Ecological Restoration Potential of Management Strategies at the Salton Sea

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February 20, 2018

Abstract

More bird species visit the wildlife refuge at the Salton Sea each than any other wildlife refuge in the western United States each year, but imminent water loss and water quality decline threaten the future of this ecosystem. These hydrological changes and the resulting ecological impact at the Salton Sea mimic future climate-change scenarios in regions across the planet, but on a much faster timescale. Many management solutions have been proposed to address the diversity of issues facing the Salton Sea, but often, bird ecology is not the central focus. This paper assesses the relationship between various high-level management strategies and the ecological pressures facing local bird groups and species. Results show that some management strategies, such as seawater import without appropriate salinity control, could still put ecological pressure on bird groups and species found at the Salton Sea. However, results also show that the strategies with the highest potential ecological relief are not necessarily the most complex and expensive. Among the most effective strategies, renewable desalination combined with vegetated wetland creation is expected to be the least expensive and also provide chemical control, increased aquatic species biodiversity and addtional ecological benefits. Depending on their ecological success, solutions deployed at the Salton Sea could serve as a benchmarks for the development of climate-change mitigation solutions in other regions.

1 Introduction

The Salton Sea harbors the most diverse bird wildlife refuge in the western United States (Refuge, a), and is an important stopover point for birds on the Pacific(Shuford et al., 2002) and Central flyways (Patten et al., 2003) - two major migratory routes(Cohen and Hyun, 2006). Millions of birds visit the Salton Sea each year and over 60% of the bird species known to breed in North America can be found in the Salton Sea(Refuge, c) ecosystem, highlighting the importance of the Salton Sea as an ecological resource. However this ecosystem is constantly changing and evolving due to various hydrological conditions.

Despite the name, the Salton Sea is not a sea; rather it is a lake that is fed by canals of the Colorado river. However, because the Salton Sea is about 280 feet below sea level, it is a 'terminal lake' - meaning that water flows in but no water flows out. Therefore, chemical compounds that have accumulated in Colorado river at the end of its journey, such as salt and heavy metals, and compounds in local agricultural runoff, such as pesticides and fertilizer, as well as waste runoff from local industries all accumulate in the Salton Sea. This has resulted in an abundance of toxic compounds, frequent eutrophic conditions, high salinity, and an overall decline of water quality(Cohen and Hyun, 2006) - transforming the Salton Sea from a place of human use and recreation to an ecosystem that supports only mutant tilapia(Riedel et al., 2002; Cohen and Hyun, 2006) and a limited number of organisms(Cohen and Hyun, 2006). Contaminants and pathogens may be linked to avian botulism and other bird diseases observed at the Sea(Shipley et al., 1999). All of these issues are threats to the Salton Sea's function as wildlife preserve.

However, the changes in water policy of the Salton Sea beginning in 2018 are potentially even more destructive. At this time, the Quantitative Settlement Agreement (QSA)(James, 2015) will go into effect, diverting water from agricultural areas to urban areas and drastically reducing the water flow to the Salton Sea. This will ultimately result in a 60% reduction of lake volume and is projected to more than triple the salinity of the lake, killing all fish, and reduce biodiversity. For example, the food web in the Sea is projected to reduce from a phytoplankton - zooplankton - copepod system that feeds a network of 10 - 20 invertebrate species of invertebrates other higher level organisms to a phytoplankton - brine fly - brine shrimp system that feeds just 2 macroinvertebrate species (Cohen and Hyun, 2006). The reduction of water inflow will also shrink estuarial areas as well, isolating individual estuarial channels and disconnecting populations of fish, including the federally and state endangered Desert Pupfish(Agency, 2015), that inhabit these estuaries(of Water Resources, 2006; Cohen and Hyun, 2006). Combined, these changes would cause ecological disruption for many organisms dependent on Salton Sea ecosystem.

In addition to threatening birds, water loss at the Salton Sea is expected to cause additional large-scale impacts to the region(Cohen, 2014). For example, the exposure of lake sediment and the emission of toxic dust that is known to cause respiratory disease[1] and property value loss along a receding shoreline[2].

Given that these issues stem from a reduction in water resources, the Salton Sea can be considered a microcosm of anthropomorphically-driven climate change, but on a much faster timescale. The upshot is that the Salton Sea could become an important demonstration of successful climate-change management strategies. Various engineering and bioremediation solutions already exist for addressing the problem of dust emissions, such as deep tilling, permaculture for restoring the soil(Ash et al., 2013), and other solutions that build upon the experience gained at nearby Owens Lake(Iovenko, 2015). Furthermore, various financial or restorative solutions, such as the Desert Shores Dust Mitigation and Channel Restoration Project(White, 2017), are available for managing property loss issues. However, the ecological issues facing the Salton Sea are much more complex and determining solutions to mitigate these problems is more challenging.

2 Importance of Salton Sea Ecology

The Salton Sea harbors 58,000 acres of bird habitat(Jones et al., 2016) as well as the Sonny Bono wildlife refuge, which is the most diverse bird refuge in the western United States. 422 bird species(Refuge, a) (over 60% of the species known to breed in North America) can be found at the Salton Sea and over 100 of these species breed on the refuge(Shuford et al., 2002). The Salton Sea's ecological importance is further highlighted by the large percentage of North American bird populations that rely on it each year, for example: 90% of the Eared Grebe population (Shuford et al., 2002), about 23% - 30% of the White Pelican population (Shuford et al., 2002), 50% of the ruddy duck population(Society), and 25% the Caspian Tern population(Society) can be found at the Salton Sea. It is also one of the most important wintering ground for the White-faced Ibis, hosting up to 20,000 of these birds each year(Shuford et al., 2002).

The Salton Sea also provides habitat for many threatened and protected species, for example, 70% of the California Burrowing Owl population(Refuge, b) and 40% of the Yuma Clapper Rail population(Shuford et al., 2002) in the US resides within the Salton Sea ecosystem.

Part of the reason that bird populations are attracted to the increasingly toxic Salton Sea is due to the loss of historical wetlands in California(Cohen, 2014). By the 1980's, studies had estimated that California had lost of over 90% of its wetlands(Cal, 1986) due to land development. More recent studies, utilizing more accurate GIS systems, have

[1] Evaporation of water will expose playa (lake sediment) which could become airborne in the presence of wind. This dust has a particle size on the scale that causes respiratory damage to humans if inhaled(Cohen and Hyun, 2006). Heavy metals and other toxins present in the sediment can cause additional health issues when attached to dust. Similar issues have been observed at nearby dry lakebeds. Nearby Owens Lake is the largest single source of hazardous dust in the United States and has exposed local residence to dust levels 10 times above the acceptable limit and cost over $1B to mitigate(Iovenko, 2015). The dust issue at the Salton Sea however, is much larger and expected to cause between $3B to $37B in respiratory health issues(Cohen, 2014) unless dust is properly mitigated.

[2] Increased exposure to dust, and a receding shoreline puts lakefront homes further from the water's edge, resulting in up to a $7B drop in property values around the Salton Sea(Cohen, 2014).

found that wetland loss across California is geographically heterogeneous, and that some regions, such as coastal southern California, have lost fewer wetlands(Stein et al., 2014) than other regions(of Geography et al., 2003; Safran et al., 2013). However, historic wetlands on coastal southern California were only a small fraction of the total historic wetlands across the state and aggregating these more recent results suggests that the overall loss of wetlands across California is about 90%, consistent with earlier estimates. The 58k acres of wetlands at the Salton Sea(Jones et al., 2016) therefore represent about 13% of California's remaining 450k acres(Cal, 1986) of wetland habitat.

The loss of wetlands along migratory routes has reduced the supply of bird habitat and therefore increased the Salton Sea's value as a natural resource. Understanding this value is important, as it determines the size, scale, and budget of ecosystem preservation and restoration projects at the Salton Sea given the pending QSA. One approach to determine this value used surveys that evaluated the public's willingness to pay to for similar California lakes and wetlands(Cohen, 2014). Scaling these results to the size of the Salton Sea suggests that the public's percieved value of maintaining the Salton Sea for the next 30 years is between \$10B - \$26B[3](Cohen, 2014). Another, perhaps more physically-accurate, method to determine the value of the Salton Sea is to estimate the total ecological cost associated with its loss. Once known, the value of solutions can therefore be determined by estimating the solution's ability to mitigate ecological loss; more effective solutions will have a positive 'return on investment' and the cost of the solution will be less than the cost of ecological loss that was mitigated.

