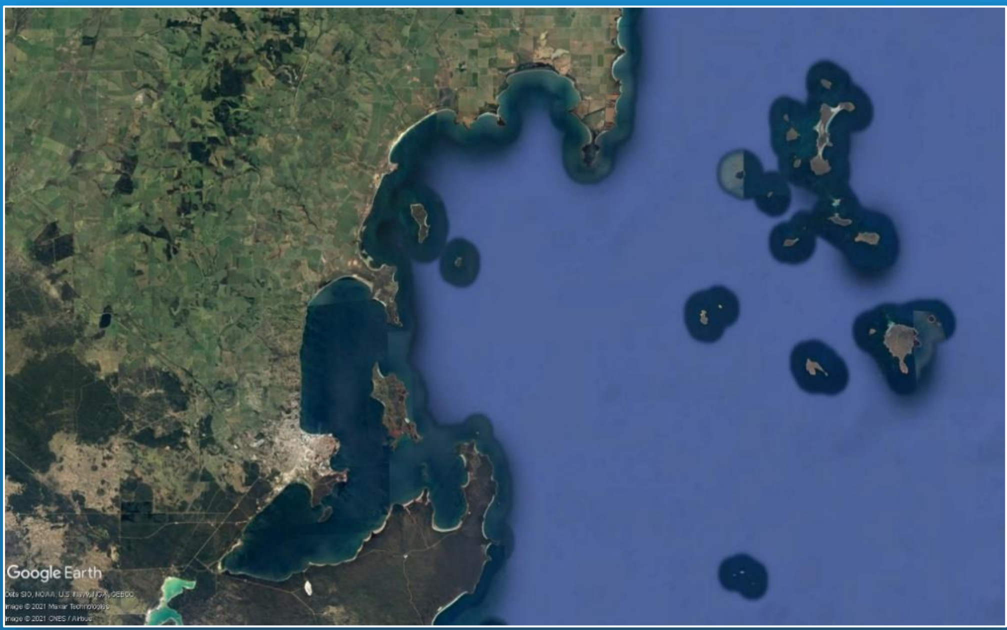
Marine Ecosystems

Literature review of potential impacts of desalination discharges in Boston Bay, with particular reference to aquaculture



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EXECUTIVE SUMMARY

SA Water are proposing to build a small seawater reverse osmosis desalination plant (4 GL yr^{-1}, with the potential for expansion to 8 GL yr^{-1}) at Port Lincoln to supplement the existing reticulated water supply from bores and the Murray River. Given the importance of aquaculture in the region, this has prompted some concern about potential impacts from the aquaculture industry. Here we review publicly available literature on the environmental impacts of desalination plants, focusing where possible on Australian studies. Impacts can result from either the seawater intake, or the brine discharge. The intake of seawater can entrain planktonic organisms and result in their loss to the system. While the total annual intake will be less than 2% of the volume of Proper and Boston bays, if the intake is in the larval dispersal pathway of blue mussels, it has the potential to impact on mussel aquaculture, which relies on wild spat collection. The source populations and dispersal pathways of these spat are currently unknown. Modern, well designed desalination plants discharge waste brine in such a way that the salinity generally drops to less than 1 psu above ambient within 100 m of the outfall. If this is met with the Port Lincoln plant, then the broader impacts of the discharge should be minimal. Provided the brine is flushed out of the bay over time, it is unlikely that it will have any broader impacts on the aquaculture industry. Any seagrasses in the immediate vicinity of the discharge, however, are likely to be lost, although if well designed this impact should extend <100m from the outfall. Expanding the current hydrodynamic modelling to examine movement pathways of the source water for the plant, would enhance our understanding of its potential to entrain blue mussel larvae. Habitat mapping around the proposed discharge point, would also provide valuable information and help with the assessment of the potential consequences for the species present.

Keywords: Aquaculture, desalination, environmental impacts, seagrass.

