Dataset Description: Shellfish Aquaculture in the North Carolina NERR: Ecosystem Services, Environmental Impacts, and a Farm-Scale Carrying Capacity Model

This document provides detailed information about five datasets that were generated through a 2016 - 2020 collaborative research project titled *Evaluation of Ecosystem Services Associated with Shellfish Culture Operations in Coastal Regions Served by the National Estuarine Research Reserve*. The project was supported by the National Estuarine Research Reserve System (NERRS) Science Collaborative, which is funded by the National Oceanic and Atmospheric Administration. All Science Collaborative supported projects that collect new data adhere to federal data sharing and archiving requirements.

Data access and archival: The datasets for this project have been archived with the NERR Centralized Data Management Office and will be made publically available in fall 2022 through a request form on the Science Collaborative project page. Prior to fall 2022, individuals may reach out to the project lead to discuss potential applications of the data.

List of project datasets

Five related datasets are described in this document:

1. Wild resource (oyster) data from reefs potentially impacted and not impacted by oyster aquaculture
2. Environmental data from sites with and without oyster aquaculture
3. Ecological data from sites with and without oyster aquaculture
4. FARM model inputs
5. FARM model outputs

About the Associated Project

Project title: Evaluation of Ecosystem Services Associated with Shellfish Culture Operations in Coastal Regions Served by the National Estuarine Research Reserve

Name of reserve(s) involved in the project: North Carolina NERR

Project period: November 2016 – June 2020

Science Collaborative project page: www.nerrssciencecollaborative.org/project/Darrow16

Project lead and contact information:

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Purpose:
North Carolina's shellfish aquaculture industry has been small but stable for over thirty years, however, regulatory changes are creating a climate for potential rapid growth. The objective of this project was to assess ecosystem services associated with oyster farms by measuring impacts of newly established shellfish aquaculture among intertidal and subtidal grow-out sites. The team proposed a decision-support framework that could incorporate environmental impact and ecosystem service criteria. End users were decision-makers on shellfish aquaculture siting within the North Carolina NERR, the NC Department of Marine Fisheries, NC Department of Natural and Cultural Resources and oyster growers.

Abstract:
The science team conducted two years of intensive field sampling in and adjacent to aquaculture operations, concentrating on wild shellfish resources and the physical and chemical environment, with an aim to link small scale perturbations (i.e., organic enrichment, oyster physiological stress biomarkers) with larger scale ecosystem-level alterations. The team also collected data on culture oyster physiology using controlled lab experiments and combined this with field data on environmental drivers and farm practices from three sites to be incorporated into farm-scale models to calculate production and nitrogen sequestration by oyster farms using different scenarios typical to North Carolina. Project outputs included data, visualization tools, and models to allow resource managers and oyster growers to achieve outcomes of effective decision-making on locations and scales of aquaculture operations.

About the Project Datasets

1. Wild resource (oyster) data from reefs potentially impacted and not impacted by oyster aquaculture

General description of data:
Data collected included gene expression (physiological stress, immune function, reproductive health), oyster population density, oyster condition index, sex ratios, demographics, and recruitment. Oyster population data from collected previous studies will be referenced for historical comparisons.

The limited exchange of enclosed estuarine embayments and the proximity of dense filter feeding shellfish could lead to depletion of phytoplankton resources that impact wild oyster populations and shellfish aquaculture operations. Shellfish aquaculture operations could create localized impacts through the disruption of flow from additional structure and increased density of filter feeders. The response of wild oysters was assessed on designated reefs at close proximity to shellfish aquaculture operations "impacted" and from reefs that were spatially distinct "reference" from the aquaculture operations but within the same embayment. Given that oysters exhibit a high degree of variation in responses, oyster populations were assessed

seasonally for density variation, condition index, sex ratios, and size distribution (demography). During the spawning season settlement was also measured on a monthly basis.

Search keywords: oyster density, recruitment, settlement, gene expression, condition index, QPCR

More about the data:

Temporal coverage: Preliminary wild resource sampling was conducted September-December 2016. Overall sampling of oyster metrics covered several timescales (quarterly, monthly, and annually), depending on the method. Quarterly sampling was initiated in March 2017 in Masonboro Island for wild oyster characteristics (oyster density, oyster condition, oyster sex ratios, habitat complexity (rugosity) and demography). Oyster recruitment was collected annually in 2018. Settlement was collected monthly 2017 (June-September) and 2018 (May-October). Habitat development was measured annually in 2018.

