Decadal Changes in Oyster Reefs in the Big Bend of Florida's Gulf Coast.

Authors:

J. R. Seavey 1, W. E. Pine, III 1, P. Frederick 1, and L. Sturmer 2 and M. Berrigan 3

1 Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL 32611, USA

2 Shellfish Aquaculture Extension Program, University of Florida, Cedar Key Marine Field Station, Cedar Key, FL 32625, USA

3 Bureau of Aquaculture Development, Florida Department of Agricultural and Consumer Services, Tallahassee, FL 32301, USA

t E-mail:jseavey@ufl.edu
Abstract. Oyster reefs are among the world's most endangered marine habitats with an estimated 85% loss from historical levels worldwide. Because of diverse ecological and social services to people and natural environments, and their sensitivity to impairment from natural and human-induced disasters, understanding the resilience of oyster reef communities to disturbance is key to developing effective conservation and restoration plans. Florida’s Big Bend coastline (Gulf of Mexico coast from Crystal River to Apalachee Bay) supports large expanses of oyster reef habitat that have existed for thousands of years in a region that is generally one of the most pristine coastal zones in the continental US. We assessed trends in oyster habitat along the Big Bend region between 1982 and 2011, by examining changes in areal extent and distance of oyster bars from shore. During our study period, we found a 66% net loss of oyster bar area (124.05 ha) with losses concentrated on offshore (88%), followed by nearshore (61%), and inshore bars (50%). Marsh-oyster bars area were more resilient during this time than sand-oyster bars (32% and 74% loss respectively). We also found that all oyster bars were generally moving inland. This rapid loss is very likely to be a departure from historical norms, and stems from multiple factors. Several lines of evidence suggest that the primary mechanism is reduced survival and recruitment as a result of decreased freshwater inputs, acting to make existing bars vulnerable to wave action and sea level rise. Once bar substrate becomes unconsolidated, the breakdown of the bar may not be reversible through natural processes. To test these predictions, we recommend restoration-based experiments to elicit the mechanisms in order to foster long-term sustainability of these critical estuarine habitats.

Key words: Crassostrea virginica; climate change; coastal conservation; Eastern Oyster; Florida; freshwater flow
INTRODUCTION

Oyster reefs are among the world's most endangered marine habitats with an estimated 85% decline worldwide (Beck et al. 2011). This loss is alarming as oyster habitat is a critical component of coastal estuaries (NOAA 2005), serving a wide array of important economic, cultural, and ecological roles (Coen et al. 2007). Vital services attributed to oyster reefs include habitat creation for numerous species (Eggleston et al. 1999), especially economically high value finfish (ASMFC 2007); coastal land protection (Borsje et al. 2011); water quality enhancement (Coen et al. 2007); carbon sequestration (Coen et al. 2007) and a multimillion dollar fishery (Coen et al. 2007, NMFS 2011). The world's largest wild oyster fishery, estimated to be larger than all other global harvests combined, is currently located in the U.S. Gulf of Mexico (Gulf; Beck et al. 2011). As of 2010, the Gulf provides over 50% of the U.S. commercial oyster harvests (Beck et al. 2011), with Florida supporting about 10% of this total (Becnel 2010).

While oyster resources in the Gulf currently support large fisheries and critical ecosystem services, oysters in this region have declined from their historic levels (Kirby 2004, Beck et al. 2011). Documented threats to the Eastern oyster (*Crassostrea virginiana*) throughout their range include overharvest (Jackson et al. 2001, Carranza et al. 2009); development and pollution (Jackson et al. 2001, Mearns et al. 2007); reductions in freshwater input to estuaries (Bergquist et al. 2006, Buzan et al. 2009); erosion from boat wakes and storm events (Goodbred and Hine 1995, Wall et al. 2005); disease (Carranza et al. 2009); oil spills (Hulathduwa and Brown 2006, Mearns et al. 2007); and global change related trends (Wright et al. 2005, Levinton et al. 2011). The Gulf is particularly vulnerable to anthropogenic oil spills due to a heavy concentration of oil production and refining in the region (Cappiello 2011) and this threat is only likely to increase
with oil demand. The Gulf is also among the most vulnerable regions in the U.S. to severe storm events and sea level rise (Ning and Abdollahi 2003). Thus, the world’s remaining oyster reef communities are concentrated in a region particularly vulnerable to disturbance from anthropogenic activity and to global change. Understanding the resilience of oyster reef communities in the Gulf to these and other threats is thus important for developing effective conservation, management, and restoration plans for this species and this globally significant habitat.

