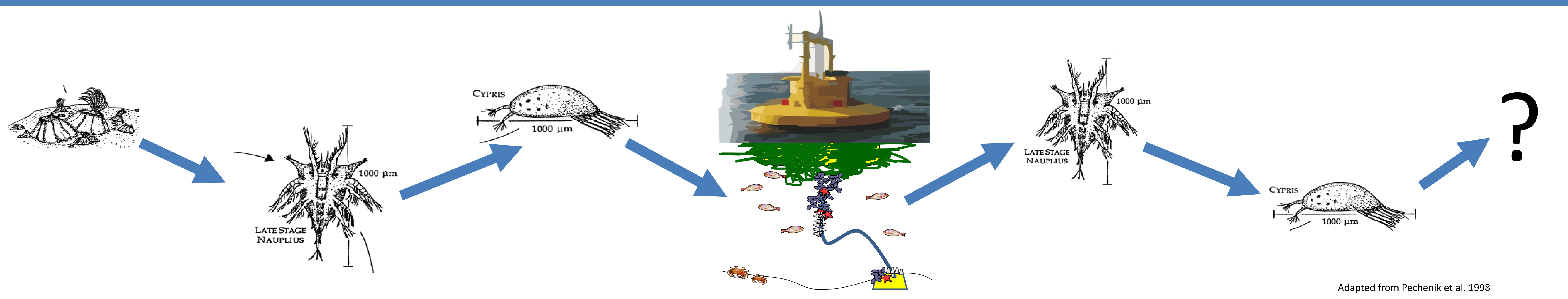
Biofouling babies could go the distance: barnacle larvae spawned at offshore habitat have greater dispersal potential

Raeanne Miller, Thomas Adams, Dmitry Aleynik, Michael Burrows, Clive Fox, Mark Inall



Adapted from Pechenik et al. 1998

Introduction

The construction of progressively large marine renewable energy arrays around the UK will substantially increase hard habitat availability in many coastal locations. The environmental effects of this habitat alteration may include changes in hydrodynamic conditions and the formation of artificial reefs (Langhamer et al 2010; Miller et al. 2013) which will be colonised by a variety of biofouling organisms. The makeup of these fouling communities will depend on local environmental conditions (Macleod 2013) and transport processes bringing larvae, juveniles, or adults to/away from the site and other natural or anthropogenic habitats.

Consequently, it has been suggested that these structures could act as stepping-stones for the spread of both native and non-native species (Petersen and Malm 2006, Shields et al. 2011), with increasing effect as more structures are installed. Current environmental impact assessment (EIA) regulations state that cumulative effects must be addressed in any EIA. Modelling studies of dispersal are ideally suited to test the relative impacts of physical and biological processes on dispersal, and can help to identify the extent of stepping-stone connectivity between natural habitats and artificial structures during the impact assessment process.

Methods

We aimed to assess the characteristics of dispersing organisms which might enhance their ability to colonise offshore renewable energy structures and spread via stepping-stones: larval behaviour, spawning habitat, and pelagic larval duration.

We coupled a high-resolution, 3-dimensional circulation model of the Firth of Lorn and surrounding waters, based on the Finite Volume Community Ocean Model (FVCOM, Chen et al. 2003) to model the transport of barnacle larvae. Barnacles are perhaps the best-studied members of biofouling communities world-wide, and are extremely common around the coasts of Scotland. Biological models of dispersal were developed for three species of barnacles, based on field surveys of horizontal and vertical zooplankton distributions and available literature data on larval duration and seabed habitat.

Particles were released from model start nodes at habitat for the selected species (**Figure 1**) and dispersed for 33 days with either a surface-seeking, bottom-seeking, or realistic re-distributive behaviour (RDB, **Figure 2**).