- Oyster density was collected quarterly from all impacted and reference reefs using haphazardly selected quadrats (0.25m x 0.25m). These measurements were collected from March 2017 to February 2019.
- Condition index (CI) of oysters was determined quarterly on a subset of oysters from each reef using the methods outlined Abbe & Albright 2003 and Hanke et al 2017. CI=dry meat weight (g)/internal shell volume (cm3).
- Sex ratio data were collected monthly during the spawning period March 2017-September 2017 and April 2018-October 2018. Sex ratios were determined based on a subset of 35 oyster from each reef.
- Gene expression data were collected via the analysis of RNA extracted from oyster gill and whole body homogenates. Quantitative PCR was conducted using a BioRad CFX instrument, all gene expression data were normalized to reference gene expression.
- Habitat complexity was collected quarterly along with measures of oyster density. This measure is determined based on a surface complexity in 1m segments.
- Size distribution of oysters on each reef was determined from all oysters that could be reasonably measured. Measurements were based on quadrat samples (0.25m x 0.25m) collected quarterly.
- Oyster recruitment was assessed using “spat bags” filled with cultch. These were deployed in the spring of each sampling year (2017 and 2018) and retrieved in December of year respectively. Data from this method included counts of live oysters as well as spat scars.
- Oyster settlement was measured on a monthly basis during the spawning period in 2017 (June-September) and 2018 (May-October). Settlement was based on monthly deployments of ceramic tiles. In previous studies these tiles showed oyster set comparable to oyster shell but provide a better estimate of settlement density.
- Habitat patch data was based on the defaunated oyster matrix deployed at a subset of sites. These patches were deployed in spring of 2018 and retrieved in November 2018. All oysters and associated fauna were identified and enumerated from these samples.

Data collection period:
November 2016 to February 2019

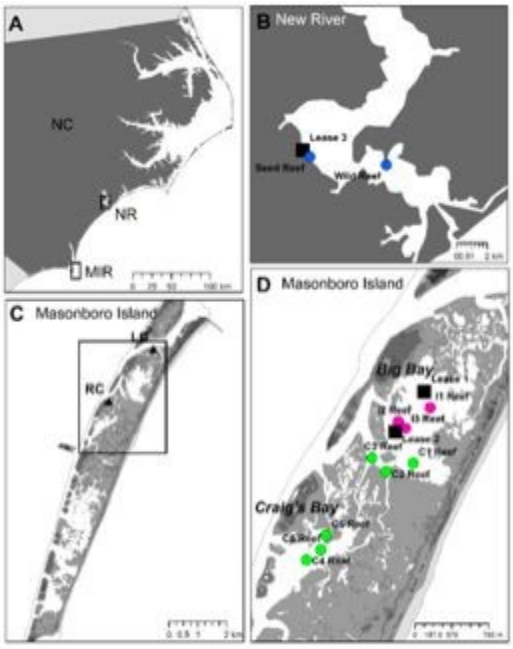
Geographic extent:

Site Description	Latitude	Longitude	Nearest Town
Masonboro Oyster Farm 1	34.1639	-77.8388	Wilmington, NC
Masonboro Oyster Farm 2	34.1602	-77.8420	Wilmington, NC
Masonboro Big Bay Impact Reef	34.1625	-77.8382	Wilmington, NC
Masonboro Big Bay Impact Reef	34.1612	-77.8417	Wilmington, NC
Masonboro Big Bay Impact Reef	34.1606	-77.8409	Wilmington, NC
Masonboro Big Bay Reference Reef	34.1573	-77.8401	Wilmington, NC
Masonboro Big Bay Reference Reef	34.1566	-77.8431	Wilmington, NC
Masonboro Big Bay Reference Reef	34.1579	-77.8447	Wilmington, NC
Masonboro Craig's Bay Ref Reef	34.1486	-77.8520	Wilmington, NC
Masonboro Craig's Bay Ref Reef	34.1495	-77.8504	Wilmington, NC
Masonboro Craig's Bay Ref Reef	34.1509	-77.8498	Wilmington, NC
New River Oyster Farm 3	34.5921	-77.4371	Sneads Ferry, NC
New River Jarrett's Point Reef	34.5778	-77.3805	Sneads Ferry, NC
New River Seed Management Reef	34.5879	-77.4327	Sneads Ferry, NC

File format: Excel (oyster density, condition index, demography, sex ratios, oyster larval settlement, oyster recruitment and gene expression)

Data Access and Archival: Data are currently archived on the UNCW server but will be permanently archived with the NERRS Centralized Data Management Office (CDMO). Processed (quality checked and reviewed) data will be publicly available in fall 2022.

Maps and Schematics for Data Collection



Map of study area in southeastern North Carolina (Panel A), including Masonboro Island Reserve ("MIR", Panels C and D), and New River ("NR", Panel B). RC and LC (Panel C) indicate SWMP long-term water quality monitoring stations near study areas in MIR. Masonboro Island Reserve aquaculture farm operations were located in the northern half of Big Bay (Panel D, Farms 1 and 2, black squares), surrounded by wild "impacted" oyster reefs (pink circles, I1, I2, I3). Reference reefs (green circle) were located where there are no current shellfish farms, in the southern portion of Big Bay (C1, C2, C3), and in Craig's Bay (C4, C5, C6). In New River (Panel B), subtidal Farm 3 (black square) is on the western side of Stone's Bay. A seed management reef and wild reef can be found nearby (blue circles), which we propose to sample in Year 2, but do not consider them "reference" nor "impacted".

