SALTON SEA WATER IMPORTATION SUBMITTAL REVIEW

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Technical Memorandum (TM) #8.2

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Reviewed by: Independent Advisory Panel

Subject Area: Supporting Environmental Analysis

Topic: Species Salinity Tolerance

This Technical Memorandum (TM) was prepared as part of the Salton Sea Water Importation Proposal Review to provide information to support and reflect the Independent Review Panel's evaluation of submitted ideas to restore the Salton Sea by water importation and provide the Salton Sea Management Program (SSMP) with approaches that are feasible. Parts of this TM may be used in the Panel's Screening Report, Fatal Flaw Report, Feasibility Report, and/or Summary Report (Reports). In the event that any discrepancies are found between the Reports and this TM, the Reports shall take precedence.

1.0 Species Salinity Tolerance

The Salton Sea historically has been home to over 400 species of bird, many fish, invertebrates, some amphibians, and plants. Identifying a salinity target for restoring the Salton Sea food web requires understanding the different salinity tolerances of these species and how they support one another. Figure 1 provides a broad overview of species that can be supported at different salinities.

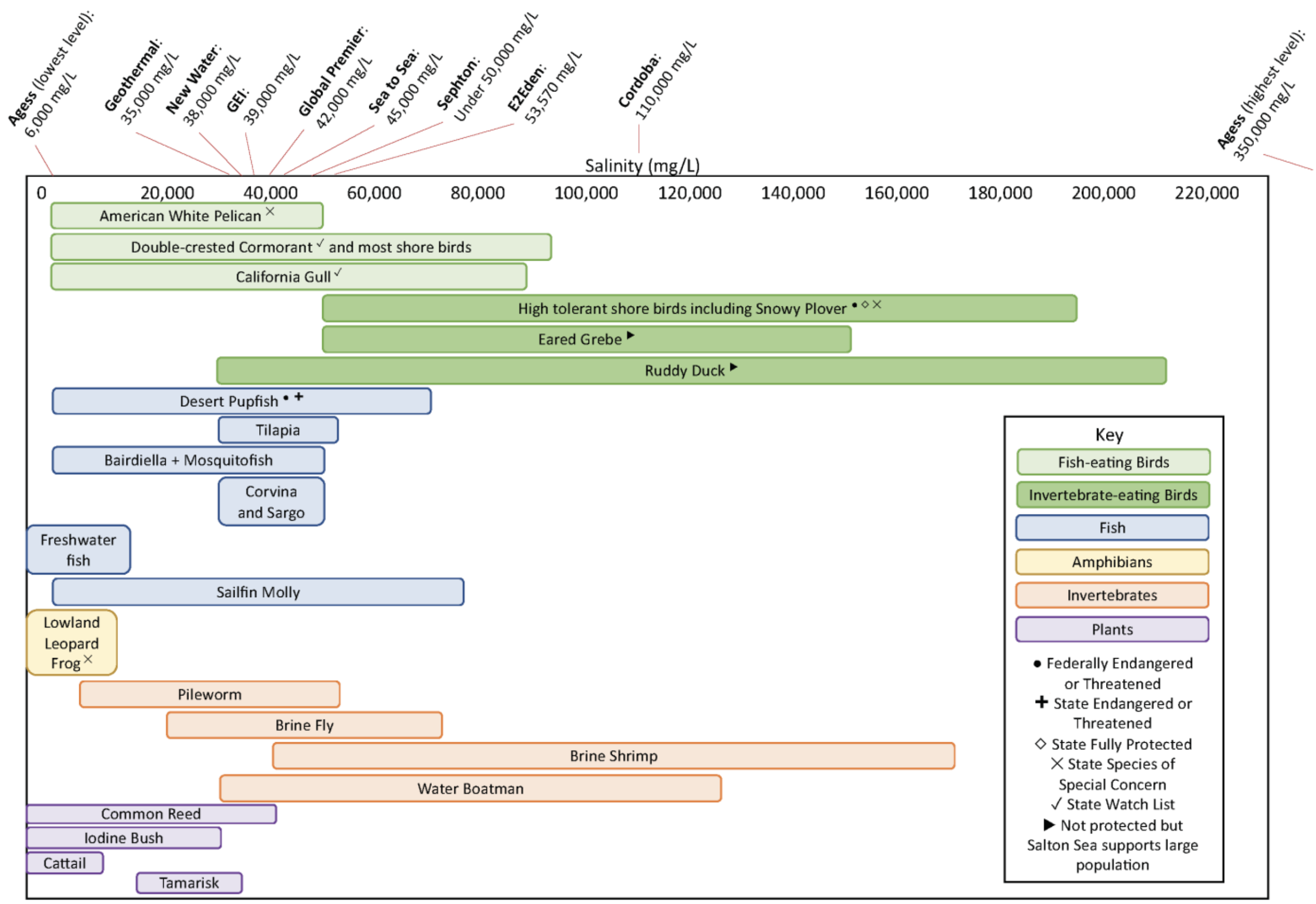

Figure 1: Select species and species groups by salinity tolerance range (mg/L).

1.1 Plants

