Research, Management and Outreach Priorities for Clam Restoration in the Indian River Lagoon, Florida

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Introduction

The Indian River Lagoon (IRL) is an Estuary of National Significance located on the east coast of Florida and is bordered by seven coastal counties. This 156-mile-long shallow lagoon complex ranges from 0.4 to 5 miles in width and is home to over 4,300 species, making it the most biodiverse estuary in the northern hemisphere (Dybas, 2002). Dominated by extensive seagrass beds and extremely clear waters, the IRL became a sportfishing and eco-recreation destination in the 1970's and has been the cornerstone of tourism in the region for the decades that followed (FDEP, 2016). However, the population on the Atlantic coast has risen dramatically over the last 20 - 30 years, and with that increase in human population has come tremendous anthropogenic impacts to water quality in the IRL. Historically, hard clams and oysters have been significant regulators of healthy water quality and economic stability in the IRL (Arnold et al., 2002). Unfortunately, a variety of threats such as eutrophication, freshwater releases, and algal blooms have drastically decreased bivalve abundance and thus filtering capacity (MacKenzie et al., 2001). As water filtration is a significant ecosystem service provided by these organisms and a critical link to IRL recovery, bivalve population restoration should be a primary objective in restoration planning.

It is well known that clams and oysters are both critical elements in the filter feeding community of the IRL. Oyster restoration has been utilized extensively throughout the IRL with variable success, and until very recently, other filter feeders, such as clams, have been widely overlooked as a restoration tool (Arnold 2001). However, the restoration community has begun using hard clams to add additional filtration capacity back into the ecosystem with the goal of improving seagrass establishment to counteract manatee loss. A significant portion of the manatee population that once thrived in the IRL have died in the last two years from starvation due to loss of seagrass forage. To combat this loss of seagrass, several large-scale efforts are underway to restore filter feeder communities to reduce algal-induced turbidity in the IRL and thus facilitate the re-establishment of seagrasses by allowing more sunlight to reach the sediment surface. These projects have had significant success in doing so over the last four years with the repatriation of over 15 million clams (Osborne et al., 2022).

Oysters and clams have different physiological capabilities and environmental needs that drive their ability to survive and grow in shallow water estuaries where environmental conditions are highly dynamic. Oysters can function across a wide range of environmental conditions but are relegated to the upper reaches in the tidal column, while clams function under a narrow range of environmental conditions and are not constrained to the tidal column upper limits (Galimany et al., 2017). By integrating bivalve species strengths into restoration practices, we may increase the likelihood of restoration success. Additionally, co-restoration of suspension-feeding bivalves with seagrass is suggested to increase seagrass growth through decreases in turbidity and increases in sediment nutrients (Peterson and Heck 2001a; Peterson and Heck 2001b; Wall et al., 2008). However, co-restoration of bivalve species with seagrass has been shown to provide positive and negative effects on both seagrass and clam growth (Gagnon et al., 2020; Valdez et al., 2020; Zhang et al., 2021). Given the multiple benefits that clam restoration may provide in the IRL, we are currently lacking the knowledge necessary to successfully implement clam restoration. Because bivalves are highly dependent on local environmental conditions, it is critical to highlight restoration needs, obstacles, and knowledge surrounding clam restoration in the IRL. The objective of this white paper is to outline current research, management, and outreach priorities as detailed by local stakeholders for successful implementation of clams in IRL restoration projects.

Methods

A one-day workshop was held on April 29th, 2022, at the Florida Oceanographic Society in Stuart, Florida in an effort to bring together local and statewide stakeholders to highlight priorities for clam restoration to move forward in the IRL. The workshop was attended by 72 individuals from multiple county (11.6 %), state (23.2 %), federal (8.69 %), academic (18.8 %), aquaculture (10.14 %), private (4.34 %) and non-profit (23.18 %) organizations. Participants were asked to split into three breakout session groups, which they all randomly rotated through. The breakout sessions were meant to highlight research, management, and outreach priorities surrounding clam restoration in the IRL. Ultimately, the knowledge gained from this workshop will fundamentally support management plans and decisions involving ecosystem restoration projects in the future. The key findings of each breakout session are collated below.

