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PROSPECTS FOR THE SUSTAINABLE MANAGEMENT OF PUBLIC OYSTER RESOURCES

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ABSTRACT Common-pool resources such as public oyster grounds are especially vulnerable to overexploitation and habitat loss. Like those elsewhere, oyster populations and habitat of Louisiana public grounds are in decline. To maintain reef habitat and increase oyster abundance, a sustainable harvest model is applied, which allows harvest above that required to maintain reef cultch stasis. The model is restrained to promote shell gain by limiting fishing by area, type (sack versus seed), effort, and season. Harvest quotas and cultch removal rates derived from shell-budget–based modeling are a foundation for sustainable management of public oyster resources.

KEY WORDS: common-pool resource, sustainability, fisheries management, oyster, *Crassostrea virginica*

INTRODUCTION

Common-pool resources are especially vulnerable to overexploitation and habitat loss. Allocation of access and limitation to extractive practices are often ineffective, and common-pool resources typically degrade to a state described as "The Tragedy of the Commons." The tragedy of the commons results from a competitive calculus, in which the benefit to the individual exploiter of a public resource exceeds his portion of the common exploitive cost plus the individual costs, if any, of noncompliance (Hardin 1968).

Beck et al. (2011) estimate that 85% of oyster reefs worldwide have been lost. In many bays and estuaries, more than 90% of reefs are functionally extinct. Most of the remaining wild capture (75%) comes from North America, in particular from the Gulf of Mexico. Historical accounts include Ford (1997) and MacKenzie (1996, 2007). Kirby (2004) described the sequence of reef destruction and fisheries collapse in North America. Fishery collapse began in estuaries nearest large northern urban centers and spread southward along the U.S. Atlantic coast. As resource depletion occurred, additional oysters were imported from areas fished from evermore distant southern estuaries. The historical sequence of exploitation and the increasing landings in Texas and Louisiana relative to North America suggest that oyster reefs there are in greatest danger of degradation (Kirby 2004). Zu Ermgassen et al. (2012) provide a further update of oyster population condition. Powell (2017) reviews recent trends in the Gulf of Mexico.

The oyster populations and reefs of the Public Oyster Grounds (POG) of Louisiana (Fig. 1) are common-pool resources that have been in decline (Fig. 2) since 2001 (Soniat et al. 2012, LDWF 2016). The Louisiana oyster grounds consist of nearly 1.7 million acres of POG and approximately 404,000 acres of private leases. The POG are used as a source of seed oysters (shell length, ℓ, less than 75 mm) that are transported to private leases for grow out and subsequent marketing. Market-size (ℓ greater than or equal to 75 mm) or "sack" oysters are also allowed to be directly marketed from the POG (Banks et al. 2016, LDWF 2016).

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The long-term average (1961–2015) landings of eastern oysters (*Crassostrea virginica*) produced from the POG and private leases is about 11 million pounds of meat (Fig. 2). In years of abundance of oysters on the POG (2000–2002), public grounds supplied about 50% of the combined annual yield; in years of scarcity (2012–2014), they supplied about 10% of the same (LDWF 2016). Thus, although private and public production show considerable variation, the interplay of private and public activity results in relatively stable long-term production. The success of the Louisiana oyster industry is due in part to this public/private partnership, in which the Louisiana Department of Wildlife and Fisheries (LDWF) plants cultch and manages the public grounds for seed production and transplant to private leases. Dugas (1988), Keithly and Roberts (1988), and Wirth and Minton (2004) provide historical accounts. The decline in stock abundance on the POG, however, directly threatens the sustainability of the public resource and indirectly threatens the sustainability of the private resource, which is subsidized by seed and cultch from the public grounds.

The present study investigates the sustainability of the public resource only. A sustainability criterion and a modeling scenario for sustainable fishing of sack and seed oysters from the Louisiana POG, which is broadly applicable to subtidal eastern oysters in North America, is defined and proposed. The 2018/2019 oyster season has been used as an exemplar representing the present state of the resource and the implications of management measures that would achieve sustainability.

MATERIALS AND METHODS

Study Area

Coastal fisheries in Louisiana, including the oyster fishery, are managed by the LDWF. The coast is subdivided into management units termed Coastal Study Areas (CSAs), which are watersheds or contiguous watersheds (Fig. 1). Seven CSAs are designated, from CSA 1 in the east to CSA 7 in the west. In 2012, LDWF consolidated CSA 1 with CSA 2 and CSA 4 with CSA 5; the traditional designation is used herein. Louisiana POG are located in all CSAs (Fig. 1). They include the public grounds of Mississippi Sound (MS), Lake Borgne (LB), and the

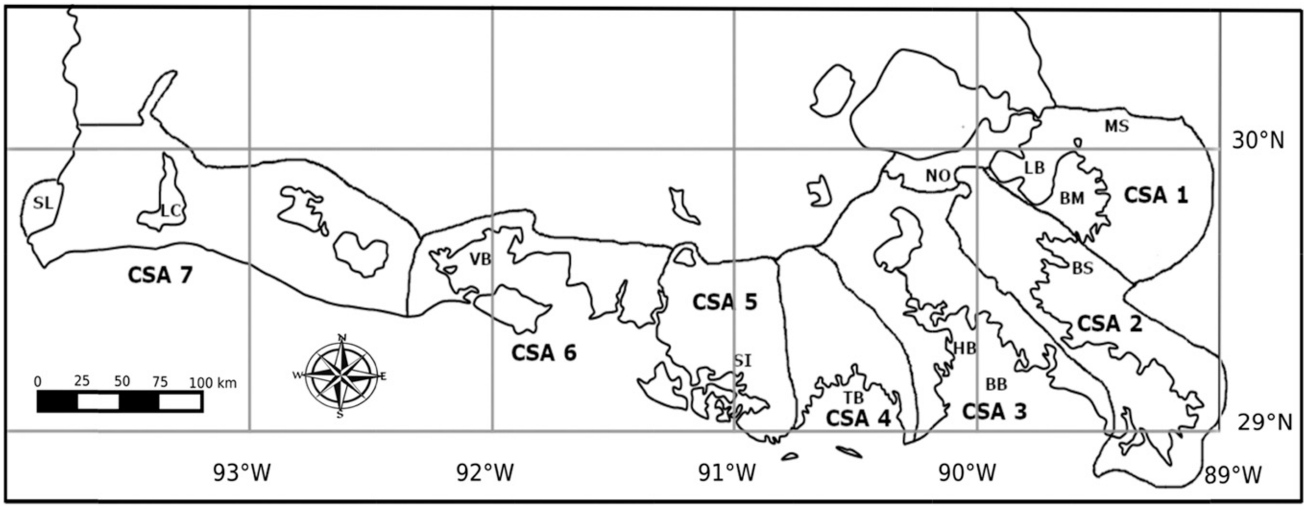

Figure 1. Boundaries of Louisiana Department of Wildlife and Fisheries (LDWF) Coastal Study Areas (CSA) and the location of Public Oyster Grounds (POG). POG are located in Lake Borgne (LB), Mississippi Sound (MS), Biloxi Marsh (BM), Breton Sound (BS), Barataria Bay (BB), Hackberry Bay (HB), Terrebonne Bay (TB), Sister Lake (SI), Lake Calcasieu (LC) and Sabine Lake (SL). The Mississippi River forms the boundary between CSA 2 and CSA 3. NO indicates the location of the City of New Orleans.