1. INTRODUCTION

SA Water are proposing to build a small desalination plant in the vicinity of Port Lincoln to supplement water currently obtained from the Uley South Basin bore field and the River Murray. Initially, the plant will supply 4 GL yr^{-1} of freshwater, obtained through reverse osmosis (RO) of seawater, with the potential for expansion to 8 GL yr^{-1}. Current annual reticulated water demand in the region is 7.24 GL yr^{-1}. Construction of the plant is anticipated to begin in early to mid-2022 and be completed by the end of 2023. Initially, it was proposed to construct the plant at Sleaford Bay, on the southern side of Jussieu Peninsula, however, logistical issues were identified with this site, and alternative sites in and around Boston Bay are now being considered.

Members of the aquaculture industry have expressed concern over the potential for the desalination plant to impact on the sector, which has a major presence in the region. Boston Bay and surrounds are important for southern bluefin tuna, yellowtail kingfish, mussel, oyster, and abalone aquaculture. Together, these industries have a total value of approximately $400 million per annum, making an important economic contribution to the region (Tanner et al. 2019, BDO EconSearch 2020).

Here, we provide a brief literature review of the potential impacts on the marine environment from the operation of a desalination plant in or around Boston Bay. Where possible, we focus on Australian literature, although we also include international literature where relevant. Potential impacts can be divided into those associated with the intake of seawater, primarily entrainment of larvae, eggs, and other plankton, and those associated with the brine discharge, primarily due to elevated salinity. The discharge water can also have an increased temperature, although this only ranges from 0-2 ^{o}C for RO desalination (Elsaid et al. 2020), and is therefore of limited relevance, and can include traces of chemical additives used as antiscalants and to clean fouling from the pipeline. Despite the increasing popularity of desalination plants for resolving water supply issues in many cities around the world, there is still a paucity of well-designed and peer-reviewed assessments of their ecological impacts (Roberts et al. 2010, Clark et al. 2018, Missimer and Maliva 2018, Kelaher et al. 2020). Much of the monitoring that has been done is published in the grey literature and is difficult to access. This limitation makes it difficult to conduct a comprehensive literature review of the impacts of desalination plants on the marine environment.

In this review, we focus purely on the impacts of operating a desalination plant, and do not examine the potential impacts of the construction. We also focus on actual impacts to the marine environment, and do not cover toxicity testing. As such, we also do not review the potential impacts of antiscalants and other potential chemical additives in the discharge water. This review relies on readily available information in the public domain. Additional documentation has not been obtained from desalination plant operators.

2. AUSTRALIAN CASE STUDIES

Several large-scale desalination plants have been constructed in Australia over the last decade or so, including on the Gold Coast, Sydney, Melbourne, Adelaide, and Perth. Apart from Adelaide, there appears to be very little publicly available information on their environmental impacts. While the Perth plant would provide a good case study for the Boston Bay plant, because it is located in a sheltered embayment (Cockburn Sound), no rigorous information on the outcomes of its environmental monitoring could be found. No monitoring reports for the Gold Coast or Melbourne plants could be located, while two published studies covering components of the monitoring of the Sydney plant are available.

2.1. Adelaide desalination plant

The Adelaide desalination plant (ADP) commenced operation in 2011, with a capacity of 100 GL yr^{-1}. While it has run for periods at full production, for much of this time it has only been operating at 10% capacity to maintain functionality (Figure 1), and has produced a total of ~190 GL of potable water. The plant is located about half-way up Gulf St Vincent, and discharges in ~17 m water depth into an area of sandy substrate with some nearby low-profile reef.

