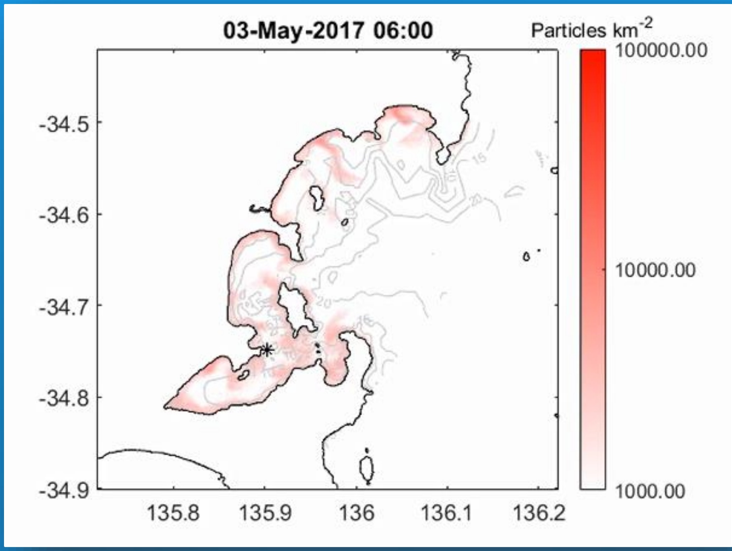
Marine Ecosystems

Addendum: oceanographic modelling of larval connectivity to inform desalination in Boston Bay



M. Doubell and C. James

SARDI Publication No. F2022/000347-1
SARDI Research Report Series No. 1165

SARDI Aquatic and Livestock Sciences
PO Box 120 Henley Beach SA 5022

May 2024

Report to SA Water

Government of South Australia
Department of Primary Industries and Regions

SA Water

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Addendum: oceanographic modelling of larval connectivity to inform desalination in Boston Bay

Report to SA Water

M. Doubell and C. James

SARDI Publication No. F2022/000347-1
SARDI Research Report Series No. 1165

May 2024

The South Australian Research and Development Institute respects Aboriginal people as the state's first people and nations. We recognise Aboriginal people as traditional owners and occupants of South Australian land and waters. We pay our respects to Aboriginal cultures and to Elders past, present and emerging.

This publication may be cited as:
Doubell, M. and James, C. (2024). Addendum: oceanographic modelling of larval connectivity to inform desalination in Boston Bay. Report to SA Water. South Australian Research and Development Institute (Aquatic and Livestock Sciences), Adelaide. SARDI Publication No. F2022/000347-1. SARDI Research Report Series No. 1165. 14pp.

Author(s): M. Doubell and C. James

Reviewer(s): M. Steer

Approved by: M. Steer
Research Director – Aquatic and Livestock Sciences

Signed:

Date: 31 May 2024

Distribution: SA Water, SARDI Aquatic and Livestock Sciences, Parliamentary Library, State Library and National Library

Circulation: OFFICIAL

ALL ENQUIRIES
South Australian Research and Development Institute – Aquatic and Livestock Sciences
2 Hamra Avenue West Beach SA 5024
PO Box 120 Henley Beach SA 5022
P: (08) 8207 5400 **F:** (08) 8207 5415
E: pirsa.sardiaquatics@sa.gov.au **W:** http://www.pir.sa.gov.au/research

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This work was funded by SA Water. The authors are grateful to Dr Hazel Vandeleur and Dr Tim Kildea for their assistance and support.

The report was approved and cleared for release by Dr Mike Steer, Research Director, SARDI Aquatic and Livestock Sciences.

EXECUTIVE SUMMARY

This addendum provides an update to the larval tracking studies of Doubell and James (2023). New larval tracking results are presented to establish the possible effect of Stokes drift on entrainment by desalination intakes in the region. In addition, an update to the original larval tracking has been undertaken for a new intake site located near Billy Lights Point.

Following the approach and assumptions presented in Doubell and James (2023), the results show that the inclusion of Stokes drift in combination with the constraining of particles to the ocean's surface layer could significantly alter the predicted particle trajectories but had negligible effect on connectivity with intakes, with less <0.1% of the total number of particles released each spawning season estimated to be entrained into an intake area with a radius of 25m.

For the new intake location near Billy Lights Point less than 0.1% of the total number of particles released each spawning season were estimated to be at risk of entrainment into an intake area with radius of 25m. At smaller spatial scales, connectivity mapping with source locations showed that up to 0.6 % of particles released from locations within 2 km of the new intake location between Billy Lights Point and Kirton Point may be at risk of entrainment. The risk of entertainment decreased with distance from the intake, with the percentage of particles likely to be at risk of entrainment from source regions across Proper Bay and Boston Bay estimated to be less than 0.4 %.

The additional results presented here are consistent with the levels of connectivity and entrainment provided by Doubell and James (2023).

