Title: Evaluating the U.S. Estuary Restoration Act to inform restoration policy implementation: a case study focusing on oyster reef projects.

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1. Introduction

Environmental change, natural perturbation, and anthropogenic activities have degraded marine habitats compared to historic levels (Kirby 2004; Lotze et al. 2006; McCauley 2015). Coastal wetlands, seagrasses, and oyster reefs alone have declined by 65-91% (Jackson 2008). Marine habitat loss is of concern because of cascading effects on biodiversity (Jones et al. 2004; Airoldi et al. 2008; Polidoro et al. 2010) and ecosystem service provision (Worm et al. 2006; Grabowski & Peterson 2007; Rey Benayas et al. 2009). In response, the science and practice of ecological restoration have expanded because of the potential to stimulate recovery of degraded or disturbed ecosystems (Aronson & Alexander 2013; Menz et al. 2013) and restoration now plays a key role in natural resource management and policy decisions (Suding 2011). Synthesis and evaluation of previous restoration activities can provide key insights as to whether restoration approaches should be continued or changed, and can be used to support an adaptive resource management framework (Gregory et al. 2006; Wortley et al. 2013). Similarly, evaluating restoration policies and management programs can provide important insight regarding the effectiveness and efficiency of policy goals and management actions.

In the United States, restoration of estuarine habitats became a national priority with the Estuary Restoration Act (ERA) of 2000 (Title 1 within the Estuaries and Clean Waters Act of 2000). The ERA defines restoration as "an activity that results in improving degraded estuaries or estuary habitat or creating estuary habitat (including both physical and functional restoration), with the goal of attaining a self-sustaining system integrated into the surrounding landscape" (ERA 2000). Goals outlined in the ERA include: promotion of estuarine habitat restoration, use of common monitoring standards, development of effective partnerships, improved cost-efficiency, and enhancement of monitoring and research capabilities to ensure sound science

(ERA 2000). Monitoring of ERA-funded projects was mandated, and targeted guidance manuals were developed to promote the use of standardized metrics and methods (Thayer et al. 2003, 2005). Additionally, the ERA required public dissemination of all project information and monitoring data. To achieve this requirement, the National Oceanic and Atmospheric Administration (NOAA), in consultation with the established Estuary Habitat Restoration Council, was charged with the development and maintenance of the National Estuaries Restoration Inventory (NERI, https://neri.noaa.gov).

Oyster reefs have experienced global losses in abundance and extent greater than any other estuarine or coastal habitat and organism (Jackson 2008; Beck et al. 2011; zu Ermgassen et al. 2012), despite management efforts that have been widespread for centuries (MacKenzie et al. 1997; EOBRT 2007). Only recently have oysters gained greater recognition for the non-food benefits they provide that support and sustain human welfare, including nutrient regulation (Piehler & Smyth 2011; Beseres Pollack et al. 2013), shoreline stabilization (Meyer et al. 1997; Scyphers et al. 2011), and recreational fishing opportunities (Zimmerman et al. 1989; Peterson et al. 2003). Restoration efforts are increasingly focused on returning these valuable ecosystem services to society (Coen & Luckenbach 2000; Brumbaugh et al. 2006; Grabowski & Peterson 2007). In 2009, the American Recovery and Reinvestment Act (ARRA) provided a funding boost to habitat restoration efforts by focusing on large-scale projects to stimulate coastal economies (zu Ermgassen et al. 2012, Edwards et al. 2013, ARRA 2009). Over $10 million were awarded for oyster reef restoration.

Despite the thousands of hours and millions of dollars invested in oyster reef restoration projects (Mann & Powell 2007; zu Ermgassen et al. 2012), their effectiveness is equivocal (Mann & Powell 2007; Choi 2007; but see Schulte et al. 2009; Powers et al. 2009), and comprehensive project assessments are generally sparse (Hackney 2000; Kennedy et al. 2011; La Peyre et al. 2014). There are unprecedented opportunities for restoring coastal and marine habitats under the 2012 Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States (RESTORE) Act, which allocates 80% of all fines paid under the Clean Water Act in response to the Deepwater Horizon disaster to the Gulf Coast Restoration Trust Fund. Billions of dollars will be available over the next 30 years to restore coastal and marine habitats, with $200 million allocated to oyster reef habitat restoration alone (Trustee Council 2015). To make the best use of these funds, lessons must be learned from previous efforts, and must be disseminated broadly in order to increase efficiency and maximize success of future efforts.