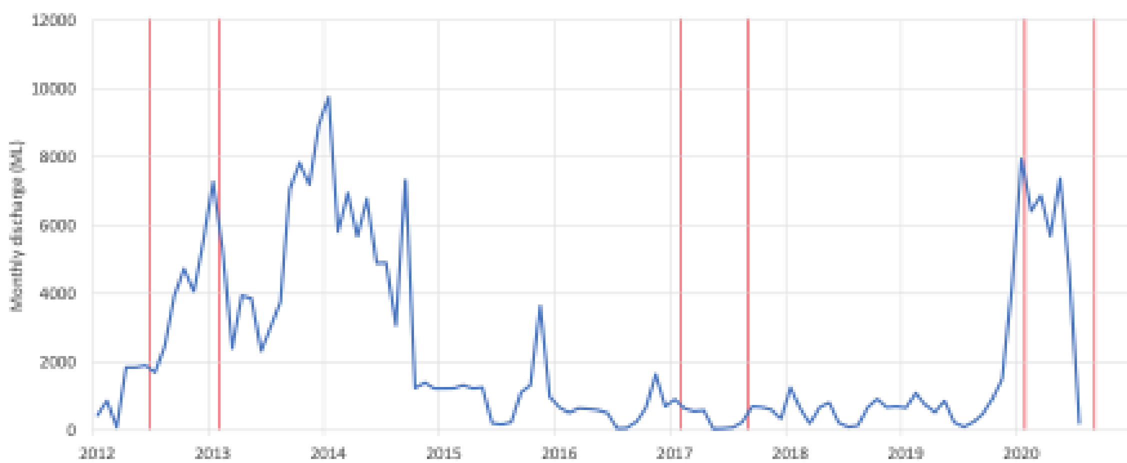

Figure 1: Monthly discharge of brine (ML) from the Adelaide desalination plant from 2012 to 2020. Red lines indicate infaunal sampling events. Source: Loo et al. (2021).

Routine monitoring of the intake and outfall water includes volume and velocity of seawater taken in and brine discharged, and water quality with a focus on salinity. Relevant license conditions include:

• average discharge salinity must not exceed the intake salinity by a factor of 2.1 for either a six-hour period, or a twenty-four-hour period.

• average salinity at 100 m from the diffuser structure must not exceed 1.3 psu above ambient salinity.

• seawater intake velocity at the entry to the intake structure must not exceed 0.15 m s^{-1} at any time.

Unfortunately, no reports that track these parameters over time are readily available, although monthly averages of some parameters are provided in quarterly reports, and some fragmentary data are available. Analysis of data from the first year of operation, however, did show that the 1.3 psu above ambient salinity threshold was not breached in that time (Kildea et al. 2013, Ayala et al. 2015a, b).

Biological monitoring has included reef, fish and infaunal community structure near the outfall compared with nearby reference sites, performed every three years. While these surveys are mentioned in yearly reports as having been done, only the infauna monitoring reports are all publicly available. The 2020 infauna monitoring report (Loo et al. 2021) included comparisons with 2013 and 2017 to examine changes in infaunal assemblages over time. There was no indication that the brine discharge from the desalination plant was impacting infaunal assemblages.

The autumn 2015 reef fish survey (Jacobs Group (Australia) Pty Ltd 2015) found no statistically significant differences between reef fish assemblages at the outfall site versus reference reefs. The total abundance of fish at the outfall site was significantly higher than at any of the reference reefs; however, this was attributed to reduced fishing pressure at the outfall site, as this site is within an Exclusion Zone that prohibits vessel access. Comparison of this data with previous fish surveys was limited because the location and habitat of the sampling changed in 2015. Comparison of the reef fish communities between outfall and reference sites in 2015 and 2018 found no evidence that the ADP was having an impact on fish communities (Brook 2018, Whitmarsh et al. 2021).

A review of the ADP's comprehensive marine monitoring data (Cheshire 2014) concluded that water quality and biological communities were largely unaffected by the operation of the plant (outside of the 100 m permitted mixing zone). In this context, the mixing zone is the region immediately around the outfall where brine dilution is permitted to be less than the target level

(Cheshire 2014), and thus where salinity might be elevated sufficiently to cause environmental harm. While there appears to have been a lot of data collected since the production of this report, it is not all readily available, and for most components of the monitoring program, it is reported in individual quarterly or annual reports with no overall assessment of the impacts, or lack thereof, over time.

2.2. Sydney desalination plant

The Sydney desalination plant, located at Kurnell, is capable of producing up to 90 GL yr^{-1} of freshwater. The intake is located ~300 m offshore of the open ocean coast, 25 m below the sea surface. The discharge is located over rocky reef at a similar distance offshore and depth. Discharged brine is twice the salinity of seawater, ~ 1 ^{o}C warmer, and returns to normal salinity and temperature within 50-75 m of the outlet (Sydney Desalination Plant 2021a), although no data are presented to support these claims. Two published studies were located on the impacts of this plant. One showed that the diversity and abundance of pelagic and demersal fish species increased when the plant was operating (Kelaher et al. 2020), and is discussed below in the section on fish. The second study examined marine invertebrates, and found a decrease in some taxa and an increase in others up to 100 m from the outfall (Clark et al. 2018), and is discussed under invertebrates below. Interestingly, the later contradicts Sydney Desalination Plant (2021a), and indicates that at 100m, salinity is still elevated by 0.8 psu above background (Clark et al. 2018). No monitoring reports appear to be publicly available.