Biloxi Marsh (BM) in CSA 1; Breton Sound (BS) in CSA 2; Hackberry Bay (HB) and Barataria Bay (BB) in CSA 2; Terrebonne Bay (TB) in CSA 4; the Sister Lake (SI) area in CSA 5; Vermilion Bay (VB) in CSA 6; and Lake Calcasieu (LC) and the Louisiana portion of Sabine Lake (SL) in CSA 7. Location, CSA, and reef size are given in Table 7.

Oyster habitat in Louisiana is characterized by copious freshwater input, high turbidity, microtidal conditions, and shallow (1–4 m) water depth (Melancon et al. 1998). Intertidal oysters are found at the seaward edge of their local distribution, but are not commercially significant, are not sampled by the LDWF, and are not a part of the present study.

Stock Assessment

The LDWF conducts annual quantitative fisheries-independent surveys on all POG. Divers remove oysters and surficial cultch from five grid samples (1.0 m^2 or 0.25 m^2) at each reef (Table 7). Live oysters and boxes (dead oysters with articulated shells) are counted, measured, and assigned to 5-mm size bins. (In the present study, oyster ''length'' is used in a fisheries context and is equivalent to standard height.) Oyster abundance on a reef is determined by multiplying mean oyster density by the reef acreage (Table 7). Details of sampling methodology, and interannual differences in assessed reef size and stock size are available as annual stock assessment reports (*e.g.*, LDWF 2016).

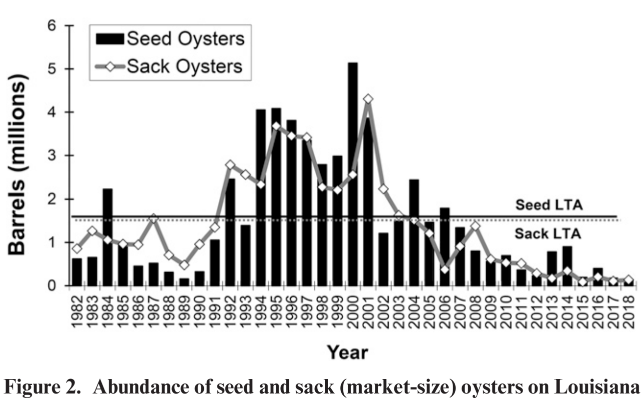

Figure 2. Abundance of seed and sack (market-size) oysters on Louisiana POG, 1982 to 2018. Surveys conducted by the LDWF. Data from SL, which is not open to fishing, are excluded. LTA = long-term average. One barrel = two Louisiana sacks (used with the permission of LDWF),

Model Overview

Primary processes and linkages of the sustainable oyster fishing model are shown in Figure 3. Oyster size and number, and cultch type and density are primary inputs to the model. For each size group, mortality is simulated and new shell is added to the reef as the size-dependent carbonate contribution of dead oysters. Both mortality and growth are simulated as functions of oyster size, and environmental temperature (or season) and salinity. Fishing effort and season duration for seed and sack oysters are used to compute the number of sacks of oysters fished. For each cultch type (oyster shell, limestone, clamshell, hooked mussels, and concrete), the volume of cultch fished is determined, natural loss is calculated, and shell added via oyster mortality is credited to the reef cultch. The time step for the oyster and cultch calculations is one month. When calculations for all size classes of oysters, all cutch types, and all months are exhausted, the results are collected and a determination of sustainable harvest is made.

Details of model equations and processes are provided by Soniat et al. (2012). Model equations and parameters are provided in Table 1, whereas model constants and coefficients are shown in Table 2. Notable changes from previous model implementations (Soniat et al. 2012, 2014) include the addition of modified equations for size-specific growth and mortality as a function of water temperature and salinity (Lowe et al. 2017, 2018). Growth ($\mathcal{G}_{sp}$) of spat ($\ell < 25$ mm) is

$$\mathcal{G}_{sp}(\ell, t) = -0.055 \times T_t^2 - 0.12 \times S_t^2 + 2.91 \times T_t - 26.18. \quad (1)$$

