Export and dispersal of crab zoeae from saltmarsh-mangrove complexes in Brisbane Water and their importance to fish

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Helograpsus haswellianus (Whitelegge, 1889)

Sesarma erythrodactyla (Hess, 1865)

Abstract

This study demonstrates, for the first time, the importance of saltmarsh-mangrove habitats to the overall foodweb dynamics in Brisbane Water Estuary. Invertebrate inhabitants of the saltmarsh-mangrove complex, such as burrowing crabs and gastropod molluscs, are net exporters of larvae that provide a significant source of food to a variety of fishes that exploit the habitat during high spring tides. This study coupled hydraulic processes with ecological investigations to simulate the dispersal of crab zoea to illustrate the connectivity between saltmarsh-mangrove complexes and other estuarine habitats within the estuary. These simulations indicate that larvae may also be exported from Brisbane Water and could be recruited to other estuarine habitats within and beyond the Hawkesbury River system.

The zooplankton communities were sampled at nearshore and more offshore locations at Palmers Lane in Cockle Bay (Brisbane Water Estuary), near extensive areas of saltmarsh habitat. Sampling was carried out on flood and ebb tides on three consecutive days during the spring tides in February 2006, when levels exceeded 1.8m AHD and thus inundated the adjacent saltmarsh. On the second and third days, a series of small and large-mesh fyke nets were deployed at the edge

of the saltmarsh habitat, *i.e.* in the fringing mangrove area, and further opportunistic sampling was conducted to elucidate the characteristics of the fish fauna utilising the saltmarsh habitat during the spring tides.

The concentrations of crab zoeae in zooplankton samples were significantly greater on the ebb than flood tide on the 2nd and 3rd days of the spring tide in both habitats (adjacent to mangroves, open water). There was no effect of habitat on the concentration of crab zoeae. On the first day of the spring tide the zooplankton community was dominated by fish eggs and copepods. The contributions of crab zoeae and gastropod larvae showed a marked and progressive increase on each ebb tide, with such increases occurring throughout Cockle Bay. The fish fauna was represented by 12 species, with two species, *Ambassis jacksoniensis* and *Atherinosoma microstoma*, being by far the most abundant. Analyses of volumetric dietary compositions demonstrated that these two species, along with the relatively rare *Redigobius* sp., focussed their feeding nearly exclusively on crab zoeae. MDS ordinations and ANOSIM demonstrated that the dietary compositions of these three species differed from those of the other nine species, which also differed among each other, implying that the 12 fish species "spread" the food resources of the saltmarsh.

The transport of crab zoeae was modelled using both drogue tracking and dispersal modelling using Delft3D hydraulic process investigations. Drogue tracking suggested that particular habitats were isolated and would be unlikely to have any connectivity with other saltmarsh-mangrove complexes. In contrast, the dispersal modelling indicated that tidal currents alone provide adequate transport to connect most of the estuary.

1. Introduction

Saltmarshes In south-eastern Australia are valued as prime waterfront real estate and as a consequence, most have been reclaimed for development in urban areas. In other areas, saltmarshes have been degraded by factors such as stock access, weed invasion, rubbish dumping, stormwater runoff and off-road vehicles (Connolly, 1999). It is also considered that the total area of saltmarsh in NSW is contracting as a result of mangrove encroachment (Saintilan and Williams, 1999, Wilton, 2002). All of these processes have been observed in Brisbane Water Estuary (Harty and Cheng, 2003) and the area of saltmarsh has declined from approximately 235 Ha in 1954 to approximately 90 Ha in 2007.

The high density of saltmarsh plants, along with the biofilms associated with the stems, leaves and root systems which bind contaminants, means they play an important role in water filtration. Furthermore, stormwater flows through these systems slow significantly, facilitating the removal of sediments, particulate matter and dissolved contaminants (Freewater, 2004).

Saltmarshes are highly productive environments (Freewater, 2004), although specific information on energy pathways and the export of detritus to adjacent habitats is limited. Invertebrates such as burrowing crabs (*Helograpsus haswellianus* and *Sesarma erythrodactyla)*, gastropod molluscs, and particularly insects and spiders, dominate the fauna of saltmarshes. Vertebrate fauna living on the saltmarsh include reptiles (lizards and snakes), amphibians (frogs), marsupials (wallabies) and other mammals (bats and rodents). Saltmarshes are also used by a large variety of birds for feeding, roosting and/or breeding and are critical habitat for many migratory species.

On the Central Coast, NSW, saltmarshes are inundated to a shallow depth only when tidal heights exceed 1.8 m AHD (Mazumdar *et al.* 2006), which is for typically shorter periods of time than saltmarshes elsewhere in the world (Mazumder, 2004). Such inundation would facilitate the movement of aquatic invertebrates between the saltmarsh and nearby mangrove and seagrass habitats. For example, burrowing crabs in south-eastern Australian saltmarshes synchronise spawning with spring tides, with the first spring high acting as a trigger for spawning, with zoeae being released on the consecutive spring tides (Mazumder 2004).

Such export of crab larvae (zoeae) is also considered to contribute significantly to estuarine foodwebs, and particularly fish species (Mazumdar 2004, Mazumder *et al*. 2006). In this context, it is relevant that, when inundated, saltmarsh provides habitat for numerous species of fish (Thomas and Connolly, 2001, Mazumder *et al.*, 2006) and a high proportion of crab larvae have been observed in the guts of a limited number of fish caught in the saltmarsh during high spring ebb tides (Mazumder *et al.*, 2006). These results indicate a direct trophic link between secondary production and these fish and thus a significant role for burrowing crabs in estuarine food webs.

Connectivity between different habitats is considered to be important for the sustainable management of Brisbane Water. In this estuary, numerous saltmarsh locations are present, which vary widely with regard to the level of disturbance, distance from the estuary mouth and distance to nearest neighbouring saltmarsh. If these habitats and their resident crabs are of critical importance to various fish species and perhaps also fisheries, then management effort to protect, restore and conserve these habitats would obviously receive a high priority. Therefore, the first objective of this study was to ascertain whether the burrowing crabs of Brisbane Water's saltmarshes were exporting large volumes of larva during spring tide events. The second objective was to quantify the fish faunas occupying saltmarshes at that time and to fully understand the trophic linkages between crab larvae and fishes, as suggested by Mazumder (2004). The third objective of this study was to model the passive transport of crab larvae exported from saltmarsh-mangrove complexes to investigate connectivity between these and other estuarine habitats.

To meet the first of these objectives, the following hypothesis was tested:

The abundance of crab zoeae will be greater in waters adjacent to saltmarsh-mangrove complexes than open water, and abundance will be greatest during the second and third spring ebb tide

To address the second objective, the saltmarsh was sampled for fish species during the same high spring tides and their gut contents analysed. The following hypothesis was tested:

Crab zoeae form a significant component of the gut contents of fish caught within the saltmarsh.

To meet the final objective of this study, the transport of crab zoeae was modelled using both drogue tracking and dispersal modelling using Delft3D hydraulic process investigations.

2. Methods

2.1 Study site

The study was conducted in Cockle Bay, located in Cockle Bay Nature Reserve (Figure 1). The reserve comprises a saltmarsh-mangrove complex, of which approximately 17 ha is saltmarsh. Whilst the site has been impacted by off-road vehicles in the past, it is still in relatively good condition and contains a good vegetation coverage. Vegetation zones with the reserve are typical of Brisbane Water, changing from swamp forest to saltmarsh, mangroves, and ultimately to seagrass meadows offshore (Figure 2).

The swamp forest species are dominated by Swamp Mahogany (*Eucalyptus robusta*), Swamp Oak (*Casuarina glauca*) and Paperbarks (*Melaleuca quinquenervia*).The saltmarsh is dominated by *Sarcocornia quinqueflora* (Figure 3) but other species, such as *Sporobolus viginicus*, *Suaeda australis, Tetragonia tetragonioides* and *Sesuvium portulacastrum,* are also present, with *Triglochin striata* and *Samolus repens* being found in wetter patches. Mangrove species include the River Mangrove (*Aegiceras corniculatum*) and the Grey Mangrove (*Avicennia marina*), while seagrasses include Eelgrass (*Zostera capricorni*) and Strapweed (*Posidonia australis*).

Invertebrate fauna is visually abundant on the site. Gastropod snails observed included *Salinator solida*, *Ophicardelus ornatus*, *Bembicium auratum*, *Littorina scabra*, and *Assiminea tasmanica*. Burrowing crabs observed at the site included *Sesarma erythrodactyla* and *Helograpsus haswellianus.*

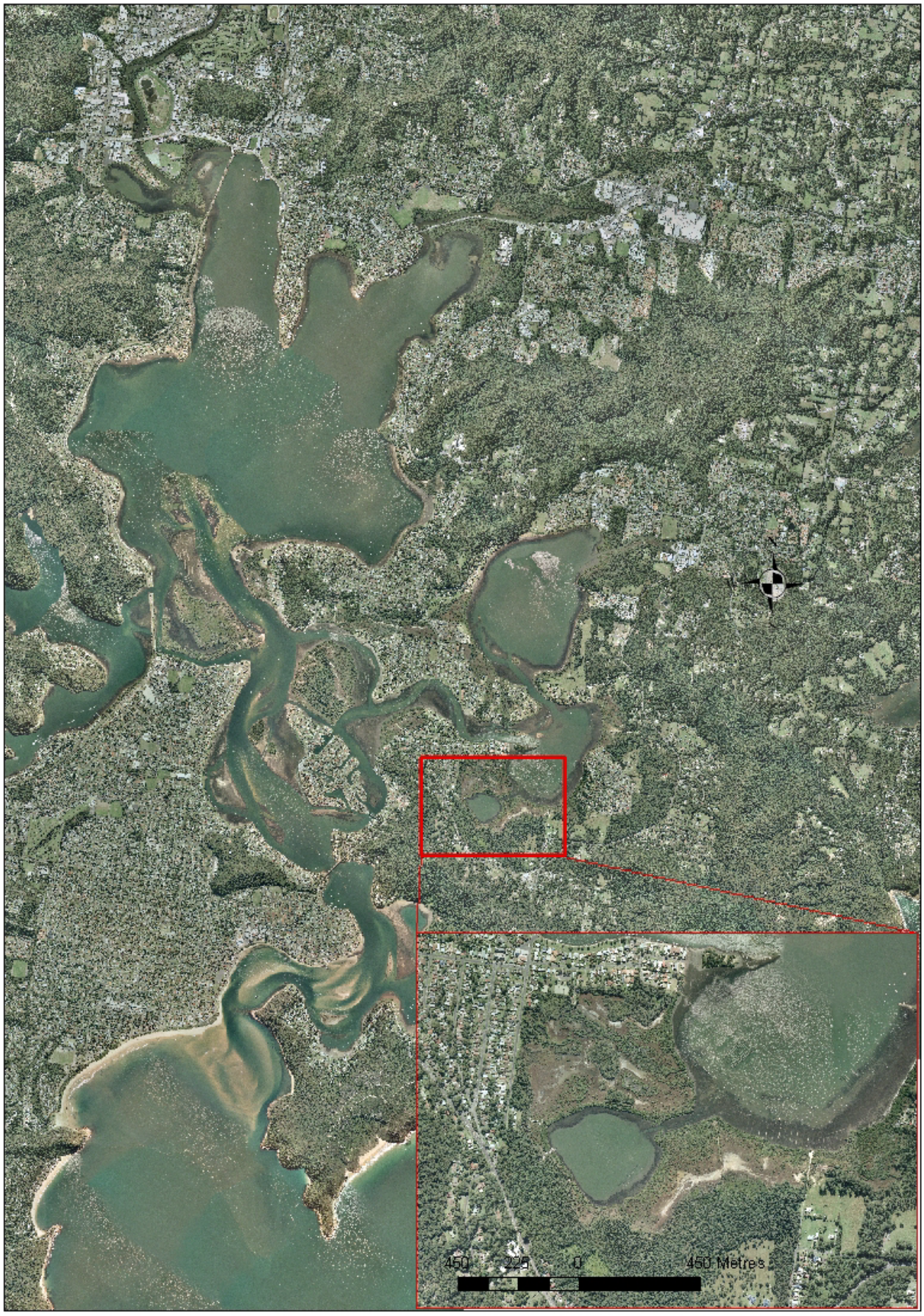


Figure 1: Location of Cockle Bay within Brisbane Water

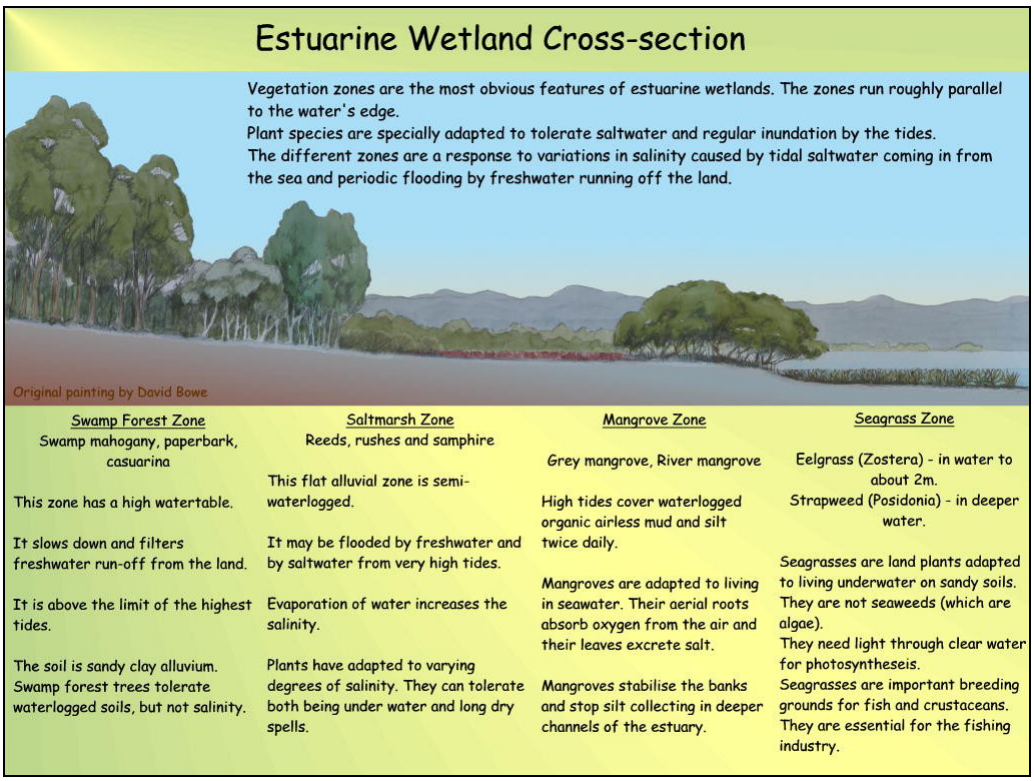


Figure 2: Typical estuarine vegetation zonation in Brisbane Water (Peter Adderley)

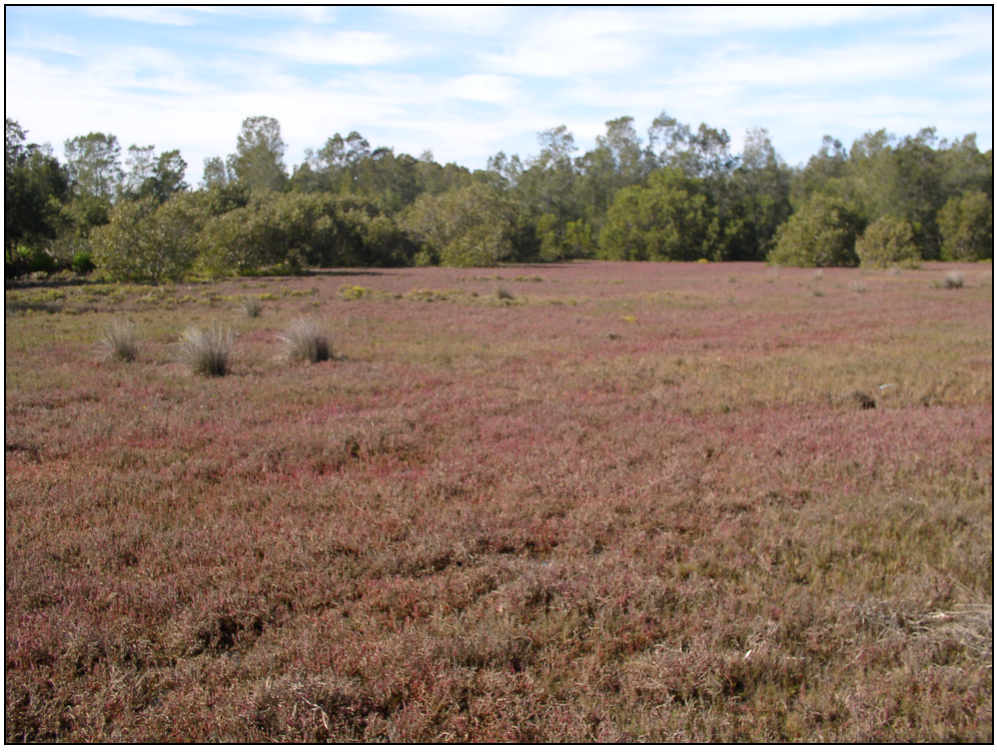


Figure 3: Saltmarsh dominated by *Sarcocornia quinqueflora*

2.2 Sampling of zooplankton, including crab zoeae

Zooplankton was sampled in two randomly selected sites within each of two habitat types (adjacent to mangrove and middle of bay) (Figure 4) on two phases of the tide (flood and ebb). Samples were taken over 3 consecutive days during a spring tide event on 26-28 February 2006 beginning

on the first day of the spring tide. The predicted tidal heights were 1.85 m, 1.94 m and 1.97 m, respectively.

Plankton tows were carried out using a 950 mm long net, with a 300 mm opening and the body of the net comprising 150 µm mesh. This net was deployed on the side of a dinghy and towed at a speed of 1-2 knots, with the distance being recorded using GPS. Three replicate tows of 5 min duration were conducted at each site and each sample was rinsed into a 50 mL jar, using 5% formalin in seawater.

Each zooplankton sample was thoroughly mixed and a total of five 1 mL successive subsamples were removed and stored separately. Zooplankton taxa were removed, identified and enumerated for each subsample. These subsamples were then adjusted upwards to correspond to the known sample volume. The densities of the zooplankton taxa in each sample were then calculated by multiplying the area of the net opening by the distance travelled and the number of each zooplankton taxa divided by that total water volume to determine the number of individuals of each taxa m^{-3}.

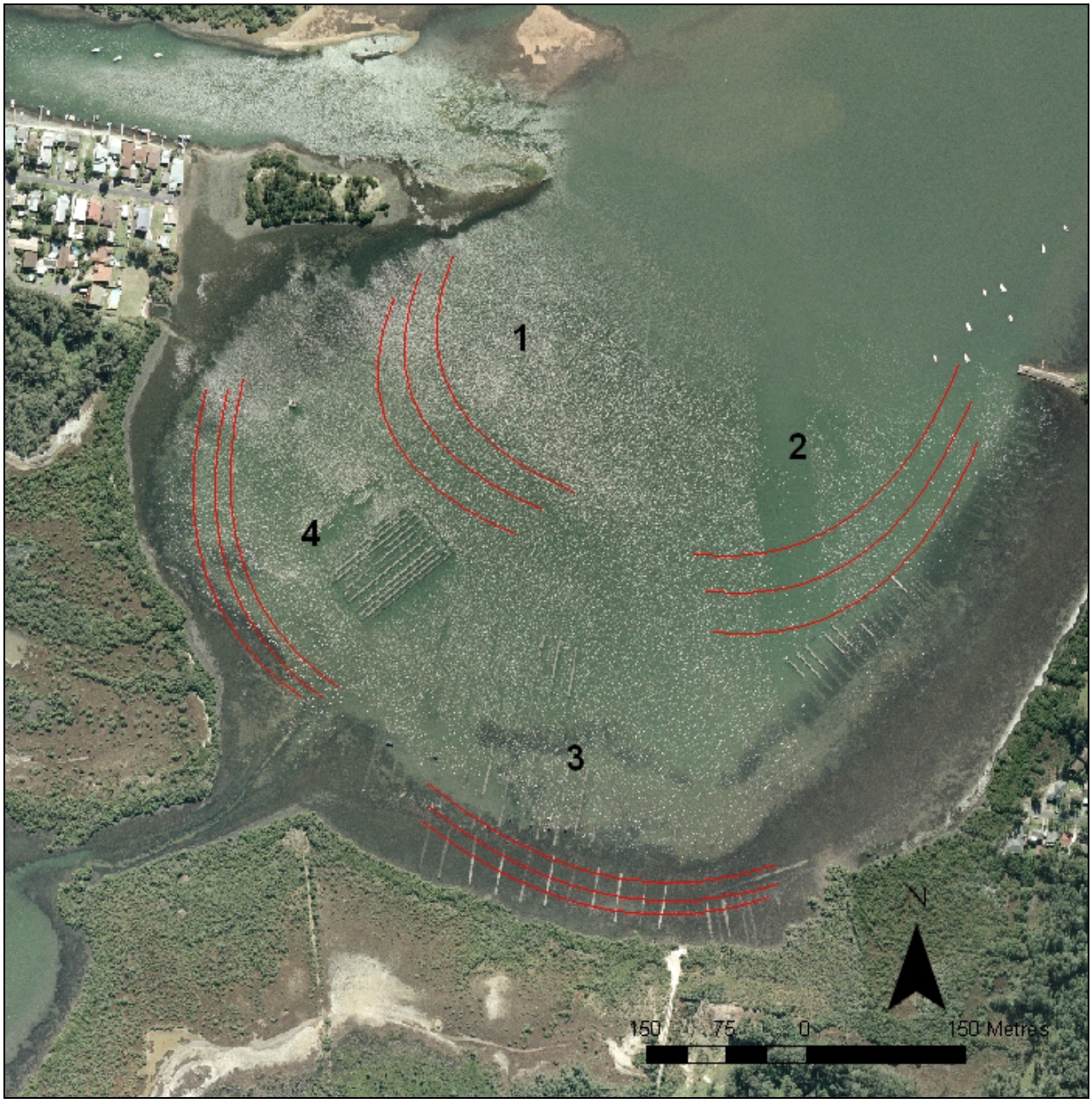


Figure 4: Sites in Cockle Bay sampled using 150µm mesh plankton net (red lines indicate path of plankton tow)

2.3 Sampling for fish and gut content analysis

A series of fyke nets was used to collect fish on 27 and 28 February, when the high tide fully inundated the saltmarsh (Connolly, 1999). Two of the seven fyke nets comprised one wing and cod-end, of ca 3 m in length, with the wing extending from the centre of the opening, and consisted of 8 mm mesh. The remaining five nets contained two wings, each extending from the side of the net opening, and a single cod-end, all of which were ca 3 m long and comprised 3 mm mesh. These seven nets were set on the high tide close to the edge of the saltmarsh, and were arranged in a loose arc so that they abutted each other, with the small-mesh nets at the centre and the larger-mesh nets at each end of the arc. Each net was anchored tightly to the substrate, with its opening facing the saltmarsh and the wings extended to form a barricade that would act to "funnel" the fish into the net on the outgoing tide. This fyke net series was estimated to access an area of at least 100 m^2 of the saltmarsh. Note, it was not possible to deploy the net within the saltmarsh habitat as water depths at high tide did not exceed 20 cm and were thus below the level at which water could enter the fyke nets.

On both days, once the high tide began to ebb, the seven fyke nets were checked at regular intervals and all fish removed, kept separate for mesh size and day, and immediately placed in an ice slurry. Since the fyke nets were joined together and thus not independent from each other, it was not possible to treat each fyke net as a replicate. The two-large mesh and five small-mesh nets therefore collectively provided two "samples" and a total of 4 samples were thus retained from the two sampling days.

Further opportunistic sampling for fish was also carried out on 27 and 28 February 2006 using a small scoop net within the saltmarsh and near the fyke nets.

All fish were identified to species level and the number of individuals of each species and their combined weight (to the nearest 0.1g) were recorded for each of the four samples. The total length (i.e. from tip of snout to edge of caudal fin) was recorded for each individual. The entire intestine was removed from a subsample of up to 40 fish, covering a wide size range, of each species for each of the two sampling days.

The intestinal tract was examined under a dissecting microscope and the gut (stomach or foregut) was identified and then cut open. The gut was scored for relative fullness on a scale of 1 (10% full) to 10 (100% full) and the contents removed. The contents were then identified to the lower possible taxon (i.e. dietary item and their frequency of occurrence - %F) and percentage contribution to the overall gut volume (%V) were recorded. In the case of crab zoeae, the individuals were also counted. Each dietary item was then allocated to one of 33 taxonomic groups, referred to as dietary categories.

