DISPERSAL IN STRATIFIED ENVIRONMENTS – A MODELING STUDY OF BLACK BREAM LARVAE IN A SALT-WEDGE ESTUARY

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For fish species with a pelagic larval stage, transport from the spawning ground to juvenile nursery habitat is a critical transition in their life history. Although the upper estuary may provide higher turbidity and food supplies, which can be beneficial to early survival, larvae must also disperse to suitable benthic habitat in which to settle. Hydrodynamics, egg buoyancy, and larval behaviour may all influence dispersal. In estuaries, especially where strong stratification in salinity is present, large velocity variations can occur over short vertical distances. Thus for small organisms in estuarine environments, hydrodynamics provides a large physical influence on their transport. However, larvae are not passive particles, having the potential to exert considerable behavioural control over their dispersal even in the presence of strong hydrodynamic influences. This study examined the balance between hydrodynamics and larval behaviour in determining the dispersal patterns of larvae of black bream (*Acanthopagrus butcheri*), an estuarine dependent species endemic to southern Australia. The study utilised a biophysical modelling approach, informed by empirical studies in both the field and the laboratory, to explore the dispersal of black bream larvae in the Mitchell River sub-estuary, part of the Gippsland Lakes in South-eastern Australia.

1 INTRODUCTION

Numerical biophysical modelling of the dispersal of eggs and plankton has become an important tool for understanding population dynamics of fishes with a planktonic larval phase. Modelling studies have identified the dispersal-related physical drivers for successful recruitment in many species[1]. However, larval behavior [2] and the ontogeny of behavior [3] can also be important factors in pelagic larval dispersal and should be included in biophysical dispersal models. Numerical biophysical modelling has been widely applied in oceanic regions and large well-mixed estuaries

Many estuaries in southern Australia, southern Africa, and other microtidal locations are classified as strongly stratified due to the dominance of geomorphic and environmental factors, which tend to suppress the mixing of fresh and salt water. Applying biophysical modeling in such regions is desirable, as they are spawning grounds for many fishes and bodies share many of the same features as coastal seas and well-mixed estuaries. However, they are subject to much greater vertical variation in salinity, temperature, turbidity, and water velocity than coastal seas. This creates unique challenges when modelling dispersal in such an environment.

Gippsland Lakes is a large, micro-tidal, salt-wedge estuary in southern Australia. Black bream are an estuarine dependent fish species, endemic to the Lakes. The population structure suggests high inter-annual variability in recruitment, which may be related to variability in freshwater flows [4]. Adult black bream utilise the upper estuary [5] to spawn pelagic eggs during the spring and early summer [6]. For fish with a pelagic larval stage, like black bream, transport from the spawning ground to juvenile nursery sites is a critical transition in their life history. This study explores the relative influence of hydrodynamics and larval behaviour in determining the dispersal patterns of black bream eggs and larvae in the Mitchell river sub-estuary, a strongly-stratified tributary of the Gippsland Lakes.

2 METHODS

This study integrated field monitoring of hydraulics and water quality of the salt-wedge, behavioral experiments in the laboratory and dispersal numerical modelling, both hydrodynamic and biophysical.. A summary of the methods is explained below andfull methods including details of model development, calibration and verification can be found in Gee [8].

Five monitoring sites were established along the Mitchell River. At each site, salinity was measured from the surface at 0.5m depth increments on 8 dates from September to December 2008. 3-dimensional velocity measurements were made at a cross-section at each site on four occasions during this period, under a range of flow conditions from 3 to 41 m^3/s. At 3 sites, water levels were monitored from May 2008 to January 2009 at 30-minute intervals.

Four laboratory experiments were conducted on black bream (*Acanthopagrus butcheri*) larvae aged 13 to 46 days old to determine swimming ability, and any evidence of depth preference or response to a halocline; and to develop an age-size relationship for *A. butcheri* larvae. Swimming ability was determined from critical swimming speed. Halocline response was tested in a vertical flume which contained a water column which was either fully fresh, fully saline, or salinity stratified. Depth preference was determined using pressure as a proxy for depth in a pressurised tank.