2. Environmental data from sites with and without oyster aquaculture

General description of data:

Data collected include water column (temperature, salinity, chlorophyll a, total suspended solids, dissolved nutrients); and sediments (bulk density, organic content, benthic chlorophyll a, particulate carbon and nitrogen content, porewater nutrients, sulfide).

Natural and restored oyster reefs can cause localized depletion of seston as tidal currents pass over shellfish beds, and the same may be true for shellfish farms. Since a given embayment has an ecological carrying capacity that is dependent on seston concentration, flow, and stocking density, this depletion of suspended phytoplankton may reduce food availability to wild populations of shellfish and other fauna. Large-scale consumption of suspended particulate matter may also affect food quality by altering seston particle size and ratios of particulate carbon and nitrogen. We assessed seston flux through oyster farms compared to nearby bare

sediment areas by measuring current velocity at peak ebb tides while taking samples for chlorophyll *a.* Water column samples focusing on food resources (chl a, TSS, particulate carbon and nitrogen) and dissolved nutrients were taken monthly up- and downstream from Aquaculture and Reference areas on ebbing tides 0.25 m from the bottom.

Bulk sediment parameters were used to indicate changes attributable to oyster biodeposition. Benthic chlorophyll *a* would indicate presence of benthic microalgae, an important primary producer and regulator of N transformations in shallow systems. Sulfide and ammonium concentrations would indicate potential for denitrification. High concentrations of hydrogen sulfide would also indicate reducing conditions in sediments due to organic accumulation/hypoxia, and potential toxicity to organisms.

Search keywords: water quality, nutrient, nitrate, ammonia, phosphate, temperature, salinity, pH, chlorophyll a, sediment, total suspended solids, particulate organic matter, bulk density, organic content, particulate carbon, particulate nitrogen, benthic chlorophyll, extractable ammonium, sulfide

More about the data:

Temporal coverage: Quarterly and monthly sampling for Masonboro Island environmental parameters began in March 2017. Masonboro Island field sampling ended in February 2019. New River field sampling was for one full year, March 2018 - February 2019.

Data collection methods:

- Water flow rates were quantified up- and down-stream of farm and non-farm (mudflat) areas under ebb and flood and spring and neap conditions.
- Water quality data (temperature, salinity, dissolved oxygen, turbidity, chlorophyll fluorescence) were collected monthly using a hand-held YSI Pro from farm and mudflat areas on an ebbing tide. Monthly water samples from aquaculture and reference areas were taken using a horizontal seston sampler. Samples were placed in darkened bottles on ice and returned to the lab where they were filtered for chlorophyll and nutrient analyses.
- EPA-approved laboratory methods were used for chlorophyll *a*, nutrients, and pore water.
- Sediment samples were taken from farm and mudflat areas in Year 1, and from farm, mudflat, and wild reefs in Year 2.
- Sediment samples for bulk characteristics and pore water were taken using cut-off syringe cores on foot at low tide in intertidal areas and a push corer from a boat in subtidal areas.
- Sediment samples were weighed, dried, and combusted for bulk density and organic content measurements. A subsample of these were analyzed for particulate carbon and nitrogen using an elemental analyzer.
- Sediment samples were analyzed for extractable ammonium, benthic chlorophyll, and sulfide using previously-established methods.

