TABLE 1. Model selection table for GLM models of oyster count data from intertidal reefs in the Big Bend of Florida, without covariates.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Model | Number of parameters | AIC | Delta AIC | AIC Weight |
| Period \* site + locality | 10 | 3154.92 | 0.00 | 0.50 |
| Period \* locality + site | 11 | 3156.40 | 1.47 | 0.24 |
| Period + locality + site | 8 | 3156.61 | 1.68 | 0.22 |
| Period + locality \* site | 14 | 3160.46 | 5.54 | 0.03 |
| Period + site | 5 | 3163.71 | 8.79 | 0.01 |
| Period \* site | 7 | 3163.72 | 8.80 | 0.01 |
| Period \* locality \* site | 25 | 3172.31 | 17.38 | 0.00 |
| Period + locality | 6 | 3310.80 | 155.88 | 0.00 |
| Period \* locality | 9 | 3316.52 | 161.60 | 0.00 |
| Period | 3 | 3318.29 | 163.37 | 0.00 |

TABLE 2. Model results for the best fitting GLM model without covariates (Table 1) of oyster counts on intertidal reefs in the Big Bend of Florida, where oyster counts = period \* site + locality + offset(log(transect length)). Parameter estimates are on log scale.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Estimate | Std. Error | z value | Pr(>|z|) |
| Intercept | 4.60458 | 0.17666 | 26.065 | < 2e-16 |
| Period | -0.04669 | 0.01374 | -3.399 | 0.000676 |
| Nearshore site | -1.61120 | 0.20049 | -8.036 | 9.25e-16 |
| Offshore site | -2.40687 | 0.21532 | -11.178 | < 2e-16 |
| Corrigan’s Reef | 0.43079 | 0.17852 | 2.413 | 0.015817 |
| Horseshoe Beach | -0.02953 | 0.18247 | -0.162 | 0.871425 |
| Lone Cabbage | -0.10235 | 0.16803 | -0.609 | 0.542459 |
| Period: site Nearshore | 0.02251 | 0.02283 | 0.986 | 0.324294 |
| Period: site Offshore | 0.05412 | 0.02262 | 2.393 | 0.016713 |

TABLE 3. Model selection table assessing improvements in the fit of best fit model from Table 1 (oyster counts = period \* site + locality + offset(log(transect length))) with the addition of covariate described.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Covariate description | Number of parameters | AIC | Delta AIC | AIC Weight |
| Mean annual daily discharge with one-year lag | 11 | 3111.86 | 0.00 | 0.51 |
| Total annual discharge with one-year lag | 11 | 3111.90 | 0.04 | 0.49 |
| Annual landings with two-year lag | 11 | 3138.39 | 26.53 | 0.00 |
| Annual trips with two-year lag | 11 | 3138.64 | 26.78 | 0.00 |
| Annual discharge year of count | 11 | 3144.38 | 32.52 | 0.00 |
| Annual landings year of count | 11 | 3147.66 | 35.80 | 0.00 |
| Total discharge year of count | 11 | 3149.74 | 37.88 | 0.00 |
| Annual trips with one-year lag | 11 | 3150.99 | 39.13 | 0.00 |
| Harvest in year of count | 11 | 3154.27 | 42.41 | 0.00 |
| Landings with one-year lag | 11 | 3155.57 | 43.71 | 0.00 |
| Total trips in year of count | 11 | 3156.14 | 44.28 | 0.00 |
| Annual discharge with two-year lag | 11 | 3156.40 | 44.54 | 0.00 |
| Annual total discharge with two-year lag | 11 | 3156.44 | 44.57 | 0.00 |

TABLE 4. Model results for the best fitting GLM model (Table 3) of oyster counts on intertidal reefs in the Big Bend of Florida where oyster counts = period \* site + locality + annual discharge with one-year lag + offset(log(transect length)). Parameter estimates are on log scale.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Estimate | Std. Error | z value | Pr(>|z|) |
| Intercept | 4.79684 | 0.15903 | 30.163 | < 2e-16 |
| Period | -0.05847 | 0.01138 | -5.137 | 2.79e-07 |
| Nearshore site | -1.63292 | 0.18054 | -9.044 | < 2e-16 |
| Offshore site | -2.36720 | 0.19730 | -11.998 | < 2e-16 |
| Corrigan’s Reef | 0.35860 | 0.16732 | 2.143 | 0.0321 |
| Horseshoe Beach | -0.18998 | 0.17244 | -1.102 | 0.2706 |
| Lone Cabbage | -0.24087 | 0.15988 | -1.507 | 0.1319 |
| Annual river discharge with one-year lag | 0.37620 | 0.05699 | 6.602 | 4.06e-11 |
| Period: site Nearshore | 0.01920 | 0.01976 | 0.971 | 0.3314 |
| Period: site Offshore | 0.04041 | 0.02063 | 1.959 | 0.0501 |

<A>References

Alleway, H.K. and S. D. Connell. 2015. Loss of an ecological baseline through the eradication of oyster reefs from coastal ecosystems and human memory. *Conservation Biology* 29:795-804.

