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Impact of desalination byproducts on marine organisms: A case study at Chuja Island Desalination Plant in Korea

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ABSTRACT

Desalination of seawater has become an important and growing industry due to the present water shortage in the world. However, the desalination may result in environmental impacts, mainly derived by the discharge into adjacent coastal waters of brine and additives produced during the desalination processes (e.g., biocides and membrane cleaning chemicals). To measurement of environmental impact by desalination, we approached environmental impact assessment (EIA) procedure [1] for the desalination plant of Chuja Island in South Korea. We conducted a series of marine bioassays using three phytoplankton, rotifer, benthic copepod and one fish species for source water, discharged brine waters and chemical additives. There was no significant toxicity of brine discharge on tested organisms but high toxicity was found at the chemical additives as chlorine and membrane cleaning chemical. In terms of the habitat susceptibility it is located in relatively insensitive habitat, open rocky shore with gravel bottom. Based on these results, even the environmental impacts by Chuja desalination plant were not significant currently, monitoring strategies have to be established and conducted to estimate long-term effects from desalination in marine ecosystem such as hard-bottom benthic monitoring along the shorelines of brine discharged area and toxicity estimation of byproducts and chemical additives using local representative marine species.

Keywords: Desalination; Environmental impact assessment; Toxicity; Phytoplankton; Zooplankton; Fish; Habitat susceptibility; Chuja Island desalination plant

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1. Introduction

The world's water consumption rate is doubling every 20 years, outpacing by two times the rate of population growth. And 40% of world population are placed water shortages situation. If this situation goes on, by the year 2025 water demand will exceed supply by 56%, due to persistent regional droughts, shifting of the population to urban coastal cities, and water needed for industrial growth [2,3]. Clearly, there is a critical worldwide need to new water supplies. Therefore, desalination has become an important and growing industry due to the present water shortage in the world, especially in Mediterranean countries [4].

However, brine and additives produced during the desalination processes (e.g., biocides, coagulants, scale control additives, antifoaming agents, metals by corrosion, and membrane cleaning chemicals) may result in environmental impacts and have different susceptibility according to the habitat types in coastal waters [1,5]. The main impact on marine communities of reverse osmosis desalination plants is caused by the discharge of an ef-

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fluent of very high salinity (70–90 psu) [6] and overall environmental impacts are reviewed [7].

There have been many studies on EIA and toxicity for desalination; whole procedures of EIA [1,8–10], benthic impacts [6], seagrass impacts [11], marine ecosystem [12,13] etc. However, these are very focused on the local coastal environment and therefore, environmental impacts by desalination may be site-specific in terms of the site locations and costal conditions of the plant sites.

In South Korea, there are 70 desalination plants (capacity of 5,700 m^3/d as total) for domestic use and 6 plants (capacity of 134,540 m^3/d as total) for industrial use. All the plants for domestic use are located in the isolated islands. However, there are no systematic guidelines for EIA of desalination in Korea. Therefore, this study introduces the systematic guidelines for EIA of seawater desalination in Korea and is a case study of Chuja island RO plant as an EIA example.

To examine environmental susceptibility of coastal habitat to desalination and toxicity of chemical additives and brine to marine organisms, we conducted a series of EIA and acute toxicity test to identify the environmental impacts by desalination and applied to Chuja Island desalination plant (CDP) as a case study. This result must be an example guideline for the selection of desalination plants in the various coastal habitats to minimize the environmental impacts by desalination in the coastal area of Korea, and also to minimize the impacts on marine ecosystem by brine discharge and chemical additives.

2. Materials and methods

All the habitat types in Korean coastal area were classified to identify the potential sites for desalination plants followed by Hoepner [1] and also we estimated if CDP is a suitable site as desalination plant. Whole desalination processes in Chuja plant (capacity of 1,000 m^3/d) were reviewed to identify the pollution sources, acceptor ecosystem, and negative impacts of discharge on marine ecosystem. The plant is located in Chuja island, between mainland and Jeju Island (Jeju Special Self-Governing Province) of South Korea. The freshwater produced from the RO plant is reserved on open reservoir mixed with rainwater and used for non-portable water. The plant uses spiral wound type RO membrane taking surface seawater (TDS 35,000 mg/L) with a recovery rate of 35–40%.