Keywords: hydrodynamic model, larval transport, desalination, dispersal, connectivity.

1. INTRODUCTION

1.1. Background

Doubell and James (2023) modelled the connectivity of blue mussel larvae to better understand the potential larval losses due to entrainment for several proposed desalination plant intake locations. The biophysical modelling simulations provided the first study of blue mussel larval transport pathways in the region. The estimated level of larval connectivity with the proposed intakes was low, with less than 0.1% of the total number of particles released throughout the spawning season estimated to be entrained in an intake area with radius of 25m.

Following the publication of Doubell and James (2023) concerns were raised by some critics that the influence of surface wave-induced transport due to Stokes drift (e.g., Feng et al. 2011) may significantly alter the entrainment estimates and were not considered. Although this would be unlikely unless the larvae remained on the surface (acting essentially as a surfactant like an oil slick), this addendum provides new larval tracking results to demonstrate effect of Stokes drift on entrainment of particles by previously proposed intakes in the region for both passive and surfactant examples. In addition, an update to the original larval tracking has been undertaken for a new intake site located near Billy Lights Point (BLP) (Table 1-1, Figure 1-1).

Table 1-1. Location of desalination plant intakes investigated in this study.

Site Name	Intake	
	Longitude (ºE)	Latitude (ºS)
Billy Lights Point – inshore	135.8855	34.7558
Billy Lights Point – extension	135.8968	34.7484
Point Boston – inshore	135.9460	34.6158
Billy Lights Point – inshore new	135.8983	34.7468