In the present study, oyster reef restoration efforts in the U.S. were examined to determine restoration progress and to identify challenges and opportunities. A database was created by compiling information from the NERI. Data were synthesized to assess: 1) spatial distribution of restoration effort and funding, 2) trends in project size and cost, and 3) effectiveness of the NERI in disseminating project information and monitoring data with respect to published guidance and Federal policies.

2. Methods

The NERI represents a national summary of restoration efforts implemented under the auspices of the ERA, and includes projects funded by the National Oceanic and Atmospheric Administration, Environmental Protection Agency, Army Corps of Engineers, Fish and Wildlife Service and the Department of Agriculture's National Resources Conservation Service. For inclusion in the NERI, projects must have been implemented after the ERA was signed into law

(7 November 2000) and must not be mitigation or legally mandated restoration. Additionally, all projects must include monitoring to assess restoration success, and the monitoring plan must meet ERA monitoring standards (NERI 2012). This database, though not inclusive of all restoration projects implemented, represents an unbiased subset of projects implemented under the guidance and goals of federal policies and funding programs.

Data summary reports were reviewed, and the NERI was queried using the habitat type filter "oyster reef/shell bottom" within the "submerged" habitat category. Full reports were examined for each project returned in the search, and all available data were collected (including: location, year implemented, area restored, project budget and funding sources). Data for project costs were designated between federal and non-federal funding sources. Project size data (i.e., acreage restored) were converted to hectares, and each project was assigned to a size class based on NERI classifications: small (<0.4 ha), medium (0.4–2.0 ha), or large (>2.0 ha). Cost per hectare was calculated for each project containing data on acreage and funding amount. Monitoring data were not reported for any of the projects examined.

Regression analyses were performed to examine trends over time (R version 3.0.1; R Core Team 2013) for number of projects, area restored, funding awarded, mean hectares per project, mean cost per project and mean cost per hectare. To examine trends since the ERA, regression analyses included only those projects implemented during or after 2000. Dollar values were converted into the same year dollars (2011 USD) according to:

$$Cost_y = (Cost_x)*(CPI_y/CPI_x), \qquad \text{(Equation 1)}$$

where *CPI* is the consumer price index and *Cost* is the project cost. Subscripts *x* and *y* denote the year of project implementation and year for which all values are converted to, respectively. Average CPI values for each year were obtained from the Bureau of Labor Statistics (BLS 2015).

Data for number of projects, area restored and funding were $\log_{10}$ transformed, and all rate data —hectares per project, cost per project and cost per hectare— were square root transformed prior to analysis to improve statistical performance.

3. Results

A total of 192 projects were returned in the NERI search. Despite ERA definitions and rules for project inclusion in the NERI, five compensatory projects were identified and excluded. The remaining 187 non-compensatory projects were examined. Although only projects implemented after the enactment of the ERA are to be included in the NERI, eight projects occurred between 1995 and 1999, and 19 projects did not include a date. The NERI did not contain any projects implemented after 2011. Only one project in the compiled dataset did not provide any funding information. Other than the distinction between federal and non-federal sources, no other budget metadata were provided in the NERI. The NERI report format provided a place for "total cost estimate for monitoring," but this was not reported for any project examined. Although all project records indicate a monitoring plan was developed, no data or assessments of restoration success were provided. Within each project summary, a table was devoted to "Monitoring Parameters and Success Criteria" and a space reserved for a URL for monitoring data. However, in every project examined, no data were available.