2.4 Data analyses - zooplankton

The hypothesis that the abundance of crab zoeae adjacent to the saltmarsh-mangrove complex will be greatest during the second and third spring ebb tide was tested by four-factor analysis of variance (ANOVA). The model consisted of the following terms: day (fixed and orthogonal with 3 levels (first, second and third day of spring tide)); stage of the tidal cycle (fixed and orthogonal with 2 levels (flood and ebb tide)); habitat (fixed and orthogonal with 2 levels (adjacent to mangroves and middle of bay); and site (random and nested in the interaction of day x stage of tidal cycle x habitat). The site factor was included to test for spatial consistency within each habitat. Two sites (approximately 200 m apart) were sampled within each habitat. Site was tested as a nested term because, although the position of the site did not change, the water body being sampled differed on each sampling occasion.

The data comprised the mean of the crab zoeae in each of the 5 sub-samples taken from each replicate sample, after adjustment upwards to correspond to the number of individuals m^{-3} (n=3). Prior to analysis, data were tested for homogeneity of variances using Cochran's test, which showed that the data did not require transformation. Wherever ANOVA detected significant

differences, the *a posteriori* Student-Newman-Keuls (SNK) test was used to determine which means were significantly different. Analyses were undertaken using GMAV (Institute of Marine Ecology, University of Sydney)

Assemblages of zooplankton were visualized by non-metric multidimensional scaling (nMDS) ordinations using PRIMER 6 software (PRIMER-E Ltd). Separate nMDS ordinations were constructed for each day of sampling (first, second and third), and were based on a Bray-Curtis dissimilarity matrix of square-root transformed data. Raw data were square-root transformed to reduce the influence of some abundant species. The raw data used was the mean of the 5 sub-samples taken from each replicate sample (n=3).

Four-factor permutational multivariate analysis of variance was used to test the null hypothesis of no difference in zooplankton assemblages between days, tidal cycle, habitat and site, using the program PERMANOVA (Anderson, 2001). Data were square-root transformed prior to analysis and Bray-Curtis dissimilarity was used as the distance measure. Unrestricted permutation of raw data was used (4999 permutations) to determine *P*-values. Significant effects were examined post hoc with *t*-test and Monte Carlo estimates of *P*-values were used because of the low number of permutations possible.

The similarity percentages routine (SIMPER) in PRIMER 6 was used to determine the groups of organisms that characterized the zooplankton assemblage of each habitat; and the groups that differentiated the zooplankton assemblages between habitats; on each tidal cycle. Data were square-root transformed prior to analysis and data from the 2 sites in each habitat was pooled for the analysis.

2.5 Data analyses – fish

The total number of fish and their overall biomass were calculated for each species for both nets on the two sampling occasions that yielded fish (27 and 28 February 2006). The total length data was presented as a length-frequency histogram with 5 mm intervals (for *Ambassis jacksoniensis*) and as a range for the other species

The percentage volumetric dietary data for individual fish were used to determine, for each species, the mean percentage contribution of each dietary category to the overall volume of their diets. The multivariate analyses focused on determining whether the overall dietary composition of each species differed significantly from each other. Thus, the mean percentage volumetric contributions of the dietary categories to the diets of up to 10-randomly selected individuals of <50 and >50 mm of *A. jacksoniensis* and 10-randomly selected individuals of *A. microstoma* and *P. signifer* and of all individuals of the remaining nine species (Kendrick and Hyndes, 2005) were square-root transformed and subjected to the Bray-Curtis resemblance measure using the PRIMER5 software (Clarke and Gorley, 2006). The similarity matrix produced for the dietary data for the individuals of all species was subjected to non-Metric Multidimensional Scaling (nMDS) ordination as described above and one-way Analysis of Similarities (ANOSIM). ANOSIM, which is a non-parametric test of significance and based upon the creation of a test statistic (R) by random permutations of the similarity matrix, is able to detect significant differences between the dietary compositions of the different fish species if the number of such permutations ≥ 35 (Clarke and Gorley, 2006, Clarke, 1993). The magnitudes of the Global R-statistic values in the ANOSIM tests were used to ascertain the extents to which dietary composition was influenced by species. Thus, R-statistic values range from 1, if the dietary composition of all samples within each group are more similar to each other than to any of the samples from any other group, down to ca 0 if the average similarities between and within groups are the same (Clarke 1993). The null hypothesis for ANOSIM tests that the dietary compositions were not significantly different was rejected if the significance level (*P*) exceeded 5%. In those cases where ANOSIM detected significant differences, SIMPER was used to determine which taxa either typified and/or distinguished between those groups.

2.6. Drogue tracking investigations

The drogue tracking feature in the Delft3D hydraulic model of Brisbane Water (Appendix 3) was applied to investigate the transport of larvae from the saltmarsh. Individual drogue tracking investigations were done for each of 15 saltmarsh locations. Each simulation involved the release of 6 drogues, 3 on 27/2/2006 and another 3 on the 28/2/2006. The simulations were begun at 00:00 on 27/2/2006 with the first release at 10:00 and the second set of drogues was released at approximately at 10:00 on 28/2/2006.

2.7 Advection-dispersal investigations

The concentrations of crab larvae from fifteen saltmarsh locations within Brisbane Water were simulated using the advection-dispersal model of the Delft3D hydraulic model (Appendix 3). The model was based on the assumption that approximately 2000 larvae m^{-3} were released during the ebbing of three consecutive diurnal spring high tides between the 27th February 2006 and the 1st March 2006 (see Results). The model included a simple decay algorithm to account for approximately 50% loss of larvae per day from fish predation. Larvae were introduced into the model as a source point. To provide a realistic spatial description of the larvae a total of 2000 source points were specified over the fifteen saltmarsh locations. Discharge rates for each source point were individually specified based on the geometry of the computational cell of the discharge location. Very low flow rates (< $10^{-3}m^3s^{-1}$) were applied to eliminate any influence on the hydrodynamic processes within the model. The model was run for a two-week period to reflect the period that crabs spend as planktonic larvae before settling out of the water column as juveniles.

3. Results

3.1 Densities of crab zoeae

ANOVA showed that the concentrations of crab zoeae were significantly greater on the ebb than flood tide on the 2nd and 3rd days in both habitats. There was no significant difference between tidal cycles on the 1st day in both habitats (Figure 5). The above accounts for the significant Day x Tide interaction in Table 1. There was significant variation between Sites in concentration of crab zoeae, but only on the ebb tide in the bay habitat on the 2nd day and on the ebb tide in the mangrove habitat on the 3rd day. There was no effect of Habitat (adjacent to mangrove vs open water) on the concentration of crab zoeae.

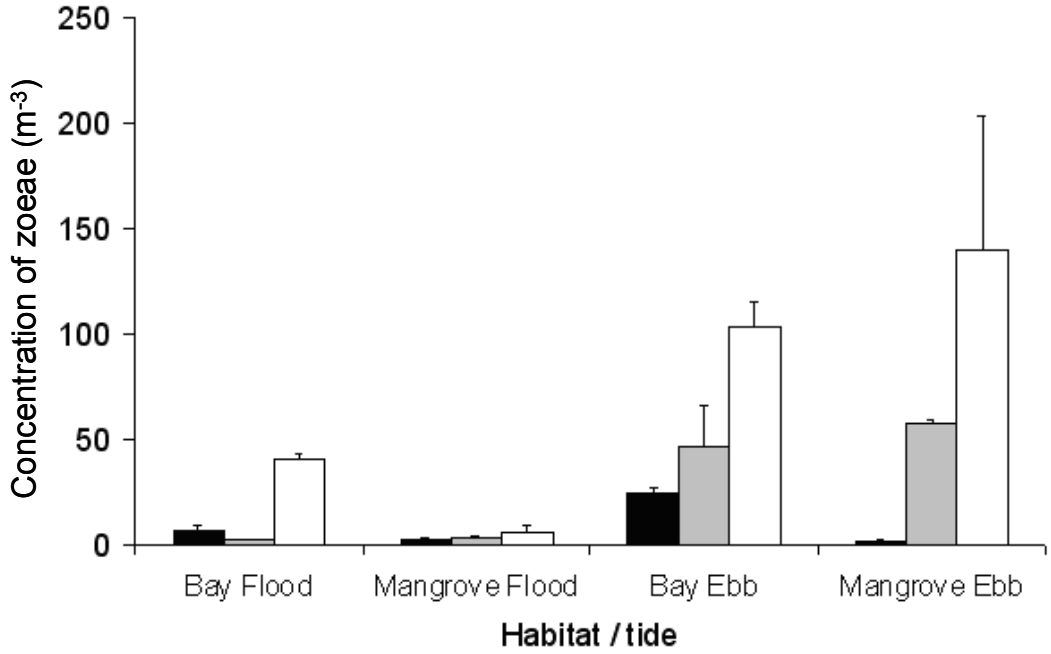


Figure 5: Changes in concentration of crab zoeae over three days of spring tides (black = 1st day, grey = 2nd day, white = 3rd day) in two habitats (mangrove, bay) at two stages of the tidal cycle (flood, ebb) in Cockle Bay. Values shown are the mean + standard error of two sites in each habitat.

Table 1: Summary of results of analysis of variance testing for variation in concentration of crab zoeae in Cockle Bay (untransformed data, Cochran's *C*=0.20, *P*>0.05).

Source of variation	DF	MS	*F*	*P*
Day (D)	2	26027.7	11.56	0.0016
Tide (T)	1	49196.5	21.85	0.0005
Habitat (H)	1	79.4	0.04	0.8542
Site (within D X T X H)	12	2251.9	10.26	<0.001
D X T	2	12279.6	5.45	0.0207
D X H	2	653.8	0.29	0.7531
T X H	1	1918.2	0.85	0.3742
D X T X H	2	3140.6	1.39	0.2854
Residual	48	219.5		

3.2 Assemblages of zooplankton

The nMDS ordination plots for each day (Figures 6-8) show a clear shift in the assemblages of zooplankton over the three days. On the 1st day there was no clear separation of samples between habitats and tidal stage (Figure 6). Samples from the bay habitat on each stage of the tide were clustered together in the centre of the ordination (shown by the clustering of samples in the middle of the ordination plot). Assemblages adjacent to the mangrove habitat differed between sites and between stages of the tidal cycle, as shown by the separation of one site of the ebb tide mangrove samples on the right of the ordination and the two sites from the flood sampling on the left of the ordination. On the 2nd day there was a clear separation of samples into groups corresponding to the two habitats and the two stages of the tide, suggesting that the zooplankton assemblages were distinctive at each combination of habitat and tide (Figure 7). There appeared to be little difference between sites within each habitat, as shown by the proximity of the replicates from each site within

each combination on habitat and tide. On the 3rd day, the assemblages were distinct in each habitat on the flood, but not ebb, tide (Figure 8). This is shown by the clear separation of the mangrove (top left of ordination) and bay habitats (bottom centre of ordination) on the flood tide, and their overlap on the ebb tide (the cluster of samples in the top right of the ordination).

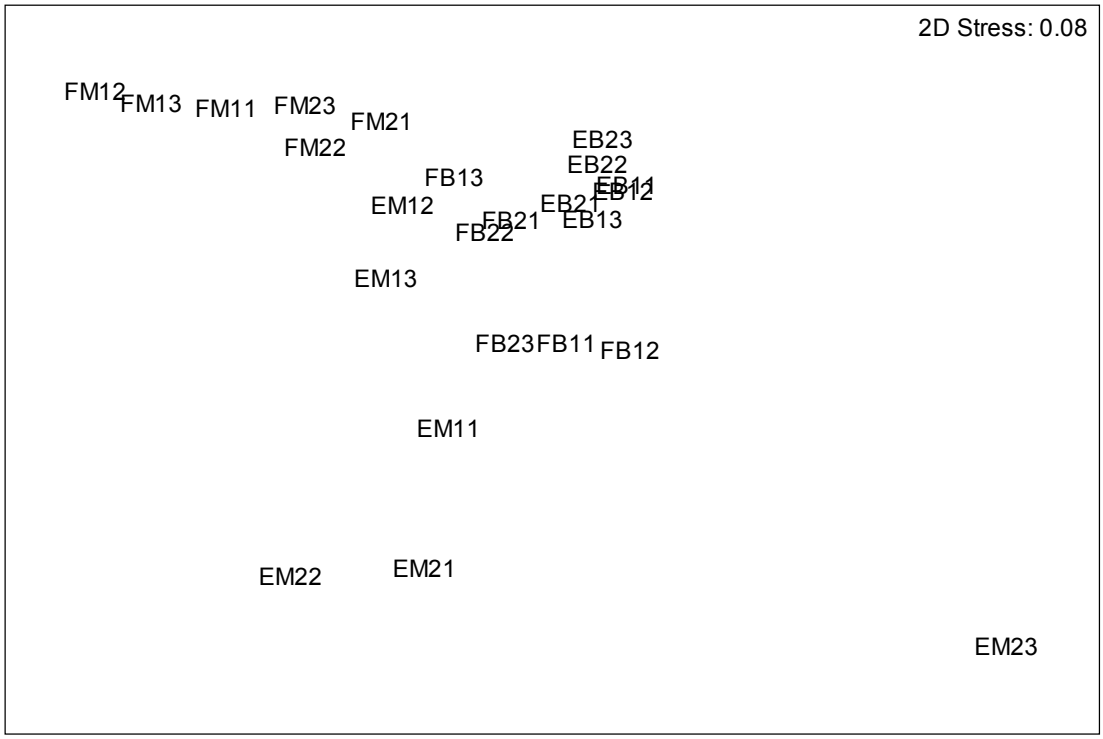


Figure 6: Non-metric multidimensional scaling ordination plots depicting variation in assemblages of zooplankton in Cockle Bay on 1st day in two habitats (mangrove M, bay B), at two stage of the tide (flood F, ebb E), in two sites within each habitat (shown by FM1, FM2 etc.). Three samples were analysed within each combination of habitat, stage of the tide, and site.

Assemblages of zooplankton were affected by a significant Day x Tide x Habitat interaction and by significant variation between Sites (Table 2). The significant interaction occurred because assemblages of zooplankton differed between bay and mangrove habitats on the flood tide on the 2nd and 3rd days of the spring tides, and on the ebb tide on the 1st day. Although there was a significant effect of Site, the only significant difference in zooplankton assemblages between Sites occurred on the 1st day, on the flood tide, in the mangrove habitat.

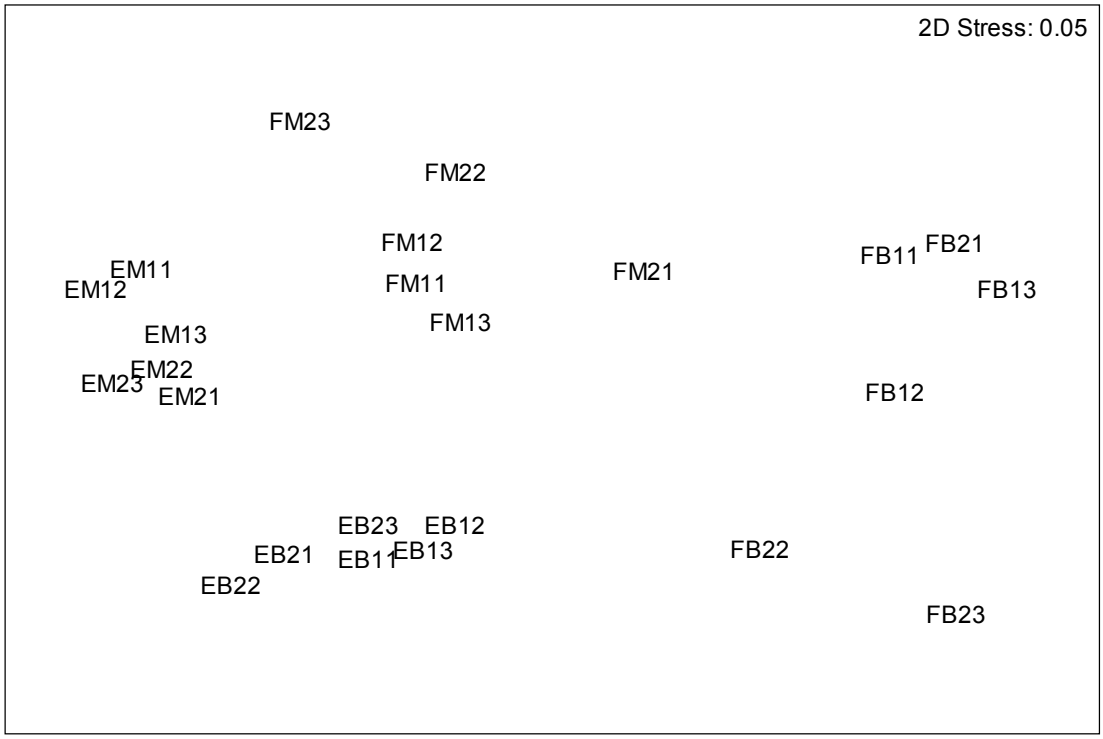


Figure 7: Non-metric multidimensional scaling ordination plots depicting variation in assemblages of zooplankton in Cockle Bay on 2nd day in two habitats (mangrove M, bay B), at two stage of the tide (flood F, ebb E), in two sites within each habitat (shown by FM1, FM2 etc.). Three samples were analysed within each combination of habitat, stage of the tide, and site

Table 2: Summary of results of four-factor permutational multivariate analysis of variance in assemblages of zooplankton in Cockle Bay.

Source of variation	DF	MS	*F*	*P*
Day (D)	2	9935.82	13.81	0.0002
Tide (T)	1	13976.80	19.43	0.0002
Habitat (H)	1	15762.63	21.91	0.0002
Site(within D X T X H)	12	719.50	1.78	0.003
D X T	2	5068.42	7.04	0.0002
D X H	2	3269.39	4.54	0.001
T X H	1	5042.60	7.01	0.001
D X T X H	2	3728.60	5.18	0.0004
Residual	48			

Post-hoc test of differences in assemblages between habitats in each combination of tide and day.

Tide	Day	Comparison of mangrove and bay habitats	
		T	*P*
Flood	1st day	2.86	0.06
Flood	2nd day	3.57	0.03
Flood	3rd day	5.10	0.02
Ebb	1st day	2.10	0.12
Ebb	2nd day	2.94	0.04
Ebb	3rd day	1.45	0.23

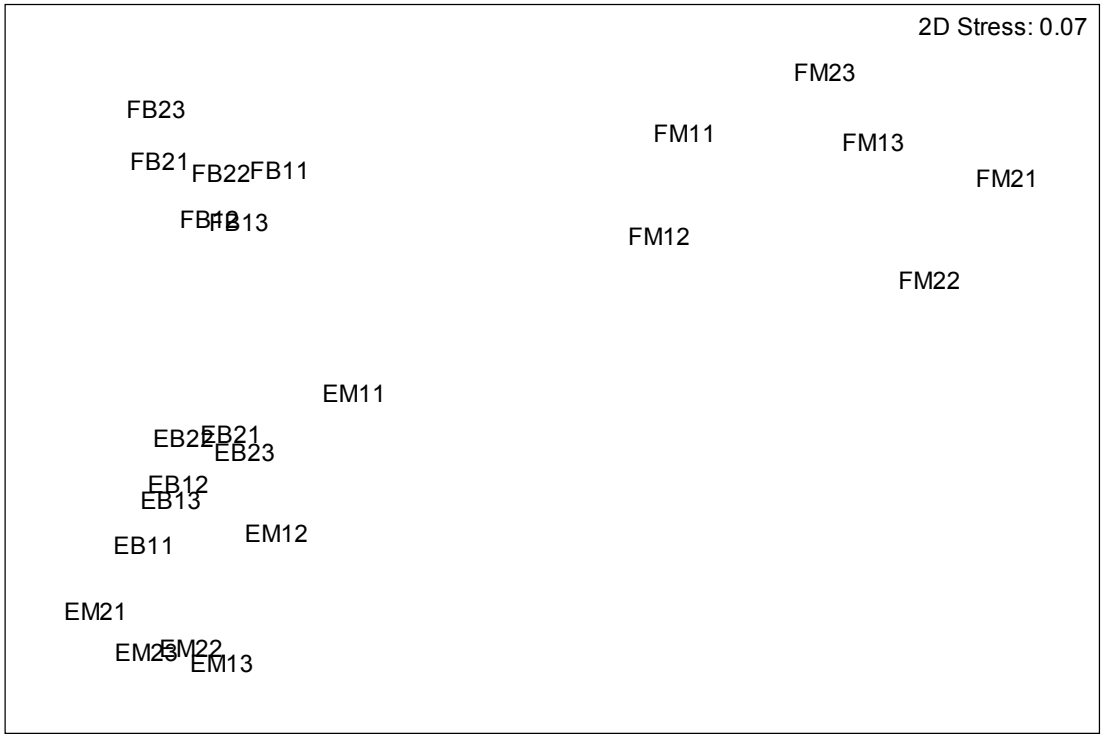


Figure 8: Non-metric multidimensional scaling ordination plots depicting variation in assemblages of zooplankton in Cockle Bay on 3rd day in two habitats (mangrove M, bay B), at two stage of the tide (flood F, ebb E), in two sites within each habitat (shown by FM1, FM2 etc.). Three samples were analysed within each combination of habitat, stage of the tide, and site

Zooplankton captured in the plankton tows over the 3 days included:

- Crab zoeae (3507)
- Copepods (2098)
- Fish eggs (2143)
- Gastropods (688)
- Nauplii (343)
- Prawn larvae (122)
- Polychaete larvae (51)
- *Obelia sp*. (38)
- Bivalves (34)
- Fish larvae (25)
- Chaetognaths (4)
- Isopods (3)
- Ctenophores (3)

A consistent suite of organisms differentiated the zooplankton assemblages of mangroves and bay on the flood tide of each tidal cycle: fish eggs, crab zoea, and copepods (Table 3). On the 1st and 3rd days of the spring tides, fish eggs were more abundant in the mangrove habitat and crab zoeae and copepods were more abundant in the bay. On the 2nd day of the spring tides all groups were more abundant in the mangrove habitat.

Different groups of organisms differentiated the zooplankton assemblages of mangroves and bay on the ebb tide over the 3 days of sampling (Table 3). On the 1st day crab zoeae, copepods and fish eggs were more abundant in the bay. On the 2nd day the assemblages of the 2 habitats differed because fish eggs, *Obelia* sp., and crab zoeae were more abundant in the mangroves. On the 3rd day the assemblages differed because gastropods and crab zoeae were more abundant in the mangroves and polychaetes were more abundant in the bay.

Table 3: Summary of results of SIMPER analysis showing zooplankton groups characterizing and differentiating mangroves and bay habitats on each tidal cycle in Cockle Bay. Groups are arranged in order of importance (to a maximum of 3 groups).

Day 1		Flood		Ebb	
		Mangrove	Bay	Mangrove	Bay
Flood	Mangrove	Fish eggs	Fish eggs Crab zoeae Copepods		
	Bay		Fish eggs Crab zoeae Copepods		
Ebb	Mangrove			Fish eggs Crab zoeae	Crab zoeae Copepods Fish eggs
	Bay				Crab zoeae Fish eggs Copepods

Day 2		Flood		Ebb	
		Mangrove	Bay	Mangrove	Bay
Flood	Mangrove	Fish eggs Copepods Crab zoeae	Fish eggs Copepods Crab zoeae		
	Bay		Copepods Crab zoeae Nauplii		
Ebb	Mangrove			Fish eggs Crab zoeae Copepods	Fish eggs *Obelia* sp. Crab zoeae
	Bay				Crab zoeae Copepods Fish eggs

Day 3		Flood		Ebb	
		Mangrove	Bay	Mangrove	Bay
Flood	Mangrove	Fish eggs Copepods Crab zoeae	Fish eggs Copepods Crab zoeae		
	Bay		Copepods Crab zoeae Fish eggs		
Ebb	Mangrove			Crab zoeae Gastropods Copepods	Gastropods Crab zoeae Polychaetes
	Bay				Crab zoeae Copepods Gastropods

3.3 Fish - small-mesh fyke net samples

The small-mesh fyke net sampling program yielded 612 individuals of eight species of fish with a total biomass of 222.3 g. The most numerically important species, by far, was the Port Jackson glassfish (*Ambassis jacksoniensis*), which was collectively represented by 478 fish of 143.3 g, and caught on both days of sampling (Table 5). The next most important species was the small-mouthed hardyhead (*Atherinosoma microstoma*), of which 95 individuals, weighing 28.5 g, were recorded on the second day of sampling. All other species were represented by less than 10

individuals over both sampling days. Of these, the mullet *Liza argentea* contributed approximately 17% to the overall biomass on both days of sampling. The maximum total lengths of the eight species ranged from between 14 and 26 mm for *Pseudogobius olorum, Craterocephalus mugiloides* and *Redigobius* sp. to 67 mm for *A. jacksoniensis* and ultimately to 119 mm for *L. argentea*. Of the fish below, samples were obtained for dietary analysis, whenever possible, of up to 40 fish for each of the eight species on each day.