3. GENERAL ECOLOGICAL IMPACTS

3.1. Macroalgae

Few studies have examined the impacts of brine discharges on macroalgae (Rodriguez-Rojas et al. 2020), which form an important component of intertidal and subtidal reef assemblages in southern Australia, including in Boston Bay. *Ectocarpus*, a small filamentous brown macroalga also found in Australia, showed decreased photosynthesis and increased physiological stress at sites 10 m and 30 m from a brine discharge, corresponding to an increase in salinity of 2.38 and 1.5 psu, in Chile (Rodriguez-Rojas et al. 2020).

3.2. Seagrasses

Seagrasses are a dominant component of the shallow subtidal and intertidal habitat in and around Boston Bay (Irving 2014). The main intertidal seagrass is *Zostera muelleri*, with species of *Posidonia*, *Amphibolis*, *Zostera* and *Halophila* all occurring in the subtidal, with the latter potentially occurring to depths of 20 m or more. *Posidonia* is likely to be the dominant taxon around the proposed outfall site, although this needs to be confirmed by visual surveys of the site. Seagrasses provide important habitat for many marine fauna, as well as being important primary producers, stabilising sediment, cycling nutrients, and storing carbon. Irving (2014) provides a review of seagrasses in Spencer Gulf.

Seagrass responses to increased salinity are species specific, with some having a broad tolerance to changes, while others can only cope with a very narrow salinity range (Cambridge et al. 2017). Within a species, actual salinity tolerances displayed at one location may not transfer to other locations, as distinct geographic ecotypes have evolved that accommodate local conditions (Cambridge et al. 2017). Very few studies have examined the response of Australian seagrass species to increased salinity.

Zostera muelleri, which primarily occurs in the intertidal, is capable of maintaining relatively high photosynthetic rates up to salinities of 400% of normal seawater, albeit measurements were only made over a 2 hr period after salinity was experimentally increased (Kerr and Strother 1985). Conversely, germination of *Z. muelleri* declines as salinity increases, consistent with its evolutionary origin from a freshwater ancestor (Stafford-Bell et al. 2016).

Posidonia australis, which occurs subtidally in Boston Bay alongside other *Posidonia* species, has a broad salinity range. In a 7-week experiment on plants collected in Botany Bay, there was no effect of increasing salinity to 57 psu on leaf growth (Tyerman et al. 1984). In another experiment in WA, mortality over 6 weeks was 33% at 46 psu and 60% at 54 psu, compared to 2% at 37 psu (Cambridge et al. 2017). Photosynthesis in both elevated salinities decreased after 6 weeks, but not 4. In a subsequent experiment, Cambridge et al. (2019) showed growth decreased in brine from the Perth desalination plant at 54 psu, but not in 46 psu, and not in water of the same salinity produced using salt, indicating that it was other components of the brine discharge causing the effect. Conversely, *P. oceanica*, which only occurs in the Mediterranean, has very little tolerance to changes in salinity, and experiences negative impacts with increases as little as 0.5-1 psu (e.g. Sanchez-Lizaso et al. 2008, Ruiz et al. 2009, Fernandez-Torquemada and Sanchez-Lizaso 2013, Capo et al. 2020).

Amphibolis antarctica, which also occurs in Boston Bay, although not as commonly as *Posidonia*, shows maximum production and biomass at 42 psu in Shark Bay, declining as salinities increase beyond this until it is absent at 64 psu (Walker 1985). Interestingly, both variables were substantially lower at 40 psu than 42 psu, although this is likely to reflect a local ecotype adapted to a hypersaline region, and thus these results may not be transferable to Boston Bay, where typical salinities are ~ 36.5-37 psu (Tanner et al. 2020).

