TECHNICAL MEMORANDUM

SUBJECT: Development of Oyster Life Table and Application to Estimate DWH Oyster Injury Metrics

DATE: August 20, 2015

TO: Marla Steinhoff, NOAA; Mary Baker, NOAA

FROM: Henry Roman, IEc and Terill Hollweg, Abt Environmental Research

---

INTRODUCTION

Oil and response activities from the Deepwater Horizon (DWH) spill led to mortality impacts in the nearshore and subtidal zones that affected oysters of all sizes – spat (<25 mm), seed (between 25 and 75 mm), and market (>75 mm) (Powers et al. 2015a; Powers et al, 2015b; Grabowski et al, 2015a; Grabowski et al., 2015b). Furthermore, these losses contributed to ongoing reproductive failures documented by the Trustees' NRDA sampling since 2010 (Grabowski et al., 2015b). In order to express these losses in a single common metric, such as market-sized equivalents or biomass, it is necessary to model the life history of an oyster in the northern Gulf of Mexico. This model (a "life table" model) provides information about survival rates and biomass of oysters as they grow from spat to seed to market size, taking into account natural mortality and fishing mortality. The life table allows us to estimate the number of market oysters ultimately expected to survive from a given population of spat or a given population of seed oysters. It also enables us to estimate, for a given loss of spat, seed, and market-sized oysters, the biomass in grams ash free dry weight (g afdw) represented by that direct kill, plus the biomass of somatic growth foregone because those oysters died prematurely. This technical memo describes the process by which we developed the oyster life table and describes how that life table was used to generate market equivalent oyster estimates and to convert those estimates into an estimate of biomass lost.

METHODOLOGY

Oyster Life Table

This section describes work conducted by Dr. Hollweg to model the growth and mortality of the Eastern Oyster. Published literature values, expert opinion, and field data were used to develop a detailed life table for the Eastern Oyster. The general inputs to the oyster life table included:

- Growth rate
- Oyster shell height to biomass relationship
- Natural mortality rate
- Fishing mortality rate
- Oyster lifespan

Due to regional differences in many of these factors, Gulf-specific values were used when possible. The following sections describe the specific data sources and information used to develop the oyster life table.

Growth rate

Von Bertalanffy growth curves were obtained from Soniat et al. (2012) and Duke (2008). Additional information was provided by Dr. Tom Soniat and Dr. Earl Melancon via email and discussions. Equation 1, below, shows the von Bertalanffy growth curve used by Soniat et al. (2012) to model harvestable oyster reefs in Louisiana.

Equation 1: $L(a) = L_{inf} \times \left[1 - e^{-k(t)\left(\frac{a-a_0}{12}\right)}\right]$

In Equation 1, L(a) is oyster length (in mm), a is age (in months), t is the simulation time (in months), and k(t) is the von Bertalanffy growth coefficient. Length at infinity, L_{inf}, was set at 151 mm based on information in Soniat et al. (2012). Age at time zero, a_0, was set as zero.

The von Bertalanffy growth coefficient, k(t), is a function of time, and calculated using the following equation:

Equation 2: $k(t) = k_0 + k_1 \times \sin\left(2\pi\left(\frac{t-t_0}{12}\right)\right)$

where t is time (in months), k_0 is the average growth rate, k_1 is the intra-annual growth rate, and t_0 is the initial month of simulation (in months).The following values for Equation 2 are as follows (based on information in Soniat et al. (2012) and correspondence with Dr. Tom Soniat):

k_0=0.8

k_1=0.09

t_0=7 (signifying August, with January = 0)

Note, t_0 was revised to June (t_0=5) in the life table based on discussions with Dr. Earl Melancon.

Duke (2008) published von Bertalanffy growth equations based on field collected data at two subtidal oyster reef sites (BB8 and BB4) in Barataria Bay, Louisiana. BB8 is a higher salinity site, and BB4 is a lower salinity site. The von Bertalanffy growth curve shown in Equation 3 was used to fit the data, where L_{inf} is length at infinity (in mm) and t is time (in years).