Data collection period: March 2017 to February 2019

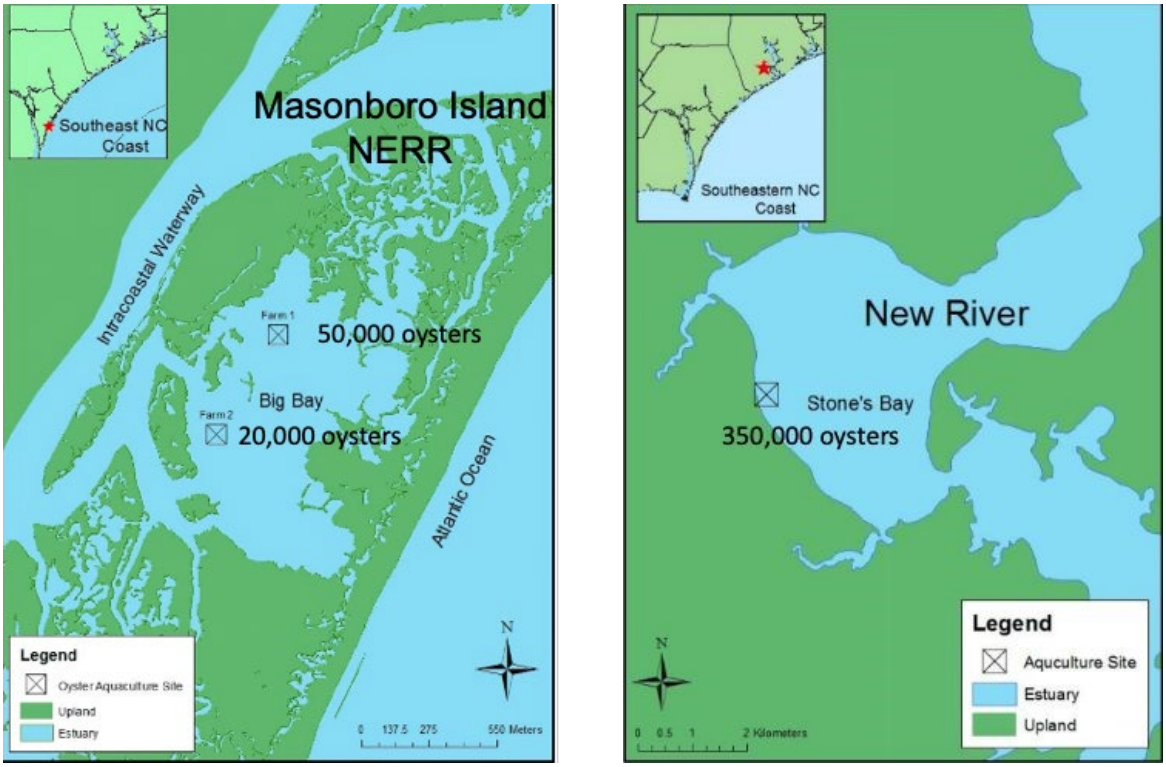
Geographic extent:

Site Description	Latitude	Longitude	Nearest Town
Masonboro Farm 1	34.1639	-77.8388	Wilmington, NC
Masonboro Farm 2	34.1602	-77.8420	Wilmington, NC
Masonboro Big Bay Mudflat 1	34.1646	-77.8393	Wilmington, NC
Masonboro Big Bay Mudflat 2	34.1579	-77.839	Wilmington, NC
Masonboro Big Bay Impact Reef	34.1625	-77.8382	Wilmington, NC
Masonboro Big Bay Impact Reef	34.1612	-77.8417	Wilmington, NC
Masonboro Big Bay Impact Reef	34.1606	-77.8409	Wilmington, NC
Masonboro Big Bay Reference Reef	34.1573	-77.8401	Wilmington, NC
Masonboro Big Bay Reference Reef	34.1566	-77.8431	Wilmington, NC
Masonboro Big Bay Reference Reef	34.1579	-77.8447	Wilmington, NC
Masonboro Craig's Bay Ref Reef	34.1486	-77.8520	Wilmington, NC
Masonboro Craig's Bay Ref Reef	34.1495	-77.8504	Wilmington, NC
Masonboro Craig's Bay Ref Reef	34.1509	-77.8498	Wilmington, NC
Masonboro Craig’s Bay Mudflat 3	34.1492	-77.8501	Wilmington, NC
Masonboro Craig’s Bay Mudflat 4	34.1487	-77.8539	Wilmington, NC
New River Oyster Farm 3	34.5921	-77.4371	Sneads Ferry, NC
New River Jarrett's Point Reef	34.5778	-77.3805	Sneads Ferry, NC
New River Seed Management Reef	34.5879	-77.4327	Sneads Ferry, NC

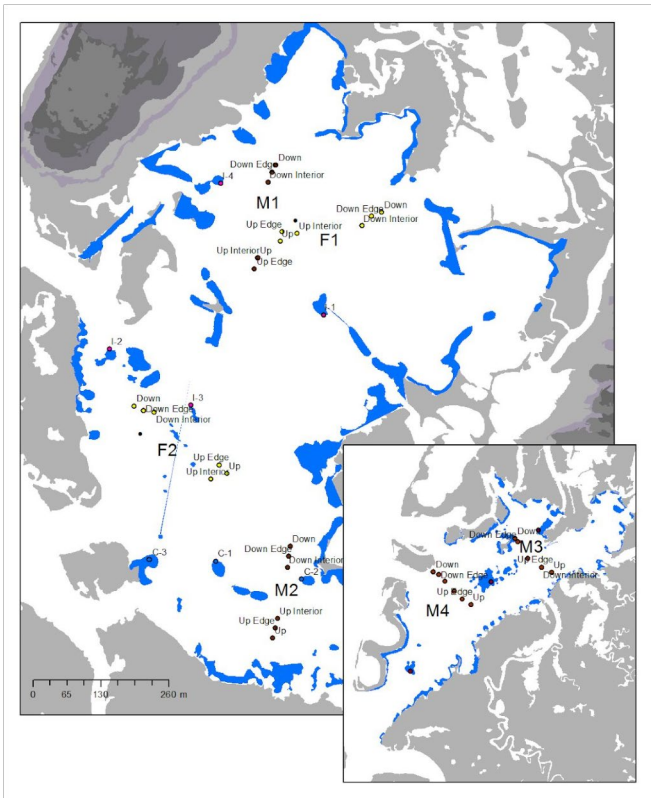
File format:
Access database >20 MB

Data Access and Archival:
Data are currently archived on the UNCW server but will be permanently archived with the NERRS Centralized Data Management Office (CDMO). Processed (quality checked and reviewed) data will be publicly available in fall 2022.