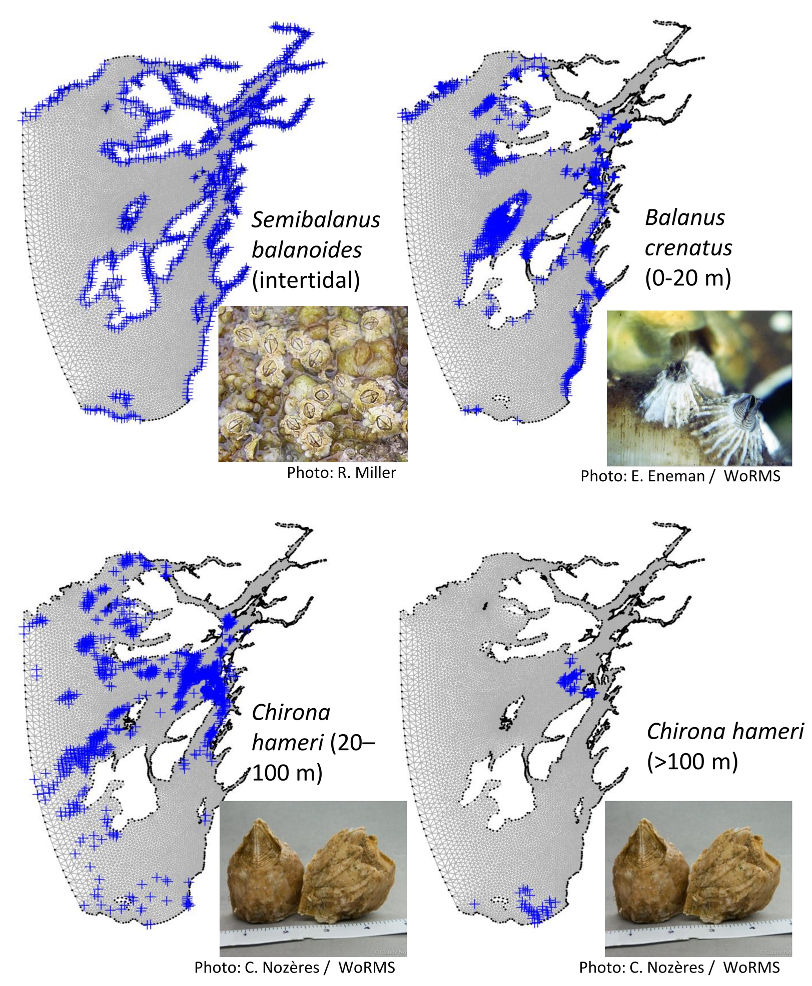


Figure 1: Model mesh start nodes and depths for particles based on JNCC habitat designations (Joint Nature Conservation Committee 2010)

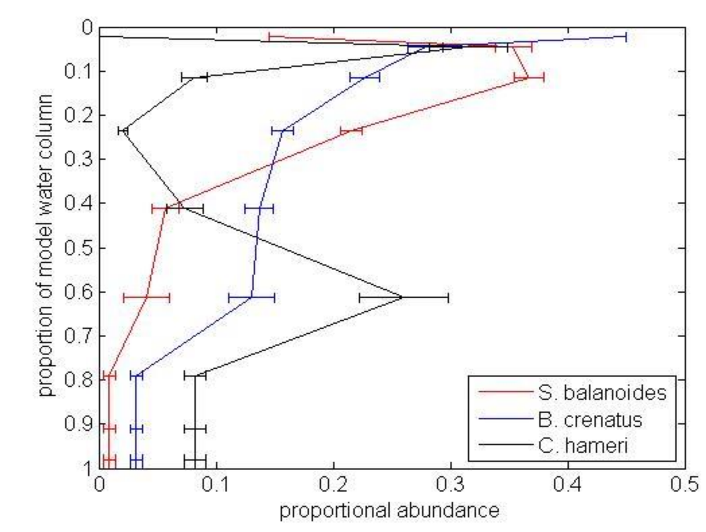


Figure 2: Vertical distribution of particles in the model, with associated standard error, used to define redistributive behaviour (RDB) of particles.