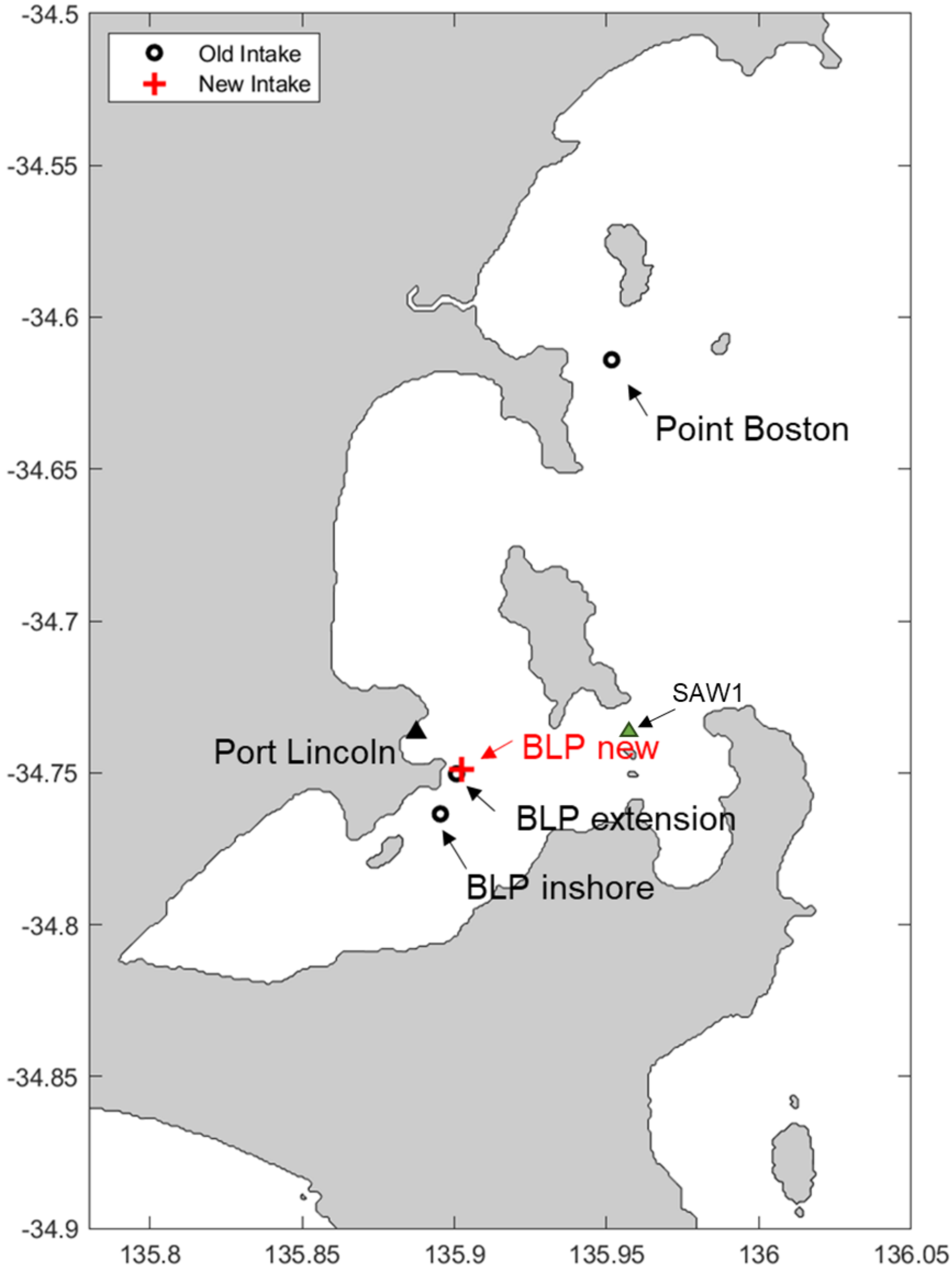


Figure 1-1. Map of the Port Lincoln region showing the location of the previously modelled proposed intake locations (black markers) and the new intake location (red marker) near Billy Lights Point (BLP). The oceanographic mooring was located at SAW1.

1.2. Objectives

The project objectives were to:

1. Use the coupled hydrodynamic and larval transport model developed by Doubell and James (2023) to establish the effect of Stokes drift on estimates of larval entrainment.

2. Use the coupled hydrodynamic and larval transport model developed by Doubell and James (2023) to update the estimates of larval entrainment for a new intake location.

2. METHODS

2.1. Ocean modelling system

In this study, a high-resolution three-dimensional hydrodynamic model was used for the Port Lincoln region to drive a particle tracking model to understand the far-field connectivity of planktonic mussel larvae with proposed intake locations. Details regarding the configuration and validation of the hydrodynamic and particle tracking models were presented in Doubell and James (2023). In summary, a 2-way nested high-resolution hydrodynamic model for Boston Bay (HRBBM) was embedded within the 1.5 km resolution Two Gulfs model (TGM) for Spencer Gulf and Gulf Saint Vincent using the open-source Regional Ocean Modelling System (ROMS, https://www.myroms.org/). The HRBBM has a horizontal spatial resolution of 300m and 15 sigma levels in the vertical. Lateral boundary conditions and interior solutions for the HRBBM are exchanged with the TGM and the model was run with a time-step of 40 s.

Both the TGM and HRBBM were forced with pressure, wind, humidity, heat-fluxes, and precipitation from global atmospheric models provided by the NCEP Climate Forecast System Reanalysis v.2 (Saha et al. 2014). Tidal forcing was provided by the global TPXO8 model (Erofeeva & Egbert 2014). Lateral oceanic boundary conditions and initial fields for TGM (i.e., temperature, salinity, currents, and sea level) were provided by the 10 km resolution Ocean Forecast Australia Model (OFAM). CSIRO's Blue Link Reanalysis 2020 (BRAN2020; Oke et al., 2013) was used for modelling the period from July 2015 to June 2021. A six-month model spin-up was run, using BRAN-derived initial conditions, from 1 July 2015 to 1 January 2016 to provide artefact-free initial conditions for the hindcast simulations. The Smagorinsky scheme (Smagorinsky, 1963) was used to calculate the horizontal eddy viscosity, and a constant horizontal tracer diffusion of 2 m^2/s was used for temperature and salt. The k-profile parameterisation of Large et al. (1994) was used for vertical diffusion and mixing. A quadratic bottom stress formulation was assumed with a bottom roughness length of 2 cm. Improvement to the model sea surface temperature (SST) was achieved by adjusting the heat-fluxes using remote sensed SST provided by the Level 4 Multi-scale Ultra-high Resolution (MUR) SST Analyses (Chin et al. 2017).

2.2. Particle tracking modelling

Larval transport was simulated using the larval transport particle tracking model (LTRANS; North et al. 2006; 2008). In summary, LTRANS uses hourly outputs from the ROMS hydrodynamic model to track the trajectories of particles in three dimensions. As described by North et al. (2008), LTRANS considers particle advection, vertical and horizontal turbulent particle motions and applies reflective boundary conditions. Current predictions from the HRBBM were interpolated in both space and time using an internal LTRANS time step of 120 seconds. Particle transport is simulated using a 4th order Runge-Kutta scheme for advection and a random displacement model to account for sub-grid scale turbulence on particle motions (Laurent et al., 2020). The horizontal diffusivity was assumed to be constant and was set at 1 m^2 s^{-1}. A logarithmic reduction in current velocities is implemented to simulate the influence of bottom friction on currents.

2.3. Effect of Stokes drift

To examine the effects of surface wave-induced transport, an effect known as Stokes drift, on particle trajectories and connectivity with desalination intakes model simulations with and without Stokes drift for three consecutive spawning seasons (2016, 2017, 2018) were compared. Since the waves in Boston Bay are almost entirely wind generated, with wave periods generally below 3 seconds and wave heights below 1 m (Figure 2-1), Stokes drift was applied using the wind-drift method described in Callies et al., (2017) based on a direct wind-drag, equivalent to 0.6% of the 10m wind applied across the surface layer of the model.