Maps and Schematics for Data Collection

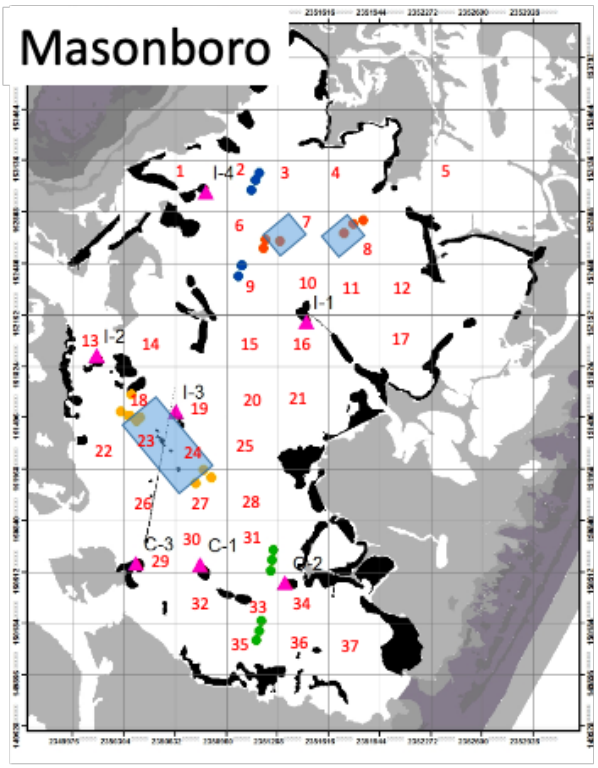


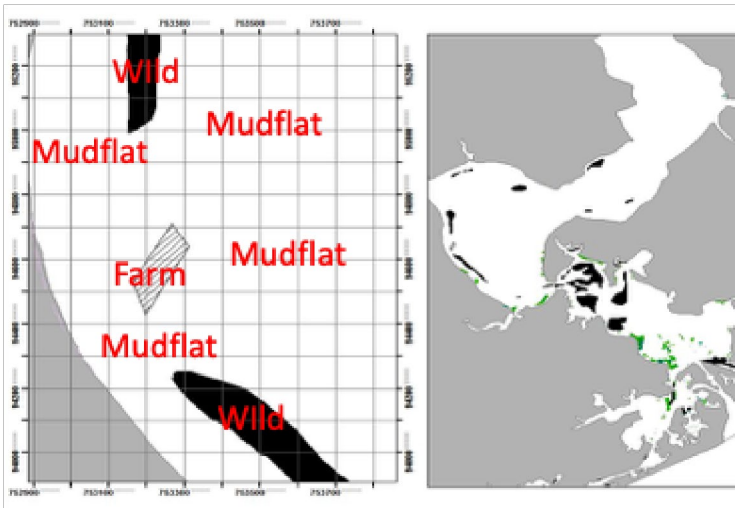
Study sites within Masonboro Island NERR (Farms 1 and 2) and the New River (Farm 3), NC.



Year 1 water and sediment sampling (left) was conducted using transects across paired farms and reference areas that had similar hydrodynamic conditions, e.g., Farm 1 and Mudflat 1; Farm 2 and Mudflat 2. Additional non-farm reference areas (Mudflats 3 and 4) were sampled in Craig's Bay.

Year 2 water sampling was conducted similarly to Year 1. Sediment sampling (below) was conducted using randomized sites from farms (hashed/shaded polygons), wild reefs (black shapes), and reference mudflats (grid cells).





3. Ecological data from sites with and without oyster aquaculture:

Including resident fauna, nekton associated with wild reefs, farms, and mudflats.

General description of data:

The presence of dense assemblages of filter feeders may have impacts on organisms that depend on oyster habitat (natural or created) including the oysters themselves. Potential localized impacts include interference with flow, trapping of session from the overlying water column and temporary depletion of phytoplankton. Associated resident fauna (those organisms that live within the oyster matrix) were sampled as part of this study along with wild oyster metrics from March 2017 to February 2019. Development of associated faunal communities was also measured using habitat patches deployed in spring of 2018 and retrieved in November 2018. In addition to associated resident fauna the larger mobile nekton were sampled quarterly from February 2018 to August 2018 the period of peak density in the system. Given the high vagility and partitioning of the 3 dimensional aqueous environment by nekton, this sampling approach used a variety of gear types to more fully identify the nekton community.

