Master Thesis

ASSESSING THE ECOLOGICAL IMPACTS OF DESALINATION ON MARINE COASTAL HABITATS FOLLOWING THE EUROPEAN UNION-MARINE STRATEGY FRAMEWORK DIRECTIVE; GOOD ENVIRONMENTAL STATUS - A REVIEW

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in the framework of the international joint Master programme

Islands and Sustainability

in partial fulfillment of the requirements for the academic degree

Master of Science

Gran Canaria, Canary Islands, Spain

June 28, 2024

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Abstract

The fast-growing technique of seawater desalination is designed to provide the increasing freshwater demand worldwide. Nevertheless, coastal ecosystems may suffer greatly ecologically from the brines that desalination facilities discharge. This paper examines the ecological effects of seawater desalination operations on marine habitats by synthesizing data from a thorough evaluation of published literature. Using information from the review, the author conducted a suitability analysis on the Spanish coast of Gran Canaria using ArcGIS. The physicochemical effects of desalination plant outputs are included by the analysis, particularly variations in the salinity levels in receiving waters. The study emphasises the possible consequences of desalination effluents on the EU-MSFD-related Good Environmental Status (GES) of the marine environment. Considered were factors including changes in benthic ecosystems, organic matter input, and nutrient enrichment. Moreover, in order to comprehend the effects of contaminants on marine biota and ecosystem health, the study highlights the need of tracking and evaluating the concentration of contaminants in desalination effluents. This work emphasises the need of sustainable management techniques to lessen negative effects on marine habitats and advances our knowledge of the ecological consequences of seawater desalination on coastal ecosystems by combining results from several studies.

1.0 Introduction

1.1 Global water scarcity and desalination as a solution

In several regions of the globe, there has been a significant and swift increase in urbanisation during the past few decades. In growing urban areas, desalination of seawater widely considered as a solution for meeting household wastewater treatment needs. To meet the water demands of the population, seawater or brackish water is desalinated using diverse methods, resulting in a waste known as brine (Lior, 2012). In most coastal regions and some mainland regions, desalination of seawater is employed to tackle the challenges of water scarcity (Gude, 2017). The worldwide desalination production capacity is about 109.22 million cubic metres per day (Desal Data and IDRA Desalination & Reuse Handbook 2023–2024). The Middle East and North Africa currently account for 47.5% of global desalination capacity, with 4826 plants (Bundschuh et al., 2021), and the Mediterranean Sea basin accounts for 75% of the EU's desalination capacity, supplying about 5 million m3 of freshwater each day (Bianchelli et al., 2022; United Nations Environment Programme. Mediterranean Action Plan, 2003). Salt, other concentrates, and chemical discharges from desalination plants into the marine environment are a major concern because they can impair the health of marine life. These discharges influence the marine coastal ecosystems' ecological composition. This in turn has an effect on the Good Environmental Status (GES) of the coastal ecosystems (Bashitialshaaer et al., 2011).

1.2 Desalination Technologies: old and emerging

Industrial desalination, as the name implies, simply means the industrial process of removing salt from seawater or brackish water to obtain fresh water. The concentrated salt from this process is collected in a rejected brine stream (El-Dessouky & Ettouney, 2002). Membrane, thermal distillation, and chemical treatments are three major techniques that are being used for water purification by desalination plants. There are certain water purification plants that use a combination of these different treatment techniques. While the feed water (brackish or seawater) is going through the membrane technique, it goes through a layer of porous material that lets water molecules pass through but stops larger, unwanted substances like viruses, bacteria, metals, and salts from doing so (Younos, 2009). Typically, membrane treatment methods employ either pressure-driven or electrical-driven technology. Pressure-driven membrane technologies, include reverse osmosis (RO), nanofiltration (NF), ultrafiltration, microfiltration, and micro-algae based bioremediation (Elsaid, Sayed, et al., 2020; Gilani et al., 2024; Ihsanullah et al., 2021). Reverse osmosis, along with nanofiltration techniques to a certain degree, are regarded as efficient methods for eliminating salt, while electrodialysis is an efficient electrical-driven membrane technology for removing salt (El-Dessouky & Ettouney, 2002; Younos, 2009).

Multiple desalination strategies are evolving to enhance system recovery, minimise energy use, reduce overall cost, promote the use of shared facilities, and, most importantly, mitigate environmental concerns. Some new ways to remove salt from water that are still being developed are forward osmosis (FO), electrodialysis and electrodialysis reversal (ED/EDR), capacitive deionization (CDI), membrane distillation (MD), adsorption desalination (AD), and humidification dehumidification (HDH) (Elsaid, Sayed, et al., 2020). Micro-algae based desalination is one of the relatively new desalination processes with several environmental advantages due to its bio-based and eco-friendly nature (Gilani et al., 2024).

Some potential advantages of the emerging techniques include reduced brine discharge pollution making it more ecologically friendly, increased biomass production, and low level of nutrient cycling. Also, microalgae biomass from brine treatment can be used to make biofuel, feed, medicines, and other items. While valorisation of microalgal biomass supports a circular economy and adds economic value (Gilani et al., 2024). Decrease in energy consumption would result in a reduction in gaseous emissions, as higher clean water recovery would lead to a decrease in the amount of both intake seawater and outfall discharge. Additionally, enhanced performance of new technologies results in reduced chemical additives and fewer pollutants in the released brine. This improvement also reduces the need for extensive pre-treatment (Elsaid, Kamil, et al., 2020; Panagopoulos & Haralambous, 2020).

1.3 Coastal Ecosystems and Ecosystem Services

Ecosystem services refer to the essential conditions and activities provided by natural ecosystems and their constituent species that support and enhance human life (Daily, 1997). There are 21 ecosystem services, which are grouped into four classifications: provisioning, regulating, habitat, and cultural (Börger et al., 2014). Coastal ecosystems perform crucial services and functions such as habitats, breeding grounds, and the storage of carbon in the seafloor, which are beneficial to other marine organisms and mankind. According to the International Council for the Exploration of the Sea (ICES), marine coastal habitat consists of highly fertile estuaries and bays that are essential breeding grounds for both commercial and recreational fish species. Additionally, this environment is home to a variety of invertebrates, such as clams and crabs, and is crucial for the prosperous implementation of mariculture operations (Galparsoro et al., 2014).

Marine vegetated habitats such as seagrass meadows are highly productive habitats found in shallow, nearshore soft-sediment seabed. They offer valuable ecosystem services in tropical to temperate waters and are commonly incorporated into various conservation frameworks, such as the European '92/43/CEE Habitats Directive (Tuya, Haroun, et al., 2014a). Seagrasses, as important primary species, have the ability to alter local environmental conditions and serve as a source of food and habitat for a diverse array of organisms (Gonzalez-Garcia et al., 2021; Riera et al., 2011; Tuya, Png-Gonzalez, et al., 2014). Furthermore, seagrasses play a crucial role as ecological engineers within seabed communities throughout a wide range of tropical to temperate oceans worldwide (Waycott et al., 2011). They play a significant role in benthic carbon sequestration, as (Trevathan-Tackett et al., 2015) highlighted, as well as serving as shelters and nurseries, according to (Zu Ermgassen et al., 2016).

Phytoplankton and zooplankton are fundamental constituents of the marine community structure because they serve as the foundation of the marine food webs (Wei et al., 2022) These species are essential to the cycling of nutrients in coastal habitats since they are important players in the planet's biogeochemical cycles (Montagnes & Fenton, 2012; Tuya et al., 2013). According to (Gaedke et al., 2010), phytoplankton synthesises organic compounds from inorganic substrates, while zooplankton herbivores help move energy up the trophic chain in coastal ecosystems. Since most phytoplankton and zooplankton are tiny and have brief life cycles, they react rapidly to physiological and environmental changes in their surroundings. Because of their unique qualities, phytoplankton and zooplankton species are often used as biological indicators and models to study how wastewater from desalination plants affects the environment (Gomes et al., 2023; Hardikar et al., 2022; Hernando et al., 2018; Song et al., 2021; Wu et al., 2012).

1.4 Impacts of desalination on Coastal Ecosystems; water intake and brine discharge

Desalination activities, together with the diverse technology employed, have multiple impacts on the ecosystem. A major impact at the stage of getting feedwater from the sea is the biodiversity loss due to impingement, entrainment, and entrapment (Lattemann & Höpner, 2008a). Impingement occurs when larger animals (usually juvenile and adult stages) are pinned against the screen mesh used for the treatment of the feedwater, while entrainment occurs when smaller organisms (usually eggs and larvae) move through the mesh. Entrapments refer to organisms that are drawn into the ingestion pipe but have not gotten to the mesh, but they lack any ways of escaping from the intake water system (Barnthouse, 2013; Hogan, 2015).

