25th November 2025

Drogue Survey Report

Vementry

Summary

Cooke Scotland undertook a drogue release survey at the proposed Vementry site in Autumn 2024 and Spring 2025. This study mapped the propagation of drogues to calculate a horizontal dispersion coefficient for use in future bath modelling applications.

The drogue survey was conducted using eight drogue releases, mapping longer-term particle fate and dispersion. Drogues were fitted with onboard GPS loggers, allowing area-based tracks to determine displacement and dispersion with lag time. Drogue tracks show a small displacement in the NW and SE direction with variable dispersion areas. The calculated horizontal dispersion coefficient ranged from 0.005 to 0.104m^2/s, providing an average horizontal dispersion coefficient of **0.0531** m^2/s.

1. Introduction

The horizontal dispersion coefficient plays an important role in the dilution of the aqueous solutions discharged into the marine environment. To ensure high environmental standards are maintained, the measured dispersion coefficient can be used in numerical models to predict the distribution and concentration of a solution or particle release.

The horizontal dispersion coefficient accounts for the random turbulent particle motion that is not inherently incorporated within the primary hydrodynamic model. This is often impossible to include due to the resolution and associated computational resources required. The application of a horizontal dispersion coefficient provides a more computationally economical method of including these processes within a wider scale model. This enables particles to be tracked over a longer period and can determine particle fate on a much larger geographical scale.

The physical dispersion process is highly variable in time and space. In the coastal marine environment, the main contributors arise from tides, bathymetry, wind, waves and freshwater input. These factors introduce irregular motion within the water body, with turbulent length scale ranging from the micro (<1m) to the macro (>1km). The drogue survey combines these factors into a single value that best represents the mixing at the site, allowing the highly complex chaotic motion to be translated into representative particle motion.

1.1 Site description

The proposed development at Vementry (figure 1) is a new farm, that will comprise of 10 120m circumference pens, arranged in a 2 x 5 formation within an 85m mooring grid. Benthic modelling of the proposed site using the SEPA default NewDepomod model indicated a maximum biomass of 1350 tonnes was compliant with all EQS criteria. This provides a stocking density of 5.61kg/m^3 during peak biomass. Further information on the proposed site infrastructure and pen layout is presented in Table 1.