However, quantifying the exact ecological value of the Salton Sea is difficult due to the variety of ecological interactions at various ecosystem scales. Properly measuring the cost of ecological loss and the value of proposed management strategies requires a holistic understanding of how changes in Salton Sea resources affect local bird populations, the larger ecosystem, and ultimately society and the economy. An approach to assess this involves:

1. Understanding the interaction between various management strategies and birds in the region, quantifying the relationship between local bird populations and habitat availability (Jones et al., 2016).
2. Estimating how local ecological effects and local population disturbance scale to macro-ecological losses along migratory flyways (given available alternative habitats), the larger foodweb, and larger ecosystem as a whole(Martino and Gao, 2016; Gao et al., 2016).
3. Determining solution details and sizes required to reduce pressure on bird populations and larger ecosystem losses to a desired level.

Regarding 3) a recent report(Jones et al., 2016) from the Audubon society has identified the amount and type of habitat used by bird groups at the Salton Sea between approximately 1999 and 2015, and has proposed that similar habitat sizes and types be maintained in management scenarios to minimize the impact and pressure on bird populations. Unfortunately, maintaining the current amount of freshwater flow and stabilizing the Salton Sea ecosystem in its current form is unfeasible given the QSA, driven by competing demands for water from other services, regional lifestyles, and contemporary business and government practice. Alternative scenarios to mimic current conditions at the Salton Sea can be extremely expensive, and, depending on the severity of the physical and economic constraints, the agencies managing the Salton Sea might need to trade-off delivering certain types and amounts of ecosystem relief. Properly evaluate such trade-offs requires a quantitative analysis that estimates the impact of partial ecosystem disruption on the larger ecosystem, society, and economy.

Fundamentally all living organisms are connected, and a disturbance in one part of the ecosystem can affect populations in other parts of the ecosystem, but quantitative research on this topic (item 2 above) is only in early stages(Martino and Gao, 2016; Gao et al., 2016). Birds provide many ecosystem services for human society, such as pest control, pollinators, scavengers, seed dispersers, seed predators, and ecosystem engineers(Whelan et al., 2008). But only some aspects of the ecological, economic, and social ripple effect triggered by perturbations to the Pacific flyway have been quantified(Rubio-Cisneros et al., 2014). For example, an acre of mangroves in the tropical wintering grounds of the Pacific flyway has been estimated to generate roughly \$1645 in US hunting permits per km^2, with hunters spending roughly 40 times that amount in hunting-related expenditures(Rubio-Cisneros et al., 2014). It is difficult to relate the value of Mexican wintering grounds to the stop-over habitat at the Salton Sea, which also depends on the capacity,

[3]Based on survey data from the San Joaquin Wetlands and Mono Lake, assuming discount rates between 4% and 6%(Cohen, 2014)

saturation level, and stopover duration at neighboring wetlands, but similar value could possibly be extrapolated for the $\sim$ 500,000 migrating waterfowl that also winter at the Salton Sea(Shuford et al., 2002). This recreational value however, likely only represents a small fraction of the total ecological value provided by birds along the Pacific flyway and the $\sim$ \$10B evaluation derived from public surveys(Cohen, 2014).

The remainder of this document contributes to the qualitative understanding of item 1 above. The goal is to assess the potential/possibility for high-level management strategies to relieve pressure on birds and bird groups at the Salton Sea and thus provide a means to qualitatively estimate the loss-mitigation potential associated with each strategy. A subset of seven bird groups(Cohen and Hyun, 2006) and 39 bird species(Cohen and Hyun, 2006; Cohen, 2014) that breed at the Sea, including 21 threatened species (Shuford et al., 2002) were considered in the analysis. Details of the bird groups and species considered here, as well as the definitions and descriptions of high-level management strategies, are discussed in the next section. Further details showing how bird species population sizes and preferences are expected to scale with the size of various habitat types and ecosystem features can be found in the recent study published by the Audubon society(Jones et al., 2016).

3 Methods

A scenario analysis was used to determine the potential for management strategies to relieve pressure on bird groups at the Salton Sea. To accomplish this, a dimensional database model was used to aggregate and compare general habitat and nutrient requirements for seven major bird groups at the Salton Sea(Cohen and Hyun, 2006; Jones et al., 2016; Refuge, a) to the potential types of habitat and nutrients offered by twelve different high-level management strategies, many of which have been proposed for the Salton Sea(of Water Resources, 2006; Agency et al., 2011; Hodges and Gensler, 2016; Solis, 2016; Krantz, 2003).

3.1 Bird Groups

Group Name	Group Habitat Needs	Group Nutrient Needs
Marshbirds	Marshlands	Marshland Insects, aquatic insects around submerged vegetation
Landbirds	Farmland	Agricultural insects, invertebrates
Fish-eating Birds	Water body, Estuary	Fish, some pelicans and cormorant will try to eat pupfish and sailfin molly though they are much smaller
Wading Birds	Farmland, Snags (for roosting), Water body, Marshland	Fish, aquatic and terrestrial invertebrates (farmland), small reptiles (farmlands), amphibians. Minor effect if Salton Sea food is limited, can adapt to a more agricultural diet
Shorebirds	Water body (Playa), Estuary, Farmland	Hypersaline Pool invertebrates/worms, Estuary Insects, Agricultural Land insects. Some birds expected to adapt diet to solely estuary and agricultural insects
Gulls and Terns	Estuaries, Water Body with small islands (For nesting), Farmland	Agricultural Insects, Estuary Insects. Black skimmer may eat pupfish and sailfin molly. Most birds of this type can adapt diet to estuary and agricultural insects

Table 1: Habitat and nutrient needs of six bird groups at the Salton Sea (Cohen and Hyun, 2006; Refuge, a; Jones et al., 2016), some habitat and nutrient preferences were inferred from habitats of species that are members of that group(Society, 2017).

Thirty-nine species of birds were considered in this analysis were grouped into 7 different bird groups based on phylogenic similarity, common habitat and food resources. These groups were chosen to be consistent with an earlier review on the ecological threat to bird groups at Salton Sea (Cohen and Hyun, 2006). Table 1 shows the bird groups considered in this analysis as well at their nutrient and habitat needs(Cohen and Hyun, 2006) are shown in Table 1. Many of these bird groups use a diversity of habitats and food sources, or may be able to adapt to other habitats or food sources.

Species Name	Group Name	Protected	Agency
American Avocet	Wading Birds	No	
American Coot	Waterfowl	No	
American White Pelican	Fish-eating birds	Yes	DF
Black Rail	Marshbirds	Yes	CR
Black Skimmer	Gulls and Terns	Yes	DFW
Black Tern	Gulls and Terns	Yes	D
Black-crowned Night Heron	Marshbirds	No	
Black-necked Stilt	Shorebirds	Yes	S
Brown Pelican	Fish-eating birds	Yes	FC
California Gull	Gulls and Terns	No	
Caspian Tern	Gulls and Terns	No	
Cattle Egret	Landbirds	No	
Cinnamon Teal	Waterfowl	No	
Common Moorhen	Marshbirds	No	
Double-crested Cormorant	Fish-eating birds	Yes	D
Dunlin	Wading Birds	Yes	S
Eared Grebe	Waterfowl	No	
Forster's Tern	Gulls and Terns	No	
Great Blue Heron	Wading Birds	No	
Great Egret	Wading Birds	No	
Green Heron	Marshbirds	No	
Gull-billed Tern	Gulls and Terns	Yes	DFW
Killdeer	Shorebirds	Yes	S
Least Bittern	Marshbirds	Yes	D
Long-billed Curlew	Shorebirds	Yes	DS
Long-billed Dowitcher	Wading Birds	Yes	S
Marbled Godwit	Shorebirds	Yes	FS
Pied-billed Grebe	Waterfowl	No	
Redhead	Waterfowl: Diving Ducks	No	
Ring-billed Gull	Gulls and Terns	No	
Ruddy Duck	Waterfowl	No	
Short-billed Dowitcher	Wading Birds	Yes	S
Snowy Egret	Wading Birds	Yes	W
Snowy Plover	Shorebirds	Yes	DRFS
Western Grebe	Waterfowl	No	
Western Sandpiper	Shorebirds	Yes	S
Whimbrel	Shorebirds	Yes	FS
White-faced Ibis	Wading Birds	Yes	D
Yuma Clapper Rail	Marshbirds	Yes	FCR