Simulations without Stokes drift followed those presented in Doubell and James (2023) for purely passive particles (i.e., neutrally buoyant, without vertical behaviour). Simulations with Stokes drift included two scenarios. In the first scenario the particles were assumed to be purely passive and could be mixed vertically throughout the water column. In the second scenario, since the effects of Stokes drift on larval transport are limited to organisms located near the surface (e.g., Monismith and Fong, 2004), particles were kept on the surface for the entire simulation.

Following the method of Doubell and James (2023), for each scenario and spawning season (May to September) particles were tracked until they exited the model domain or passed within a radius of 1 km of the previously proposed desalination intake locations (Figure 1; BLP inshore, BLP extension and Point Boston). The monthly spawning events lasted 5-days and involved the daily release of 10 particles from the HRBBM grid cells within 1 km of the coast (Figure 2-2). To estimate the percentage of particles with connectivity to the different intake pipe locations with a potential entrainment radius of 25 m, the total proportion of particles released during each spawning season with connectivity to within 1 km of the intake was downscaled by adjusting for the reduced cross-sectional area of the entrainment zone (i.e., $\pi 25^2/\pi 1000^2$).

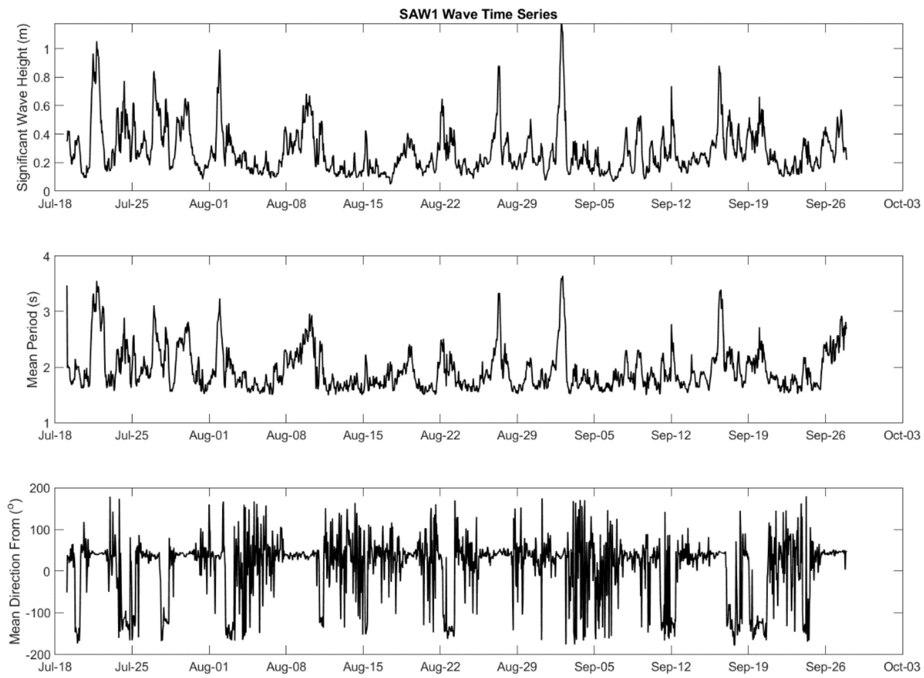


Figure 2-1. Wave observations taken at Site SAW1 using wave monitoring ADCP.

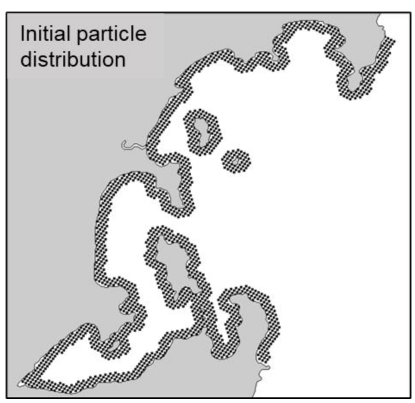


Figure 2-2. Initial distribution of particles corresponding to location model grid cells within 1 km of the coast.

2.4. Connectivity with the new proposed intake location

The new proposed intake location provided by SA Water near Billy Lights Point is located approximately 230 m north of the previously modelled Billy Lights Point extension location (Figure 1-1). The modelling approach followed that described in Doubell and James (2023), with connectivity assessed over three consecutive spawning seasons (2016, 2017, 2018). Vertical advection and turbulent mixing were improved using the values computed within the HRBBM. Based on recent sensitivity studies (Mitchell et al., 2023) the number of particles released per day in each grid cell was increased from 10 to 100 to improve the statistical confidence in the results and to allow tracking to within 300m of the intake. In total, 883,500 particles were released during each monthly spawning event, with a total of 4,417,500 released per spawning season, or 13,252,500 particles released over the three seasons.