We measured water quality from source water and discharge using handheld multiparameter instrument (model 556 MPS, YSI, USA) and also conducted acute toxicity test using three phytoplankton, two zooplankton and one fish species for source water, condensed water, discharged water and adjacent natural seawater, and chemical additives. Source water is the water in storage tank before being fed to membrane, condensed water represents the water after desalination process before discharged, and discharged water is flowing water to adjacent shores.

Three phytoplankton test species, *Isochrysis galbana*, *Tetraselmis suecica*, and *Chlorella vulgaris* were obtained from Korea Microalgae Culture Center (KMCC), and have been maintained in *f*/2 media at 23–24°C under continuous illumination (3,000–4,000 lux) in the laboratory for over 1 year. The endpoint of phytoplankton toxicity test is 72 h population growth inhibition. Population growth rates (PGR) were calculated as the following; $r = (\ln N_t - \ln N_o)/t$ (r = PGR, N_t = number of individuals at time t, N_o = initial population density, t = h). The number of cells was counted using inverted microscope (Model CKX41SF, Olympus Cooperation, Japan). Then, population growth inhibition rates were estimated by the comparison between the PGR at treated concentrations of brine and control level. The details on test method are in Table 1. The test materials for acute toxicity test are source, condensed, discharged, and adjacent natural seawaters, and chemical additives as chlorine and membrane cleaner (as amine, KLEEN MCT511, GE Betz, Korea).

Rotifer, *Brachionus plicatilis*, and benthic copepod, *Tigriopus japonicus*, were obtained from Dr. H.G. Park at Gangneung-Wonju National University, Gangwon Province 210-702, Korea, and have been maintained in the lab since February, 2003. Juvenile mortalities are the major endpoints for rotifer and copepod acute toxicity test. Test conditions are presented in Table 2.

Olive flounder juveniles, *Paralichthys olivaceus*, were purchased from commercial hatchery. They were about

Table 1
Test conditions for the definitive chronic toxicity test for phytoplankton species

Parameters	Test condition
Test type	Static non-renewal
End point	Population growth inhibition (EC_{50})
Test organism	*C. vulgaris, I. galbana, T. suecica*
Test duration	72 h
Test temperature	23±1°C
Light type	Fluorescent lamp (universal white)
Light intensity	3,000–4,000 lux
Light period	Continuous
Test chamber	50 mL test tube
Dilution water	Natural seawater
Renewal of test solution	None
Test solution volume	30 mL
Culture media	*f*/2
Initial density	5,000–10,000 cells/mL
Test concentrations	Five + control
Number of replicates per concentration	4
Test acceptability criterion	PGR(r) ≥ 0.04/h at control

Table 2
Summary of test conditions for the definitive acute toxicity test with the marine rotifer *Brachionus plicatilis* and benthic copepod, *Tigriopus japonicas*

Parameters	Test conditions	
	Rotifer	Benthic copepod
Test type	Static non-renewal	Static non-renewal
Duration	24 h	48 h
Endpoint	Mortality (24 h – LC50)	Mortality (48 h – LC50)
Test organism	*Brachionus plicatilis*	*Tigriopus japonicas*
Age of test animals	24 h old neonate	48–72 h old nauplius
Test temperature	25 ± 1°C	22 ± 1°C
Light intensity	Dark	Ambient levels
Test chamber size	15 mL	20 mL
Test solution volume	5–10 mL	10 mL
Dilution water	Filtered seawater	Filtered seawater
Renewal of test solution	None	None
Aeration	None	None
No of individuals/chamber	10	20
Feeding regime	None	None
Test concentrations	Five + control	Five + control
Number of replicates	5	5
Test acceptability criterion	>90% survival at control	>90% survival at control

1 cm in total length and maintained in the laboratory for 7 days for acclimation. Details on toxicity experiments are presented in Table 3. Also, details on the fish acute toxicity test can be found on the references [14–17]. The above test species have been designated as standard species for toxicity test due to their availability, sensitivity and ecological representative in Korean coastal waters [16].