Table 2: Associated groups and protection status of bird species considered in this analysis(Cohen and Hyun, 2006; Cohen, 2014; Shuford et al., 2002). Birds are considered 'protected' if they are characterized as threatened or endangered by the protection agencies listed in column 4. Agency key: F = federally endangered, C = California endangered or threatened, D = California Department of Fish and Wildlife Species of Special Concern, S = National Shorebird Protection Program, W = National Waterbird Conservation Program, B = US Fish and Wildlife Service Bird of Conservation Concern, R = IUCN Endangerment Red List

The 39 species considered in this study are shown in table 2 below. twenty-one of these species are classified as threatened or endangered(Shuford et al., 2002; Cohen, 2014) by at least one governmental or independent agency. Approximately 200 more species of birds at the Salton Sea either are members of or use resources similar as the 6 non-agricultural bird groups considered here(Refuge, a). Similar results are expected to apply to these $\sim$ 200 species as well. Furthermore, bird groups and species that are present at the Salton Sea but not considered here, such as birds of prey(Refuge, a), could also be impacted as the overall productivity and energy transfer through the Salton Sea ecosystem declines.

3.2 Management Strategies

Solutions proposed to manage the impending environmental issues at the Salton Sea (of Water Resources, 2006; Agency et al., 2011; Hodges and Gensler, 2016; Solis, 2016; Krantz, 2003) typically provide at least one of the following four ecosystem functions:

Estuarial wetland creation - provides habitat resources for birds and other organisms that prefer brackish water. Resources created include expanded mudlfats, ponds and estuarial branches. Wetlands and ponds would need to range in depth (up to 1m deep to support preferences of some ducks and fish eating birds(Jones et al., 2016)) and size to support a variety of fish - ranging from the desert pupfish to tilapia, and large enough for take-off and landing of water birds.

Vegetated wetland creation - dense vegetation along the banks of wetlands provides habitat for breeding, nesting of marshbirds, wading birds and ducks (Jones et al., 2016; Cohen and Hyun, 2006). Rails feed on invertebrates and seeds along embankments, ducks and marshbirds forage on or around aquatic vegetation growing in water(Jones et al., 2016), and geese feed directly on vegetation itself(Society, 2017). (Jones et al., 2016)

Salinity control and water quality control - prevents regions of Salton Sea from becoming too salty or too contaminated to support life. Examples of salinity control include the use of barriers to separate hypersaline regions from saline regions within the Salton Sea, creation of stable saline lakes or ponds that contain fish along the edge of the receding Salton Sea, as well as desalination.

Water import - retains water levels and lake volume at contemporary or historic levels. Maintaining water levels would preserve islands used by gulls and terns for nesting(Jones et al., 2016), snags used by some wading birds for roosting(Cohen and Hyun, 2006), and ensure sufficient shoreline length for shorebirds water surface area for fish eating birds and other bird populations that use it. Typical water import solutions at the Salton Sea include constructing channels that connect the Salton Sea to the Gulf of California(Solis, 2016). Such channels would be gravity-fed, as the current surface of the Salton Sea is about 235 feet below sea level.

For example, solutions proposed in the Salton Sea Ecosystem Restoration Program(of Water Resources, 2006), such as the creation of 'Salinity Habitat Complexes' and 'Marine Seas'(of Water Resources, 2006), focus on salinity control and achieve this using floating barriers that separate less salty estuarial waters from the hypersaline main water body. The Species Conservation Habitat proposal (Agency et al., 2011) creates estuarial wetlands such as mudflats and various sizes and depths of brackish water ponds along and next to the Salton Sea. The Oceanwater Corridor Restore the Salton Sea Program (OCRSSP)(Hodges and Gensler, 2016) proposes to import saltwater from the ocean to maintain water levels in the Salton Sea and prevent water loss. This program also creates vegetated wetlands and deploys salinity control measures. Wetlands are created by flowing the ocean water though aquaculture, ocean water farming, and mangrove systems. Salinity control is implemented via floating barriers to stratify salinity across regions of the lake, pumps and drainage ditches to deliver hypersaline water from the Salton Sea to groundwater sinks and/or aquaculture fields, as well as salt harvesting. Desalination of the Salton Sea has been discussed for decades(Krantz, 2003) typically in the form of evaporation ponds(Krantz, 2003) used for salt harvesting or thermal distillation plants, which have already been demonstrated and tested at Salton Sea at small scale(Sephton, 2014). A do-nothing solution provides no ecosystem functions and has the largest impact to the local ecology(Cohen and Hyun, 2006).

Future environmental scenarios at the Salton Sea depend on the ecosystem functions provided by the solutions. Here, a *solution* is considered detailed, specific, properly-scaled implementations of a higher level *strategy* that incorporates a particular combination of ecosystem functions. Table 3 provides details of the high level strategies considered in this analysis with the ecosystem functions provided by each. The author anticipates that once an appropriate strategy is determined and clearly defined, cost-effective solutions and methods for achieving that strategy can be identified.

Table 3: Management scenarios at the Salton Sea. First column: Scenario Name, Second Column: Ecosystem functions provided (W=Wetland Creation, D = Salinity Control, S = Seawater Import), Third Column: Habitat provided in the scenario, Fourth Column: Food Resources provided in the scenario. Fifth Column: Solution Description.

Strategy Name	Ecosystem Functions Provided	Strategy Description	Habitat Resources	Food Resources
Unmanaged	U	Minimal change in land/ecosystem management. Sonny Bono Refuge will remain, but with reduced inflow from Colorado resulting in reduced Marsh area, reduced marsh water volume and higher concentration of fertilizer, chemicals, etc.	Remaining Wetlands and Marshes (Reduced Area and Quality), Remaining Water Body and Shoreline (Reduced Area and Quality, No Protected Snags), Farmland	Brine Shrimp - Brine Fly Salton Sea food chain, Reduced Quantity of and Quantity of Marshland Food Chain, Loss of fish (Desert Pupfish, Sailfin Molly) in Wetland Food Chain, Farmland Food Chain
Wetlands	W	Creation of fresh and brackish estuarial wetlands and/or ponds in addition to desert pupfish channels. Ponds and wetlands support growth of large fish and have area large enough for bird takeoff and landing. Consistent with the Salton Sea Species Conservation Habitat Project (SCH).	Remaining Water Body and Shoreline (Reduced Area and Quality, No Protected Snags), Farmland, Additional brackish ponds / wetlands, Remaining Marshes (reduced area and quality)	Brine Shrimp - Brine Fly Salton Sea food chain, Brackish shallow water food Chain, Reduced quantity and quality of marshland food chain, Farmland Food Chain
Wetlands + Vegetation	VW	Creation of fresh and brackish estuarial vegetated wetlands and/or ponds in addition to desert pupfish channels. Similar to Species Conservation Habitat, but with additional vegetated wetlands	Remaining Water Body and Shoreline (Reduced Area and Quality, No Protected Snags), Farmland, Additional Marshes and vegetated wetlands	Brine Shrimp - Brine Fly Salton Sea food chain, Marshland Food Chain, Farmland Food Chain
Salinity Control	D	Salinity control achieved via salinity control methods such as Saline Habitat Complex or Deep Marine Sea(Hodges and Gensler, 2016), desalination using thermal desalination methods. Considers salinity control of sub-regions or entire lake. Reduced water inflow in Sonny Bono Marsh areas.	Desalinated Water Body and Shoreline (Reduced Area, No Protected Snags), Farmland, Remaining Wetlands and Marshes (Reduced Area and Quality)	Increased Salton Sea Food Chain Biodiversity, Farmland Food chain, Reduced quantity and quality of marshland food chain, Could lose pupfish and sailfin molly if estuarial drains are not connected
Salinity Control + Wetlands	DW	Smaller water body but with salinity control, achieved via salinity control methods (described above). New brackish water ponds / wetlands would be created	Desalinated water body and Shoreline (Reduced Area, No Protected Snags), Remaining marshes (reduced area and quality), additional brackish shallow water ponds and wetlands, farmland	Growth in Salton Sea food chain biodiversity, Brackish shallow water food chain, reduced quantity and quality of marshland food chain, Farmland food chain