Equation 3: $\mathrm{L}_t = \mathrm{L}_{inf}\left(1 - \mathrm{e}^{-\mathrm{k}(\mathrm{t}-\mathrm{t}_0)}\right)$

Inputs for BB8 are as follows:

L_{inf} = 115.6 (in mm)

k = 0.6136

t_0=-0.0876 (in years)

Note: Error in Figure 21 in Duke (2008). Changed values from -0.876 to -0.0876. Confirmed with Dr. Earl Melancon.

Inputs for BB4 are as follows:

L_{inf} = 90.7 (in mm)

k = 0.7359

t_0=-0.1123 (in years)

The three growth equations were averaged, and a fit was performed to the averaged data (termed "combination fit") with the following values for Equation 3:

L_{inf} = 118.906 (in mm)

k = 0.7125

t_0=-0.0577 (in years)

The Von Bertalanffy growth curves from Soniat et al. (2012) and Duke (2008), as well as the combination fit, are shown in Figure 1.

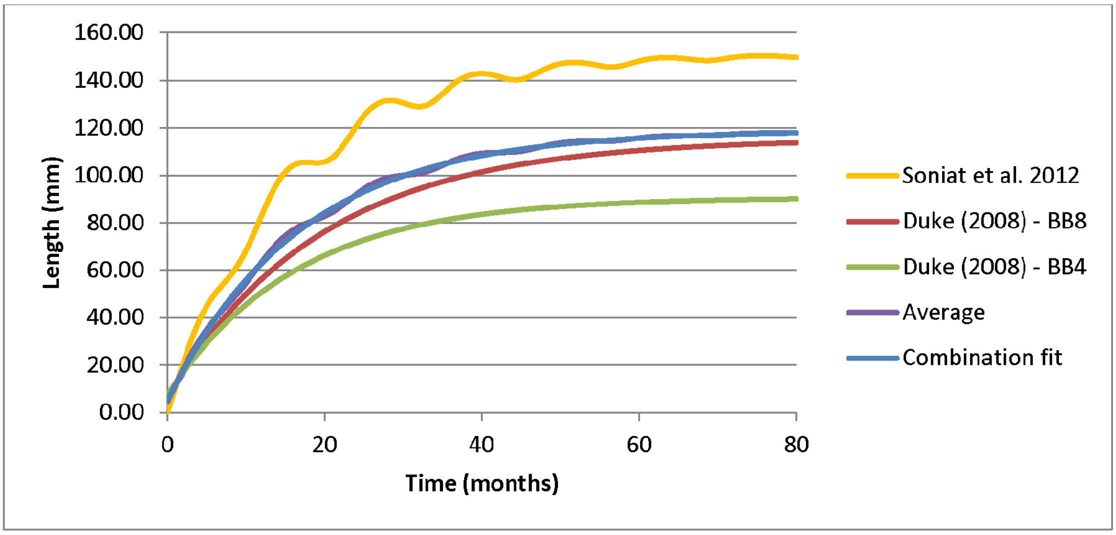

Figure 1. Von Bertalanffy growth curves from Soniat et al. (2012) and Duke (2008), as well as the average of the three growth curves and the fit of the averaged data (termed "combination fit").

Oyster shell height to biomass relationship

Oyster length (shell height) was converted to tissue ash-free dry weight biomass using equations from Luckenbach et al. (2005; Equation 4) and Heck (unpublished data; Equation 5), as follows:

Equation 4: $B = 0.000007 * SH^{2.8614}$

Equation 5: $B = 0.000003 * SH^{3.0073}$

In Equations 4 and 5, B is ash-free dry weight biomass (in grams) and SH is shell height (in mm).

