

## FATE OF CORAL AND FISH LARVAE AROUND CORAL REEFS

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This study focuses on the fate of coral and fish larvae in the central region of the Great Barrier Reef of Australia. Specifically the study focuses on the role of hydrodynamics in the recruitment of coral and fish larvae on individual reefs, in order to develop predictive tools for better management of these living resources.

AIMS has collected extensive field data on the physical oceanography of the Great Barrier Reef during the last 15 years. These data have been combined with the results of laboratory and modeling studies to describe water circulation in a topographically complex environment. This circulation is three dimensional and complex. The 'far-field' circulation around an individual reef is not uniform but has considerable horizontal shear generated by the presence of a matrix of reefs. Field and model studies reveal significant residual currents that result from the non-linear interaction of the instantaneous currents driven by the wind, the East Australian Current and the tides, with the complex bathymetry. Shadow zones are formed by the bathymetry where retention is high, and these are distributed non-uniformly within areas of rapid flushing. The data set is very complex and requires visualisation through computer animation; this was done using IBM Data Explorer.

Currents around individual reefs are strongly three-dimensional. Results of field, laboratory and numerical studies are used to describe the three-dimensional circulation in barotropic island wakes. Bottom friction generates a closed circulation characterised by a strong upwelling (typically  $10-20 \text{ m hour}^{-1}$ ) in the bulk of the eddy and an even larger downwelling velocity in a narrow zone around the edges of the eddy. This downwelling exists at the solid boundaries of the island and also all along the separation streamline. This circulation can be realistically modelled numerically provided the intense turbulence in the free shear layer is explicitly parameterized (Figure 1).

This secondary circulation aggregates buoyant material, such as coral eggs, along the edges of the eddy even in well-mixed coastal waters. Computer animation using IBM Data Explorer of the distribution of coral eggs around a coral reef following a mass spawning episode shows the formation of a plume spreading away from the reef with the prevailing net currents, with great patchiness within the plume, together with topographically-induced retention within the reef-lagoon system. These data are used to calibrate a small-scale advection-dispersion model for the fate of larvae for the first few days after spawning (Figure 2). The model generally underestimates the patchiness of the distribution of coral larvae, because of the inability to explicitly parameterize topographically-induced processes leading to the formation of topographically-induced, very small-scale (m to tens of m) fronts around a salient topography.

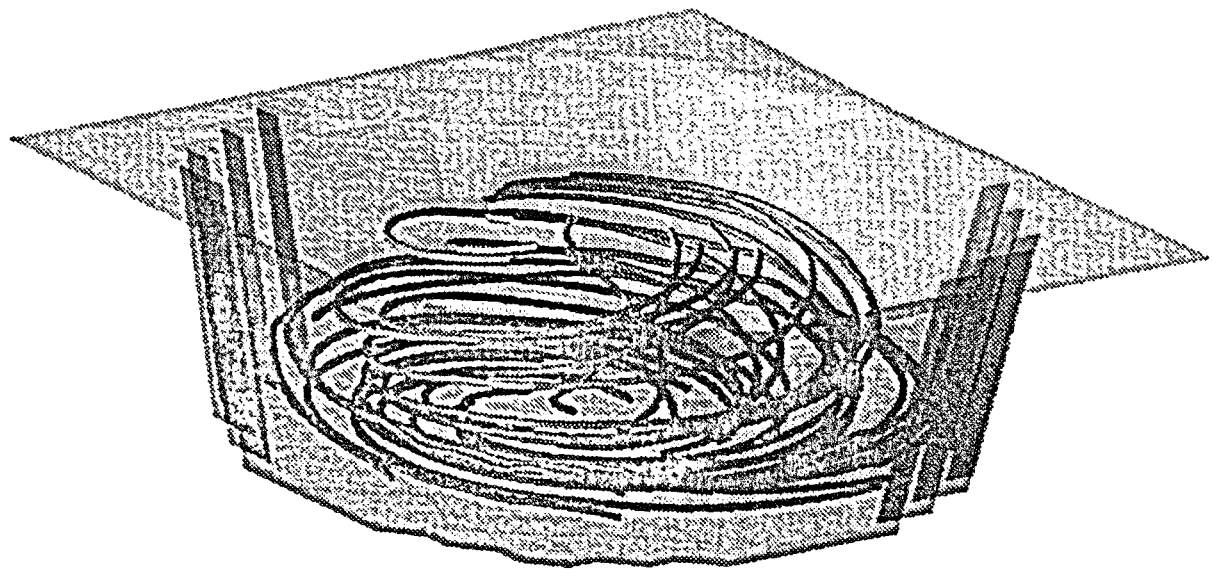


Figure 1. Trajectories of non-buoyant particles released near the bottom in an eddy in shallow waters. The eddy is 2000 m wide and 5 m deep.