Salinity Control + Wetlands + Vegetation	DVW	Smaller water body but with salinity control, achieved via salinity control methods (described above). Reduced water inflow in Sonny Bono Marsh areas but new vegetated wetlands would be created	Water Body and Shoreline (Reduced Area, No Protected Snags), Additional Marshes and wetlands, Farmland	Growth in Salton Sea Food Chain Biodiversity, Marshland Food Chain, Farmland Food chain
Saltwater Import	S	Seawater Imported, but salt would accumulate and salinity would steadily rise, eventually resulting in a dead sea. Assumes Sonny Bono Wildlife Refuge would be separated and preserved as is using some type of barrier	Restored Water Body and Shoreline (uninhabitable quality), Farmland, Remaining Marshes (Reduced Area and Quality)	Microorganism Salton Sea Food Chain, Farmland Food Chain, Reduced Quantity and Quality of marshland food chain, Could lose pupfish and sailfin molly if estuarial drains are not connected
Saltwater Import + Wetlands	SW	Seawater Imported to maintain water level, but salinity would rise, eventually resulting in a dead sea. New Wetlands and brackish water ponds would be created	Restored Water Body and Shoreline (Uninhabitable), Farmland, Remaining marshes (reduced area and quality), additional brackish shallow ponds and wetlands	Microorganism Salton Sea food chain, brackish shallow water food chain, reduced quantity and quality of marshland food chain, Farmland Food Chain
Saltwater Import + Wetlands + Vegetation	SVW	Seawater Imported to maintain water level, but salinity would rise, eventually resulting in a dead sea. New Wetlands/marshland would be created	Restored Water Body and Shoreline (Uninhabitable), Farmland, Additional marshes and wetlands	Microorganism Salton Sea food chain, Full Marshland Food Chain, Farmland Food Chain
Saltwater Import + Salinity Control	SD	Seawater imported to maintain water-level and in combination with desalination using thermal desalination methods.	Restored, Desalinated Water Body and Shoreline, Farmland, Remaining Marshes (Reduced Area and Quality)	Growth in Salton Sea food chain biodiversity, Reduced Quantity and Quality of wetland food chain, Could lose pupfish and sailfin molly if estuarial drains are not connected, Farmland food chain
Saltwater Import + Salinity Control + Wetlands	SDW	Seawater imported to maintain water-level in combination with desalination using thermal desalination methods. New marshlands and vegetated wetlands added. As with all other solutions, there will be reduced freshwater inflow into Sonny Bono Wildlife Refuge.	Restored Desalinated Water Body and Shoreline, Farmland, Remaining Marshes (Reduced Area and Quality), Additional brackish shallow ponds and wetlands	Growth in Salton Sea Food Chain Biodiversity, Brackish shallow water Food Chain, reduced quantity and quality of marshland food chain, Farmland Food chain
Saltwater Import + Salinity Control + Wetlands + Vegetation	SDVW	Seawater imported to maintain water-level in combination with desalination using thermal desalination methods. New marshlands and vegetated wetlands added. As with all other solutions, there will be reduced freshwater inflow into Sonny Bono Wildlife Refuge.	Restored Desalinated Water Body and Shoreline, Farmland, Additional Marshes and wetlands	Growth in Salton Sea Food Chain Biodiversity, Marshland Food Chain, Farmland Food chain

3.3 Assessing Impact

Figure 1: Matrix showing the potential impact of management strategies on bird groups at the Salton Sea. The vertical rows in the grid correspond to different management strategies and the horizontal columns correspond to bird groups. The scenarios are ordered by the number of ecosystem functions provided, shown in the first column. The color indicates the expected pressure of the scenario on the row on the bird group in the column. Green indicates little to no pressure, orange indicates moderate pressure, and red indicates high pressure. Pressure is based on the total food and habitat score for each scenario - bird group combination, as defined in section 3.3. An interactive version of the figure is available on tableau public: https://public.tableau.com/views/EcologicalRestorationPotentialofManagementStrategiesattheSaltonSea/InteractiveBirdType-ScenarioMap?:embed=y&:display_count=yes&publish=yes

Pressure on bird groups will depend on their needs and the resources available in each future scenario. To assess this, habitat and nutrient needs of each bird group were compared to the habitat and nutrient resources potentiall provided by each strategy. A qualitative nutrient and habitat score was assigned to each each combination of habitat and bird group. Scores ranged from 0-3 with 3 representing the most pressure on a bird group. For example a scenario resulting in a complete loss of food chain for a bird group was assigned a score of 3, whereas an adaptable food chain alteration was assigned a nutrient score of 1. Reduction of food available was also assigned a score of 1, but food reduction combined with a food chain alteration resulted in a score of 2. Similarly, reduction of habitat area or an adaptable change away from in lost habitat types resulted in a habitat score of 1. Simultaneous habitat change and reduction were assigned a habitat score of 2, and full loss of habitat was assigned a score of 3. The habitat score and nutrient score were added together to determine a total qualitative measure of pressure on a bird group for each management scenario. Total scores of 0 or 1 were categorized as low pressure, a total score of 2 was categorized as moderate pressure, and a score of 3 or higher was categorized as high pressure.

Table 3 in the appendix shows the scores for each bird group and management scenario as well as reasons for each. The final step of the analysis aggregates the results from this scenario analysis to determine the pressure from each management scenario on bird groups, species and protected species at the Salton Sea. It assumes that solutions will be scaled sufficiently to relieve all pressure associated with the solution's ecosystem function. Results therefore approximate best-case scenarios.

