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Ecological Restoration, Water Quality Improvement, and Flood Resilience: A Case Study of the South Bay Salt Pond Restoration Project

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Abstract:

South San Francisco Bay is an important ecological area in the region. It is home to many migratory birds and has been a buffer against coastal flooding. Land reclamation in the last century has however destroyed this area. Consequently, this affected many species, water quality, and the natural function of flood regulation. To tackle this issue, the local government, the Environmental Protection Agency (EPA), and colleges worked together to create the South Bay Salt Pond Restoration Project. The research findings of this paper, the project aims at restoring salt ponds into tidal wetlands. The objective of this study is to obtain an assessment of the project's success in terms of habitat restoration, water quality improvement and adjustment of flood control, and to offer useful views and suggestions for future studies to assist guiding and influence the efforts of future restoration programs as well as ecological studies in comparable coastal wetland areas.

Keywords: South Bay salt pond restoration project; biodiversity; water quality; flood protection.

1. Introduction

For over a century, land reclamation and salt production have caused significant damage to coastal wetlands in the South San Francisco Bay. The area of tidal flats and salt marshes has decreased significantly, which may cause habitat loss and hydrological function degradation [1]. Recently, coastal wetlands play an important ecological role and are also vital to the purification of water and flooding mitigation. This will improve the ecosystem services through the restoration of the urban wetlands.

According to the data, the South Bay Salt Pond Restoration Project has been implemented since early 20th century with an area of about 15100 acres [2]. The goal of this project is to convert the salt pods, which have been used for a long time for salt making, into wetlands and habitats over time. This could also introduce ecological improvement and public interaction with nature [3]. Due to large scale impact and long mechanism time, the project become a representative case for wetland ecological restoration research. Many universities and cooperation use this project as significant precedent.

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Earlier studies mainly emphasized the responses of waterbird communities, the restoration, tidal dynamics and sedimentation processes of wetlands. As noted in the synthesis report phase-1 and the ones. Nevertheless, over longer timescales integrated analyses of biodiversity metrics, multiple water quality metrics, and flood control measures remains lacking.

The analysis in this study combines changes in biodiversity indicators and water quality indicators over time, and the effectiveness of flood control measures to assess impacts of restoration actions in the local environment. The aim of the study is to provide probably evaluations and recommendation that are practicable for similar projects of wetland restoration and thus provide the scientific evidence and recommendation for protecting and poring urban coastal wetlands in the future.

2. Ecological Benefits

2.1 Habitat Restoration

The indicator species used in this research to assess habitat restoration effectiveness is the Snowy Plover. The snowy plover is sensitive to changes in our habitat It can only reproduce when specific conditions are met. Because the plant growth is too high, there is a risk of predation. In addition, humans and vehicles trampling them can also pose the same risk.

The Snowy Plover can only survive in a specific salinity of water and soil. They primarily feed on small invertebrates on the mudflats. The abundance of these prey species depends on good water quality and sediment condition. An increasing number of Snowy Plovers demonstrates the variety of benthic organisms. In addition, the United States has listed the Snowy Plover as a threatened species [4]. Their recovery is of both ecological and scientific significance. The Snowy Plover is one of the continuously monitored species in this project. The project has monitored the population size, nest distribution, and reproduction success of Snowy Plover since 2006, which provides a strong basis for further study [5].

In conclusion, the snowy plover makes a good indicator species for assessing ecological restoration success. The project will prevent vegetation succession on site and enhance area monitoring. Planting suitable vegetation will limit predatory access. It will provide a protected area for nesting and brood rearing. The Snowy Plover population trend from 2006 to 2024 is shown in the following graph.