Salinity tolerance of plants located on surrounding playa and freshwater or brackish wetlands should be considered in the water importation feasibility analysis as these species form the base of the Salton Sea ecosystem food web. The salinity tolerance for seven vegetation types found around the Salton Sea are listed in Table 1. It should be noted that tolerance is often life stage dependent, with species gaining salt tolerance as they mature (Choudhuri, 1968).

Table 1: Plants located on playa or wetlands surrounding the Salton Sea

Category	Common Name	Species Name	Tolerance
Primary species within the shrublands in the Sonoran Desert (Nye et al., 2021)	**Creosote Bush**	*Larrea tridentata*	• Optimum: 500 mg/L (Marshall, 1995)
Sparsely vegetate playa; Rare vegetation on perimeter of Salton Sea (CDFW, 2021)	**Iodine Bush**	*Allenrolfea occidentalis*	• Occurs up to 30,000 mg/L soil salinity • Optimum: 10,000 mg/L (Mozingo, 1987)
Wetlands (Shuford et al., 2000)	**Cattail**	*Typha latifolia*	• Maximum tolerance: 5,627 mg/L (Shay and Shay, 1986) to 11,300 mg/L (Penfound and Hathaway, 1938)
Wetlands (Shuford et al., 2000)	**Common Reed**	*Phragmites australis*	• Tolerance: 0-45,000 mg/L (Lissner and Schierup, 1997; Chambers et al., 2003) • New colonization unlikely above 10,000 mg/L (Chambers et al., 2003) • Optimum is 5 mg/L (Lissner and Schierup, 1997)
Wetlands (Shuford et al., 2000)	**Tamarisk**	*Tamarix racemosa*	• 18,000-36,000 mg/L (USDA Forest Service, 2016)
Rare vegetation on perimeter of Salton Sea (CDFW, 2021)	**Blue Palo Verde**	*Parkinsonia florida*	• 1,800 mg/L (High Commission for the Development of Arriyadh, 2014)
Rare vegetation on perimeter of	**Honey Mesquite**	*Prosopis glandulosa*	• Can tolerate 6,000 mg/L

Salton Sea (CDFW, 2021)	(Felker et al., 1981)