4 Scenario Analysis Results

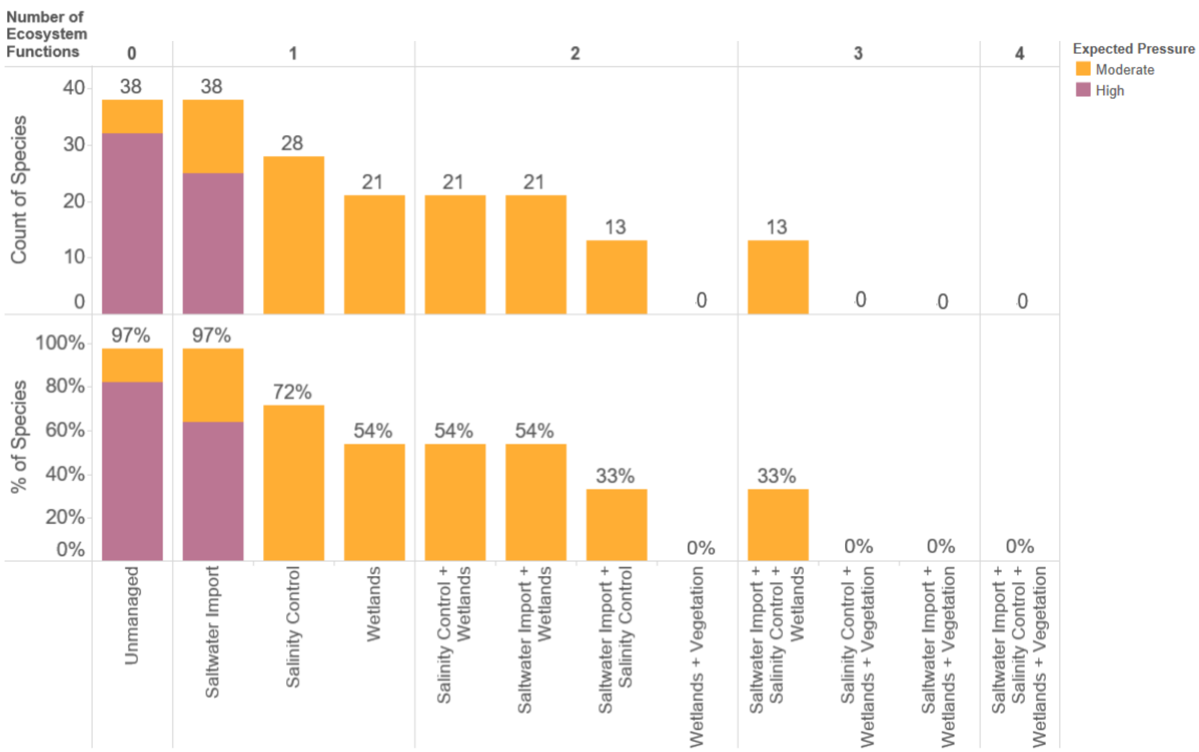

Figure 2: Top: Bar chart showing the count of bird species included in this study that are potentially impacted by each Salton Sea management scenario. Bar height corresponds to the number of species. Management scenarios are shown the horizontal axis along with number of ecosystem functions provided by each. Bars are stacked, with red bars indicating the number of species facing high pressure, and orange bars the number of species facing moderate pressure. The total number of species impacted by each scenario is shown at the top of each stacked bar. Bottom: Bar chart showing the percentage of bird species in this study at the Salton Sea potentially impacted by each management scenario. Bar height corresponds to the percentage of species. Management scenarios are on the horizontal axis along with the number of ecosystem functions provided by each. Bars are stacked, with red bars indicating the percentage of species facing high pressure, and orange bars indicate the percentage of species facing moderate pressure. The total percentage of species is shown at the top of each stacked bar.

The potential impact of each management scenario on each bird group, as shown in Figure 1. Scenarios are ordered by ecosystem function. In general, those with more ecosystem functions provide more relief across bird groups. Bird groups with shared habitat types(Refuge, a; Cohen and Hyun, 2006) and available alternative food chains (Cohen and Hyun, 2006), such as marshbirds, geese, gulls tend to show moderate pressure rather than high pressure for strategies providing few ecosystem functions. The unmanaged scenario clearly has the highest potential impact on the bird

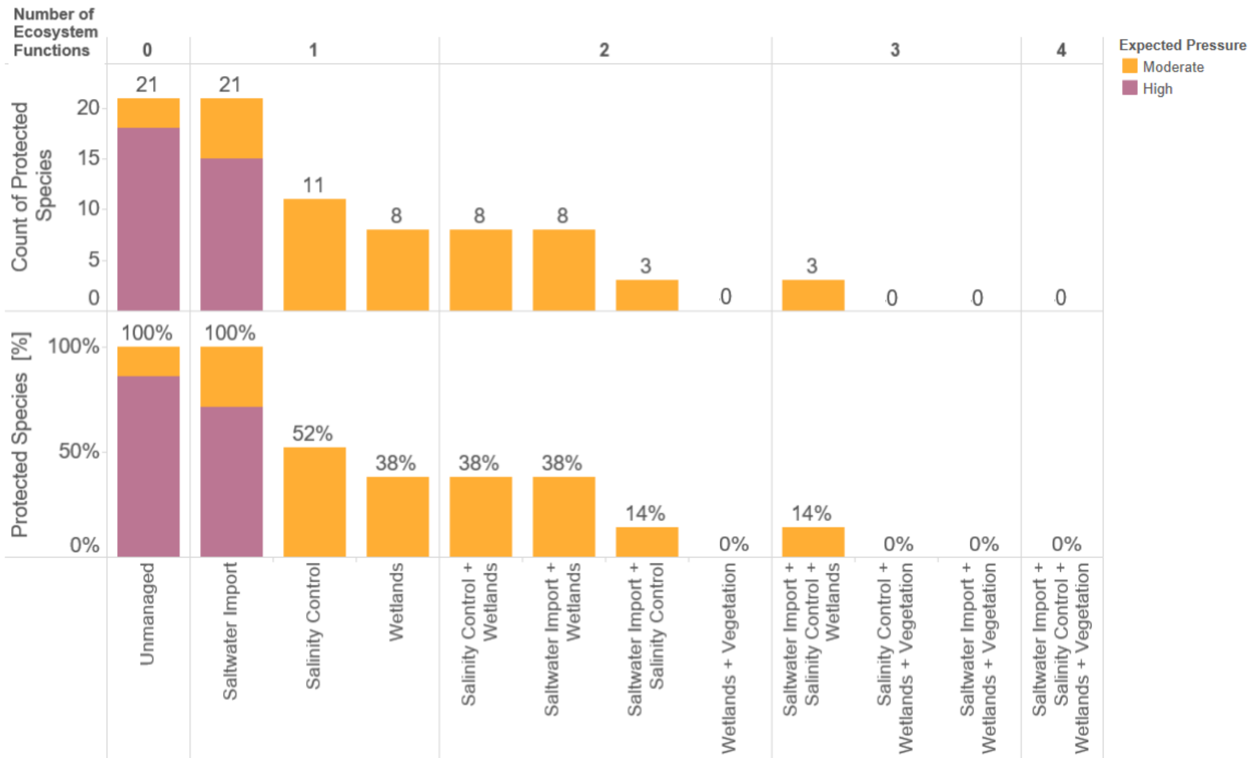

Figure 3: Top: Bar chart showing the count of threatened bird species included in this study that are potentially impacted by each Salton Sea management scenario. Bar height corresponds to the number of threatened species and management scenarios are on the horizontal axis. Bars are stacked, with red bars indicating the number of threatened species facing high pressure, and orange bars indicating the number of threatened species facing moderate pressure. The total number of threatened species impacted by each scenario is shown at the top of each stacked bar. Bottom: Bar chart showing the percentage of threatened bird species in this study impacted by each Salton Sea management scenario. Bar height corresponds to the percentage of threatened species and management scenarios are on the horizontal axis. Bars are stacked, with red bars indicating the percentage of threatened species facing high pressure, and orange bars indicating the percentage of threatened species facing moderate pressure. The total percentage of threatened species impacted by each scenario is shown at the top of each stacked bar.

groups at the Salton Sea. Four strategies have the greatest potential to relieve pressure across all bird groups, and mitigate the most of the $\sim$ \$10B of ecological loss(Cohen, 2014). These four strategies range in complexity and number of ecosystem function, but all of them include wetlands and vegetation, suggesting these two functions are a needed requirement to relieve pressure across all bird groups. The creation of vegetated wetlands alone has the potential to address the needs of all bird groups, provided that a sufficient amount of wetlands and ponds are created to satisfy bird needs. Desalination/salinity control with vegetated wetlands is another scenario that offers similar relief across bird groups and may be cheaper than constructing large amounts of wetlands alone. This comparison is discussed further in the next section. Furthermore, since Figure 1 shows that a few strategies without saltwater import have the potential to relieve pressure on bird groups, suggesting that water import may be unnecessary for preserving bird ecology at the sea.

The percentage of bird species affected by each scenario is shown in Figure 2. The unmanaged scenario as well as seawater import without salinity control scenario put pressure on most of the species considered here. Seawater import without salinity control places large pressure on bird populations because it flows large volumes of salt to the Salton Sea. Salt would steadily accumulate until it precipitates out of the Salton Sea, resulting in Dead-Sea-like conditions that only support bacteria and microorganisms. Seawater import strategies therefore need to be combined with some form of salinity control or fish-laden marshland creation to be ecologically viable solutions. Figure 2 also indicates that any strategy implementing just one ecosystem management function would only relieve pressure from a fraction of bird species. For example, wetland creation without vegetation would provide only partial relief to many of the bird groups and species that rely on dense vegetation for habitat and aquatic vegetation for foraging.

Figure 3 shows the percentage of threatened species impacted by each management scenario. Damage to these protected species comes at higher ecological cost and, as in Figure 2, relief for protected species increases as the number of ecosystem functions delivered increases. But only the same four most effective strategies have the potential to minimize the impact to protected species.