In the study area RU3, the total number of Snowy Plovers generally showed a growing trend. According to the project 2003 report, the adult population was 72. A spike in adult population was noted between 2006 and 2008 with adults increasing from 100 in 2006 to 200 in 2007. This population was noted to drop back to 130 in subsequent years. Thus the conclusion was drawn that since the spike in adult population was noticed in the project, the earlier restoration measures were cheaper but were successful. On the other hand the earlier degradation of the wetland still needs time to recover. From the year 2009 onwards, the rise was quite significant. There's a peak of about 280 in this period. This suggests that some early restoration might have created comfortable breeding habitat. But from 2011 there was again a sharp drop and the number dropped down to near 150. Furthermore, from 2012 to 2017, the number showed a steady increase from 150 to 250 indicating that restoration measures started to work and there was stability in breeding phase. Between 2018 and 2020, the number of the species fell again, from 250 to about 145 due to external disturbance and hydrological conditions. Then, between 2021 and 2024, the number of mammals increased at a rapid pace, reaching about 370 in 2023 and staying above 330 in 2024, higher than 2006 [6].

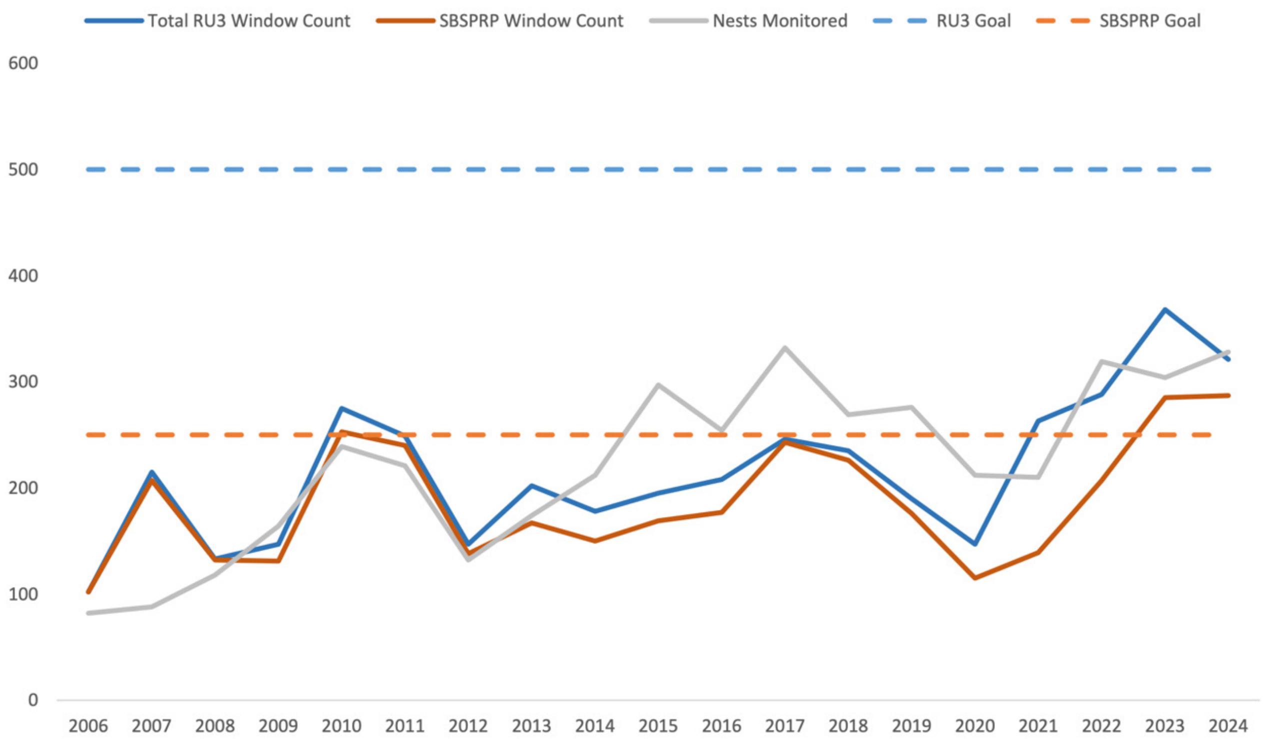

Fig. 1 Western snowy plover and California least tern monitoring

The Figure 1 area's population of Snowy Plovers has increased from about 100 over 18 years to a peak of 370. The current number is well above the target. Long-term monitoring data indication fluctuations in the overall trend during the process of restoration reflecting that with the implementation of SBSPRP, the habitat in the region has gradually improved and the Snowy Plover population has recovered. The growth rate of an indicator species reveals the reproductive success of that species itself and indirect indications of wetland food resources, salinity and general improved conditions that support the long-term viability of that species. The regional ecosystem is recovering as a result of the efforts being made to restore the ecosystem [7].

