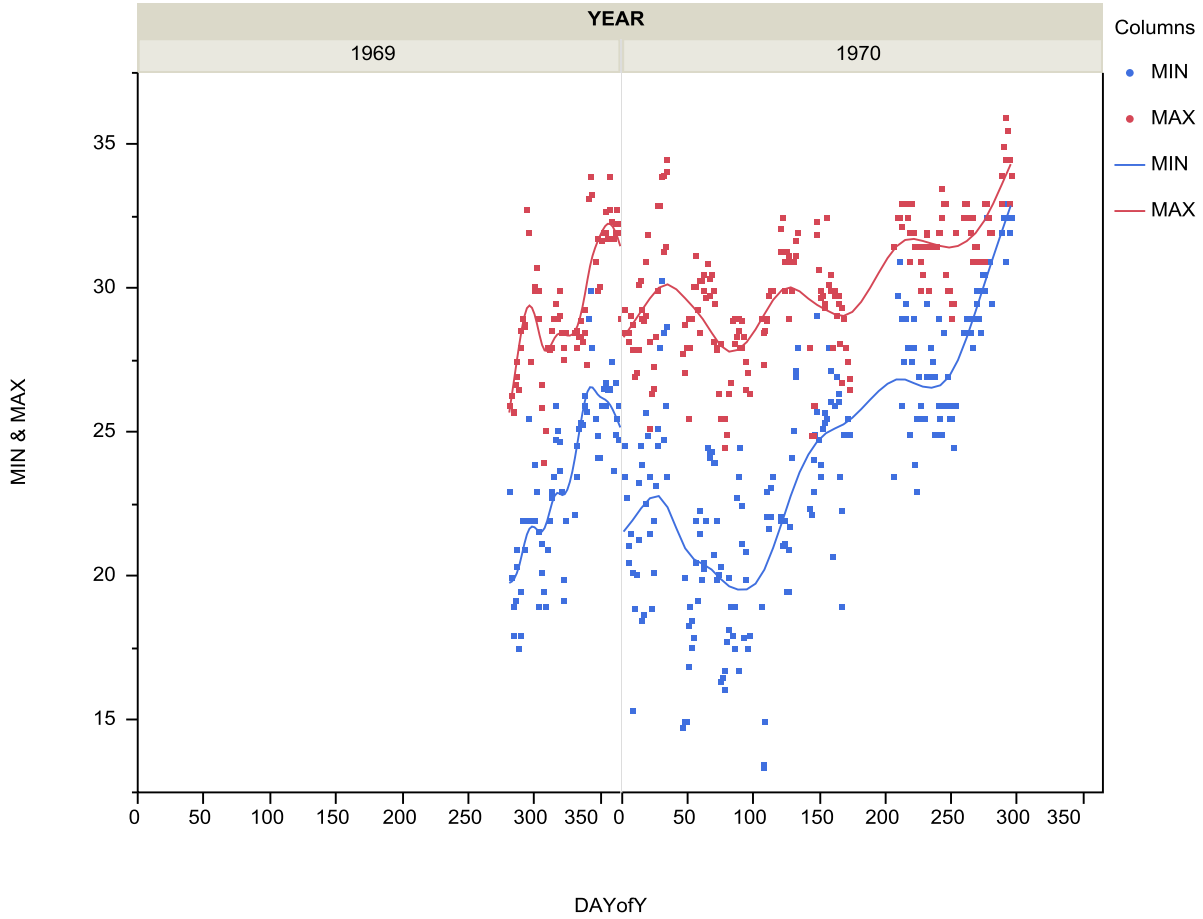


Figure 16. Salinity (in ppt) minima and maxima measured at Piver's Island from 1969 to 1970. The lines are Loess fits to the respective data types to illustrate trends in the data.

The bulk of the salinity maxima fall below 32 ppt for much of the interval, as do all the salinity minima. The daily mid salinity (mean of the daily minimum and maximum) is 27 ppt over the time interval. The mean daily deviation is 6 ppt. Towards the end of 1970 both the minima and maxima converge towards full seawater salinity. There is no indication that the pattern arises from seasonal events; salinity extremes are much higher and less different in the fall of 1970 than the fall of 1969.