[Figure 1 here]

Oyster reef restoration projects included in the NERI spanned all coastal states of the contiguous U.S. except Maine (Fig. 1). Number of projects varied among states, with half of all projects implemented in Florida, Maryland and Virginia (43, 26 and 25 projects, respectively).

Over 150 ha of oyster habitat have been restored, of which nearly 62% occurred collectively in Florida, Virginia and North Carolina (42.6, 26.2 and 24.1 ha, respectively).

Nearly 20% of all projects did not include data on acreage restored, or reported zero acres. Closer examination of these projects revealed that some did not include on-the-ground restoration but rather complementary efforts such as shell recycling programs or education and outreach. Other projects did include on-the-ground efforts, but no acreage was reported. The remainder of projects ranged in size from 0.004–19.8 ha, with a mean project size of 0.99 ha (median = 0.24). The small (<0.4 ha) size class contained the most projects (43%), yet accounted for only 5% of total area restored (Table 1). The majority (64%) of total area restored has been accomplished through large (>2.0 ha) projects, which represent less than 10% of all projects (Table 1).

[Table 1 here]

A total of $45.3 million was awarded for the implementation of the projects examined in the present study, with an annual average over $3.3 million (Fig. 2). Between 2000 and 2011, the number of projects implemented per year ranged from 3 to 20 (Fig. 2). Florida, Virginia and North Carolina received approximately 53% of the total $45.3 million awarded. Overall, nearly two-thirds of total funding originated from federal sources, and one-third from non-federal dollars. Non-federal funding sources contributed over 60% of total funding during 2003, 2004, 2007, and 2008; Federal funds represented over 90% of total funding during 2009 and 2010 (Fig. 2). Alabama and Louisiana relied most heavily on federal funding, with non-federal contributions of only 5.9% and 7.3% of total funds received in each respective state. Washington and Texas received the most non-federal support, which contributed 67.8% and 66.3% of total funding received by each state, respectively.

Projects ranged in total cost from \$500-\$5,000,000, with a mean project cost of \$243,731 across all size classes, including those reporting zero acreage (median = \$105,250). For all projects with acreage and cost reported, mean cost per hectare decreased exponentially with increased project size (Table 1), from \$3,477,339 ha^{-1} for small projects (median = \$1,235,527) to \$97,989 ha^{-1} for large projects (median = \$41,043). In general, large projects were supported primarily by federal funds, providing over 87% of total project funding. Small projects relied on non-federal funding to support 48% of project costs.

[Figure 2 here]

The largest influx of funding was observed during 2009 (Fig. 2), and was driven by the ARRA. Our dataset contained seven ARRA projects implemented in 2009 and 2010. This influx of funding, with the intent to enable rapid implementation of large, "shovel-ready" projects, resulted in a similar increase in habitat area restored during 2009 (Fig. 2). Of the more than 150 ha of oyster reef habitat restored through projects in our dataset, nearly 32% occurred during 2009 alone.

Linear regression analyses indicated weak to moderate trends for project size and cost per hectare (Fig. 3). Average project size increased over time ($r^2 = 0.32$, $p = 0.055$), from 0.36 ha in 2000 to 1.07 ha in 2011 (Fig. 3a). Average cost per hectare decreased over time ($r^2 = 0.60$, $p = 0.003$), from \$2,169,042 ha^{-1} in 2000 to \$517,950 ha^{-1} in 2011 (Fig. 3a). No significant trends over time were identified for number of projects, total area restored, total funding awarded or mean project cost. ARRA projects were removed from the dataset and additional regression analyses were conducted to examine whether this large influx of funding and effort disproportionally influenced the results. Trends were stronger for both project size ($R^2 = 0.44$, $p = 0.019$) and cost per ha ($R^2 = 0.62$, $p = 0.002$) when these projects were excluded (Fig. 3b).