Salinity and temperature changes, sedimentation, increased turbidity, and reduced light penetration are some of the pressures affecting the benthic ecosystem by desalination activities. In the process of desalinating seawater, chlorine, polyphosphates, and sulfuric acid are used in different chemical forms for pre-treatment and biofouling. This happens a lot in reverse osmosis (RO) plants. The water that comes in is first treated with chlorine to diminish biofouling, and then it is treated again with sodium bisulphite to get rid of the chlorine before it goes into the RO units. This keeps the membrane from getting damaged easily (Lattemann & Höpner, 2008b). Distillation plants use copper-nickel alloy heat exchangers to reduce brine contamination from copper corrosion in thermal plant reject streams. Reverse osmosis brine may contain trace levels of iron, nickel, chromium, and molybdenum. Copper, like other metals can accumulate in sediments following transport and deposit. Point discharges may increase silt concentrations, which is a major concern. Benthic organisms frequently uptake metals present in sediments and transport them to other organisms, leading to food contamination since they often serve as the foundation of the marine food chain (Riera et al., 2013)

Several studies have been done to show how changes in salinity, temperature, contaminants, and other pressures from desalination activities affect coastal habitats, especially the communities that live on the bottom (Belatoui et al., 2017; Blanco-Murillo et al., 2024; de-la-Ossa-Carretero et al., 2016; Fernandez-Torquemada et al., 2005; Tsioli et al., 2022; Tuya et al., 2013). Scientists (Tsioli et al., 2022a) used different techniques like transcriptomics, ionomics, physiological measurements, immunofluorescence, and electron microscopy to look at how the Mediterranean seagrass *C. nodosa* reacts to changes in temperature and salinity. In different studies, Fernandez-Torquemada et al. (2013) and Fernández-Torquemada & Sánchez-Lizaso 2011a) looked at how changes in salinity affected the growth and survival of two Mediterranean seagrasses, *Cymodocea nodosa* and *Zostera noltii*. These studies looked at how C. nodosa responded to both slow and fast changes in salinity and how echinoderms could be used to find and study the effects of brine discharges from desalination plants.

Many studies have found effects like oxidative damage (Capó et al., 2020) plant growth being slowed down, less abundance, slower leaf growth (Fernández-Torquemada & Sánchez-Lizaso, 2005; Tsioli et al., 2022). and high death rates in many species. While most of these impacts are due to salinity changes, the responses of the seagrass are also dependent on other factors such as seasonality and temperature changes both natural and those from climate change (Dauvin, 2023; Fernández-Torquemada & Sánchez-Lizaso, 2011).

1.5 Significance and Structure of the Study

Extreme, sudden, and long-lasting changes in salinity can cause physiological stress, either on their own or in combination with changes in temperature, turbidity, or pH (Hernando et al., 2018; Tsioli et al., 2022a). The state changes have the potential to affect the feeding, nursery, migratory abilities, and/or mortality of creatures with limited mobility, particularly those belonging to benthic communities. These communities play a crucial role in the ecological integrity of the marine food web (Tuya, Haroun, et al., 2014b). Hence, there is a need to study and identify the impacts of anthropogenic activities on marine coastal ecosystems.

Prior to this, numerous studies, including in-situ investigations and reviews, have been conducted to examine the environmental effects of desalination plants (Elsaid, Kamil, et al., 2020; Ihsanullah et al., 2021; Panagopoulos et al., 2019; Roberts et al., 2010a; Sahu, 2021). Nonetheless, the current and future rise in desalination activities, driven by the growing water scarcity caused by population growth and climate change, necessitates further research. Also, the impacts of recent advancements in commercial desalination technologies and emerging desalination technologies on the coastal ecosystem need to be considered from inception. Furthermore, it is crucial to identify and advocate for sustainable adaptation and mitigation strategies. In this paper, we will follow the EU-MSFD and talk about how the discharge from desalination plants might affect the Good Environmental Status (GES) of coastal ecosystems. We will prepare a suitability/sensitivity map using of Gran Canaria, Canary Islands, Spain, as a case study to showcase the impacts. Some management measures are also recommended.

The study provides a summary as follows: Section 2 discusses the materials and methods used in the study. The results are presented in the third section, while the discussion of the results, author’s suggestions for further research, and conclusions are presented in the fourth and final section.

2.0 Methodology

2.1 Study Design

2.1.1 Conducting the literature review.

The review is carried out following the guide from (Foo et al., 2021). Although the guide was made for systematic review in the field of medical sciences, it was adapted to suit this study (Fig. 1). To begin the study, a research question was formulated, as this serves as the basis for the literature scoping and screening processes. Based on the research question, a preliminary search was conducted on Google Scholar to identify keywords and a guide for inclusion and exclusion terms. Keywords were used interchangeably to conduct searches on the Web of Science, ScienceDirect, and Scopus databases. The final search string, inclusion and exclusion terms, and the number of articles from each database are presented in Table 1. Grey literature from institutional databases, conference papers, and blogs were also consulted for this study.

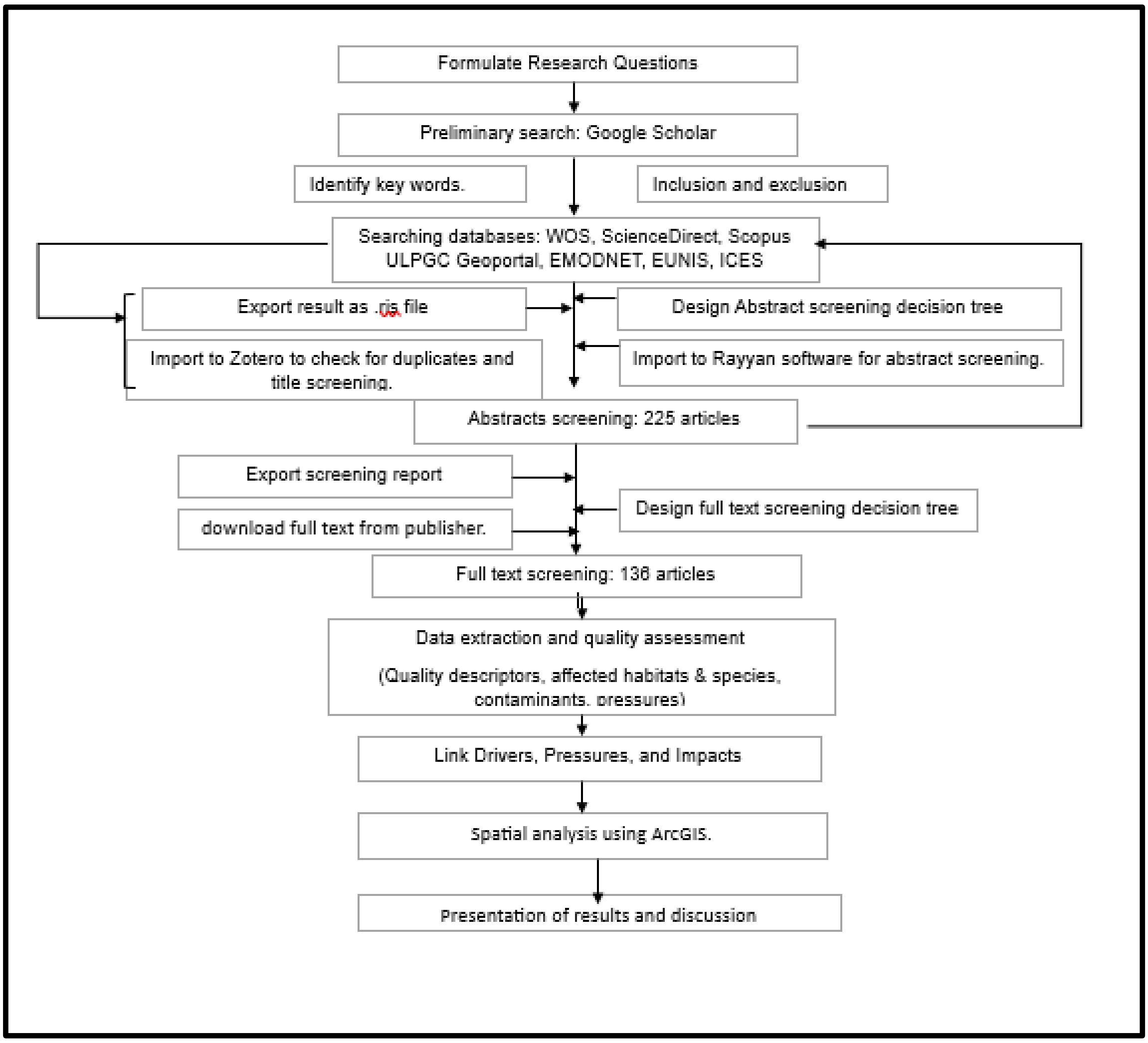

Figure 1: Research Design

Table 1: Literature search string showing databases, inclusion and exclusion terms.

Search Strings	Query link	Database	No. of Results	Inclusion	Exclusion
ALL=((("submarine outfall*" OR "submarine discharge*" OR "brine discharge*" OR "wastewater discharge*" OR desalination) AND ("impact*" OR "effect*" OR "ecological Impact") AND (marine OR coastal) AND (ecosystem) NOT ("energy consumption" OR energy OR technolog* OR construction OR solar)))	https://www.webofscience.com/wos/woscc/summary/f18caf31-7616-43ef-8f90-4cb4469fdad9-dd68bf42/relevance/1	Web of Science Core Collection	210	"submarine outfall" "submarine discharge" "brine discharge*" "wastewater discharge*" desalination "impact*" "effect*" "ecological" "ecosystem" "marine" "coast*"	"energy" "energy consumption" "technolog*" "construction" "solar"
Term(s): ecological AND impacts AND (desalination OR "brine discharge" OR "brine disposal") NOT (energy OR solar OR technology))	https://www.sciencedirect.com/search?qs=ecological%20AND%20impacts%20AND%20%28desalination%20OR%20%22brine%20discharge%22%20OR%20%22brine%20disposal%22%29%20NOT%20%28energy%20OR%20solar%20OR%20technology%29%29&origin=personal&zone=history#submit	ScienceDirect	361	"submarine outfall" "submarine discharge" "brine discharge*" "wastewater discharge*" desalination "impact*" "effect*" "ecological" "ecosystem" "marine" "coast*"	"energy" "energy consumption" "technolog*" "construction" "solar"

