



National Carrier Project Company

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Review of Tolerance of Corals to Hypersalinity

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Abbreviations and Acronyms

AAWDC	Aqaba-Amman Water Conveyance and Desalination
AAWDCP	Aqaba-Amman Water Desalination and Conveyance Project
ALT	Alanine Aminotransferase
CAT	Catalase
CCA	Crustose Coralline Algae
CHA	Critical Habitat Assessment
ESIA	Environmental and Social Impact Assessment
GoA	Gulf of Aqaba
IFC	International Finance Corporation
LDH	Lactate Dehydrogenase
MDA	Malondialdehyde
SOD	Superoxide Dismutase

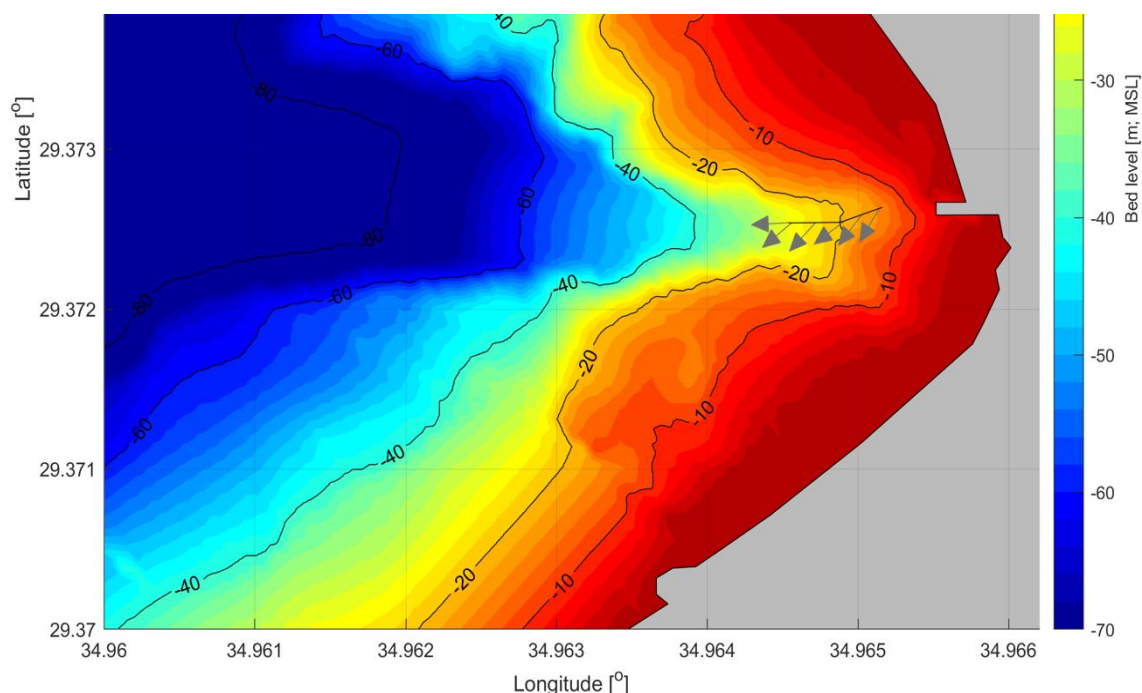
Purpose and Scope of Document

The purpose of this document is to undertake a review of salinity tolerances for coral that will be exposed to AAWDCP brine discharge and to present a salinity risk assessment with a recommended salinity tolerance. The review will provide a synthesis of peer-reviewed literature and other available reports (including environmental impact assessments, and regulatory guidance) that have addressed the tolerance of corals to hypersalinity conditions, focusing on species relevant to the discharge area. Emphasis has been placed on chronic and acute exposure effects, life-stage sensitivities, and ecosystem-level impact.

1 Background Review of Available Project Information

The current EPC design (case 5) proposes to use an outfall diffuser with 6 ports between approximately 15 and 30m water depth (Figure 1-1, Source: Deltares AAWDCP - Rapid assessment recirculation modelling - 17 March 2026). The diffuser will be placed in the centre of a sandy canyon, which is bordered by a fringing reef.

Figure 1-1: Bathymetry and Location of Outfall Pipe and Diffuser Ports



The 2024 National Monitoring Program recorded a salinity range of 40.36 psu to 40.73 psu at the Industrial Zone station, which is the closest to the study area. The report noted a slight increase in salinity over the period 2020 to 2024 in the summer months, possibly reflecting the influence of temperature (via increased evaporation) on salinity. For modelling purposes, a background salinity of 40.7 psu has been used. Characteristics of the modelled hypersaline brine plume that are relevant to a review on hypersaline tolerances for corals are shown in Table 1-1.