Both of these data sets suggest that waters near Beaufort Inlet had salinity values lower during substantial intervals of time during the 1970's, as was indicated by the DENR DWQ data in *SalWise*. We cannot rule out that at least some, if not all, of the DENR DWQ data were sampled in a conditional regime during the 1970's and early 1980's, however, independent data sets also indicate that freshwater sources may have had greater influence on coastal salinities than they appear to have in the last 25 years.

This analysis illustrates that interpretation of isolated salinity records can be fraught with difficulties. Sampling programs, with specific goals, can generate salinity records that have intentional biases (as to when or where sampling occurs) to meet program-specific needs. Only comparison of the

results of a single data set to the results of multiple data sets can reveal whether observed salinity patterns are site specific, time interval specific, or program specific. Further effort is needed to digitize management records and research data from the years prior to 1990, to confirm or refute the apparent patterns in the existing *SalWise* data. One strength of *SalWise* is that for the past quarter century, the discovery and accumulation of data for most bodies of water is well advanced and examination of salinity data can be done using multiple, independent sources.

Cautionary Notes about Use and Interpretation

Use of SalWise data should be guided by the firm understanding that environmental datasets often possess biases that can be intentional or imposed by field conditions and/or logistics. For example, a program based on point sampling may not be able to access a site at low tide, necessitating the collection of samples at higher tide levels only. In many nearshore estuarine environments, like tidal creeks, salinity and water temperate levels can be strong affected by tide level. Low tides tend to create lower salinity regimes by having a larger portion of the water mass coming from terrestrial freshwater run off. Biases may be most commonly associated with point sampling and less so where sensors are deployed that record data at regular intervals over long periods of time. However, with data collected from sensors, great care must be exercised by the program researchers to properly calibrate the sensors and not include data after uncorrectable baseline drift has occurred. We did not, for example, import data from the North Carolina National Estuarine Research Reserve Program due to questions of data quality related to signal drift. Once their drift issues are addressed, these data will be added to *SalWise*. The *SalWise* team has attempted to identify and either correct or eliminate suspect data from *SalWise*. It is, however, the ultimate responsibility of one using water quality data retrieved from *SalWise* to understand as thoroughly as possible sampling biases and other programmatic issues, which may require reading mission/objectives statements and methods descriptions of the source programs whose data are included in materials retrieved from *SalWise*.

Public Access to *SalWise* through the *North Carolina Coastal Atlas (NCCA)*

To provide public access to *SalWise*, Lindquist and Fegley established a relationship with the *North Carolina Coastal Atlas* (*NCCA*) team, led by Associate Professor Tom Allen and Research Associate Rob Howard at East Carolina University. The *NCCA* is an online mapping and investigation system that provides data, both static and interactive maps, and information for exploration, analysis and learning about coastal issues and resources. The *NCCA* covers the entire coastal plain, including the twenty Coastal Area Management Act (CAMA) counties, the estuaries and rivers, and adjacent marine areas. The Atlas is an exceptional learning, management and research platform for students, managers, scientists, teachers, and the public. The *NCCA* combines physical, ecological, and human-use data to support education, management and decision-making. Thematic maps allow non-technical and advanced users to examine and interact with geospatial information on topics such as coastal hazards or shoreline change. The maps allow users to select their area of interest, cartographic layers, and also search for reference, archival, and research data. *NCCA* is built upon a core of ESRI ArcGIS Server technology providing the underlying scientific and cartographic layers and open-source consumable map layers. The *NCCA* customizes maps but also provides Open Geospatial Consortium (OGC) services to collate these and other interoperable layers for users of desktop GIS. The *NCCA* is presently undergoing an upgrade to a new infrastructure based on custom-written backend code that will allow the Atlas to become a more flexible geospatial platform going forward.