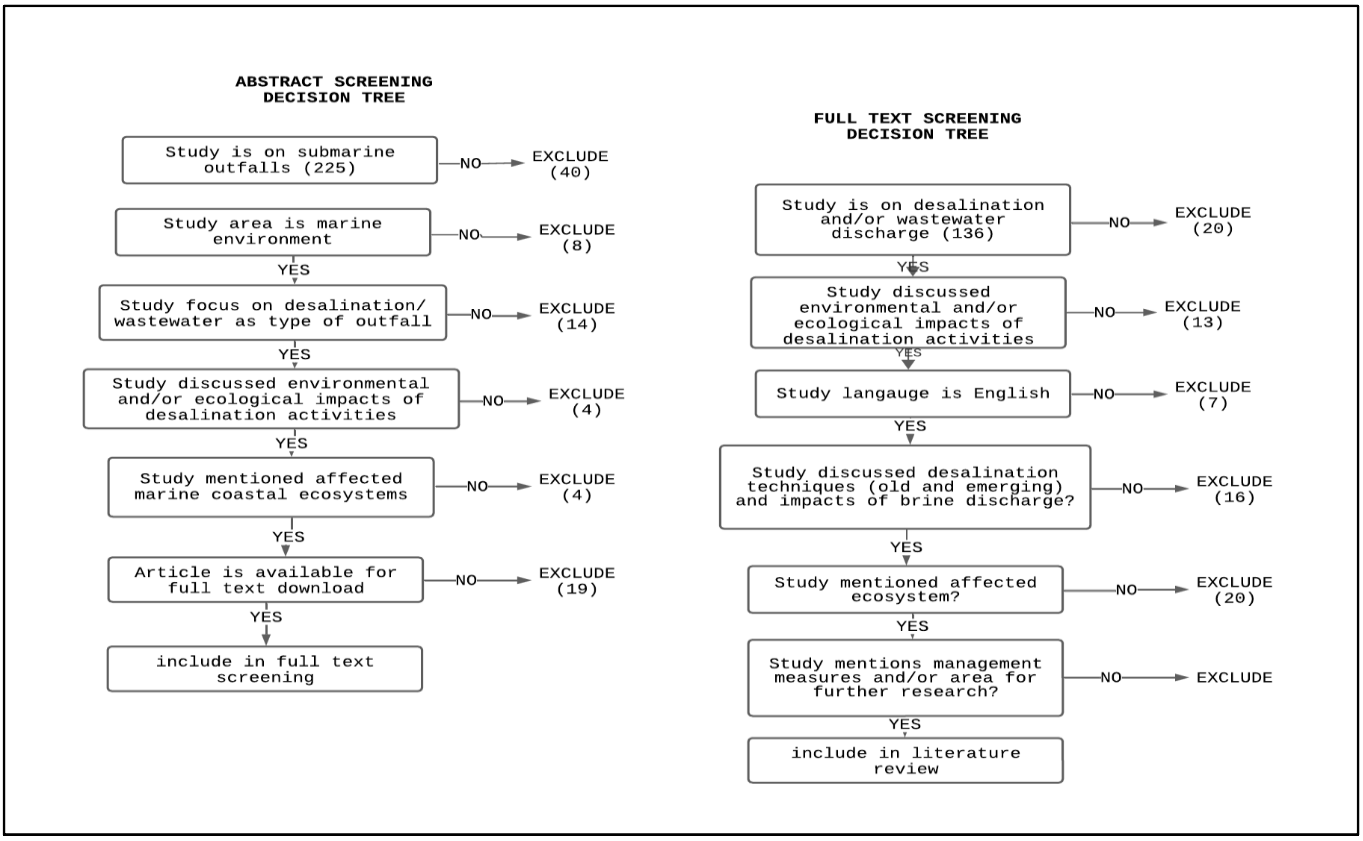

Figure 2: Literature Screening Decision Tree

Two decision trees (Fig. 2), one for the abstract screening and the other for the full text screening, were designed using the research objectives to ensure that the kind of literature that is reviewed contains the necessary information required for the study. The titles and abstracts from all search databases were downloaded in *.ris* format and uploaded to the Zotero reference manager for detection and removal of duplicates. Also, a quick title and abstract pre-screening was done on Zotero based on keywords using the report generated. This gave a total of 225 article titles and abstracts, which were imported into the Rayyan.ai software for proper abstract screening. The number of abstracts included or excluded in the full text screening based on the guide in the decision tree is shown in Figure 2. The full-text pdf of 136 articles was imported into the Rayyan.ai software for full-text screening, which yielded 40 articles that were reviewed for the study.

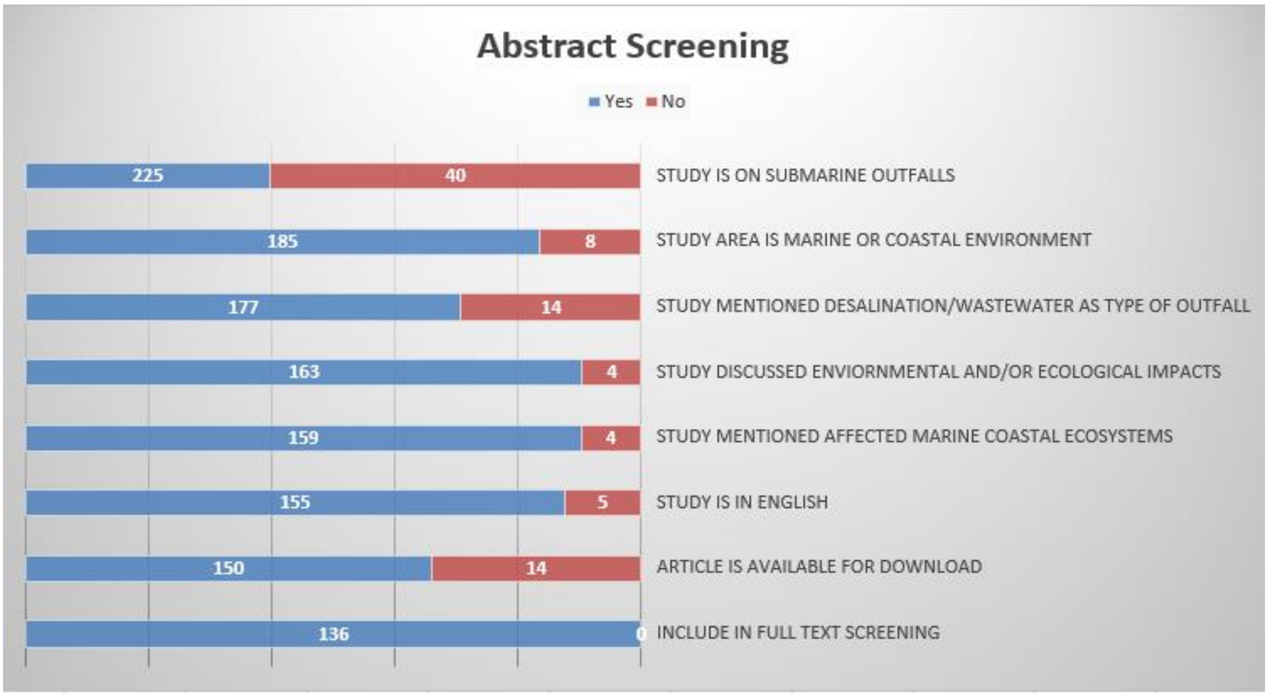

Figure 3: Chart showing abstract screening decisions

2.1.2 Creating Impact-GES Checklist

The systematic literature review focused on studies related to desalination activities around the world, though most of the information is concentrated in the North Atlantic and Mediterranean Seas. I concentrated on the ecological implications for marine coastal ecosystems and effective mitigating measures. All the data extracted was organised according to the Good Environmental Status (GES) of the European Marine Strategy Framework Directive (2008/56/EC). This helped to figure out the main impacts of desalination activities on habitats and the severity of those impacts. This study adhered to the European Commission Decision 2017/848/EU's concept of Good Environmental Status (GES) for European maritime waterways, which includes 39 criteria and 11 qualitative descriptors. This study focuses on 6 out of 11 descriptors that are relevant to desalination activities. Following the ODEMM linkage guideline (White et al., 2013) on how to use the EU-MSFD GES framework in impact studies. A checklist was made that effectively shows the linkage between the quality descriptors, pressures, and criteria. This was done by using the information from the literature review on the effects of desalination activities and possible ways to lessen these effects. The ODEMM linkage table makes it easy to see the connection between the pressures found from desalination activities and the quality indicator that tells us about the marine ecosystem's GES. The outputs are presented in the results section and further discussed to explain the linkages in the discussion section.

2.1.3 Spatial Analysis Process

The effects of desalination discharge on the coast of Gran Canaria were mapped out using datasets on the Good Environmental Status (GES) in the study area. The suitability/sensitivity mapping was conducted in ArcGIS using the most recent geospatial datasets for the Canary Islands gotten from the University of las Palmas de Gran Canaria geoportal. Selected criteria were considered in the data source and GIS analysis to map the sensitive habitats. The selected criteria based on the checklist, dataset used, and data sources are shown in table 2. The Geographic Information System (GIS) suitability modelling tool was used to map the potential of impact based on the final score calculation of the spatial feature datasets. The suitability mapping extends up to a distance of 5 km from the shoreline of Gran Canaria Island. All the datasets cover the entire Canary Islands, but due to time constraints, the analysis for this study was limited to Gran Canaria (GC) Island. GC is the second largest of the Canary Islands, and 86% of the water is generated from desalination (Gómez-Gotor et al., 2018).