Research Priorities Key Findings

Each of the three breakout sessions addressing research priorities included participants with moderate to significant scientific background. Those with experience in various areas of restoration were most vocal. However, all ideas were captured to give participants a voice and the opportunity to make judgements on priorities. Each breakout group began with each participant providing at least one research priority question which was listed on a large white board. Then, following a short discussion period, individuals were asked to choose their primary priority from that list. The top three questions chosen were assigned to small groups to expand upon with ideas on methods to employ and hypotheses to test. Subsequently, the three independent sessions highlighted similar priority questions, which need to be addressed for more robust restoration practices in the IRL. The questions which should be prioritized in research are outlined below:

How is success of clam restoration measured and assessed?

Although there are no standardized methods for assessing success in clam restoration projects, simple growth rate, survivorship, and fate tracking measures are currently the most useful (Osborne et al., 2020). Perhaps a more robust method can be developed, however, the current approach does seem to be efficient, while not allowing for tracking of offspring. Discussion of genetic markers or genetic testing of offspring was also discussed. However, it was noted that this methodology would be both time consuming and expensive. The benefit of such genetic profiling would be very useful in justifying the current method of using locally-sourced surviving clams that appear to be a better suited variety due to previous exposure to harmful algal blooms and other environmental stressors. Further, better understanding of genetic diversity in the IRL would be of great interest in future efforts to increase diversity when water quality improves. Another point of discussion centered around quantifying the effects of clam restoration on water quality, which to date, has not been possible in IRL or any other project sites that participants were aware of. This is due, ostensibly, to the vast volumes of water and the relative infancy of current clam restoration efforts such that significant differences in water quality cannot be attributed to regional restoration efforts. Concerns of fluctuating salinity and potential use of agrochemicals in the watershed having negative effects on clam survivorship were also discussed, however, these scenarios were not considered to be priorities at this time.

Do clam/seagrass interactions improve restoration efficiency?

Most participants agree that understanding the potential mutually beneficial relationship between clams and seagrasses is a critical priority because of the potential to accelerate seagrass restoration in the IRL and other places where primary production has shifted from rooted vegetation to algae (Gagnon et al., 2020). It is widely believed that clams benefit seagrasses in three main ways. First, biofiltration activity increases sunlight penetration to sediment surfaces where seagrasses are either recovering, recruiting, or are actively being re-established. Secondly, clams increase seagrass nutrient availability through filtration and aggregation of organic particles which fall to the sediment surface (termed benthic coupling) where microbial decomposition processes provide seagrasses with increased exposure to nutrients. Finally, in areas where herbivory is prominent (e.g. manatees), entrainment of clams by seagrass roots and rhizomes provide an anchoring mechanism where entire plants may avoid dislodgement by large herbivore grazing. All of these assumed benefits are largely unproven, and it was unanimous amongst participants that these assumptions be tested.

What clam density is effective or appropriate for restoration efforts?

Participants agreed that several factors would influence the overall planting density for specific projects. However, determining the relative importance of these factors is a significant question for each individual project or for optimizing implementation of future projects. For example, if a project has water quality improvement as a primary goal, then medium to low density planting is acceptable as it would allow for optimizing filtration rates and particle removal, while restoration projects aimed at restoring functional populations may wish to plant more densely to optimize reproduction efficiency. Current commercial aquaculture practices utilize a range of planting densities based upon food availability, optimizing growth rate, and available space. These are not often priorities of restoration projects, and thus commercial aquaculture densities serve only as guidelines at this time. Research into the effectiveness of different planting densities was suggested to address this unknown.

What is the current genetic structure of wild clam populations, and what changes have they undergone?