Table 5: List of fish species, size range, total numbers and biomass and percentage contribution to the numbers and biomass of fish obtained using the small-mesh fyke nets near saltmarsh at Cockle Bay on 27 and 28 February, 2006.

Species	Length (mm)	27 February 2006 No.	%	Biomass	%	28 February 2006 No.	%	Biomass	%
Ambassis jacksoniensis	14-67	226	93.8	105.6	74.5	251	69.9	37.7	46.5
Atherinosoma microstoma	24-43					95	26.5	28.5	35.1
Liza argentea	64-119	8	3.3	25.2	17.8	1	0.3	13.7	16.9
Mugilogobius paludis	37-41	3	1.2	2.8	2.0				
Gerres subfasciatus	13-88	2	0.8	8.0	5.6	6	1.7	0.7	0.9
Pseudogobius olorum	26	2	0.8	0.2	0.1	4	1.1	0.3	0.4
Craterocephalus mugiloides	23					1	0.3	0.1	0.1
Redigobius sp.	15					1	0.3	0.1	0.1
Total		241		141.8		371		81.1	

3.4 Fish - opportunistic samples

Opportunistic sampling of fish was defined as using either the large-mesh fyke net, small net or capture by hand, and targeted those species that were observed directly feeding in the saltmarsh habitat, but did not appear susceptible to capture by the small-mesh fyke nets. These included (1) large individuals of the toadfish *Tetracenos hamiltoni,* which was observed to be directly feeding on crabs and would also tunnel beneath the small-mesh fyke nets, (2) two individuals of yellowfin bream *Acanthopagrus australis* and one individual each of silver bream *Rhabdosargus sarba* and the silver biddy *Gerres subfasciatus*, that were entangled in the large-mesh fyke nets, and (3) a school of blue-eye *Pseudomugil signifer*, that were in shallow water on the saltmarsh flat. Thus, four species (*P. signifer, T. hamiltoni, A. australis* and *R. sarba*) were captured using other methods other than the small-mesh fyke net. All individuals were retained for subsequent dietary analysis. Details of their numbers, biomass and size range are shown in Table 6, but should not be used to infer relative abundance in saltmarsh.

Table 6: List of fish species, their size range and total numbers and biomass recorded using opportunistic sampling in saltmarsh at Cockle Bay on 27 and 28 February, 2006.

Species	Length (mm)	Numbers	Biomass
Pseudomugil signifer	14-31	26	2.9
Tetractenos hamiltoni	88-114	6	131.0
Acanthopagrus australis	78-118	2	36.4
Gerres subfasciatus	16	1	0.1
Redigobius sp.	14	1	0.1
Rhabdosargus sarba	79	1	8.2
Totals		37	177.7

3.5 Fish - gut contents

For two of the three fish species that were represented by 20 or more individuals, *i.e. A. jacksoniensis* and *A. microstoma*, crab zoeae made an extremely high contribution, *i.e.* 95.0 and 100%, respectively to the overall diets (Table 7). The diet of the remaining abundant species, *P. signifer*, comprised mainly foraminiferans, insect larvae and terrestrial insects, which collectively contributed 97.8% to the overall dietary volume.

Of the remaining nine species, crabs made a substantial contribution, i.e. 83.3%, to the diets of only *T. hamiltoni* (Table 7). Crab zoeae comprised the entire foregut contents of the two individuals of *Redigobius* sp. and contributed 4.0% to the overall dietary volume of *G. subfasciata*. Taxa other than crabs made moderate contributions, *i.e.* >15%, to the diets of the other fish species. Thus, polychaetes were important in the diets of *G. subfasciatus* and *P. olorum*, while harpacticoid copepods made large contributions to the diets of *C. mugiloides* and the first species. Moreover, aquatic plants were important for *R. sarba* and fine detritus featured in the diets of *L. argentea* and *P. olorum* (Table 7).

The numbers of crab zoeae in the guts of *A. jacksoniensis* and *A. microstoma* are shown in Table 8. Approximately 92 and 75% of all guts examined for *A. jacksoniensis* and *A. microstoma* contained crab zoeae, respectively, with mean numbers of ca 272 and 228 zoea being recorded in those guts, respectively (Table 8). The maximum of 1017 zoeae was recorded for a 27 mm individual of *A. jacksoniensis.*

Ambassis jacksoniensis within size classes of 10-49 mm TL ingest almost exclusively crab zoeae (Figure 9). The contribution of zoeae progressively declined to ca 79% in fish of 50-59 mm and then to ca 35% in the largest fish, i.e. 60-69 mm. Fish in the two largest size classes also ingested coarse detritus, polychaetes, harpacticoid copepods and isopods (Figure 9).

Table 7: Percentage volumetric contributions of the different dietary categories and unidentifiable material to the overall diets of the 12 fish species near saltmarsh at Cockle Bay. *A.a, A. australis, C.m, C. mugiloides, G.s, G. subfasciatus, L.a, L. argentea, P.o, P. olorum, R.s, R.sarba, Red, Redigobius sp.* and *T.h, T. hamiltoni.*

Dietary categories	*A. jacksoniensis*	*A. microstoma*	*P. signifer*	*A.a*	*C.m*	*G.s*	*L.a*	*M.p*	*P.o*	*R.s*	*Red*	*T.h*
Foraminiferans	-	-	53.8	-	40.0	0.1	-	-	-	-	-	-
Polychaetes	1.4	-	-	-	-	17.0	-	-	50.0	-	-	-
Gastropods	-	-	-	-	-	0.1	-	-	-	3.0	-	0.8
Harpacticoid copepods	1.7	-	1.3	-	20.0	63.3	-	-	2.5	-	-	-
Ostracods	-	-	1.0	-	5.0	0.3	-	-	-	-	-	-
Amphipods	-	-	-	-	-	-	-	-	-	-	-	0.8
Isopods	0.1	-	-	-	-	-	-	-	-	-	-	-
Shrimps	-	-	-	-	-	-	-	-	-	-	-	-
Crabs	-	-	-	-	-	-	-	-	-	-	-	83.3
Crab zoeae	**95.0**	**100.0**	**-**	**-**	**-**	**4.0**	**-**	**-**	**-**	**-**	**100.0**	**-**
Fish	0.1	-	-	17.5	-	-	-	5.0	-	-	-	-
Fish larvae	-	-	-	-	-	-	-	5.0	-	-	-	-
Terrestrial insects	-	-	13.5	2.5	2-	-	8.9	-	-	-	-	-
Insect larvae	<0.1	-	30.5	2.5	15.0	0.1	-	-	2-	-	-	12.5
Terrestrial plants	<0.1	-	-	-	-	-	-	-	-	-	-	-
Aquatic plants	<0.1	-	-	-	-	-	2.2	5.0	-	95.0	-	2.5
Fine detritus	-	-	-	-	-	-	88.3	-	27.5	-	-	-
Coarse detritus	1.6	-	-	2.5	-	-	0.6	-	-	2.0	-	-
Unidentifiable material	-	-	-	75.0	-	15.0	-	85.0	-	-	-	-
Number with food	65	15	29	2	1	9	9	1	3	1	2	6

Table 8: Number of guts of *A. jacksoniensis* and *A. microstoma* that contained crab zoeae, and the range, mean and SE of the number of zoeae.

Species	Guts with zoeae	Range	Mean (SE)
A. jacksoniensis	60	5-1017	271.7(24.8)
A. microstoma	15	110-381	227.8(24.3)

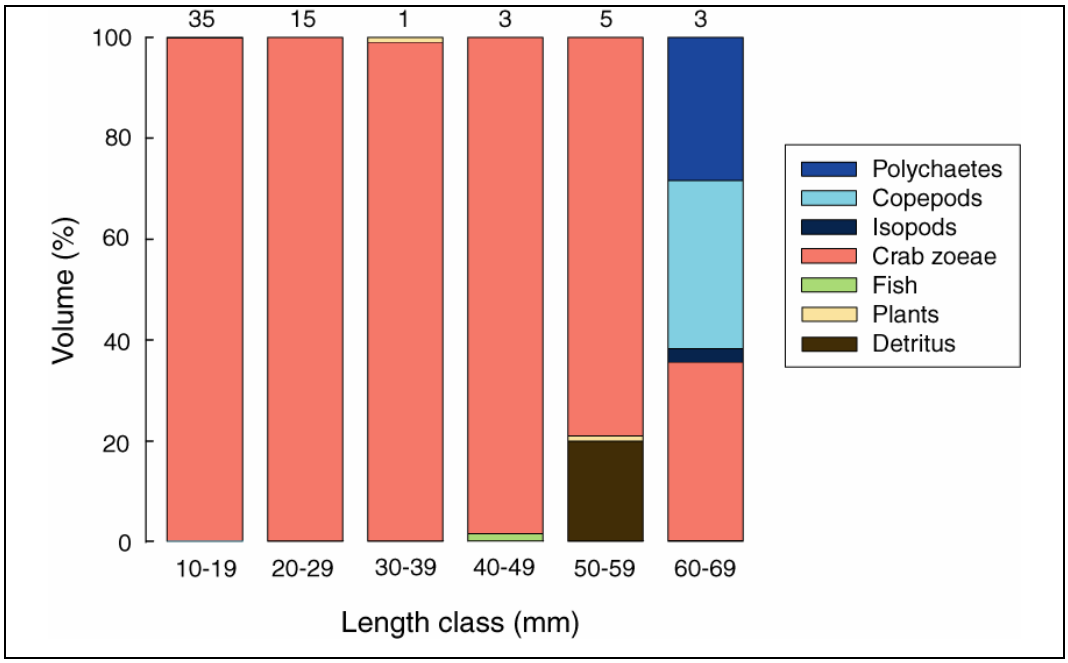


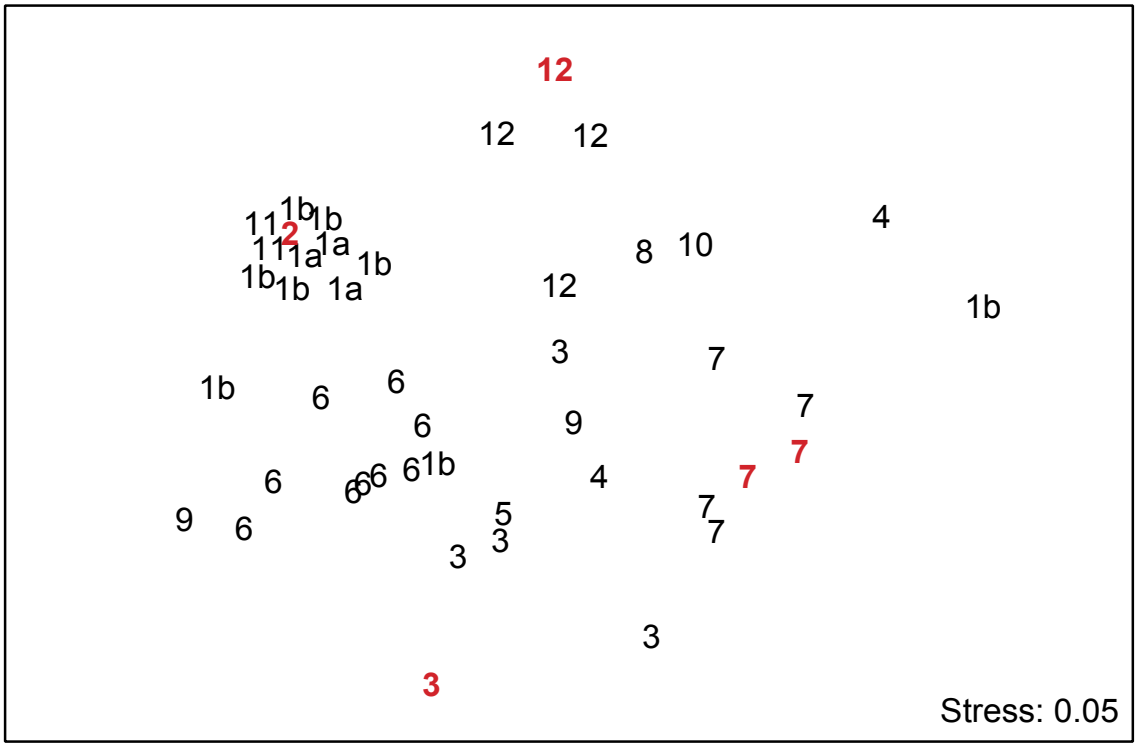
Figure 9: Mean percentage volumetric contributions of the various dietary categories to the diets of sequential 10 mm length classes of *Ambassis jacksoniensis* recorded near saltmarsh at Cockle Bay. The number at the top of the column denotes the number of guts in that length class.

ANOSIM of the mean percentage volumetric contributions of the different dietary categories to the diets of individuals of the twelve species showed that, overall, the diets differed significantly between species, and the accompanying Global R-statistic value was high (Global R = 0.693, P<0.001).

Pairwise ANOSIM comparisons demonstrated that the diets of *A. jacksoniensis* were highly significantly different from all but two species, with R-statistic values ranging between 0.895 and 0.940 (Table 8). The latter two species (*A. microstoma* and *Redigobius* sp), which likewise ingested crab zoeae (Table 6), did not ingest a significantly different suite of prey, and recorded low R-statistic values (Table 8). The diets of *A. microstoma* also significantly differed from all species but *Redigobius* sp, with R-statistic values ranging between 0.532 and 0.653.

nMDS ordination also supported the results of ANOSIM (data not shown), with the diets of individuals falling on different parts of the plot. However, to increase the visual clarity of the plot, nMDS ordination was performed again on the mean percentage volumetric contributions of the different dietary categories to the diets of up to 10 individuals of each of the twelve species, and separating small from large *A. jacksoniensis*, with the resultant plot being shown in Figure 10. This plot shows the relative closeness of the points for *A. jacksoniensis, A. microstoma* and *Redigobius*

sp. and that the points for the diets of individuals of *P. signifer* and *C. mugiloides* also lie very close together. The points for the other eight species were spaced over the plot (Figure 10).



1a = small *A. jacksoniensis*	5 = *C. mugiloides*	10 = *R. sarba*
1b = large *A. jacksoniensis*	6 = *G. subfasciatus*	11 = *Redigobius* sp.
2 = *A. microstoma*	7 = *L. argentea*	12 = *T. hamiltoni*
3 = *P. signifer*	8 = *M. paludis*	
4 = *A. australis*	9 = *P. olorum*	

Figure 10: nMDS ordination of the mean percentage volumetric contributions of the various dietary categories to the diets of up to 10 individuals of each of the 12 species recorded near saltmarsh at Cockle Bay. Numbers in red indicate that more than one individual of that species falls in that area of the plot.

Table 9: Results of pairwise ANOSIM tests on the mean percentage volumetric contributions of the different dietary categories to the diets of individuals of each of the twelve fish species recorded near saltmarsh at Cockle Bay. *, P<0.05, **, P<0.005, ***, P<0.001. R-statistic values are italicised where there were less than 35 permutations in the ANOSIM test.

Fish species	*A. jacksoniensis*	*A.m*	*P.s*	*A.a*	*C.m*	*G.s*	*L.a*	*M.p*	*P.o*	*R.s*	*Red*
A. microstoma	0.108										
P. signifier	0.896***	0.532***									
A. australis	0.936**	0.580**	0.339*								
C. mugiloides	0.931*	0.583*	*-0.129*	*-0.500*							
G. subfasciata	0.895***	0.537***	0.465***	0.914*	*0.481*						
L. argentea	0.940***	0.653***	0.522***	0.965*	*1.000*	0.972***					
M. paludis	0.937***	0.577**	0.479***	*-0.167*	*0*	0.895**	0.945**				
P. olorum	0.934***	0.574**	0.388**	*-0.167*	*-0.333*	0.601**	0.892**	*0*			
R. sarba	0.937*	0.583*	*0.484*	*-0.500*	*1.000*	*0.926*	*1.000*	*-0.333*	*0*		
Redigobius sp.	-0.145	-0.164	0.487**	*0.500*	*1.000*	0.796**	*1.000*	*0.333*	*0.250*	1.000	
T. hamiltoni	0.939***	0.615***	0.477***	*0.932*	*1.000*	0.958**	*1.000*	0.843**	*0.793*	*1.000*	*1.000*

3.6 Drogue tracking

Locations of the 15 saltmarshes from which drogues were released are provided in Figure 12. Figures 13 to 19 represent the drogue tracks for larvae released in Paddy's Channel (site 5) at the spring high tide on 27 February 2006. Figure 13 is near the first release (10:00 27/2/2006), and the subsequent plots (Figures 14 to 19) are the completed tracks at successive higher high tides. Note, a second set of drogues was released at approximately 10:00 28/2/2006. After 5 successive tide cycles (Figure 19) the drogues have moved between the Gosford Broadwater and Broken Bay, but not into Woy Woy Bay and the Kincumber Broadwater, for example. At many locations, the drogues indicated that the larvae are dispersed for substantial distances from the saltmarsh at which they were spawned (Figures 19, 24, 26-27, 30-32). In contrast, it was also noted that drogues at other locations (sites 1-4, 7, 10 and 11) did not far at all (Figures 20-23, 25, 28-29).

Figure 12: Locations of 15 saltmarshes used to simulate drogue tracking

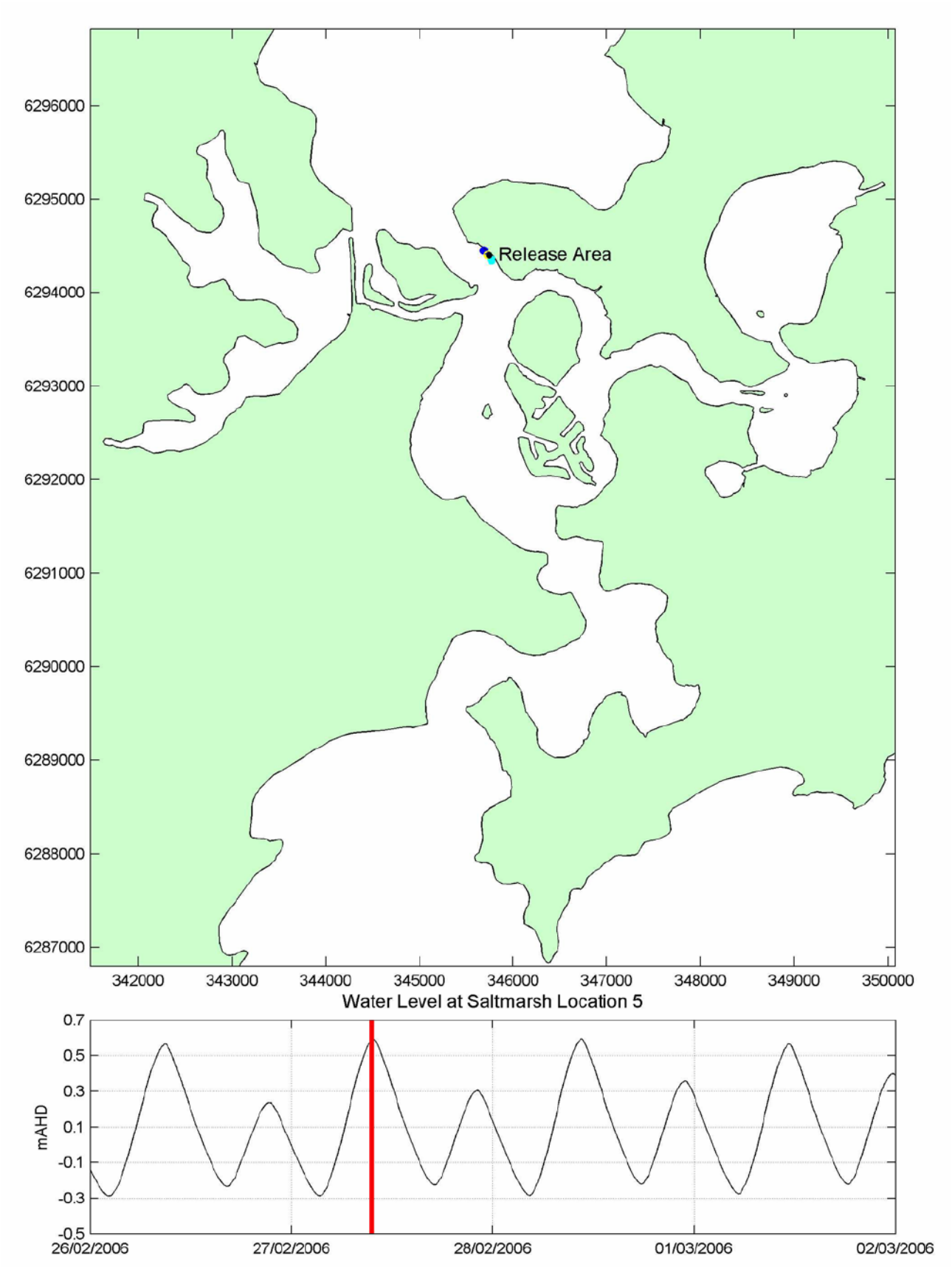


Figure 13: Drogue tracking release area at Paddys Chanel (site 5)

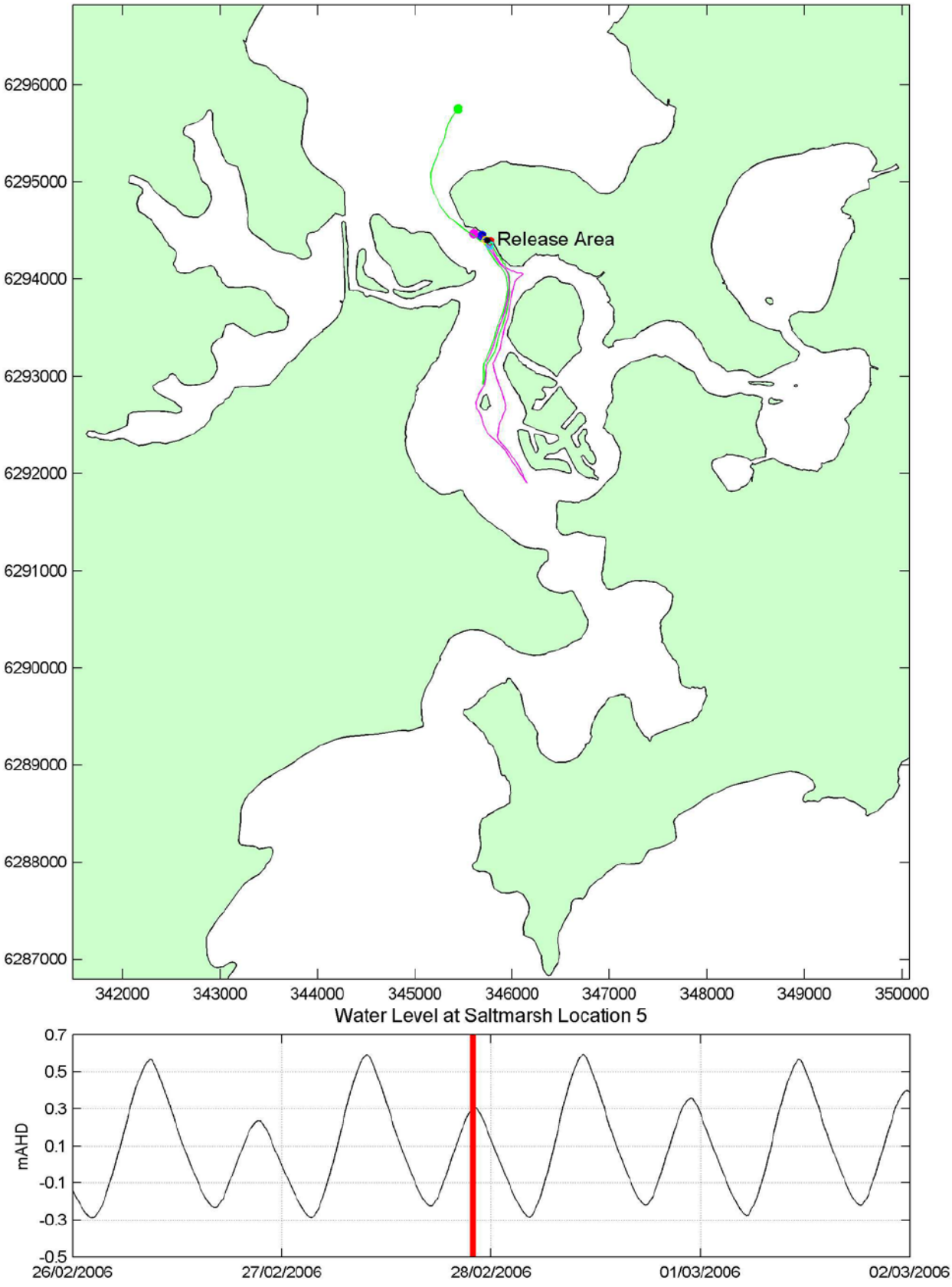


Figure 14: Drogue tracking from Paddys Chanel (site 5) at second high tide on 27/02/06