Search keywords: Nekton, associated fauna, oyster reefs

More about the data:

Temporal coverage: Preliminary sampling was conducted in September- December 2016. Associated resident fauna were sampled quarterly from March 2017 to February 2019. Nekton for both sites were sampled three times, quarterly, in Year 2.

- Associated resident fauna was collected quarterly from all impacted and reference reefs in Masonboro Island using haphazardly selected quadrats (0.25m x 0.25m). These measurements were collected from March 2017 to February 2019. All fauna recovered from excavations were enumerated and identified. Note that 2018 sampling only reflects Big Bay sampling locations.
- Habitat patch data was based on the defaunated oyster matrix deployed at a subset of sites. These patches were deployed in spring of 2018 and retrieved in November 2018. All associated fauna were identified and enumerated from these samples.
- Nekton sampling was conducted from February 2018 to August 2018. To reduce the chance of interference among sampling gear types, only one gear type was sampled at a location (reef or shellfish aquaculture operation on any given day).
    - *Sweep net* samples were along the edge of target reefs (within 1m) and shellfish aquaculture operations. Each sampling consisted of 2 (5m) tows at each location. All nekton captured were identified, enumerated, and measured for both standard length and total length.
    - *Seine nets* - Using a standard seine with 4ft bag end, 2 (5m) long tows were pulled along each sampling location (reef, shellfish aquaculture operations, open sand flat). All nekton captured were identified, enumerated, and measured for both standard length and total length.
    - *Minnow traps* - This sampling gear was used intensively on a monthly basis from May 2018 to August 2018. Traps were deployed on a rising tide and

allowed to fish for 4 hours. This gear was deployed in "on-reef" (1m into the oyster reef) and "off-reef" (1m outside the edge of the oyster reef). Minnow traps were deployed in sets of 6 traps with 3 traps baited and 3 traps unbaited. All nekton captured were identified, enumerated, and measured for both standard length and total length.

- *Breder traps* - This passive sampling gear was sampled quarterly from February 2018 to August 2018. This gear was allowed to fish for 2hr on a rising tide. This gear was deployed at target reefs (impacted and reference), shellfish aquaculture leases, and open reference sites) in sets of 9. All nekton captured were identified, enumerated, and measured for both standard length and total length.
- *Lift nets* - This gear was deployed in August 2018 at select impacted, reference and shellfish aquaculture sites. All nekton captured were identified, enumerated, and measured for both standard length and total length.
- *Video observations* - This sampling method was sampled in February 2018, May 2018, and August 2018 at select impacted, reference and shellfish aquaculture sites.

Data collection period:
September 2016 to February 2019

Geographic extent:

Site Description	Latitude	Longitude	Nearest Town
Masonboro Oyster Farm 1	34.1639	-77.8388	Wilmington, NC
Masonboro Oyster Farm 2	34.1602	-77.8420	Wilmington, NC
Masonboro Big Bay Impact Reef	34.1625	-77.8382	Wilmington, NC
Masonboro Big Bay Impact Reef	34.1612	-77.8417	Wilmington, NC
Masonboro Big Bay Impact Reef	34.1606	-77.8409	Wilmington, NC
Masonboro Big Bay Reference Reef	34.1573	-77.8401	Wilmington, NC
Masonboro Big Bay Reference Reef	34.1566	-77.8431	Wilmington, NC
Masonboro Big Bay Reference Reef	34.1579	-77.8447	Wilmington, NC
Masonboro Craig's Bay Ref Reef	34.1486	-77.8520	Wilmington, NC
Masonboro Craig's Bay Ref Reef	34.1495	-77.8504	Wilmington, NC

Masonboro Craig's Bay Ref Reef	34.1509	-77.8498	Wilmington, NC
New River Oyster Farm 3	34.5921	-77.4371	Sneads Ferry, NC
New River Jarrett's Point Reef	34.5778	-77.3805	Sneads Ferry, NC
New River Seed Management Reef	34.5879	-77.4327	Sneads Ferry, NC

File format: Excel (associated resident fauna identification, associated fauna abundance, nekton identifications, abundance, standard length, total length). Still images (.jpg time lapse video observations).

Data Access and Archival:
Data are currently archived on the UNCW server but will be permanently archived with the NERRS Centralized Data Management Office (CDMO). Processed (quality checked and reviewed) data will be publicly available in fall 2022.

4. FARM model inputs

Including aquaculture oyster lease size, oyster size, grow-out numbers, stocking density, mortality; oyster clearance rates, respiration rates, egestion rates over range of temperatures, salinities, food concentrations. Also uses environmental data inputs (water column).