As some projects have claimed utility in choosing local genetic varieties to tackle specific environmental problems or hurdles, it was discussed at length what genetic diversity or potential bottlenecks may be introduced by using this method. Much of the clam restoration in the IRL has used specific broodstock isolated from waters exposed to significant environmental degradation leveraging short-term natural selection to derive a resistant variety of native *Mercenaria* clam that is well suited to IRL-specific environmental issues. Other projects on the Gulf Coast have also employed this strategy, yet no one has successfully proven with molecular testing whether there are specific genetic markers for optimizing restoration. Baker and others (2008) determined regional genetic diversity in Florida waters using mRNA analysis to show partitioning of populations in large geographic areas that were somewhat distinct from each other. Some participants suggested that a similar study be conducted, or that more advanced molecular tools be utilized, to delve into genetic diversity and impacts of selective broodstock use across the state. Participants also discussed how additional genetic diversity has been imported into Florida waters through aquaculture, which often purchases seed and sometimes broodstock from other states. Research into clam genetics in the IRL is paramount to answering these questions.

What is the nutrient removal efficiency of clams used in restoration?

In many cases, optimization of restoration dollars requires accounting for the cost to remove excess nutrients such as nitrogen (N) and phosphorus (P) from the water column in the form of algae or organic particles. To date, little work has been done to substantiate the N or P abatement value of clam restoration. For instance, tissue concentration of N and P is well known, however, the pool of nutrients stored in biomass is relatively transient and can easily re-enter the aquatic pool if animals die or are consumed by predators within the system. It was recognized that aquaculture and harvesting of planted clams is required to consider the nutrients truly removed from the system. One caveat to this situation is that clam beds are thought to aid in nitrate removal by oxygenating surface sediments and encouraging microbially-mediated denitrification, which is then not biologically available for growth. Unfortunately, P does not have a biogeochemical cycle that allows for complete removal. It was deemed highly important to determine the level at which restored clam beds may aid in the permanent removal of N in the IRL.

Management Priorities Key Findings

Similar to the research breakout sessions, the participants had diverse backgrounds and experience with management. This influenced how they interpreted the definitions of management and restoration. Some interpreted management to mean management of a project, others focused on resource management within the system, while still others discussed regulatory programs. In addition, the definition of “clam restoration” was debated. There are two types of clam restoration, one is restoration of clam populations, and the other is the use of clams to improve environmental conditions. Each of these have different management implications but also share some commonalities in approach such as issues with how to monitor success, project scale, and the integration of projects with multiple goals.

Each person was asked to place their top management priority on a whiteboard. The priorities were then grouped by similarity, and the top three priorities from each of the three breakout sessions were further assessed. Below are the key highlights and issues identified in the Management Breakout session:

Increasing Monitoring Success

Many projects are designed with only vague, big picture goals and do not have explicit metrics of success. Without these measures, monitoring efforts may track parameters that do not adequately capture a restoration project's success or provide opportunities for adaptive management. Some participants indicated that the monitoring of success should be a requirement of clam projects in the IRL and/or a prerequisite for permit approval, funding, and/or reporting. Below are several suggestions for improving the monitoring and assessment of a project for determining success:

- Project goals need to be clearly defined with measurable success criteria. Robust goals and monitoring outcomes can then lead to adaptive management and contingencies.
- Short- and long-term (> 2 years) monitoring needs to be incorporated into restoration plans. This will allow stakeholders to monitor if the clam restoration effort has developed a sustainable population and to share lessons learned. Fate tracking will also allow for stakeholders to ascertain if clam leases are increasing natural recruitment.

At a programmatic level, it was suggested that monitoring criteria be comparable and/or standardized across projects for both biological and water quality parameters. These standardized monitoring criteria should be implementable by academics, non-profits, or any other entity participating in a clam restoration effort. This would allow for greater system-wide assessment by managers and help identify target areas for future project locations. It would also provide opportunities for managers to decide how to address unsuccessful projects.