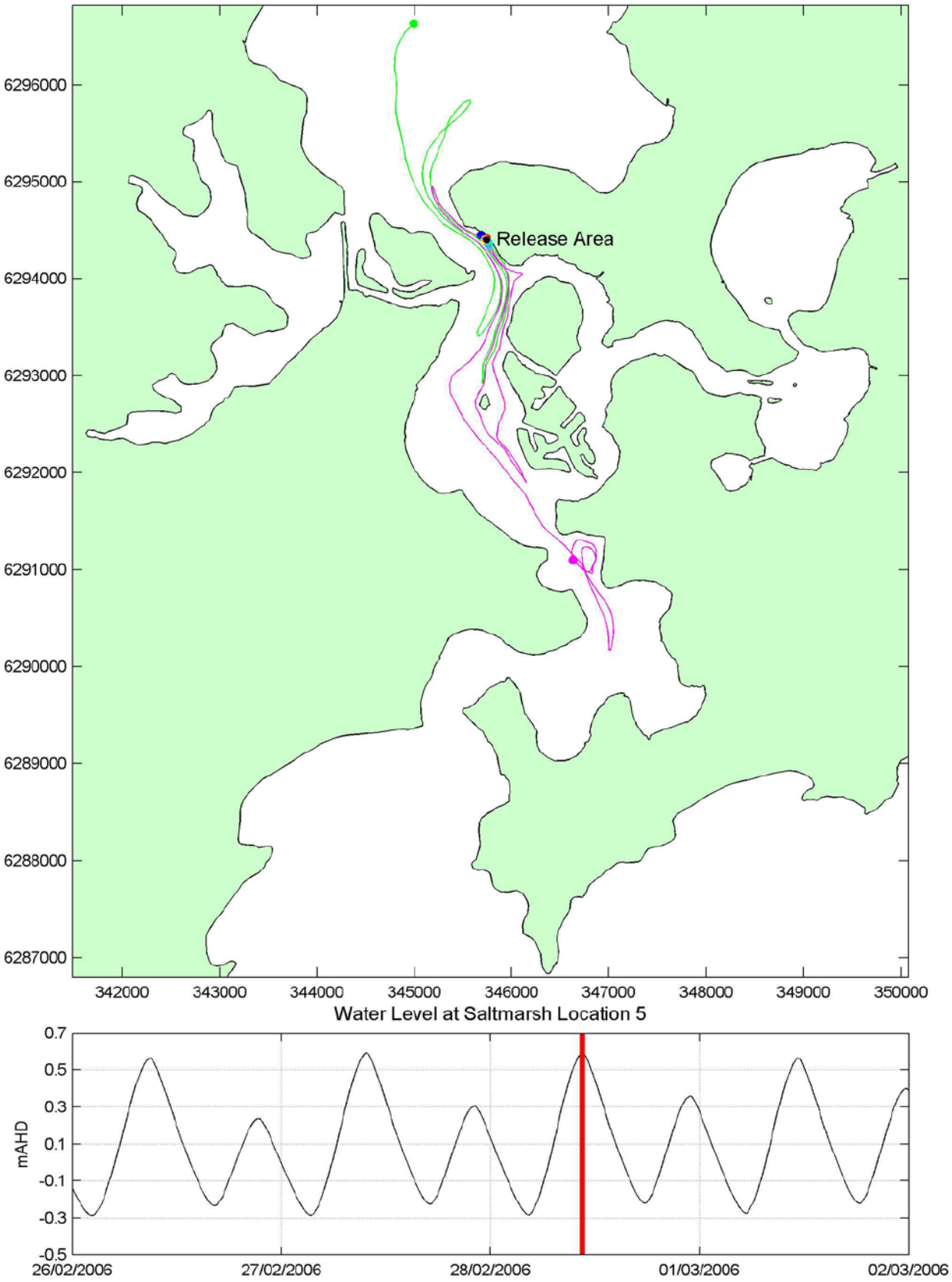


Figure 15: Drogue tracking from Paddys Chanel (site 5) at spring high tide on 28/02/06 near release of second set of drogues

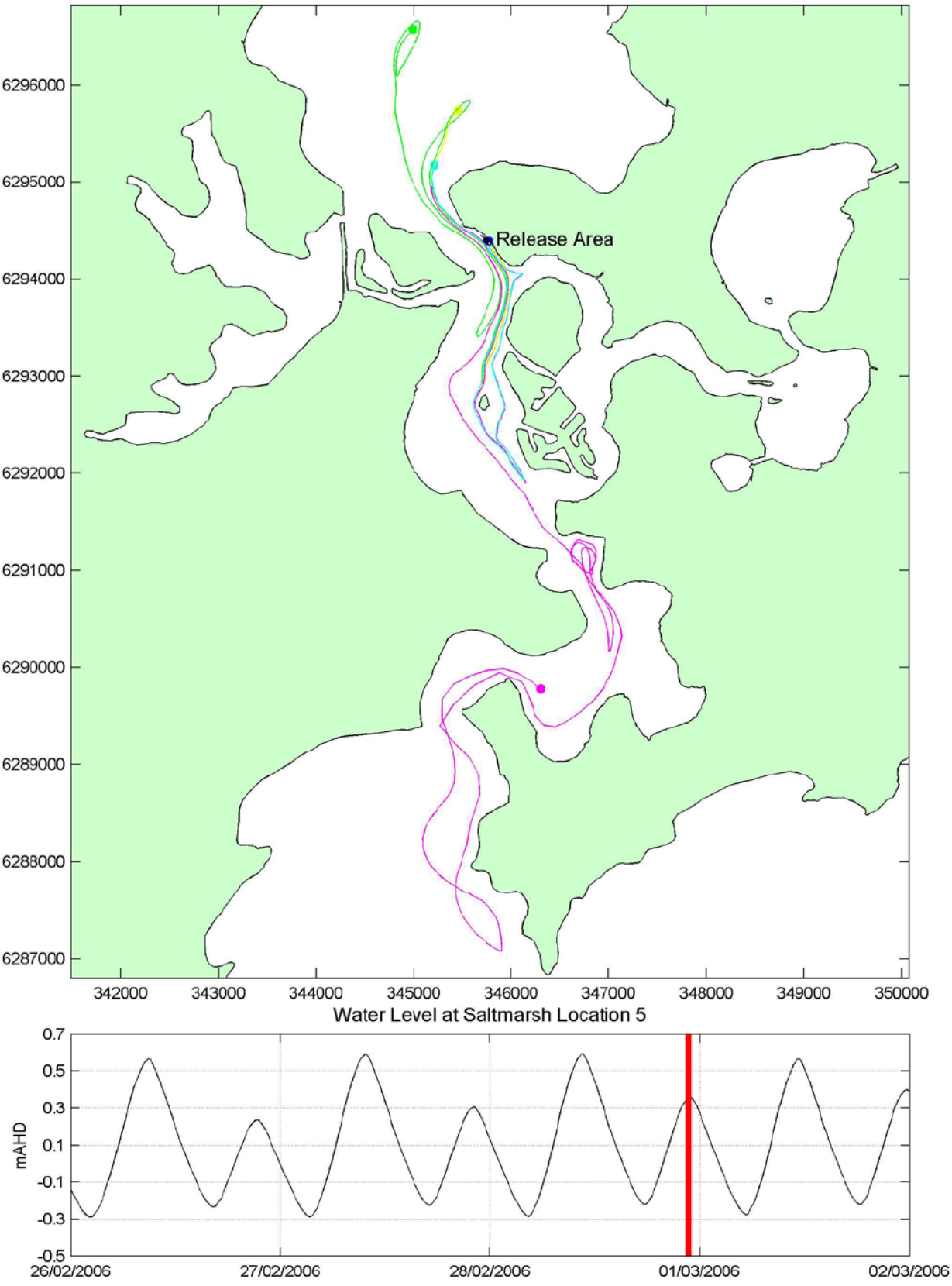


Figure 16: Drogue tracking from Paddys Chanel (site 5) at second high tide on 28/02/06

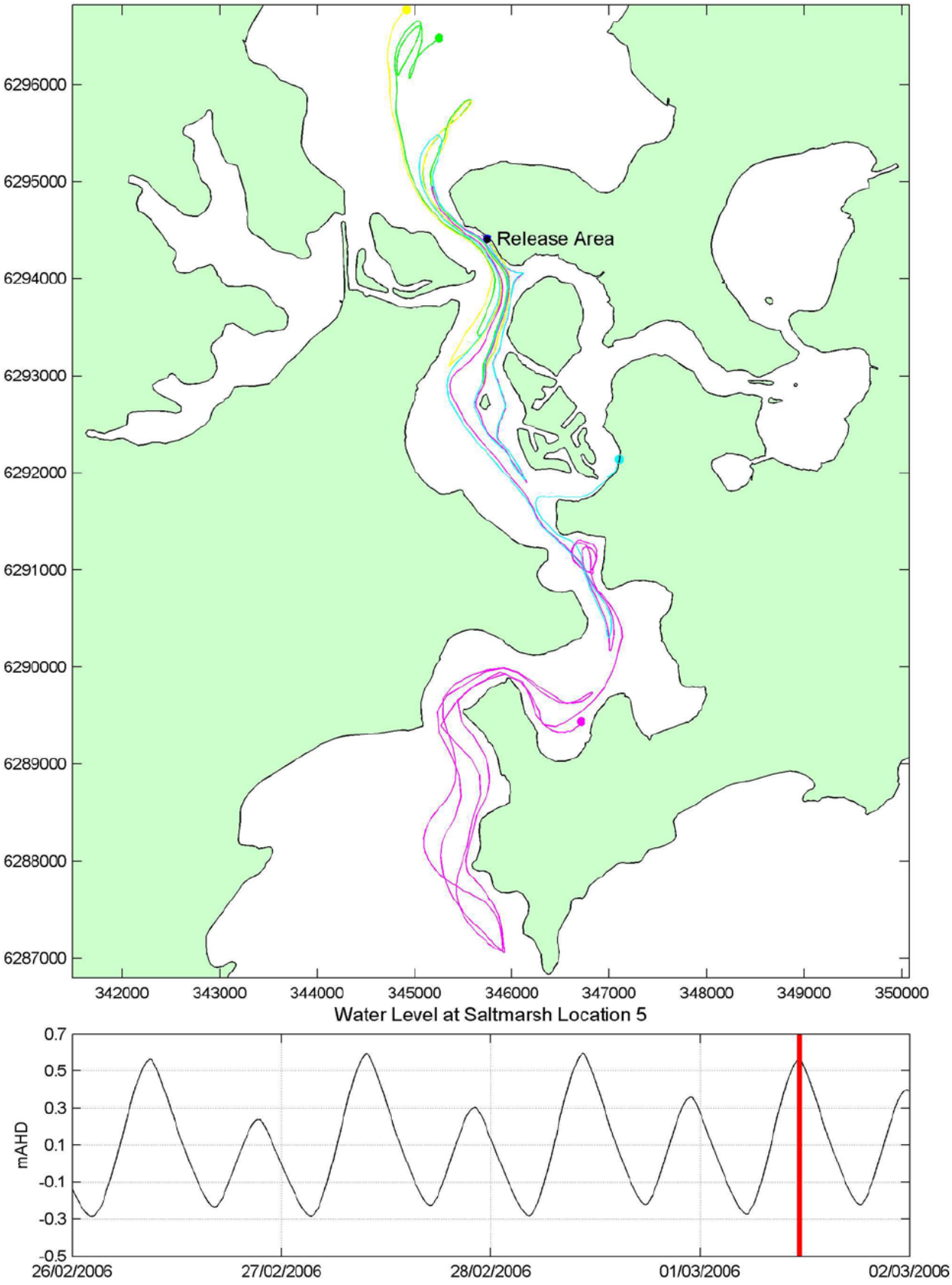


Figure 17: Drogue tracking from Paddys Chanel (site 5) at spring high tide on 01/03/06