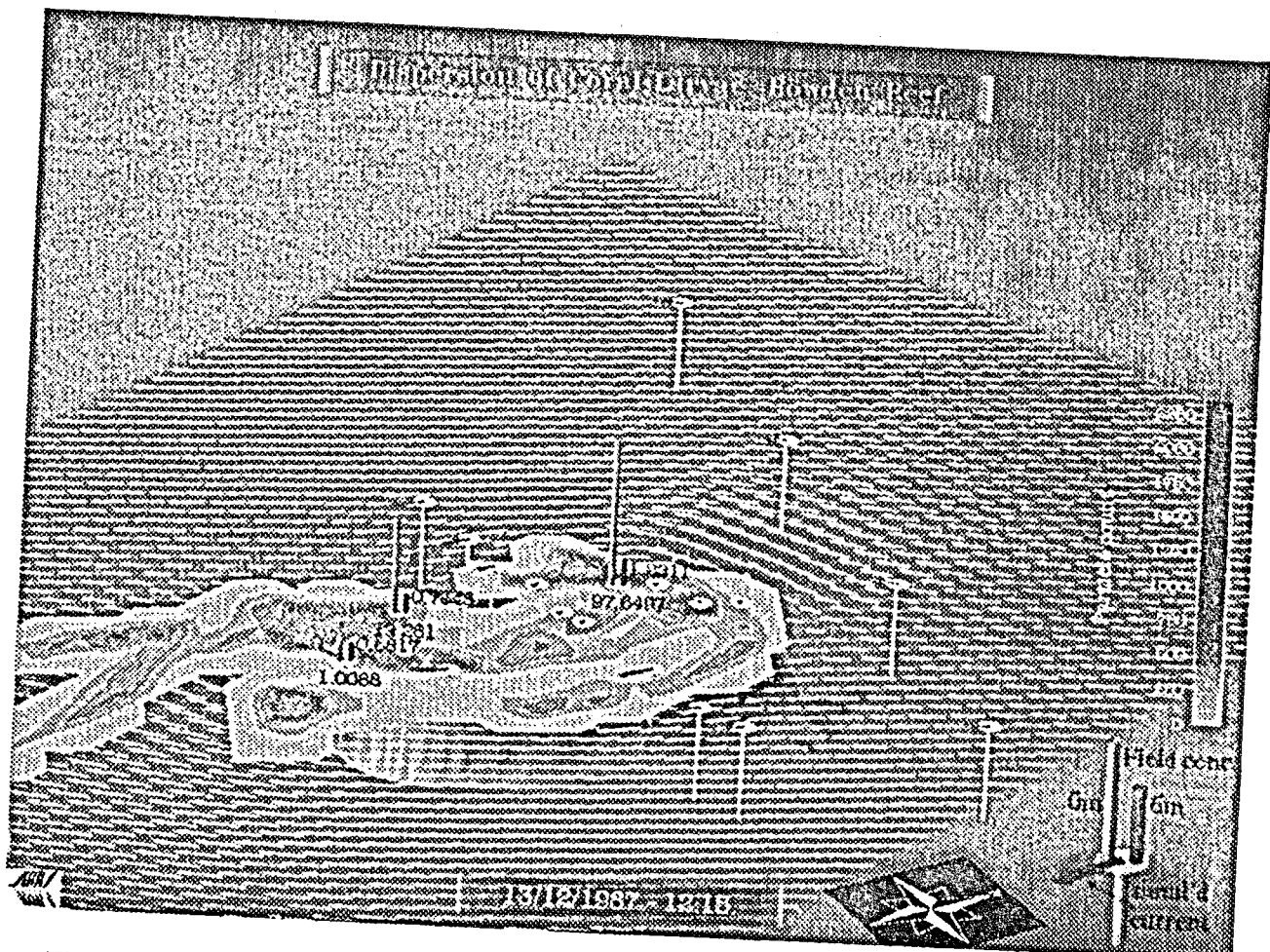


Figure 2. Three-dimensional visualisation of the bathymetry of Bowden Reef, Great Barrier Reef, observed (bars) instantaneous distribution of coral larvae at sampling points (located by pins) at two depths (left= near the surface, right= at 6 m depth) and predicted plume of coral larvae at the same time following mass spawning.