In all the spatial features used, the dataset for the study area was extracted by using the clip tool. The feature datasets were converted into a raster format using the 'feature to raster' function and then reclassified so that all the rasters would not remain in their individual units but on an assigned scale of 1 to 10. On the scale, 2 represents low-impact areas that are highly suitable for the location of discharge outfalls, while 10 represents severe impact areas that are non-suitable. The raster calculator tool was then used to combine all rasters by weighting derived through the AHP. All analyses were carried out in the ESRI ArcGIS software. The analytical hierarchy process (AHP) from Goepel (2014) and Saaty (1990) was used to find out how the discharge of desalination might affect the GES of the coastal ecosystem. The Analytic Hierarchy Process (AHP) is a quantitative method that uses multiple criteria to evaluate complex decision-making processes (Nurda et al., 2020). This method has been successfully used in many areas, such as maritime spatial planning (Abramic et al., 2022).

Using a multi-criteria decision analysis and based on expert's opinions, paired matrices were created. One matrix was for the qualitative descriptors, which are the criteria in the Analytic Hierarchy Process (AHP); the second matrix was for the spatial features of GES. The spatial features were considered sub-criteria. This was done exclusively for quality descriptors, which consist of three or more datasets (specifically, QD1, QD4, and QD5). An adequate consistency ratio (CR) to support the pairwise comparisons is deemed to be equal to or less than 0.10, according to Saaty (2001). Multiplying the AHP analysis's ratings of the impact of the criteria and sub criteria yielded the final weights (pWi). The impact level was determined by adding up the various spatial features of the GES, with each feature being weighted based on its expected impact. The calculation is as follows:

$$R = \Sigma\ pWi*CVi,$$

where pW is an i GES spatial feature weight, and CV is the i GES spatial
feature impact contribution (i.e., severely impacted, highly impacted, medium impact, minimal impact, and low impact)

Table 2: Criteria, spatial dataset used in suitability mapping with their sources.

GES quality descriptor	Code	Description	Spatial data coverage	Dataset source
QD1 Biodiversity	Benthic habitats (QD 1.1–1.7)	Harmonised marine benthic habitats following EUNIS (Faunal communities on moderate energy infralittoral rock; Atlantic and Mediterranean moderate energy infralittoral rock; Kelp and seaweed communities on sublittoral sediment, Macaronesian [Cymodocea] beds, Infralittoral fine sand, Sublittoral sand; Maerl beds)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10400-20191001
QD4 Marine food webs	QD 4.1. Benthic invertebrates	Modelled biomass of other benthic invertebrates (Kg/Km2)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10566-20200225
	QD 4.2. Phytoplankton	Modelled biomass of Phytoplankton (Kg/Km2)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10574-20200225
	QD 4.3. Zooplankton	Modelled biomass of Zooplankton (Kg/Km2)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10583-20200225
	QD 4.4. Seagrass/seaweed	Modelled biomass of Seagrass/Seaweed (Kg/Km2)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10576-20200225

	QD 4.5. Urchins	Modelled biomass of urchins (Kg/Km2)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10582-20200225
QD5 Eutrophication	QD 5.1. (nitrate and phosphate)	Accumulation of pressures that can lead to the entrance of nutrients (nitrate and phosphate).	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/32b65d0f-4b54-47f8-8175-a33d18aca8be
	QD 5.3. Chlorophyll-a	Copernicus mean values of Chlorophyll-a (µg/m3)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10199-20191001
	QD 5.4. Dissolved oxygen	Copernicus mean values of Dissolved oxygen (mM/m3)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10219-20191001
	QD 5.5. Silicate	Copernicus mean values of Silicate (µM/l)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10239-20191001
	QD 5.6. Iron	Copernicus mean values of Iron (nM/m3)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10204-20191001
	QD 5.7. Primary production	Copernicus mean values of Primary production (µg/m3)	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10234-20191001

QD8 and QD9: Contaminants	QD 8 and 9: Accumulated pressures leading to salinity changes	Submarine outfalls off the coast of the Canary Islands	All Canary Islands	http://www.geoportal.ulpgc.es/geonetwork/srv/eng/catalog.search#/metadata/ES_ECOAQUA_MSPMD_DATASET10029-20191001

2.2 Study Area: Gran Canaria

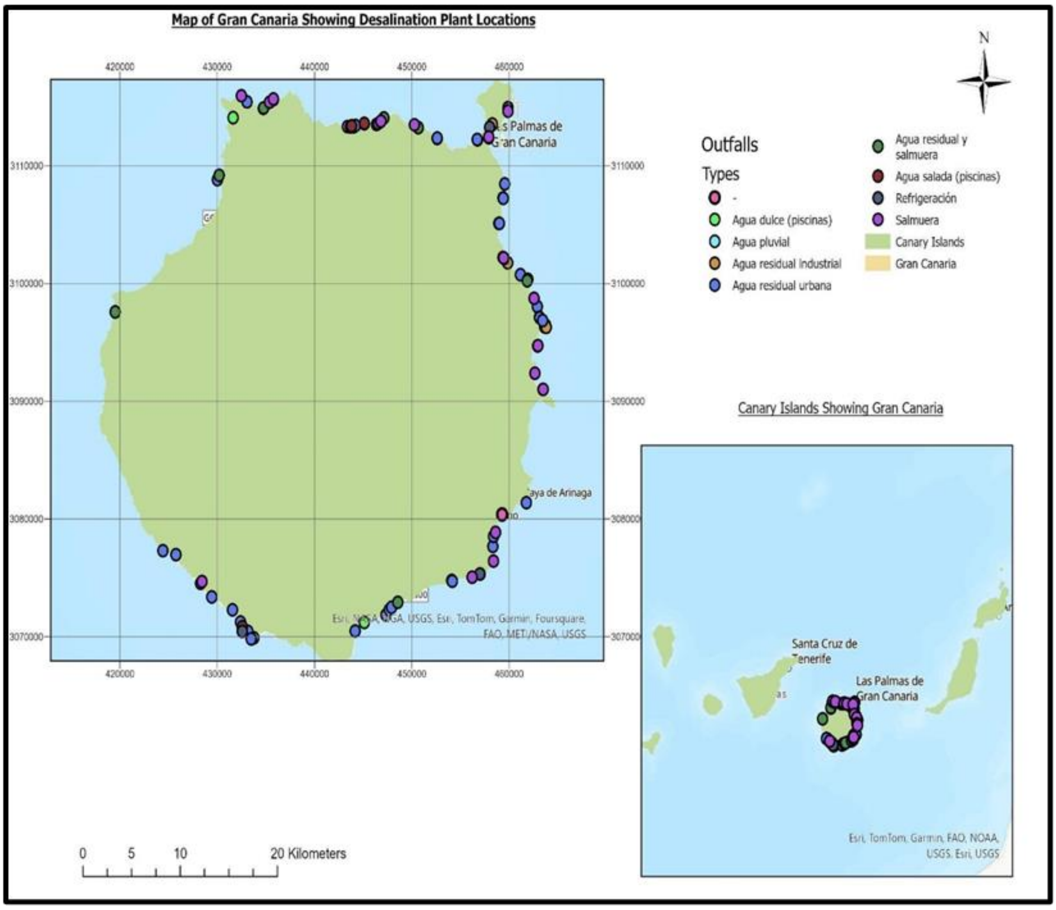

Figure 1:Map of Gran Canaria showing outfalls location off the coast.

Located in the Atlantic Ocean between 28^0 and 30^0 north latitude, near the coast of Morocco, Africa, are seven main islands that make up the Canary Islands. The climate of the archipelago is arid, more so on the islands nearer Africa, such as Fuerteventura, Lanzarote, and Gran Canaria, than on the islands farther from the continent, such as La Gomera, La Palma, El Hierro, and Tenerife (Sadhwani et al., 2005). The eastern islands' sandy shores are more prevalent than the coastline's harsh terrain, which consists primarily of rocky formations. The continental shelves are linear, with more expansion on older islands such as Lanzarote, Fuerteventura, Gran Canaria, and La Gomera. The islands have a lot of precipitous sea bottoms and rocky, perpendicular slopes called "veriles.". Caves, tunnels, and ledges are also common due to the volcanic origin of the islands. Canyons, subsurface landslides, and coastal shelves are the main features of the continental slope's seafloor. The most fruitful locations are the continental shelves of the islands.

Gran Canaria shown in Figure 4 in relation to its position in the Canary Islands, is the third in age and size among the islands in the archipelago, and was formed from a volcanic eruption (Ferrer-Valero et al., 2017). The total area size is 1560 km^2, with a coastline of 236.14 km, occupying 21% of the archipelago's total size (ISTAC 2018). The island is known for its diverse geography, thriving tourism industry, robust economy, rich biodiversity, and stunning coastal environment, all of which lead to urban growth. Tourism plays a vital role in Gran Canaria’s economy, attracting millions of visitors each year. Its year-round mild climate, pristine beaches, and vibrant nightlife make it a popular destination. Resorts like Playa del Inglés and Maspalomas offer a wide range of accommodations, entertainment venues, and recreational activities Additionally, the island's cultural heritage, including historic towns like Vegueta and Teror, also contribute to its appeal (Tovar et al., 2022).

Biodiversity thrives on Gran Canaria thanks to its diverse habitats. The island is home to unique plant species, including the emblematic Canarian palm tree. Its natural spaces, such as the Doramas Jungle and the Bandama Natural Monument, offer opportunities for hiking and exploring (Ferrer-Valero et al., 2017). The coastal environment of Gran Canaria is a significant attraction. Its beaches range from bustling urban strands to more secluded and untouched areas. Urban growth has been a noticeable trend on the island, particularly in the southern region, where tourist infrastructure and residential areas have expanded rapidly. While this growth has brought economic benefits, it also poses challenges in terms of sustainable development and the preservation of natural resources (Fernández-Palacios et al., 2021).