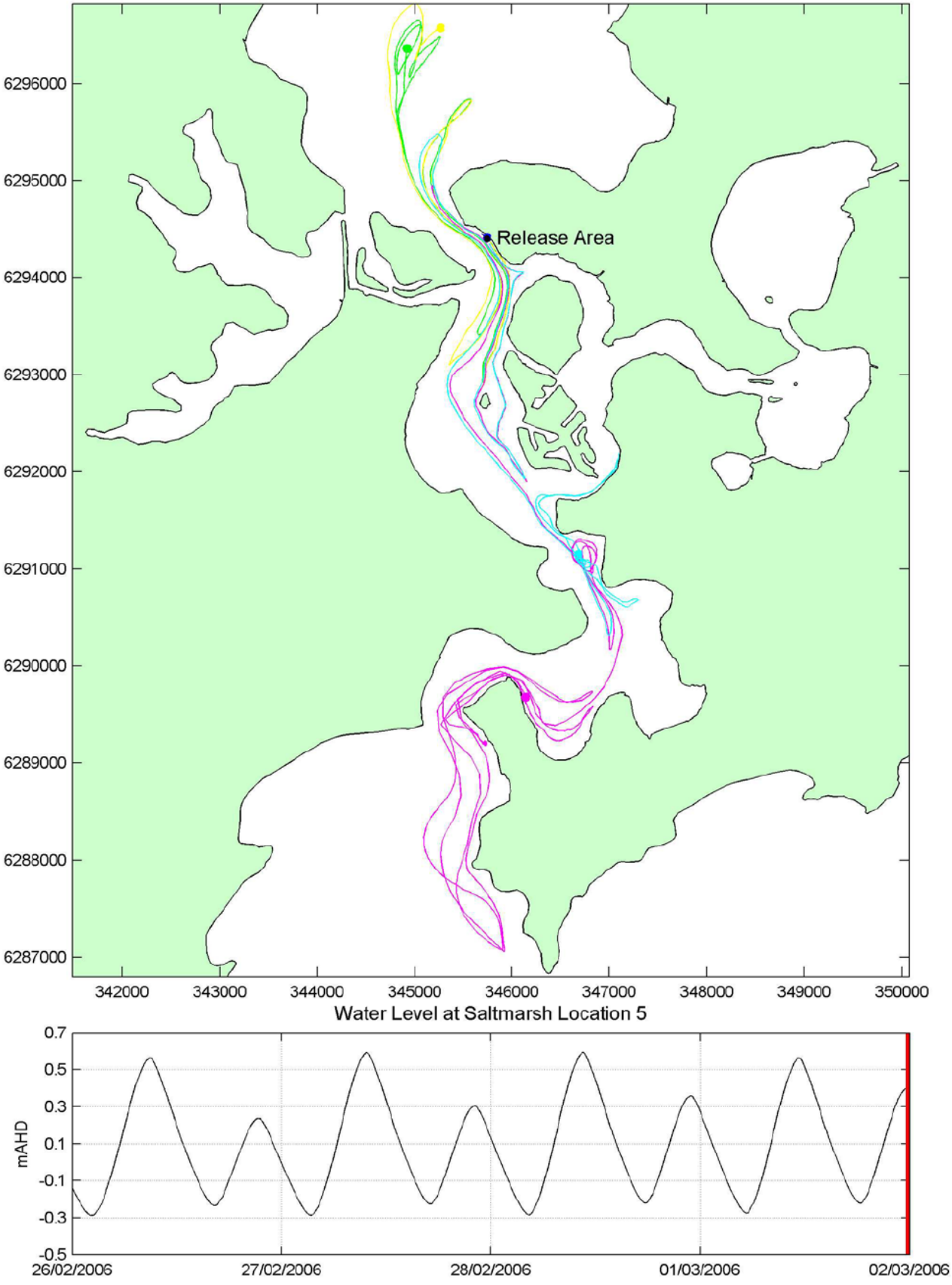


Figure 18: Drogue tracking from Paddys Chanel (site 5) completed at 02/03/06

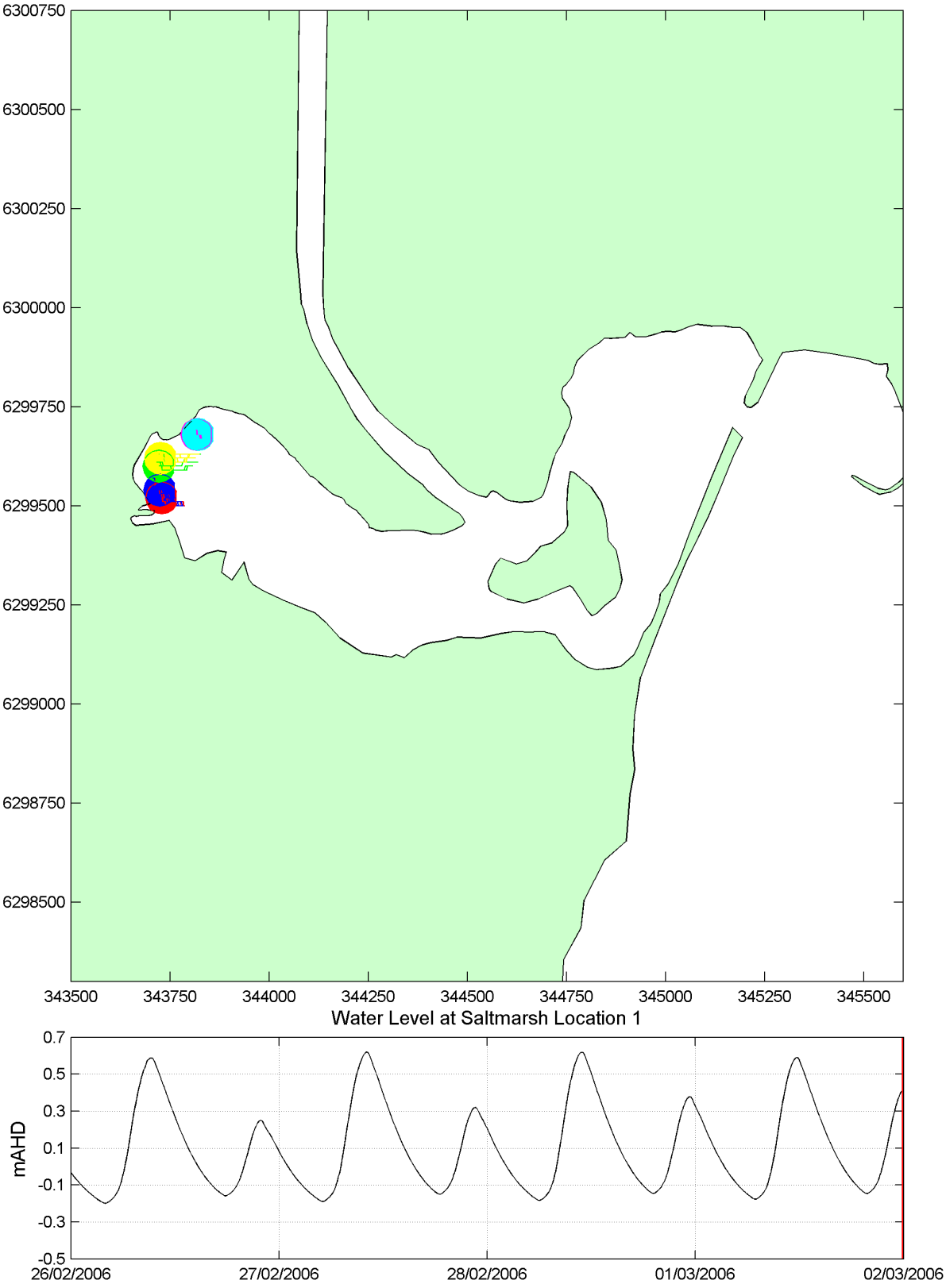


Figure 19: Drogue tracking from Fagans Bay (site 1) completed at 02/03/06

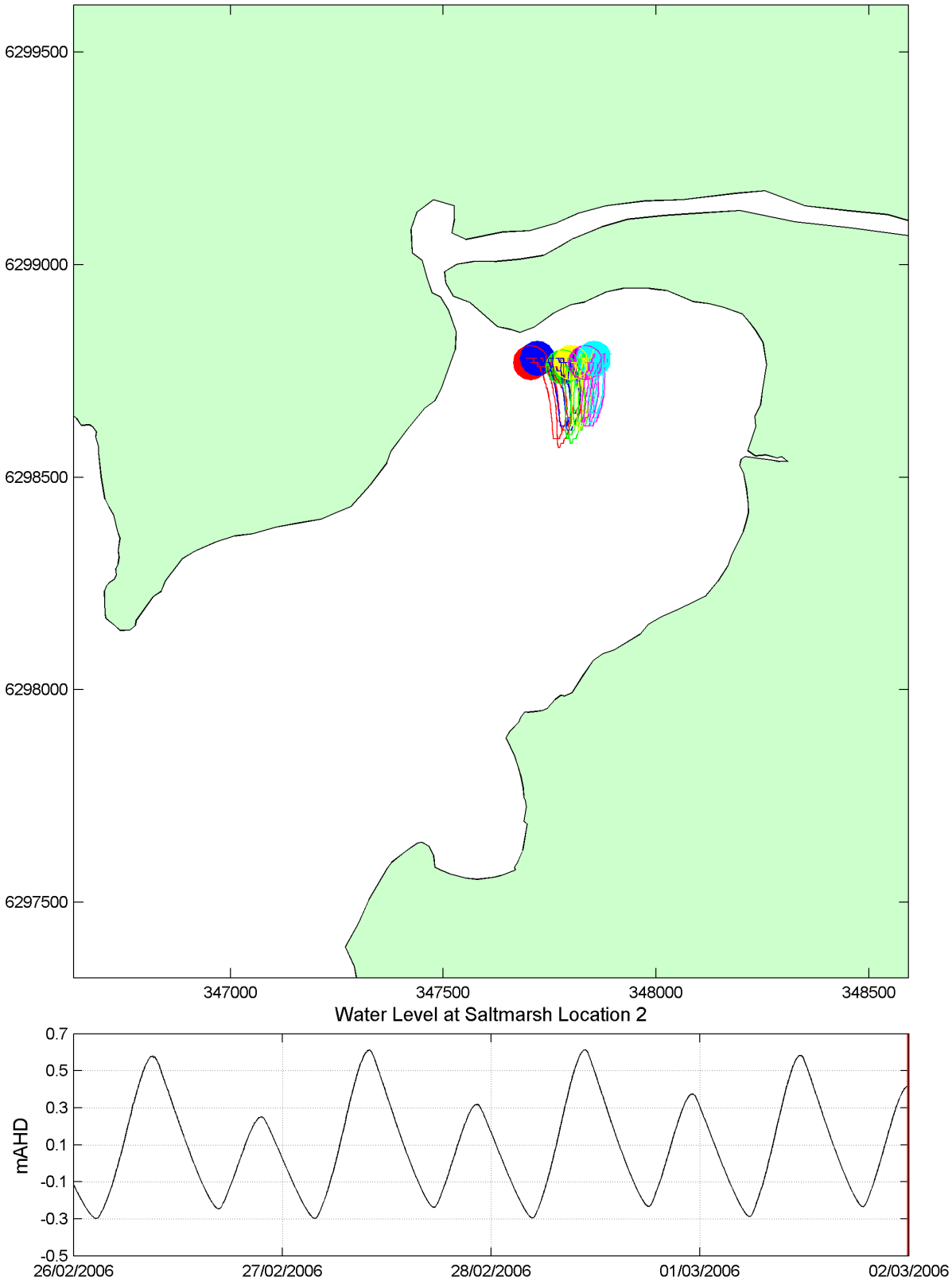


Figure 20: Drogue tracking from Green Point (site 2) completed at 02/03/06

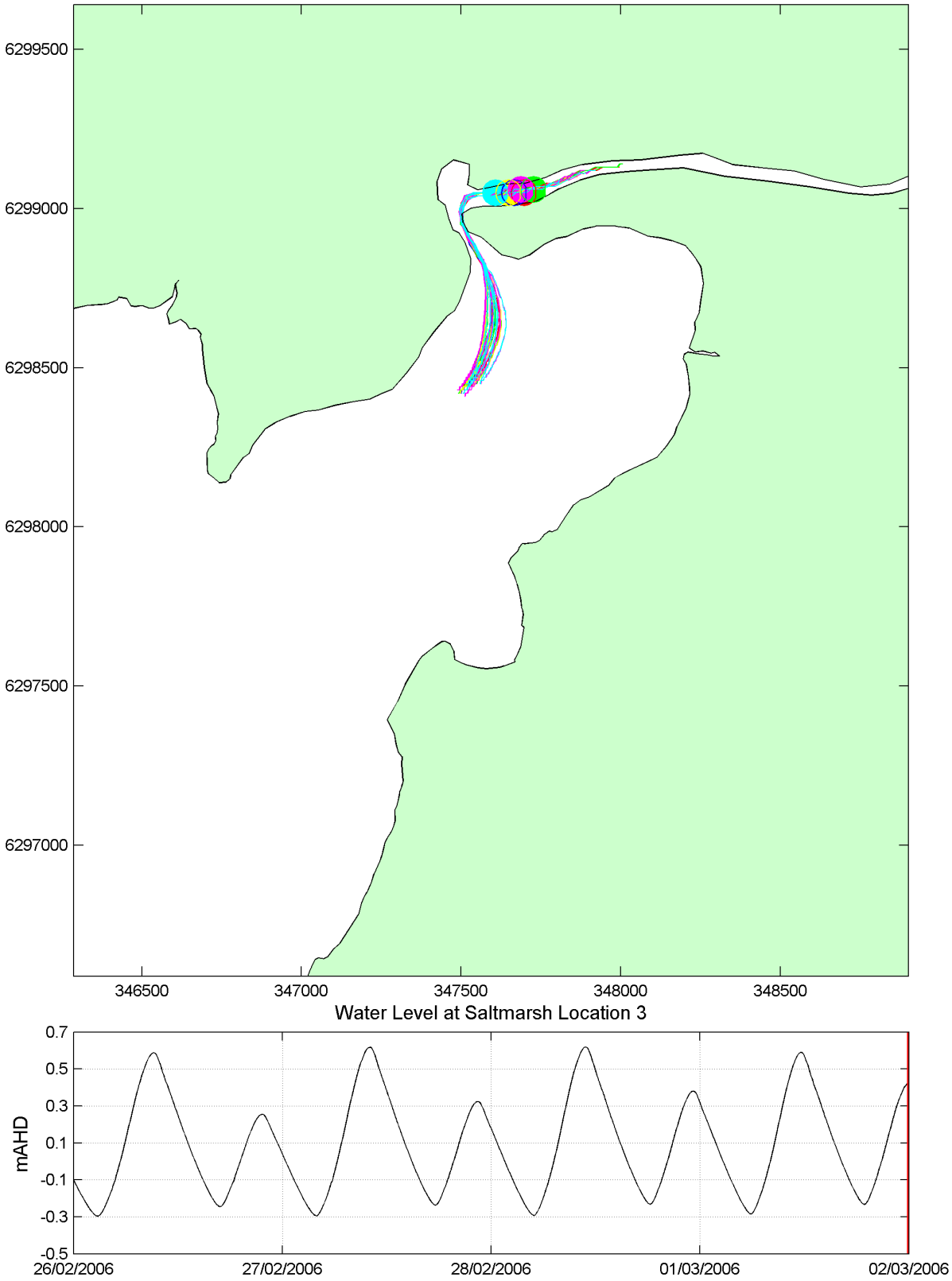


Figure 21: Drogue tracking from Erina Creek (site 3) completed at 02/03/06

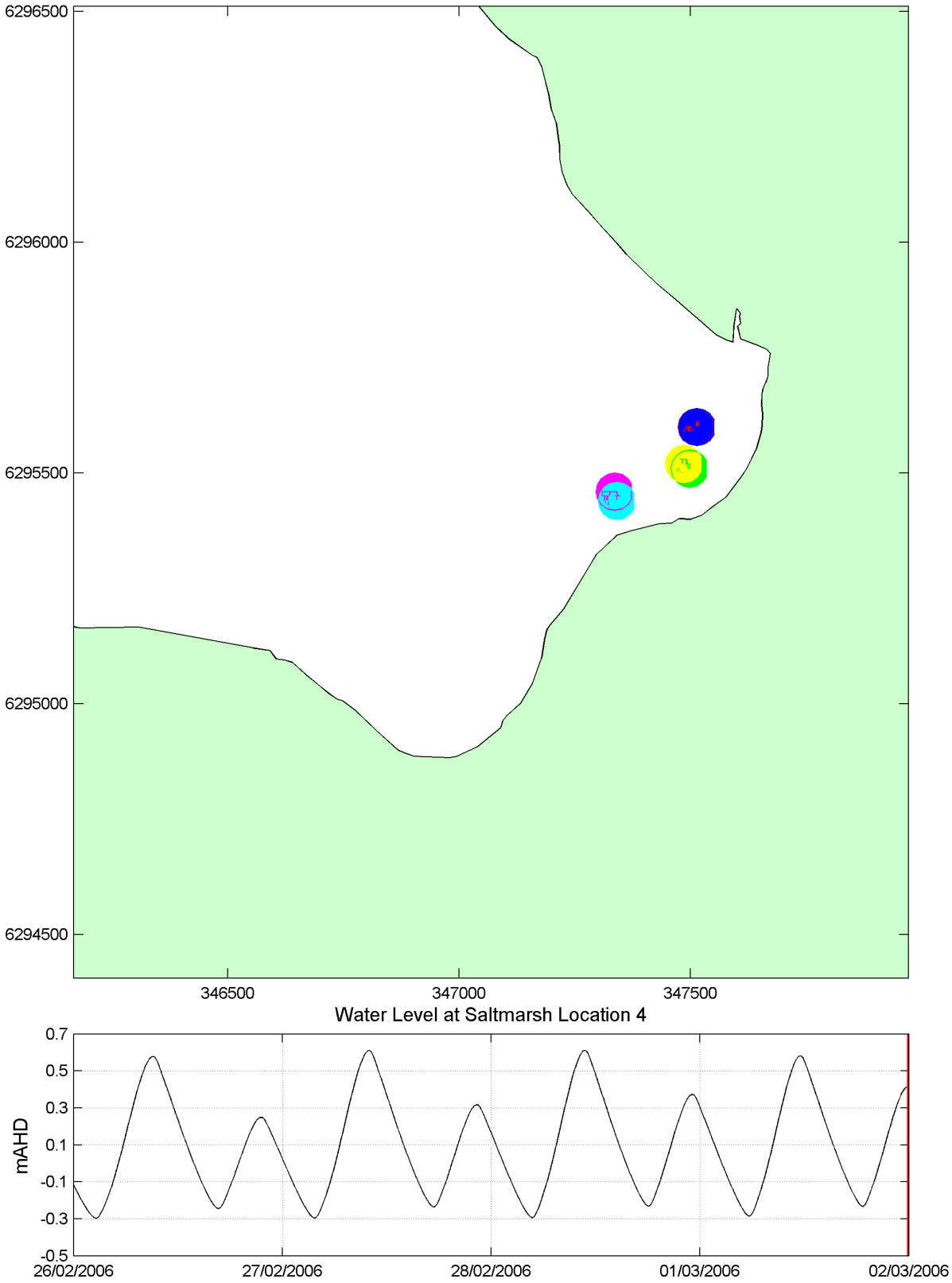


Figure 22: Drogue tracking from Yattalunga (site 4) completed at 02/03/06

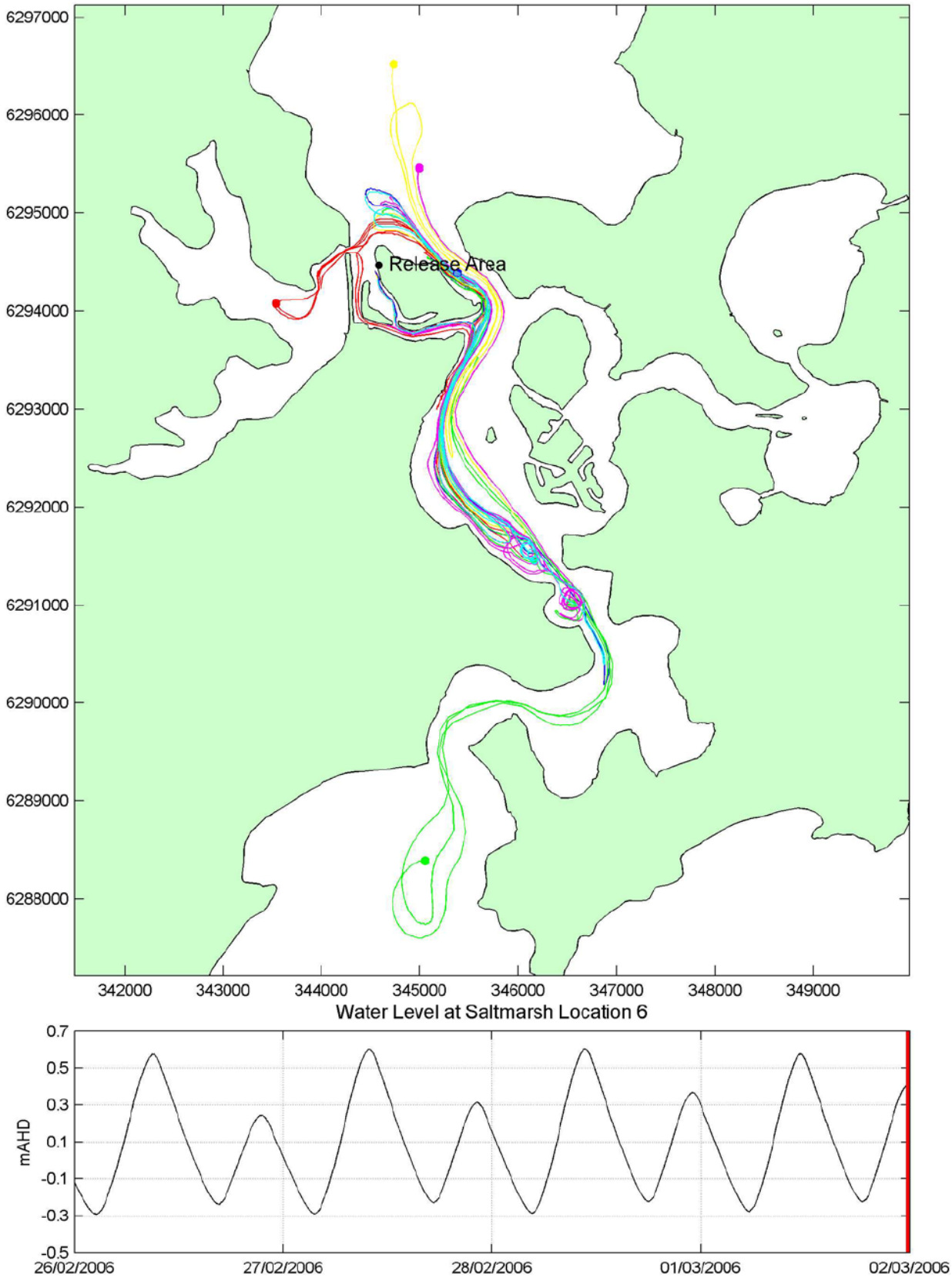


Figure 23: Drogue tracking from Pelican Island (site 6) completed at 02/03/06

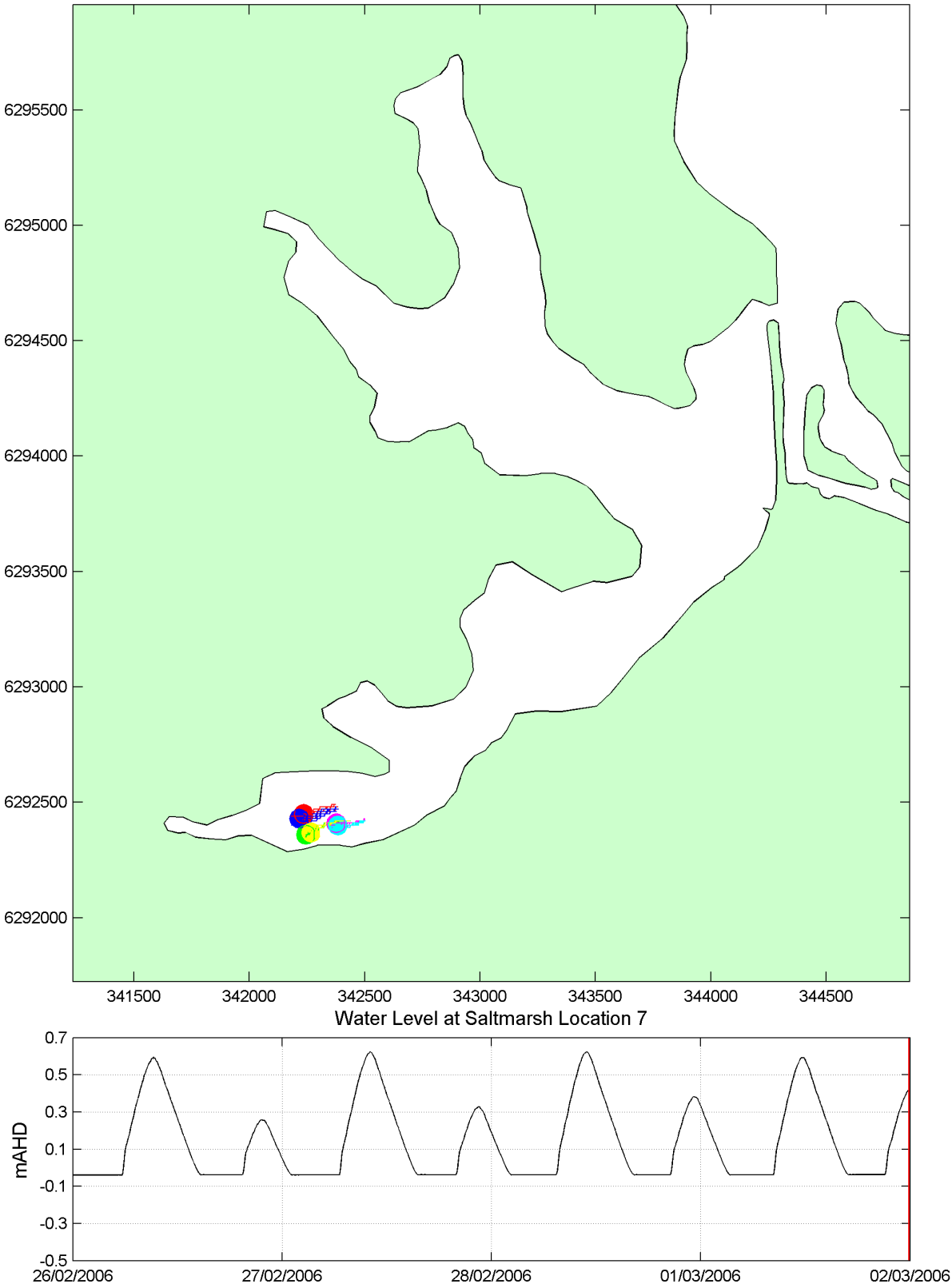


Figure 24: Drogue tracking from Correa Bay (site 7) completed at 02/03/06

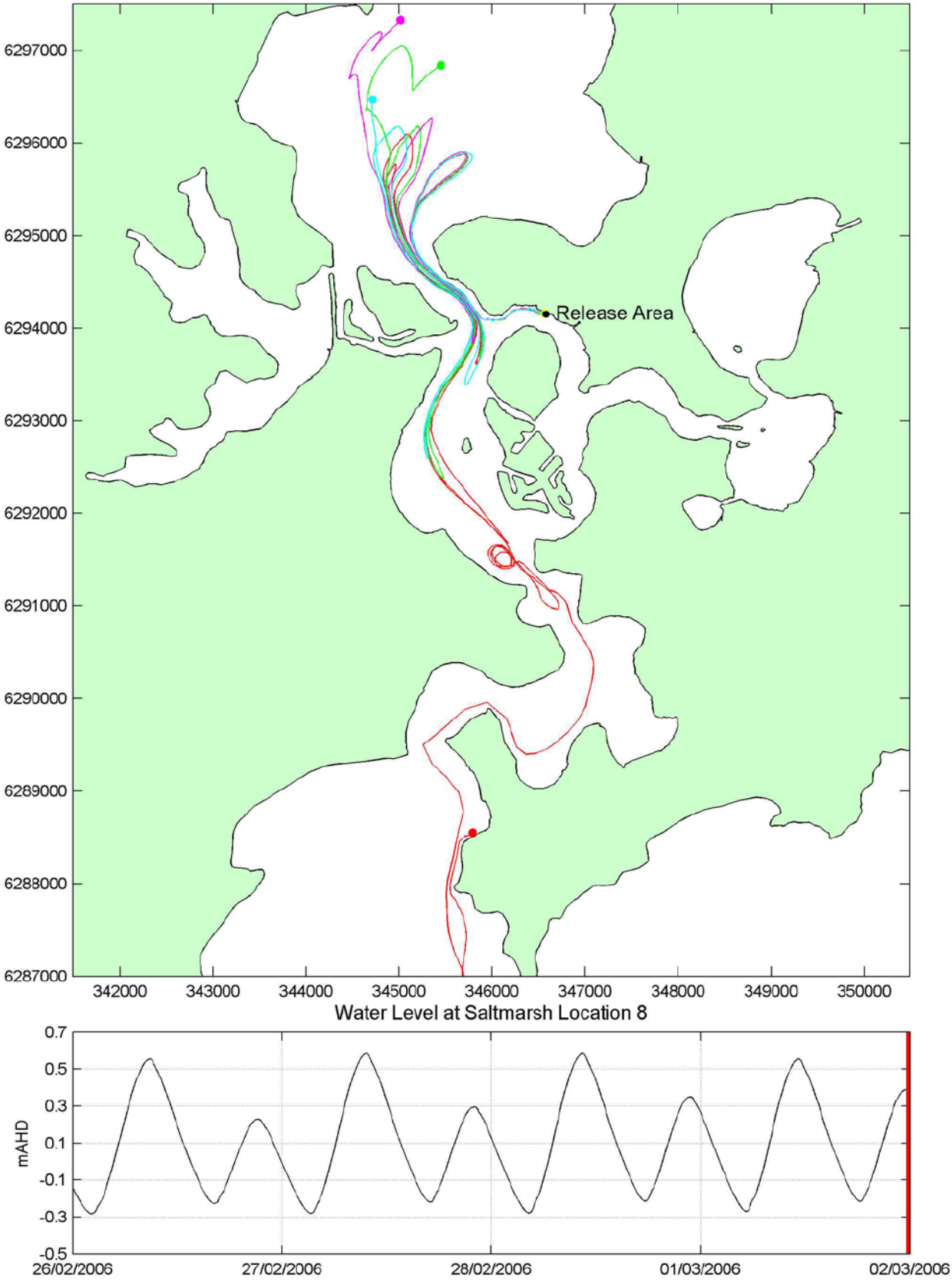


Figure 25: Drogue tracking from Davistown (site 8) completed at 02/03/06

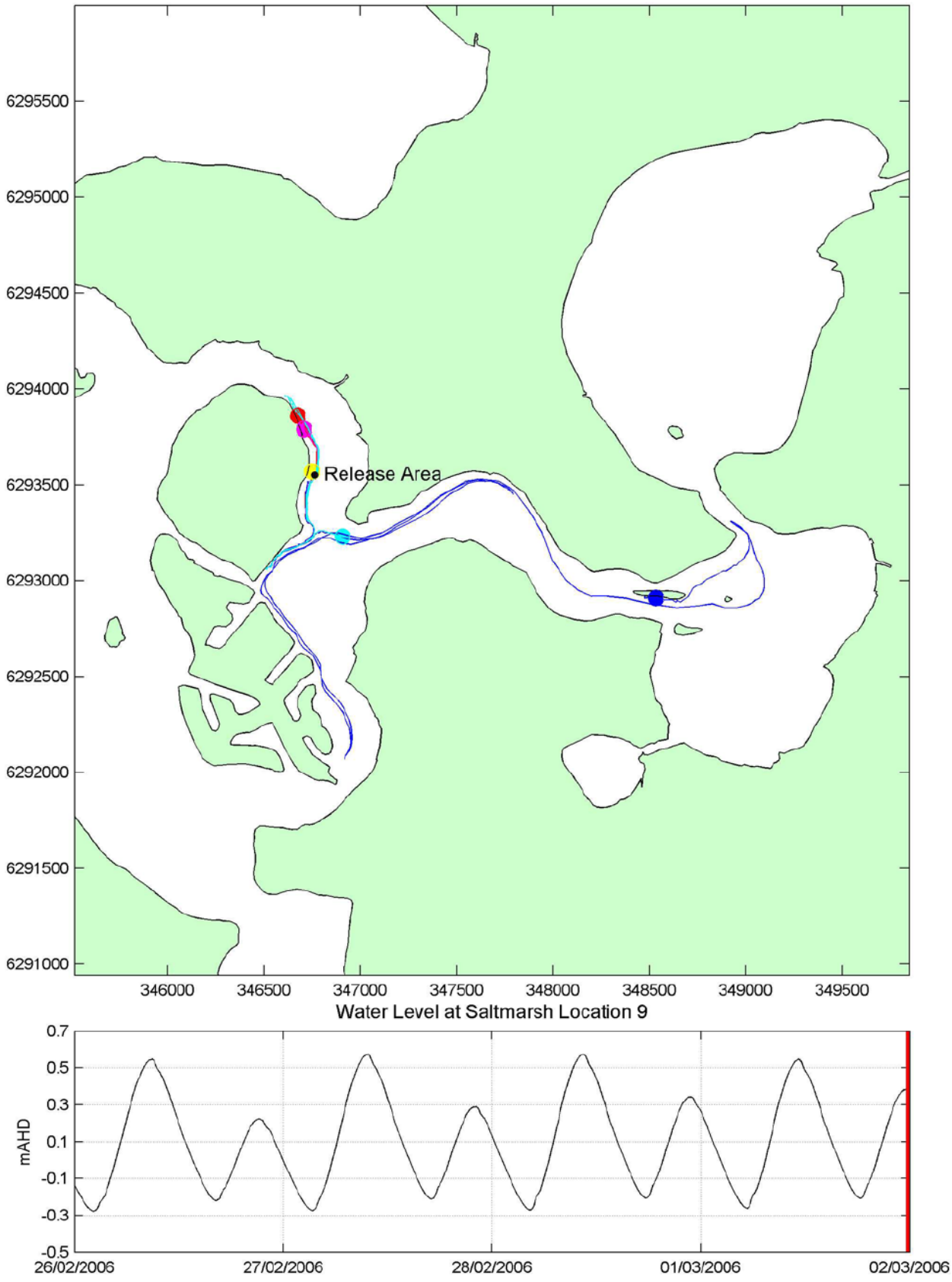


Figure 26: Drogue tracking from Rileys Island (site 9) completed at 02/03/06

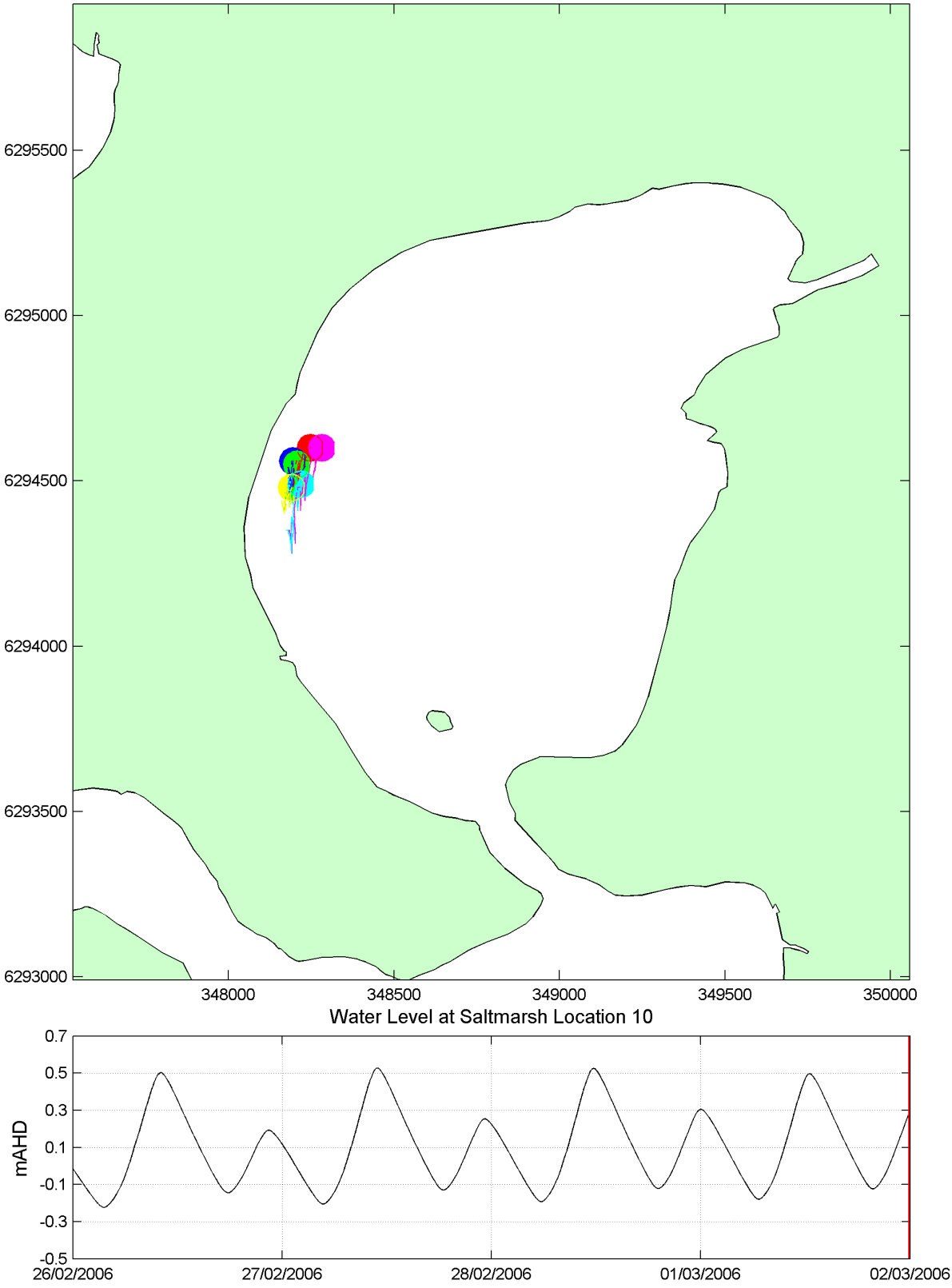


Figure 27: Drogue tracking from Saratoga (site 10) completed at 02/03/06

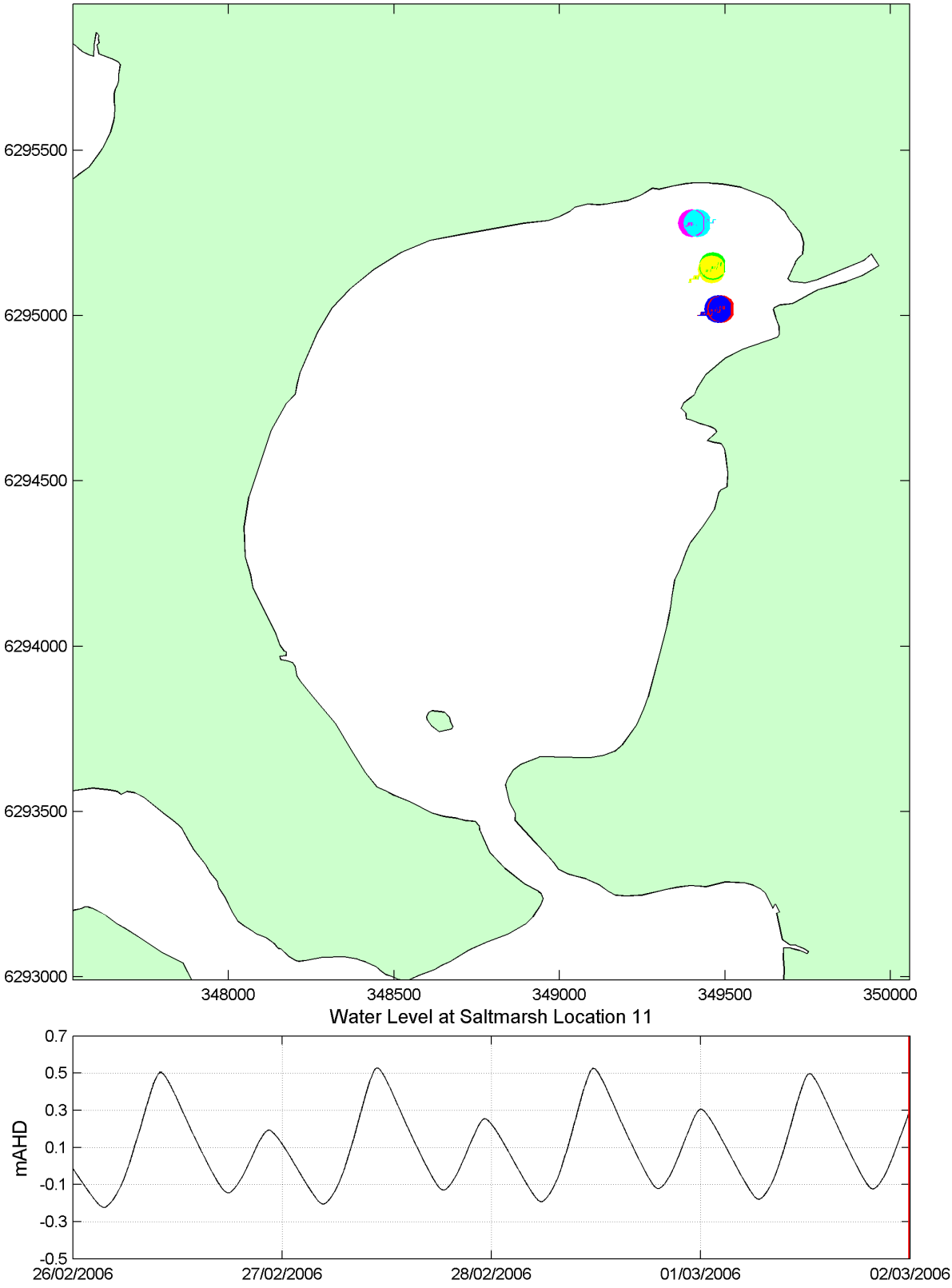


Figure 28: Drogue tracking from Kincumber (site 11) completed at 02/03/06

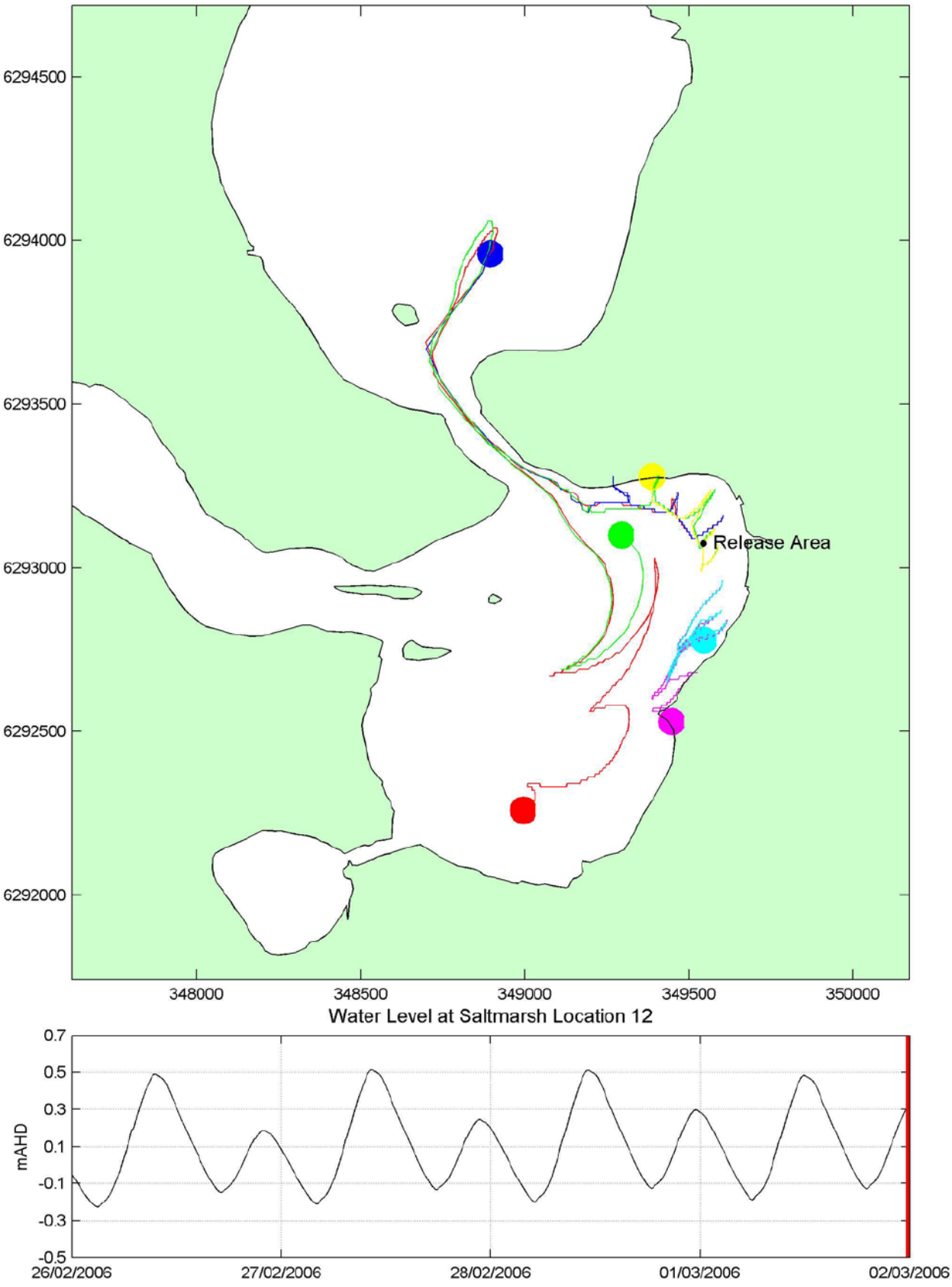