Growth ($\mathcal{G}_{se}$) of seed oysters ($\ell \geq 25$ mm and <75 mm) is

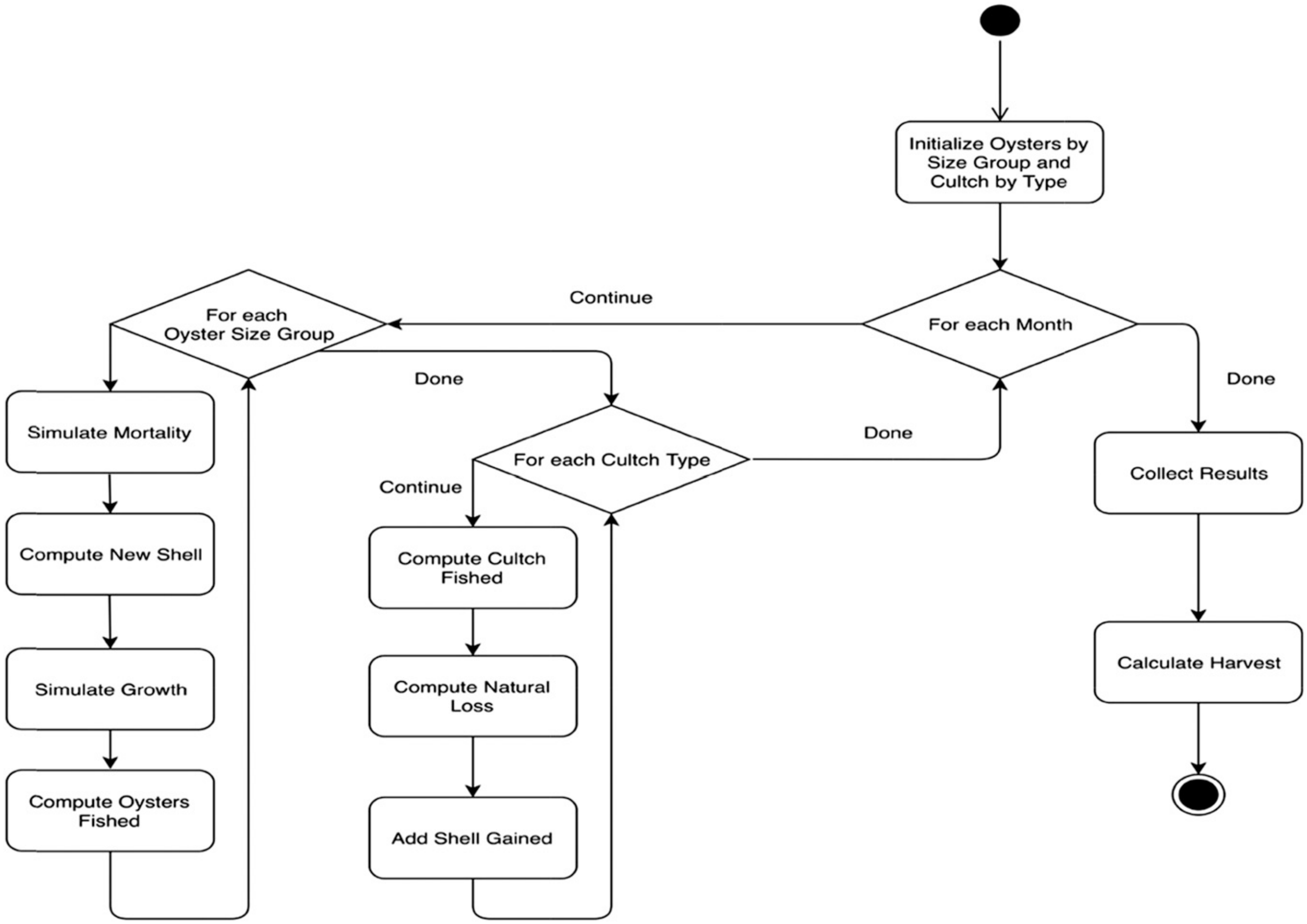

Figure 3. Schematic of major model processes.

$$\mathcal{G}_{\mathrm{se}}(\ell,t) = -0.036\times T_t^2 + 1.97\times T_t + 0.012\times S_t - 19.49. \quad (2)$$

Growth ($\mathcal{G}_{sa}$) of sack oysters ($\ell \geq 75$ mm) is

$$\mathcal{G}_{\mathrm{sa}}(\ell,t) = -0.0074\times T_t^2 - 0.0068\times S_t^2 + 0.29\times T_t + 0.22\times S_t - 2.18. \quad (3)$$

Lowe et al. (2017, 2018) were able to derive a mortality equation for sack oysters only. The monthly mortality fraction ($\mathcal{M}$) for sack oysters is

$$\mathcal{M}_{\mathrm{sa}}(\ell,t) = 0.00095\times T_t^2 + 0.0027\times S_t^2 - 0.037\times T_t - 0.072\times S_t + 0.78, \quad (4)$$

where ℓ is the oyster length (mm), t is the time, T_t is the temperature (°C) at time t, and S_t is the salinity at time t. Mortality rates for spat and seed are parameterized as previously (Soniat et al. 2012, 2014) and are given in Table 1.

Spat growth (Eq. 1) is maximal at high T (>27.0°C) and high S (>22). Spat growth declines above 30°C and is markedly reduced at T less than 20°C and S less than 15. Seed oyster growth (Eq. 2) is increased at T between 22°C and 30°C. Seed growth is maximal at a T of 27.8°C and an S of 26.8, and declines at T greater than 30°C and at combinations of low T (<15°C) and low S (<15). Growth of sack-sized oysters (Eq. 3) is maximized at lower T and S than that for spat and seed. Growth is reduced at the extremes of both T and S; the most significant reduction occurs at T greater than 30°C and S less than 10. Mortality of sack oysters (Eq. 4) is minimal at a T of 17.1°C and an S of 12.4 (Lowe et al. 2017, 2018).

Temporal and Spatial Restrictions to Sack and Seed Fishing

In CSA 1, fishing was restricted to a November through February season with sack fishing evenly distributed across the season and seed fishing restricted to November. In CSA 2, sack-only fishing was allowed during a November through February season; effort there was evenly distributed. Coastal Study Area 3 was open to fishing for sack oysters from November through February with effort evenly distributed; sack fishing was allowed in November only. Fishing was not permitted in CSA 4 because of a lack of resource. Closure of CSA 5 is the result of a policy of biennial rotation, paired with contrapuntal openings in HB (CSA 3). The season in CSA 6 extended from November through March, with most of the sack effort and all of the seed effort exerted in March. Coastal Study Area 7 includes LC and SL (Fig. 1); where fishing is allowed, only sack fishing is permitted. Sack fishing in LC was allowed from November through February, with effort evenly distributed in those months.

TABLE 1.

Model equations and parameters.

Equation	Variables and comments
Initial number of oysters by size group, $N_0(g) = \frac{1}{R}\sum_{r=0}^{R}\frac{\mathrm{OS}_{r,g}}{A_r}$	g, oyster size group index R, number of replicates sampled $\mathrm{OS}_{r,g}$, oyster counts from data samples for replicate r of size group g A_r, area sampled (m^2) for replicate r
Initial cultch mass by cultch type, $M_0(c) = \frac{1}{R}\sum_{r=0}^{R}\frac{\mathrm{CS}_{r,c}}{A_r}$	c, cultch type index R, number of replicates sampled $\mathrm{CS}_{r,g}$, cultch mass (g) from data samples for replicate r of cultch type c A_r, area sampled (m^2) for replicate r
Mortality rate of spat and seed oysters, $k(\ell,t) = \begin{cases} m_{J,0} + m_{J,1} \times \sin\left(2\pi \times \frac{\mathrm{mo}_t - t_{\mathrm{avg}}}{12}\right), & \ell \geq \ell_{\mathrm{Seed-Thresh}} \\ m_{A,0} + m_{A,1} \times \sin\left(2\pi \times \frac{\mathrm{mo}_t - t_{\mathrm{avg}}}{12}\right), & \ell \geq \ell_{\mathrm{Seed-Thresh}} \end{cases}$	ℓ, oyster length (mm) t, time mo_t, month (1–12) number corresponding to simulation time t
Monthly mortality fraction of market-sized oysters, $\mathcal{M}(\ell,t) = 0.00095 \times T_t^2 + 0.0027 \times S_t^2 - 0.037 \times T_t - 0.072 \times S_t + 0.78$	ℓ, oyster length (mm) t, time T_t, temperature (°C), at time t S_t, salinity, at time t
General mortality fraction of oysters, $m(\ell,t) = \begin{cases} 1 - \exp[-k(\ell,t)/12], & \ell < \ell_{\mathrm{Sack-Thresh}} \\ \max[0.0, \mathcal{M}(\ell,t)], & \ell \geq \ell_{\mathrm{Sack-Thresh}} \end{cases}$	ℓ, oyster length (mm) t, time
Growth, $\mathcal{G}(\ell,t) = \begin{cases} -0.055 \times T_t^2 - 0.12 \times S_t^2 + 2.91 \times T_t - 26.18, & \ell < \ell_{\mathrm{Seed-Thresh}} \\ -0.036 \times T_t^2 + 1.97 \times T_t + 0.012 \times S_t - 19.49, & \ell_{\mathrm{Seed-Thresh}} \leq \ell < \ell_{\mathrm{Sack-Thresh}} \\ -0.0074 \times T_t^2 - 0.0068 \times S_t^2 + 0.29 \times T_t + 0.22 \times S_t - 2.81, & \ell \geq \ell_{\mathrm{Sack-Thresh}} \end{cases}$	ℓ, oyster length (mm) t, time T_t, temperature (°C), at time t S_t, salinity, at time t
Length, $\mathcal{L}(g,t) = \begin{cases} \mathrm{LS}_g, & t = 0 \\ \mathcal{L}(g,t-1) + \max[0.0, \mathcal{G}(\mathcal{L}\{g,t-1\},t)], & t \geq 1 \end{cases}$	g, oyster size group index t, time LS_g, original sampled size (mm) for size group g
Oyster volume, $V_{\mathrm{oyster}}(\ell,N) = \frac{N \times V_{\mathrm{Sack}}}{\mathrm{OPS}_A \times \ell^{\mathrm{OPS}_B}}$	ℓ, oyster length (mm) N, number of oysters
Cultch volume, $V_{\mathrm{cultch}}(c,M) = \frac{M}{d_c \times p_c \times V_{\mathrm{Sack}}}$	c, cultch type index M, mass of cultch (g)
Shell mass from dead oyster, $S_{\mathrm{oyster}}(l) = M_A \times \ell^{M_B}$	ℓ, oyster length (mm)
Cultch dissolution fraction (monthly), $f_{\mathrm{loss}}(c) = \left[1 - (1 - r_c)^{\frac{1}{12}}\right]$	c, cultch type index
Number of dead oysters (monthly), $D(g,t) = N(g,t-1) \times m[L(g,t),t]$	g, oyster size group index t, time
Number of oysters, $N(g,t) = \begin{cases} N_0(g) & t = 0 \\ [N(g,t-1) - D(g,t)] \times [1 - f_{\mathrm{se},o}(\mathcal{L}(g,t),t)] \times [1 - f_{\mathrm{sa},o}(\mathcal{L}(g,t),t)] & t \geq 1 \end{cases}$	g, oyster size group index t, time $f_{\mathrm{se},o}(\ell,t)$, effective fishing fraction of oysters of length ℓ due to seeding at time t $f_{\mathrm{sa},o}(\ell,t)$, effective fishing fraction of oysters of length ℓ due to sacking at time t
Cultch gain (from oyster mortality), $M_{\mathrm{gain}}(c,t) = \begin{cases} \sum_{g \in G} D(g,t) \times S_{\mathrm{oyster}}(\mathcal{L}(g,t)), & c = C_{\mathrm{bs}} \\ 0.0, & \text{otherwise} \end{cases}$	G, total set of oyster size groups C_{bs}, the cultch type index corresponding to oyster shell
Cultch mass, $M(c,t) = \begin{cases} M_0(c) & t = 0 \\ [M(c,t-1) \times (1 - f_{\mathrm{loss}}(c)) + M_{\mathrm{gain}}(c,t)] \times [1 - f_{\mathrm{se},c}(c,t)] & t \geq 1 \end{cases}$	c, cultch type index t, time $f_{\mathrm{se},c}(c,t)$, effective fishing fraction of cultch of type c due to seeding at time t