With respect to physio-chemical parameters, the north to south Canary Current and the ascending or upwelling motion of deep seawater influence the salinity and temperature of the waters of GC. The offshore portion of the islands has calm weather due to trade winds and the archipelago's barrier effect on atmospheric and marine circulation, which affects marine biodiversity. Because of the subtropical nature of its seas, this region provides a diverse range of ecosystems and abundant biodiversity. Notably, it is home to distinct species of cetaceans, marine turtles, and seabirds (Ideias, n.d.).

When it comes to water as a natural resource, the Canary Islands have a high level of water stress, which indicates that the demand for water exceeds the supply. Low rainfall results from the latitude, the proximity of the African continent, and the ocean currents (Gómez-Gotor et al., 2018). With most of its population concentrated in Tenerife (949,471) and Gran Canaria (865,756), the Canary Islands have a total population of roughly 2.2 million (European Commission, 2019). Population density in both islands is more than 400 persons per square kilometre (Riera et al., 2013). The pressure from tourists is also rather great. For instance, Gran Canaria welcomes almost 4.5 million tourists a year (Tovar et al., 2022). The population of the Canaries has risen by almost 25% in the last 20 years (INE, 2024). As the population rises, so does the need for water resources. But during the past century, water use has grown at a rate more than twice that of population increase (Tavares et al., 2022); in addition to urban consumption, water demands from sectors such as tourism, agriculture, livestock, and industry have also increased.

To tackle this challenge, the archipelago has turned to desalination, among other resource management technologies, to source potable water. 315 desalination facilities with a total production capacity of 663,463 m^3/day are spread over the Canary Islands: 127 in Gran Canaria, 85 in Fuerteventura, 64 in Lanzarote, 34 in Tenerife, 5 in El Hierro, and 1 in La Gomera (Canary Water Centre Foundation, 2024). Figure 4 shows the location of outfalls off the coast of Gran Canaria where the effluents from desalination plants are discharged into the marine space. Approximately 4000 identified unique species in terrestrial and marine environments make the Canary Islands a biodiversity hotspot. But in the last few years, concerns have been raised about how anthropogenic factors affect the biodiversity of the archipelago, especially on the capital islands. Climate change, increased population, non-native species, overfishing, pollution, and coastal development are the main dangers to the marine biodiversity of the Canaries (Trew & Maclean, 2021).

3.0 Results

3.1 Marine Coastal Ecosystems Affected by Desalination

Desalination activities, especially at the water intake and disposal phases, have different effects on marine coastal environments (Chang, 2015; Höpner & Windelberg, 1997). This is because the source water is gotten from the open sea, and the effluent brine is equally disposed to the sea, mostly within a few kilometres from the coast. The release of brine into the ocean has a significant influence on various marine flora and fauna, and the extent of these effects depends on the tolerance of each species as well as the physicochemical condition of the specific habitat. Echinoderms and most invertebrates have a minimal ability to adjust their internal osmotic concentration to that of their environment (Fernandez-Torquemada et al., 2013). Thus, osmo-conformers are sensitive to small salinity changes. Fish and most vertebrates, on the other hand, are osmo-regulators, which means they may change their internal osmotic concentration by collecting organic salts, adding water, or excreting ions (Fernández-Torquemada et al., 2019). Osmo-regulators' salinity tolerances vary. The high energy expenditure of osmoregulation lowers growth rates and increases mortality in organisms exposed to salt levels beyond their optimal tolerance ratio (Fernandez-Torquemada et al., 2005; Riera et al., 2011). Table 3 shows a list of some species affected by brine discharge and the impacts as gathered from various literature.

As a result, desalination discharge has an impact on the ecosystem of the coastal region, specifically benthic and pelagic communities (Lattemann & Höpner, 2003; Ying et al., 2020). The release of brine directly affects benthic organisms (echinoderm, polychaete, seagrass, and seaweed), which live on or near the seafloor (Cabaço et al., 2008a; Fernández-Torquemada et al., 2013; Sánchez-Lizaso et al., 2008). The brine, which is highly concentrated and has a greater density than seawater, sinks to the seafloor, creating a stratified system. This can have detrimental effects on benthic organisms, impacting their population size, species variety, and ecological diversity (Bianchelli et al., 2022; Diaz et al., 2008). Seagrass beds and algal communities in close proximity to the discharge site may undergo alterations in salinity and light exposure as a result of the presence of brine (Rodríguez-Rojas et al., 2020). These modifications can impact their development and viability (Cabaço et al., 2008b; Rodríguez-Rojas et al., 2024; Sandoval-Gil et al., 2023).

Another group that brine discharge may have an impact on are pelagic organisms in the water column (Varkitzi et al., 2018; Ying et al., 2020). Brine's elevated salinity and temperature can interfere with their physiological functions. For instance, the survival of larvae and their breeding characteristics may be affected (Riera & Delgado, 2020; Ying et al., 2020). Additionally, brine disposal has an impact on planktonic organisms like phytoplankton and zooplankton, which are crucial to marine ecosystems (Garcia & Bonel, 2014). Brine discharge can alter their distribution and abundance, impacting food webs and nutrient cycling (Gomes et al., 2023; Hernando et al., 2018).

Migratory species living in coastal areas close to desalination facilities, such as fish and invertebrates, are another aspect of biodiversity that brine discharge can affect (Pihl et al., 2006; Pihl & Wennhage, 2002). These species may come into contact with the concentrated saltwater discharge known as the brine plume. as they are migrating (Robinson et al., 2017). The modified marine environment resulting from brine can impact their bahaviour and physiological processes. The changes in salinity and chemical composition can exert pressure on these creatures, impacting their growth, reproduction, and overall well-being (Pihl et al., 2006).

3.1.1 Affected Ecosystems in Gran Canaria

Table 3 lists the Gran Canaria habitats and related species that the desalination discharge may have an impact on. Of particular interest are the *Cymodocea nodosa* and the *Avrainvillea canariensis (A. canariensis). A. canariensis* is a green siphonous marine macroalgal genus belonging to the family *Dichotomosiphonaceae* (order *Bryopsidales*), which also includes *Dichotomosiphon* (type genus) and *Cladocephalus*. Decaisne first proposed the genus in 1842, and as of right now, 30 species of Avrainvillea have taxonomically accepted names based on morphology and, for eight of them, DNA data (Lagourgue et al., 2023)a. The genus has a worldwide tropical and subtropical distribution across the Atlantic, Indian, and Pacific oceans. Ecologically, species of *Avrainvillea* are found from the intertidal down to 60 m on sand, mud, reefs, or seagrass beds (Lagourgue et al., 2023). The distribution in the seascape depends on species and environmental conditions and ranges from physically distant individuals to dense mound-building colonies (Littler & Littler, 1992). *A. canariensis* A.Gepp & E.S.Gepp may be neo-endemic to the Canary Islands (Eastern Atlantic) (Ribeiro et al., 2019).

It has been shown that C. nodosa is very sensitive to high salt levels and low doses of sodium metabisulfite (Blanco-Murillo et al., 2024; Fernandez-Torquemada et al., 2005). This means that chemical contaminants and high salt levels from brine make the effects on the seagrass even worse (Tsioli et al., 2022). Additionally, harmful effects were seen in fish living in the area between the phanerogams and the sandy bottoms (Verdiell-Cubedo et al., 2007). These fish were *Synodus saurus, Bothus podas*, *Microchirus azevia,* and *Trachinus draco.* A study conducted by Portillo et al. (2014a) demonstrates that brine has a harmful effect on C. nodosa starting from the second month of exposure and even with small increases in salinity (≥2.2 psu). In the experimental control areas, the average percentage of necrosed leaf remained consistent or slightly increased (36.8 psu), with values around

10% in both spring and summer. However, in the impact zones (39 and 40 psu), the percentage approached 30%.

After six months of being exposed to higher salinity, there was a big drop in the number of species. Desalination discharge is bad for marine phanerograms, especially *C. nodosa*, but it is also bad for other parts of the benthos, like meiofauna (Bianchelli et al., 2022b). The spill changes the population structures and abundance patterns of the infralittoral sand substrates close to the outfalls. The number of the most common groups of meiofauna, especially nematodes, at distances of 0 m, 5 m, and 15 m from the discharge point (Riera et al., 2011).

Table 3: List of the Gran Canaria habitats and related species potentially impacted by desalination discharges.

MSFD_Broad	**EUNIS_CODE**	**EUNIS_NAME**	**Location**	**Number**	**Species**	**Number**
Infralitoral rock and biogenic reef	A3.24	Faunal communities on moderate-energy infralittoral rock	GCN	80	*Diadema africanum* (sea urchin) (echinoderm)	
	A3.2	Atlantic and Mediterranean moderate-energy infralittoral rock	GCN	140	*Diadema africanum*	
	A3.3	Atlantic and Mediterranean moderate-energy infralittoral rock	GCS	79	*Diadema africanum*	
Infralittoral mixed sediment	A5.52	Kelp and seaweed communities on sublittoral sediment	GCN	17	*Avrainvillea canariensis* (macroalgae)	
Infralittoral mixed sediment, Infralittoral sand	A5.52	Kelp and seaweed communities on sublittoral sediment	GCN	35	*Caulerpa prolifera*	29
					Caulerpa prolifera (macroalgae) *Avrainvillea canariensis*	6
	A5.5311	Macaronesian [Cymodocea] beds	GCN	25	*Cymodocea nodosa* (seagrass)	
			GCS	1813		

Infralittoral sand	A5.23	Infralittoral fine sand	GCN	67	*Heteroconger longissimus* (eel)	55
			GCS	46		46
					Heteroconger longissimus Caulerpa spp.	GCN:12
	A5.52	Kelp and seaweed communities on sublittoral sediment	GCS	319	*Caulerpa spp.*	
	A5.2	Sublittoral sand	GCN	290		
			GCS	2351		
Infralittoral coarse sediment	A5.51	Maerl beds	GCN	49	*Diadema africanum*	
			GCS	13		0

3.2 Impacts of Desalination Discharge on GES

In the following subsections, we will show how the discharge from desalination affects the good environmental status (GES) of the coastal marine environment for each of the quality descriptors (QD) that are related to desalination activities.