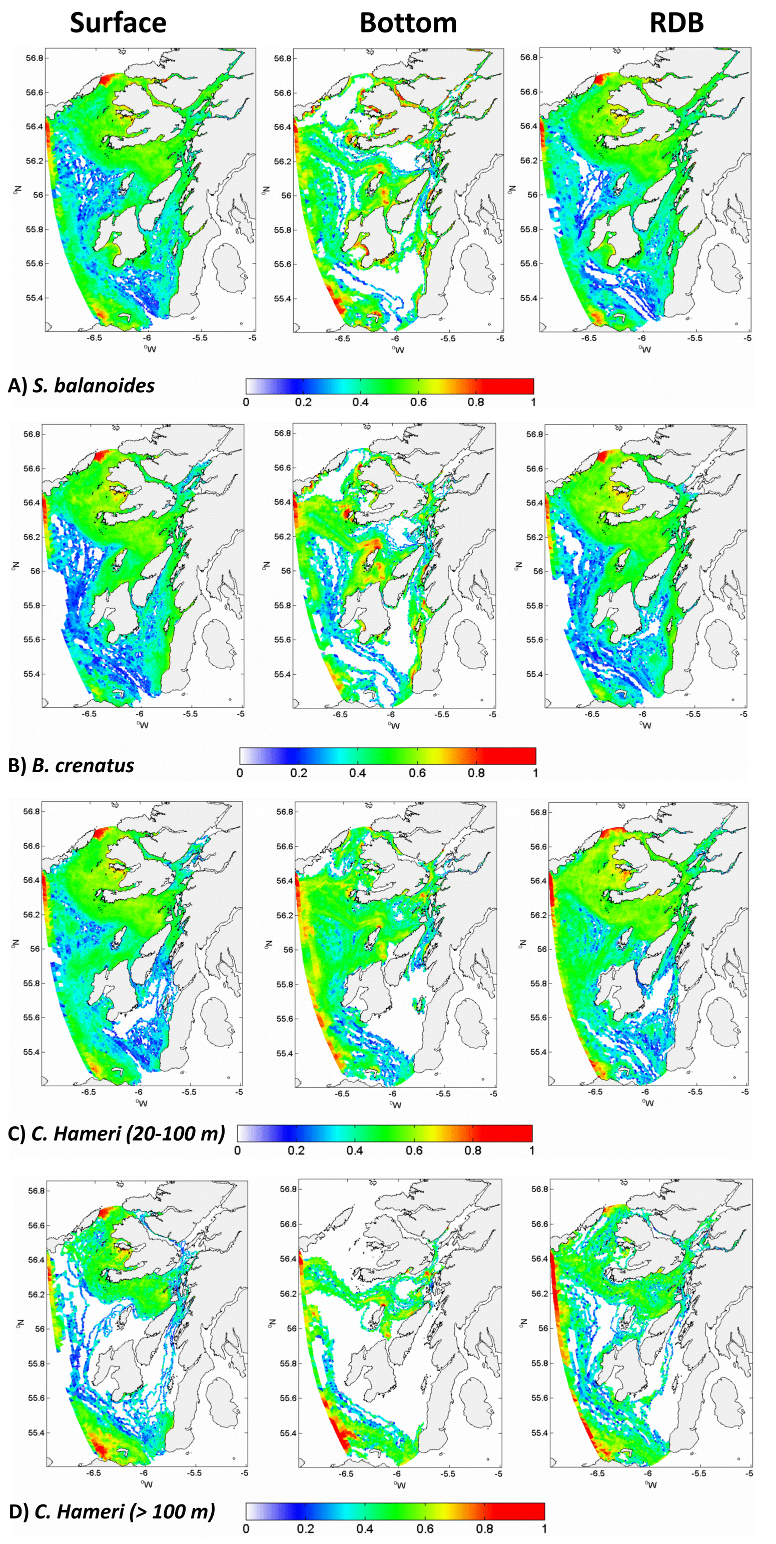


Figure 3: Density maps of summed model timesteps spent in each model cell by particles. A value of 0 represents a cell unoccupied for the duration of the model run, while a value of 1 represents cells with overall maximum occupation.