2.2 Water Quality Improvement

Since the initiation of the project, researchers have continuously monitored water quality across numerous ponds in the region, covering a wide range of indicators such as temperature, pH, dissolved oxygen, salinity, and concentrations of various metals and their ecological impacts. This study draws on water quality reports from 2004 (the early stage of the project), 2013 (the conclusion of Phase I), and 2023 [8-10].

During the initial stage of the project, researchers conducted monitoring across all ponds. In the research, dissolved oxygen (DO) concentrations in all ponds were below 5.0 mg/L. Three ponds' dissolved oxygen concentration are under 3.0 mg/L and one pond dropping below 1.0 mg/L. Such conditions add stress on fish populations. particularly in ponds with DO below 3.0 mg/L, hypoxia could easily occur, leading to large-scale fish mortality. pH levels varied among ponds, but most values remained below 8.5. (For reference, the suitable pH range for the survival of fish and other aquatic organisms is approximately 6.5-8.5.) This suggests that at the start of the project, dissolved oxygen shows significant ecological risks. the pH levels in South Bay salt ponds were in a range capable of supporting biodiversity.

In 2004, although some ponds are tidal systems influenced by tidal inflows, none of the ponds exceeded the circulation threshold of 44 ppt during that year. However, salinity levels in most ponds remained high, often above 30 ppt. This kind of condition is unsuitable for most freshwater fish and other aquatic species to live. This indicates that, at the early stage of the project, while salinity did not surpass critical limits that would cause severe ecological consequences, it still required regulation and careful management in subsequent restoration phases. Consistent with this, one of the explicit goals of the South Bay Salt Pond Restoration Project was to gradually reduce salinity levels to a range of 5-30 ppt, thereby mimicking the natural estuarine ecosystem [3]. There were no precise data on water temperature and metal concentrations available for statistical estimation and analysis; However, based on project reports and monitoring records, water temperature in the ponds was largely depend on seasonal and weather-related variations, without other dominant influencing factors. In

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contrast, metal concentrations during 2004 did not meet the water quality standard. Overall, the water quality conditions at the initial stage (2004) showed huge gaps from the restoration targets, indicating the need for further improvement.

Data from 2013 (mid-term assessment) showed an improvement in salinity conditions. During approximately 693 measurements, the majority of salinity values fell in the range of 16-30 ppt. Only a few samples approach the circulation threshold of 44 ppt. Although some ponds reached hypersaline conditions for a few times, the overall trend had shifted toward moderate salinity levels. At the same time, dissolved oxygen (DO) experiences improvement, reaching values as high as 10.6 mg/L. Among all measurements, only about 25 samples recorded DO concentrations below 3.0 mg/L, and none fell below 2.0 mg/L. This suggests that periods of oxygen stress had been greatly reduced. Oxygen conditions were suitable for the survival of most aquatic organisms, supporting the diversity of fish and invertebrate populations. Water temperature fluctuated with seasonal and meteorological variation, so it did not show sustained extreme anomalies, suggesting that external climatic factors were not the dominant source of stress during this period [8].

By 2023, the data still supported this positive trend. Salinity levels in the majority of ponds remained below the 44 ppt threshold. Only a few ponds or individual sampling periods exceed the limitation. pH values stayed within the optimal ecological range of 6.5-8.5, with a few peaks near 9.0. These elevated values were not widespread. Most of them were associated with shallow ponds.