3.2.1 Biodiversity and Food web

Impacts of desalination discharge, especially hypersalinity, can be observed up to about 4km from the outfalls (Fernandez-Torquemada et al., 2005). The impacts depend on the quantity of discharge, availability of treatment and dilution technologies, and the location of outfalls. Gran Canaria currently has about 167 outfalls from different plants and 127 of them discharge brine and urban wastewater. Some of the desalination plants dilute the brine with urban wastewater before discharging into the sea. 57% of the outfalls discharge an average of 350 m^3 per hour. Biodiversity within 0 to 3000 metres from the outfalls is highly impacted. These are species in the moderate-energy infralittoral rock of the Atlantic and Mediterranean, as well as kelp and seaweed communities on sublittoral sediment, Macaronesian [*Cymodocea*] beds, and Maerl beds (see Table 3).

Figure 5 shows that the area of impact reached up to the 5 km buffer zone in the southern part of the island, while it extended into the 4 km zone in the northern part. Shades of purple indicate areas containing seagrass, Cymodocea beds and macroalgae, which are considered very important because of their ecological significance and high sensitivity to state changes (Tsioli et al., 2022). The distance from outfalls depicted by buffer of 500 m to 5 km is used to show the areas of influence of the discharge. Proximity to outfalls, especially within 3 km, results in low suitability scores (see map legend). Studies have shown that the negative impacts of desalination discharges are quite high in these zones (Fernandez-Torquemada et al., 2005; Frank et al., 2019). As the distance from the outfall increases, the suitability improves. Areas beyond 5 km from outfalls are less affected by discharge impacts and thus exhibit higher suitability for locating outfalls. In table 4, specific impacts of salinity changes on some benthic communities are mentioned.

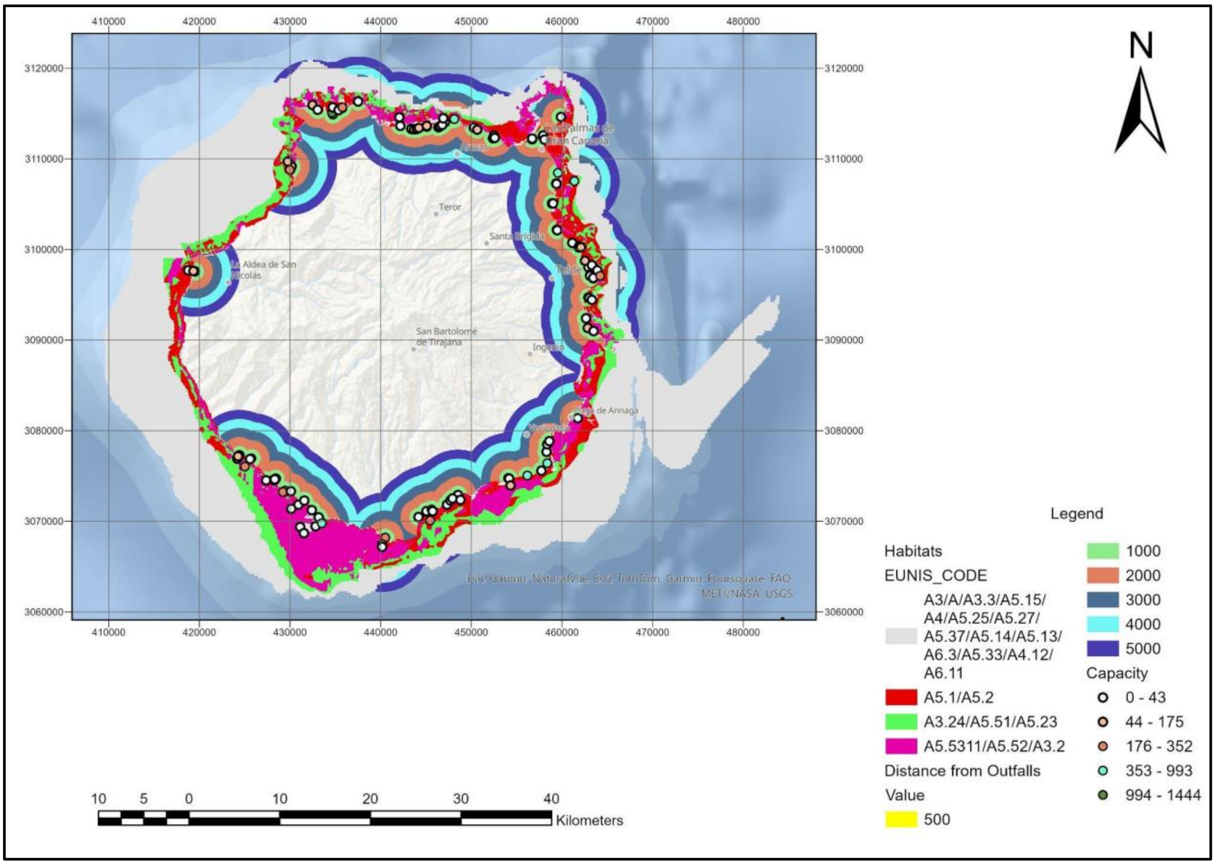

Figure 4:Map showing relationship between habitats, discharge capacity and distance from outfalls.

Table 4: Effect of desalination discharge on some coastal biodiversity

Species	Salinity/Temp tolerance level	Non-tolerant level	Effect at non-tolerant level	References
(*P.Oceanica*)	25 - 39psu	Above 39	Notable decrease in leaf growth, heightened mortality, increased necrosis, and accelerated senescence.	(Capó et al., 2020; Fernández-Torquemada & Sánchez-Lizaso, 2005)

			Stable abundance and growth.	(Sola et al., 2020)
C. nodosa	17 - 41psu 25 °C	<16, above 48	High mortality, reduced leaf growth, and changes in cell structure.	(Fernández-Torquemada & Sánchez-Lizaso, 2011b; Tsioli et al., 2022)
Z.noltii	2 - 41psu /25^{0}C	above 42	-High mortality and reduced leaf growth. -Induced nutrient enrichment, -High nitrate concentrations in Zostera noltii leaves indicate a physiological response to nitrogen intake. -Increased Nitrogen in sediment organic matter,	(Cabaço et al., 2008b)
Phytoplankton/Zooplankton	40psu	Above 40	-Stunted population growth. -Reduction in species diversity. -Acute abundance decline and increased mortality.	(Gomes et al., 2023b; Saeed et al., 2019)
Meiofauna/macrofauna (e.g., amphipods, nematodes, echinoderms)	36 – 38psu	Above 39	- Reduced abundance, diversity and variability in the structure of meiofaunal assemblages. -Impoverishment of Mollusca, Crustacea and Anellida assemblages. -Significant differences in the taxonomic compositions.	(Bianchelli et al., 2022b; Riera et al., 2011)
Kelp/alga turfs			-Increased abundance of alga turfs due to hypersalinity. -Reduced abundance of kelps due to hypersalinity.	(Kelaher & Coleman, 2022)
Invertebrates (e.g mollusc, limpets)	35 - 35.5	36 - 40	-Oxidative stress was increased -Antioxidant defence and biotransformation enzymes in limpet were high, clearly affecting their physiological processes. -Damage to DNA and lipids	(Benaissa et al., 2020)
Benthic Bacteria			-Increased abundance of halophytic species. -Reduced abundance of heterotrophic	(Frank et al., 2019)

			bacteria due to osmotic stress caused by hypersalinity.	

3.2.2 Quality Descriptor 5

Brine discharge contains nitrogen and phosphorus, which can lead to the accumulation of nutrients in coastal waters (Gomez et al., 2020). The literature provides evidence that nutrient enrichment resulting from desalination activities has a significant role in driving eutrophication processes in coastal ecosystems. The continuous release of nutrients can lead to the accumulation of organic matter and the alteration of nutrient dynamics in the receiving water bodies. These nutrients can originate from the desalination process itself or from the additives used to maintain plant infrastructure (Roberts et al., 2010).

Elevated levels of nutrients can result in eutrophication, which stimulates the growth of algae and causes disturbances in marine ecosystems (Ruso et al., 2007). These blooms have the potential to decrease the amount of dissolved oxygen in the water, leading to hypoxia and having a detrimental effect on benthic creatures (Garcia & Bonel, 2014). The discharge of brine can cause eutrophication, which can lead to changes in species composition, a decrease in biodiversity, and disturbances in the ecological equilibrium of marine habitats (Frank et al., 2019). The deposition of organic matter and nutrients derived from desalination effluents can lead to a decrease in oxygen levels in marine habitats, which can have negative effects on benthic animals and the overall functioning of the ecosystem (Tuya et al., 2013).

3.2.3 Quality Descriptor 6

Seafloor integrity may be impacted by brine disposal because it can change the biochemical makeup of sedimentary organic matter, which includes biopolymeric carbon and chlorophyll-a (David et al., 2010). Brine discharge-related alterations in sediment properties could have an impact on the quality of meiofauna habitat, which could disturb their distribution and abundance (Bianchelli et al., 2022). Organic matter accumulation from brine discharge can increase sedimentation rates, leading to the deposition of organic material on the seafloor. This process can contribute to nutrient cycling and potentially exacerbate eutrophication in affected areas (Gomez et al., 2020).