Figure 29: Drogue tracking from Bensville (site 12) completed at 02/03/06

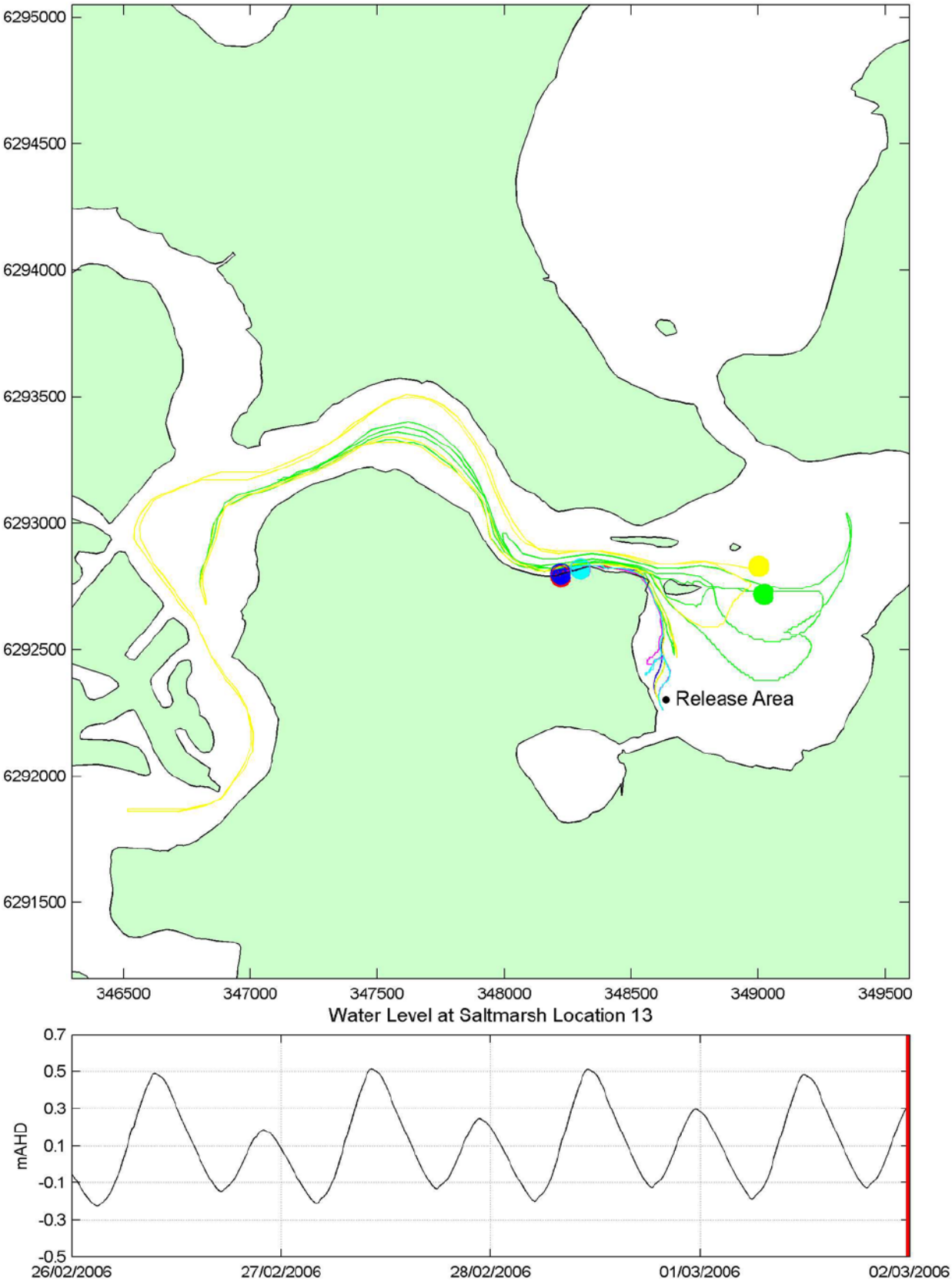


Figure 30: Drogue tracking from Cockle Bay (site 13) completed at 02/03/06

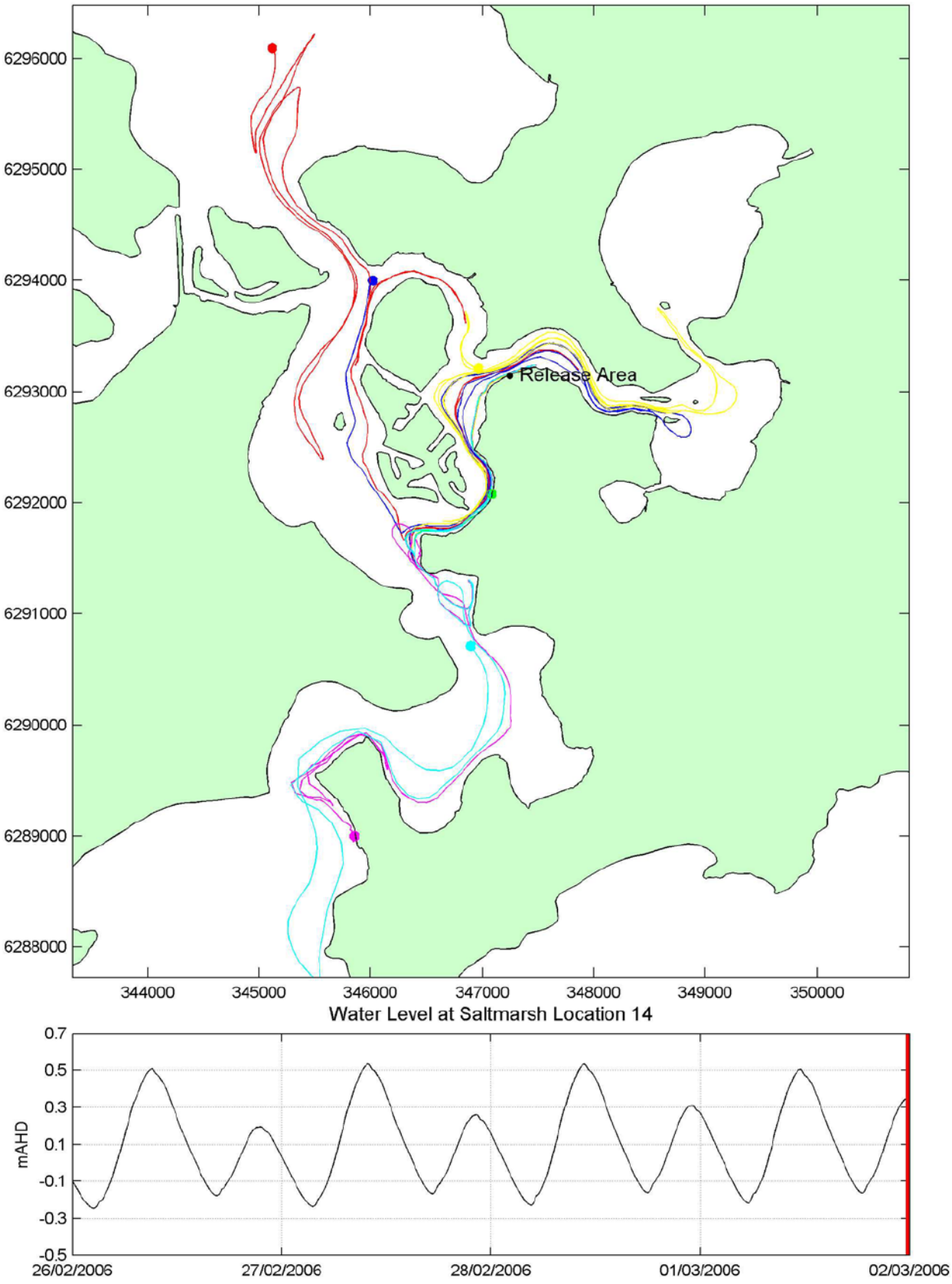


Figure 31: Drogue tracking from Empire Bay (site 14) completed at 02/03/06

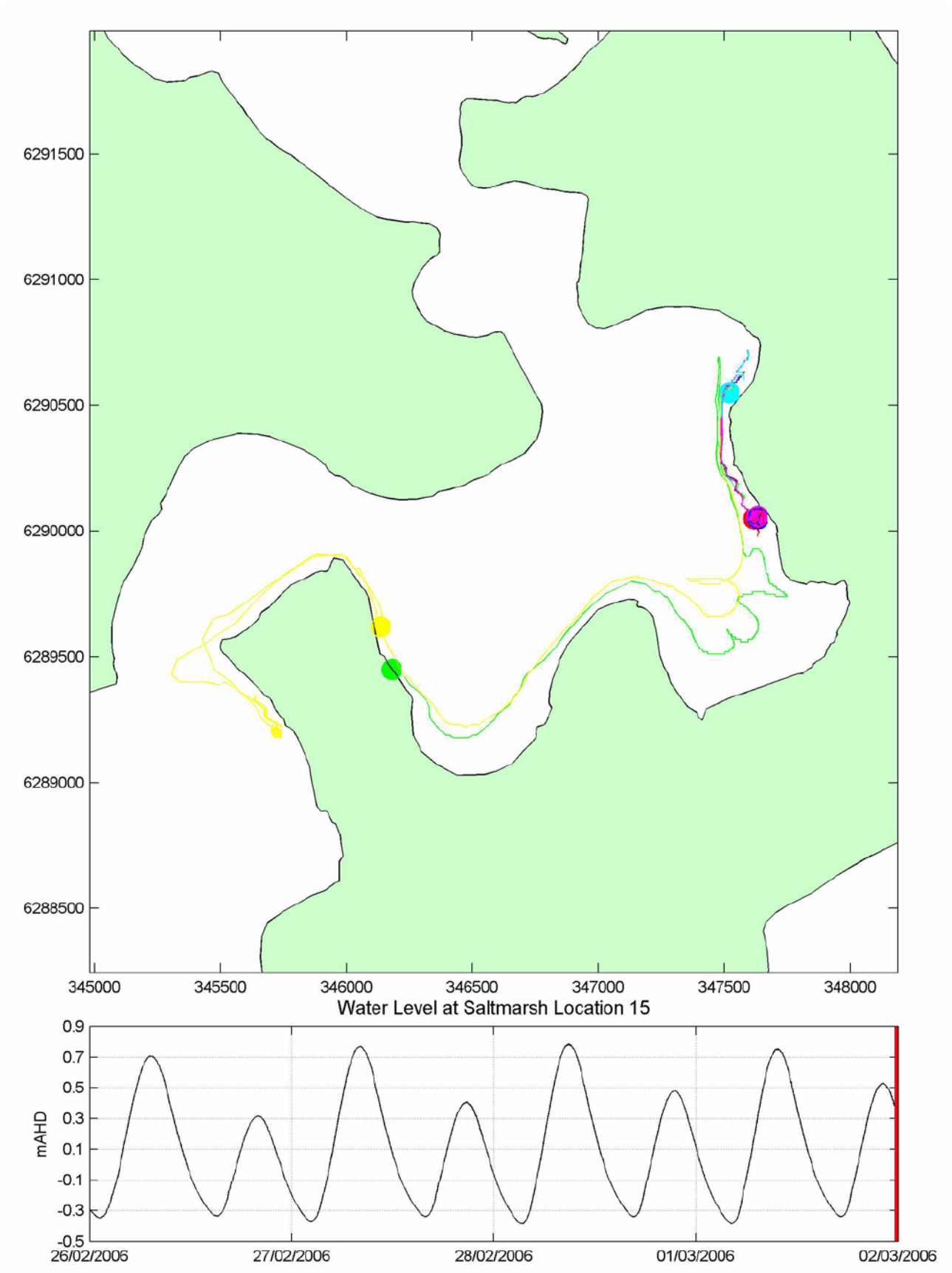


Figure 32: Drogue tracking from Rileys Bay (site 15) completed at 02/03/06

3.7 Advection-dispersal simulation

The model was run for a 2-week period (00:00 27/02/06 - 00:00 11/03/06). Figures 33 to 40 represent larvae concentrations (m^{-3}) at 12-hour intervals over a 96-hour period. Figure 33 (12:00 27/02/06) corresponds to the approximate end of the first larvae release period. Figure 37 (12;00 01/03/06) corresponds to the approximate end of the last larvae release period and represents the highest concentration of larvae (< 5,000 m^{-3}) during the simulation period. In contrast to the drogue tracking simulations, the results indicate that dispersal via tidal currents alone provides an adequate vehicle for transporting larvae throughout the estuary and that some are exported from the system into Broken Bay.

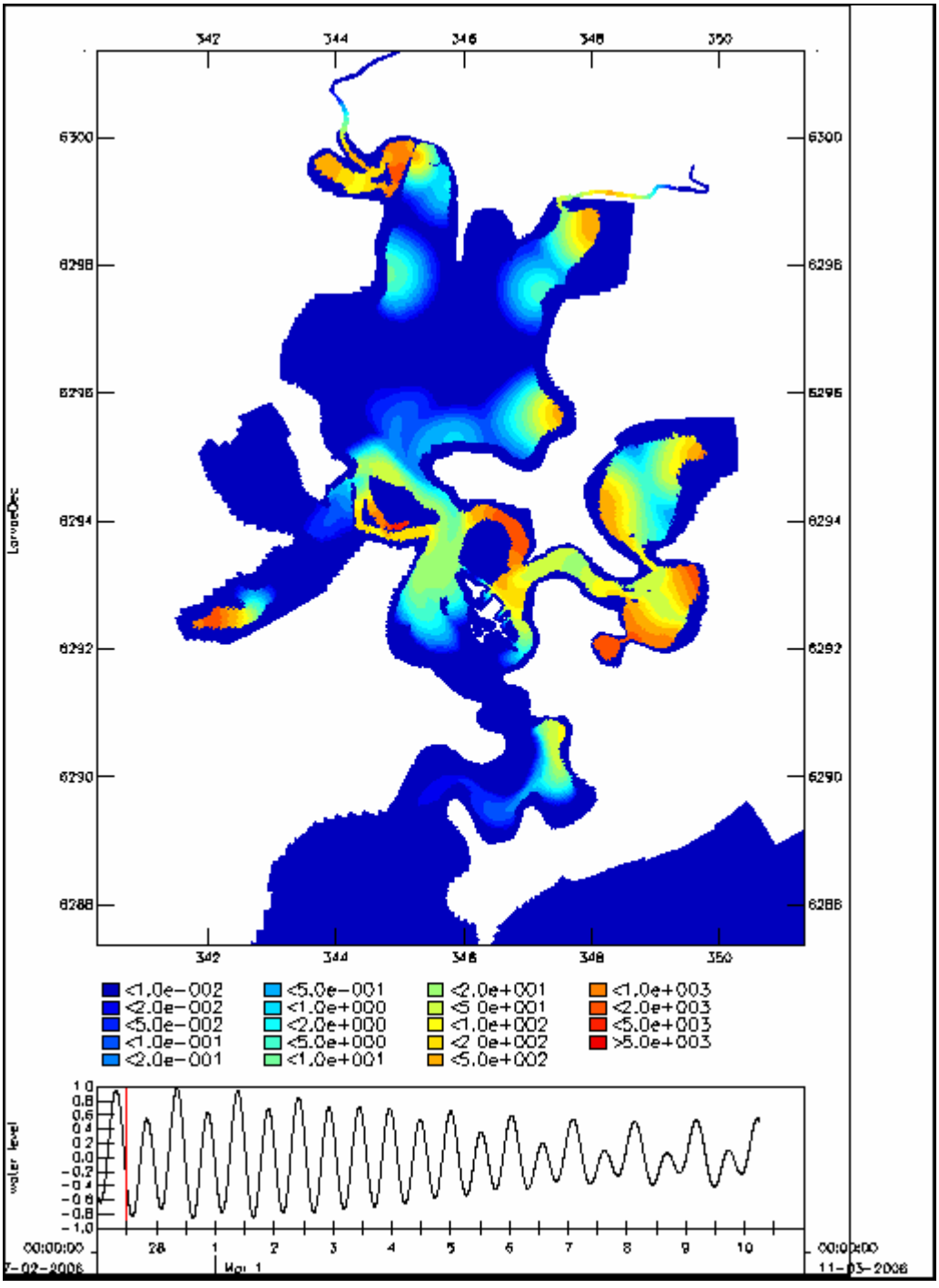


Figure 33: Larval transport - decaying tracer modelling (m^{-3}) - corresponds to the approximate end of the first larvae release period (12:00 27/02/06).