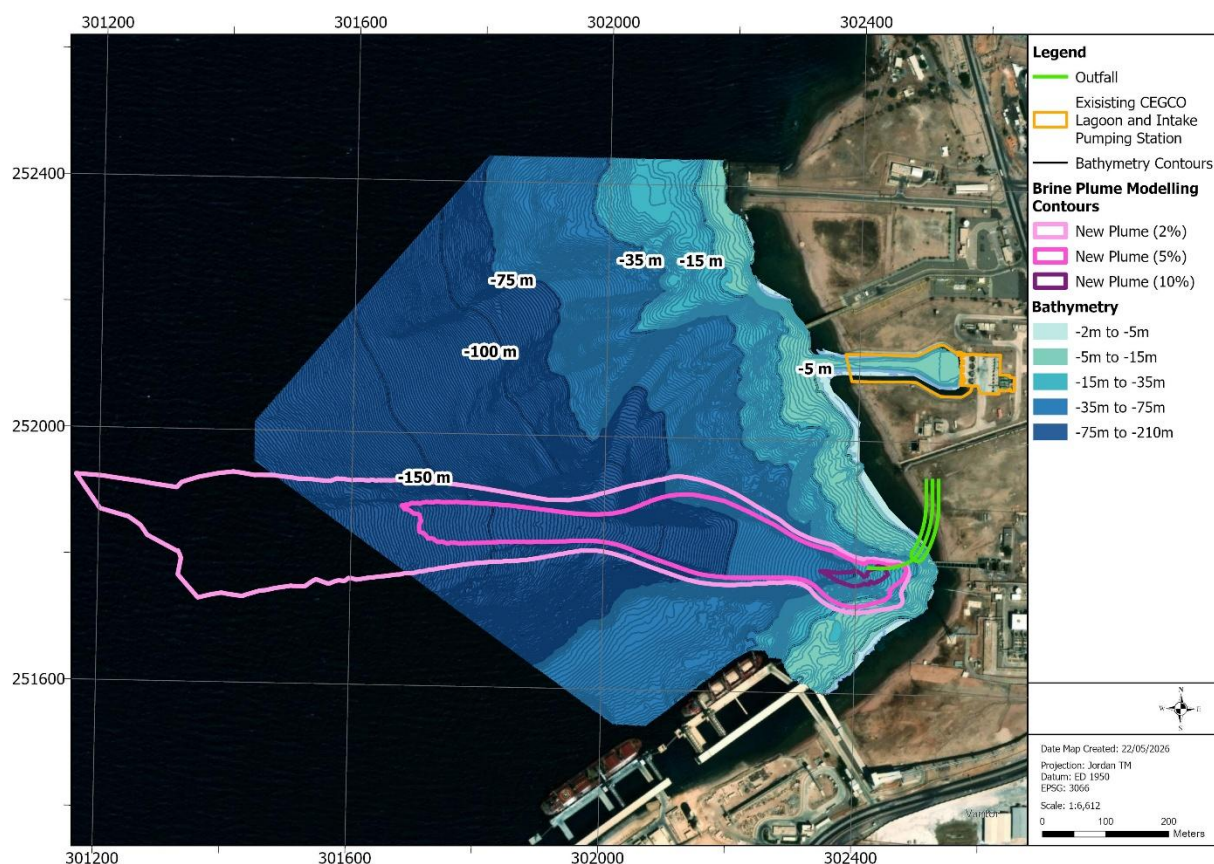
Table 1-1: Relevant Characteristics of Brine Discharge for Review of Coral Tolerance to Hypersalinity

Hypersaline Brine Discharge Characteristic	Parameter
Excess salinity	+34.8 psu
Distance to impact point (Ports 1 – 3 at ~15 – 20m)	15m
Dilution (& salinity) at impact point (Ports 1 – 3)	8.4 (44.84psu)
Distance to impact point (Ports 4 – 6 at ~20)	23m
Dilution (& salinity) at impact point (Ports 4 – 6)	9.6 (44.33 psu)
Distance to end of near field	48 – 72m
Dilution (& salinity) at end of near field	13 – 14.5 (43.38 – 43.10 psu)

Based on the assessment the boundaries where salinity will exceed 2%, 5% and 10% above ambient have been modelled (Figure 1-2).