Locally, both *A. antarctica* and *Posidonia* are tolerant of reduced salinities over periods of at least 7 weeks (Westphalen et al. 2005), but their response to increased salinity has not been examined. Both do occur in the upper gulfs, however, where they are exposed to salinities >40 psu over summer (Westphalen et al. 2004). Given the above, it is likely that seagrasses in Boston Bay will not be impacted by the brine discharge beyond the immediate area around the discharge point where mixing occurs if salinity is not elevated by >1 psu, although what upper threshold they can survive is currently unclear.

3.3. Invertebrates

Marine invertebrates include a diverse array of taxa, and are likely to have differing responses to desalination plant discharges. In the only published Australian study, recruitment of polychaetes, bryozoans and sponges decreased on panels placed at impact sites 100 m and 30 m from the outfall of the Sydney desalination plant during operation in comparison to reference sites 1.5-5 km away (Clark et al. 2018). Conversely, barnacle recruitment (primarily the introduced *Magabalanus coccopoma*) increased at the impact sites. In both cases, the impact was greater at 30 m, where salinity increased by 1 psu, compared with 100 m, where salinity only increased by 0.8 psu. Ascidian cover did not show any changes. There were no differences between impact and reference sites during an extended plant shutdown. As the differences observed were unexpected given the small increase in salinity documented, the authors hypothesized that the impacts were related to changes in water velocity, which were calculated to be roughly double ambient at the 100 m site.

In Spain, infaunal polychaetes were significantly impacted by a brine discharge from a 50 GL yr^{-1} desalination plant that caused an increase in salinity to 49 psu within 250 m of the discharge point (Del-Pilar-Ruso et al. 2015). After a diffuser was added to the discharge, salinity decreased to ~1 psu above ambient at the most impacted sample site, and after two years the assemblage had recovered in terms of diversity and richness, but not abundance or community composition.

Also in Spain, a study of echinoderm abundance in the plume of a brine discharge showed that even small increases in salinity (0.3-0.4 psu) could lead to a complete loss of echinoderms in a seagrass meadow (Fernandez-Torquemada et al. 2013). The assemblage studied included sea cucumbers, starfish and sea urchins. When the brine was diluted with seawater prior to discharge, the salinity at the impact site returned to ambient, and echinoderm densities recovered. In this study, the impact site was 2 km directly offshore from the desalination plant, which discharged brine at 68 psu directly onto the shore, rather than subtidally through diffusers. At another location, Gacia et al. (2007) also found a loss of echinoderms in a seagrass meadow with salinity up to 2.5 psu above ambient.

In California, 16 invertebrate species (6 echinoderms, 2 cnidarians, 1 crustacean, 6 molluscs, 1 polychaete) were exposed to salinities ~1 psu above ambient for 5 ½ months with no ill effect (Voutchkov 2011). Three of these species were also tested for 19 days at up to 4 psu above ambient, also with no ill effect. In another Spanish study, 12 months of sampling mobile invertebrates before and after a desalination plant commenced operating showed no impacts on community structure (Raventos et al. 2006). Salinity at the site returned to normal within 10 m of the discharge pipe, and impact site transects were within this zone, although no data is given on actual salinity levels.

3.4. Fish

There have been two recently published papers on the impacts of desalination plants on temperate fish assemblages in Australia. Brine discharges between 661 and 1287 ML $month^{-1}$ from the Adelaide desalination plant did not have any detectable impact on fish assemblages assessed using baited remote underwater video, with species diversity and abundance being similar to those found on other nearby artificial reef habitats not exposed to increased salinity

(Whitmarsh et al. 2021). In contrast, fish diversity and abundance increased during operation of the Sydney desalination plant compared to before it commenced operation (but after construction), but there was no effect when the plant was not discharging (Kelaher et al. 2020). While benthic fishes did not appear to respond to the discharge, both pelagic and demersal species increased in abundance, including a number targeted by commercial and recreational fishers. In both studies, salinities were <1 psu above ambient within 100 m of the outfall.

3.5. Larval entrainment

Depending on the design, the intakes of desalination plants, like those of power plants, have the potential to impinge and entrain marine organisms. Impingement is when larger organisms are trapped on the screens covering the intake and can largely be avoided with low velocity intakes. Entrainment is when smaller planktonic organisms, including larvae and eggs, with limited or no swimming ability are sucked into the intake. It is possible to avoid most entrainment with subterranean intakes, although these are not always feasible (Missimer and Maliva 2018, Elsaid et al. 2020).