A 3-dimensional hydrodynamic model of the Mitchell River sub-estuary was developed to give physical boundary conditions for the biophysical model. The model was developed in 3DD Suite. Model calibration was done by comparing modelled and measured: (1) water levels for part of the monitoring period, (2) salinity profiles for all 5 sites on 3 dates, and (3) vertical velocity profiles for all 5 sites on 4 dates. The model was independently verified by comparing modelled and measured salinity profiles for all 5 sites on 5 dates.

A biophysical model was developed comprising an advection-diffusion particle tracking model, with additional algorithms to add a non-random component to particle movement to represent larval behavior. The behavioural algorithms simulated egg buoyancy, larval depth preference, salinity response, halocline response, and horizontal swimming. Each behavior could be activated independently and parameter values were dependent on particle age and informed by the laboratory measurements. The model was tested with code review, visual tests, extreme input tests, particle aggregation tests, spot checks and working tests, as recommended by Grimm and Railsback [8].

Larval simulations were evaluated using a pattern-oriented approach [8] to compare modelled larval distributions with observed larval distributions. Two of the patterns were: (1) The majority of observed larvae were sampled 9 - 18 km upstream from the mouth at flows less than 1100 ML/day [9]; and (2) The majority of larvae were found at sites with stratification such that there was at least 10 PSU difference between the surface and bed salinity [10]. A number of different model parameterisations were tested based on the results of the laboratory study. A passive-drift case was also tested, in which dispersal was modelled only using advection and diffusion.

3 RESULTS

3.1 Black bream larval behavior experiments

Critical swimming speed ranged from 6.4 to nearly 22 cm/s and although size was a better predictor than age, speed was highly variable even among similarly sized larvae. In the presence of a halocline, 13 day old larvae were located significantly deeper in the water column, whereas there was no significant difference between the depth of 13 day old larvae in unstratified conditions nor in the depth of 21 day old larvae in either stratified or unstratified conditions. Thirteen day old larvae were strongly surface attracted (Figure 1a), and the proportion of larvae in the top half of the tank was close to 1 regardless of the equivalent depth (using tank pressure are a proxy for depth). Thirty five day old larvae were not surface attracted, however as the equivalent depth in the tank increased beyond 6.6m, larvae were more than 50% likely to be observed in the top half of the tank (Figure 1b). Results for 45 day old larvae were similar to those for 35 day old larvae (not presented here).

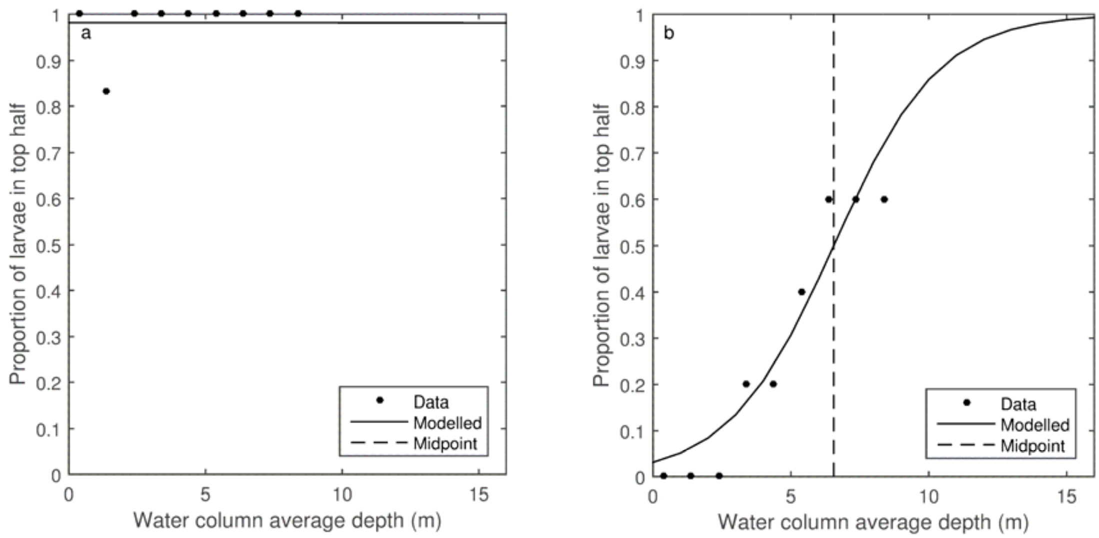

Figure 1: (a) Barokinetic response of 13 day old larvae (b) Barokinetic response 35 day old larvae..