1.2 Invertebrates

Salinity influences which invertebrates can exist in the Salton Sea and therefore influence the fish and bird populations (SDSU, no date; Simpson and Hurlbert, 1998). About 15 invertebrate species have been recorded within the Salton Sea, but many plummeted in abundance in 2005 and are now considered very rare or locally extirpated (SDSU, no date; Coe et al., 2000; Kuperman et al., 2000; Anderson et al., 2007). Invertebrates consume algae and provide an important food source to other invertebrate species, fish, and shorebirds (SDSU, no date; Coe et al., 2000; Kuperman et al., 2000). The 2005 barnacle population loss negatively impacted the pile worm population, which rely on barnacle shells for habitat (Coe et al., 2000; Anderson et al., 2007). The pile worm declines harmed fish and bird populations that rely on the pile worm as a food source, most notably Eared Grebes (Kuhl and Oglesby, 1979; Kuperman et al., 2000; Anderson et al., 2007). The water boatman (*Corixidae)* population has increased in recent years and are found in the higher salinity regions at the edges of the Salton Sea (Kirby, 2019; SDSU, no date). Brine shrimp and potentially brine fly also likely currently exist in the Salton Sea based on their salinity tolerance (Table 2) and provide an important food source to birds and the water boatman (Cohen and Hyun, 2006; SDSU, no date). Selecting a salinity goal for the Salton Sea should take into consideration the tolerance of different invertebrate species, especially those that support other invertebrate populations. Table 2 lists the salinity tolerances of the invertebrates currently and historically found at the Salton Sea.

Table 2: Invertebrate Tolerance

Common Name	Species Name	Tolerance
Pileworm	*Nereis (Neanthes) succinea*	• Tolerate up to 65,000 mg/L • Reproduce up to 45,000-50,000 mg/L (Kuhl and Oglesby, 1979)
Brine Shrimp	*Artemia franciscana*	• Max adult tolerance: 300,000 mg/L • Newly hatched max tolerance: 170,000 mg/L (Conover and Bell, 2020) • Minimum tolerance: 40,000 mg/L (Nougué et al., 2015)

Brine Fly	*Ephydra*	• Most productive habitat range: 25,000-75,000 mg/L (Roberts et al., 2016)
Barnacle	*Balanus amphitrite saltonensis*	• Abundance declines: 50,000 mg/L • Max tolerance: 70,000-80,000 mg/L (Simpson and Hurlbert, 1998)
Water Boatman	*Trichocorixa reticulata*	• Recorded in Gulf of California: 37,000-44,000 mg/L (Scudder, 1976) • Max tolerance: 110,000 mg/L (Euliss et al., 1991) • Reported at 126,000 mg/L (TetraTech, 2004)

1.3 FISH

Both marine and freshwater fish have resided in the Salton Sea, although many recorded fish are non-native to the region. Of the 51 recorded species found in the Salton Sea, only the Desert Pupfish is endemic to the Salton Sea Basin, while a few entered the basin via the Colorado River, namely Carp, Rainbow Trout, Razorback Sucker, and Striped Mullet (Riedel and Costa-Pierce, 2002; USFWS, 2008; CNRA, 2021). Recorded fish can be grouped into three tolerance categories: about 10,000 mg/L, 30,000 mg/L to 50,000 mg/L, and above 50,000 mg/L. Some fish have wider tolerances than others. For instance, the Desert Pupfish (*Cyprinodon macularius*) are adapted to both freshwater and high salinity conditions (Nye et al., 2021). See Table 3 for 13 species of fish historically found in the Salton Sea and their known salinity tolerances.

Salinity tolerance can range within a species between life stages, with reproduction and egg survival generally having a lower salinity tolerance than adults (Keeney, no date; Stolberg and Horn, 2008; Hijuelos et al., 2016; Davis, 2021). Once an optimum salinity tolerance is passed, osmoregulation is negatively impacted, causing such issues as decreased growth rate (Riedel and Costa-Pierce, 2002) and organ failure (Salati et al., 2011). Temperature can also impact salinity tolerance in fish; Tilapia's ability to tolerate salinity decreases below 15°C or above 35°C (Riedel and Costa-Pierce, 2002). Due to rising Salton Sea salinity, the only remaining fish species within the Salton Sea in 2008 was the California Mozambique Tilapia, although other species are still found in the surrounding inflows and marshes, including the Desert Pupfish (USFWS, 2008; Nye et al., 2021). Stable fish populations in the Salton Sea are necessary in supporting fish-eating birds, such as the Brown Pelican.