Beck, M.W., M. Odaya, J. J. Bachant, J. Bergan, B. Keller, R. Martin, R. Mathews, C. Porter and G. Ramseur. 2000. Identification of priority sites for conservation in the northern Gulf of Mexico: an ecoregional plan. The Nature Conservancy, Arlington, VA. Available online https://tinyurl.com/yyrc79ev September 2019

Beck, M.W., R. D. Brumbaugh, L. Airoldi, A. Carranza, L.D. Coen, C. Crawford, O. Defeo, G. J. Edgar, B. Hancock, M. C. Kay and H. S. Lenihan, 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. *Bioscience* 61:107-116.

Benke, A. C. 1990. A perspective on America’s vanishing streams. *Journal of the North American Benthological Society* 9:77-88.

Bergquist, D.C., Hale, J.A., Baker, P. and Baker, S.M., 2006. Development of ecosystem indicators for the Suwannee River estuary: oyster reef habitat quality along a salinity gradient. *Estuaries and Coasts* 29: 353-360.

Bolker, B.M., 2008. *Ecological models and data in R*. Princeton University Press.

Brooks, M.E., Kristensen, K., van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Machler, M. and Bolker, B.M., 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *The R journal*, *9*(2), pp.378-400.

Buzan, D., Lee, W., Culbertson, J., Kuhn, N. and Robinson, L., 2009. Positive relationship between freshwater inflow and oyster abundance in Galveston Bay, Texas. *Estuaries and Coasts*, *32*(1), pp.206-212.

Carranza, A., O. Defeo and M. Beck. 2009. Diversity, conservation status and threats to native oysters (Ostreidae) around the Atlantic and Caribbean coasts of South America. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *19*(3), pp.344-353.

Chatry, M., R.J. Dugas, and K.A. Easley. 1983. Optimum salinity regime for oyster production on Louisiana’s state seed grounds. Contributions in Marine Science 26: 81–94.

Coen, L.D., R.D. Brumbaugh, D. Bushek, R. Grizzle, M.W. Luckenbach, M.H. Posey, S. P. Powers and S. G. Tolley. 2007. Ecosystem services related to oyster restoration. Marine Ecology Progress Series, 341, pp.303-307.

Farrell, M.D., Good, J., Hornsby, D., Janicki, A., Mattson, R., Upchurch, S., Champion, K., Chen, J., Grabe, S., Malloy, K. and Nijbroek, R., 2005. Technical report: MFL establishment for the lower suwannee river and estuary, little fanning, fanning, and manatee springs. *Water Resource Associates, Inc., Tampa, Florida*.

Fisch, N.C. and Pine, W.E., 2016. A complex relationship between freshwater discharge and oyster fishery catch per unit effort in Apalachicola Bay, Florida: an evaluation from 1960 to 2013. *Journal of shellfish research* 35: 809-826.

Florida Fish and Wildlife Conservation Commission. 2019. Commercial fisheries landings summaries. Available online https://tinyurl.com/yxdd8qhc. August 2019

Florida Department of Agriculture and Consumer Services. 2019. Shellfish harvesting area maps. Available online https://tinyurl.com/y3tnqlpq. August 2019

Frederick, P., Vitale, N., Pine, B., Seavey, J. and Sturmer, L., 2016. Reversing a rapid decline in oyster reefs: effects of durable substrate on oyster populations, elevations, and aquatic bird community composition. *Journal of shellfish research*, *35*(2), pp.359-368.

Gazeau, F., Quiblier, C., Jansen, J.M., Gattuso, J.P., Middelburg, J.J. and Heip, C.H., 2007. Impact of elevated CO2 on shellfish calcification. *Geophysical research letters*, *34*(7).