For the Melbourne desalination plant, modelling was used to predict the reduction in larval abundance in the zone of influence around the intake (Department of Sustainability and Environment 2006). This zone varied in size with larval duration, ranging from <2km^2 for 1-day larval duration, to hundreds of km^2 for larvae of 120 days duration. Predicted reductions in larval abundance were always <2%. These modelled reductions were for a 200 GL yr^{-1} plant, which is 25 times larger than the proposed plant at Port Lincoln. The modelled plant was also on a high energy coastline, compared to the more sheltered proposed location of the Port Lincoln plant.

For the Adelaide desalination plant, Cheshire (2014) developed a rough estimate of the likely consequences of entrainment for Australian sardine. This indicated that when operating at full capacity (100 GL yr^{-1}), entrainment would be equivalent to increasing the commercial catch by in the order of 0.001%

Based on larval sampling, it was estimated that a ~4 GL yr^{-1} desalination plant in Sant Cruz, on an open ocean coast, would increase mortality of larvae from a range of fish species by <0.1% (Tenera Environmental 2010). Mortality of the crustacean species studied was predicted to be even lower.

4. IMPACTS ON AQUACULTURE

No literature could be found on the direct impacts of seawater desalination on aquaculture operations or production. Any potential impacts could be separated into two categories: impacts of the brine discharge, and impacts of entrainment in the intake water.

The brine discharge could affect aquaculture either through increased salinity, or the discharge of other chemicals such as antiscalants. Assessment of chemical impacts requires an understanding of what chemicals may be added to the discharge water, and it is recommended that relevant ecotoxicology studies, such as those done for the Adelaide desalination plant and the previously proposed Olympic Dam plant, as well as others around Australia and potentially elsewhere, be reviewed. If these previous studies do not cover relevant aquaculture species, then they may need to be the subject of appropriate whole effluent toxicity testing. Relevant species will depend on the location of the discharge and the predicted dispersal pathway of the plume, but could include blue mussels, oysters, and yellowtail kingfish. Blue mussels would be particularly relevant, as the industry relies on the collection of wild spat, whereas the oyster and kingfish industries rely on hatchery cultivation, providing a greater opportunity to separate the early life phases, which are likely to be the most sensitive, from the impacts of brine discharge. The potential for salinity impacts will be governed by the location of the discharge outlet and how rapidly the discharge is diluted. In open areas, salinity increases generally drop to < 1psu within 100 m of the discharge point (e.g. Kelaher et al. 2020, Whitmarsh et al. 2021), although this will need to be confirmed by hydrodynamic modelling for the proposed discharge site in Boston Bay. Provided there are no aquaculture leases, or substantial blue mussel wild stocks, in areas with >1 psu elevation in salinity, it is unlikely that increased salinity will impact on aquaculture operations. The other possible pathway for increased salinity to impact aquaculture would be if the discharge is placed in a major pathway of blue mussel larval dispersal.

The proposed desalination plant could have a more direct impact on the blue mussel industry if the intake is placed in the dispersal pathway of larval blue mussels, because any larvae entrained into the intake would be lost. The larval phase of blue mussels lasts for 1-1.5 months (Zagata et al. 2008), providing an extended period of opportunity for them to become entrained if the intake is not appropriately positioned. However, with an intake of only 20 GL yr^{-1} at maximum production, compared to an estimated volume of 1280 GL for Boston and Proper Bays (estimate provided by SA Water), this is only likely to impact if the intake is positioned directly in a major dispersal pathway. It should be noted, however, that these dispersal pathways are currently unknown, and further work may be needed to assess the likely impacts of entrainment on mussels.