Table 3: Fish salinity tolerance

Common Name	Species Name	Tolerance
Desert Pupfish	*Cyprinodon macularius*	• Eggs and adults: Freshwater – 70,000 mg/L • Larvae: Max 90,000 mg/L (Keeney, no date)
California Mozambique Tilapia	*Oreochromis mossambicus x O. urolepis hornorum*	• Adults can tolerate up to 120,000 mg/L if change is gradual (UC Davis, 2021) • Reproduction can only occur under 69,0000 mg/L (UC Davis, 2021) • Highest growth rate: 14,000 mg/L (Riedel and Costa-Pierce, 2002) • Optimum salinity: 30,000-55,0000 mg/L (Riedel, 2016)
Razorback Sucker	*Xyrauchen texanus*	• Larvae can be produced: 600-8,900 mg/L • Long-term survival: 12,800-14,700 mg/L (Stolberg and Horn, 2008)
Bairdiella	*Bairdiella icistia*	• Freshwater – 45,000 mg/L (Riedel and Costa-Pierce, 2010)
Orangemouth Corvina	*Cynoscion xanthulus*	• 29,000-45,000 mg/L (Fish & Wildlife, 1985)
Sargo	*Anisotremus davidsoni*	• 29,000-45,000 mg/L (Hagar, no date)
Carp	*Cyprinus carpio*	• Tolerate up to 12,000 mg/L • Gill and kidney changes above 6,000 mg/L (Salati et al., 2011)
Red Shiner	*Cyprinella lutrensis*	• Max: 10,000 mg/L (Matthews and Hill, 1977)
Channel Catfish	*Ictalurus punctatus*	• Tolerate: 0-11,000 mg/L • Optimum: less than 4,000 mg/L (FAO, 2021)

White Catfish	*Ameiurus catus*	• Max: 14,000 mg/L (Kendall and Schwartz, 1968)
Largemouth Bass	*Micropterus salmoides*	• Optimum for young: 0-1,600 mg/L • Optimum for adults: 500-5,000 mg/L • Adults can tolerate up to 12,000 mg/L (Hijuelos et al., 2016)
Mosquitofish	*Gambusia affinis*	• Freshwater - 50,000 mg/L • Some reports of survival up to 58,800 mg/L (Chervinski, 1982)
Sailfin Molly	*Poecilia latipinna*	• Freshwater - 80,000 mg/L (Hagar, no date)

1.4 Birds

Salinity tolerance in birds refers to the ability to excrete salt consumed via drinking water directly or eating prey (e.g., invertebrates or fish). Some avian species have salt glands, organs that excrete salt to enable the bird to maintain homeostasis when consuming saltwater (Schmidt-Nielsen, 1959), which can change in size within an individual according to age, habitat salinity, prey consumed, and temperature (Gutiérrez et al., 2012). Species that do not have salt glands are unable to consume saltwater instead of freshwater; exceeding salinity tolerance in birds results in weight loss and death (Purdue and Haines, 1977). Fish-eating birds generally tolerate a range of salinities from 0-50,000 mg/L, waterfowl tolerate a range of about 30,000-200,000 mg/L, and shorebirds a general range of 50,000-200,000 mg/L (Table 4).

Table 4: Bird Tolerance. Low salinity is about 20,000-60,000mg/L, moderate salinity is about 90,000-150,000mg/L, and high salinity is above 150,000mg/L (estimated from Siegel and Bachand (2002)).

Common Name	Species Name	Tolerance	Salt Gland Presence
American White Pelican	*Pelecanus erythrorhynchos*	• 0-50,000 mg/L (Jones et al., 2016)	Yes (Redrobe, 2014)
Double-crested Cormorant	*Phalacrocorax auritus*	• 0-100,000 mg/L (Jones et al., 2016)	Yes (Schmidt-Nielsen, 1959)