The management of oyster habitat in the Gulf and the South Atlantic region has largely concentrated either on enhanced production through seeding and addition of settlement substrate (cultch), or the management and mitigation of anthropogenic threats such as boat wakes, water management and pollution (Coen et al. 2007). Emerging threats such as sea level rise, increasing storm intensity, and changes to ocean chemistry are much less understood partly because these "treatments" occur at very broad spatial scales and partly because oyster community response to these stressors may be locally confounded with other stressors such as dredging or overharvest. Detection of these broad scale and possibly dominant effects therefore requires either that local anthropogenic effects be statistically known or better, nonexistent.

Within the Gulf, Florida’s Big Bend coastline (Crystal River to Apalachee Bay) supports large expanses (at least 25 km) of oyster reef habitat that have existed for thousands of years (Grinnell 1972, Hine et al. 1988, Wright et al. 2005). Unlike much of the rest of the Gulf coastline, the Big Bend is largely undeveloped with 30% of the land area and over 60 miles of coastline in the Big Bend under conservation protection (Main and Allen 2007). Human population density, impervious surface area, and road density in the Big Bend are among the lowest in Florida and the percent of intact natural land cover is relatively high (Geselbracht
In part due to low development status, the coastal habitat in this region has not been heavily impacted from boat traffic, dredging operations, industrial or residential pollution, eutrophication, and other anthropogenic threats. Despite this comparatively pristine environment, declines in oyster resources have been suspected since the 1970’s according to local watermen. An earlier assessment of oyster resources in the Suwannee River Sound suggested that offshore bars declined between 1972 and 2001 (Bergquist et al. 2006). However, the spatial and temporal extent of this decline is unknown, as are possible mechanisms.

To assess trends of oyster habitat in the Big Bend region of Florida, we compared aerial photographs from five time periods between 1982 and 2011. From these data we built maps of the spatial extant and relative condition of oyster resources across this 29-year period. We supplemented our inferences from the imagery with snapshot field surveys during this same time period and extensive ground surveys during 2011 to provide estimates of change in spatial extent of oyster reefs, type of oyster reef, and population structure (proportion live/dead, density, size structure). We conclude with recommendations for prioritizing research and conservation of oyster resources in this unique region of the Gulf.

METHODS

Study Area

Our study area along Florida's Big Bend, stretched from Cedar Key FL to Horseshoe Beach, FL (Fig. 1). This area has been described as "a siliciclastic, sand-starved, low-wave-energy system dominated by marshes that face the open sea” (Hine et al. 1988). Irregular limestone bedrock topography and ancient sand dunes create unique geology in this region (Hine et al. 1988). The Suwannee River delta is located in the northern half of our study area and
provides the majority of surficial fresh water inputs into this coastline supplemented by numerous springs and seeps (Wright et al. 2005). Coastal shoreline vegetation communities are dominated by *Juncus* and *Spartina* salt marsh that include many tidal inlets and embayments. Oyster reefs along this coastline are largely intertidal.

**Study Design**

We divided the study area into four focal areas of interest based on proximity to the Suwannee River estuary (Fig. 1). This design allowed for variance in freshwater input with sites closer receiving more stable freshwater inflow compared to sites further from the river mouth.

**Data Collection**

Aerial photographs (resolution = 0.3 m) from 1982 (February 18), 1995 (January 28), and 2001 (November 11) were obtained from the Florida Department of Transportation, Survey and Mapping Office (LABINS 2011). The exact tide height for each year's aerial photography is unknown, but based on comparing known, permanent ground locations the 2001 photo appears to been taken at a higher tide level compared to other photos. Due to this tide level, oyster bar estimates for 2001 are likely more conservative compared to the actual number of bars. We captured digital orthoimaginary for 2010 on February 26, during low (-0.15 m) tide at a 0.3 m resolution (Aerial Cartographics of American Inc., Orlando, FL). To help interpret aerial imagery, we used ground photographs from 1995 through 2010 taken within our focal areas.