Geselbracht, L. 2007. Conservation action plan for marine and estuarine resources of the Big Bend Area of Florida. The Nature Conservancy, Florida Chapter. Available online: <https://public.myfwc.com/crossdoi/fundedprojects/SWG_Final_Geselbracht_05047.pdf> (September 2019)

Geselbracht, L., Freeman, K., Kelly, E., Gordon, D.R. and Putz, F.E., 2011. Retrospective and prospective model simulations of sea level rise impacts on Gulf of Mexico coastal marshes and forests in Waccasassa Bay, Florida. *Climatic Change*, *107*(1-2), pp.35-57.

Grabowski, J.H., R. D. Brumbaugh, R. F. Conrad, A.G. Keeler, J. J. Opaluch, C. H. Peterson, M. F. Piehler, S. P. Powers and A. R. Smyth, 2012. Economic valuation of ecosystem services provided by oyster reefs. *BioScience* 62:900-909.

Grinnell, R. S., Jr. 1972. Structure and development of oyster reefs on the Suwannee River delta, Florida. Dissertation. State University of New York, Binghamton, New York, USA.

Grizzle, R., Ward, K., Geselbracht, L. and Birch, A., 2018. Distribution and Condition of Intertidal Eastern Oyster (Crassostrea virginica) Reefs in Apalachicola Bay Florida Based on High-Resolution Satellite Imagery. *Journal of Shellfish Research*, *37*(5), pp.1027-1039.

Gutiérrez, J.L., Jones, C.G., Strayer, D.L. and Iribarne, O.O., 2003. Mollusks as ecosystem engineers: the role of shell production in aquatic habitats. *Oikos*, *101*(1), pp.79-90.

Harley, G.L., Maxwell, J.T., Larson, E., Grissino-Mayer, H.D., Henderson, J. and Huffman, J., 2017. Suwannee River flow variability 1550–2005 CE reconstructed from a multispecies tree-ring network. *Journal of hydrology*, *544*, pp.438-451.

Hine, A. C., D. F. Belknap, J. G. Hutton, E. B. Osking,and M. W. Evans. 1988. Recent geological history and modern sedimentary processes along an incipient, low-energy, epicontinental-sea coastline: Northwest Florida. Journal of Sedimentary Petrology 58:567–579.

Kaplan, D.A., Olabarrieta, M., Frederick, P. and Valle-Levinson, A., 2016. Freshwater detention by oyster reefs: quantifying a keystone ecosystem service. *PloS one*, *11*(12), p.e0167694.

Kimbro, D. L., White, J. W., Tillotson, H., Cox, N., Christopher, M., Stokes‐Cawley, O., ... & Stallings, C. D. (2017). Local and regional stressors interact to drive a salinization‐induced outbreak of predators on oyster reefs. Ecosphere, 8(11), e01992.

La Peyre, M.K., A. D. Nickens, A. K. Volety, G. S. Tolley, and J. F. La Peyre. 2003. Environmental significance of freshets in reducing Perkinsus marinus infection in eastern oysters Crassostrea virginica: potential management applications. *Marine Ecology Progress Series* 248:165-176.

La Peyre, M.K., Gossman, B. and La Peyre, J.F., 2009. Defining optimal freshwater flow for oyster production: effects of freshet rate and magnitude of change and duration on eastern oysters and Perkinsus marinus infection. *Estuaries and Coasts*, *32*(3), pp.522-534.

Locker, S.D., Reed, J.K., Farrington, S., Harter, S., Hine, A.C. and Dunn, S., 2016. Geology and biology of the “Sticky Grounds”, shelf-margin carbonate mounds, and mesophotic ecosystem in the eastern Gulf of Mexico. *Continental Shelf Research*, *125*, pp.71-87.

Main, M.B. and Allen, G.M. 2007.Florida’s environment: North central region. Wildlife Ecology and Conservation Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida, USA. available online https://ufdc.ufl.edu/IR00003472/00001

Mattson, R.A. 2002. A resource-based framework for establishing freshwater inflow requirements for the Suwannee River Estuary. *Estuaries* 25:1333-1342.

Miller, A.W., Reynolds, A.C., Sobrino, C. and Riedel, G.F., 2009. Shellfish face uncertain future in high CO2 world: influence of acidification on oyster larvae calcification and growth in estuaries. *Plos one*, *4*(5), p.e5661.

Montague, C. L. and H. T. Odum. 1997. Introduction: The Intertidal Marshes of Florida's Gulf Coast in Coultas C.L., 1997. Ecology and Management of Tidal MarshesA Model from the Gulf of Mexico. CRC Press.