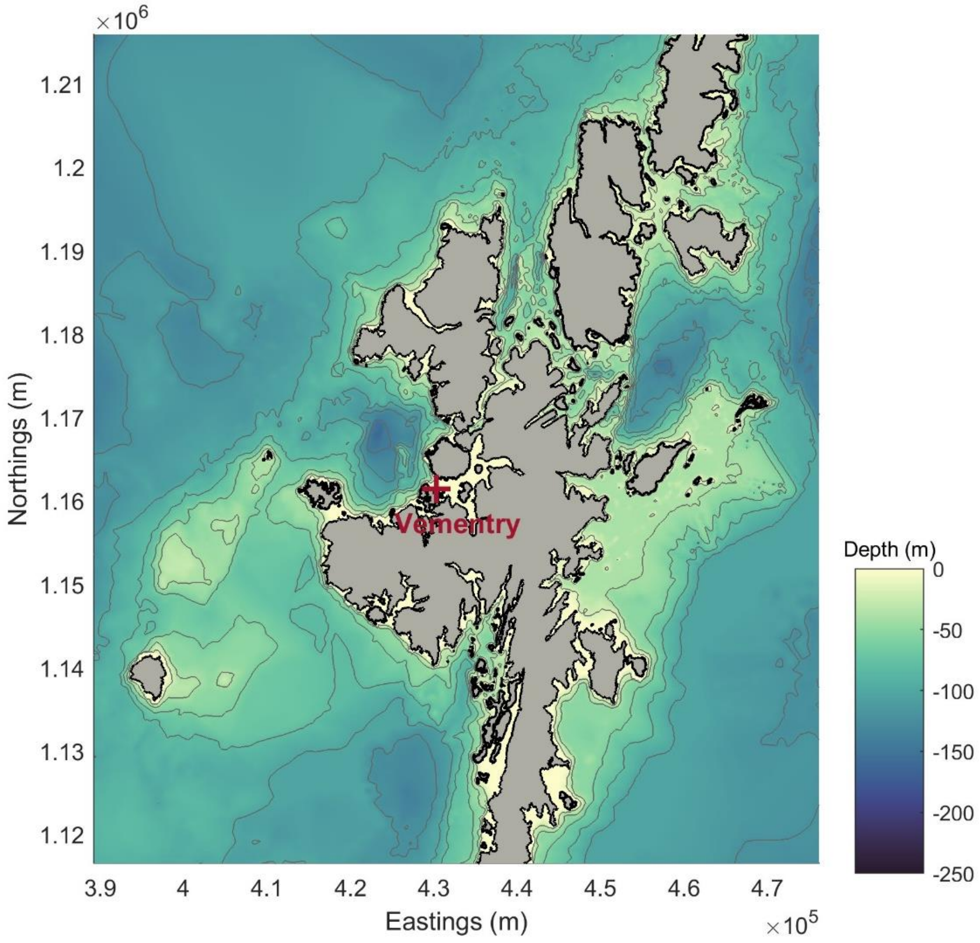


Figure 1. Site location (red cross) and bathymetry with depth contours at 20m intervals.

Table 1 – Site infrastructure and pen layout.

	Vementry (Proposed)
Consent number	CAR/L/5006546
Company	Cooke Aquaculture Scotland
Receiving water	Swarbacks Minn
Site centre (OSGB36)	430285.52 E, 1161466.97 N
Current meter location (OSGB36)	430285 E, 1161466 N
Distance to shore (km)	0.3

Average water depth (m)	58.2
Maximum biomass (t)	1350
Total number of pens	10
Number of pen groups	1
Formation	2 x 5
Pen group orientation (°)	295.5
Pen shape	Circular
Pen circumference (m)	120
Mooring grid (m)	85

2. Methodology

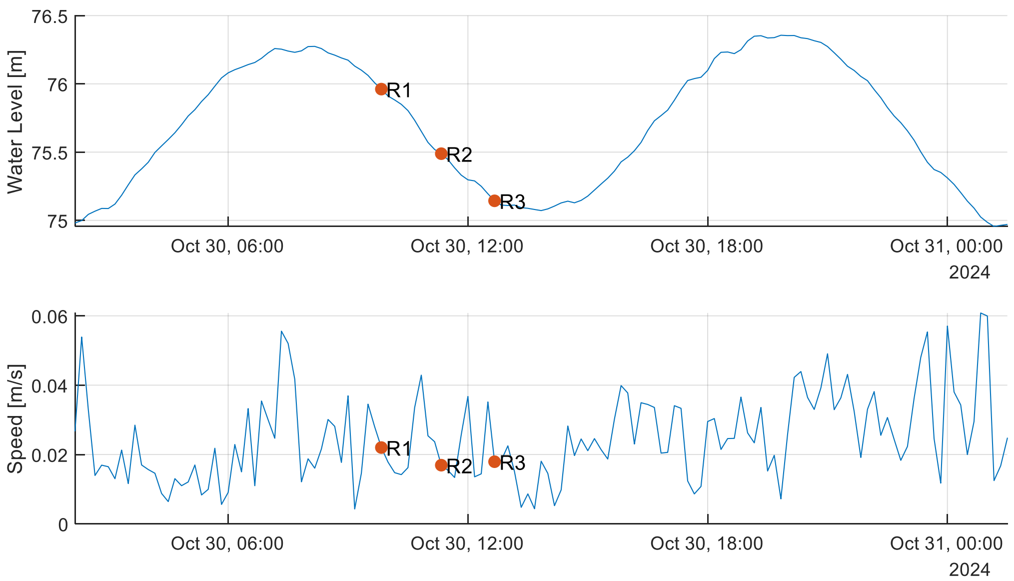
Drogue Release

A total of eight drogue releases were performed across 3 separate survey days 30/10/2024, 27/11/2024 and 23/05/2025. During the drogue survey, an ADCP was deployed at the site centre location to determine tidal phase and near surface flow speeds. The details of the drogue release time and track duration are shown in table 2 and figure 2.