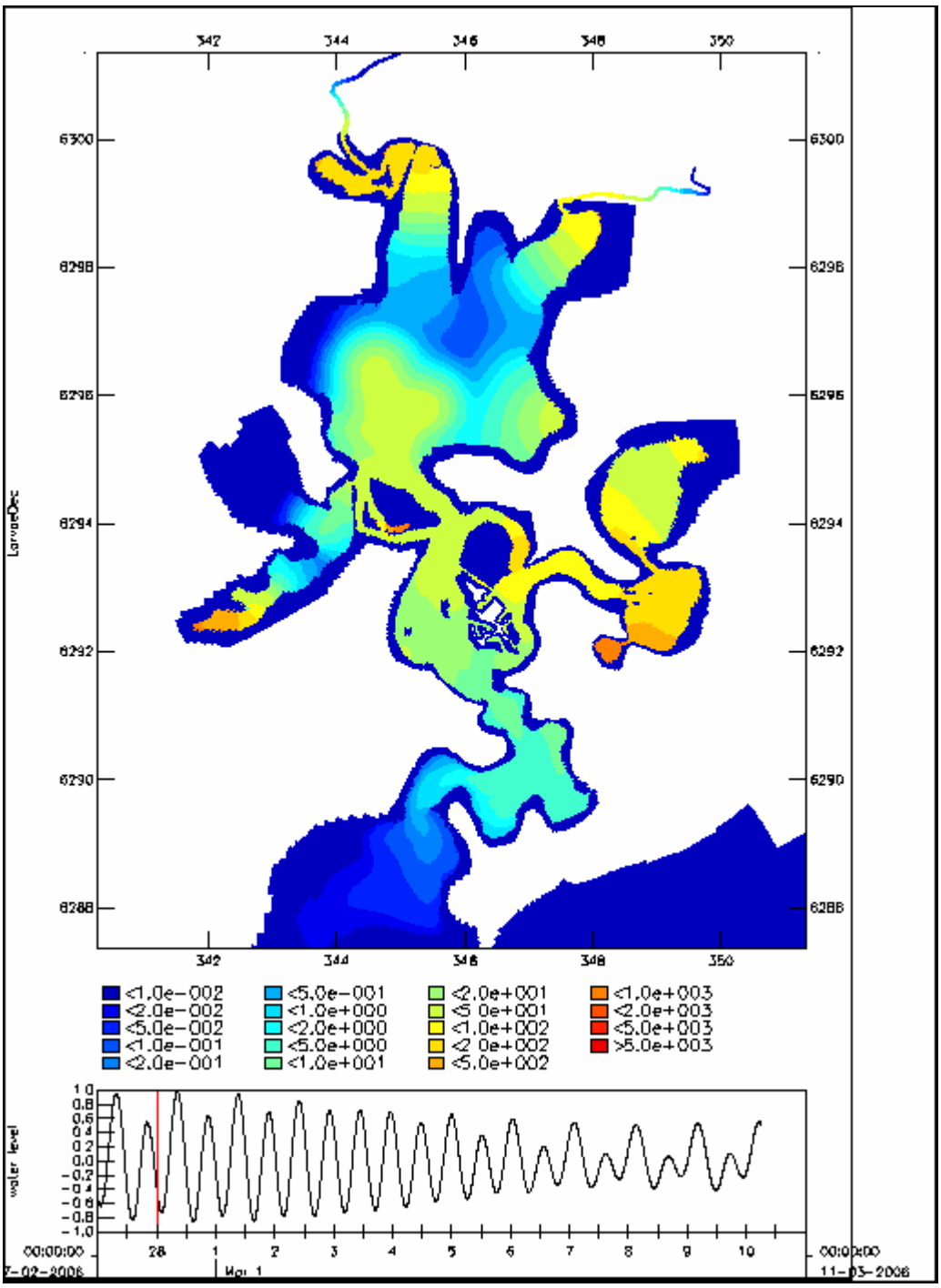


Figure 34: Larval transport - decaying tracer modelling (m^{-3}) (00:00 28/02/06)

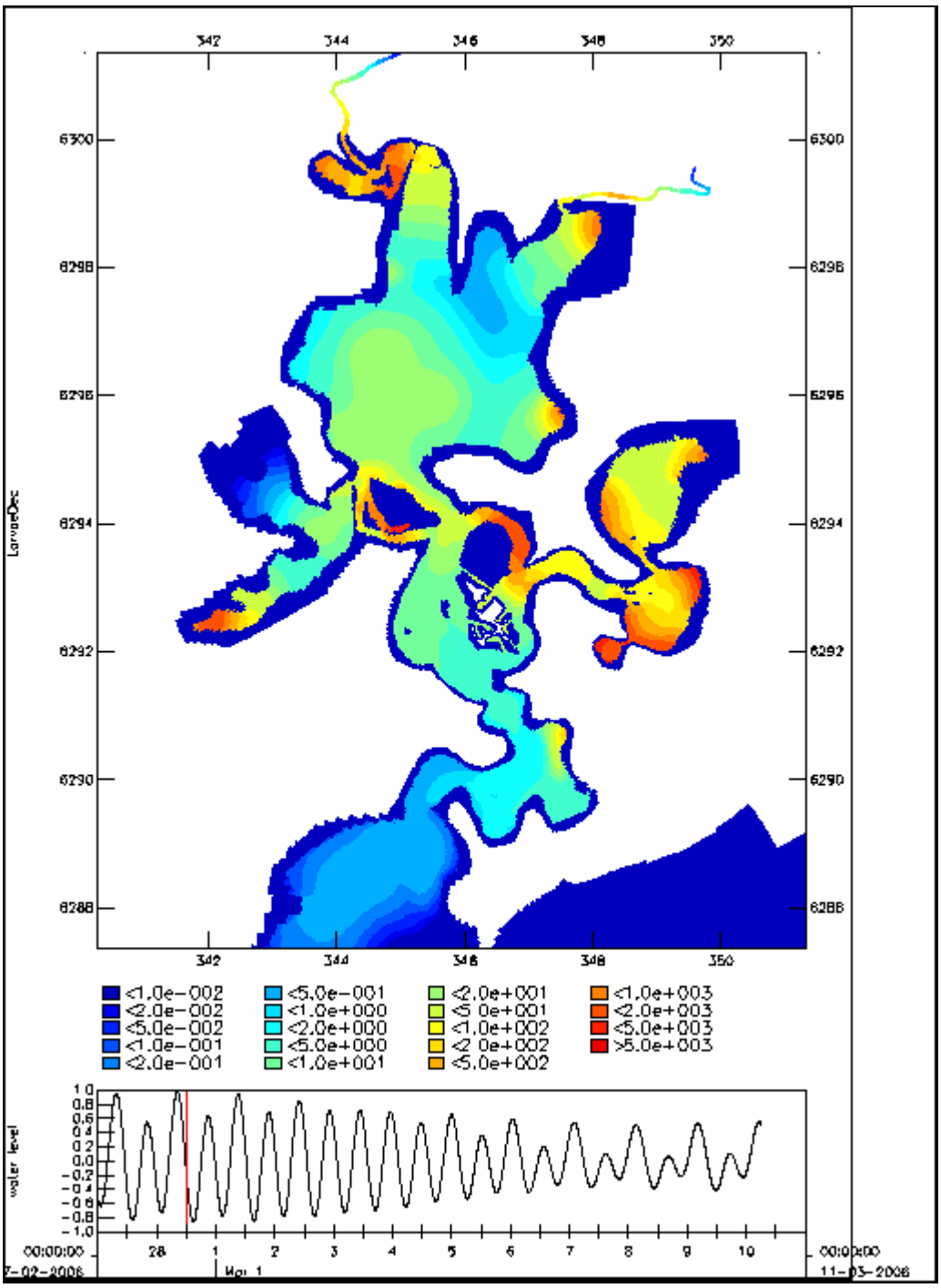


Figure 35: Larval transport - decaying tracer modelling (m^{-3}) (12:00 28/02/06)

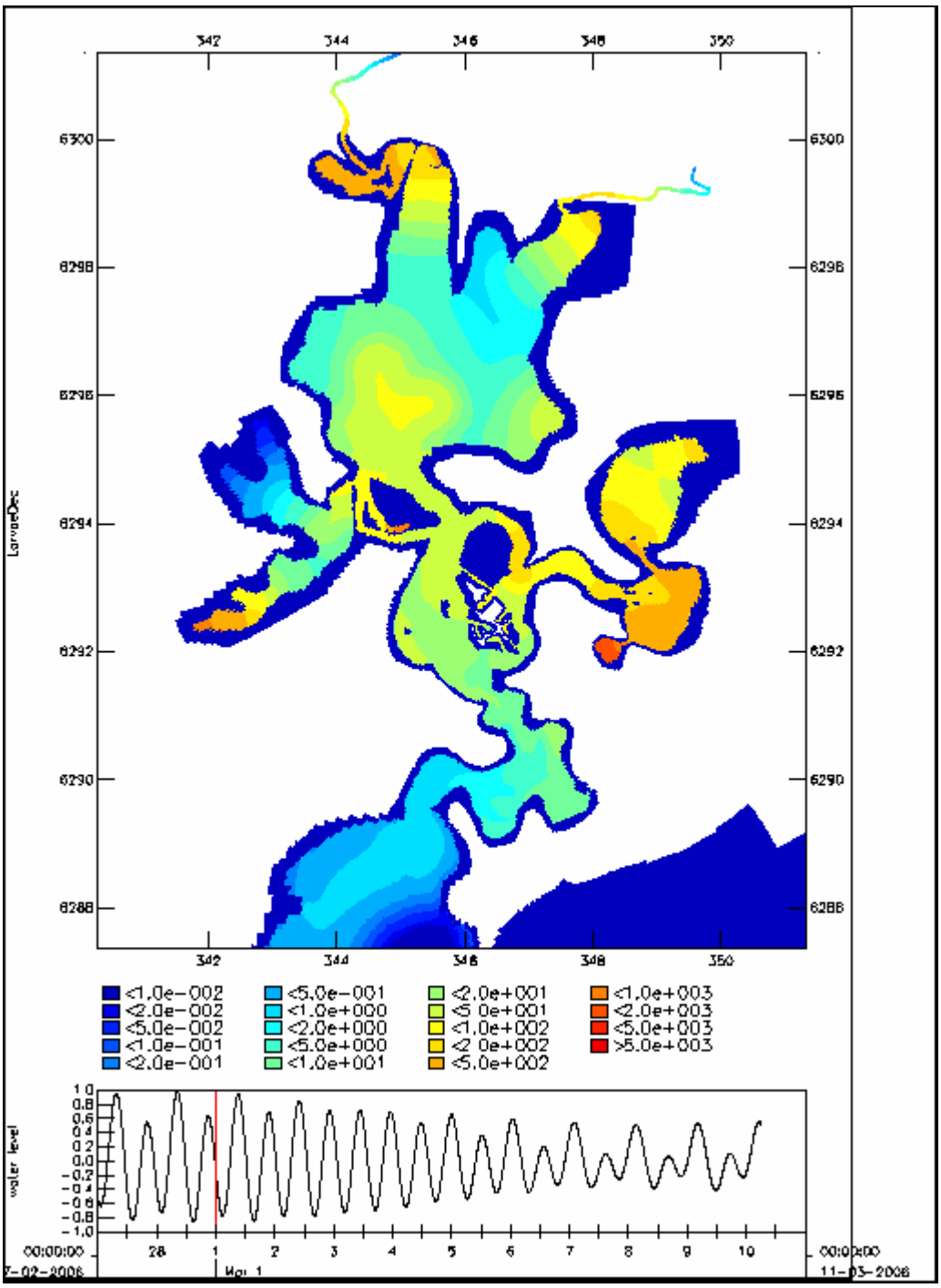


Figure 36: Larval transport - decaying tracer modelling (m^{-3}) (00:00 01/03/06)

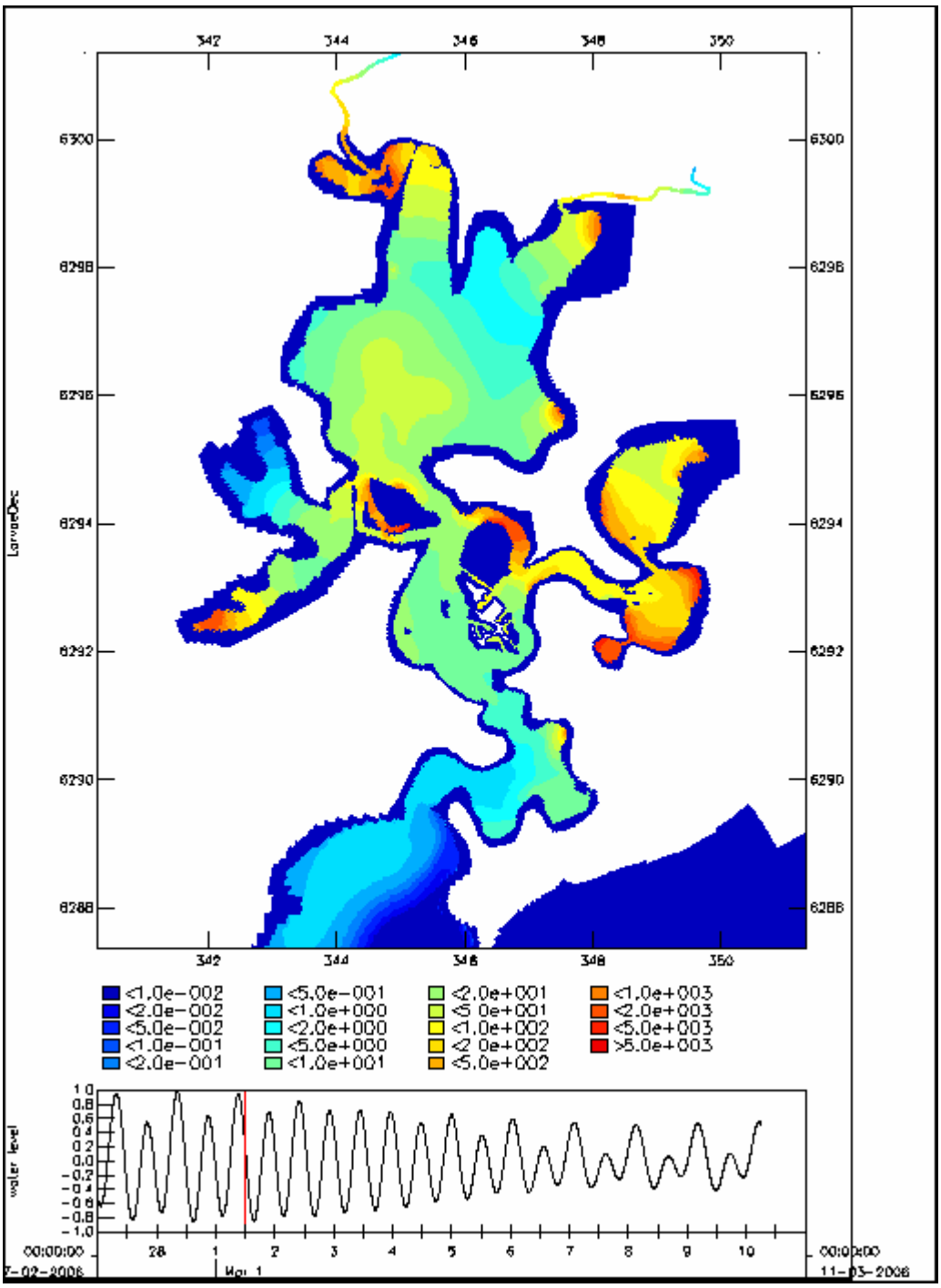


Figure 37: Larval transport - decaying tracer modelling (m^{-3}) approximate end of the last larvae release period (12:00 01/03/06)

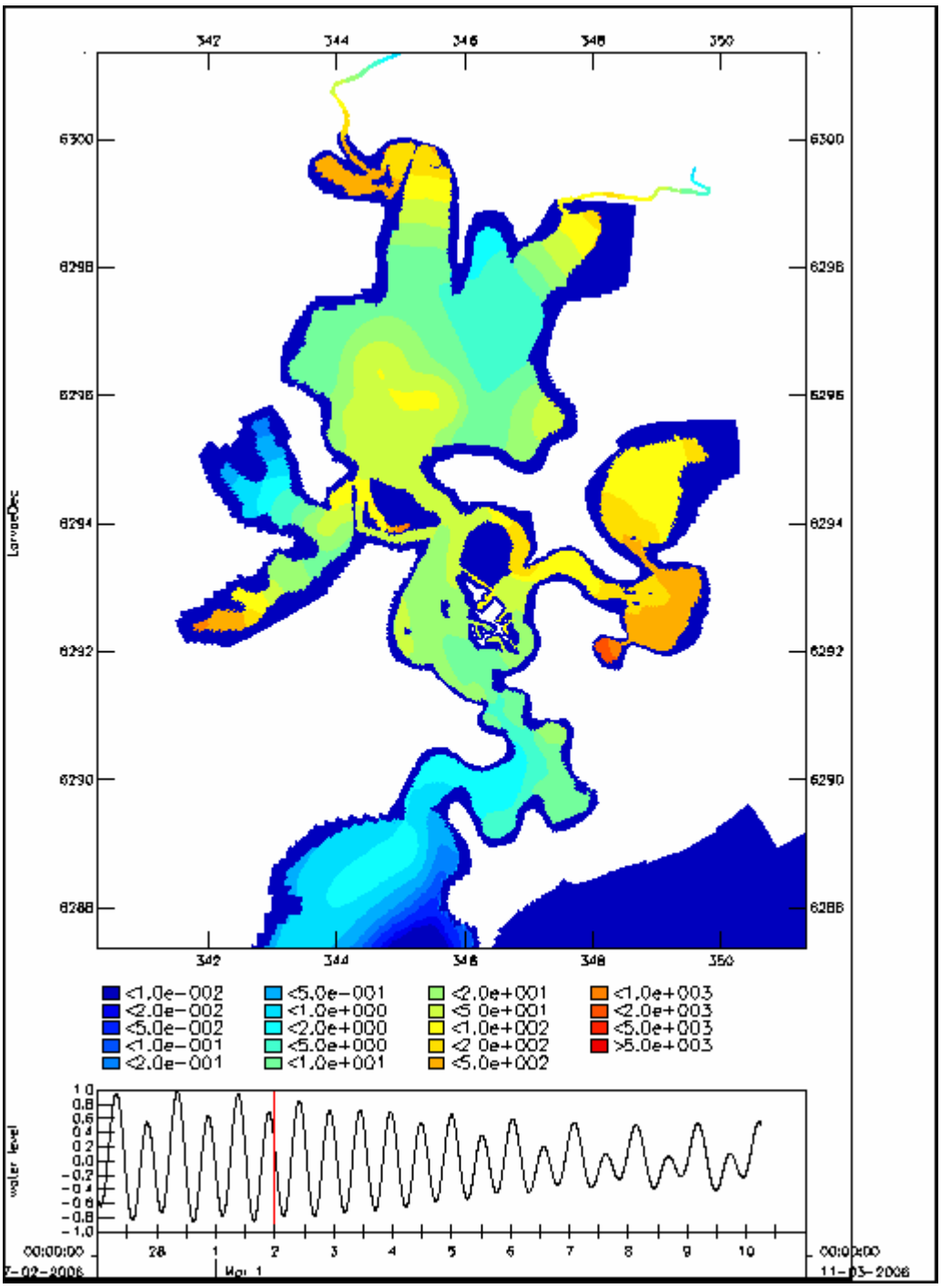


Figure 38: Larval transport - decaying tracer modelling (m^{-3}) (00:00 02/03/06)

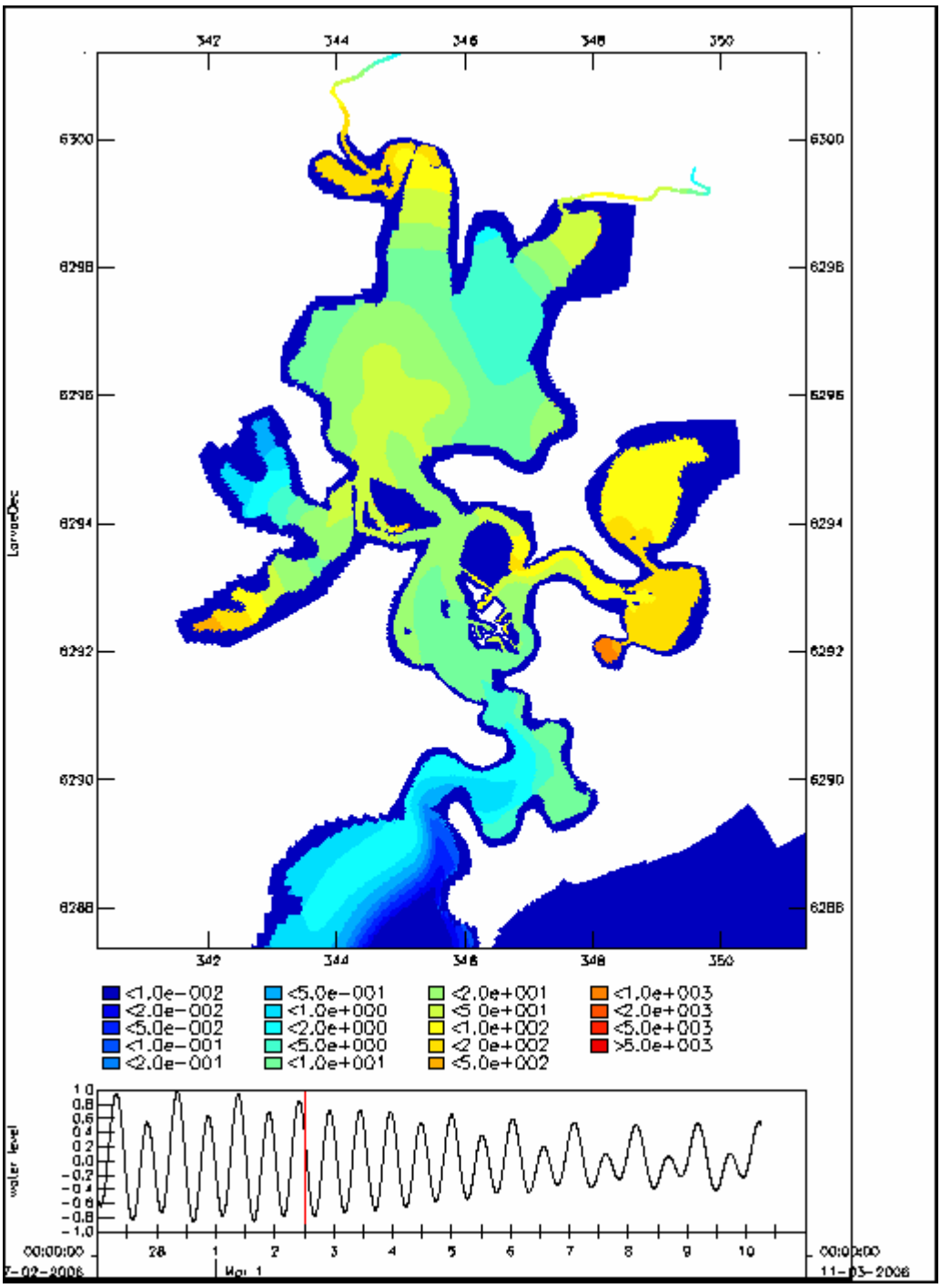


Figure 39: Larval transport - decaying tracer modelling (m^{-3}) (12:00 02/03/06)

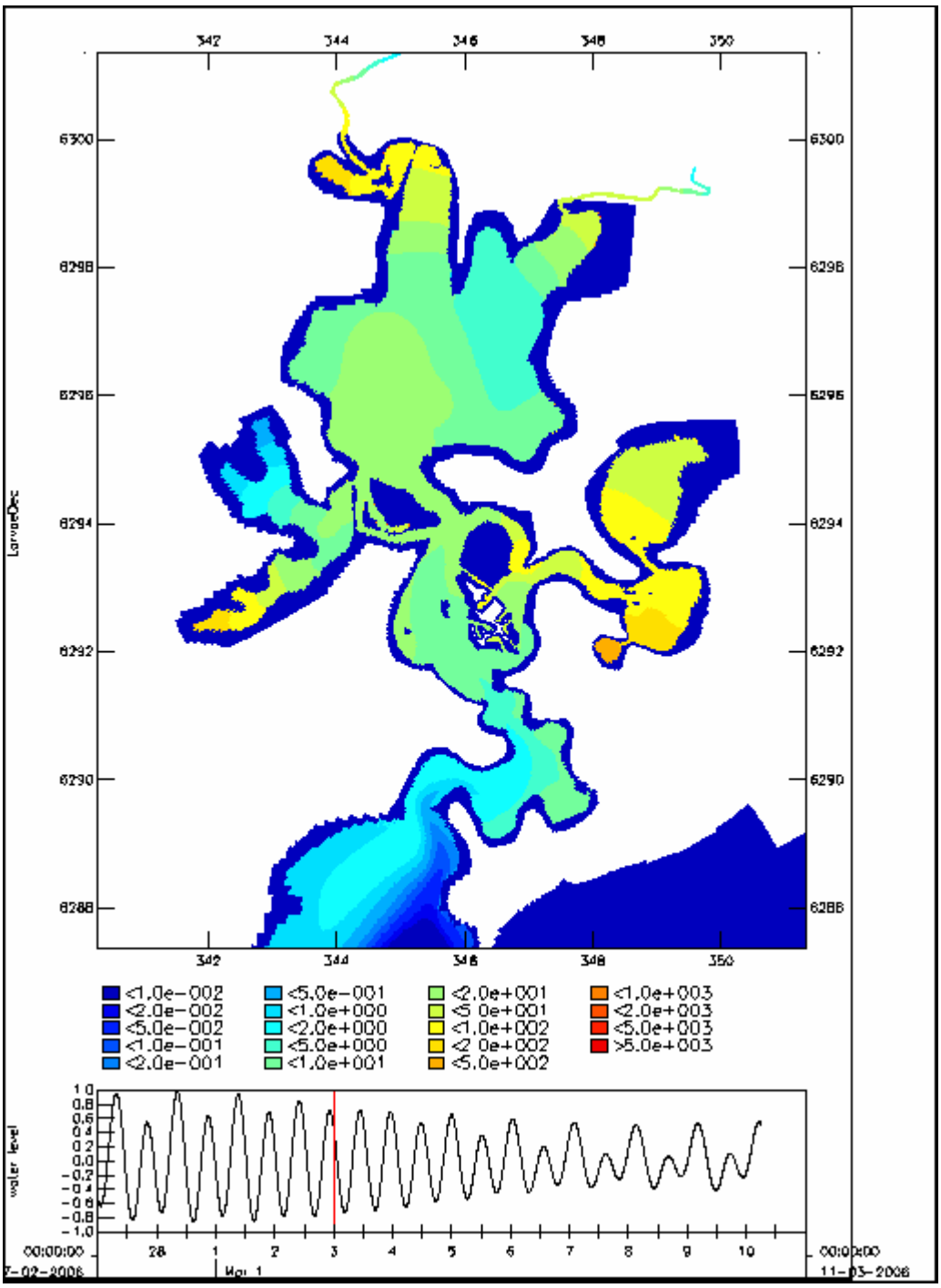


Figure 40: Larval transport - decaying tracer modelling (m^{-3}) (00:00 03/03/06)

Figure 41 indicates that larvae are still abundant (< 50m^{-3}) in Brisbane Water 4 days after the end of the last larval release period. Figure 42 indicates that by the end of the 2-week simulation period the concentration of larvae has decreased considerably though some persist (< 0.2 m^{-3}).