TABLE 2.

Model constants and coefficients.

Constant	Definition	Value					Units
Length							
$L_{Seed\text{–}Thresh}$	Minimum size of seed-sized oyster	25.0					mm
$L_{Sack\text{–}Thresh}$	Minimum size of sack-sized oyster	75.0					mm
Mortality							
$m_{J,0}$	Juvenile mortality coefficient	1.203972804					–
$m_{J,1}$	Juvenile mortality exponent	1.1					–
$m_{A,0}$	Adult mortality coefficient	0.510825624					–
$m_{A,1}$	Adult mortality exponent	0.41					–
t_{avg}	Month of average mortality	6					Month (1–12)
Conversions							
V_{Sack}	Oyster sack capacity	52.85					L
OPS_A	Oysters-per-sack coefficient	1.767×10^8					–
OPS_B	Oysters-per-sack exponent	–2.926					–
M_A	Oyster shell mass coefficient	0.0004					–
M_B	Oyster shell mass exponent	2.8213					–
Cultch properties		Oystershell	Limestone	Clamshell	Hooked mussel	Concrete	
d_c	Cultch density	2,200	2,518	2,286	1,667	2,285	g/L
p_c	Cultch packing coefficient	0.590	0.571	0.425	0.258	0.531	–
r_c	Cultch annual loss rate	0.1	0.01	0.3	0.8	0.001	–

Sabine Lake is never open to fishing and is thus not included in the present simulations (Tables 3 and 4).

Simulation Scenarios

The simulations of sustainable harvest require as input a prescribed fishing season, fishing location, sack and seed fishing pressures (Table 3), and the proportion of sack to seed fishing (Table 4). Monthly mean T from central coastal Louisiana is used to construct a look-up table (Table 5) that is applied to all reefs. Mean monthly T varies from 11°C in January to 29°C in July and August. Three monthly S profiles (Melancon et al. 1998) are used in simulations for all reefs, providing low (annual mean $S = 8.8$), moderate (annual mean $S = 14.4$), and high (annual mean $S = 20.7$) salinity scenarios (Table 6).

A no-net-cultch-loss (NNCL) reference point is used as the endpoint for simulations. That is, when cultch density in the simulation equals the original (stock assessment) density, the simulation ceases. Initial simulations are conducted without fishing. If without fishing the reef loses cultch, it is considered "not fishable" (Table 7), and no further simulations are conducted. Such reefs have an insufficient density of oysters needed to support reef stasis, much less carbonate removal by fishing. "Fishable reefs" are further simulated to determine sustainable harvest, using the NNCL reference point. In some cases, the model achieves NNCL and the simulation is solved; in other cases, the simulation exhausts *a priori* constraints (fishing season, sack and seed pressures, and proportion of sack to seed fishing) before reaching NNCL (Table 7). Such reefs have a net cultch gain. Both conditions are considered sustainable.

TABLE 3.

Sack and seed fishing pressures for each CSA, based on recent fishing pressures (percent in effort/month).

CSA	Sack/Seed	September	October	November	December	January	February	March	April
1	Sack	0	0	25	25	25	25	0	0
	Seed	0	0	100	0	0	0	0	0
2	Sack	0	0	25	25	25	25	0	0
	Seed	0	0	0	0	0	0	0	0
3	Sack	0	0	25	25	25	25	0	0
	Seed	0	0	100	0	0	0	0	0
4	Sack	0	0	0	0	0	0	0	0
	Seed	0	0	0	0	0	0	0	0
5	Sack	0	0	0	0	0	0	0	0
	Seed	0	0	0	0	0	0	0	0
6	Sack	0	0	5	5	5	5	80	0
	Seed	0	0	0	0	0	0	100	0
7	Sack	0	0	25	25	25	25	0	0
	Seed	0	0	0	0	0	0	0	0

TABLE 4.

The proportion (percent) of seed fishing to sack fishing in 2018 for each CSA.

CSA	Seed	Sack
1	10	90
2	0	100
3	10	90
4	0	0
5	0	0
6	90	10
7	0	100

Sustainable harvests of sack and seed are determined by reef for the three S scenarios (Table 7); sustainable harvests from reefs within a CSA are summed to give CSA totals, and CSA totals are summed for statewide totals (Table 8).

RESULTS

Sustainable harvests by reef are shown in Table 7. Of 84 reefs, 62 showed no possible sustainable harvest of seed or sack oysters under any *S* scenario (high, moderate, and low). Four reefs showed a sustainable harvest under some *S* scenarios (Hackberry 2008 Cultch Plant, low *S*, moderate *S*; Hackberry 2012 Cultch Plant, moderate *S*; Highspot Reef, low *S*; and Middle Reef, low *S*, moderate *S*). Eighteen reefs, just 21.4% of the total, showed sustainable harvest of seed or sack oysters under all *S* scenarios.