Table 2. Details of the individual drogue releases.

	Drogue Release Time (GMT)	**Plume track duration (mm:ss)**	**Number of Drogues**
R1	30/10/2024 09:53:00	35:00	3
R2	30/10/2024 11:25:00	60:00	5
R3	30/10/2024 12:40:00	45:00	5
R4	27/11/2024 09:15:00	60:00	5

R5	27/11/2024 10:30:00	80:00	5
R6	27/11/2024 12:10:00	95:00	5
R7	23/05/2025 12:30:00	75:00	5
R8	23/05/2025 13:57:00	70:00	5



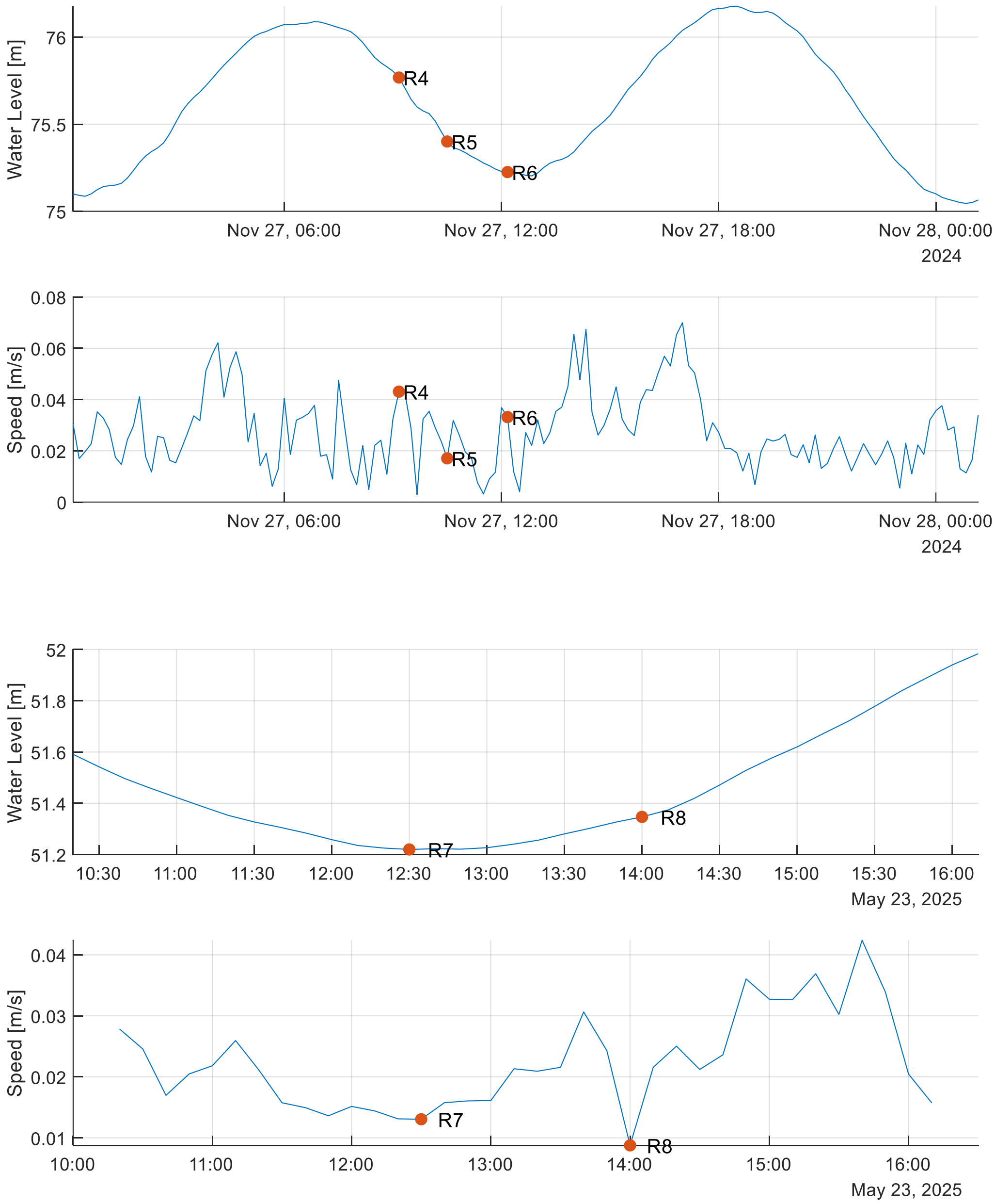
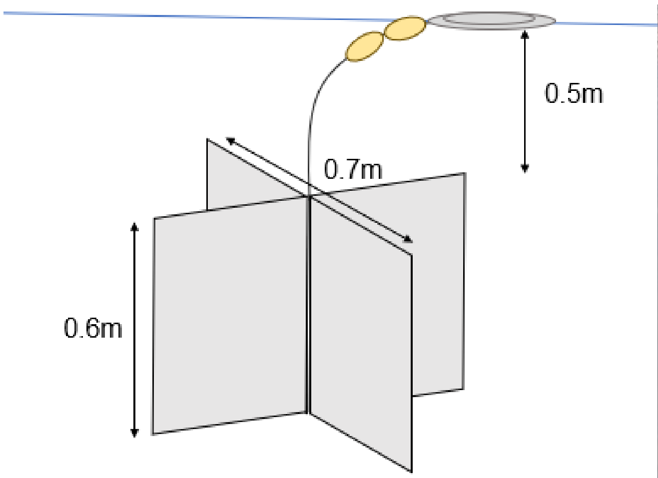