Observed and predicted plumes of coral larvae after mass spawning show great patchiness and qualitative agreement, though quantitative agreement is poor. One reason for this is that the model under-estimates the patchiness. Another reason is the assumption of no inflow of larvae from reefs further upstream. Computer animation of the observed and predicted data sets suggests that much of the discrepancy between the model and the data may be due to this assumption. Over the periods of two to three weeks necessary for coral larvae to settle, coral recruitment on individual reefs appear to result both from self-recruitment and from the influx of larvae from reefs upstream.

For a particular reef, the level of self-recruitment of coral larvae, or alternately the level of recruitment of larvae from other reefs, is thus dependent on the small-scale hydrodynamics controlling the dispersion and retention of larvae around the reef. This process is amenable to modeling.

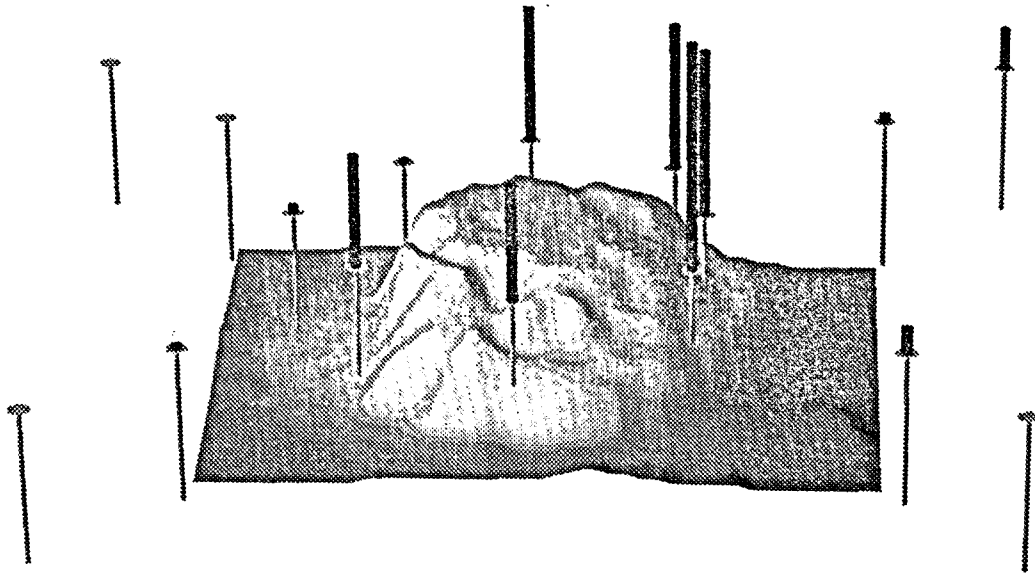
The recruitment of fish larvae can also be expected to be influenced by hydrodynamic advection of the passive egg and larval stages. However, one can expect large differences from species to species due to their different swimming behaviour and depth selection. To study these processes, pre-settlement stages of reef fishes, including large pelagic juveniles, have been sampled by automated, submersible light-traps deployed over several seasons at different distances from reefs of different size, shape and cross-shelf position. These data have been used to determine if fish recruitment is due to movement of the fish larvae between coral reefs, and if the spatial patterns of larval supply are controlled by the water circulation around the coral reefs. Larval abundance at all taxonomic levels varies greatly in space and time, with total diversity approaching 1000 taxa. This mass of information necessitates computer visualisation techniques to help reduce some of this complexity to manageable proportions.

Daily sequences of catch per unit effort from some of these reefs have been animated with IBM Data Explorer. The two main study sites were Bowden Reef, a 6 km wide coral reef with a lagoon, and Helix Reef, a 1 km wide platform reef with no lagoon. Both reefs are relatively isolated from other reefs. Traps at different distance from Helix Reef show pelagic juveniles moving through the far-field in patches (Figure 3). Those belonging to benthic taxa (e.g., Pomacentridae) concentrate near the reef, especially on the downstream end. Complementary patterns, e.g., avoidance of shallow water, are shown by some pelagic taxa (e.g., Nomeidae). When sampled and analysed on finer scales, this downstream area shows sharp differences in assemblage structure over 500 m with benthic taxa aggregated very close to the reef at night. Some long-term retention may be possible in these areas.