In CSA 1, a sustainable harvest of seed oysters (abbreviated hereafter as H_{SE}) and sack oysters (abbreviated hereafter as H_{SA}) was available (Table 7). For the low *S* regime, H_{SE} and H_{SA} were 7,324 and 28,757 sacks, respectively. For the moderate *S* regime, H_{SE} was 6,681 sacks and H_{SA} was 36,217 sacks. Under high *S* conditions, H_{SE} was 5,968 sacks, whereas H_{SA} was 9,018 sacks. In CSA 2, a sustainable harvest of sack or seed was not possible on any reef. Coastal Study Area 3 supported a small sustainable harvest—an H_{SE} of 473 sacks and an H_{SA} of 1,039 sacks at low *S*, an H_{SE} of 374 sacks and an H_{SA} of 1,057 sacks at moderate *S*, and an H_{SE} of 409 sacks and an H_{SA} of 242 sacks at high *S*. No fishing was scheduled in 2018/2019 in CSAs 4 and 5 (see Methods and Table 4), and so no simulations were run. In CSA 6, applying the low *S* scenario, H_{SE} was 3,680 sacks and H_{SA} was 43 sacks. Applying the moderate S scenario, H_{SE} was 1,526 sacks and H_{SA} was 3 sacks. No sustainable harvest was available under the high *S* scenario. No seed fishing is allowed in CSA 7 (see Methods and Table 4), and so simulations were carried out for sack fishing only. The low *S* regime estimate yielded an H_{SA} of 91,147 sacks, the moderate *S* regime estimate an H_{SA} of 133,339 sacks, and the high S regime estimate an H_{SA} of 41,095 sacks. Thus, for 2018/2019, CSA 1 provides the greatest sustainable harvest of seed oysters, whereas the greatest sustainable harvest of sack oysters is available in CSA 7.

TABLE 5.

Mean monthly water temperatures from Eugene Island, central coastal Louisiana. Data from https://www.currentresults.com/Oceans/Temperature/louisiana-alabama-average-water-temperature.php#c.

Month	Temperature (°C)
January	11
February	12
March	16
April	20
May	24
June	28
July	29
August	29
September	28
October	23
November	17
December	13

TABLE 6.

Monthly mean salinities for low-, moderate-, and high-salinity years, and annual mean salinities (from Melancon et al. 1998).

Month	Low salinity	Moderate salinity	High salinity
January	9.8	18.3	18.8
February	9.0	15.0	21.8
March	7.3	15.3	20.5
April	6.5	13.8	22.3
May	7.3	12.8	21.8
June	9.0	12.8	17.8
July	5.5	11.3	16.3
August	7.3	11.0	18.5
September	9.0	14.0	19.3
October	11.8	16.0	23.0
November	12.3	16.3	23.8
December	11.5	16.0	25.0
Annual mean	8.8	14.4	20.7

Total sustainable harvests projected for 2018/2019 under the NNCL definition of sustainability are presented as the sum of harvests from all CSAs for each *S* regime (Table 8). For low *S*, the H_{SE} was 11,477 sacks and H_{SA} was 120,986 sacks. For moderate *S*, H_{SE} was 8,581 sacks and H_{SA} was 170,616 sacks. For high *S*, H_{SE} was 6,377 sacks and H_{SA} was 50,355 sacks. Thus, the maximum H_{SE} was achieved at low *S*, whereas the maximum H_{SA} was achieved at moderate *S*. Seed harvests varied among *S* regimes by a factor of about 1.8, whereas comparable sack harvests varied by a factor of about 3.4. Regardless, the total projected sustainable landings are well below the historical mean (Fig. 2).

DISCUSSION

Harvests were projected for the 2018/2019 season under the NNCL definition of sustainability. Statewide, 62 of 84 reefs considered herein showed no sustainable harvest under any *S* regime. Stock sizes of seed and sack oysters in 2018 are at historic lows—well below long-term averages—and continue a declining trend apparent since 2000 (Fig. 2). Soniat et al. (2012) applied shell-budget modeling for a retrospective analysis of the POG of CSA 2. They determined the extent to which actual harvest exceeded sustainable (simulated) harvest. From 1999 to 2009, sustainable harvests of sack and/or seed oysters were exceeded in 2002 to 2005 and 2007 to 2008. The greatest estimated sustainable harvest in CSA 2 was 816,468 sacks of seed

TABLE 7.

Reef location, size (acres), and sustainable harvest estimates for the 2018/2019 season. Location of reefs by CSA/region of POG, and latitude/longitude. Public Oyster Grounds are in Mississippi Sound (MS), the Biloxi Marsh (BM), Breton Sound (BS), Hackberry Bay (HB), Barataria Bay (BB), Terrebonne Bay (TB), the Sister Lake (SI) area, Vermilion Bay (VB) and Lake Calcasieu (LC). Oyster density (O) is in numbers per m^2. Cultch mass (C) is in g per m^2. Harvest of seed and sack (market-sized) oysters is in sacks. The subscript A indicates initial conditions, whereas the subscript B indicates post-simulation conditions. Reefs that are "not fishable" as defined in the text are indicated. No initial oysters (no init. oysters), no initial substrate (no init. subst.), and no oysters or substrate (no resource) are indicated. Simulations can be sustainable with conditions, (Sust. w/cond.), in which fishing constraints are fulfilled before reaching the no-net-cultch (NNCL) loss standard or "solved", in which the NNCL standard is met. Salinity conditions (S) are low, moderate (mod.), or high as indicated in Table 6. CP, cultch plant; SP, shell plant.