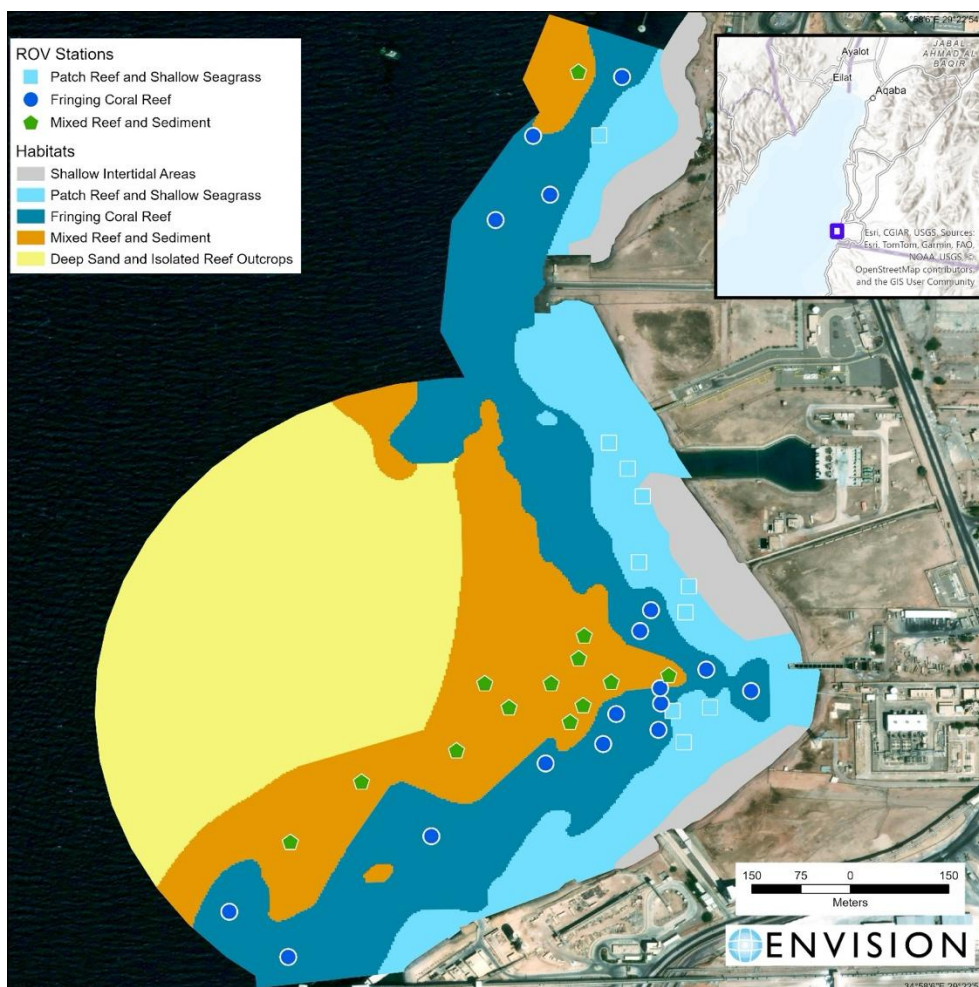
The bathymetry shown in Figure 1-2 shows that the shoreline is bounded by a narrow fringing reef in the order of 250m wide before sloping steeply to depth. Figure 1-2 presents the modelled plume boundaries for elevated salinity levels of 2%, 5%, and 10% above ambient (40.7 psu), together with bathymetry for case 5, the latest EPC design. The figure indicates that the 10% above ambient plume boundary is largely confined within the canyon and, although 5% and 2% plume orientation is predominantly within the canyon, the boundaries do overlap with the steeply sloping walls of the fringing reef to the north and south.

Figure 1-2: Modelled Plume Boundaries



The marine habitats have been broadly characterised by a baseline survey (Figure 1-3, Source: Envision Marine Habitats Baseline Report December, 2025 & Figure 1-4) that covers the nearshore embayment and adjacent deeper waters, spanning intertidal rock platforms, shallow subtidal zones, fringing reefs, mesophotic reef slopes and deeper soft sediments.

Figure 1-3: Broad Marine Habitat in the Study Area

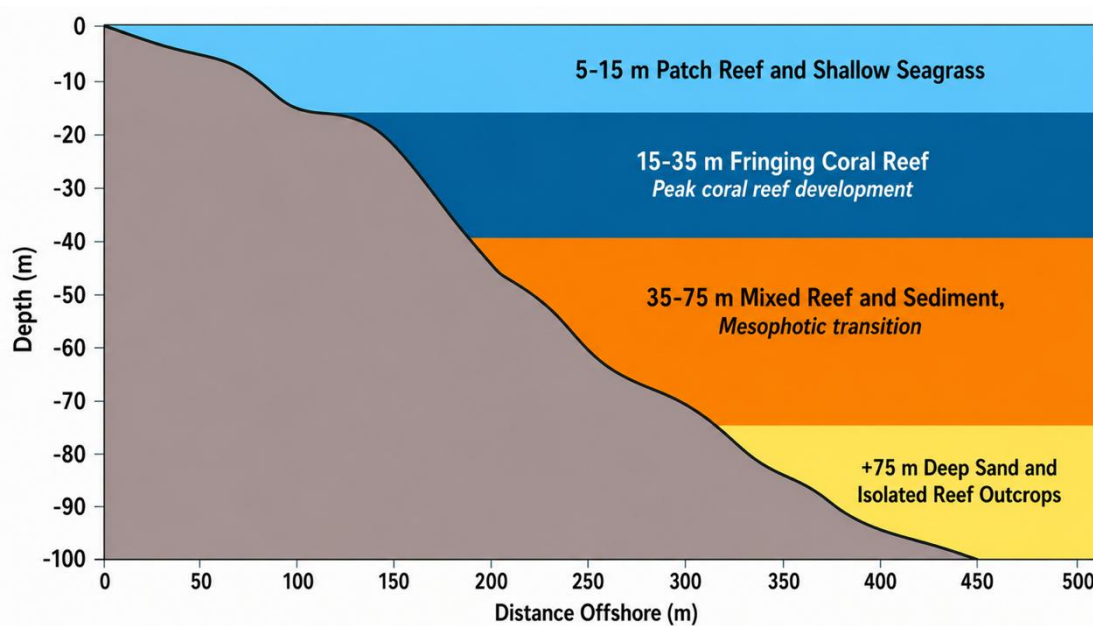


The baseline survey has identified the major coral types (to family/genus level) and other fauna and flora that characterise the habitat types. However, the features and spatial properties of the habitat types and fauna and flora of the canyon and its bordering reef/substrate are not known in detail. The baseline survey is currently being refined and detailed by further surveys, in particular the detailed habitat characteristics of the canyon floor and adjacent fringing reef walls in order to calculate the quantity and identify the types of coral that will be subject to the brine discharge.