Mulholland, P.J., Best, G.R., Coutant, C.C., Hornberger, G.M., Meyer, J.L., Robinson, P.J., Stenberg, J.R., Turner, R.E., VERA‐HERRERA, F.R.A.N.C.I.S.C.O. and Wetzel, R.G., 1997. Effects of climate change on freshwater ecosystems of the south‐eastern United States and the Gulf Coast of Mexico. *Hydrological Processes*, *11*(8), pp.949-970.

National Oceanographic and Atmospheric Administration (NOAA) Fisheries. 2019a. Commercial Fisheries Landings. Online database available <https://tinyurl.com/y4yhnre3> August 2019

National Oceanographic and Atmospheric Administration (NOAA). 2019b. NOAA Tides and Currents. Online database available <https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8727520> August 2019

National Oceanographic and Atmospheric Administration (NOAA). 2019c. National Centers for Environmental Information. Online database available <https://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp> August 2019

Orlando, S.P. Jr., L.P. Rozas, G.H. Ward, and C.J. Klein. 1993. Salinity Characteristics of Gulf of Mexico Estuaries. Silver Spring, MD: National Oceanic and Atmospheric Administration, Office of Ocean Resources Conservation and Assessment. 209 pp.

Pine III, W., Walters, C., Camp, E., Bouchillon, R., Ahrens, R., Sturmer, L. and Berrigan, M., 2015. The curious case of eastern oyster *Crassostrea virginica* stock status in Apalachicola Bay, Florida. *Ecology and Society*, *20*(3).

Powell, E.N., Gauthier, J.D., Wilson, E.A., Nelson, A., Fay, R.R. and Brooks, J.M., 1992. Oyster disease and climate change. Are yearly changes in *Perkinsus marinus* parasitism in oysters (*Crassostrea virginica*) controlled by climatic cycles in the Gulf of Mexico?. *Marine ecology*, *13*(3), pp.243-270.

Powell, E.N. and Klinck, J.M., 2007. Is oyster shell a sustainable estuarine resource?. *Journal of Shellfish Research*, *26*(1), pp.181-195.

Pusack, T.J. and Stallings, C.D., 2017. Local and regional stressors interact to drive a salinization‐induced outbreak of predators on oyster reefs. *Ecosphere*, *8*(11), p.e01992.

Pusack, T.J., Kimbro, D.L., White, J.W. and Stallings, C.D., 2019. Predation on oysters is inhibited by intense or chronically mild, low salinity events. *Limnology and Oceanography*, *64*(1), pp.81-92.

R Core Team 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.

Raabe, E.A. and Stumpf, R.P., 2016. Expansion of tidal marsh in response to sea-level rise: Gulf Coast of Florida, USA. *Estuaries and Coasts*, *39*(1), pp.145-157.

Saetta, D., Ishii, S.K., Pine III, W.E. and Boyer, T.H., 2015. Case study and life cycle assessment of a coastal utility facing saltwater intrusion. *Journal‐American Water Works Association*, *107*(10), pp.E543-E558.

Sassaman, K.E., Wallis, N.J., McFadden, P.S., Mahar, G.J., Jenkins, J.A., Donop, M.C., Monés, M.P., Palmiotto, A., Boucher, A., Goodwin, J.M. and Oliveira, C.I., 2017. Keeping pace with rising sea: The first 6 years of the Lower Suwannee Archaeological Survey, Gulf coastal Florida. *The Journal of Island and Coastal Archaeology*, *12*(2), pp.173-199.

Seavey, J.R., Pine III, W.E., Frederick, P., Sturmer, L. and Berrigan, M., 2011. Decadal changes in oyster reefs in the Big Bend of Florida's Gulf Coast. *Ecosphere*, *2*(10), pp.1-14.

Southwick Associates 2015. Demographic, economic, and growth initiative analysis: Big Bend Region of Florida. Technical Report. Available online https://tinyurl.com/y2h5xxuf

Suwannee River Water Management District. 2019. Suwannee River Minimum Flows and Levels. Online database of reports. Available http://www.srwmd.state.fl.us/114/Suwannee-River (accessed August 2019).

Turner, R.E.. 2006. Will lowering estuarine salinity increase Gulf of Mexico oyster landings?. *Estuaries and Coasts* 29:345-352.

United States Supreme Court. 2018. Transcript of Oral Argument, Florida v. Georgia, 138 S. Ct. 2502 (No. 142, Original), Available: <https://www.supremecourt.gov/oral_arguments/argument_transcripts/2017/142-orig_p8k0.pdf>. August 2019

Ward, G. M., P. M. Harris, and A. K. Ward. 2005. Chapter 4: Gulf Coast Rivers of the Southeastern United States *in* Rivers of North American. A. C. Benke and C. E. Cushing editors. Elsevier.