Reef	Acreage	Latitude	Longitude	O_A	C_A	Status	O_B	C_B	H_{SE}	H_{SA}	S
CSA 1/MS											
Cabbage	1,804	30.15306	–89.22556	0.6	2,874	Not fishable	0.2	2,594	0	0	Low
						Not fishable	0.3	2,588	0	0	Mod.
						Not fishable	0.3	2,588	0	0	High
Grand Banks	1,066	30.14778	–89.36028	12.2	4,715	Not fishable	3.7	4,514	0	0	Low
						Not fishable	4.7	4,413	0	0	Mod.
						Not fishable	5.1	4,338	0	0	High
Grand Pass	1,804	30.14278	–89.23972	0	1,871	No init. oysters	0	1,684	0	0	Low
						No init. oysters	0	1,684	0	0	Mod.
						No init. oysters	0	1,684	0	0	High
Grassy	1,066	30.15	–89.46667	2	154	Sust. w/cond.	0	218	3,675	14,685	Low
						Solved	0	154	3,232	24,854	Mod.
						Sust. w/cond.	0.2	281	3,412	7,000	High
Halfmoon	1,066	30.11944	–89.43194	0.6	0	No init. subst.	0	9	512	3,693	Low
						No init. subst.	0	16	452	2,783	Mod.
						No init. subst.	0.2	17	305	547	High
Millenium	1,066	30.11278	–89.44611	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Petit	1,066	30.09806	–89.47889	0.4	0	No init. subst.	0	11	410	2,523	Low
						No init. subst.	0	4	451	3,366	Mod.
						No init. subst.	0.1	21	349	667	High
Round Island 2011 CP	291	30.11974	–89.45672	10.4	619	Sust. w/cond.	0.6	717	3,208	13,289	Low
						Sust. w/cond.	2.1	656	3,022	10,877	Mod.
						Sust. w/cond.	4.1	745	2,449	1,998	High
CSA 1/BM											
Holmes	1,592	29.93833	–89.20667	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Johnson Bayou	200	30.0875	–89.31083	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Martin	1,592	29.96	–89.20833	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Morgan Harbor	2,954	29.79583	–89.32861	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Drum Bay	1,596	29.88861	–89.29194	1.6	1,939	Not fishable	0.3	1,844	0	0	Low
						Not fishable	0.6	1,832	0	0	Mod.
						Not fishable	0.7	1,800	0	0	High
East Karako	1,020	30.02	–89.23389	0	2,052	No init. oysters	0	1,847	0	0	Low
						No init. oysters	0	1,847	0	0	Mod.
						No init. oysters	0	1,847	0	0	High
Three Mile	1,020	30.03917	–89.35278	0.4	345	Not fishable	0.1	325	0	0	Low
						Not fishable	0.2	314	0	0	Mod.
						Not fishable	0.2	313	0	0	High
Shell Point	47	30.02306	–89.35194	6.6	5,546	Solved	0.6	5,546	441	783	Low
						Solved	1.2	5,546	427	486	Mod.
						Solved	3.2	5,546	107	20	High

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TABLE 7.

continued

Reef	Acreage	Latitude	Longitude	O_A	C_A	Status	O_B	C_B	H_{SE}	H_{SA}	S
Turkey Bayou	1,804	30.10472	–89.29861	0	43	No init. oysters	0	30	0	0	Low
						No init. oysters	0	30	0	0	Mod.
						No init. oysters	0	30	0	0	High
West Karako	1,020	30.01194	–89.28306	0	1,076	No init. oysters	0	929	0	0	Low
						No init. oysters	0	929	0	0	Mod.
						No init. oysters	0	929	0	0	High
CSA 2/BS											
Lonesome 2009 CP	243	29.60803	–89.54012	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Battledore	271	29.46412	–89.42875	0	559	No init. oysters	0	502	0	0	Low
						No init. oysters	0	502	0	0	Mod.
						No init. oysters	0	502	0	0	High
Bay Crabe	511	29.55697	–89.57682	0	2	No init. oysters	0	1	0	0	Low
						No init. oysters	0	1	0	0	Mod.
						No init. oysters	0	1	0	0	High
Bay Gardene	632	29.58272	–89.64577	0	103	No init. oysters	0	82	0	0	Low
						No init. oysters	0	82	0	0	Mod.
						No init. oysters	0	82	0	0	High
Bay Long	923	29.50833	–89.59167	0	110	No init. oysters	0	99	0	0	Low
						No init. oysters	0	99	0	0	Mod.
						No init. oysters	0	99	0	0	High
Bayou Lost	275	29.60088	–89.61727	0	48	No init. oysters	0	42	0	0	Low
						No init. oysters	0	42	0	0	Mod.
						No init. oysters	0	42	0	0	High
Black Bay	716	29.59685	–89.5657	0	21	No init. oysters	0	19	0	0	Low
						No init. oysters	0	19	0	0	Mod.
						No init. oysters	0	19	0	0	High
California Bay	923	29.51112	–89.56667	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Curfew	715	29.53685	–89.53348	0	451	No init. oysters	0	400	0	0	Low
						No init. oysters	0	400	0	0	Mod.
						No init. oysters	0	400	0	0	High
East Bay Crabe	511	29.55665	–89.56982	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
East Bay Gardene	632	29.58167	–89.62195	0	129	No init. oysters	0	111	0	0	Low
						No init. oysters	0	111	0	0	Mod.
						No init. oysters	0	111	0	0	High
East Pelican	1,445	29.49952	–89.52645	0	101	No init. oysters	0	90	0	0	Low
						No init. oysters	0	90	0	0	Mod.
						No init. oysters	0	90	0	0	High
East Stone	829	29.58306	–89.51472	0	55	No init. oysters	0	50	0	0	Low
						No init. oysters	0	50	0	0	Mod.
						No init. oysters	0	50	0	0	High
Elephant Pass	202	29.54125	–89.5641	0	422	No init. oysters	0	380	0	0	Low
						No init. oysters	0	380	0	0	Mod.
						No init. oysters	0	380	0	0	High
Horseshoe	829	29.60261	–89.49386	0	152	No init. oysters	0	137	0	0	Low
						No init. oysters	0	137	0	0	Mod.
						No init. oysters	0	137	0	0	High
Jessie	275	29.63502	–89.6182	0	473	No init. oysters	0	426	0	0	Low
						No init. oysters	0	426	0	0	Mod.
						No init. oysters	0	426	0	0	High
Lonesome	715	29.61355	–89.5568	0	23	No init. oysters	0	18	0	0	Low
						No init. oysters	0	18	0	0	Mod.
						No init. oysters	0	18	0	0	High

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TABLE 7.

continued

Reef	Acreage	Latitude	Longitude	O_A	C_A	Status	O_B	C_B	H_{SE}	H_{SA}	S
Mangrove Point	1,445	29.479	–89.54004	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
North Black Bay	829	29.61278	–89.50902	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
North California Bay	715	29.5279	–89.54102	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
North Lake Fortuna	1,727	29.6794	–89.48487	0	97	No init. oysters	0	87	0	0	Low
						No init. oysters	0	87	0	0	Mod.
						No init. oysters	0	87	0	0	High
South Black Bay	715	29.56033	–89.53443	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
South Lake Fortuna	1,727	29.6502	–89.50435	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Snake	716	29.63397	–89.56423	0	9	No init. oysters	0	8	0	0	Low
						No init. oysters	0	8	0	0	Mod.
						No init. oysters	0	8	0	0	High
Stone	715	29.57612	–89.54145	0	372	No init. oysters	0	324	0	0	Low
						No init. oysters	0	324	0	0	Mod.
						No init. oysters	0	324	0	0	High
Sunrise Point	923	29.49475	–89.56655	0	4	No init. oysters	0	4	0	0	Low
						No init. oysters	0	4	0	0	Mod.
						No init. oysters	0	4	0	0	High
Telegraph	715	29.516	–89.53232	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
West Bay Crabe	511	29.56522	–89.5866	0	20	No init. oysters	0	15	0	0	Low
						No init. oysters	0	15	0	0	Mod.
						No init. Oysters	0	15	0	0	High
West Pelican	923	29.50695	–89.54583	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Wreck	4,486	29.56472	–89.48306	0	341	No init. oysters	0	305	0	0	Low
						No init. oysters	0	305	0	0	Mod.
						No init. oysters	0	305	0	0	High
CSA 3/HB											
BB 2004 CP	40	29.33028	–89.94	0.2	1,760	Not fishable	0	1,756	0	0	Low
						Not fishable	0	1,757	0	0	Mod.
						Not fishable	0.1	1,745	0	0	High
North Hackberry 2004 SP	10	29.41722	–90.0325	0	76	No init. oysters	0	68	0	0	Low
						No init. oysters	0	68	0	0	Mod.
						No init. oysters	0	68	0	0	High
South Hackberry 2004 SP	25	29.38833	–90.0525	0	1,074	No init. oysters	0	1,017	0	0	Low
						No init. oysters	0	1,017	0	0	Mod.
						No init. oysters	0	1,017	0	0	High
Hackberry 2008 CP	50	29.42528	–90.01528	1.2	1,435	Solved	0.1	1,435	41	50	Low
						Solved	0.2	1,435	33	41	Mod.
						Not fishable	0.6	1,412	0	0	High
Hackberry 2012 CP	200	29.42007	–90.052	1.2	2,056	Not fishable	0.1	2,039	0	0	Low
						Solved	0	2,056	4	7	Mod.
						Not fishable	0.4	2,007	0	0	High
Hackberry 2014 CP	30	29.42098	–90.0231	6.2	3,229	Solved	0.3	3,229	378	816	Low
						Solved	1.4	3,229	302	750	Mod.
						Solved	2.5	3,229	360	168	High