Knowledge of the zonation of habitat types and distribution of fauna and flora, and specifically within the study area, is important because this will determine the sensitivity to the brine discharge. The baseline survey found a clear depth-related pattern. Very shallow zones support relatively low coral cover on mobile or sediment-influenced substrates. Coral cover (Table 1-2 & Figure 1-4, Source: Envision Marine Habitats Baseline Report December, 2025) increases to 30m, reaching locally high values where stable hard substrate and moderate light coincide, with a diverse assemblage of branching, massive and plating growth forms. Below approximately 35m, coral abundance declines as light levels fall, although mesophotic corals remain present into the 50 - 70m range. At depths between 30m and 60m, the baseline survey found that the diversity of corals was dominated by species that were sediment tolerant

(reflecting a change from contiguous reef substrate to more patchy sand/rubble substrate) and from taxonomic families (e.g. Agariciidae, Lobophylliidae and Mirulinidae) that are known to be more tolerant to salinity variance and increases. Below 60m, the ratio of sand to hard substrate increases with depth, and where hard substrate is available, coral cover is less than 15% and is dominated by *Leptoseris* ^[11].

Figure 1-4: Depth Profile Through the Project Area with the Broad Marine Habitats



Seagrass cover is concentrated in shallow, sheltered areas and diminishes with depth and exposure. The detailed characteristics of the canyon area and deeper reefs (below 60m) that are likely to be impacted by the brine discharge plume have not been characterised in detail, which is the subject of ongoing survey work.

Table 1-2: Depth Characteristics of Coral Reefs

Depth Zone	Coral Cover	Description (Main Characteristics)
5 – 15m	<5 – 30%	Small isolated colonies through small patch reefs to contiguous reef substrate with shallower areas with coral cover and diversity increasing with depth.
15 – 35m	30 - 84%	Fringing reef slope with increasing coral cover and diversity with depth. Coral colony forms change from branching and massive shapes to table with massive shapes as depth increases indicating adaption to lower light levels.
35 – 75m	<20 – 50 %	Substrate begins to change to patchy hard, rubble and sediment with reducing coral cover and diversity with depth and shift to plating and massive shapes.
75 – 150m	15 - <10 %	Increasingly less and more patchy hard substrate dispersed amongst sediment areas. Coral cover reported up to 15% where hard substrate is present.

Note: Descriptions for 5 - 60m are based on the Envision Baseline Habitat report and below 60m are from Reference [11, 51]. Zones to 35m are described as photic (corals rely on photosynthesis for survival), 35m to 60 -75m as upper mesophotic (corals increasingly rely on other feeding strategies as light progressively diminishes) and 75 - 150m Lower mesophotic.

In the context of coral reefs in the Gulf of Aqaba, the photic zone can extend to approximately 170m depth^[1, 9], which has a strong influence on the characteristics of reef ecosystems. This means that scleractinian (reef-building) corals that are more usually confined to 40-70m can be present to much greater depths and overlap over an extended area with deeper water reef fauna that inhabit the mesophotic zone¹ (usually 30-40m to 150m)^[10, 11, 12, 18, 19]. At these depths, reefs can be dominated by sponges, algae, and deep-water corals (including Octocorals), as well as Scleractinian coral types, which are normally found in shallower waters. The physiology of corals from deeper depths are generally adapted to a lower light and higher pressure environment through adapting their physiology, symbiosis^[31], metabolic and cellular processes^[55, 56] with the effect that:

- Coral species undergo physiological changes to host different symbiotic algae and coral morphologies adjust skeleton growth form to maximise light capture (e.g. massive to plating morphologies)^[71]
- Species richness (biodiversity and coral cover) are reduced as depth increases, as fewer coral species are able to adjust to the deeper environmental conditions
- Reproduction strategies change from large-scale spawning events at depths above 30m to lower intensity spawning (10-20% participation vs. 100%) at 150m so that deeper reefs are less able to recover from degradation compared to shallower reefs^[72]

In addition to an extended photic zone, the Gulf of Aqaba is characterised by high salinity and temperature^[4] compared to most other coral reef regions of the world; the reef fauna and flora are already acclimated² to a relatively higher salinity and temperature environment, and thus this review focuses on literature that addresses tolerance to elevated salinity from similar regions, namely; the Red Sea (including Gulf of Aqaba) and Arabian Gulf.

¹ **Photic reefs** are shallow-water coral ecosystems (0–30m) bathed in bright sunlight, relying on photosynthesis for the survival of reef-building corals. In contrast, **mesophotic reefs** exist in increasingly lower light levels with depth, forcing corals and organisms to rely on other feeding strategies.

² **Acclimation** is the reversible, physiological adjustment an organism undergoes in response to a changing environment to improve its tolerance. Acclimation shifts the tolerance curve, expanding the range of conditions an organism can handle.

Tolerance is the ability of an organism to survive or function within a certain range of environmental conditions (e.g., specific temperatures or salinities) and is the absolute limit an organism can withstand (what it can handle).

2 Literature Search: Systematic Search of Academic Databases and Reputable Online Data Sources

To begin to understand the potential impacts of the brine plume, a literature search has been conducted to review the current understanding of the effects of hypersalinity on the biology and ecology of the fauna and flora present within the identified habitats.

The review includes experimental studies, field observations, and meta-analyses reporting quantitative salinity thresholds and excludes studies lacking rigour or regional relevance. The focus for the potential effect from the hypersalinity of brine discharge is on coral reefs, and their associated fauna and flora, as they have been identified as Critical Habitat³.