Wilberg, M.J., Livings, M.E., Barkman, J.S., Morris, B.T. and Robinson, J.M., 2011. Overfishing, disease, habitat loss, and potential extirpation of oysters in upper Chesapeake Bay. *Marine Ecology Progress Series*, *436*, pp.131-144.

Wilberg, M.J., Wiedenmann, J.R. and Robinson, J.M., 2013. Sustainable exploitation and management of autogenic ecosystem engineers: application to oysters in Chesapeake Bay. *Ecological applications* 23:766-776.

Wright, E. E., A. C. Hine, S. L. Goodbred, and S. D. Locker. 2005. The effect of sea-level and climate change on the development of a mixed siliciclastic carbonate, deltaic coastline: Suwannee River, Florida, USA. Journal of Sedimentary Research 75:621–635.

Zu Ermgassen, P.S., M. D. Spalding, B. Blake, L. D. Coen, B. Dumbauld, S. Geiger, J. H. Grabowski, R. Grizzle, M. Luckenbach, K. McGraw and W. Rodney. 2012. Historical ecology with real numbers: past and present extent and biomass of an imperilled estuarine habitat. Proceedings of the Royal Society B: Biological Sciences, 279:3393-3400.

Figure 1. Map of the study area, showing locations of sampling sites within localities of major oyster reef complexes. Within each locality, note that transects were placed on reefs representing a gradient from inshore to offshore. For offshore reefs, note the coastwise orientation and linearity of reefs.

Figure 2. Histogram of probability density function (y-axis) of live oysters counted (x-axis) on intertidal reefs in Suwannee Sound, Florida. The red line represents the predicted density of oyster counts if these data follow a negative binomial distribution.

Figure 3. Predicted oyster counts using the best-fit negative binomial model offset by transect length from each locality CK = Cedar Key, CR = Corrigan’s reef, HB = Horseshoe Beach, and LC = Lone Cabbage based on data from 2010-2019. Colored lines represent Inshore (red), Nearshore (blue), and Offshore (green) sites within each locality. Shaded regions represent 95% CI on the predicted values.

Figure 4. Mean daily discharge by year (panel A) and associated variance (panel B) and CV (panel C) of daily discharge and total annual discharge (panel D) for the Suwannee River measured at USGS Wilcox gauge from October 1941 to December 2018. Red LOWESS smoothing line provided to show general trends in discharge. Blue dashed line is the average mean daily discharge, variance, CV, or total annual discharge from 1941-2018.

Figure 5. Mean daily discharge by year (panel A) and associated variance (panel B) and CV (panel C) of daily discharge and total annual discharge (panel D) for the Suwannee River measured at USGS Wilcox gauge from January 2010 to December 2018. Red LOWESS smoothing line provided to show general trends in discharge. Blue dashed line is the average mean daily discharge, variance, CV, or total annual discharge from 1941-2018.

Figure 6. Oyster landings (whole meat weight, panel A), oyster fishing trips (panel B), and oyster catch per trip (CPUE, panel C) for Suwannee Sound, Florida (Levy, Dixie, Taylor counties) from 1986-July 2019. Data for 2018 and 2019 are provisional.

Figure 7. Predicted oyster counts using the best-fit negative binomial model offset by transect length including mean annual daily discharge with a one-year lag as a covariate. Shaded regions represent 95% CI on the predicted values.

Figure S1. Predicted oyster counts using the best-fit negative binomial model offset by transect length (oyster counts = period \* site + locality + offset(log(transect length))) fit to 1000 simulated data sets (black lines) for all localities combined based on data from 2010-2019. Solid blue line is predicted values fit to observed (actual) field data.

Figure S2. Kernel density plot (y-axis) and p-value (x-axis) for the “period” beta term fit to the model oyster counts = period \* site + locality + offset(log(transect length)) from 1000 simulated datasets.

Figure S3. Panel A: Monthly Palmer drought severity index (y-axis) for north Florida (red line) and southeast Georgia (black line) by year (x-axis). Negative values indicate periods of drought and positive values periods of higher soil moisture. Data from NOAA 2019c. Panel B: Monthly mean sea level (y-axis, solid black line) over year (x-axis) from NOAA station 8727520, Cedar Key, Florida with a linear model (dotted black line) plotted for reference. Average seasonal cycle removed by NOAA (NOAA 2019b).