When users connect to the *SalWise* database on the *NCCA*, they will begin on a "landing" page having an explanation of salinity's crucial roles in estuarine ecology and coastal management and what *SalWise* offers to users. From the landing page, *SalWise* users will be able to navigate to:

- graphical displays of *SalWise* spatial coverage and general examples of salinity regime characteristics across the State's estuarine waters;

- tabular and graphical displays of *SalWise* database features;
- a RESTful web API that allows programmatic access to the *SalWise* database;
- an interactive map with zoom and choice of data/display functions;
- a database query and data download page: and, importantly,
- a data submission page to provide a facile means for research groups, not-for-profit organizations, and government agencies with salinity and water temperature data not in *SalWise* to offer their data for inclusion in the database.

This last feature will help *SalWise* capture the greatest amount of data possible, thereby further increasing its utility as a lynchpin tool for managing estuarine species and habitats, understanding natural and anthropogenic drivers of salinity regime changes in coastal environments and planning for future disturbances related in increasing sea-level rise and other coastal modifications that alter estuarine salinity regimes.

Future Directions

Future efforts to expand and improve *SalWise* will focus on the following priority items. All data intended for addition to *SalWise*, regardless of source, will be examined for QA/QC prior to inclusion.

1. Establishing procedures for receiving and incorporating data from on-going programs that have already contributed data to the current version of *SalWise*, including for example, the Biological Programs at the NC Division of Marine Fisheries and FerryMon. These protocols will also be applied to new programs with on-going water quality monitoring effort that are added to the *SalWise* portfolio, such as the water quality monitoring being conducted by the North Carolina Coastal Reserve System.

2. Transfer the salinity, water temperature, and fecal indicator bacteria data contained in the paper-based records of the North Carolina Shellfish Sanitation Program into electronic spreadsheets that can be incorporated into *SalWise*. These include "standard" sampling data covering ~1960 to ~1998 and all "conditional" sampling data from the 1960s to present. These data cover part of a period of time that has relatively little reported water quality data for North Carolina. These data are crucial for examining long-term trajectories in estuarine salinity and water temperatures and efforts to identify major drivers controlling these critical estuarine environmental parameters.

3. Acquiring, vetting and incorporating salinity, water temperature, and other water quality parameters from multiple academic research groups here in North Carolina and from institutions outside of North Carolina. We anticipate setting up a system through the NC Coastal Atlas for academic research groups to submit data to the *SalWise* team. These data are a rich, largely un-tapped resource of water quality data that are increasingly including data from continuously monitoring stations that will allow expanding the suite of hypothesis testing possible using *SalWise*-extracted data.

4. Expand the search for and inclusion of historical datasets in *SalWise*. In addition to works reported in journal papers and technical reports, there are many theses and dissertations in the libraries of NC universities that contain substantial quantities of data, both as summarized data and in some instances the original point sampling information. Attempts will also be made to find original records for water quality data reported in summarized form in both past and contemporary works.

5. Expand the level of cooperation and integration between the *SalWise* and North Carolina Coastal Atlas team. More in-depth interactions between these two groups will result in enhanced viewing, analysis and data extraction procedures for water quality data in *SalWise* and streamline the inclusion of new data to the database.

6. Expand the database to include other physical, chemical and biological water quality parameters, such as levels of dissolved oxygen and pH.

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Appendices

Appendix 1 – Data Sources and Metadata

ModMon (*SalWise* Program 5):

The Neuse River Estuary Modeling and Monitoring project (ModMon) is a collaborative effort between research groups at the UNC Institute of Marine Sciences and the North Carolina Department of Environmental Quality (NC-DEQ). The Neuse River has been monitored on a bimonthly basis since 1994 at eleven sites located from above New Bern to the mouth of the Neuse River as it enters the Pamlico Sound. Salinity and temperature are recorded at 0.5 meters depth intervals at each of the 11 stations. For more information on the ModMon program go to www.unc.edu/ims/neuse/modmon/

FerryMon (*SalWise* Program 10):

FerryMon data were obtained from Prof. Hans Pearl's research group at the UNC Institute of Marine Sciences. For the FerryMon water quality monitoring program, four ferries, operated by the Ferry

Division of the NC Department of Transportation, have been equipped with surface water monitoring flow through systems that record data at 3-minute intervals. For more information about the FerryMon program go to www.ferrymon.org

pCO_2 (*SalWise* Program 12):

The "pCO_2" study was a dissertation project conducted by Joey Crosswell under the supervision of Prof. Hans Paerl at the UNC Institute of Marine Sciences to examine CO_2 flux characteristics in the Neuse River Estuary (Crosswell et al. 2012). Dr. Crosswell's study used a flow through analysis system operated from a small boat that collected water quality parameters every two seconds over the period of each sampling cruise. Salinity and temperature data were extracted from the archived pCO_2 project data for inclusion in SalWise.