From June 2010 to March 2011, we also conducted intensive ground-based surveys of specific bars within each of the four focal areas to document reef condition. We did not sample the Suwannee Reef because no intertidal oysters were found at this location in initial ground
surveys. At each of the remaining focal areas (Horseshoe Cover, Lone Cabbage, and Corrigan’s reef), we sampled nine oyster bars (three each at inshore, nearshore, and offshore locations). At each bar, we established a permanent, 0.15-m wide transect oriented to include maximum change in elevation across the bar. We counted all live oysters within the belt transect and counted live/dead ratios within a $\frac{1}{4}$ m$^2$ quadrat placed at random distances along and away from the transect. We recorded this information during surveys at extreme low tides in June, July, August, October, and December 2010.

To examine the hypothesis that low freshwater discharge from the Suwannee River negatively affected oyster populations through periods of increased salinity (Bergquist et al. 2006), we examined Suwannee River discharge information from 1942 to 2009 (USGS 2011, USGS Station # 02323500). We also examined the relationship between discharge volume and rainfall on an annual basis using a basin-wide averaged rainfall data provided by the Suwannee River Water Management District (Lake City, FL).

Analysis

Aerial photographs were georeferenced and intertidal oyster bars were hand digitized at a 1:3,000 m scale with a 10-m$^2$ minimum mapping unit into three categories: marsh-oyster, sand-oyster and unresolved (Fig. 2). Marsh-oyster was characterized by fine sediment with a surface visibly dominated by *Spartina alterniflora* and oysters occurring as individuals and clumps. Sand-oyster bars were composed primarily of coarse sand and shell fragment matrix interspersed with oysters of varying densities, and having little or no vegetation and a lighter colored appearance on aerial photos than the marsh-oyster type. The shortest distance from the mainland shoreline to the closest edge of each bar was calculated based on the 2004 Florida Fish
and Wildlife Research Institute's Florida Shoreline Map (FGDL 2011). We assigned each bar to one of three distance-to-shore categories (inshore, nearshore, offshore) using the Jenks Optimization method in ArcMap 10 (ERSI 2010), which classifies data such that variance within classes is reduced and variance between classes is maximized. We also recorded area, sample year, and bar type for each of the bars sampled.

RESULTS

Net change in area of oyster habitat

Ground truthing of the 2010 digitized map was based on 20 on-the-ground photos and our 36 field survey sites and showed 100% correct match between these known bars and our digitized maps in identifying both oyster bars and classifying bar type. Georeferencing aerial photographs produced horizontal errors between 5.5 to 12.9 m between sample years at any given bar, which is 15 to 30% of the average bar size. To avoid bias, we ignored changes less than 0.017 ha in our analysis.

We digitized 3,800 oyster bars total across all sampling years with an average area of 0.19 ha (SD = 0.58) and mean distance from the mainland of 351 m (SD= 586). Offshore bars averaged 1837.56 m (SD=816.40), nearshore bars averaged 490.42 m (SD=350.74), and inshore bars averages 86.84 m (SD=129.32) from the shoreline. Across focal areas and years, Corrigan's Reef had the highest oyster bar density (0.17 bar/ha), followed by Lone Cabbage (0.13 bar/ha), Horseshoe Cove (0.08 bar/ha), and Suwannee Reef (0.01 bar/ha). Though we expected to see more oyster bar area in 2001 compared other years due to the high tide level in the imagery, all sites—except Horseshoe Cove—showed a declining trend in total oyster habitat from 1982 thru
2001, followed by an apparent increase for in 2010 (Fig. 3). This apparent increase in the last decade of the study was an artifact driven by a conversion of high-relief bars with high oyster densities to bars with low-relief dominated by sand and dead shell. Thus, the apparent spreading of these bars was actually a final stage of oyster reef loss which we refer to as "collapse" (Fig. 4). Based on tracking individual bars, we identified a 66% net loss of oyster bar area from 1982 to 2010 (Table 1). Loss of bar area among focal areas varied between 49% to 100%, with 30% to 100% of that loss due to collapse.