5 From Strategies to Solutions

Combined, figures 1-3 emphasize that seawater import without either salinity control or relevant supporting ecological systems will not relieve pressure on bird populations at the Salton Sea. On the other hand, seawater import with salinity control and marshland creation would relieve the most pressure on birds - but this is also the most complex and expensive solution of those considered here. Part of the cost and complexity of this solution derives from the seawater canal itself. The shortest route for importing seawater sources water from the Gulf of California and involves either a) filling Laguna Salada, a dry lake in Mexico, with ocean water from the Gulf of California and constructing an approximately 40 mile long canal connecting Laguna Salada to the Salton Sea(Solis, 2016), or b) an approximately 100 mile long canal from the Gulf of California itself. Such a project requires bi-national agreements and, depending on the length of the channel, could cost \$1B (Solis, 2016) to construct the canal system alone. The OCRSSP seawater import plan (Hodges and Gensler, 2016) proposes the construction of the longer channel, which would require costly pumping of 520kAF/yr of ocean water up to the high point of the route. An additional value of OCRSSP is that seawater import will maintain volume of the lake, mitigate dust emissions, and preserve lakefront property. However, the cost and complexity of this project could make it less attractive, if a less costly combination of other solutions can offer similar performance.

Figures 1-3 also suggest that the least complex strategy with the potential to mitigate pressure across all bird groups involves the creation of vegetated wetlands. However, to be successful, 'wetland only' strategies would have to be of sufficient size to meet bird preferences(Jones et al., 2016). Sizes of wetland types preferred by current bird populations at the Salton Sea have been estimated: 10k acres of playa, 30k acres of mudflats and shallow water, 20k acres of mid-depth water (15cm - 30cm), 50k acres of deep water (>30cm), and 2k acres of vegetated wetlands(Jones et al., 2016). This scenario is currently feasible within the 10-year plan recently announced by the California Department of Natural Resources and Salton Sea Authority (Agency et al., 2017; Sahagun, 2017), however, as the sea recedes, it may be difficult to create wetlands and ponds of that magnitude in size in the current New river and Alamo river estuaries alone. Part of this plan may include the construction of the Species Conservation Habitat (Agency et al., 2011) which involves the creation of new wetlands and brackish ponds in the New and Alamo River estuaries. But the SCH only includes 3770 total acres of unvegetated playa, mudflats and ponds - much smaller than the expected preferred habitat area. The SCH may be initially sufficient as the Salton Sea recedes and continues to support a limited food-web and bird habitat, but will likely become insufficient once the Sea shrinks to a much smaller volume and no longer supports vertebrate life(Cohen and Hyun, 2006). The cost of creating tens of thousands of acres of wetland habitat sufficient for bird preferences is unclear, but the California Department of Water Resources and Department of Fish and Game has estimated the cost of creating expanded canals and estuaries to connect desert pupfish populations to be on the order of \$1B(of Water Resources, 2006), and the creation of a Saline Habitat Complex containing 38,000 acres of shallow and deep water wetlands up to 2m deep at the New and Alamo River estuaries would cost over \$2B(of Water Resources, 2006).

The SCH restricts vegetation growth in order to reduce mosquito vectors and limit the exposure of wildlife to selenium (Se) poisoning(Agency, 2015). However, in large wetland areas with slow flow, long residence times, and moderate dissolved Se inflow concentrations below the EPA limit, Se will deposit in sediemnts and be mobilized back into the food chain by microbial metabolism(Presser and Luoma, 2010; Lemly, 2002) regardless of the presence of vegetation. Its not clear whether the presence of vegetation will increase or decrease the deposition of bioavailable Se in sediments and the overall transfer of Se up the food chain[4]. More research is likely needed to better identify whether including vegetation at the flow rates and selenium concentrations in the expanded wetlands along the new river estuaries would contribute to increased selenium accumulation to toxic levels up the food chain or possibly reduce selenium bioaccumulation in the long term, compared to non-vegetated wetlands. Figures 1-3 show that wetland strategies without vegetation would put pressure on some bird groups and species. However, if vegetation is included in wetland solutions, Se monitoring and testing would likely be needed. Furthermore if Se concentrations become too high in the future, the wetland creation strategy may be unviable for fish inhabiting wetlands and many fish-eating and wading birds. As an alternative to vegetation on wetlands, dense vegetation on nearby exposed playa (used for dust suppression)(Agency et al., 2017) might provide some alternative habitat for marshbirds and birds using vegetation for nesting, but more research likely will need to be done to evaluate fitness.

Given the large size requirements for wetlands and possibly dangerous levels of selenium concentrations, a perhaps more feasible and possibly less expensive strategy combines desalination/salinity control efforts with the construction of smaller vegetated wetlands ('Salinity Control + Wetlands + Vegetation' strategy in Figures 1-3). Many options exist for implementing salinity control systems. A commonly-suggested option is to deploy barriers across parts of the Salton Sea to separate the hypersaline region of the lake from saline regions of the lake. Solutions such as the Saline Habitat Complex or Marine Sea described in the Salton Sea Ecosystem Restoration Program(of Water Resources, 2006) leverage this technology, and are estimated to cost between \$3B to \$6B. Evaporation ponds are another solution proposed to control salinity and remove salt(Krantz, 2003). However this solution may not be as feasible after the QSA begins and the sea starts to shrink; larger evaporation ponds will be needed to control quickly rising salinity levels, diverting water from the sea shrinking it to an even smaller size. Another, more viable, option for salinity control is desalination by thermal desalination plants. An appropriately sized desalination plant could remove the salt from the Salton Sea with a temporary transient period of high salinity as the sea shrinks, after which salinity would drop to a controllable, low level. Because of the very high salt concentrations present in the Salton Sea, thermal distillation (Sephton, 2014) would be the most cost-effective desalination technology, with the added benefit that it would also remove heavy metals, pesticides and other toxic dissolved compounds and could run off local renewable geothermal energy[5](Sephton, 2014). The size and cost of the plant required depends on how long of a transient period is tolerable; a plant that could process 50 kAF of Salton Sea water per year would cost $\sim$ \$250M (Sephton, 2017). This cost is much lower than the \$3B to \$6B cost of the Saline Habitat Complex solutions and possibly less expensive than wetland/ponds only solutions. With respect to ecology, desalination combined with vegetated wetland creation may be the most feasible and effective strategy, resulting in a smaller but sustainable Salton Sea.

Recent ecological simulations have found that maintaining a healthy large deep water body may also provide additional value to bird species that don't directly use it(Jones et al., 2016). For example, machine learning models have found that some shorebirds, gulls and terns strongly prefer having large areas of deep water nearby, in addition to preferences for larger shore area and shallow water areas(Jones et al., 2016). These types of indirect interactions between the Salton Sea itself and bird ecology reveal additional importance of maintaining a healthy large Salton Sea, best achievable with strategies that include Salinity Control and or Seawater Import with Salinity Control strategies.

In addition to cost and ecological performance, the time to deploy a solution is another performance measure to

[4] Selenium concentrations in the New River, freshwater marshes along the New River, Brawley Wetlands, and Species Habitat Ponds along the New River ranged from 1.2 - 4.2 μ-g / L (Agency, 2015). These are all below the EPA limit (Luoma and Presser, 2009). The expansion of wetlands and ponds will increase the residence time of water in wetland areas, slow down the flow, resulting in the deposit of more Se from water into sediments. The continued deposit of Se in sediments can then become incorporated into the microbial foodweb(Presser and Luoma, 2010), re-introduced to the larger food web, accumulating in fish(Lemly, 1987; Presser and Luoma, 2010). While plants also contribute to the recycling of Se in the food web through detrital material, plants can also immobilize(De Souza et al., 1998) and volatize Se(Lin and Terry, 2003; Hansen et al., 1998; Lemly, 2002), essentially removing it from the ecosystem. Because bioaccumulation of Se in the food chain is a complex process(Lemly, 2002), the inclusion of plants in wetlands with moderate Se concentrations (below EPA limits) could regulate Se, preventing its prolonged accumulation in wetlands. Inclusion of plants could also limit the transfer of Se to the Salton Sea itself, which could be released back into the Salton Sea food chain in the future (Byron and Ohlendorf, 2007).