3.2.4 Quality Descriptor 8 and 9

Brine discharge from desalination may contain a diverse range of pollutants, such as metals, hydrocarbons, anti-fouling agents, and other contaminants (Roberts et al., 2010). The pollutants can come from the seawater input, the desalination process, or the additives employed in plant operations (Chang, 2015). Discharging these pollutants into coastal waters can cause both direct and indirect impacts on marine organisms and the overall health of the ecosystem (Robinson et al., 2017). The dispersion pattern of pollutants resulting from brine discharge might differ based on factors such as the discharge site, rates of dilution, and prevailing environmental conditions (Robinson et al., 2017; Saeed et al., 2019). Contaminants have the potential to build up in sediments located close to discharge outlets, which can have an impact on the benthic communities and the overall quality of the sediment (David et al., 2010; Haarr et al., 2022). As observed in figure 6, the impacts of contaminants ranges from highest to lowest; red to green, with the severe, high, and medium impacts experienced in the red, orange and yellow parts which represent within 3 km from the outfall.

Bioaccumulation of hazardous metals and other substances in biota can cause physiological stress, reproductive abnormalities, and population decreases. Chronic brine discharge toxins can affect ecosystem dynamics and weaken coastal ecosystems (Benaissa et al., 2020; Thain et al., 2008). Efficient monitoring programmes are crucial for evaluating the level of pollutants in desalination effluent and their influence on coastal ecosystems (de-la-Ossa-Carretero et al., 2016). Researchers can monitor changes in pollutant levels and assess the efficiency of mitigation strategies by using modern analytical techniques and biomonitoring technologies (Chang, 2015). Implementing techniques such as pre-treatment, dilution, and alternate disposal options can effectively decrease the level of pollutants in brine discharge and mitigate any ecological hazards (Saeed et al., 2019).

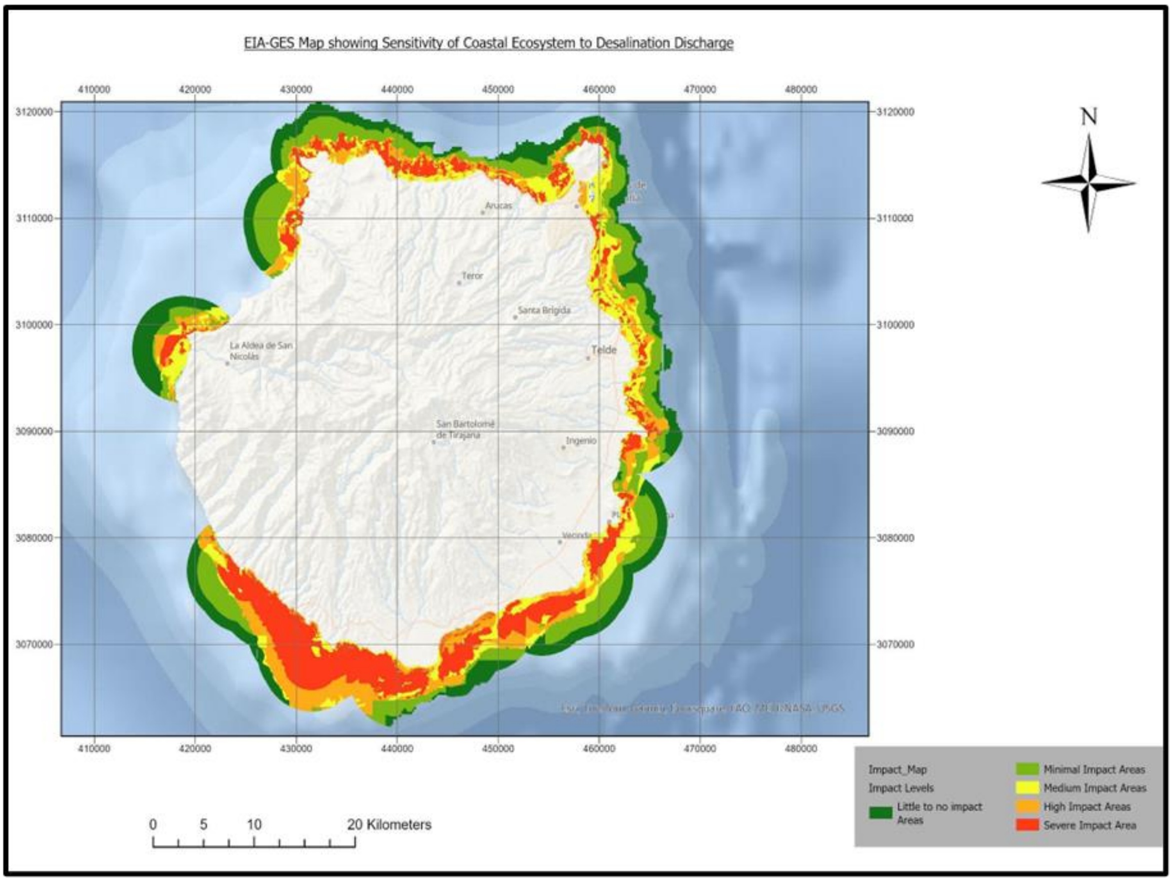

Figure 5: Suitability/sensitivity Map showing impact of desalination discharge at different distances from the outfall

Table 5:Summary of the derived impacts from desalination discharge and their associated mitigation measures.

GES Quality Descriptor	Ecological issues	Impact mitigation measures
QD 1&4: Benthic Habitats and food webs	Reduced abundance, diversity, and variability in the structure of benthic community assemblages. Differences in the taxonomic compositions all because of salinity changes causing osmotic stress. Changes in meiofaunal assemblage populations, seagrass health, diversity, and abundance, can affect energy transfer between different trophic levels, potentially leading to changes in community structure and ecosystem functioning, which can have cascading effects on higher trophic levels within the food web.	Outfalls should be in regions with suitable hydrodynamic characteristics, such as strong currents and energetic waves, as well as topographic and geological features, like sandy substrates. Additionally, the depths of brine discharge should be greater than the depths of the deepest thermocline to ensure rapid dilution of the brine in seawater and prevent its long-lasting presence.
QD5: Eutrophication	decrease in oxygen levels and a reduction in the amount of light available for photosynthesis.	Implementing strategies to decrease the amount of nutrients being introduced. Using advanced treatment methods, like diffusers to mix the effluents, to keep the amount of contaminants and organic substances that get into the estuarine ecosystem to a minimum.
QD6: Seafloor integrity	Increased nutrients. Changes in sediments	Proper use of diffusers and optimized outfall designs to aid dilution and minimize settling of nutrients.
QD 8&9: Concentration of contaminants	Accumulation and transfer of contaminants such as metals along the trophic levels. Changes in physiological process of marine biota.	Pre-treatment of discharge to reduce quantity of contaminants. Microalgae-based remediation

4.0 Discussion

4.1 Assessing the Good Environmental Status of the Marine Coastal Ecosystem in Gran Canaria

In Figure 6, the desalination discharge suitability map for Gran Canaria Island is shown. This map shows how the overall suitability is based on three main factors derived from the quality descriptors: the benthic habitat, the distance to outfalls, and the outfall discharge capacity. The map employs a chromatic progression ranging from green (indicating high suitability/less affected) to red (indicating low suitability/highly affected) in order to graphically represent the suitability scores throughout the study area. Benthic habitats are essential in determining the appropriateness of maritime environments. Areas with seagrass beds and macroalgae, represented by green and yellow colours, are designated as very sensitive because of their ecological significance and susceptibility to disruptions. These environments sustain a wide range of marine organisms and offer crucial ecosystem services. Therefore, areas that possess such rich biodiversity, such as *Cymodocea nodosa* and *Avrainvillea canariensis*, are given priority for conservation and sustainable utilisation.

The proximity of discharge points has a substantial impact on the appropriateness of maritime regions. Proximity to outfalls, particularly within a 3-kilometre radius, leads to low suitability scores due to the possible adverse effects of discharges. As the distance from the outfall increases, the appropriateness of the area improves. Regions located more than 5 km away from outfalls experience fewer negative effects from discharge and so demonstrate greater appropriateness. The capacity of outfall discharge is an additional criterion that determines the impact of the discharge on the coastal marine ecology. Outfalls that have high discharge capacities, ranging from 500 to 1000 m3 per hour, release larger quantities of wastewater. This can result in more significant environmental degradation. The majority of the large-scale discharge outlets are in the Las Palmas province as a result of the high population density generated by the influx of tourists. Fortunately, most of these plants treat or dilute the brine with urban wastewater before releasing it, however, it is recommended that the discharge pipes be extended beyond a distance of 5 km in order to further minimise the substantial adverse effects of high-volume discharges on the marine ecosystem. The negative consequences of high discharge volumes can outweigh the ecosystem services provided by benthic populations in the ecosystem.

The suitability analysis, which combines the weighted impact of benthic habitat, proximity to outfalls, and discharge capacity, provides a detailed understanding of the impacts of desalination discharge on marine ecosystems. The 3 km area surrounding the outfalls has moderate suitability scores, indicating a combination of favourable benthic habitats and a moderate distance from the low-capacity outfalls. Conversely, areas with low suitability are primarily found near the high-capacity outfalls. This highlights the substantial impact of discharge capacity on the sensitivity of the coastal marine environment.

The findings from this study offer important information for the management of marine environments. They indicate that places with high suitability should be given priority for conservation efforts, whereas areas with low suitability near high-capacity outfalls may need more stringent pollution control methods. Furthermore, the results emphasise the importance of continuous monitoring and additional research to improve the suitability analysis and facilitate well-informed decision-making in marine environmental management.