5. SITING

Across the literature reviewed, it is broadly agreed that the positioning of the discharge site is critical for reducing the ecological impacts of desalination plants (Roberts et al. 2010). Ideally, the discharge should be in a high energy, well flushed site, where the brine will be rapidly diluted and dispersed (Sagastegui and Sala 2006, Petersen et al. 2019). Importantly, where possible, it should avoid sensitive habitats such as seagrass meadows and reefs (Hopner and Windelberg 1997, Sagastegui and Sala 2006, Roberts et al. 2010), and preferably target areas with already impacted sandy substrates (Petersen et al. 2019). However, both the Perth and Sydney desalination plants appear to contravene at least some of these principles, apparently without environmental impact. The Perth desalination plant is located in Cockburn Sound, an enclosed body of water with a low flushing rate, and has been reported to have limited to no ecological impacts (International Water Association 2016), although no peer reviewed studies or monitoring reports appear to be publicly availableto support this. While the Sydney desalination plant discharges into a high energy open ocean environment, it does so on a rocky reef, with little impact on the components of the marine community assessed outside of a small mixing zone (Kelaher et al. 2020, Sydney Desalination Plant 2021b). Irrespective, hydrodynamic models should be used to understand the potential dispersal of the brine plume, and how rapidly it will be diluted. This work is currently being undertaken by SARDI’s oceanographic team and includes a 12-month field program to validate the model outputs.

The other aspect of siting of the plant that needs to be addressed is the location of the intake structure. Operationally, there is a need to ensure that the intake does not entrain high salinity water, either from shallow inshore areas with low flushing, or from the brine outfall. Environmentally, a key issue is to assess the potential extent of entrainment of blue mussel larvae.

6. CONCLUSIONS

Despite the paucity of high quality publications on the marine environmental impacts of desalination plants, this literature reviewed suggests that a well-designed desalination plant with the intake designed and placed to minimise entrainment of marine organisms, and an outfall designed to promote mixing and not in a vulnerable area, should have minimal environmental impacts beyond 100-200 m from the outfall. This conclusion is primarily based on the fact that it should be possible to design the plant so that salinity is not elevated by more than 1 psu beyond 100 m from the outfall. Whilst a threshold salinity increase for environmental impacts cannot be derived from the literature available, the data available suggest that it is unlikely that there will be a substantial impact on areas where salinity is elevated by no more than 1 psu. Given the small size of the proposed Port Lincoln plant (initially 4 GL yr^{-1}, with later expansion to 8 GL yr^{-1}) compared to most of the plants studied (50-100 GL yr^{-1}), it should be possible to ensure that the plant does not have any adverse impacts on the environment or other users of the area, including aquaculture. As the proposed desalination plant may be located in the vicinity of the current SA Water wastewater treatment plant (WWTP) at Billy Lights Point, one possibility to increase mixing may to be discharge the two waste streams together. The effectiveness of such a strategy will depend in part on the variability in the WWTP flows, and it needs to be confirmed that a mixed discharge does not have increased impacts due to the alteration in the ionic balance, as has been suggested elsewhere (Missimer and Maliva 2018). An alternative strategy may be to mix the brine with additional seawater, although this will require a larger intake and result in the entrainment of additional larvae.

To minimize environmental impacts, it will be important to ensure that the brine is discharged in such a way that it is rapidly mixed with the surrounding water, and that the receiving water body is well flushed. Hydrodynamic modelling and field studies are currently being undertaken to examine these issues. If the mixing zone is confirmed to be small, then the primary impact of the discharge will be on the immediate surrounding environment, which in this case is potentially a seagrass meadow. This needs to be confirmed through field surveys, and potential impacts on any seagrass species present, as well as associated fauna, examined.

It is also important to understand where the water being taken in is coming from and going to, as well as the potential for the plant to entrain mussel larvae, in order to avoid impacts on the blue mussel industry, which relies on wild spatfall. It is thus recommended that the current hydrodynamic modelling be extended to examine the source water, and that larval sampling be undertaken at the proposed intake site, with a focus on blue mussel larvae.

There is a paucity of readily accessible and peer-reviewed information on the environmental effects of operational desalination plants. Even in Australia, where the regulatory regime is strong, and it appears that there are robust monitoring programs in place (e.g. Sydney, Melbourne, Adelaide and Perth), little of this information is published. Monitoring reports only appear to be available for the Adelaide desalination plant, through the South Australian Environmental Protection Authority website, and even these are fragmentary, with reports examining individual monitoring events rather than providing holistic analyses of all data collected over the course of the monitoring program. While the information that is available suggests that a well-designed and located desalination plant in Boston Bay should have minimal environmental impact, it would be beneficial in future if environmental monitoring reports take a more holistic approach than is generally demonstrated, and importantly, that they are readily available.

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