Dynamics of change in oyster habitat

Offshore bars lost the most area (88%), followed by nearshore (61%) and inshore (50%) (Table 1). Further, bar collapse was more common offshore (100% of bars) compared to nearshore and inshore bars (37%). Across the 28 years of our data, offshore areas were the most susceptible to loss - Suwannee lost 100% of offshore bars, Lone Cabbage lost 77%, Corrigan's Reef lost 43%, and Horseshoe Cove offshore bars increased by 30% (Fig. 5). This decline in offshore oysters was also observed in our field surveys and ground photos (Fig. 4). During 2010, we found the highest oyster densities at inshore sites (about 40-50 oysters/m² and lowest (and most variable) at offshore sites (generally 3-30 oysters/m²) across all focal areas. Proportion of oysters that were alive was generally >50% across all focal areas and sites, with the highest proportion of live oysters generally found in inshore areas (upwards of 80%) and lowest proportion found offshore (~40-50%). Near and inshore bars also decreased over the 28 years examined, though we found modest increases among marsh-oyster bars in 2010 described below.

Oyster bar types were not evenly distributed or impacted across the study area over time. Marsh-oysters composed 38% of inshore bars, 21% of nearshore bars, and none of the offshore
bars. Sand-oysters were 61% of inshore bars, 79% of nearshore, and 100% of offshore bars. Because most sand-oyster bars were offshore, the loss of offshore bars contributed much to the loss of sand-oysters over all. We found that between 1982 and 2010, 74% of sand-oyster bar area was lost, followed by unresolved bars (56%) and marsh-oyster bars (32%) (Table 1). Sand-oyster bar count decreased by 10-16% over each time step 1982 to 2001 and didn't change in 2001 to 2010. Total sand-oyster bar area in 1982 was 112.16 ha, followed by 87.61 ha in 1995, 44.81 ha in 2001, and 142.60 ha in 2010. Between 1982 and 2001, the number of marsh-oyster bars was relatively steady between 262 to 303 bars, then increased 37% in 2010. Marsh-oyster bar area slowly increased from 16.05 ha in 1982 to 36.95 ha in 1995, 25.54 ha in 2001, and 56.40 ha in 2010. However, marsh-oyster habitat type remained a relatively small proportion of the total oyster bar area throughout the study.

**Inland movement**

The distance from the mainland decreased for all bar types over time. Over the entire study period, sand-oyster bars were generally further from shore (average = 489m, SD = 678.3) compared to marsh-oysters (average = 134.1m, SD = 225.2). From 1982 to 2010, the mean distance from shore to sand-oyster bars decreased from 601.7m (SD = 802.3) to 403.9m (SD = 557.8). Off-shore bars did not show any decrease in distance because they were nearly all lost and did not have new habitat to colonize. Distance from shore to marsh-oyster bars showed decreased an average of 60 m over time (1982:162.0m (SD=303.4), 1995: 165.2 (SD=246.2), 2001: 117.7 (SD=187.1), 2010: 108.6m (SD=159.8 ). A Kruskal-Wallis rank sum test found significant differences in the marsh-sand bar distance over time (K-W chi-squared: 9.76, df=3, p-value= 0.02).
Changes in Suwannee River Discharge

We examined discharge volume for the Suwannee River collected from 1957 to 2008 and rainfall data collected from 1941 to 2008. The relationship between annual discharge volume and annual basin-wide rainfall was not constant, with a significantly lower annual yield ratio (annual discharge/annual total rainfall, all stations) during the period 1995 to 2008 ($x = 1.991$, s.d. = 0.81, $n = 14$) than in the previous 38 yr ($x = 2.77$ cu m/cm rainfall, s.d. = 0.65, $n = 38$; log-transformed data, $t = 4.02$, $df = 50$, $p < 0.0001$, Fig. 6). Average annual rainfall was not statistically significantly different during these two periods ($t = 0.17$, $p > 0.50$). We also found that low discharge events (<1 s.d. below period of record monthly mean lows) were significantly more common during the period 1995 to 2008 (4.23 months/yr) than during the previous 55 years (0.42 months/yr, Chi squared = 135.5, $p << 0.0001$, Fig. 7)