Figure 2. Tidal elevation and near-surface current velocity with the drogue release times for each survey day on the 30/10/2024 (top), 27/11/2024 (middle) and 23/05/2025 (bottom).

Drogues were released at a single point at the proposed site centre location. Each drogue consisted of a sub-surface sail, similar to a CODE/DAVIS drifter, with a surface buoy housing an Iridium GPS system. Each release lasted approximately 1 hour with a sample interval of 5 minutes. A diagram of the drogue used is shown in figure 3. These drogues are reduced in size to improve performance in shallow coastal waters, these modifications also improved deployment, retrieval, and storage options once on the vessel. Due to the non-standardised sizing of the drogue, the drag area ratio was calculated to determine the drag between the surface and subsurface equipment. This calculation is shown in Table 4, where drag coefficient is estimated based on the profile shape of the equipment. The drogues are shown to have a drag ratio of 61.11. The Global Drifter Programme Barometer Drifter Design Reference (A. Sybrandy et al, 2009) states that the drifter should maintain a drag area ratio of more than 40. This criterion is comfortably achieved by the drogue used in this study.



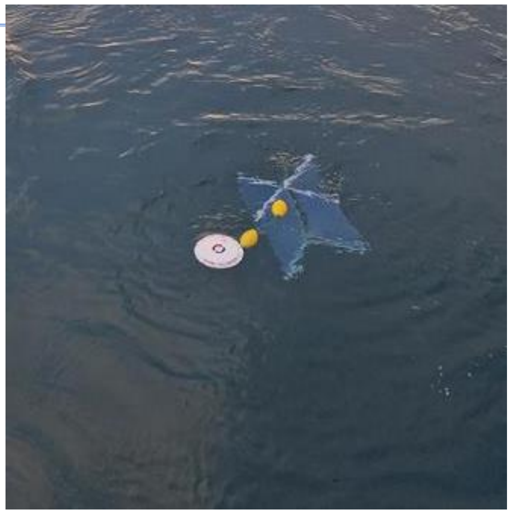


Figure 3. (left) Diagram of drogue with measurements. (right) Photo of drogue sinking immediately after deployment.

The effect of the wind on the drogue can be quantified using the wind slip equation parametrised in Lumpkin and Pazos (2007). This determines wind slip (U_{slip}) as the wind-induced velocity of the drogue. This relationship is shown as

$$|U_{slip}| = \frac{A}{R} U_{wind}$$

where R is the drag area ratio, A is a constant equal to 0.07 and U_{wind} is the wind velocity.