3. RESULTS

3.1. Effect of Stokes drift

The inclusion of Stokes drift resulted in differences in the predicted particle distributions, but only when the particles were constrained to the ocean surface (Figure 3-1). Differences in particle distributions between simulations with and without Stokes drift for passive particles were negligible because only a small proportion of particles are in the surface layer at any given point in time. Figure 3-2 shows that for all scenarios <0.1% of the total number of particles released per spawning season were estimated to be entrained in an intake area with radius of 25 m. This demonstrated that the inclusion of Stokes drift made negligible difference to the predicted levels of entrainment. For the case of surface trapped particles, the inclusion of the Stokes wind-drift led to decreased connectivity in 6 of the 9 cases, and significantly less connectivity in 4 cases (Figure 3-2), presumably due to increased flushing by the wind-drift.

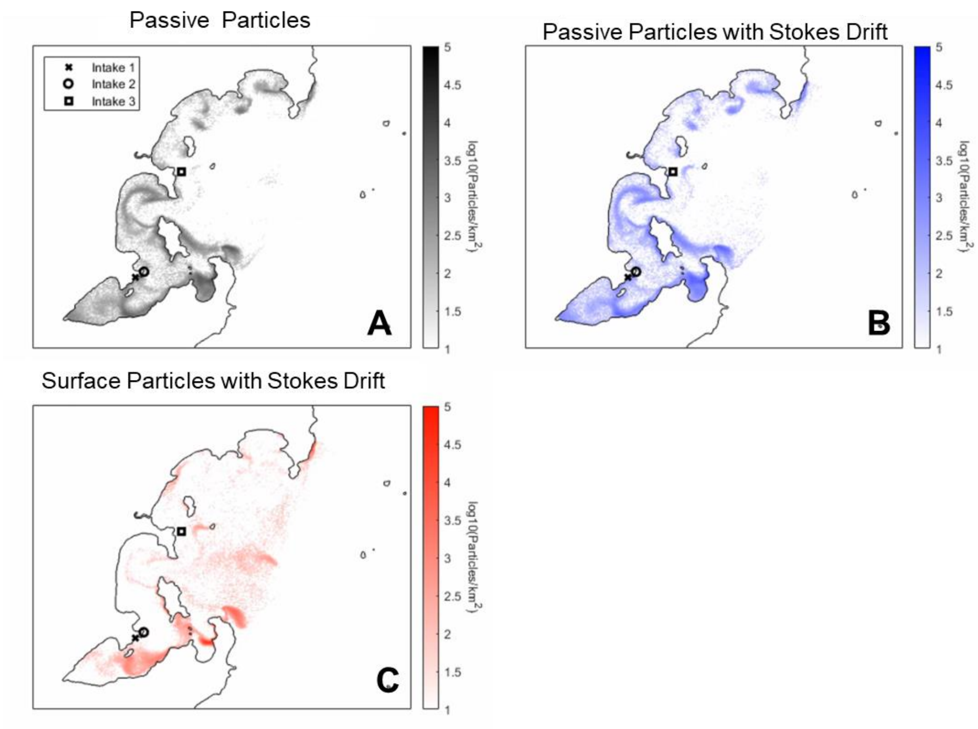


Figure 3-1. Example snapshot the particle distributions (particle densities) on 7 May 2018, modelled under different model scenarios (A) passive particles without Stokes drift, (B) passive particles with Stokes drift, and (C) with particles constrained to the ocean surface with Stokes drift. Intake locations for Billy Lights Point (BLP) inshore (intake 1), BLP extension (intake 2) and Point Boston (intake 3) are provided in the legend.

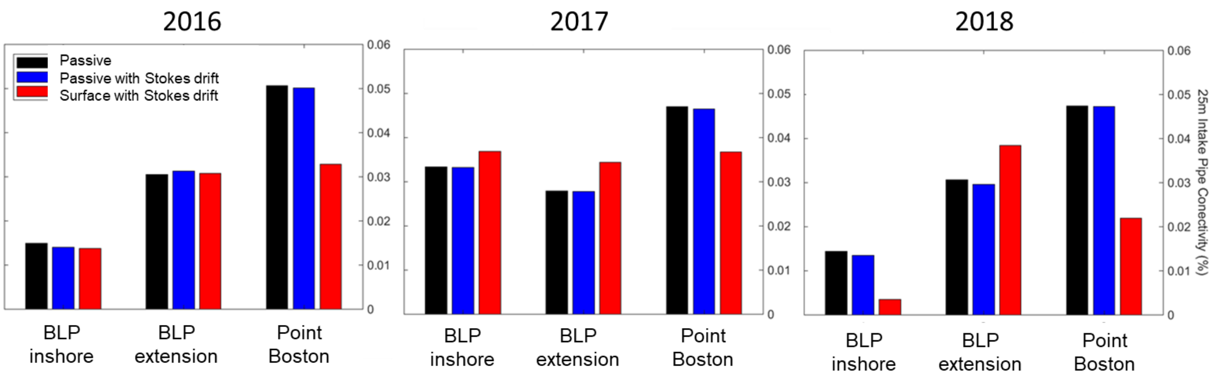


Figure 3-2. Comparison of the estimated percentage of particles (representative of larvae) released per spawning season (2016-2018) which came within 25m radius of intakes for the three scenarios studies (i) passive particles with no Stokes drift, (ii) passive particles with Stokes drift and (iii) particles held in the surface layer with Stokes drift. The intake locations corresponded to the Billy Lights Point (BLP) inshore, BLP extension, and Point Boston locations shown in Figure 1-1.