Table 3
Summary of test conditions and test acceptability criteria for juvenile fish survival test

Parameters	Test condition
Test type	Static non-renewal
Test duration	5 days
End point	Mortality (5 d – LC_{50})
Test organism	Olive flounder, *Paralichthys olivaceus* juvenile
Age of test organism	25–30 days
Temperature	20.0 ± 1.0°C
Light intensity	Ambient laboratory level
Test chamber size	1,000 mL glass beaker
Test solution volume	800 mL
Dilution water	Filtered natural or artificial seawater
Renewal of test solution	None
Aeration	None, unless DO falls below 4.0 mg/L
Initial organism density	10 individuals/beaker
Feeding regime	Artemia nauplii
Test concentrations	Five + control
Number of replicates	3
Test acceptability criterion	>90% survival at control

3. Results

3.1. Identification of pollution sources

The whole processes of desalination at CDP were monitored to identify the pollution sources from the plant. Membrane cleaner and chlorine were chemical additives for cleaning and water treatment. Membrane cleaner (KLEEN MCT511, GE Betz, Korea) of 100 kg were used once a year for filter and housing cleaning and chlorine only during summer months (June-August) for produced water. Desalinated water was sent to the open reservoir and mixed with rainwater to be used as non-portable water, not for drinking. Therefore, chemical additives were not commonly used for pre- and post- water treatment. Brine was discharged into gravel bottom shore without further treatment. Therefore, the target materials for examination and toxicity test we selected are discharged water, membrane cleaner, and chlorine for this study.

3.2. Analysis of the acceptor ecosystem

We classified habitat types along the Korean coasts by Hoepner's classification [1] and found 11 types out of

15 coastal habitat types. The most common habitat types were mud tidal flat, estuary, bays and slat marshes in the west and south coast, and sand beaches and rocky coast in the east coast. Coastal sabkhans, fjord, and mangrove flats were not found in the Korean coast. Based on the sensitivity of habitat type for desalination plant, rocky coasts are lowest and salt marshes/mangrove flats are highest in sensitivity. CDP was located in the coast with gravel and bed rock bottom which was lowest in sensitivity to desalination impacts (Table 4).

Brine was discharged into coast directly without further treatment at CDP. Acceptor ecosystem was typical gravel shorelines found in Korean coast and covered by 5–10 cm (diameter) gravels and bed rocks. Discharged brine water directly penetrated into gravel bottom with no surface water flow and mixed with natural seawater around shorelines. About 0.5 psu increase in salinity was observed in receiving natural seawaters and very limited to 1m seaward from the shorelines.

3.3. *Analysis of the links between sources and acceptor*

Water chemistry were measured between source water and discharge, and revealed significant differences in water quality parameters. Dissolved oxygen (DO) decreased significantly in condensed water, and salinity, suspended particulate matter (SPM) and water temperature increased significantly in condensed and discharged water (Fig. 1). Salinity increased about 30–40% from 33 psu for source water to 45 psu for discharges. Decrease of DO in condensed water might be due to the increase of salinity and water temperature, and SPM due to the concentration of source water by desalination processes.

Table 4
Habitat types and sensitivity on desalination plant construction

Habitat types	Sensitivity
High energy coast, rocky or sand with coast-parallel coast	Lowest
Exposed rocky coast	↓
Mature shoreline	
Coastal upwelling	
High energy soft tidal coast	
Estuary and estuary-similar system	
Low energy sand-, mud-, and beach rock flat	
Coastal sabkhas	
Fjords	
Shallow low energy bays and semi enclosed lagoons	
Algal (cyanobacterial) mats	
Seaweed bays and shallows	
Coral reefs	
Salt marshes	
Mangrove flats	Highest