2.1 Literature Limitations

The literature almost exclusively reports relatively short-term laboratory exposure experiments (less than 1 month) and coral types that are common to upper reef zones (above 35m) rather than those found in deeper zones. Because laboratory conditions cannot mimic natural ecological conditions, results from laboratory versus in situ observations often predict greater ecological risks compared to the latter ^[49, 73] (e.g. reference [6] compared to [8]).

2.2 Background

Coral reefs have a highly heterogeneous assemblage of flora and fauna characterised by organisms permanently attached to a rocky substrate that is itself often, or mostly, of biogenic origin. The health of reef organisms is important because the maintenance and growth (and resistance to erosion) of the substrate is dependent on the viability of the organisms that produce it.

This review focuses on literature available specifically addressing hypersalinity. Hypersaline conditions are typically described as salinity exceeding 35 – 40 psu or 10% above ambient levels. This is because corals are generally assumed to be stenohaline osmoconformers (organisms that do not expend energy on actively adjusting the salt concentration in their bodies (osmoconformers) and can only survive a very small fluctuation in the salinity of the water (stenohaline) and so are adapted to thrive at 32–35 psu with some capacity to withstand short-term spikes to 40 – 45 psu ^[13, 27, 54]. In Jordanian waters of the Gulf of Aqaba, ambient salinity levels have been recorded between 40.27 and 42.15 psu, with a range between 40.36 and 40.73 at a monitoring location close to the study area in 2024 ^[66]. Understanding the possible consequences of persistent long-term exposure of the fauna and flora of the coral reef ecosystems in the study area, where organisms are ‘pre-acclimated’ to hypersaline conditions, is important to define the risk for long-term alteration of the biodiversity in the study area and what the consequences of this might be.

2.3 Impacts of Hypersaline Conditions

Sensitivity to elevated salinity can vary significantly between different species through impacts to their physiology, metabolism and reproductive success, as well as shifts in community structure and reduced resistance to secondary stressors ^[3]. For coral communities’ studies have shown that impacts can arise through ^[3,4, 5, 6, 7, 69, 70].

- **Coral Bleaching and Tissue Damage:** Elevated salinity levels can lead to a break down the symbiotic relationship between corals and their photosynthetic algae (zooxanthellae). Studies

³ Aqaba Amman Water Conveyance and Desalination (AAWDC) Project. Marine Critical Habitat Assessment (CHA). 2025.

indicate that salinities above 42 psu can lead to partial, severe, or total bleaching depending on species and the extent and duration of salinity increase

- **Reduced Calcification and Growth:** Corals exposed to hypersaline conditions show a 20-50% decrease in calcification rates (normal conditions $1 - 2 \text{ g CaCO}_3 \text{ cm}^{-2} \text{ yr}^{-1}$), meaning they cannot build their skeletons effectively
- **Reduced Photosynthesis and Metabolism:** High salinity restricts photosynthesis of zooxanthellae, reducing the energy available to the coral host
- **Microbiome Restructuring:** Long-term exposure to high salinity forces a significant shift in the bacterial communities (microbiome) associated with coral, which may help them adapt but often at the cost of overall fitness

The specific conditions found in the Gulf of Aqaba means that corals (and other flora and fauna) are already acclimated to the existing elevated saline conditions and show enhanced tolerance to even higher saline conditions ^[13, 14].

3 Effects of Hypersaline Conditions on Reef-building Coral

Reefs in the Gulf of Aqaba include a range of different calcifying reef-building organisms (Table 3-1) that produce skeletons that can build and contribute to reef substrate accretion ^[18,19].

Table 3-1: Main Coral Types and Their Function to Coral Reef Ecosystems

Taxonomic Group	Role
Scleractinia	Scleractinian corals (stony corals) are the foundational ecosystem engineers of coral reefs. Through the secretion of calcium carbonate skeletons, they construct the massive 3-dimensional physical framework of the reef. Most reef-building Scleractinia host symbiotic algae (family Symbiodiniaceae) within their cells. Through photosynthesis, these algae provide the coral with up to 98% of their energy requirements, including vital carbohydrates and lipids that allows stony corals to grow rapidly enough to form massive reef structures in shallow, nutrient-poor tropical waters.
Octocorals	Octocorals, including sea fans, sea whips, and soft corals, are vital ecosystem engineers but are not light dependent and can populate a greater range of habitats. Unlike stony corals, they feature flexible internal skeletons and provide critical three-dimensional habitat. They have unique microbial partnerships that allow them to survive harsh environments. Their skeletons help cement and consolidate reef substrate.
Hydrozoa	Carbonate hydrozoans (often called hydrocorals) play critical ecological roles on coral reefs by providing structural habitat, maintaining biodiversity, and contributing to reef accretion. Although symbiotic with algae and light dependent they are often more resilient to harsh environments than stony corals.
Coralline algae	Coralline algae, particularly crustose coralline algae (CCA), act key structural components and glue of coral reefs. They secrete hard calcium carbonate skeletons, which cement the reef structure together, resist intense wave energy at the reef crest, provide crucial chemical cues for coral larvae to settle, and suppress the growth of opportunistic fleshy macroalgae helping to maintain substrate that favours coral (all types) growth.

The baseline survey was not designed to identify individual fauna depth and distribution ranges and focussed on Scleractinian corals. However, all coral types would be expected to be present at all depths except Hydrozoans (Millepora) which are generally found above 30m depth.