Hugh Porter (SalWise Program 15):

Hugh Porter was a researcher at the UNC Institute of Marine Sciences. He and his collaborators collected water quality data throughout North Carolina's larger sounds and smaller coastal estuaries from 1945-1967. These data were stored on paper cards at IMS. Data from these cards were digitized into an electronic spreadsheet, yielding 14,523 data points, that was imported into *SalWise*.

Shellfish Sanitation (*SalWise* Program 20):

Salinity and temperature data were obtained from the Shellfish Sanitation (SS) and Recreational Water Quality Section of the North Carolina Division of Marine Fisheries. This program maintains ~1250 monitoring stations in the state's coastal estuarine water bodies. Over time, some stations have been dropped from the monitoring program, usually if the site resides in waters that are reclassified as prohibited for shellfish harvesting, and new stations have been added as coastal development warranted. The vast majority of the SS sampling stations are close to shorelines in shallower waters where shellfish are harvested and recreational beaches are located. The SS program conducts two types of monitoring: (1) "standard" for which samples are collected at ~two-month intervals and (2) "conditional" for which rainfall trigger levels lead to closures of affected water bodies that are subsequently sampled over the following days until the level of a bacterial indicator of fecal contamination falls below a prescribed level. Water quality data from conditional sampling campaigns have not been transferred to electronic spreadsheets and have not been included in the *SalWise* database. Standard sampling data were generally available in an electronic format from 1989 to present. The SS program has salinity and water temperature data from standard and conditional sampling dating back to the 1960s; however, these data are stored as paper records that have not been transferred yet to electronic spreadsheets. These older data are not yet included in *SalWise*. Temperature data were converted from Fahrenheit to Celsius prior to addition to *SalWise*

North Carolina Department of Environment and Natural Resources (DENR) [As of 2015, DENR has been rebranded as the Department of Environmental Quality (DEQ)] – Division of Water Quality (DWQ); STORET (*SalWise* Programs 30, 31) and WQX (*SalWise* Program 32) Housed Data:

Salinity, water temperatures, and other physical and chemical water parameters collecedt by the Division of Water Quality are uploaded to the EPA's STORET (STOrage and RETrival; data up through up 2009) and Water Quality Exchange (WQX; data post 2009) data warehouses. Within the STORET search/download engine, the data are partitioned into Legacy (*SalWise* program 30) and Modernized (*SalWise* Program 31) categories, with data pre- and post-1999, respectively. The STORET and WQX systems were used to search for and download salinity and water temperature data collected by the NC Division of Water Quality. DWQ depth data were recorded in feet; these data were converted to meters for *SalWise*.

All STORET DWQ salinity and water temperature data were downloaded for the following watersheds (EPA water body code followed by water body name):

03010107	Lower Roanoke
03010203	Chowan
03010205	Albemarle
03020103	Lower Tar
03020104	Pamlico
03020105	Pamlico Sound
03020103	Bogue-Core Sounds
03020204	Lower Neuse
03030001	New River
03030005	Lower Cape Fear

Defense Coastal/Estuarine Research Program (DCERP) (*SalWise* Programs 50, 52, 54, 56):
In 2006, the Strategic Environmental Research and Development Program (SERDP) launched the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL), which lies within the lower New River watershed in central coastal North Carolina. DCERP salinity and water temperature data for *SalWise* were downloaded using DCERP's 'Monitoring and Research Data Information System' (MARDIS). *SalWise* program numbers 50, 52, 54 and 56 refer to benthic water column, mainstem, shallow shore and water column DCERP sub-programs, respectively. More information about DCERP can be found at https://dcerp.rti.org/

North Carolina Department of Environment and Natural Resources (DENR) [As of 2015, DENR has been rebranded as the Department of Environmental Quality (DEQ)] – Division of Marine Fisheries (DMF) (DMF and *SalWise* Program #s: 119, 120, 195, 465, 466, 467, 471, 517, 570, 611, 635, 640, 697, 915, 916):
The *SalWise* project team worked with George Joyner of the NC DMF to obtain all salinity and water temperature data that NC DMF collected throughout their various biological programs. Below is a list of the programs that were included in *SalWise* database. The Program ID numbers are those used internally at DMF and were used in *SalWise*.