3.2. Connectivity with the new intake location

Figure 3-3 shows a snapshot of the predicted particle distributions on 30 September at the end of each spawning season for the years 2016-2018. Inter-annual differences in the local circulation patterns driven by winds result in different spatial distribution of particles from year to year. Regardless of these differences, for all seasons <0.1% of the total number of particles released per spawning season was estimated to be entrained into an intake area with a radius of 25m.

The percentage of particles from each source location estimated to arrive within a radius of 25 m of the new intake location for each spawning season, as well as the composite map averaged over the three spawning seasons, is shown in Figure 3-4. Spatial connectivity with the intake is estimated to be greatest within approximately 2 km of the intake and is concentrated on the region between Billy Lights Point and Kirton Point. At these scales, approximately 0.6% of the total number of particles released each spawning season were estimated to arrive within 25 m radius of the new intake location. Small differences in the regional connectivity between the new intake and Proper Bay and Boston Bay can be seen across years and are related to annual differences in the wind driven circulation patterns. For example, connectivity with Proper Bay is reduced while connectivity with Boston Bay is increased in 2018 compared to 2017. At spatial scales greater than a few kilometres from the intake the levels of connectivity with source locations reduce with distance, with less than 0.4 % of the particles released from their source locations across Boston and Proper Bay estimated to arrive within 25 m radius of the new intake location.