The wind slip for a variety of operational wind speeds is shown in Table 3. This indicates low wind-induced velocities associated with the drogue, even in relatively strong winds. To ensure minimal wind effects on the drogues, wind slip should ideally be kept below 1 cm/s. For the drogues used in this study this equates a maximum wind speed of 8.7m/s (19.5mph).

Table 3 Drag area ratio and wind slip of drogues.

Sub-surface Equipment			
	Area (m^2)	**Drag coefficient (C_d)**	**Drag Area (A x C_d)**
Sails 0.35m x 0.6m	0.42	1.4	0.588

Mast 0.6m x 0.022m	0.015	1	0.015
Tether 0.5m x 0.004	0.002	1.17	0.002
Surface Equipment			
Buoy (x2) 0.075m x 0.12m	0.007	0.47	0.007
Drifter Sensor 0.25m x 0.035m	0.009	0.1	0.001
Drag Area Ratio			**61.11**

Wind Slip				
Wind Speed			**Wind induced slip (m/s)**	**Wind induced slip (cm/s)**
Beaufort Scale	**mph**	**m/s**		
2	7	3.1	0.0036	0.36
3	12	5.4	0.0062	0.63
4	18	8.0	0.0092	0.92
5	24	10.7	0.0123	1.23
6	31	13.9	0.0159	1.59

To calculate a dispersion coefficient, the drogue locations are used to calculate the mean squared displacement (MSD). This takes the distance of the perimeter drogue from the centroid location for each time step.

$$MSD = \frac{1}{N}\sum_{i=0}^{N}\left|x^{i}(t) - x^{i}(0)\right|^{2}$$

$$K_h = \frac{1}{4}\,MSD/dt$$

where, N is the number of points in the boundary, $x^{i}(t)$ is the *i*-th points distance of the drogue boundary and $x^{i}(0)$ is the centroid location of the drogue fleet. The dispersion coefficient (Kh) is then calculated using the synchronised time step (dt).

A linear fit is applied to the MSD and time interval data, where the dispersion coefficient (Kh) can also be calculated from the fit gradient.

The post-processing of the drogue data synchronises all deployed drogues to the same time step.

3. Results

Drogue Release

The time-synchronised drift tracks from all releases are shown in figure 4. Drogues are shown to travel in Southeast and northwest directions. As time from the release point increases, the drogues are shown to separate. The net transport of the drogues ranges between 110m and 423m with average speeds ranging from 0.02 to 0.11m/s. This is consistent with the data collected by the ADCP.