Increasing Project Scales

Frequently, restoration projects are conducted at very small scales and independent of other efforts in a watershed. These projects, while potentially informative of technique successes and failures, provide limited ecosystem impact by themselves. For ecosystem restoration to be successful, projects need to influence areas large enough to impact ecosystem function. Below are several ideas put forth to increase project impact and scale:

- Projects with multiple components and sites lead to meaningful results and should be prioritized. If a large-scale project is not feasible, collaboration and cooperation between small-scale projects should be prioritized. A linkage of stakeholders and researchers to communicate and work towards common objectives will create a larger geographic scale of restoration and facilitate the dissemination of information on successful results.
- Utilization of standardized language, monitoring methods, and sampling frequency between projects will create more meaningful dialogue and collaboration across partners.
- Creation of an independent entity to oversee and manage multiple projects across the system will create better workflow, project accountability, and dissemination of results.
- Formation of a 10-year plan for system-level management of restoration, which includes independent tracking and accountability assessments, will facilitate meaningful restoration efforts.

It was agreed upon that implementation of these ideas requires an overarching agency (either federal or state) to take the lead on project oversight. Establishment of a program manager from an already established entity [e.g., the IRL National Estuary Program (IRLNEP)] would leverage existing connections and relationships when establishing such a management agency.

It was suggested that the first step would be to assemble a coalition of stakeholders including federal, state, and local government representatives, academic researchers, non-profit scientists, and aquaculture farmers. The coalition would design an initial 10-year plan for clam restoration projects in the IRL, which would include development of standardized methods, targeted project locations, reporting requirements, metrics of success and coordination of annual workshops to facilitate dissemination of information and collaboration. The program manager (e.g., IRLNEP) would be charged with implementing the plan and tracking project progress. The coalition would be further charged with assessing ecosystem-level success and revising/updating the plan as needed to improve restoration efforts.

Incorporation of Co-Restoration Projects

Restoration projects tend to focus on one target species or goal, such as seagrass, oysters, clams, or water quality improvement, and not at ecosystem-level function. Co-restoration projects are better able to address ecosystem-level problems by focusing on multiple components. For example, a restoration project that co-locates clams and seagrass can offer synergistic benefits. However, projects need to be thoughtfully designed to maximize benefits for all targeted components without detrimental effects to one species.

Understanding Water Quality Issues

At the watershed scale, all restoration projects need to take water quality issues into consideration. Restoration projects can be designed to improve water quality while restoring habitat or may require upstream water quality improvement for success. A designated program management entity would be ideal for connecting restoration projects through their goals and objectives. For example, if water quality improvement is required for a project’s success (i.e., need clear water for establishment of seagrass), the entity can help identify locations in the lagoon where water quality projects are resulting in clearer water, subsequently suggesting ideal locations for restoration. While the projects are separate, they can work together to improve overall ecosystem health and connectivity of stakeholders.

Creating Economic Incentives through State Programs

The most successful way to spur restoration of an ecosystem is to monetize it; to provide financial incentives for stakeholders to undertake activities that promote restoration. The breakout group participants had multiple suggestions on how to incentivize ecosystem restoration. Below are a few examples:

- Create financial demand for N credits in Basin Management Actions Plans (BMAPs) and Total Maximum Daily Loads (TMDLs).
- Connect clam restoration to TMDLs with BMAP nutrient credits.
    - All stakeholders, researchers, and industry should report their results publicly, and share information with policy makers to inform BMAPs and TMDLs.
    - Better identify geographic areas in need of nutrient reduction through clams.

    - Recognize filter feeders as a mitigation product similar to seagrass beds and mangroves.
- Award credits only after success of a project has been documented.
    - Assign dollar value to credits.
    - Pay clam farmers and aquaculture to plant and monitor clams.
- Create a restoration market for clam farmers to be able to sell stock not suitable for the food industry because of size.

Implementation of these suggestions would require coordination and authorization from the Florida Department of Environmental Protection. The source of funding for these incentives would need to be identified in the State budget process.