DISCUSSION

Overall, we found a decrease of 124 ha of oyster habitat between 1982 and 2010 in the Big Bend of Florida, with a monotonic, nonreversing decline over time. This decrease was not trivial, as it represents a net 66% decline of oyster reef habitat. The pattern of loss was highly nonrandom, with offshore and sand-oyster bars experiencing the greatest decline, and a decreased loss closer to shore. At inshore bars, marsh-oyster bars increased over this time period (mostly due to new bars forming), but this expansion was not sufficient to offsetting the losses offshore and sand-oyster bars. We consider the loss of offshore sand-oyster bars ecologically very significant for a number of reasons. First, these bars have existed since 2,800 to 4,000 years before present (Grinnell 1972, Wright et al. 2005), suggesting that something fundamental has changed to induce such a sudden (30-40yrs) decline. Second, these offshore bars were
functionally important as fringing reefs, reducing wave action in nearshore and inshore areas during storms (Grinnell 1972, Coen et al. 2007), and acting as a linear, coastwise dam for entrainment both of sediment and freshwater behind them (Grinnell 1972, Wright et al. 2005).

Third, according to local watermen, in recent history these bars were the most productive for local fisheries, producing high densities of large-sized oysters compared to bars closer to shore. Understanding the mechanisms behind this rapid loss is therefore of importance to the management of these resources and as a guide to restoration actions.

**What factors are likely driving changes in oyster resources in the Big Bend?**

Although eastern oyster populations can tolerate a wide range of salinities for short periods, they are vulnerable both to high and low salinity levels (White and Wilson 1996). Bergquist et al. (2006) suggested that droughts and associated increases in salinity might be important in explaining losses of reefs in Suwannee Sound. We suspect that the increased variability in freshwater input as represented in the discharge and rainfall data from the Suwannee River may have impacted the oysters in our study area over the last 28 yr as salinity is known to influence recruitment survival and disease resistance in Eastern oyster populations (White and Wilson 1996).

In the non-embayed, shallow, highly karstic region we studied, salinities can be strongly affected by several factors including freshwater inputs, complex local currents, and local offshore springs. Although there are a number of salinity monitoring stations along the coast, these are generally spatially distinct, often offshore, and have short duration of time history. In the absence of direct measurement of salinities, freshwater inputs are probably the best proxy for inferring salinity dynamics. The Suwannee River is the major source of freshwater in this region,
historically producing the largest pulses of freshwater during spring months and during tropical storm activity in late summer. The period of greatest declines in oyster habitat during the study period coincided with a more than nine-fold increase in the incidence of low-flow events in the Suwannee, and a significant negative change in the relationship between discharge and rainfall. Since annual rainfall has not changed significantly during the period of study, these characteristics suggest that usage or retention of freshwater for human uses is the main driver of the reduced discharge of the Suwannee.

We consider the coincidence of sharply reduced freshwater discharge and declines in oyster habitat to be suggestive of a possible relationship, but not diagnostic. However, two other observations lean support to existence of a mechanistic relationship. First, we saw a dramatic difference both in total area and in robustness and densities of oysters between inshore and offshore habitat. Although river discharge is the dominant parameter in freshwater inputs, the region is quite karstic and a significant amount of freshwater inputs may come from seepage and overland flow from extensive coastal and inland wetlands (Raabe and Bialkowska-Jelinska 2007). This more diffuse freshwater has a very short plume from the land’s edge, and a relatively weak zone of influence. Seepage and overland flow therefore, probably buffer inshore bars from salinity changes more than offshore bars. Second, it is known that springs of varying sizes exist in the coastal zone (Raabe and Bialkowska-Jelinska 2007, 2010). One of these springs is within 2 km of the Corrigan’s reef complex, which has survived surprisingly well considering its distance from the Suwannee River mouth. These three features (temporal coincidence of declines in oyster habitat with reduced discharge, resilience of inshore bars, and resilience of bars close to a spring) are consistent with the idea that persistence of oyster communities in this region are driven by pulsed access to freshwater.
We propose that extended periods of high salinity are likely to have stressed oyster populations, particularly on offshore bars, to the extent that the physical structure of bars was affected by both mortality of older oysters, and the loss of significant recruitment. Once the structure of bars was weakened, bars became less resilient to wave action, particularly during storm events. Since most of the bars in our study area are built on riverine sediments (Wright et al. 2005), the breakup of oyster structure would likely trigger a spreading of sediment, and loss of vertical profile. Once this chain of events occurs, an offshore bar would be difficult to re-establish since there little appropriate substrate remains for spat to recruit to and survive. Our incidental observations during 2010 indicate that spat do often arrive on offshore bars in high densities, but that they do not survive in the shifting sediments, which also offer no refuge from predators.