General description of data:
The Farm Aquaculture Resource Management (FARM) model combines physical and biogeochemical models, bivalve shellfish growth models, and decision-process models for determination of shellfish production and assessment of water quality changes on account of shellfish cultivation (Ferreira et al., 2007). The model simulates processes at the farm scale (100-1000 m), considering advective water flow and transport of relevant water properties. These include total particulate matter, phytoplankton and organic detritus (particulate organic matter), dissolved inorganic nitrogen, and dissolved oxygen. The model combines inputs for oyster physiology (ingestion, egestion, respiration, excretion) and monthly environmental driver data from the site to predict individual oyster growth, which is calibrated to observed oyster growth rates. Individual oyster growth is scaled up to the farm using grow-out numbers, stocking densities, mortalities, and farm dimensions.

Search keywords:
FARM model, feeding, clearance rate, ingestion rate, egestion, respiration, excretion, mortality, stocking density, growth

More about the data:
Temporal coverage: Monthly sampling for Masonboro Island environmental drivers began in

March 2017 and ended in February 2019. New River field sampling was for one full year, March 2018 - February 2019. Lab measurements of oyster feeding/respiration rates were conducted quarterly in Year 1 (2017).

- Oyster length data were collected monthly from a subset of growout cages in each lease, and weight/condition index were collected quarterly to create growth curves. Monthly mortality rates were noted while collecting oysters from cages.
- Oyster clearance and egestion rate measurements were conducted quarterly using a temperature-controlled flow-through seawater system.
- Oyster respiration and excretion rates were measured using individual respiration chambers and measuring ammonium concentration changes throughout respiration trials.
- Aquaculture-specific information (stocking density, numbers of oysters, planting, harvest) was reported monthly by growers.
- The FARM model was applied and calibrated according to Ferreira et al. (2007) and Bricker et al. (2015) using model inputs in a mass-balance approach with a monthly timestep to simulate oyster growth and nitrogen removal on a population level.

Data collection period:
March 2017 to February 2019

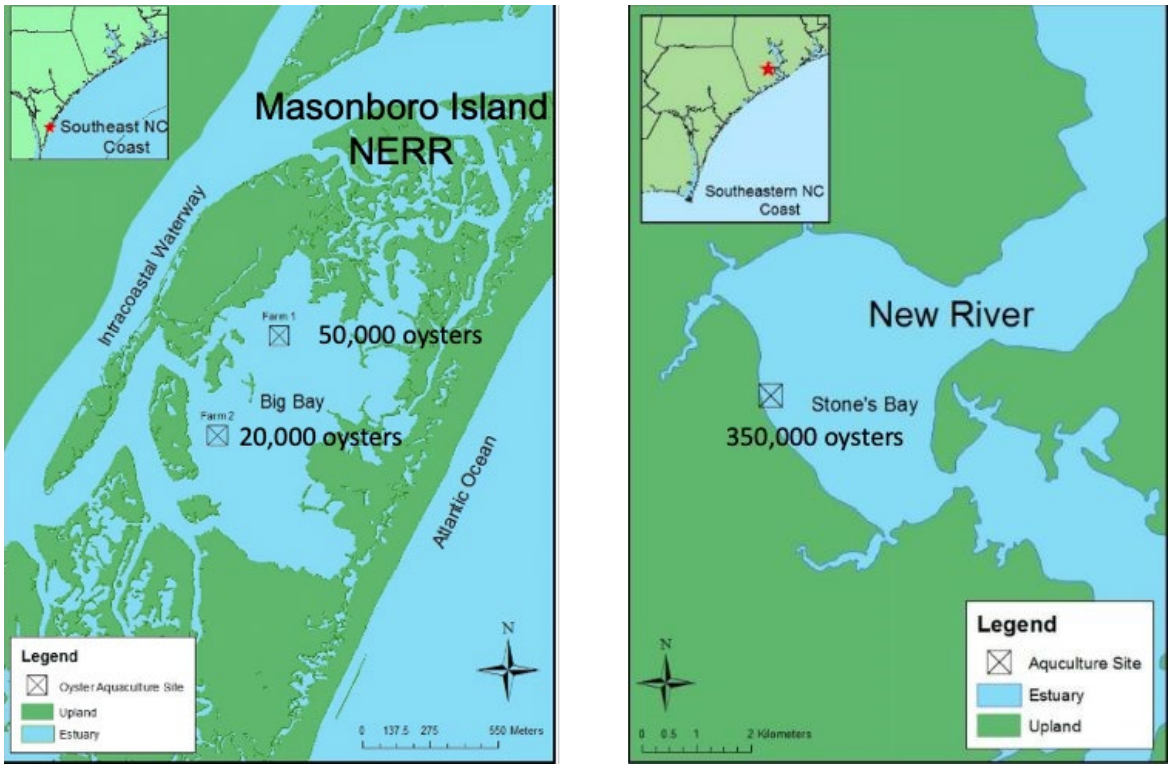
Geographic extent:

Site Description	Latitude	Longitude	Nearest Town
Masonboro Oyster Farm 1	34.1639	-77.8388	Wilmington, NC
Masonboro Oyster Farm 2	34.1602	-77.8420	Wilmington, NC
New River Oyster Farm 3	34.5921	-77.4371	Sneads Ferry, NC

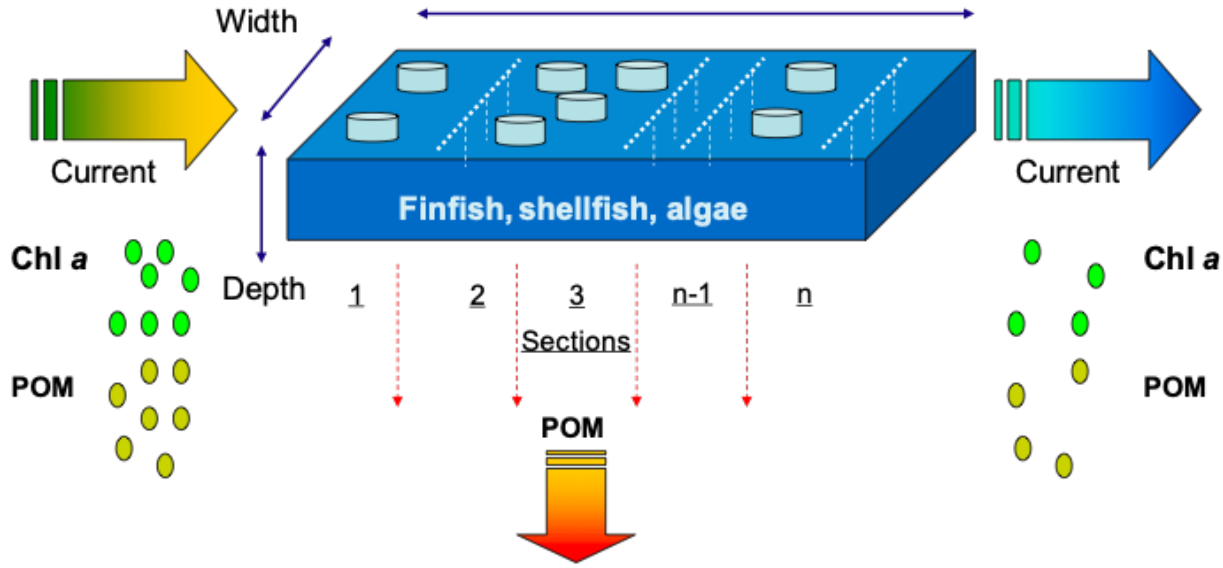
File format:
Individual Microsoft excel spreadsheets for: Monthly environmental driver data, oyster physiological rates, oyster size, farm characteristics.

Data Access and Archival:
Data are currently archived on the UNCW server but will be permanently archived with the NERRS Centralized Data Management Office (CDMO). Processed (quality checked and reviewed) data will be publicly available via within two years of the project end.

Maps and Schematics for Data Collection



Study sites within Masonboro Island NERR (Farms 1 and 2) and the New River (Farm 3), NC.



Generalized schematic of the FARM model, representing suspended food (chlorophyll a, POM) transported by currents through the farm. Shellfish feed on the suspended food, deposit waste POM beneath the farm, and water with less food emerges on the downstream side.

5. FARM model outputs

Including aquaculture oyster size, harvest weight, water column chlorophyll, POM, TPM, dissolved oxygen, total revenue, total cost, profit, N removed, ecosystem service value, time to market size.

General description of data:
The FARM Model is described in "Model inputs" above. Model outputs will correspond to model inputs from Farms 1, 2, and 3 in Years 1 and 2 (2017 and 2018) of the study.

Search keywords:
FARM model, oyster size, harvest weight, water column chlorophyll, POM, TPM, dissolved oxygen, total revenue, total cost, profit, N removed, ecosystem service value, time to market size, ecosystem services, nitrogen mitigation, nitrogen sequestration

More about the data:

- The FARM model was applied and calibrated according to Ferreira et al. (2007) and Bricker et al. (2015) using model inputs in a mass-balance approach with a monthly timestep to simulate oyster growth and nitrogen removal on a population level.

Data collection period:
November 2016 to February 2019

Geographic extent:
See Model Inputs

File format:
Microsoft excel spreadsheets for: Oyster size at harvest, total farm harvestable biomass, nitrogen mitigated by harvest, value of harvest, value of nitrogen mitigation, person equivalents of nitrogen mitigation, POM, dissolved oxygen

Data Access and Archival:
Data are currently archived on the UNCW server but will be permanently archived with the NERRS Centralized Data Management Office (CDMO). Processed (quality checked and reviewed) data will be publicly available via within two years of the project end.

Maps and Schematics for Data Collection:
See Model Inputs