Outreach Priorities Key Findings

The diverse group of participants also discussed the prioritization of outreach messaging regarding clam restoration. Firstly, the breadth of potential audience stakeholders was defined within a perceived range of influence on society at large (Fig 1). In this context, the key elements for messaging are outlined below:

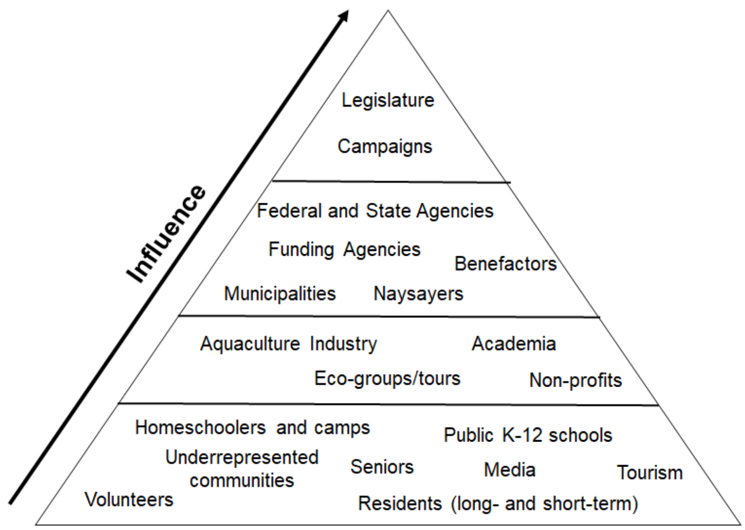

Figure 1. Pyramid of Influence

Outreach Messaging Strategy Overview

Multiple outreach tools, including but not limited to; media platforms, K-12 hands-on learning tools, academia, NGOs, industry (including development community), government (especially local), should be utilized for packaging the message regarding the importance of clam restoration. Entities (yet to be determined) developing the suite of outreach products must target all age groups with age-appropriate curricula designed for visitors and Florida residents. The message must be clear and target-appropriate. All active partners in clam restoration should be responsible for reviewing draft and final outreach products and for their dissemination once made final. This will foster a commonality in the message across all active partners which will create trust and foster partnerships among stakeholders and avoid mixed messaging and confusion to the public. The partner entities and respective roles in the partnership should be emphasized in outreach products as well as the collective mission. A well-written slogan, such as ‘It’s about clam time’ or ‘All clams on deck’ or ‘Healthy clams = Healthy lagoon = Healthy you,’ is very useful for communicating a message to all stakeholders.

Key Outreach Message Topics

There are several key concepts that the workshop participants stressed as critical to the outreach message. It is important to emphasize that clams are a natural part of the system, their populations have fluctuated in the past, and that they are an indicator species for certain aspects of water, habitat, and estuarine quality. Past successes such as nursery culturing and survivorship and growth of outplanted stock should be highlighted. Success must be well-defined and well-messaged and should include the cost of doing nothing. The context of clam connectivity to the system and the ecosystem services they provide should also be included. In particular, the water quality context is critical in that clams are just one of many filter feeders and that filter feeders are just one component of a restored system. It must be emphasized that clams will not fix the impaired water quality issues that the IRL is currently experiencing. Stormwater input and the legacy load of nutrients remain the main drivers in causing impairment, and each of us is responsible to some degree for being part of the solution given our connection to the estuary. Outreach products should include a section on filtration and clearance rates of clams in order to clarify the limited capacity of the organism for affecting system change. Some discussion on the sustainability of the restoration initiative is also warranted as related to clams at the population scale, with an honest assessment focusing on past successes and failures. This can be described in the context of the funding required for ongoing clam restoration. Though some funds have been secured and expended to date, additional funding remains necessary to scale up the initiative. The economic impact and return on investment scenarios should be outlined, noting that these elements are part of the ongoing research effort to inform the public about how funds (mostly public dollars) are being used to maximize efficiency. Ideally, the restoration effort will create self-sustaining clam populations such that commercial and recreational fisheries are re-established.