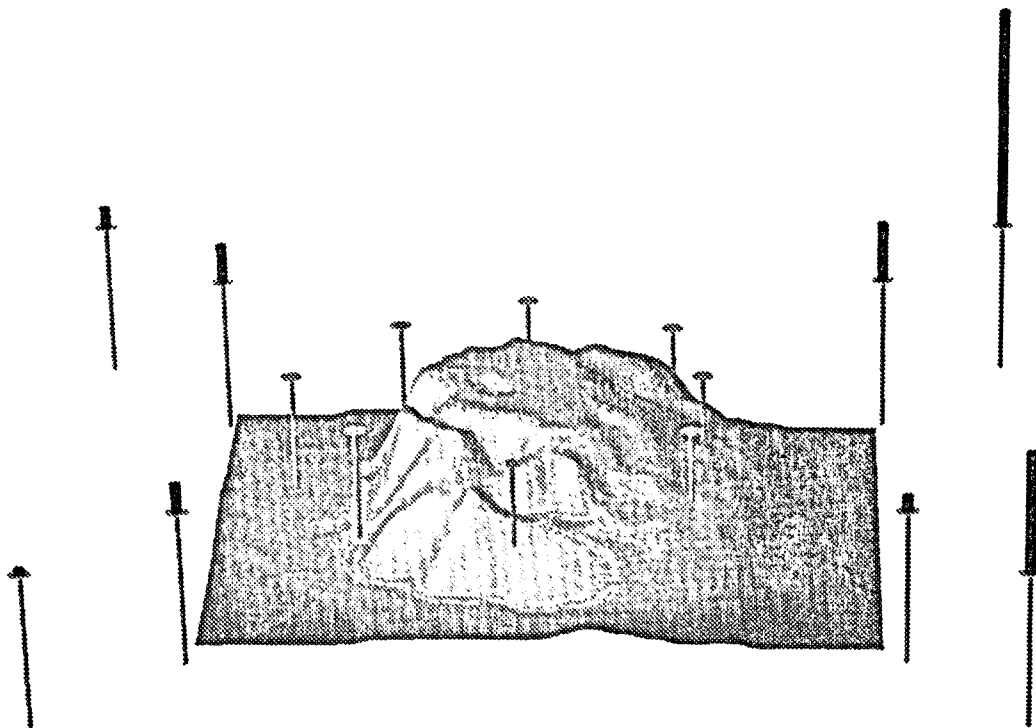
The second example from Bowden Reef, a much larger reef, shows recurrent concentrations of pre-settlement stages of benthic taxa on opposite ends of the reef where tidal interactions produce quasi-stationary eddies (Figure 4). High, albeit temporary, concentrations in these places contrast with consistently low catches elsewhere around the reef indicating that larval supply is influenced, at least initially, by oceanographic retention features in the near field.