[5] Possible energy sources for the desalination system include waste heat from local geothermal plants, geothermal energy, as well as solar energy. The amount and cost of energy supply also depends on the size of the geothermal system. After the transient period and once the salinity has been reduced to the target level, the desalination system can likely be driven off local power plant waste heat alone, since the salt flux from the New and Alamo rivers are small

consider, as the Salton Sea will begin rapid change in early 2018. For example, depending on the size of desalination plant, time to build the plant as well as the time required to reduce salinity to target levels could take decades. Building a canal and growing salt marshlands could require a similar timescale, whereas the building of ponds could be much quicker. The importance of time to deployment however, depends on the resiliency of the Salton Sea ecosystem and the time to recover from a prolonged disturbance. Ecological systems often demonstrate amazing resilience to quickly bounce back from disaster once viable conditions resume, as seen for example in the recovery of the Mount St. Helens ecosystem after volcanic eruption. Minimizing the impact of short-term damage may not be as important as highly functional ecosystem health in the long-term.

While implementation of the management scenarios discussed here would provide much relief for bird populations as the lake recedes, other ecological issues for birds at the Salton Sea still remain. Fertilizer runoffs and high concentrations of fertilizer cause growth of microorganisms, eutrophication, and de-oxygenation of the Salton Sea, killing fish and other wildlife at the sea. Scientists are researching the role of decomposing fish, among other local environmental factors, in avian botulism outbreaks at the Salton Sea (Shipley et al., 1999; Refuge, b). Heavy metals such as selenium accumulate in the sea and can be toxic for chicks growing up in the Salton Sea(Cohen and Hyun, 2006). Historically, the Salton Sea has been purposed as a sump for local agriculture and operating plants and as a result, it accumulates pesticides and other chemicals from these sources. But the biological dynamics linking the chemical, biological, and physical processes and the interaction between trophic levels in the food chain are not yet clearly understood(Shipley et al., 1999). Thermal distillation of the Salton Sea and part of its incoming water flow could mitigate some of these chemical issues, but a more holistic solution to preserving the Salton Sea ecosystem would include controlling release of chemicals from their source, by means of more efficient farming practices that improve soil health and water retention, such as permaculture(Ash et al., 2013). Changes associated with these more holistic permaculture solutions and practices may take some time to adopt and implement, but some technologies, such as thermal-distillation desalination(Sephton, 2014), could be deployed more rapidly to remove these chemicals from the Sea itself.

Acknowledgments
The author thanks Callen Hyland, Tom Sephton, and other members of the Salton Sea community and the San Diego Wet Lab for thoughtful discussion and feedback on this paper. The author also thanks the Living Room La Jolla and its baristas for providing an enjoyable workspace and ample supply of coffee.

If you found this work compelling and informative, *please make a tax-deductible donation* on our fundraiser page `https://fundrazr.com/81HqSf?`. Your contributions support this work, independent science and research, and other sustainability projects at the Salton Sea.

Appendix

Table 4: Habitat and food pressure on bird groups for various Salton Sea Management Scenarios. Column 2 shows the Management Scenario Key (U=unmanaged, W = wetland/marshland expansion, D = salinity control, S = Seawater Import). Columns 4, 6, 7 indicate the habitat, food, and total score respectively (see section 3.3 for meaning of individual scores). Column 8 converts the total score into a qualitative pressure (Low: Score <2, Moderate: Score = 2, High: score >2). Reasons for the scores are provided in column 9 with related references. Bird needs and expected adaptation are from references (Cohen and Hyun, 2006; Refuge, a; Jones et al., 2016; Society, 2017)

Bird Group Name	Solution Scenario	Habitat Expected Effect	Habitat Score	Nutrient Expected Effect	Nutrient Score	Total Score	Outcome	Reason
Marshbirds	U	Size Reduced	1	Size Reduced	1	2	Moderate	Reduced marshland habitat size and reduced size of preferred foraging area. Higher concentration of compounds in runoff due to less water flow and less dilution
Landbirds	U	No	0	No	0	0	Low	
Fish-eating Birds	U	Size Reduced	1	Food Chain Lost; Adaptation: No	3	4	High	Loss of food chain, reduced habitat
Wading Birds	U	Size Reduced, Some Habitat Type lost; Adaptation: Maybe	2	Food Chain Altered, Size Reduced; Adaptation: Expected	2	4	High	Loss of snag habitat for breeding, many wading birds prefer vegetation nesting and shallow water near dense vegetation(Jones et al., 2016), diet expected to shift to more agricultural diet (Cohen and Hyun, 2006)
Waterfowl	U	Marshland and Open water size reduced	1	Food Chain Altered, Size Reduced; Adaptation: Long Transition	2	3	High	Waterfowl use both open water and wetland habitats. Most forage directly on vegetation or around aquatic vegetation. Vegetated wetland habitat used for Breeding. Expected to transition to a brine shrimp food chain at the Salton Sea, until 2060 when the sea becomes too salty to support shrimp (Cohen and Hyun, 2006).
Shorebirds	U	Size Reduced	1	Food Chain Altered, Size Reduced; Adaptation: Expected	2	3	High	Expected to adapt to feed on brine flies at shores, also uses marshland and agricultural lands (Cohen and Hyun, 2006).

Gulls and Terns	U	Size Reduced, Some Habitat Type lost; Adaptation: Maybe	2	Size Reduced	1	3	High	Loss of preferred island nesting habitat, adapt to reduction of preferred estuarial and shoreline diet by relying on agricultural and other wetland food (Cohen and Hyun, 2006)
Marshbirds	W	Size Reduced	1	Size Reduced	1	2	Moderate	Reduced marshland habitat size and reduced size of preferred foraging area. Higher concentration of compounds in runoff due to less water flow and less dilution
Landbirds	W	No	0	No	0	0	Low	
Fish-eating Birds	W	No	0	No	0	0	Low	Assumes enough deep ponds/wetlands created and stocked with fish such as tilapia
Wading Birds	W	Some Habitat Loss, Marshland size reduced; Adaptation: Maybe	2	No	0	2	Moderate	Loss of snag habitat for breeding, many wading birds prefer vegetation nesting and shallow water near dense vegetation (Jones et al., 2016), diet expected to shift from Salton Sea diet to similar fish planted in new wetlands and ponds and agricultural land diet
Waterfowl	W	Size Reduced	1	Size Reduced	1	2	Moderate	Marshland habitat for breeding reduced. Bot land and aquatic vegetation reduced for foraging. Assumes individual ponds and wetlands large enough for take-off and landing, support for pileworms, copepods, full brackish food chain, and deep enough for foraging.
Shorebirds	W	No	0	No	0	0	Low	Alternative pond and mudflat diet will be similar to current Salton Sea, but smaller volume.
Gulls and Terns	W	Some Habitat Loss; Adaptation: Maybe	1	No	0	1	Low	Loss of some island habitats for nesting. Mostly estuarial birds so expanding estuaries will serve them well for food chain

Marshbirds	VW	No	0	No	0	0	Low	
Landbirds	VW	No	0	No	0	0	Low	
Fish-eating Birds	VW	No	0	No	0	0	Low	Assumes enough deep ponds/wetlands created and stocked with fish such as tilapia
Wading Birds	VW	Some Habitat Loss; Adaptation: Maybe	1	No	0	1	Low	Loss of snag habitat, diet expected to shift from SS diet to more marshland and agricultural land diet
Waterfowl	VW	No	0	No	0	0	Low	Assumes individual ponds and wetlands large enough for take-off and landing, support for pileworms, copepods, full brackish food chain, and deep enough for foraging. However total pond area at mid-water and shallow depths (based on Species Conservation Habitat Monitoring and Adaptation Plan) is likely to be less than similar type of area in current Salton Sea
Shorebirds	VW	No	0	No	0	0	Low	Alternative pond and mudflat diet will be similar to current Salton Sea, but smaller volume.
Gulls and Terns	VW	Some Habitat Loss; Adaptation: Maybe	1	No	0	1	Low	These birds prefer marshland and vegetated wetlands
Marshbirds	D	Size Reduced	1	Size Reduced	1	2	Moderate	Still have reduced habitat area and increased concentration of compounds due to less water flow for dilution
Landbirds	D	No	0	No	0	0	Low	
Fish-eating Birds	D	Size Reduced	1	No	0	1	Low	Though Habitat size will be reduced by 50%, desalination may bring food chain fish productivity to levels similar to current