From 2004 to 2023, the region shown the improvement in two factors, salinity and dissolved oxygen. The project also reach the ecological restoration targets. In addition, the later reports notice a decline in concentrations of heavy metals in pond waters, and reflect the long-term effectiveness [9,10].

In summary, the local environment condition becomes more habitable, there are reduced salinity levels and lower pollution loads. These improvements create more comfortable conditions for ecosystem restoration. And validate the effectiveness of the project.

2.3 Flood Regulation Capacity

Much of the area in South Bay has lost mudflats because of the historic wetland (before restoration). These natural wetlands were absent. These also lower the strength of storm surges and runoff's buffering capacity. Don't Rephrase - In 2003, the project identified flood risk management as one of its core aim [3]. Flood regulation is ensured by a series of essential interventions. In the mid-term and in recent years, critical site modifications have contributed significantly towards enhancing flood buffering. To protect the wetlands from devasting floods, it are using intervention measures. These measures include levee breaches, tidal marshes restoration, upland transition zone construction and protecting & reinforcement of existing levees [11].

A levee breach at Ravenswood (the R4 pond) in December 2023 opened about 300 acres (121 ha) to tidal flows to restore wetland function. This was a former industrial salt pond. Restoration of wetlands can help soak up some of the water volume and energy from storm surges or high tides. Thus, these tidal and storm events reduce flood pressure on inland communities.

One more instance is the Phase II project at the Ravenswood Complex, which restored about 295 acres of tidal wetlands, improved hydrological exchange with the Bayfront Canal and involved levee reconstruction and upland transition zone creation. The design features of the wetlands and mudflats help in temporary storage or dissipation of tidal water during storm. They prevent the inundation or impact on inland people despite high external tide levels. The overall project area encompasses approximately 15,100 acres of former industrial salt pond lands of the South Bay Salt Pond Restoration project. These areas are slowly changing from industrial or isolated uses into tidal wetlands, mudflats, bird habitats, and transition zones. The restoration has created a huge wetland corridor that has great flood buffering functions at the theoretical and practical levels at this scale.

Although there are no publicly available long-term monitoring data on peak flow reduction or storage capacity for the SBSPRP, levee breaches, tidal marsh restoration, and transition zone construction provide multiple points of estimation. For instance, the opening of a 300-acre wetland can absorb tidal water for about half an hour to several hours, during storm surges or extreme high tide, or diffuse tidal pressure across the wetland rather than hitting on levees. The flood depth and flood damages faced by the neighbouring communities can be greatly lowered by such processes.

The increased ability of flood buffers to protect local communities means that their flood risk will fall as well as the damage to real estate, transport infrastructure and public facilities during storm surge events, while costs of insurance or investment in hard infrastructure will also lessen.

3. Conclusion

In short, the South Bay Salt Pond Restoration Project, after over 20 years of implementation, has illustrated the many ecological and social benefits of wetland restoration. The restored wetlands reduce habitat disturbance for threatened species like the Snowy Plover, regional water quality improves in key indicators like salinity and dissolved oxygen, and the flood regulating and buffering function gradually recovers, all contributing to the overall health of our ecosystems. The wetland has improved in landscape and environmental value. Thus, the quality of life of the residents and the landscape improvement can help these areas get a boost in future property values. Through long-term monitoring, public education and community participation, the same project has effectively integrated ecological protection with social awareness, which has educational and exemplary value.

In the future, integration of wetland restoration into green infrastructure investment strategies at the regional and national levels should also enhance resilience to climate change, sea-level rise, and extreme weather events. The policy recommendations are to continuously expand the coverage of Green activities and Public Engagement Programs and promote co-management and sharing of benefits in conservation and utilization in the community. A long-term monitoring system should be established that tracks not just water quality, flood risk and biodiversity indicators but that over time starts to accommodate social benefit variables in order to provide scientific support for policy and funding decisions. Future studies should entail assessments of ecological and social benefits and make use of cross-regional and multi-case comparative studies to extend the lessons learnt from the South Bay to other urban wetland restoration practices for the better protection and sustainable development of urban ecosystems.

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