[Figure 3 here]

4. Discussion

Ecological restoration has become a global priority, with considerable implications for science, society and policy (Cairns & Heckman 1996; Suding 2011; Aronson & Alexander 2013). Restoration of estuarine and coastal habitats became a national priority in the United States with the ERA of 2000. Political investment in habitat restoration continued with the enactment of the ARRA in 2009, and more recently the RESTORE Act of 2012. The restoration of oyster reef habitats is of particular concern due to the extent and magnitude of documented losses, the numerous ecosystem services oyster reefs provide, and their importance in supporting valuable fisheries (MacKenzie et al. 1997; Beck et al. 2011; Grabowski et al. 2012).

Restoration efforts to date have generally been ad hoc and site- or project-specific. Individual oyster reef restoration projects are frequently small scale (<0.4 ha), implemented by relatively small groups, and have occurred within short-term grant funding periods of 1-2 years (EOBRT 2007). Although these characteristics often make small projects desirable to funders by allowing broad distribution of available resources, it is unlikely that large functioning ecosystems will ever be achieved through the cumulative effects of small-scale projects (Manning et al. 2006; EOBRT 2007; Choi 2007; Mann & Powell 2007). Increased economies of scale and ecological benefits can be realized through the integration of small with large restoration projects wherever possible (Hobbs & Norton 1996; Schulte et al. 2009; 100-1000: Restore Coastal Alabama 2015; Soulé & Terborgh 1999).

Examination of restoration projects for other habitats within the NERI indicates that oyster reef projects may be particularly small. Within the submerged habitat category, 44% of projects comprise oyster reef (one of nine habitat types), yet these only account for 2% of area restored (NERI 2012). The total area of oyster reef restored by projects in this analysis represents only 0.17% of an estimated 86,000 ha lost from 28 bays across the U.S.A. (zu Ermgassen et al. 2012). The small scales at which most projects are implemented may not effectively sustain, enhance or restore ecosystem services, and the relatively large costs per unit size can be inefficient or even wasteful (Aronson et al. 2006; Rey Benayas et al. 2009).

One of the most promising findings in the present study is that ERA-funded oyster reef restoration projects have increased in size and decreased in per unit costs over the past decade. It is increasingly recognized that the small scales at which most projects are implemented may not effectively sustain, enhance or restore functioning ecosystems or desired ecosystem services (Choi 2007; Mann & Powell 2007; Rey Benayas et al. 2009). In the present analysis, mean project size increased over time, yet the majority of projects were relatively small (<0.4 ha). Opportunities to implement larger projects may be available with RESTORE Act funding. For example, the American Recovery and Reinvestment Act (ARRA) of 2009 included goals to fund large-scale projects. The dataset compiled in this analysis contained seven projects implemented in 2009 and 2010 under the ARRA, with six of them directly engaging in reef construction activities. During 2009, when the largest ARRA projects were implemented, mean project size increased from 1.4 to 4.0 hectares. In general, projects implemented under the ARRA enabled proof-of-concept techniques to be scaled up to effect ecosystem-level changes (Pendleton 2010; Schrack et al. 2012), better facilitating future large-scale restoration efforts.

While there has been a push toward the implementation of larger projects, it is also important to understand relative success between small and large projects, the degree to which ecosystem service provision scales with habitat acreage restored, and how to effectively evaluate the cumulative effects of small projects (Hobbs & Norton 1996; Thayer et al. 2005; Brumbaugh et al. 2006). Further, the move to a larger-scale framework for restoration does not mean that small-scale restoration should be dismissed but that smaller efforts should fit into a larger, coordinated guiding structure so that the contribution and effectiveness of small projects can be maximized (Soulé & Terborgh 1999). In fact, community-based restoration projects, though typically small in scale, provide valuable experiences that have large social impacts (Cairns & Heckman 1996; Leigh 2005). Oyster harvesting formed the foundation of countless coastal communities across history and reflects generations of lifestyle and tradition (MacKenzie et al. 1997; Brumbaugh et al. 2006). Community involvement in restoration projects connects contemporary societies to these cultural keystone species, educates the public, and fosters environmental stewardship (Leigh 2005; Miller & Hobbs 2007). As restoration efforts increase, so does societal demand for the restoration of valuable ecosystem services. Inclusion of smaller community-based efforts in larger plans for system restoration could maximize the long-term contribution and effectiveness of such efforts while maintaining the unique social benefits these projects provide.