Results

Particle transport and dispersal distances (Table 1):

- Mean transport distances ranged from 189 km to 659 km
- Mean dispersal distances ranged from 17.5 km to 74.4 km
- Particles at the surface had greatest transport
- Particles with RDB had greatest net dispersal
- A substantial proportion of particles were transported offshore towards western and northern model boundaries **(Figure 3)**

Habitat / start location

- For particles with similar vertical behaviours, those starting at coastal intertidal locations did not travel as far as those starting at offshore locations

Vertical positioning routines

- Vertical positioning strongly influenced dispersal paths and transport distances
- Dispersal patterns for particles with similar vertical positioning routines were more similar than for particles with identical particle release locations **(Figure 4)**

Realistic / redistributive behaviour (RDB)

- Model runs with RDB were similar to those with surface-seeking behaviour for *S. balanoides*, *B. crenatus*, and *C. hameri* (20-100 m start)
- *C. hameri* particles released from >100 m did not group in a similar fashion,
- Depth of particle release and number of particles may have been an influence

Table 1: Summary of transport and net dispersal distances (km) for all model runs, where n is the number of particles released in each run, followed by mean and standard deviation of particle transport and net dispersal. The highest (orange) and lowest (blue) values of each metric are highlighted.

			Transport (km)		Net dispersal (km)	
Habitat type	**Behaviour**	**N**	**mean**	**SD**	**Mean**	**SD**
Intertidal	Surface	940	476.4	184.7	59.1	35.1
Intertidal	Bottom	940	189.0	143.4	67.5	32.6
Intertidal	*S. balanoides*	940	485.5	173.0	62.9	32.6
0 m- 20 m	Surface	939	566.0	121.8	71.4	38.4
0 m- 20 m	Bottom	939	263.3	103.8	17.5	23.0
0 m- 20 m	*B. crenatus*	939	542.2	133.2	24.6	24.5
20 m- 100 m	Surface	925	596.0	104.7	38.6	26.9
20 m – 100 m	Bottom	925	285.0	115.7	47.6	28.1
20 m – 100 m	*C. hameri*	925	432.4	98.7	61.0	33.3
100 m – 200 m	Surface	90	658.9	131.0	69.7	33.1
100 m – 200 m	Bottom	90	403.0	180.7	60.4	27.9
100 m – 200 m	*C. hameri*	90	496.9	113.4	74.4	42.7

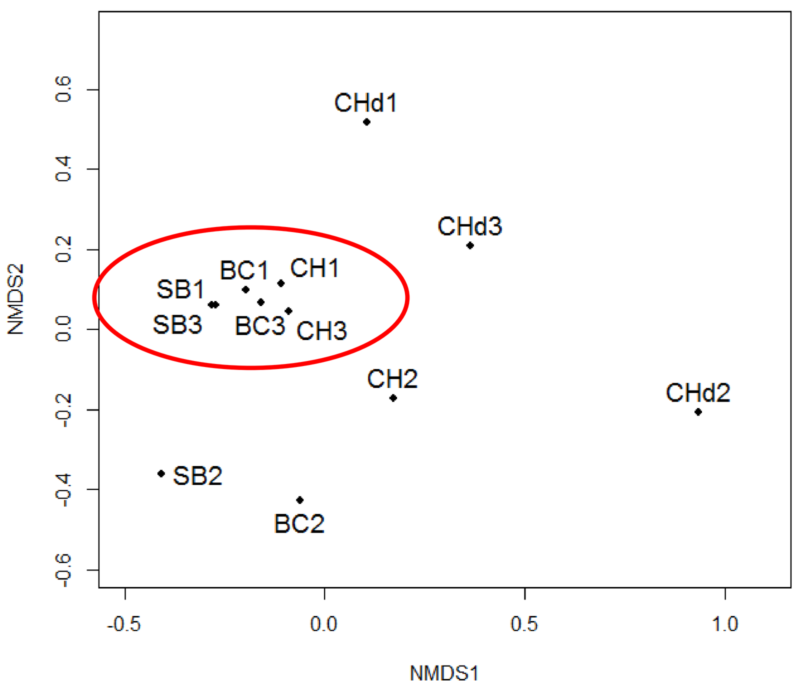


Figure 4: nMDS ordination of modelled particle distributions. Species: SB, *S. balanoides*; BC, *B. crenatus*; CH, *C.hameri* 20-100 m start; CHd, *C. hameri* > 100m start. Model runs: 1, surface; 2, bottom; 3, RDB.