Snowy Plover	*Charadrius alexandrinus*	• Hypersaline (Robert et al., 2016)	Yes (Purdue and Haines, 1977)
Long-billed Curlew	*Numenius americanus*	• Can tolerate moderate salinity (Roberts et al., 2016)	Unclear but likely (Other *Numenius* have salt glands (Gutiérrez et al., 2012))
California Gull	*Larus californicus*	• Optimum for adults: 90,000 mg/L • Chicks can tolerate less (Mahoney and Jehl, 1985)	Yes (Mahoney and Jehl, 1985)
Black-necked Stilt	*Himantopus mexicanus*	• Can tolerate moderate salinity (Roberts et al., 2016) • Forage in waters of 130,000-180,000 ppt (Siegel and Bachand, 2002)	Yes (Hamilton, 1975)
Dunlin	*Calidris alpina*	• 50,000 -200,000 mg/L (Jones et al., 2016)	Yes (Gutiérrez et al., 2012)
Killdeer	*Charadrius vociferus*	• Mostly freshwater, but can tolerate moderate salinity (Roberts et al., 2016)	Yes (Purdue and Haines, 1977)
Long-billed Dowitcher	*Limnodromus scolopaceus*	• 0-100,000 mg/L (Jones et al., 2016)	Yes (Hughes, 1970)
Marbled Godwit	*Limosa fedoa*	• 0-100,000 mg/L (Jones et al., 2016)	Unclear but likely (Other *Limosa* have salt glands (Gutiérrez et al., 2012))
Short-billed Dowitcher	*Limnodromus griseus*	• 0-100,000 mg/L (Jones et al., 2016)	Unclear but likely (Other *Limnodromus* have

			salt glands (Hughes, 1970))
Western Sandpiper	*Calidris mauri*	• 50,000-200,000 mg/L (Jones et al., 2016)	Unclear but likely (Other *Calidris* have salt glands (Gutiérrez et al., 2012))
Whimbrel	*Numenius phaeopus*	• Can tolerate moderate salinity (Roberts et al., 2016)	Unclear but likely (Other *Numenius* have salt glands (Gutiérrez et al., 2012))
Eared Grebe	*Podiceps nigricollis californicus*	• Optimum: 109,000-124,000 mg/L • Tolerate: 50,000-150,000 mg/L (Jones et al., 2016)	Yes (Gutiérrez et al., 2012)
Ruddy Duck	*Oxyura jamaicensis rubida*	• Optimum: 29,300 mg/L • Max tolerance: 215,700 mg/L (Athearn et al., 2012)	Yes (Hughes, 1970)

1.5 Amphibians

Amphibians are generally unable to tolerate high salinities, leading to death, abnormalities, and lowered weights and growth rates (Griscom et al., 2008). Most amphibians are not found in saline habitats, but the Lowland Leopard Frog (*Rana yavapaiensis*), which was previously extinct in the Salton Sea region and is a State Species of Special Concern, can tolerate brackish waters and now has a population in the Sonny Bono Wildlife Refuge wetlands (Ruibal, 1959; Parker, 2019; CNDDB, 2021b). Likewise, the Woodhouse Toad (*Bufo woodhousii)* and Bullfrog (*Rana catesbeiana)* can also tolerate brackish water and are present in the wetlands (Table 5). The wetlands water is reported to be Imperial Irrigation District Class 1 irrigation water, meaning it has a low salt content (USFWS, 2021), and a blend of Alamo River water and water from the Salton Sea (WestWater Research, 2018). Based on Alamo River salinity, the wetlands have an estimated salinity of 2,100 mg/L (Salton Sea Authority, 2016), categorizing the wetlands as slightly saline (freshwater is up to 1,000 mg/L and slightly saline is 1,000-3,000mg/L) (USGS, 2018).

Table 5: Amphibian Salinity Tolerance

Common Name	Species Name	Tolerance
Woodhouse Toad	*Bufo woodhousii*	• 100-5,300 mg/L (salinity of waterbody species located in a 2008 Wyoming survey) (Griscom et al., 2008)
Lowland Leopard Frog	*Lithobates yavapaiensis* (formerly *Rana yavapaiensis)*	• Max tolerance (eggs): 5,000 mg/L • Max tolerance (adults): 13,000 mg/L (Ruibal, 1959)
Bullfrog	*Rana catesbeiana*	• Tadpoles die at 6,000 mg/L (Ward et al., 2015)

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