Larger projects are frequently more cost efficient because of declining average fixed costs that include construction costs such as mobilization, demobilization, and loading facility set-up (Chitkara 1998). There are significant fixed costs associated with most restoration projects, and as a result, the cost-per-unit-area for relatively small projects can be exceptionally high while the cost-per-unit-area for large scale projects can be relatively low (King & Bohlen 1994; Spurgeon & Lindahl 2000). Further research to identify advancements in restoration techniques and economies of scale for restoration activities are needed to maximize efficiency and impact of investment (Cairns & Heckman 1996; Spurgeon & Lindahl 2000; Manning et al. 2006; Menz et al. 2013).

Making informed funding decisions about habitat restoration projects calls for reliable restoration cost data (King & Bohlen 1994; BenDor et al. 2015). However, restoration cost data are frequently vague or unavailable (Spurgeon & Lindahl 2000; Bernhardt et al. 2005; BenDor et al. 2015). In the present analysis, only total project cost was identified, delegated between federal and non-federal funding sources. No other details were provided to identify various cost components by task (e.g. pre-construction, construction, post-construction) or input category (e.g. labor, materials, equipment). It is important for new practitioners and scientists entering the field of restoration ecology to be able to determine reliable estimates of the costs of designing, implementing, and monitoring restoration projects to ensure project completion and monitoring success. It is equally important for policy makers and managers to understand how funds are being allocated to improve efficiency and effectiveness of funding processes.

Despite the creation of guidance documents for monitoring (Thayer et al. 2003; 2005), and ERA mandates to make monitoring data publicly available through the NERI, no monitoring data were available for any of the 187 projects examined in this analysis. This lack of data is not likely an accurate portrayal of monitoring activities, but rather, a reflection of obstacles in data dissemination, whether by lack of data provision or database maintenance. Regional databases of habitat restoration projects compiled through direct contact with individual scientists, practitioners and agencies have similarly reported a lack of project data. Kennedy et al. (2011) and La Peyre et al. (2014) described how only approximately one-half and one-quarter of oyster reef restoration projects in the Chesapeake Bay and northern Gulf of Mexico, respectively, were monitored or reported, hindering evaluation of project effectiveness. This lack of data is not specific to oyster reef restoration projects. For example, low monitoring and reporting rates were found for salt marsh restoration in northwestern Europe (Wolters et al. 2005) and river restoration in the U.S. (Bernhardt et al. 2005).

As restoration efforts increase, this inability to assess project outcomes is particularly troublesome (Suding 2011; La Peyre et al. 2014). Ongoing efforts seek to improve monitoring data collection and dissemination. For example, recent collaborative efforts have aimed to address challenges of monitoring, including issues of data compatibility, integration and management (Baggett et al. 2014; Waddell & Olson 2015, NAS 2016). And, while there are many scientific publications that describe comprehensive monitoring efforts and results (e.g. Lenihan & Peterson 1998; Grabowski et al. 2005; Geraldi et al. 2013), it is difficult to determine the proportion of total restoration efforts these studies represent (Hackney 2000). Without effective dissemination of project data and lessons learned, limited resources may be wasted on duplicate efforts. As policies related to ecological restoration expand, it is important to make sure that policies and programs are written with clear, achievable goals and adequate funds are allocated to administrative oversight. Unprecedented opportunities for comprehensive habitat restoration and scientific advancement will be available in the U.S. through the RESTORE Act. Nearly $6.5 billion will be dedicated solely to ecosystem restoration efforts, with an additional $1.5 billion assigned for monitoring, adaptive management and administrative oversight (Trustee Council 2015). Restoration and research conducted under the auspices of the RESTORE Act have great potential to advance restoration science throughout the U.S.A. and globally. While the biggest impacts of these efforts will most directly affect the Gulf of Mexico, the knowledge gained can easily transfer to other areas. It is important for the restoration community as a whole to be invested in how these projects are being implemented, how the data are being managed, and how that information will ultimately be used.