Wading Birds	D	Marshland Size Reduced, Some Habitat Type lost; Adaptation: Maybe	2	No	0	2	Moderate	Loss of snag habitat for roosting, many wading birds prefer vegetation nesting and shallow water near dense vegetation. desalination may bring food chain fish productivity to levels similar to current
Waterfowl	D	Marshland Size Reduced	1	Size Reduced	1	2	Moderate	Reduced size of marshlands for breeding and foraging needs. Increased compound runoff concentration in estuaries.
Shorebirds	D	No	0	No	0	0	Low	
Gulls and Terns	D	Some Habitat Loss; Adaptation: Maybe	1	Size Reduced	1	2	Moderate	loss of some island habitats for nesting, reduction of preferred estuarial and shoreline habitat. Desalination may bring increased food productivity however.
Marshbirds	DW	Size Reduced	1	Size Reduced	1	2	Moderate	Still have reduced habitat area and increased concentration of compounds due to less water flow for dilution
Landbirds	DW	No	0	No	0	0	Low	
Fish-eating Birds	DW	No	0	No	0	0	Low	
Wading Birds	DW	Marshland Size Reduced, Some Habitat Type lost; Adaptation: Maybe	2	No	0	2	Moderate	Loss of snag habitat for breeding, many wading birds prefer vegetation nesting and shallow water near dense vegetation
Waterfowl	DW	Size Reduced	1	Size Reduced	1	2	Moderate	Reduced size of marshlands for breeding and foraging needs. Increased compound runoff concentration in estuaries.
Shorebirds	DW	No	No	0	0	Low		
Gulls and Terns	DW	Some Habitat Loss; Adaptation: Maybe	1	No	0	1	Low	loss of island habitats for nesting
Marshbirds	DVW	No	0	No	0	0	Low	
Landbirds	DVW	No	0	No	0	0	Low	
Fish-eating Birds	DVW	No	0	No	0	0	Low	
Wading Birds	DVW	Some Habitat Loss; Adaptation: Maybe	1	No	0	1	Low	loss of snags for roosting

Waterfowl	DVW	No	No	0	0	Low		
Shorebirds	DVW	No	No	0	0	Low		
Gulls and Terns	DVW	Some Habitat Loss; Adaptation: Maybe	1	No	0	1	Low	loss of island habitats for nesting
Marshbirds	S	Size Reduced; Adaptation: Maybe	1	Size Reduced	1	2	Moderate	Marshland birds, some salt may diffuse into marshes in the seawater import scenario
Landbirds	S	No	0	No	0	0	Low	
Fish-eating Birds	S	No	0	Food Chain Altered; Adaptation: No	3	3	High	Dead Sea
Wading Birds	S	Marshland Size Reduced; Adaptation: Maybe	1	Food Chain Altered, Size Reduced; Adaptation: Expected	2	3	High	Reduction in estuarial habitat and loss of Salton Sea Diet as it will be a dead sea. Can adapt diet to estuary and agriculture (Cohen and Hyun, 2006)
Waterfowl	S	Size Reduced; Adaptation: Maybe	1	Food Chain Altered, Size Reduced; Adaptation: No	3	4	High	Waterfowl use marshland habitat for breeding and open water and marshland habitat for foraging, often around aquatic vegetation or on vegetation directly. Expected to transition to a brine shrimp food chain, but the sea becomes too salty to support shrimp for a Saltwater import scenario only
Shorebirds	S	Estuary Size Reduced; Adaptation: Maybe	1	Food Chain Altered, Size Reduced; Adaptation: Expected	2	3	High	Diet ok for hypersaline invertebrates(Cohen and Hyun, 2006) but not dead sea. Estuary habitat reduced. Will adapt diet to estuary and agricultural (Cohen and Hyun, 2006)
Gulls and Terns	S	Size Reduced; Adaptation: Maybe	1	Size Reduced; Adaptation: Maybe	1	2	Moderate	Marshland birds, some salt may diffuse into marshes in the seawater import scenario
Marshbirds	SW	Size Reduced; Adaptation: Maybe	1	Size Reduced	1	2	Moderate	Marshland birds, some salt may diffuse into estuaries/wetlands in the seawater import scenario

Landbirds	SW	No	0	No	0	0	Low	
Fish-eating Birds	SW	No	0	No	0	0	Low	Large enough habitat in mid and shallow depths, but Salton Sea will be a dead sea and food only available in created wetland areas
Wading Birds	SW	Marshland Size Reduced	1	Size Reduced	1	2	Moderate	Snags offer protection and can shift diet from Salton Sea fish to Similar Fish in created ponds and wetlands. But created wetlands at the south of the Salton Sea will likely have smaller area than current wetlands
Waterfowl	SW	Marshland Size Reduced; Adaptation: Maybe	1	Size Reduced; Adaptation: Maybe	1	2	Moderate	Reduced marshland area for breeding and foraging. Also some salt may diffuse into estuaries/wetlands in the seawater import scenario
Shorebirds	SW	No	0	Size Reduced; Adaptation: Maybe	1	1	Low	Should have enough wetland nutrient resources of similar type but some will adapt diet
Gulls and Terns	SW	No	0	No	0	0	Low	
Marshbirds	SVW	No	0	No	0	0	Low	
Landbirds	SVW	No	0	No	0	0	Low	
Fish-eating Birds	SVW	No	0	No	0	0	Low	Assumes ponds and/or wetlands deep enough and stocked with larger fish such as tilapia
Wading Birds	SVW	No	0	No	0	0	Low	Snags offer protection and can shift diet from SS to more agricultural
Waterfowl	SVW	No	0	No	0	0	Low	
Shorebirds	SVW	No	0	No	0	0	Low	Should have enough wetland nutrient resources, providing similar diet, also expected to adapt adapt diet
Gulls and Terns	SVW	No	0	No	0	0	Low	
Marshbirds	SD	Size Reduced; Adaptation: Maybe	1	Size Reduced; Adaptation: Maybe	1	2	Moderate	Still have reduced habitat area and toxicity
Landbirds	SD	No	0	No	0	0	Low	

Fish-eating Birds	SD	No	0	No	0	0	Low	
Wading Birds	SD	Marshland Size Reduced	1	No	0	1	Low	Snags avail, but reduced marshland size
Waterfowl	SD	Marshland Size Reduced; Adaptation: Maybe	1	Size Reduced; Adaptation: Maybe	1	2	Moderate	Reduced marshland area for breeding and foraging. Also some salt may diffuse into estuaries/wetlands in the seawater import scenario
Shorebirds	SD	No	0	No	0	0	Low	
Gulls and Terns	SD	No	0	No	0	0	Low	
Marshbirds	SDW	Size Reduced; Adaptation: Maybe	1	Size Reduced; Adaptation: Maybe	1	2	Moderate	still have reduced marshland habitat area and toxicity
Landbirds	SDW	No	0	No	0	0	Low	
Fish-eating Birds	SDW	No	0	No	0	0	Low	
Wading Birds	SDW	Marshland Size Reduced	1	No	0	1	Low	
Waterfowl	SDW	Marshland Size Reduced; Adaptation: Maybe	1	Size Reduced; Adaptation: Maybe	1	2	Moderate	Reduced marshland area for breeding and foraging. Also some salt may diffuse into estuaries/wetlands in the seawater import scenario.
Shorebirds	SDW	No	0	No	0	0	Low	
Gulls and Terns	SDW	No	0	No	0	0	Low	
Marshbirds	SDVW	No	0	No	0	0	Low	
Landbirds	SDVW	No	0	No	0	0	Low	
Fish-eating Birds	SDVW	No	0	No	0	0	Low	
Wading Birds	SDVW	No	0	No	0	0	Low	
Waterfowl	SDVW	No	0	No	0	0	Low	
Shorebirds	SDVW	No	0	No	0	0	Low	
Gulls and Terns	SDVW	No	0	No	0	0	Low	

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