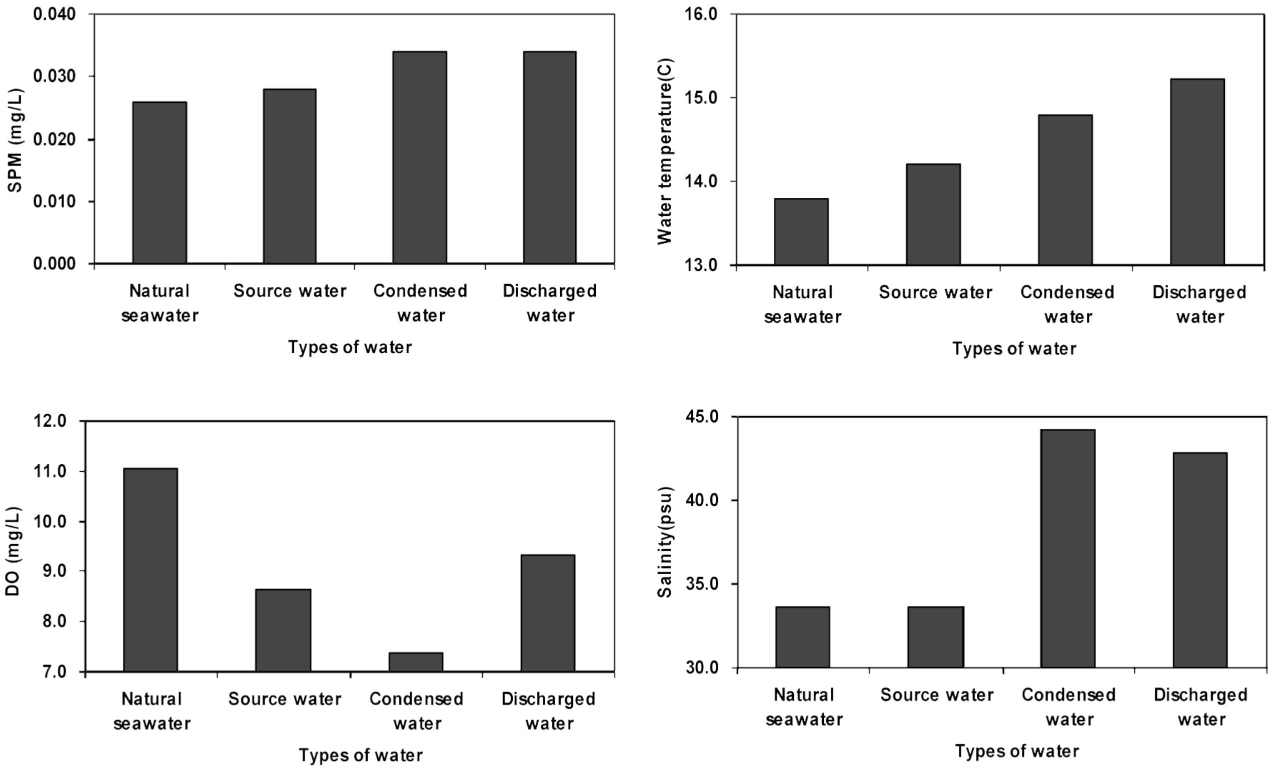

Fig. 1. Comparison of water quality between source and discharged water.

Toxicity test between four types of waters revealed no significant differences in inhibition of population growth rates (PGR) of phytoplankton. Only *I. galbana* showed lower PGR for the condensed water and other plankton species showed no significant differences in plankton PGR by tested water types (Fig. 2). Also, average mortality rates for rotifer and benthic copepod were below 7% and over 90% of exposed individuals of organisms were survived during test periods (Fig. 2). Based on this observation brine discharge may not have significant acute toxicity on marine planktons even increase in salinity by desalination.

However, the toxicity of chlorine and membrane cleaner on fish larvae was significant in terms of the exposed concentrations (Fig. 3). For chlorine toxicity test LOEC (lowest observed effective concentration) of flounder juvenile was less than 2.5 mg/L and mortality increased to 100% over LOEC. Membrane cleaner also showed high mortality with the exposed concentration over 75 mg/L and 100% mortality at 300 mg/L.

4. Conclusion and suggestions

The discharge of an effluent of high salinity from RO desalination plants has a strong impact on marine communities [18] including seagrass [11], infaunal community on soft bottom [6], and plankton community [12]. In this study most of the test species showed a threshold effect over 40 ppt of salinity in terms of their growth and mortality, and therefore, discharged brine must be maintained below 40 ppt after diffused to minimize the brine impact to the marine organisms.

Additives for membrane cleaning and post water treatment etc also had significant impact on the adjacent natural environment. From this study we found chemical additives had more significant acute toxicity than hypersaline water. Chlorine and membrane cleaner showed high toxicity on flounder juvenile. Toxicity of chlorine appeared to be a threshold effect: an abrupt increase in mortality was observed over a narrow range of toxicant concentration. The similar observation was found at winter flounder, *Pseudopleuronectes americanus*,