5. Conclusion

Large investments are being made for marine habitat restoration, and there is a need for improved strategies to ensure effective project implementation, comprehensive monitoring, and data dissemination so that restoration projects make meaningful contributions to science, policy and society (Bjorndal et al. 2011; Aronson & Alexander 2013; McNutt 2015). Environmental restoration projects have faced increased scrutiny, making transparency about restoration goals and outcomes essential for maintaining and building support for continued restoration efforts. Additionally, restoration ecology is a growing field. It is critical that new and current researchers, practitioners, and decision-makers are able to learn from past projects and apply that collective knowledge to future restoration efforts. Finally, effective communication between researchers, practitioners, and decision-makers is necessary to ensure that the restoration science and policy evolve together.

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Footnote: Multiple attempts were made via email and phone over the course of six months to contact persons responsible for NERI database management to answer questions that still remain unanswered throughout this manuscript.

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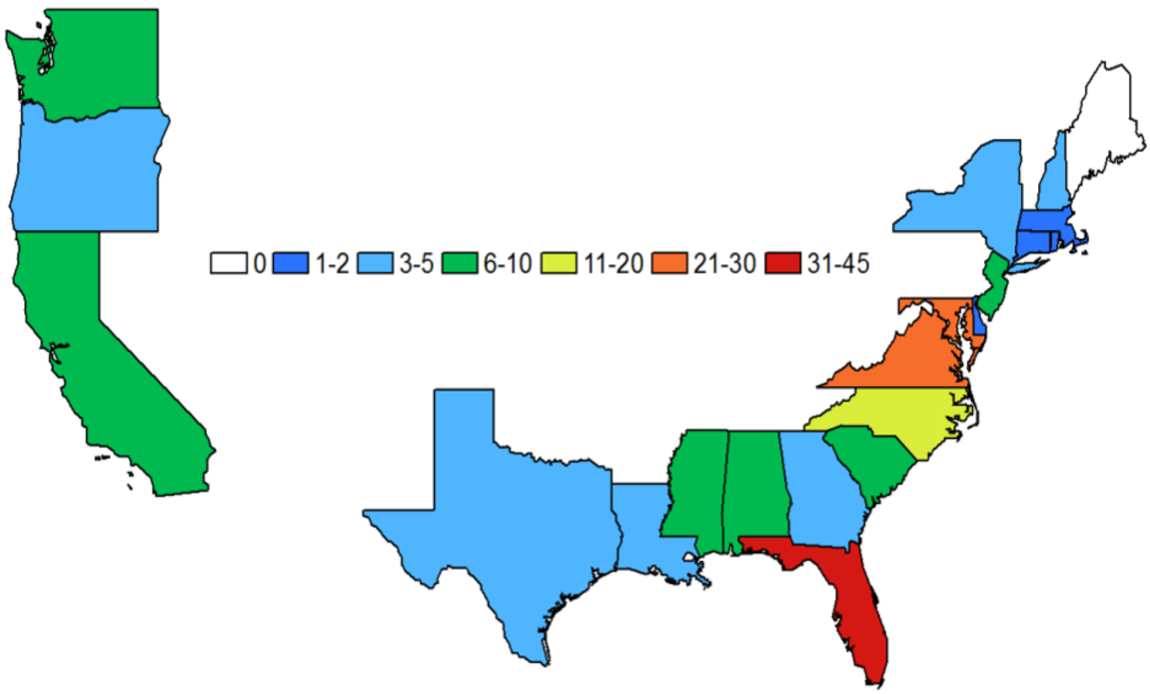
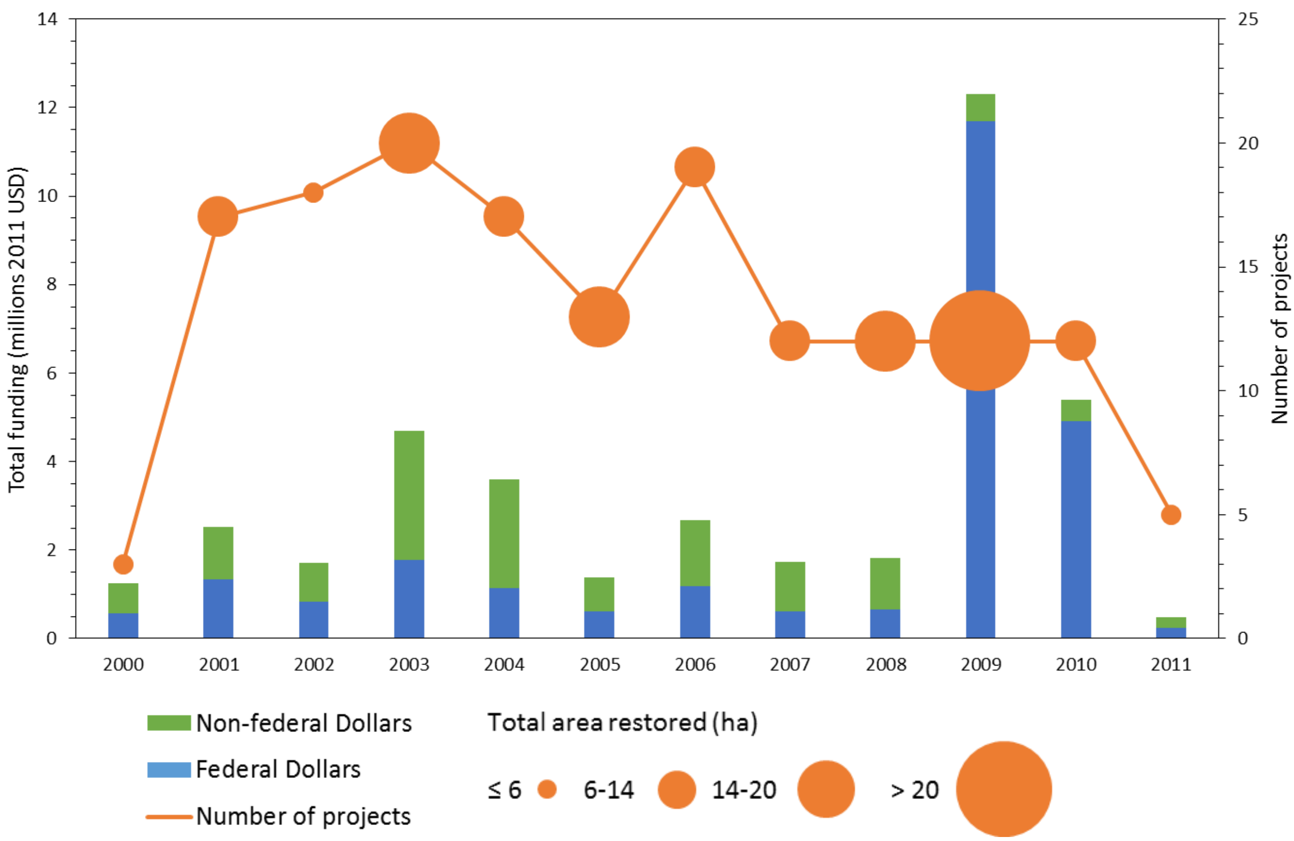

0
1-2
3-5
6-10
11-20
21-30
31-45



Total funding (millions 2011 USD)
Number of projects
0
2
4
6
8
10
12
14
0
5
10
15
20
25
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Non-federal Dollars
Federal Dollars
Number of projects
Total area restored (ha)
≤ 6
6-14
14-20
> 20