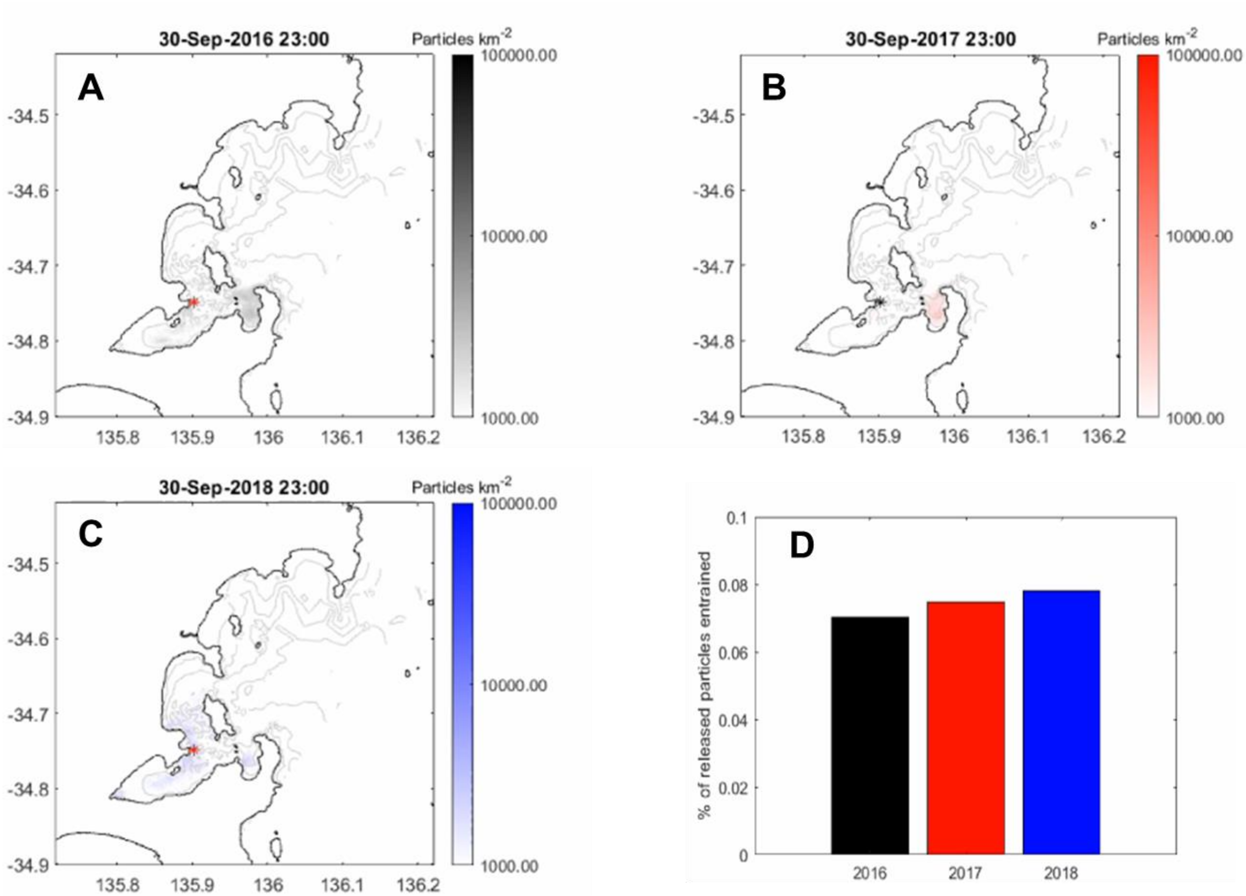


Figure 3-3. Example snapshot of particle distributions (particle densities) on 30 September at the end of each spawning season for (A) 2016, (B) 2017 and (C) 2018. (D) Estimated percentage of all particles (representative of larvae) released per spawning season (2016-2018) that were within a radius of 25m from the new intake location.

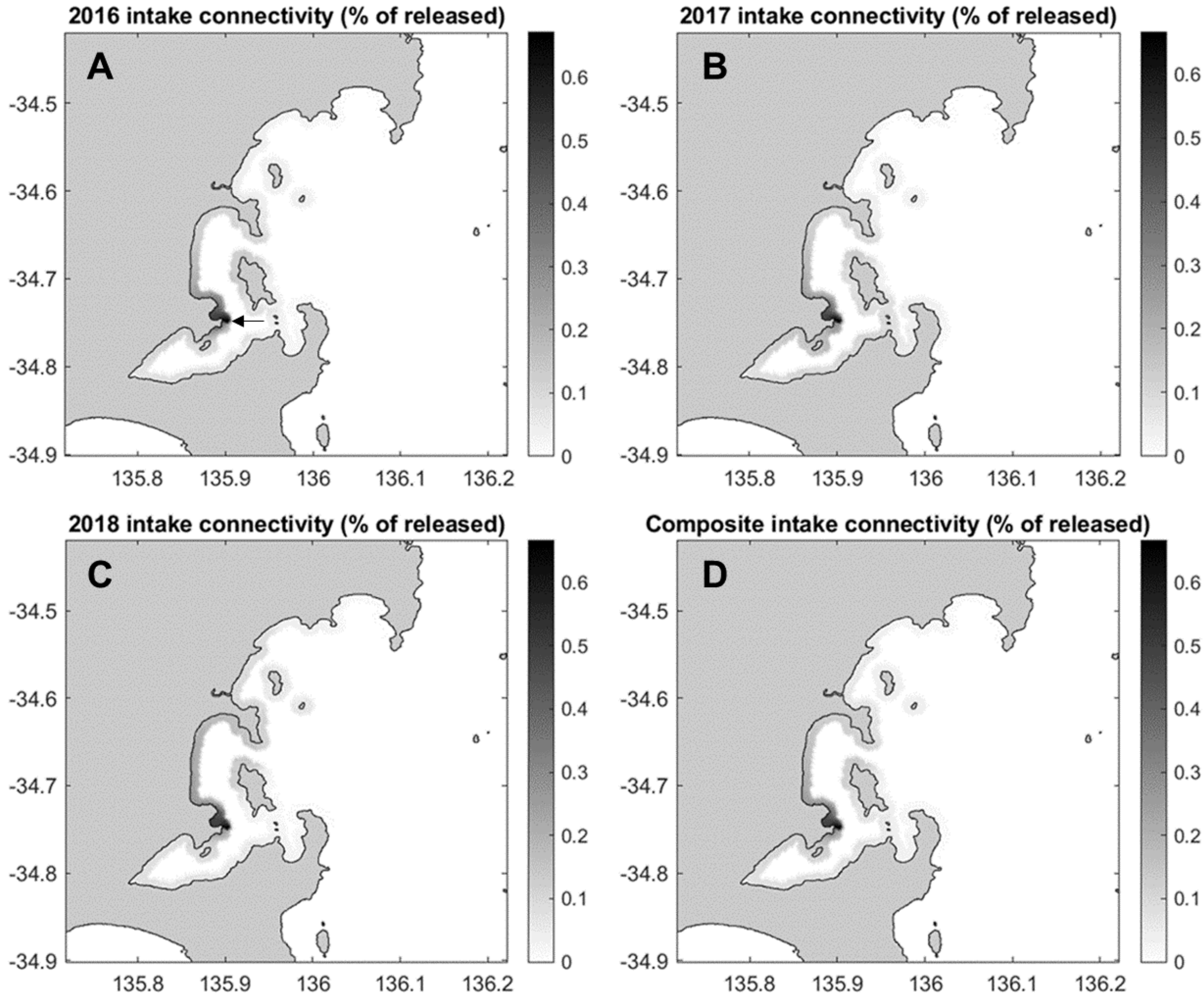


Figure 3-4. Modelled connectivity of larvae with the new Billy Lights Point intake location showing the percentage of larvae from each release point estimated to come within a 25m radius of the intake. A, B and C show the mean distribution averaged over each monthly spawning events for the 2016, 2017 and 2018 spawning seasons, respectively. (D) The mean connectivity distribution averaged over the three spawning seasons is shown in A, B and C. The black arrow in the top left plot (A) indicates the intake location.