4.2 Ecological impacts of desalination discharge

The degree of ecological impacts of desalination discharge on the marine coastal environment is dependent on certain factors, such as the frequency and capacity of brine discharge. Plants with seasonal production and less brine disposal have minimal impact compared to plants with frequent production and large brine discharges (Bianchelli et al., 2022).

4.2.1 Biodiversity and Marine food web

The functioning of ecosystems, such as the movement of nutrients and energy, and the variety of species, can be affected by desalination discharge, which can alter marine trophic levels (Bianchelli et al., 2022). Eutrophication resulting from desalination effluents can influence primary producers, zooplankton, benthic organisms, and higher trophic levels within the marine food web. This influence can affect the availability of food resources for different trophic levels in the marine ecosystem, potentially leading to shifts in community structure and species interactions (Gomes et al., 2023).

Higher-trophic organisms like worms may become less abundant because of osmotic stress from SWRO brine, which in turn indirectly affects the population of heterotrophic bacteria. When there is a decrease in the number of bacterivorous organisms like nematodes and foraminifers, it can result in an increase in bacterial growth and alterations in the structure of the microbial food web (Frank et al., 2019). In a study carried out by (Frank et al., 2019), to determine the impacts of three desalination plants in the Israeli coast, it was discovered that the diversity of meiofauna experienced a significant decrease of approximately 67%. A shocking 92% drop in the number of different meiofaunal species, such as nematodes, rotifers, gastrotrichs, platyhelminthes, annelids, tardigrades, arthropods, and Mollusca, was seen at the outfall station. While the abundance of halophytic species experienced an increase.

The release of brines from desalination facilities can also modify the amount and biochemical makeup of the organic matter found in sediment, including chlorophyll-a. Studies have discovered that the discharge of hypersaline water from desalination plants has led to a decrease in the number and variety of small and large marine organisms, as well as changes in their taxonomic composition. Additionally, several important species, such as amphipods and copepods, have experienced mortality as a result of this hypersalinity. Nematodes, Oligochaeta, and some other taxa, on the other hand, can handle high levels of brine discharge and have become more important even when they are close to outfalls (Bianchelli et al., 2022a; Riera et al., 2011).

4.2.2 Eutrophication

Eutrophication is often associated with nutrient enrichment, particularly nitrogen and phosphorus, which can lead to excessive algal growth and decreased water clarity, affecting the health of marine ecosystems (Cabaço et al., 2008b). These enrichments of nutrients stem from human activities such as domestic, industrial, and urban discharges (Garcia & Bonel, 2014). Desalination plant discharge can affect marine ecosystems in a variety of ways, such as nutrient enrichment, elevated levels of phosphate and nitrogen, organic matter input, and decreased oxygen concentrations (Gomes et al., 2023). Desalination effluents may have elevated levels of nitrogen and phosphorus, which can stimulate the growth of algae and increase the amount of nutrients in coastal waters (Roberts et al., 2010).

Due to the high levels of eutrophication along the intertidal southwest coast of the Río de la Plata estuary, research showed that the plankton community changed a lot. This included different sizes, fractions, and major taxonomic groups. A strong connection was found between a lot of bacterioplankton, picophytoplankton (chlorophytes and cyanobacteria), and microzooplankton (rotifers, aloricate ciliates, and tintinnids) in polluted and nutrient-rich parts of the Río de la Plata estuary. Eutrophication in the area was a result of different outfall discharges (Garcia & Bonel, 2014).

The discharge from desalination can also introduce organic matter into marine habitats, which could change the composition of sediment and affect biogeochemical processes. The organic matter can also enhance microbial activity, oxygen consumption, and nutrient cycling in sediments which can have an impact on benthic ecosystems (Gomez et al., 2020). It is essential to comprehend the connection between nutrient inputs from brine discharge and eutrophication to evaluate environmental consequences. Gaining insight into the mechanisms via which nutrient enrichment influences ecosystem dynamics is essential for establishing sustainable strategies that reduce the impact of desalination on coastal habitats.

4.2.3 Seafloor integrity

Due to its greater density compared to saltwater, the brine flows downward towards the seafloor because of gravity (Krek et al., 2022). Discharging brine from desalination facilities can introduce effluents with high salinity and other chemicals into the marine environment, which has the potential to change the composition and features of sediment (Holmer et al., 2009; Robinson et al., 2017). The infiltration of brine and its accompanying by-products can result in alterations in sediment composition, levels of organic material, and the accessibility of nutrients, which can have an impact on the ecological conditions of benthic communities that reside in the sediment. Brine sedimentation on the seabed can lead to the buildup of minerals, salts, and other materials that affect the biogeochemical processes and sediment quality in coastal regions (Garrote-Moreno et al., 2014). Brine disposal can affect the stability of the seafloor by changing the chemical makeup of organic matter in the sediment, such as chlorophyll-a and biopolymeric carbon. The release of brine can alter sediment properties, which may impact the habitat quality for meiofauna. This, in turn, can potentially cause disturbances in their quantity and distribution.

4.2.4 Concentration of contaminants

The effluent from desalination facilities may have elevated levels of chemicals, high temperatures, and salt concentrations, which have the potential to modify the environmental conditions of the marine waters (Roberts et al., 2010). The marine biota's metabolic rates, physiological processes, diversity, and abundance could all be harmed by these conditions. Certain marine species react poorly to the chemical concentrations in the desalination effluent which can have a negative impact on them (Rodríguez-Rojas et al., 2020). A change in biodiversity in the vicinity of plant discharges may result from high pollutant concentrations in desalination effluents, which may have adverse effects on some species (David et al., 2010).

As suggested by (Lattemann & Höpner, 2008b) monitoring studies are necessary to examine the effects of desalination waste on marine organisms, including the levels of pollutants and their impact on biodiversity and the health of the environment. For instance, there is a need to monitor the *A. canariensis* species proposed to be neo-endemic to the Macaronesia to avoid loss of the species and its associated services to the marine environment. Long-term monitoring is crucial to assess changes in community resilience and to develop strategies for reducing the impact of contaminants in desalination effluents.

Treatment prior to brine effluent discharge, should be encouraged in all plants to eliminate or decrease the presence of pollutants, including heavy metals, organic compounds, and biocides. This process effectively reduces the concentration of dangerous substances in the water that is released. Replacing dangerous chemicals, like chlorine, with alternative treatment methods might lessen the immediate impact to unintended organisms and decrease the amount of toxic substances released.

4.3 Benefits of Sustainable brine disposal and management measures.

Earlier research suggested that dense jets were not very good at mixing effluent (Roberts et al., 2010). However, more recent studies have shown that mixing brine effluent with seawater effectively is very important for reducing the size and length of salinity changes caused by brine discharge (Bockel et al., 2024; de-la-Ossa-Carretero et al., 2016). Ultimately, this promotes the recovery of benthic communities by creating conditions conducive to the return of organisms from unaffected areas. Where effective mixing mechanisms, such as diffusers, are implemented, the concentrated brine is dispersed and diluted more rapidly into the surrounding seawater. As a result of this efficient mixing process, the salinity levels in the affected area can return to near-natural levels relatively quickly. When the salinity levels rise quickly, it makes it easier for benthic organisms, like amphipods, from nearby sites that were not affected to move in (de la Ossa-Carretero et al., 2016). When the initial brine discharge has a focused effect, it causes a disturbance that, when properly fixed, allows species from nearby areas that were not directly affected by the rise in salinity to recover and move back in.

Microalgae are essential in effectively and economically managing brine output from desalination plants. They not only help reduce environmental pollution but also provide valuable biomass products, making them a sustainable option. Microalgae possess the capacity to efficiently remove nutrients, such as nitrogen and phosphorus, from brines. Research has indicated that microalgae may effectively capture and store important nutrients, with certain types showing excellent abilities to remove nitrate, phosphate, fluoride, and other components. Microalgae have the ability to eliminate organic compounds and heavy metals from brines using methods such as biosorption and bioaccumulation. These methods aid in diminishing the concentration of contaminants in the brine. Microalgae harness the nutrients found in brine to generate biomass. The biomass can be collected and utilised for several purposes, such as biofuels, animal feed, and pharmaceuticals. The biomass generated during the cleanup process is highly valuable and can be utilised in several sectors. The microalgae biomass produced after brine treatment can be further processed to extract important substances such as lipids, carbohydrates, proteins, natural colours, and antioxidants. These chemicals are utilised in various industries such as food and feed, cosmetics, medicines, and biofuel manufacturing.

4.4 Conclusion

In this study, synthesized information from published articles and spatial data have been used to showcase the impact of desalination discharge on the good environmental status of on marine ecosystems, particularly focusing on coastal habitats. The GIS suitability study undertaken in this research has provided significant spatial insights into the vulnerable areas located within a 3 km radius from the outfall and at a depth of -25m on Gran Canaria Island. The impacts were assessed based on 6 out of the 11 quality descriptors of the EU-MSFD. Desalination discharge has impacts on biodiversity and food web by releasing brine, as well as, other chemical contaminants into the sea. The seafloor is equally affected by nutrient enrichment leading to eutrophication. Some management measures and new technologies that have been proposed to mitigate the impacts of the discharge were also mentioned in this study. Overall, this thesis has conducted a thorough examination of the influence of desalination activities on coastal habitats by the application of GIS suitability analysis, while also including findings from several research papers.

The findings of this thesis underscore the importance of considering the environmental consequences of desalination operations in coastal regions. enabling stakeholders to make informed decisions regarding site selection, discharge management, and environmental monitoring strategies for desalination plants. Overall, this thesis contributes to the growing body of knowledge on the environmental impacts of desalination on coastal habitats and provides a foundation for sustainable management practices to minimize adverse effects on marine environments. Through continued research and proactive management strategies, we can strive to balance the growing demand for freshwater with the conservation of coastal ecosystems for future generations.

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