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TABLE 7.

continued

Reef	Acreage	Latitude	Longitude	O_A	C_A	Status	O_B	C_B	H_{SE}	H_{SA}	S
Lower Hackberry	5	29.38822	–90.05253	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Middle Hackberry	5	29.40169	–90.02917	1.8	600	Sust. w/Cond.	0	651	40	114	Low
						Solved	0	600	21	193	Mod.
						Sust. w/Cond.	0.1	754	38	60	High
Upper Hackberry	5	29.42164	–90.03069	1.8	151	Sust. w/Cond.	0	180	14	59	Low
						Sust. w/Cond.	0.1	158	14	66	Mod.
						Sust. w/Cond.	0.6	214	11	14	High
CSA 4/TB											
Lake Felicity	40	29.315	-90.44444	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
CSA 5/SI											
Grand Pass	107	29.25861	–90.93333	1.6	1,087	Not fishable	0.2	1,062	0	0	Low
						Not fishable	0.4	1,061	0	0	Mod.
						Not fishable	0.7	1,006	0	0	High
Junop Bayou De West	34	29.23583	–91.06167	0.2	664	Not fishable	0	607	0	0	Low
						Not fishable	0.1	600	0	0	Mod.
						Not fishable	0.1	599	0	0	High
Mid SI	56	29.235	–90.9275	0	142	No init. oysters	0	129	0	0	Low
						No init. oysters	0	129	0	0	Mod.
						No init. oysters	0	129	0	0	High
Old Camp	140	29.21583	–90.94667	0	729	No init. oysters	0	656	0	0	Low
						No init. oysters	0	656	0	0	Mod.
						No init. Oysters	0	656	0	0	High
Rat Bayou	34	29.21667	–91.04833	0.2	134	Not fishable	0	130	0	0	Low
						Not fishable	0.1	123	0	0	Mod.
						Not fishable	0.1	122	0	0	High
South SI 1994 SP	513	29.22472	–90.90889	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
SI 2004 CP	82	29.225	–90.91444	1.2	1,641	Not fishable	0.3	1,584	0	0	Low
						Not fishable	0.6	1,556	0	0	Mod.
						Not fishable	0.6	1,553	0	0	High
CSA 6/VB											
Bayou Blanc	15	29.51333	–91.75833	3.4	4,267	Not fishable	0.8	3,825	0	0	Low
						Not fishable	1.9	3,719	0	0	Mod.
						Not fishable	1.9	3,708	0	0	High
Big Charles	15	29.61417	–91.98694	2	2,543	Not fishable	0.3	2,399	0	0	Low
						Not fishable	0.5	2,375	0	0	Mod.
						Not fishable	1.1	2,308	0	0	High
Dry	10	29.68639	–91.90194	0	851	No init. oysters	0	748	0	0	Low
						No init. oysters	0	748	0	0	Mod.
						No init. oysters	0	748	0	0	High
Highspot	250	29.49197	–91.75785	4.6	2,218	Solved	0.7	2,218	411	3	Low
						Not fishable	1.7	2,147	0	0	Mod.
						Not fishable	2.6	2,046	0	0	High
Indian Point	100	29.61889	–92.00889	1.6	3,186	Not fishable	0.2	2,976	0	0	Low
						Not fishable	0.2	2,967	0	0	Mod.
						Not fishable	0.9	2,898	0	0	High
Lighthouse Point	30	29.57972	–92.03444	3.6	3,466	Not fishable	0.5	3,329	0	0	Low
						Not fishable	0.8	3,306	0	0	Mod.
						Not fishable	1.9	3,179	0	0	High

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TABLE 7.

continued

Reef	Acreage	Latitude	Longitude	O_A	C_A	Status	O_B	C_B	H_{SE}	H_{SA}	S
Middle	20	29.45278	–91.72389	2.2	326	Solved	0.2	326	123	2	Low
						Solved	0.9	326	42	0	Mod.
						Not fishable	1.3	315	0	0	High
North	10	29.47917	–91.80778	2.4	1,308	Not fishable	0.5	1,260	0	0	Low
						Not fishable	1.2	1,194	0	0	Mod.
						Not fishable	1.4	1,164	0	0	High
Nickle	100	29.41939	–91.70775	13	3,062	Solved	1.7	3,062	3,146	38	Low
						Solved	4.4	3,062	1,484	3	Mod.
						Not fishable	7	2,993	0	0	High
Rabbit	15	29.51111	–91.5975	0	2,360	No init. oysters	0	1,962	0	0	Low
						No init. oysters	0	1,962	0	0	Mod.
						No init. oysters	0	1,962	0	0	High
Sally Shoals	5	29.65444	–91.87111	0	2,059	No init. oysters	0	1,583	0	0	Low
						No init. oysters	0	1,583	0	0	Mod.
						No init. oysters	0	1,583	0	0	High
CSA 7/LC											
Calcasieu 2009 CP	295	29.84333	–93.31861	0.2	1,474	Not fishable	0	1,473	0	0	Low
						Not fishable	0	1,473	0	0	Mod.
						Not fishable	0.1	1,462	0	0	High
Nine Mile	527	29.885	–93.32694	0	0	No resources	0	0	0	0	Low
						No resources	0	0	0	0	Mod.
						No resources	0	0	0	0	High
Big Washout	295	29.85667	–93.33833	1.2	1,532	Not fishable	0.1	1,477	0	0	Low
						Not fishable	0	1,498	0	0	Mod.
						Not fishable	0.3	1,454	0	0	High
Chenier	10	29.84945	–93.28372	17	4,137	Sust. w/cond.	0.1	4,485	0	1,078	Low
						Sust. w/cond.	1.2	4,377	0	1,158	Mod.
						Sust. w/cond.	5.6	4,795	0	291	High
Lamberts	240	29.84121	–93.27682	2.6	914	Sust. w/cond.	0	974	0	5,808	Low
						Solved	0	914	0	8,546	Mod.
						Sust. w/Cond.	0.3	1,083	0	2,802	High
Little Washout	295	29.85028	–93.34083	2.8	826	Solved	0.2	826	0	4,074	Low
						Solved	0.3	826	0	3,555	Mod.
						Sust. w/cond.	1.2	829	0	661	High
Mid Lake	295	29.85417	–93.32889	1	932	Not fishable	0.1	932	0	0	Low
						Solved	0	932	0	644	Mod.
						Not fishable	0.2	921	0	0	High
Northeast Rabbit Island	366	29.85694	–93.38222	1.4	1,378	Not fishable	0.1	1,359	0	0	Low
						Solved	0.1	1,378	0	781	Mod.
						Not fishable	0.3	1,329	0	0	High
Northwest Rabbit Island	755	29.85935	–93.39211	1.6	345	Sust. w/cond.	0	453	0	14,029	Low
						Sust. w/cond.	0	350	0	23,988	Mod.
						Sust. w/cond.	0.1	536	0	7,593	High
Southeast Rabbit Island	366	29.84306	–93.37556	0.2	718	Not fishable	0	660	0	0	Low
						Not fishable	0	660	0	0	Mod.
						Not fishable	0.1	649	0	0	High
West Cove Transplant	366	29.8475	–93.36972	0	902	No init. oysters	0	809	0	0	Low
						No init. oysters	0	809	0	0	Mod.
						No init. oysters	0	809	0	0	High
West Rabbit Island	755	29.84694	–93.395	7.2	1,800	Sust. w/cond.	0	1,908	0	47,857	Low
						Solved	0.3	1,800	0	63,158	Mod.
						Sust. w/cond.	1.6	2,150	0	20,035	High
West Cove Central	755	29.85549	–93.40901	3	405	Sust. w/cond.	0	535	0	18,301	Low
						Solved	0	405	0	31,509	Mod.
						Sust. w/cond.	0.1	648	0	9,713	High