The Gulf of Aqaba has a very high water clarity⁴, such that many coral species exhibit a depth range extending across photic and mesophotic zones far greater than other regions. As light is attenuated by depth and reefs become progressively more mesophotic, they are characterised by substrate that is antecedent (built on relic terraces from previous sea level stands) with diversity reducing and growth form (becoming more platy and encrusting). Reefs at mesophotic depths include coral types, particularly Octocorals, that exhibit high tolerance to hypersalinity and other environmental stresses ^[13, 20, 21].

In general, the ability of all types of coral to tolerate and acclimate to high salinity levels is linked to two features:

1. An accompanying restructuring of their microbiome towards beneficial bacteria (e.g., *Pseudomonas veronii*), which help to manage the salt stress ^[13]
2. The upper limits of tolerance of corals' symbiotic algae, where photosynthesis during short-term exposure studies has been found to be significantly inhibited by salinity levels of 55-60 psu, whilst extreme levels (70 ppt) caused irrecoverable damage ^[8, 27, 41]

3.1 Scleractinia (Stony Reef-building Corals)

Corals in the Gulf of Aqaba tolerate ambient salinity levels of 40 to >41 psu ^[6], which is higher than the global average range of 32 – 35 psu, and supports high biodiversity reefs ^[18]. The Persian Gulf is another region where hypersalinity can be as high as 50 psu, and there are healthy viable coral reef systems albeit with reduced biodiversity compared to other reef regions ^[4, 8, 58]. This strongly suggests that some coral species have a capacity to acclimate long-term to elevated salinity levels.

Research has shown that some species in northern Red Sea regions, such as the Gulf of Aqaba, can tolerate up to 48-50 psu ^[47] over a one-week exposure experiment. Some species such *Acropora*, *Fungia*, *Platygyra* and *Stylophora pistillata* showed tolerance to even higher concentrations (45psu up to approx. 51-55 psu) over a short period of time ^[13, 15, 34], although the calcification rates (growth rates) were 8-fold decreased and showed signs of mucus release as a sign of stress over approximately one month of incubation.

The effect of salinity on coral reproduction has mainly been investigated in the context of hyposalinity. Results suggest that lower (hyposalinity) and higher (hypersalinity) salt levels can affect fertilisation success, structural and developmental deformities in the resulting embryos, lowering larval survival rates and consequential decreased settlement and recruitment onto substrate ^[53, 68, 74, 75, 76].

Cultured symbionts (*Symbiodinium*) associated with these corals have also demonstrated remarkable resilience, withstanding salt-adjusted laboratory conditions ranging from 25-55 psu through the prominent presence of the symbiont *Symbiodinium hermophilum* that shows strong local adaptation not only to high temperatures but also to the exceptionally high salinity ^[27].

While corals have been shown to exhibit extreme resilience, their capacity to handle 48-50 psu is likely at the edge of their physiological limits, and this tolerance could become overwhelmed by combined additional pressures. For instance, some species of *Acropora* and *Platygyra* bleached at around 51-51.3 psu and *Stylophora pistillata* exhibited high tolerance, with bleaching occurring closer to 55 psu ^[4, 41, 42], with the effect being associated with the decline in the symbiotic algae.

⁴ Characterized by incredibly low turbidity (low suspended particles), the depth at which 1% of surface sunlight (photosynthetically active radiation) penetrates frequently exceeds 110 metres compared to 20 to 40 metres in other coral reef regions ^[52].

Laboratory experiments have incubated coral fragments representing three branching species (including *Stylophora pistillata*, *Acropora tenuis*, and *Pocillopora verrucosa*) in seawater with elevated salinity (about 10% above ambient) with and without antiscalant present^[6]. Results showing a negative response were attributed to osmotic stress, and a significantly greater impact was noted for treatments that included antiscalant. However, the study was relatively short, consisting of 2-4 weeks of incubation, and other studies have shown that although there may be a significant reduction in calcification and photosynthesis in the short term, the microbiome could remain stable. Long-term exposures can result in unchanged photosynthesis levels and visually healthy coral colonies, indicating long-term acclimation to high-salinity levels, accompanied by major restructuring of the coral microbiome^[4, 13].

It should be noted that most of the research has been conducted over relatively short periods of time ranging from a few hours to one month and includes *in vivo* and *in vitro* experiments that can make direct extrapolation to natural *in situ* conditions difficult^[43, 44].

A longer 3 month, as yet unpublished laboratory experiment, which exposed two branching coral species, *Stylophora pistillata* and *Acropora sp.*, to different brine enrichment levels (2%, 5%, and 10% above ambient salinity) was conducted by the Jordanian Marine Science Station in 2024. A number of stress markers, including Malondialdehyde (MDA), Lactate Dehydrogenase (LDH), Alanine Aminotransferase (ALT), and antioxidant enzymes including Superoxide Dismutase (SOD) and catalase (CAT) were measured in the incubated corals.

The two incubated coral species showed a clear dose-dependent response to increasing salinity from brine exposure. At low exposure (+2%), both *Stylophora pistillata* and *Acropora sp.* showed minimal or no significant physiological stress, with stable or slightly altered biomarkers and high survival (100% in *S. pistillata*). At moderate exposure (+5%), both species exhibited increased oxidative stress markers (MDA, LDH, ALT) and activation of antioxidant defenses (SOD and CAT), indicating the onset of physiological and metabolic stress. However, *Acropora sp.* showed stronger effects, including a noticeable drop in survival (68%). At high exposure (+10%), both species experienced severe oxidative stress, with elevated damage markers and reduced antioxidant enzyme activity (SOD and CAT), indicating overwhelmed defense systems. This resulted in clear cellular damage and a sharp decline in survival, especially in *Acropora sp.*, showing it is more sensitive to salinity stress than *Stylophora pistillata*.