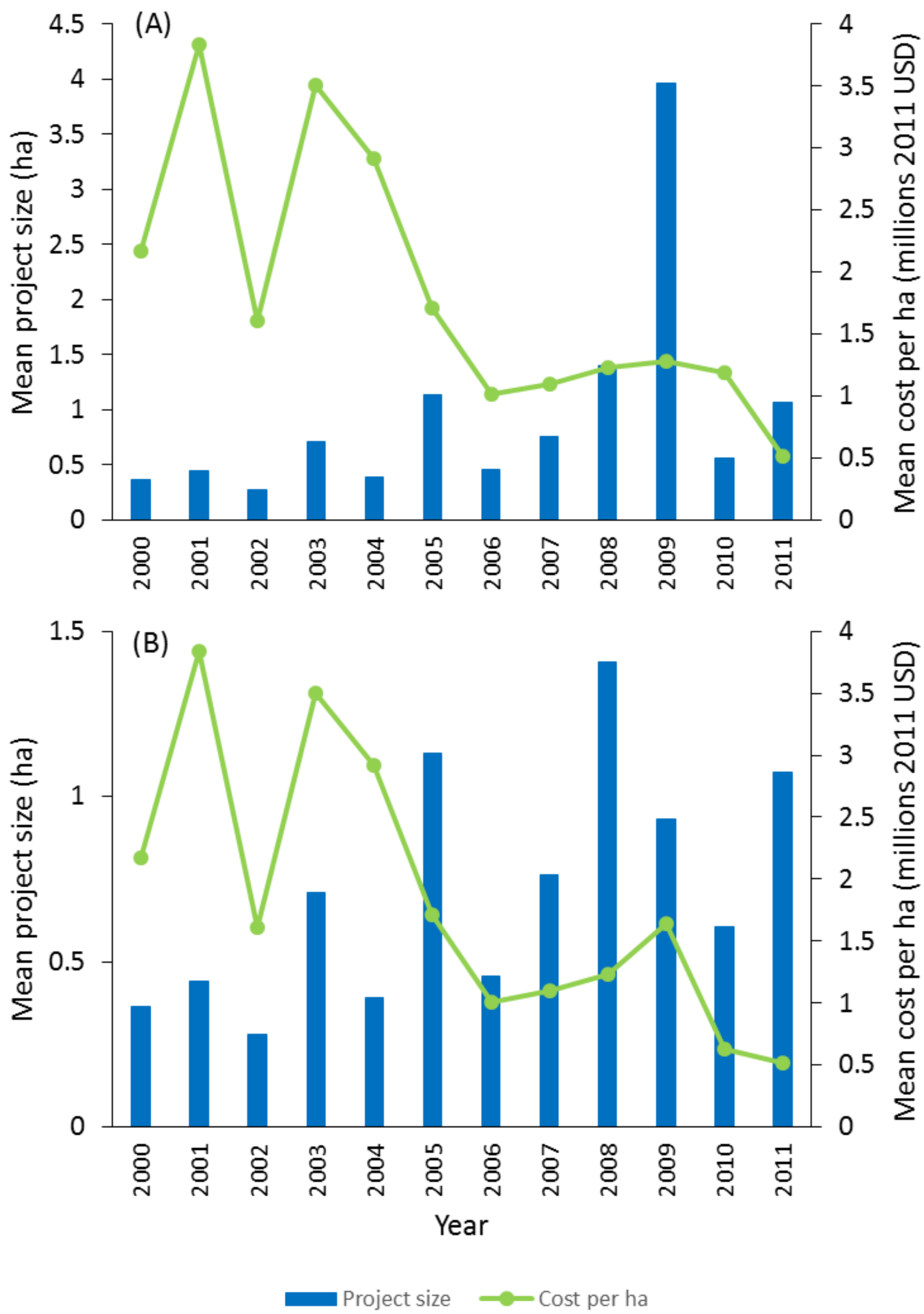

(A)
(B)
Mean project size (ha)
Mean cost per ha (millions 2011 USD)
Year
Project size
Cost per ha
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

Table 1. Summary of oyster restoration projects by size class.

Size class	Number of projects	Total area restored (ha)	Mean cost per ha (USD)
Small (< 0.4 ha)	80	7.5	$3,477,339
Medium (0.4 - 2.0 ha)	55	46.7	$337,399
Large (> 2.0 ha)	17	96.4	$97,989