Additional oyster shell height to biomass equations were considered, but not incorporated into the life table, including: Ross and Luckenbach (2006), Livingston et al. (1999), Bahr and Lanier (1981), Pollack et al. (2011), and White et al. (1988). These alternative datasets describe very different growth forms compared with the Luckenbach et al. (2005) and Heck (unpublished data) datasets that exhibit more typical growth curves. The oyster shell height to biomass curves are shown in Figure 2.

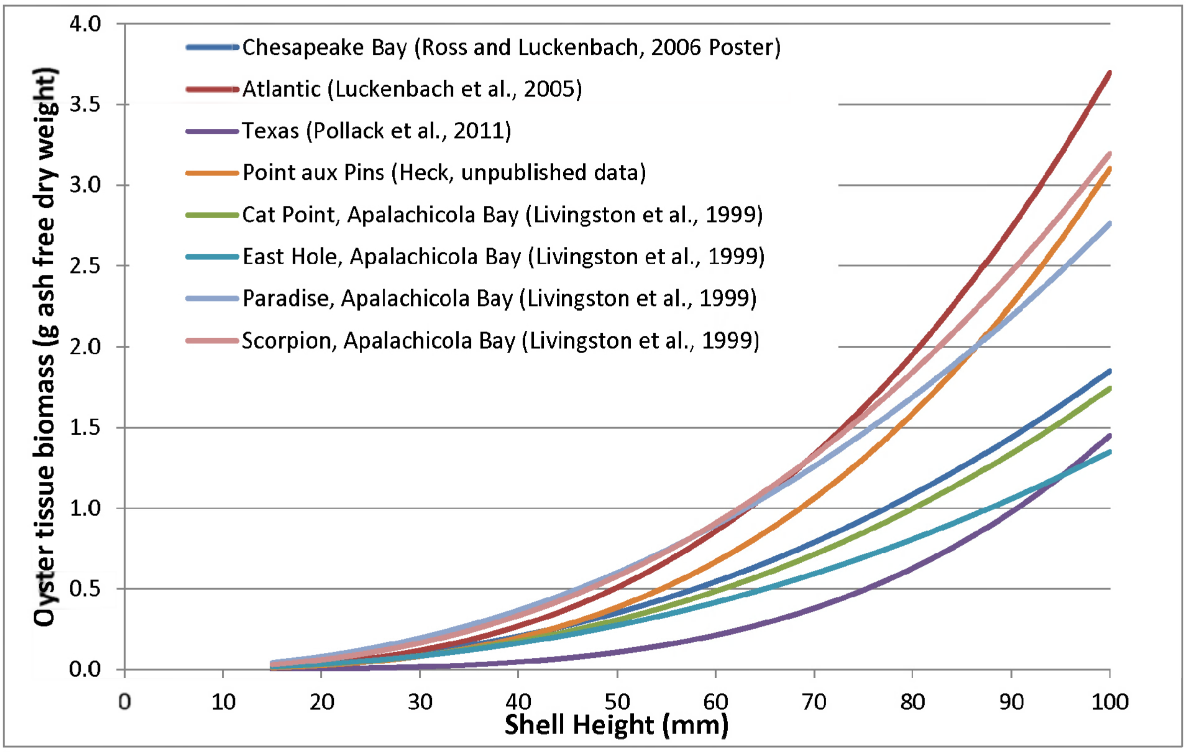

Figure 2. Oyster shell height to biomass equations from the literature and unpublished data.

Mortality

The natural mortality rate (m) and fraction dying per unit time (M) were obtained from Soniat et al. (2012), with additional information provided by Dr. Tom Soniat via email. See equations 6 and 7 for the calculation of m and M, respectively.

Equation 6: $m(t, L) = m_0 + m_1 \times \sin\left(2\pi \times \left(\frac{t-t_{avg}}{12}\right)\right)$

In Equation 6, t is time (in months) and t_{avg} is the time of average mortality (in months). The values for m_0 and m_1 are different for juveniles (L<25 mm) and adults (L≥25 mm). The following inputs for Equation 6 were used in the life table (based on correspondence with Dr. Tom Soniat):

t_{avg} = 5 (signifying June, where January = 0)

m_0 for juvenile (L<25mm) = 1.2

m_1 for juvenile (L<25mm) = 1.1

m_0 for adult (L≥25mm) = 0.51

m_1 for adult (L≥25mm) = 0.41

Equation 7: $M(t, L) = 1 - e^{-m(t,L)/12}$

In Equation 7, the fraction dying per unit time, M, is a function of the natural mortality rate (m; from Equation 4), time (t, in months), and oyster length (L, in mm).