The techniques used in clam restoration should also be described. It should be noted that a science-based technique is critical to success in collecting native, regional broodstock to spawn and grow out. Progeny are then outplanted to strategic areas with suitable conditions for survival and growth, with protection from predation or other disturbances. In this manner, site selection criteria must be well-established and described, though exact locations of outplanted beds are not divulged to best protect desired outcomes. A passionate plea to avoid disturbing these beds is critical because they are used for restoration and related research on its effectiveness. The issue of local clam harvesting and consumption in general should be addressed, with assistance from Florida Fish and Wildlife Conservation Commission (FWC) for messaging. Details outlined should include ongoing water quality issues, such as certain phytoplankton which can produce toxins. If targeted protective regulations are established for given locations, as led by FWC, then the specifics and reasoning behind those regulations should be advertised appropriately. Lastly, any techniques used regarding genetic aspects of the project and their respective importance to the restoration strategy should be emphasized. This includes genotyping, state laws and policies regarding broodstock and progeny, gene expression, and other related techniques.

Conclusions

Significant nutrient additions over the last 50 years to the IRL have resulted in a catastrophic shift in primary productivity from rooted macrophytes (seagrasses) to algal dominance in the water column. Such a shift has degraded many ecosystem functions and has imperiled many species that require seagrasses for food or habitat. Restoration of filter feeder communities, specifically the hard clam *Mercenaria mercenaria* or *Mercenaria campechiensis,* is one of several critical restoration strategies being employed to restore the IRL ecosystem. To expand this aspect of restoration to a meaningful level, the workshop described here was held to garner input from all stakeholders, including aquaculture industry, agency and university scientists, resource managers, non-profit groups, and the general public. Three major areas were identified and breakout sessions were held to discuss and generate priorities for research, management, and outreach activities. Within each breakout, several themes kept emerging, bringing to light the common ideas and goals that participants came to the workshop with.

Stakeholders stressed that a standardization of the measures of success for clam restoration projects is a necessity to ensure future funding investment by both the State of Florida and federal restoration funding sources. Beyond the measurement of success, the logistical aspect of planting density is also indicated as a metric that may be optimized with future research activities as recent projects have focused on high density for optimal reproduction. While these sites have not been investigated for nutrient removal efficiency beyond standing stock biomass, the potential for clam beds to accelerate nutrient removal processes such as denitrification are of great interest and are a priority for future research. Finally, as seagrass restoration via out-planting is also an aspect of restoration that has garnered increasing interest and funding, the question of co-restoration of seagrasses and clams together has been of paramount importance. Many have suggested that synergistic relationships between bivalves and seagrasses will improve seagrass restoration efforts, likely the highest priority determined by the workshop participants. The need for this research is immediate and could be pivotal for future efforts to restore seagrass habitat in the IRL.

Participants also suggested that clam restoration projects in the IRL would benefit from an overarching management entity that could provide guidance on standardized monitoring methodology, project location, and coordination with other projects to maximize ecosystem-level restoration benefits. The entity could also encourage co-restoration projects with both clams and seagrasses co-located, or projects strategically located to take advantage of the benefits of a near-by water quality improvement project. They could also track project success and failure and provide adaptive management approaches for future restoration projects, while encouraging communication among stakeholders. Economic incentives administered by the Florida Department of Environmental Protection could also motivate an increase in restoration activity within the IRL by engaging multiple stakeholders.

Clam restoration has recently taken center stage in the IRL, and the past successes, failures, and lessons learned regarding each project represent an important storyline in the overall restoration goals for this diverse, productive, and historically-important estuarine system. Packaging this message for a wide audience is paramount to continuing the work accomplished thus far. Bringing together a diverse assemblage of participants to talk through IRL clam restoration was the first step in highlighting the needs and priorities of local stakeholders and the effectiveness of the partnership established is a testament to the passion shown by regional partners to affect positive change within the IRL.

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