In addition, sea-level rose 5cm in our study during the last 28 yr (NOAA 2010) which likely contributed to the decline of oyster reefs in the Big Bend. Due to the extremely low gradient of the coastline in this area, small increases in sea level lead to widespread changes in the ecology and sedimentary geology of this area. Hine et al. (1988) noted that this region had undergone submergence as a result of SLR during the past 5,000 yr and that recent tide-gauge data indicate that this submergence is continuing and increasing “to a pace four times the radiocarbon-based rate (4 cm/100 yr)”. Cedar Key has a nearly 100 year record of tide-gauge data and over this period, indicating that the annual increase is now about 1.8 (+/- 0.19) mm/yr (NOAA 2010). Updating the sea-level rise rates reported by Hine et al. (1988) and Hicks (1983) with data through 2006 shows that the observed rate from the NOAA tide-gauge station is now about 4.5 times the radiocarbon-based rate reported in Hine et al. (1988) and the gauge data reported by Hicks (1983). Further, the estimate for future sea-level rise for Cedar Key over the
next 70 years is 3.6 mm/yr (Walton 2007), which could increase oyster reef decline dramatically.

Sea-level rise has likely combined with storms to enhance wave energy during storm events, leading to increased erosion during storm events over time. In fact, sea-level rise, storminess, and drought have all been implicated in the loss of many coastal biotic communities throughout the Gulf of Mexico including forests (O'Brien et al. 1994, Denslow and Battaglia 2002), coral reefs (Lidz and Shinne 1991, Jokiel and Brown 2004), salt marsh (Reed 1990, Silliman et al. 2005, Zedler 2010), and other coastal communities (Ross et al. 2000). In our study area, drought (Desantis et al. 2007) and storms (Williams et al. 2003) also have been documented to work in concert with sea-level rise to increase soil salinity, leading to vegetation die-off. One particular storm- 1993 extratropical storm that brought a water surge of 2.5 m into Waccassassa Bay (NCDC 1993)- caused significant dieback of forest tree species with high sensitive to increased salinity (Williams et al. 2003). This storm was also implicated in stories from local watermen as the threshold event that broke up several stressed off-shore reefs in our study area.

The severity and pattern of climate change impacts in this region are closely linked to topography. Hine et al. (1988) identified morphological features of this region that are formed and influence by the interactions between sediments, underling geology, and freshwater discharge. One of these features, included oyster reefs, that Hine et al (1988) reasoned were maintained via (1) the availability of hard substrate for oyster-reef nucleation; (2) reduced salinities which discourages oyster predators; and (3) strong tidal currents (which are oriented laterally along this coast) which increase available food resources for oysters. After proposing a geological succession model that we confirm with our analysis, the authors postulated that
“...as sea level continues to rise, the outer bioherms [organic reef in a mound shape] experience rising salinity. Eventually, the linear shell mounds can no longer support oyster growth due to increased predator infestation. Many shells composing the deeper, outer bioherms are highly degraded and biologically corroded (numerous Clionid sponges). In addition to bioerosion, these outer bars are exposed to open wave attack, resulting in shell dispersal and causing general morphological degradation of the entire feature.”

This speculation appears, according to our analysis, to be playing out in the Big Bend region and if climate change predictions prove to be correct, is likely to play out in a larger more dramatic manner in the future.

Recommendations for prioritizing research and conservation of oyster resources

While our hypothesized chain of events is currently the most likely explanation for the observed patterns, the evidence we offer is correlative and non-experimental. We suggest that field experiments may offer insight into these processes. We recommend that restoration experiments be carried out to test the importance of freshwater input, reef structure, bar elevation. Experimental restoration, testing various reef structure building methods could be established across a gradient of distance to shoreline and distance to known freshwater sources. This would enable an exploration of the relative important of freshwater versus reef structure in established and maintaining health oyster habitat.