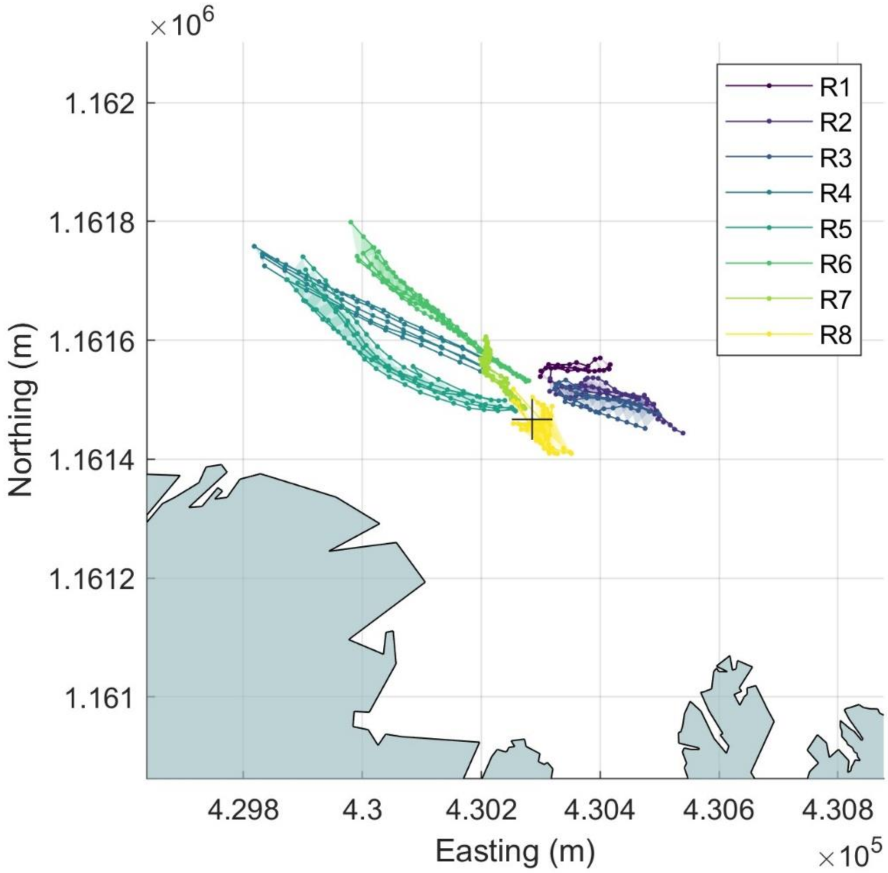


Figure 4. Time-synchronised drogue tracks for each release.

The calculated MSD of the drogue releases are shown in figure 5. A linear regression fit is applied to the data for each release. This shows while there is a continual increase in dispersion there remains a temporal variation with some instances of a reduction in the area coverage. The variation statistics, gradient and calculated dispersion coefficients are shown in table 4. Larger variations in spatial coverage of the drogues are shown in R3 and R8 and consistent dispersion is shown in R6.

The drogue calculated dispersion coefficient ranges from 0.005 to 0.104 m^2/s with an average dispersion coefficient of **0.0531 m^2/s**. The largest value occurs at the beginning of the flood tide, where R8 records a value of 0.104 m^2/s. The lowest dispersion occurs during R7 (0.005 m^2/s) at low water, which shows initial low dispersion followed by a spike that is not maintained.