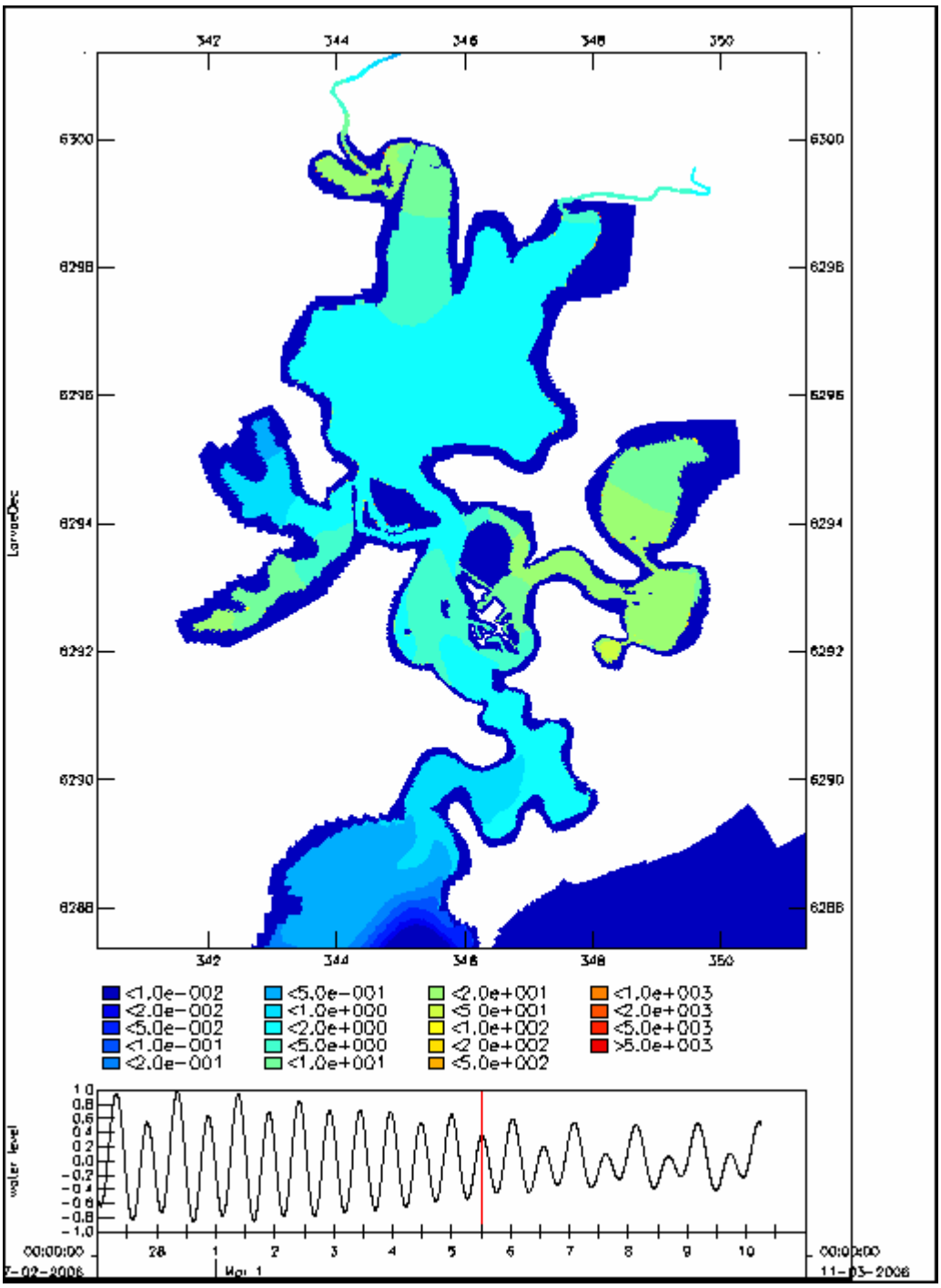


Figure 41: Larval transport - decaying tracer modelling (m^{-3}) (12:00 05/03/06) 4 days after end of the last larvae release period

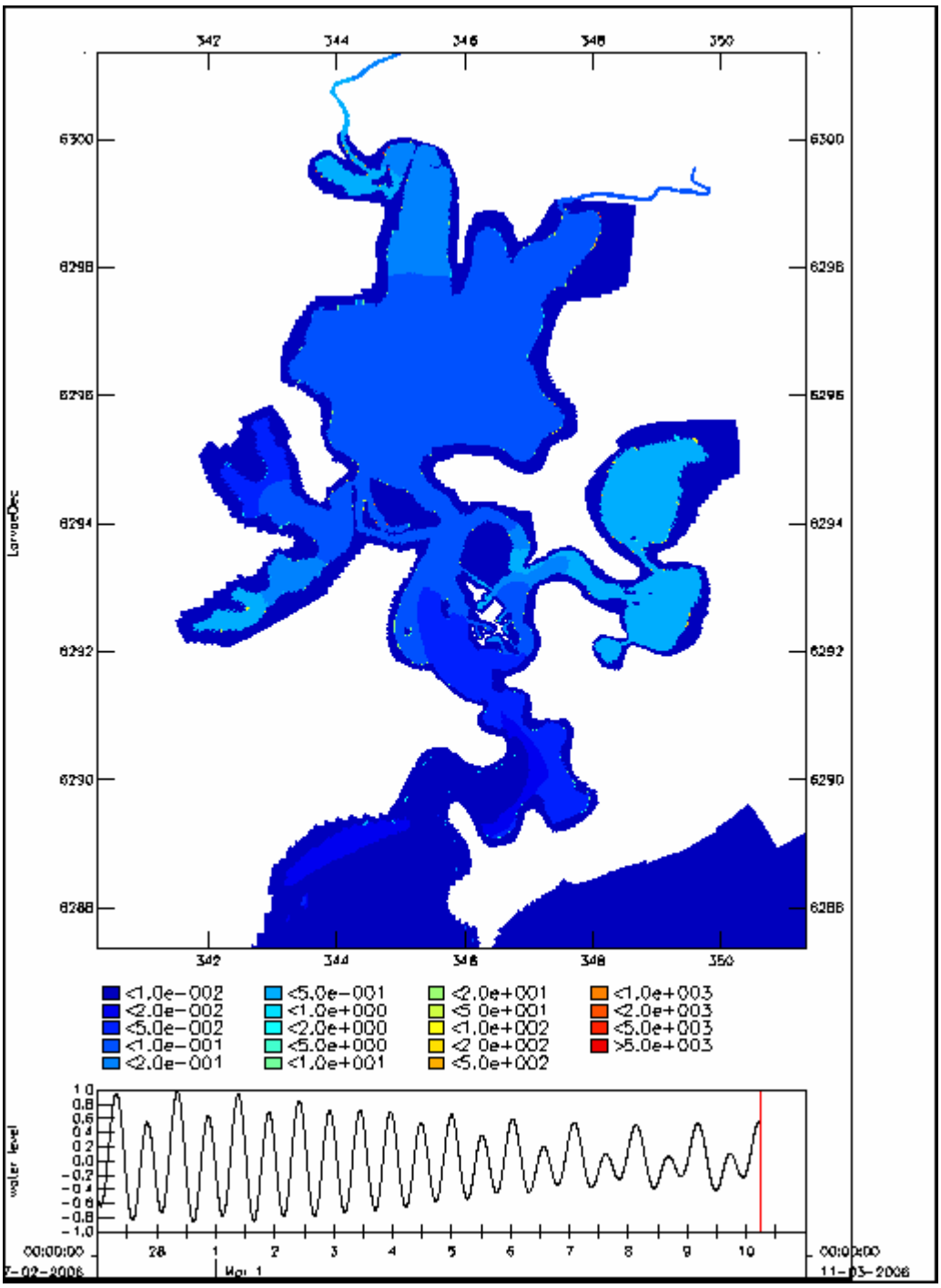


Figure 42: Larval transport - decaying tracer modelling (m^{-3}) (06:00 10/03/06) end of 2 two-week simulation (9 days after end of the last larvae release period).

4. Discussion

4.1 Zooplankton and crab zoeae within Cockle Bay

This study has shown that crab larvae (zoeae), which arise from burrowing crab species within a saltmarsh-mangrove complex in Brisbane Water, are released in large numbers on the all but the first day of a spring tide event in February 2006. It is likely that the two crab species that are abundant in such habitats (e.g. *Helograpsus haswellianus* and *Sesarma erythrodactyla)* have acted as the source for these zoeae. This is consistent with work carried out further south in NSW, at a saltmarsh in Botany Bay, which also showed that crabs release large quantities of larvae after inundation of saltmarshes during spring tide events (Mazumder et al. 2006). Although the present conclusions are based on a single spring tide event, the strong parallels with the results of Mazumder et al. (2006) for each spring tide event throughout the year, strongly implies that such release is likely to occur year-round in Brisbane Water. The above is also consistent with work in similar systems elsewhere (Dittle and Epifanio, 1990, Dittle *et al.*, 1991). Thus, in North America, larvae of the fiddler crab *Uca* spp. are flushed from the saltmarshes soon after hatching, usually occuring when ebb tides are at their maximum (Christy and Stancyk, 1982).

A maximum concentration of 203.7±15.23 (mean and se) crab zoeae was recorded in the present study, representing the average of 3 replicate samples in one site among seagrasses adjacent to the saltmarsh-mangrove complex on the ebb tide on the 3rd day of the spring tide. Mazumder (2004) was able to sample the zoeae exported directly from the saltmarsh and reported a mean abundance (for all months) of 2124.63 m^{-3} for Towra Point, Botany Bay. Mazumder (2004) sampled the saltmarsh contribution from a break in the levee (or runnel) between the saltmarsh and the mangroves (Figure 43), which he described as a "fixed point from which saltmarsh inputs and outputs could be assessed" (Mazumder, 2004). For September 2002, Mazumder (2004) recorded the mean concentration of crab zoeae from saltmarsh (6485.75±37.86 se), mangroves (47925±4.53 se), seagrasses (132±11.01 se) and the bay (79.25±3.12 se) (Figure 44). In the present study, the bay samples were taken at a distance of more than 300 m from the saltmarsh, which is approximately twice as far as the bay samples of (Mazumder, 2004) and so should not be compared. However, the seagrass meadow samples can be compared and the results are similar to the Mazumder (2004) results from Towra Point seagrass meadows (203.7±15.23 se c.f. 132±11.01 se).

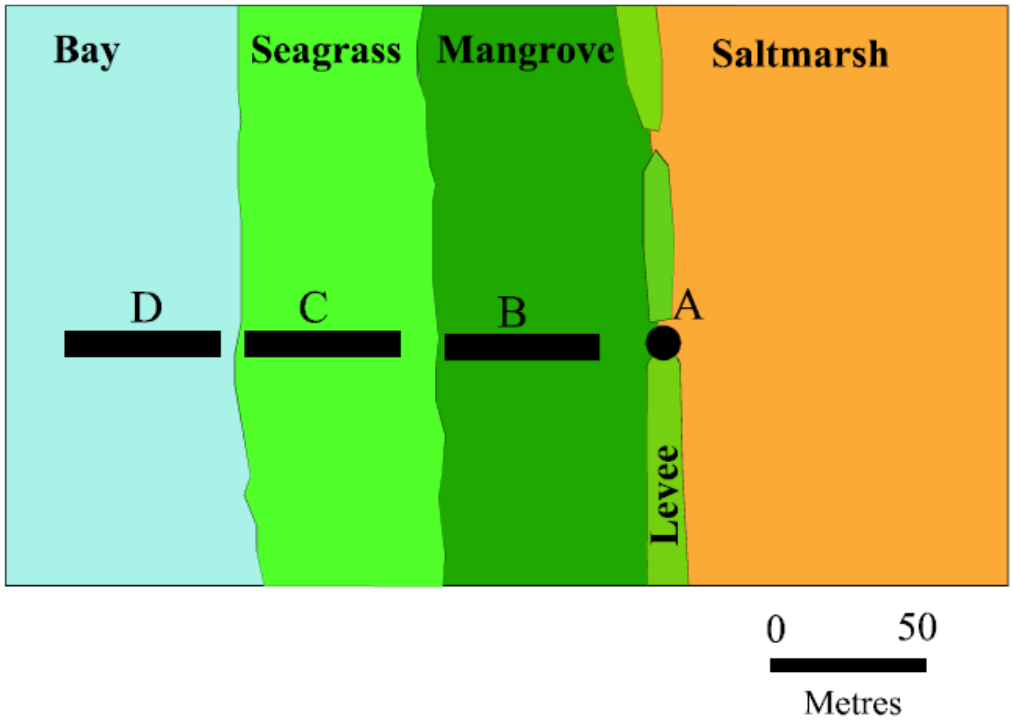


Figure 43: The position of a transect in saltmarsh, mangrove, seagrass and bay habitats for sampling zooplankton at Towra Point, Sydney, NSW. (Mazumder, 2004)

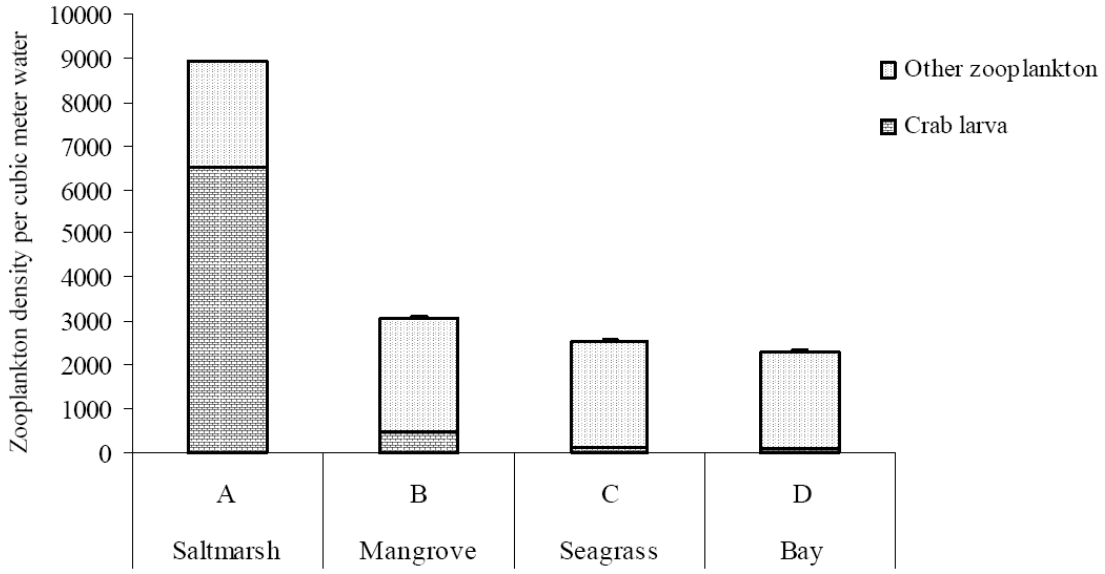


Figure 44: Mean (+SE) zooplankton abundance in different locations towards the Bay at Towra Point in September 2002. (Mazumder, 2004)

Our work also showed that the concentrations of very small and planktonic stages of gastropods (microgastropods) increased during the spring tide event (data not shown). This also parallels the results by (Mazumder *et al.*, 2006, Mazumder, 2004), which showed that saltmarsh gastropods (*Assiminea tasmanica*, *Salinator solida, Littoraria luteola and Ophicardelus sp*.) export larvae in almost all months of the year.

The densities of copepods, including their nauplii (data not shown), were higher on the flood than ebb tides, which supports the contention by Mazumder et al. (2006) that saltmarshes, in contrast to crab zoeae and micro gastropods, can act as a sink for copepods

4.2 Fish and feeding within saltmarsh at Cockle Bay

A total of 12 fish species, comprising 612 individuals, were collected using a variety of sampling gears on the ebb tide from saltmarsh habitat. *Ambassis jacksoniensis* (the Port Jackson glassfish) was by far the most abundant, followed by the hardyhead (*Atherinosoma microstoma*). These two species, like four of the remaining species (blue eye *Pseudomugil signifer*, the hardyhead *Craterocephalus mugiloides* and three gobies, *Mugilogobius paludis, Pseudogobius olorum* and *Redigobius sp*.), reach only a small size, i.e. less than 70 mm TL. Small numbers of the juveniles of the mullet (*Liza argentea*) and single individuals of the two sparids (*Acanthopagrus australis* and *Rhabdosargus sarba*) and the silver biddy (*Gerres subfasciatus*) were recorded, while large individuals of the toadfish (*Tetratcenos hamiltoni*) were also captured. The above species are representative of fish faunas in estuaries in NSW (Allen *et al.*, 2002) and have been previously recorded in Brisbane Water (University of Newcastle, unpubl. data). The fact that such large numbers of fish are found in such a transient saltmarsh habitat, which is inundated by water for ca 3 days on each spring tide event, highlights the importance of this habitat type to these fish species (Thomas and Connolly, 2001). This situation is similar to that recorded in north-eastern Australia, in which juveniles were relatively abundant in the tidal creeks adjacent to mangrove habitats, which contained high densities of crab zoeae upon which they fed (Robertson *et al.*, 1988).

The crab zoeae that were released in large numbers on the second and third days of the high tide sequence formed the basis of the diets of three of the 12 species of fish that utilised the saltmarsh

habitat at this time. Thus, the majority of individuals of *A. jacksoniensis* and *A. microstoma,* which were abundant in the saltmarsh environment, and of the small goby *Redigobius* sp., of which only two individuals were captured, consumed either mainly or exclusively crab zoeae. The focus by *A. jacksoniensis* on crab zoeae is similar to that observed by Mazumder *et al*. (2006) in Botany Bay and in a Queensland saltmarsh (Thomas and Connolly, 2001). The main source of the crab zoeae in the present study is likely to be *Sesarma erythrodactyla*, which reproduces mainly in summer (Mazumder 2004).

Apart from crab zoeae, other taxa that were ingested by fish included foraminiferans and insects (*P. signifer*), polychaetes (*P. olorum* and *G. subfasciatus*), copepods (*C. mugiloides*), plant material (*R. sarba*) and detritus (*L. argentea* and *P. olorum*). Such results concur with those for the same or similar species in other estuaries (Morton *et al.*, 1987, Mazumder, 2004). Gastropods were recorded in only two fish species and in negligible amounts, which concurs with the results reported by (Bell *et al.*, 1984). However, crabs contributed nearly 85% to the volume of the diets of the toadfish *T. hamiltoni* with, on one occasion, an individual being captured with a crab (*H. haswellianus)* in its mouth, which shows that adult crabs can also act as an important food source for estuarine fish.

Although Mazumder also recorded crab zoeae in the guts of *L. argentea*, unlike the results of our study, the individuals in the present study were much larger, i.e. ca 100 mm vs 50 mm, and thus are not directly comparable. It is relevant that other mugilids undergo size-related changes in diets, with smaller individuals feeding more broadly on small invertebrates, such as crustaceans, in comparison to larger individuals, which consume mainly detritus (Platell *et al.*, 2006).

A small size-related change was also observed in *A. jacksoniensis*. Thus, while small it fed nearly exclusively on crab zoeae and, once this species exceeded 50 mm in size, it began to broaden its diet to include copepods and also more benthic prey, such as polychaetes and detritus. Such size-related shifts are common in fish species and can reflect changes in mouth morphology and feeding behaviour, as well as the environments in which fish are found (Platell *et al.*, 2006).

The wide diversity of prey ingested by the 12 fish species in the saltmarsh environment, when accompanied with MDS ordination and ANOSIM tests of significance, demonstrates that these fish species show a strong partitioning of the food resources in the saltmarsh habitats, with the exception of those three species that ingest mainly crab zoeae. In this case, any potential for competition for this food resource would be ameliorated by its superabundance at the time.

4.3 Drogue tracking

The drogue tracking investigation indicated that some saltmarsh areas were isolated from others and larvae released from these locations would not be dispersed far beyond the shore. This would present challenges for the management of these habitats because it suggests that they may be particularly vulnerable to disturbances and have little opportunity to recover. Should these isolated habitats become significantly degraded they could not be assisted in recovery by the recruitment of new stock from other areas of the estuary. Therefore, these habitats would require special consideration for protection and conservation. However, the decaying tracer advection-dispersion simulations partly contradicted these findings (see next section).

4.4 Advection-dispersion simulations

The advection-dispersion simulations indicated that the hydrodynamics of the system would probably transport the larvae to most corners of the estuary. Indeed, these simulations suggested that the larvae would be exported beyond the boundaries of the estuary and be able to colonise other habitats and the larvae would undoubtedly be prey for fishes beyond Brisbane Water. The modelling demonstrated that hydrodynamic processes, alone, are sufficient to provide larvae the opportunity to recolonise degraded or impacted saltmarsh and mangrove habitats in Brisbane Water.

4.5 Conclusions

The limitations in the present study would preclude the reaching of sound conclusions on the patterns of dispersal of crab larvae exported from saltmarshes. Thus, the advection-dispersal simulations were a first pass at this system and did not fully understand and incorporate the behaviour of the larvae into the model. For example, some zooplankton are known to migrate through the water column to either avoid the sunlight or to swim towards it. There may be other environmental cues that trigger vertical migration. Research on the spatiotemporal distribution of *Callinectes sapidus* larvae indicates that they are concentrated near the bottom of the sea bed (Reyns *et al.*, 2006). Consideration of the movement of currents at differing depths needs to be considered in the development of simulation models. Differences in the spatiotemporal distribution of *Helograpsus haswellianus* and *Sesarma erythrodactyla* in the water column are not known. Further work could also be conducted to examine the influence of different wind regimes on larval transport.

This work does, however, provide a good foundation to progress our understanding of connectivity processes within Brisbane Water and to extrapolate this understanding to other estuarine environments in NSW. It can be used towards assessment of management decisions regarding conservation effort and future planning for Brisbane Water and its catchments. This work demonstrates the importance of saltmarsh and their resident crabs in the supply of food to certain fishes, which in turn are important links in the foodweb of temperate estuaries in NSW.

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