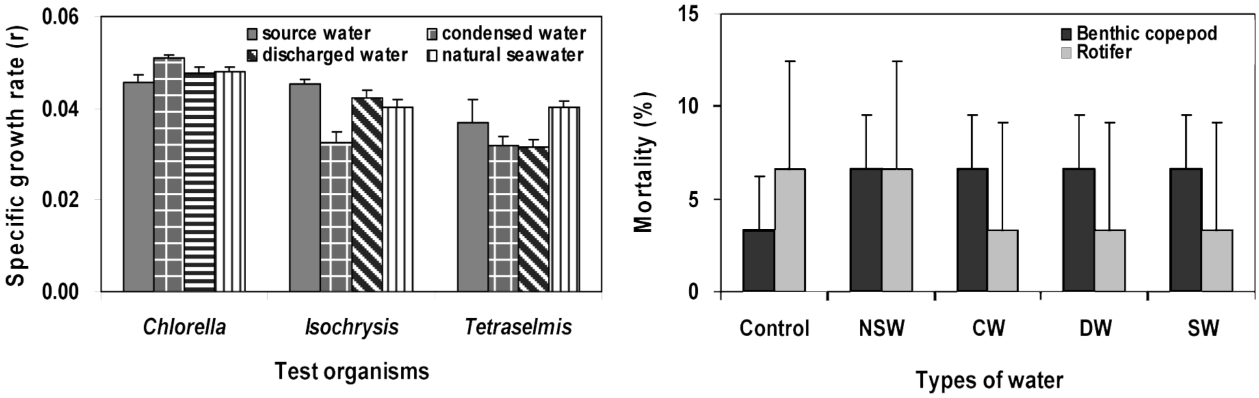

Fig. 2. Comparison of acute toxicity of phytoplankton and zooplankton using source water and brine discharge. NSW; natural seawater, CW; condensed water, DW; discharges water, SW; source water.

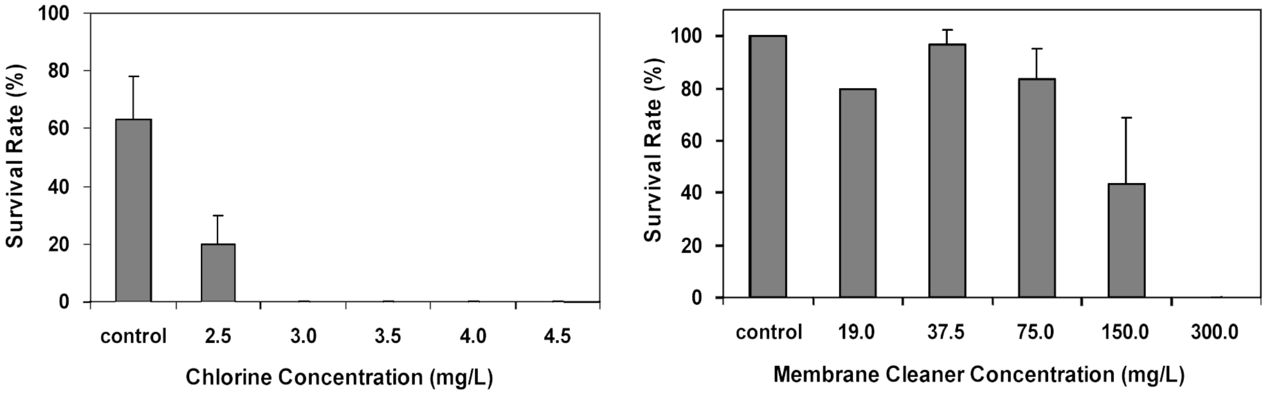

Fig. 3. Acute toxicity of chlorine and membrane cleaner to olive flounder fry.

scup, *Stenotomus versicolor*, and killifish, *Fundulus heteroclitus* and showed sharp increase in fish mortality over specific concentration of chlorine [19]. The sensitivity of fish juvenile on chlorine depended on the water temperature, more sensitive with increase of temperature [20]. Accordingly, increased water temperature at condensed and discharged water observed at CDP may have more toxic effect on marine organisms.

As CDP is a small desalination plant (1,000 m^3/d) and use of chemical additives is very limited, EIA process has not been established for the plant operation. There was no regular measurement for water and adjacent environmental quality around the plant. As the first step we suggest that macro faunal and floral monitoring along the coast of the intake and outfall must be conducted at least once a year to identify the possible changes in macrocommunity. It is not necessary to test toxicity of effluents and chemical additives because of its limited use at this time. In case of increased production of freshwater and chemical use for water treatment, however, we recommend regular monitoring of water quality and also toxicity test for EIA. The use of toxicity test with indigenous species is highly recommendable as toxicity test results can vary in terms of the species. The above test species as primary produces, primary and secondary consumers are highly recommendable due to its wide distribution in Korea coast.

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