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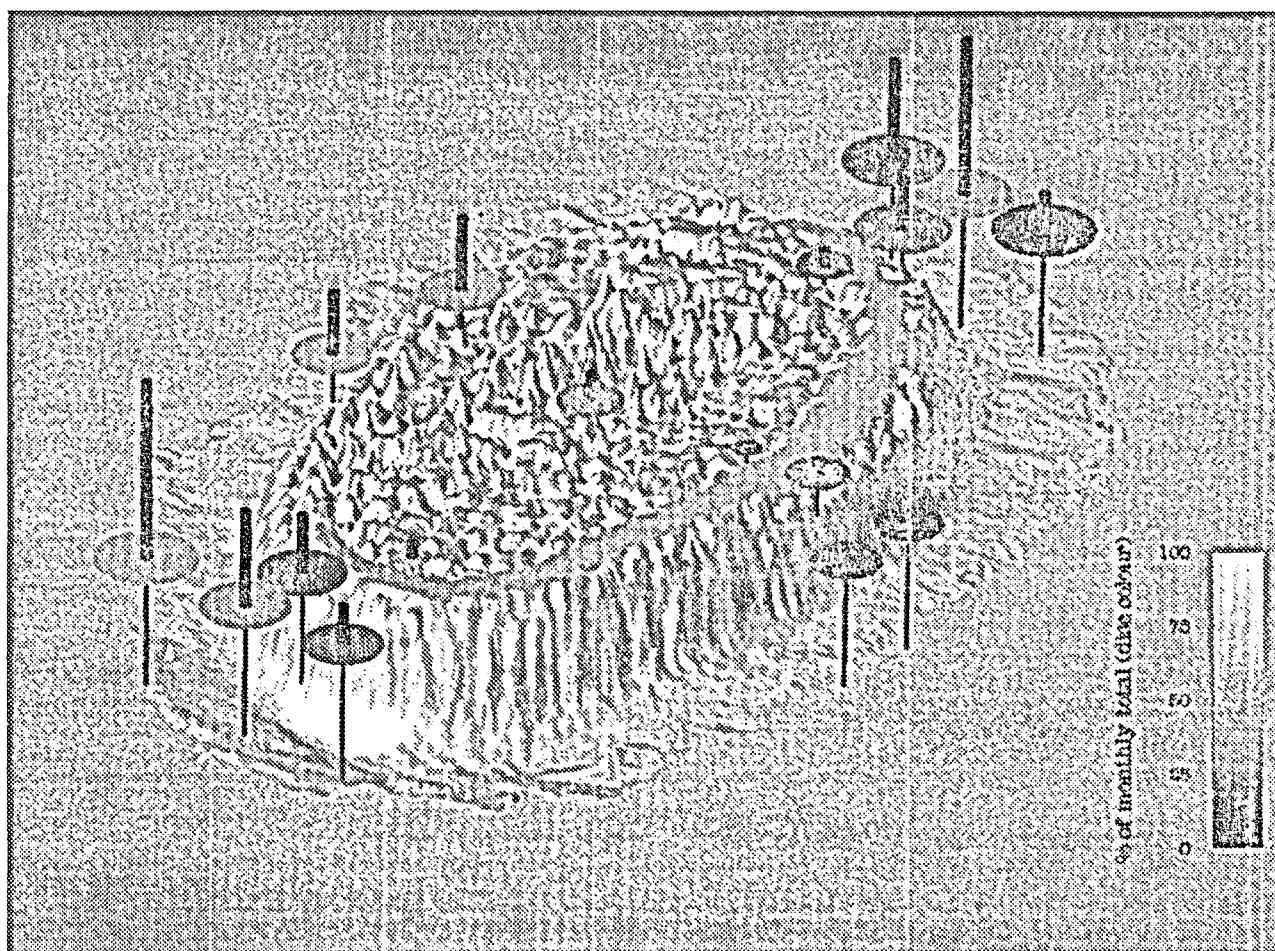
**Figure 3.** In 1989/90, 16 light-traps were anchored in three shells around Helix Reef (800 m diameter): 8 traps within 100 m of the reef crest, 4 traps at 2 km, and 4 traps at 6 km. The perspective in this figure looks northwards, against the mainstream current; tidal flows are perpendicular. All traps fished for 3 hr per night and were cleared daily.



Above: Catches on 3 December 1989 of *Chromis tripteralis*, a benthic fish that is attracted to the reef. Low patchy catches in the far-field contrast with consistently high abundance at all near-field locations except the northwest sector. The greatest catch on that night was 54 individuals and all catches are expressed on the same linear scale.



Above: Catches on 31 January 1990 of *Psenes arafuensis*, a pelagic fish that avoids the reef. Consistent presence at all far-field locations contrasts with the complete absence of this species in the near-field. The tallest bar represents a catch of 194 individuals.



**Figure 4.** In 1992/3, 17 light-traps were anchored around the perimeter and inside the lagoon of Bowden Reef (6 km long x 3 km wide) to monitor fine-scale patterning in larval supply and penetration of fish across the reef crest. The perspective in this view is towards the northwest (the long axis of Bowden is aligned north-south) and against the mainstream current. Reversing tidal flows are almost north-south and the interaction of the two flow regimes produces quasi-stationary eddies at the two ends of the reef. Traps anchored in these locations consistently have high catches relative to those on the windward front of the reef (southeast) and inside the lagoon. These differences are submerged in this image because it is a composite of the total catch of all damselfishes from 17 January 1993 and the patterns of individual species are only loosely correlated. On this day, the greatest catch in any trap was 219 individuals and all other catches are scaled accordingly. Unlike the previous representations (Figure 3), this image contains two additional quanta of information about the catches. The size of the disk at the base of each column represents the total catch at that site pooled over the fishing period, usually 10 days around the new moon. The colour of these disks (not so evident in grey-scale) fluctuates each day to indicate the proportion of the monthly catch represented by the daily total. All of this information on absolute and relative abundance patterns can be viewed repeatedly in an animated sequence to explore spatial and temporal coherence in these complex data sets, which is especially useful when superimposed against the predicted flow regime.