Fishing mortality was estimated to be 10% loss per month for subtidal oyster reefs based on discussions with Dr. Earl Melancon. The fishing mortality was applied from September to March to oysters 75 mm or greater.

Oyster lifespan

Oyster lifespan was set at 60 months based on discussion with Dr. Sean Powers.

Additional calculations were performed in the life table, which included:

- Number of live individuals at the beginning of the timestep and end of the timestep

- Number of live individuals at the midpoint of the timestep (average of number of individuals at the beginning and end of timestep)
- Number of oysters that died from natural mortality during timestep
- Number of oysters that died from natural and fishing mortality during timestep
- Tissue weight at the beginning of the timestep and end of the timestep
- Tissue weight at the midpoint of the timestep (average of tissue weight at the beginning and end of timestep)
- Weight gained per individual during timestep
- Live oyster production during timestep, which was calculated by multiplying the number of live individuals at the midpoint of the timestep by the weight gained per individual during that timestep

Estimating Market-equivalents and Biomass Lost

In this section, we describe work conducted by Mr. Roman to apply the lifetable in the injury assessment calculations.

Market Equivalents

Spat, seed, and market-sized oysters lost were combined into a single metric of market-equivalent oysters by weighting the spat and seed losses by the expected survival rate of that size class to market size and then summing those values with the market oyster losses.

$$Market\ Equivalents = L_{spat} * S_{spm} + L_{seed} * S_{sem} + L_{mkt}$$

Where:

L_{spat} = estimated spat oyster losses (#)
S_{spm} = probability of survival from spat to 75 mm market-sized oyster (unitless)
L_{seed} = estimated seed oyster losses (#)
S_{sem} = probability of survival from 25 mm seed to 75 mm market-sized oyster (unitless)
L_{mkt} = estimated market-sized oyster losses (#)

The survival values, S, were determined from the life table model as the ratio of the number of individuals alive at the starting age class time step divided by the number of individuals alive at the time step when the oyster reaches 75 mm in size.

Estimating Biomass Losses

Market equivalent oyster losses are converted to an estimate of biomass loss using the information in the life table. The biomass loss consists of the following two parts:

1. The biomass of the market equivalent oyster losses (# of market equivalent oysters lost x average biomass of one 75 mm market-sized oyster); and
2. The production (i.e., somatic growth) foregone because of the oyster kill. In other words, this represents how much additional biomass was not generated from growth of the prematurely dead oysters. (# of market equivalent oysters lost x mean production over remaining lifetime of 75 mm oyster)

We used 1.8 g afdw for the average biomass of one 75 mm oyster; this value is estimated based on the length/weight relationship presented in Luckenbach et al., 2005.

Mean production (growth) of one 75 mm market oyster over the rest of its lifetime was estimated as the discounted sum of incremental monthly biomass growth from the month the oyster reaches 75 mm until 60 months of age. Monthly biomass values were based on Luckenbach et al., 2005. Biomass was discounted at annual rate of 3%.

RESULTS

Market Equivalent Survival Rates

Table 1 shows the results of the life table analysis of the survival of a ~5 mm spat oyster to a 75 mm market sized oyster and the survival of a 25 mm seed oyster to a 75 mm market oyster.

Survival from:	Percent Survival
spat to market	30%
seed to market	56%

Table 1. Oyster survival probabilities to 75 mm market size from lifetable based on Soniat et al., 2012 and Duke (2008).