119	Estuarine Gag Trawl Survey
120	Estuarine Trawl Survey
195	Pamlico Sound Survey
465	Cold Stun Sampling
466	Sea Turtle Bycatch Monitoring
467	Alternative Platform Observations
471	Pamlico River Blue Crab Fishery
517	Fish Pot Study
570	Commercial Shrimp Trawl Fishery Characterization
611	Oyster Sanctuary Evaluations
635	Shellfish Bottom Mapping
640	Hard Clam Survey
697	Bay Scallop Monitoring
915	Fisheries Independent Assessment (FIA)
916	Fisheries Independent Assessment Program/Ocean Gillnet

Appendix 2 – Extracting Data from *SalWise*

Below we provide very basic instructions for selecting subsets of *SalWise* data from either MicroSoft Access or ArcGIS. Knowledgeable users of these programs may ignore this appendix as it is very elementary and is intended to help novice users explore *SalWise*.

Data subsets from Microsoft Access:

Database Structure

The SalWise database has three tables:

1) Program IDs: Each dataset used to create the *SalWise* database was given a unique program ID. NC Division of Marine Fisheries programs had program numbers associated with them, so these numbers were used for theID's of these programs. Also included in this table is the program name and the associated source of the data.

2) Salinity: This table contains all the salinity (ppt) and temperature (ºC) data along with Date/Time, Latitude/Longitude, depth of recorded data (meters), ProgramID, and WaterBody/Region (as defined by the North Carolina Division of Marine Fisheries).

3) WaterBody Names: Nomenclature, from the North Carolina Division of Marine Fisheries, was used for the waterbody names, waterbody number and the region of each waterbody.

Access Query Methods

Opening SalWise.mdb database will initially direct the user to the 'Single_Parameter_Query_Form' form for the database. Microsoft Access may generate the security warning, "Some active content has been disabled. Click for more details." Click "Enable Content" to continue.

Single Parameter Query Form

Currently, *SalWise* can be queried using three criteria.

"Select by Date Range": To query *SalWise* based on range of dates, click on the 'Select by Date Range' button. A pop-up window will appear saying, "You are about to run a make table query that will modify data in your table." Click yes to allow this action. Enter 'Start Date' and 'End Date' using the input format mm/dd/yyyy. After entering the end date, *SalWise* will generate a table with the default name **SalWise Date**. Before completing the generation of the table, a pop-up will say, "You are about to paste xxxx (the number of records retrieved) into a new table." Click yes to allow this action. Double click the table located in the Table window of the query page to open the table in Access. If multiple date range queries are made, rename the existing table (right click and rename), because additional date queries will overwrite to the default SalWise Date Table.

"Retrieve Water Body Data": To obtain data for a specific waterbody, scroll through the list of waterbody names to find the name of the waterbody and enter it exactly as it appears in the list into the box next to the Retrieve Water Body Data selection button. [Note - the same sequence of pop-up statements as described in the "Select be Date Range" section above appear during any query action.] Once clicked, *SalWise* will generate a table with the default name "SalWise Water Body." Double click this table to see resulting data. Rename this default data table as described in the "Select be Date Range" section above.

"Select by Program ID": To obtain data for a specific Program, click on the "Select by Program ID" button. Scroll through the list of Programs to find the ID number (left side of list) for the program of interest. Enter the desired Program's ID number in the "Enter Parameter Value" pop-up and click OK.

SalWise will then generate a default query results table named **SalWise ProgramID**. This results table will appear in the Table window of the query page. Double click this table to see retrieved program data. Again, if subsequent Program ID queries are made, rename the existing table prior to conducting a new "Select by Program ID" query.