3.2 Biophysical modelling

All modelled combinations of larval behavior were able to reproduce the majority of observed larval distribution patterns. Figure 2 illustrates this for pattern 1 – that the majority of observed larvae were sampled 9 - 18 km upstream from the mouth at river discharges of less than 1100 ML/day. Where Figure 2 (a) shows the observed population distribution, and figure 2 (b) shows the modeled distribution, where relative count is the sum of proportional abundance for each time point in the model at a given spatial location. A peak in larval concentration was commonly observed at 3km upstream of the river mouth during high-flow conditions, however no model structures were able to reproduce this peak.

Passive-drift and 5 other behavioural parameterisations including combinations of egg buoyancy, depth preference, salinity preference, halocline response, and horizontal swimming all produced similar modelled distributions.

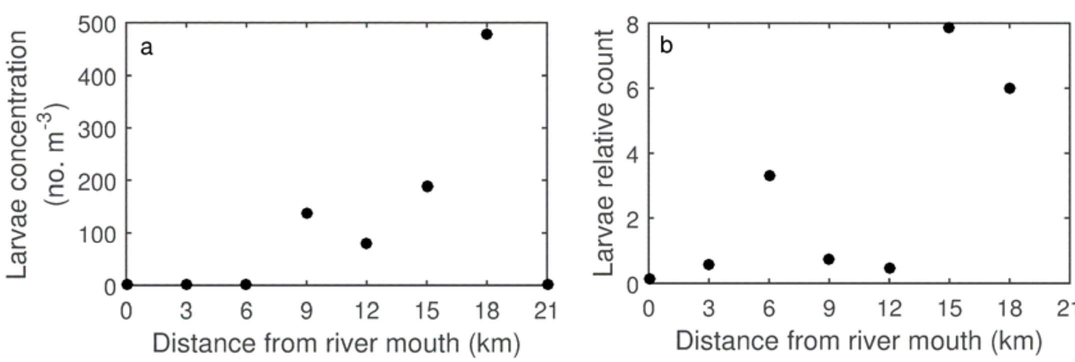

Figure 2: (a) Observed upstream larval concentrations [9], (b) modeled upstream larval concentrations.

4 DISCUSSION

Although larval behaviours observed in the laboratory suggested a potentially strong influence on dispersal, this was not realized in the modelling study. The biophysical modelling experiments showed that the suite of behaviours modelled in this study has very little influence on dispersal, at least in the early to mid-part of the larval stage. The behaviours chosen for this modelling exercise all have the effect of increasing larval retention within the sub-estuary. However, the passive drift case [7] demonstrated that the salt-wedge environment was itself quite retentive, and modelled distributions included high proportions of larvae in the upper estuary, even in high flow conditions.

The inability of passive-drift or model structures including behaviour to reproduce the peak of larvae around 3km upstream of the mouth under high flow situations suggests that behaviours which encourage dispersal of larvae may influence larval population patterns more than retentive behaviours. Such dispersive behaviours act counter to the retentive nature of the highly-stratified salt wedge environment.

While behavioural paradigms in early life history modelling often focus on the importance of behavior for larval retention, these studies have predominantly been conducted in more dispersive environments of open coastal seas. Even the more "retentive" environments such as upwelling zones or large well-mixed estuaries are vastly less retentive than a narrow, micro-tidal salt-wedge estuary like the Mitchell. In highly retentive environments like the Mitchell River, larval behavior may not be important for retention, because of the retentive nature of hydrodynamic conditions.

5 CONCLUSIONS

The Mitchell River sub-estuary of the Gippsland Lakes is a classic salt wedge estuary, with a high-degree of stratification which remains in place under a wide range of flows. While black bream larvae demonstrate a range of dispersal-relevant behaviours, their swimming abilities and the behaviours modelled in this study are unlikely to be significant to population level larval dispersal patterns. In highly stratified environments, dispersive behaviours are likely to have a greater influence on larval dispersal patterns than retentive behaviours.

6 ACKNOWLEDGMENTS, APPENDICES, AND REFERENCES

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