3.2 Octocorals

Octocorals exhibit high tolerance to high salinity, often showing superior resilience compared to scleractinian (reef-building) corals. Many species, particularly in the Indo-Pacific and Red Sea, can withstand salinities of 48–60 psu, allowing them to dominate in disturbed or high-stress environments^[13, 20, 21, 32]. Experimental studies have found that high salinity (60 psu) exposure to octocorals such as *Sinularia flexibilis*, *Paralemnalia thyrsoidea*, and *Sinularia compressa* facilitated the release of symbiotic cells without damaging their viability.

3.3 Hydrozoa

Millepora (fire corals) are important contributors to coral reefs in the Red Sea and the Gulf of Aqaba, particularly *Millepora dichotoma*. There is no specific literature available regarding their tolerance to hypersalinity and extreme temperatures; however, the genus is known for extreme physical, biochemical and behavioural plasticity, allowing it to adapt its growth form to high-energy and variable environments^[28, 29, 67].

3.4 Coralline Algae

Tropical crustose coralline algae are essential for reef building and coral settlement. They exhibit resilience to high salinity conditions such as those of the Gulf of Jordan. Their tolerance is likely attributed to their ability to adjust photosynthetic efficiency and manage ionic balance under extreme environmental conditions ^[1, 11, 25, 26]. Coralline algae have been found to exhibit a wide depth distribution in the Gulf of Jordan to depths in excess of 150m and, in depths below 100m may become the dominant seabed cover ^[12]. There are no studies from the Gulf of Jordan on tolerance of coralline algae to elevated salinity levels.

3.5 Seagrass

Seagrasses in the Gulf of Aqaba have a depth distribution range of 1 to 50m ^[22]. The baseline survey recorded seagrass cover on sandy substrate of 10% at 15m (the upper depth boundary of the brine discharge plume). Exposure experiments conducted on *Halophila stipulacea* presented that up to 10% increase in salinity above ambient (i.e. 44-45 psu) led to stress ^[57]. This study showed that exposure from +5% salinity onward induced measurable stress, and +10% salinity resulted in pronounced cellular impairment, indicating a shift from adaptive responses to damage ^[57]. Studies from other regions have shown that effects of hypersalinity on seagrasses were more pronounced, with long-term exposure impairing photosynthesis and altering osmotic balance, resulting in ~69% mortality at 54 psu after 6 weeks ^[23].

An incubation experiment was conducted by the Marine Science Station to examine how the seagrass *Halophila stipulacea* responds physiologically to simulated desalination brine exposure under controlled laboratory conditions. *Halophila stipulacea* represents one of three seagrass species present in the Jordanian coast of the Gulf of Aqaba. In this exposure experiment, plants with associated sediments from the Gulf of Aqaba were exposed for a short period of two months to increased salinity levels (+1%, +5%, and +10% above ambient).

Physiological stress was evaluated using antioxidant enzymes and lipid peroxidation as an indicator of cellular damage. Results presented a clear salinity-dependent stress response: antioxidant activity increased with rising salinity, while higher treatments caused significant oxidative damage. Exposure from +5% salinity onward induced measurable stress, and +10% salinity resulted in pronounced cellular impairment, indicating a shift from adaptive responses to damage.

The study concluded that sustained salinity increases associated with desalination activities can induce significant sub-lethal stress in seagrass ecosystems prior to any visible signs of degradation. However, longer-term incubation experiments are still required to confirm and better understand the effects of each level of salinity increase on seagrass communities.

3.6 Summary of Saline Tolerances

The response of reef-associated taxa to hypersaline conditions varies significantly across functional groups, exposure duration, and magnitude of salinity increase. Table 3-2 summarises quantitative salinity tolerances, exposure conditions, and observed physiological responses reported in the literature, with an emphasis on studies relevant to the Gulf of Aqaba and comparable environments. The appraisal synthesises evidence across major reef taxa groups to support the identification of salinity tolerance thresholds.

Table 3-2: Appraisal of Salinity Tolerance Thresholds and Responses for Major Reef Taxa

Group	Reported Tolerance (psu / % Above Ambient)	Evidence Type & Duration	Observed Effect	Study Quality & Limitations	Applicability to AAWDCP	Weight of Evidence	Implication for Threshold
Scleractinia (reef-building corals)	48–50 (short-term); bleaching 51–55; stress at +5–10%	Lab + short-term incubation (hours–1 month)	Reduced calcification (up to ~8×), mucus release, bleaching, mortality at +10%	Strong experimental base but short duration ; limited long-term field validation	High (dominant reef builders in plume depth range)	High (short-term), Moderate (long-term)	Chronic stress begins ≥ +5%; significant risk ≥ +10% Tolerance overlaps with predicted plume (~44 psu), but long-term exposure risk remains uncertain
Coral symbionts (Symbiodinium)	25–55	Laboratory studies	High tolerance; supports host adaptation	Lab-based; indirect ecological relevance	High (controls coral resilience)	Moderate	Adaptation of symbionts underpins coral tolerance in GoA Extends tolerance but does not remove coral stress thresholds
Octocorals	48–60	Experimental (short-term)	High resilience; viable symbionts at 60 psu	Limited quantitative thresholds for mortality; few long-term studies	Moderate–High (present in mesophotic zones)	Moderate	Likely more tolerant than reef-building corals and may dominate under Likely tolerate > modelled plume; not limiting receptor