4. CONCLUSIONS

Updated biophysical modelling of planktonic blue mussel larvae based on the approach and assumptions presented by Doubell and James (2023), indicated that less than 0.1% of the total number of particles released each spawning season are likely to be at risk of entrainment by the newly proposed desalination plant intake location near BLP. At smaller spatial scales, connectivity mapping with source locations showed that up to 0.6 % of particles released from locations within 2 km of the new intake location between Billy Lights Point and Kirton Point may be at risk of entrainment. The risk of entertainment decreased with distance from the intake, with the percentage of particles likely to be at risk of entrainment from source regions across Proper Bay and Boston Bay estimated to be less than 0.4 %.

Sensitivity studies investigating the effects of Stokes drift on entrainment levels showed the inclusion Stokes drift in combination with the constraining of particles to the ocean's surface layer could significantly alter the predicted particle trajectories. However, the inclusion of Stokes drift into the model had a negligible effect on connectivity with intakes, with less <0.1% of the total number of particles released each spawning season estimated to be entrained in an intake area with a radius of 25m.

The additional results presented here are consistent with the levels of connectivity and entrainment provided by Doubell and James (2023).

REFERENCES

Callies, U., N. Groll, J. Horstmann, H. Kapitza, H. Klein, S. Maßmann, and F. Schwichtenberg. 2017. Surface drifters in the German Bight: model validation considering windage and Stokes drift, Ocean Sci., **13**: 799–827.

Chin, T.M, J. Vazquez-Cuervo and E.M. Armstrong. 2017. A multi-scale high-resolution analysis of global sea surface temperature, Remote Sensing of Environment, **200**:154-169.

Doubell, M. and C. James. 2023. Oceanographic monitoring and far-field modelling to inform desalination in Boston Bay. Report to SA Water. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2022/000347-1. SARDI Research Report Series No. **1165**. 71pp.

Erofeeva, G., and L. Egbert. 2014. TPXO8-ATLAS, v1. Oregon State University, College of Earth, Ocean, and Atmospheric Sciences.

Feng M., N. Caputi, J. Penn, D. Slawinski, S. de Lestang, E. Weller, and A. Pearce. 2011. Ocean circulation, Stokes drift, and connectivity of western rock lobster (*Panulirus cygnus*) population. Canadian Journal of Fisheries and Aquatic Sciences. **68**(7): 1182-1196.

Large, W.G., J.C. McWilliams, and S.C. Doney, 1994. Oceanic vertical mixing: a review and a model with a nonlocal boundary layer. Reviews of Geophysics, **32(4)**: 363-403.

Laurent C., S. Querin, C. Solidoro, and D.M. Canu. 2020. Modelling marine particle dynamics with LTRANS-Zlev: implementation and validation. Environmental Modelling & Software, **125**: 104621.

Mitchell K.B., C. James, J. Gascooke, and S.C. Leterme. 2023. Modelling marine microplastics accumulation zones through freshwater discharge sources: Simulated release from the Onkaparinga River and Torrens River, South Australia. Marine Pollution Bulletin, **194**: 115334.

Monismith S.G. and Fong D. A. (2004), A note on the potential transport of scalars and organisms by surface waves, *Limnology and Oceanography*, 4. doi: 10.4319/lo.2004.49.4.1214.

North, E. W., R. R. Hood, S.Y. Chao, and L. P. Sanford. 2006. Using a random displacement model to simulate turbulent particle motion in a baroclinic frontal zone: a new implementation scheme and model performance tests. Journal of Marine Systems, **60**: 365-380.

North, E. W., Z. Schlag, R. R. Hood, M. Li, L. Zhong, T. Gross, and V. S. Kennedy. 2008. Vertical swimming behavior influences the dispersal of simulated oyster larvae in a coupled particle-tracking and hydrodynamic model of Chesapeake Bay. Marine Ecology Progress Series, **359**: 99-115.

Oke, P. R., P. Sakov, M.L Cahill, J.R. Dunn, R. Fiedler, D.A. Griffin, ... and A. Schiller. 2013. Towards a dynamically balanced eddy-resolving ocean reanalysis: BRAN3. Ocean Modelling, **67**: 52-70.

Saha, S., S. Moorthi, X. Wu, J. Wang, S. Nadiga, P. Tripp, D. Behringer, Y.T Hou, H.Y. Chuang, M. Iredell, and M. Ek 2014. The NCEP climate forecast system version 2. Journal of Climate **27(6)**: 2185-2208.

Smagorinsky J.S. 1963. General circulation experiments with the primitive equations. Mon. Weather Rev., **91**: 99–164.