This study suggests that even in the absence of major coastal development and anthropogenic stressors, oyster habitat may be at considerable risk in the Gulf, a globally important region for oysters (Beck et al. 2011). In this case, it seems most likely that increasing human uses of freshwater inland may be an important factor resulting in habitat loss. Global
climate change and increased development is expected to raise sea-level, limit freshwater availability, and increase storm intensity in Florida's near and long-term future (Twilley et al. 2001, Purtlebaugh and Allen 2010). Planning for the conservation of oyster habitat in the Gulf should include scenarios that encompass the interaction of global change, and local stressors of human origin.

ACKNOWLEDGEMENTS

This project was supported by grants from Florida Sea Grant, U.S. Fish and Wildlife Service, University of Florida Institute of Food and Agriculture Science, and U.S. Federal Stimulus Funds. We thank the many University of Florida students who volunteered to help with field work. We extend special thanks to Drew Dutterer, Jerry Beckham, and Laura Adams for field support.
Atlantic States Marine Fisheries Commission (ASMFC) 2007. The importance of habitat created by shellfish and shell beds along the Atlantic coast of the U.S. Atlantic States Marine Fisheries Commission, Washington, DC.


Environmental Systems Research Institute (ERSI) 2010. ArcMap 10. Redlands, California, USA.


Table 1. Net loss of oyster bar area from 1982 to 2010 in sampled areas of Florida's Big Bend, displayed by focal area, oyster bar type, and distance-to-shoreline. "Collapse" loss describes oyster bars that experienced erosion and submergence over time. "Total loss" includes collapsed bars and those that disappeared between time steps without evidence of erosion/submergence.

<table>
<thead>
<tr>
<th></th>
<th>Total Loss hectares</th>
<th>Collapse hectares</th>
<th>Total Loss hectares</th>
<th>Collapse hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(% of 1982 oysters)</td>
<td>(% of total loss)</td>
<td>(% of 1982 oysters)</td>
<td>(% of total loss)</td>
</tr>
<tr>
<td><strong>Focal area</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horseshoe Cove</td>
<td>16.68 (49)</td>
<td>13.50 (81)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Cabbage</td>
<td>40.54 (73)</td>
<td>12.25 (30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrigan's Reef</td>
<td>61.08 (65)</td>
<td>23.78 (30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suwannee Reef</td>
<td>5.74 (100)</td>
<td>5.74 (100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>124.05 (66)</td>
<td>55.27 (45)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Distance-to-shoreline category</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inshore</td>
<td>34.37 (50)</td>
<td>25.05 (37)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nearshore</td>
<td>36.3 (61)</td>
<td>22.44 (37)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offshore</td>
<td>53.38 (88)</td>
<td>53.38 (100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Oyster bar type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marsh-oyster</td>
<td>5.17 (32)</td>
<td>4.77 (92)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand-oyster</td>
<td>84.12 (74)</td>
<td>40.69 (48)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unresolved</td>
<td>32.82 (56)</td>
<td>9.38 (30)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure Captions

Figure 1. Map of study area in the Big Bend of Florida. Box A indicates the four oyster reef complexes that were the focus of the historic trend analysis. Box B shows the field survey stratification for one example reef complex.

Figure 2. Example of oyster bar classification in both the orthophotographs used to digitize bars (on the left) and ground photographs from ground truthing (on the right).

Figure 3. Total oyster bar per hectare at each focal area for each sample period in Florida's Big Bend.

Figure 4. Examples of off-shore oyster bars photographs from 1995 compared to more recent conditions on the ground in Florida's Big Bend.

Figure 5. Total oyster bar per hectare at each distance-to-shore category for each sample period in Florida's Big Bend.

Figure 6. Annual freshwater discharge/annual rainfall in the Suwannee River drainage basin, 1957 - 2008.

Figure 7. Number of months low discharge (<1 s.d. below period of record monthly mean) from the Suwannee River, 1942 – 2009.
The graph shows the annual discharge (m²/rainfall cm) over various years from 1950 to 2020. The data points are scattered, indicating variability in discharge with time. The line of best fit suggests a decline in discharge over the years. The coefficient of determination, $R^2 = 0.2037$, indicates a moderate correlation between the variables.