TABLE 8.

Sustainable harvests of seed (H_{SE}) and sack oysters (H_{SA}) in sacks, by CSA and low-, moderate-, and high-salinity regime (*S*), as defined in Table 6. Reefs without initial substrate (Table 7) are not included. Statewide sums (total) are given by salinity regime.

CSA	H_{SE}	H_{SA}	*S*
1	7,324	28,757	Low
	6,681	36,217	Mod.
	5,968	9,018	High
2	0	0	Low
	0	0	Mod.
	0	0	High
3	473	1,039	Low
	374	1,057	Mod.
	409	242	High
4	0	0	Low
	0	0	Mod.
	0	0	High
5	0	0	Low
	0	0	Mod.
	0	0	High
6	3,680	43	Low
	1,526	3	Mod.
	0	0	High
7	0	91,147	Low
	0	133339	Mod.
	0	41,095	High
Total	11,477	120986	Low
	8,581	170616	Mod.
	6,377	50,355	High

oysters (in 2000) and 3065,531 sacks of sack oysters (in 2001). This contrasts with an estimated maximum sustainable harvest of 11,477 sacks of seed and 170,616 sacks of sack oysters for the entire state of Louisiana in 2018 (Table 8). The lack of fishable reefs, low stock abundances, and diminishing harvests (sustainable or otherwise) indicate a decline in the common-pool resource of the state POG.

The cause or causes of the "Tragedy of the Commons" of POG are the subject of considerable debate and speculation among oyster growers, agency biologists, academicians, and members of nongovernment organizations (see Mann & Powell 2007). Ultimately, reefs are sustained by recruitment, without which they inevitably decline. Without recruitment, no other trajectory other than reef degradation is possible—both *in situ* and, in the present formulation, *in silico*. Sustainable reefs produce and recruit larvae, provide refuge for newly settled spat, and support survival and growth to adult size. Natural (non-fishing) mortality of large adult oysters provides the bulk of the carbonate essential to maintain shell balance or reef accretion (Powell & Klinck 2007, Mann et al. 2009, Southworth et al. 2010). Thus, a sufficient number of oysters must grow to adult size and their shells remain in place to support reef persistence. Recruits in the present model are young-of-the-year oysters, as determined by the annual stock assessment. The sustainable oyster fishing model determines sustainable harvest, given the initial stock abundance and size distribution. Implicit in the application of the model is the notion that quality reefs support reproduction, larval set, and spat survival. Soniat (2017) explored the relationship between cultch density and oyster density and found that essentially all of the harvest from Louisiana POG in the 2016/2017 oyster season was from reefs with ≥1,000 g/m^2 of cultch and ≥25 oysters/m^2. This cultch value is considerably below an analogous division by Mann et al. (2009) for the James River and by Southworth et al. (2010) for the Great Wicomico, both Chesapeake Bay, which suggests that either a division at 1,000 g/m^2 does not identify the most productive reefs or that recruitment potential per gram carbonate is higher for the Louisiana reefs in comparison with those in the Chesapeake Bay. The latter is more likely (Powell et al. 2012). The establishment of reef cultch and oyster abundance reference points is the subject of continued study (Powell et al. 2018). Nonetheless, the present model permits shell gain by constraining fishing by area, type (sack versus seed), effort, and season (Tables 3, 4 and 7).

The history of management of federal fisheries might focus on the period before and after adoption of statutory reference points related to maximum sustainable yield (Restrepo et al. 1998). Many federally managed stocks have been rebuilt over the last 20 y (Rosenberg et al. 2006, NOAA 2017). By contrast, although much attention has been given to management of the East and Gulf coast oyster fisheries (Jordan & Coakley 2004, Mann & Powell 2007, Vanderkooy 2011), with the exception of the New Jersey fishery in Delaware Bay (Powell et al. 2018), none has performed sustainably or been rebuilt to sustainability over this time frame. The lamentable status of the Louisiana public grounds unfortunately is not unusual (Hargis & Haven, 1994, Rothschild et al. 1994, Zu Ermgassen et al. 2012, Camp et al. 2015, Pine et al. 2015). Although proximate reasons may be manifold, they certainly include three. (1) Climate change likely has reduced the productivity of the oyster in the Gulf of Mexico (Powell 2017), a reduction that imperils time-honored approaches to management that have not proved sufficiently responsive to challenge. (2) Overfishing has occurred chronically, abetted by the absence of a modern reference point system to judge the status of the stock (Powell et al. 2018), an issue to which the model used in this contribution was designed to address. (3) The seed fishery is extremely destructive in that it removes both live animals and cultch, the latter in disproportionate measure without, in most cases, sufficient production of carbonate for repayment (Soniat et al. 2012).

For the Ancients, comedy was not funny—or at least it need not be. Instead, comedy was a chronicle of events for which a happy ending is possible. By contrast, tragedy was a narrative for which a disastrous conclusion is inevitable. Hardin (1968) gives conditions under which tragic outcomes are averted ("mutual coercion mutually agreed upon"); thus, the term tragedy is used therein in the modern sense to indicate a disastrous, yet avoidable consequence. For the oyster industry, sustainable harvest quotas and cultch removal rates derived from shell-budget-based modeling and applied through effective management make happy endings possible. Thus, whereas the chronicle of the use of public oyster resources is tragedy in the modern sense, oyster resource management is comedy in its ancient meaning.

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