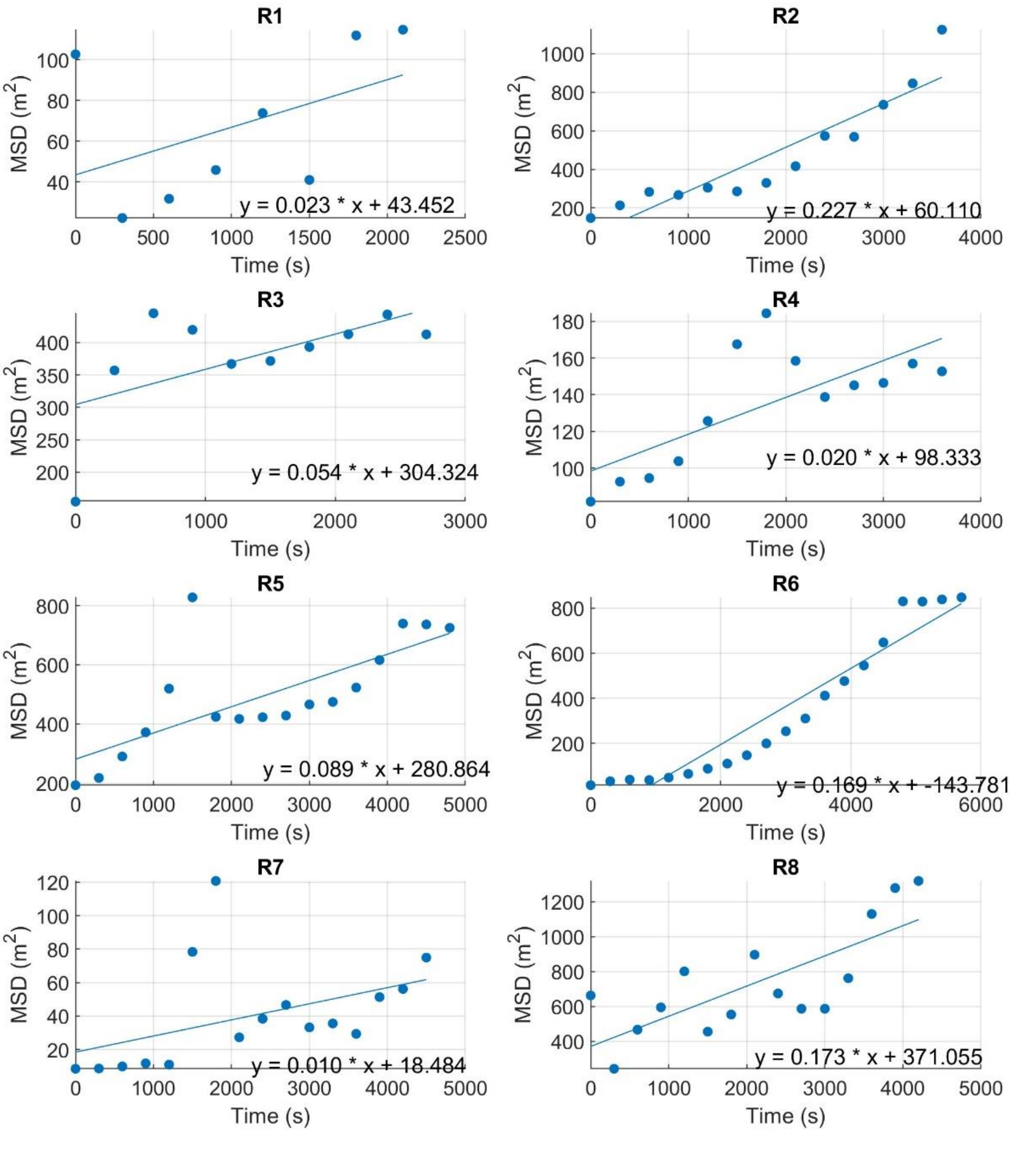


Figure 5. MSD over time with a linear fit line equation for drogue releases 1 to 8.

Table 4. Line fitting statistics and dispersion coefficients for each release.

	R1	R2	R3	R4	R5	R6	R7	R8
Pearson correlation coefficient	0.455	0.924	0.587	0.729	0.728	0.955	0.442	0.755
RMS Error	31.5	105.4	64.6	21.2	122.8	90.8	27.0	194.5
NRMSE	0.340	0.108	0.222	0.206	0.193	0.109	0.241	0.181
Fit gradient	0.023	0.227	0.054	0.020	0.089	0.169	0.010	0.173
Dispersion coefficient	**0.014**	**0.074**	**0.103**	**0.026**	**0.070**	**0.024**	**0.005**	**0.104**

4. Conclusion

This report shows the calculation of the horizontal dispersion coefficients using drogues from 3 separate deployment dates. Up to five drogues were deployed in each survey and tracked for between 35-95 minutes. Drogue tracks were used to help identify initial particle fate and to calculate dispersion at various stages in the tide, these values were then averaged to determine a local representative horizontal dispersion coefficient.

The results showed moderately low advection pathways of the drogue group within each survey. This showed path distances ranging from 110m and 423m with average speeds ranging from 0.02 to 0.11m/s, in the NW or SE direction. The drogue calculated dispersion coefficient ranges from 0.005 to 0.104 m^2/s with an average dispersion coefficient of 0.0531 m^2/s.

It is recommended that the mean dispersion coefficient is used for future bath treatment modelling. For Vementry, a horizontal dispersion coefficient of **0.0531 m^2/s** should be applied.

References

Lumpkin, R., and Pazos M. , (2007) *"Measuring surface currents with Surface Velocity Program drifters: The instrument, its data, and some recent results"* Lagrangian Analysis and Prediction of Coastal and Ocean Dynamics, A. Griffa et al., Eds., Cambridge University Press, 39–67.

Sybrandy. A. L, P. P. Niiler, C. Martin, and W. Scuba, E. Charpentier, D. T. Meldrum (2009) *"Global Drifter Programme Barometer Drifter Design Reference"* Available at: https://www.ocean-ops.org/doc/DBCP/svpb_design_manual.pdf (Accessed December 2023)