Production Foregone Estimates

Production foregone was estimated as 1.3 g afdw per 75 mm oyster in the subtidal, and 2.4 g afdw for a 75 mm oyster in the nearshore. The mean production is higher for nearshore oysters because these oysters are not harvested, which increases their survival probability and growth potential.

REFERENCES

- Bahr, L. M. and W. P. Lanier. 1981. The Ecology of Intertidal Oyster Reefs of the South Atlantic Coast: A Community Profile. FWS/OBS-81/15. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C.
- Duke, R.W.Jr. 2008. "Oyster Survival and Growth within the Barataria Estuary." MS Thesis, Nicholls State University.
- Livingston, R. J., R. L. I. Howell, N. Xufeng, F. G. I. Lewis, and G. C. Woodsum. 1999. Recovery of oyster reefs (Crassostrea virginica) in a gulf estuary following disturbance by two hurricanes. Bulletin of Marine Science 64(3):465-483.
- Luckenbach, M. W., L. D. Coen, P. G. Jr. Ross, and J. A. Stephen. 2005. Oyster reef habitat restoration: Relationships between oyster abundance and community development based on two studies in Virginia and South Carolina. Journal of Coastal Research SI 40:64-78.
- Pollack, J. B., H.-C. Kim, E. K. Morgan, and P. A. Montagna. 2011. Role of flood disturbance in natural oyster (Crassostea virginica) population maintenance in an estuary in south Texas, USA. Estuaries and Coasts 34:187-197.
- Powers, S. P., J. H. Grabowski, H. Roman, A. Geggel, S. Rouhani, J. Oehrig, M. Baker. 2015a. Consequences of Large Scale Hydrographic Alteration During the Deepwater Horizon Oil Spill on Subtidal Oyster Populations. DWH NRDA Oyster Technical Working Group Manuscript.
- Powers, S. P., S. Rouhani, M. C. Baker, H. Roman, J. Grabowski, S. B. Scyphers, J. Murray, J. M. Willis & M. W. Hester. 2015b. Loss of Oysters as a Result of the Deepwater Horizon Oil Spill Degrades Nearshore Ecosystems and Disrupts Facilitation Between Oysters and Marshes. DWH NRDA Oyster Technical Working Group Manuscript.
- Grabowski, J.H., S. P. Powers, H. Roman, & S. Rouhani. 2015a. Impacts of the 2010 Deepwater Horizon Oil Spill and Associated Response Activities on Subtidal Oyster Populations in the Northern Gulf of Mexico. DWH NRDA Oyster Technical Working Group Manuscript.
- Grabowski, J.H., S.P. Powers, H. Roman, J. Murray, H.M. Marrison, et al. 2015b. Oyster Reproductive Injury. DWH NRDA Oyster Technical Working Group Manuscript.
- Ross, P.G. and M. W. Luckenbach. 2006. Relationships between shell height and dry tissue biomass for the eastern oyster (Crassostrea virginica). International Conference on Shellfish Restoration. Poster

- Soniat, T. M., J. M. Klinck, E. N. Powell, N. Cooper, M. Abdelguerfi, E. E. Hofmann, J. Dahal, S. Tu, J. Finigan, B. S. Eberline, J. F. La Peyre, M. K. La Peyre, and F. Qaddoura. 2012. A shell-neutral modeling approach yields sustainable oyster harvest estimates: A retrospective analysis of the Louisiana State primary seed grounds. Journal of Shellfish Research 31(4):1103-1112.
- Soniat, T. M., N. Cooper, E. N. Powell, J. M. Klinck, M. Abdelguerfi, S. Tu, R. Mann, and P. D. Banks. 2014. Estimating sustainable harvests of eastern oysters, Crassostrea virginica. Journal of Shellfish Research 33(2):381-394.
- White, M. E., E. N. Powell, and S. M. Ray. 1988. Effect of parasitism by the pyramidellid gastropod Boonea impressa on the net productivity of oysters (Crassostrea virginica). Estuarine, Coastal and Shelf Science 26:359-377.