Group	Reported Tolerance (psu / % Above Ambient)	Evidence Type & Duration	Observed Effect	Study Quality & Limitations	Applicability to AAWDCP	Weight of Evidence	Implication for Threshold
Hydrozoa (Millepora)	No quantitative data	Observational	High plasticity inferred	Major data gap ; no salinity thresholds	Unknown	Low	Uncertainty—cannot constrain threshold
Coralline algae	Broad tolerance; algae 1–70 (optimum 10–50)	Mixed studies (lab + field)	Maintain function under high salinity	Generalised algal data; not all reef-specific	Moderate (reef stabilisation role)	Moderate	Some evidence of highly resilient; may increase dominance under disturbance
Seagrass	Stress at +5% (~42–43); strong damage at +10% (~44–45); mortality ~54 psu	Lab + medium-term (weeks)	Oxidative stress, impaired photosynthesis, mortality	Good experimental data; some duration relevance	Moderate (shallower zones mainly)	High	More sensitive than corals; shallow habitats most at risk Sensitive receptor: threshold likely $\leq +5\%$

4 Salinity Risk Assessment from Salinity Tolerance Thresholds

Based on the literature review the following conclusions can be drawn:

- Most reef-building corals tolerate short-term exposure up to ~48–50 psu, with stress and bleaching emerging above ~51 psu
- The modelled plume (~44 psu; +8%) sits within observed tolerance ranges, but:
 - Overlaps with stress thresholds in experiments (+5–10%)
 - Long-term exposure data are lacking, making this a risk of chronic sub-lethal impact rather than acute mortality

4.1 Derived Recommended Salinity Threshold

The AAWDCP ESIA used a reference of 2% increase in salinity as a benchmark. Evidence from the literature strongly supports a conclusion that reef systems will be able to tolerate and acclimate to changes in salinity. The literature also indicates that there are some corals, and especially those already acclimated to living in deeper waters (below 60-75m) that will tolerate a $\leq +5\%$ above ambient salinity increase ($\approx \leq 42\text{--}43$ psu under typical GoA baseline conditions). A scientific justification for this is that the literature indicates:

- Consistent stress onset: Multiple experimental studies show onset of physiological stress in corals and seagrasses begins at approximately +5% salinity increase
- Seagrass sensitivity: Among assessed receptors, seagrasses exhibit clear sub-lethal stress at +5% and severe damage at +10%, making them the most sensitive ecological receptor
- Coral response envelope: Reef-building corals tolerate higher salinity in short-term studies (up to ~48–50 psu), but show reduced calcification, metabolic stress, and bleaching beyond ~+5–10%

However, there is significant uncertainty regarding the consequences of persistent and constant long-term exposure to elevated salinity levels compared to short-term (< 1 month) exposure. This is because:

- Most studies are short-term (hours to weeks), and there is limited evidence for chronic exposure, increasing risk uncertainty at higher salinity levels
- Tolerance is species-specific, particularly within scleractinian corals
- Local hydrodynamic behaviour of the plume (mixing, dilution) and co-stressors (temperature, antiscleractinants) may adjust impacts
- There is an absence of quantitative thresholds for hydrozoa and some benthic taxa

5 Conclusion

Overall, reef-building corals in the Gulf of Aqaba exhibit relatively high short-term tolerance to elevated salinity; however, measurable physiological stress occurs at increases of +5-10% above ambient, and the ecological consequences of persistent long-term exposure at these levels remain uncertain.

A precautionary salinity increase limit of $\leq +5\%$ above ambient is recommended to protect sensitive reef-associated ecosystems in the Gulf of Aqaba, recognising that higher levels (e.g. ~+8% predicted at plume touchdown) fall within experimentally observed stress ranges and may result in chronic sub-lethal ecological impacts under prolonged exposure.

However, in the context of the AAWDCP project this review has identified critical knowledge gaps, namely:

1. The biology and ecology below 60m and in the environs of the canyon where the outfall is to be located require the collection of additional data to support decision-making.

This shortcoming is being addressed through a targeted survey programme, and once results are known, the outcomes can be contextualised in relation to those found from this literature review to identify risks associated with the brine discharge under its current configuration. A monitoring programme implemented during operations will allow impacts to be assessed against predictions and support the development of adaptive mitigation strategies.

2. The specific sensitivity of the types of corals found within the study area and that will be exposed to the brine plume at the new outfall location, and the associated elevated salinity and iron, is not known in detail. This is because the literature that is available has not assessed the long-term exposure of corals in the specific context of the coral types that will be exposed to the bio-, physicochemical conditions within the brine plume.

It is recommended to conduct exposure experiments to mimic conditions of the brine discharge and field conditions (light, water chemistry⁵) that will provide a better understanding of coral sensitivity, tolerance and acclimation potential.

⁵ N.B. Depth as an environmental parameter cannot be replicated in an experimental setting but through use of appropriate controls to compare between corals collected from depth under experimental/control conditions, this affects from this parameter can be isolated.

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