Discussion

Transport and dispersal

- Transport and dispersal distances were within the expected range for species with relatively long-lived larvae (10s – 100s km, Shanks 2009)
- The minimum dispersal distances suggest that many particles are retained near start habitat, while long-distance dispersal may have important connectivity impacts on distant populations
- Strong horizontal currents do not always correlate with substantial transport, e.g. *S. balanoides* particles have greatest transport for surface and RDB runs, but net dispersal is greatest for bottom-seeking particles.

Offshore renewable energy structures

- The transport of particles released in deeper water, far from shore was enhanced when compared to those released in shallower water (<20 m). These particles spend less time in near-shore friction-slowed currents and turbulence (e.g. 'sticky water', Wolanski 1994) before entering stronger, directional offshore currents.
- The offshore locations of renewable energy arrays suggests that larvae released from colonised devices are likely to reflect particles spawned at deeper, offshore locations in this model (> 20 m, e.g. *C. hameri*).
- Offshore structures may have high connectivity: once colonised they could act as sources of larvae to distant habitats, which could be of particular concern in the case of non-native species.
- Nested hydrodynamic models coupled to well-parameterised particle-tracking routines are useful for exploring transport of a species to and from an array and between networks of arrays along coastlines.

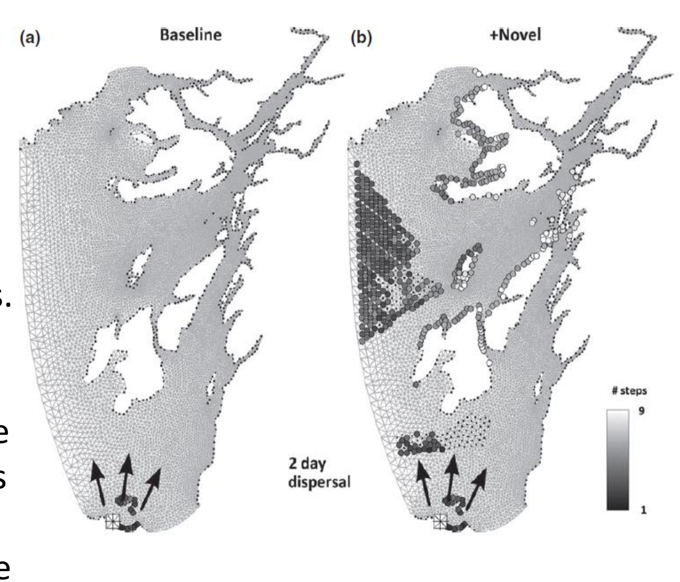


Figure 5: Number of discrete dispersal events required to access rocky habitat by progeny of a population on the Northern Ireland coastline (box/asterisk) (a) omitting and (b) including habitat provided by marine renewable energy devices, for a species with 2-day larval duration. Black indicates 1 step is required, white indicates 9 steps. Sites marked with a small black dot are inaccessible from the source site. From Adams *et al*. 2014.

Further applications

Stepping-stone connectivity

- Adams et al. (2014) demonstrated that offshore renewables could act as stepping stones for many species **(Figure 5)**
- Amplified transport and dispersal of larvae spawned at these structures suggests that they may be particularly good stepping stones.

Further model application

- This model could be adapted to reflect dispersal of species of ecological interest (e.g. polychaetes *Sabellaria* sp. and horse mussels *Modiolus modiolus)* or commercial relevance.
- Detailed information on spawning locations, pelagic larval duration, larval vertical distributions and migrations, and mortality rates is needed.

EIA / cumulative effects

- Modelling studies can clarify the scale of cumulative changes in connectivity processes from planned installations
- These include emergent benefits (i.e. increase in biodiversity / productivity) or detriments (i.e. spread of non-native species, biofouling causing mechanical failure of devices) of the new habitat they create.

Dr. Raeanne G. Miller
Scottish Association for Marine Science
Scottish Marine Institute
Oban, Argyll, PA37 1QA

e. Raeanne.Miller@sams.ac.uk
t. 01631 559 000

Literature Cited:

Adams, T.P., Miller, R.C., Aleynik, D., Burrows, M.T. (2014). Offshore marine renewable energy devices as stepping stones across biogeographical boundaries. Journal of Applied Ecology 51(2): 330-338.
Chen, C., Liu, H., Beardsley, R.C. (2003). An unstructured grid, finite-volume, three-dimensional, primitive equations ocean model: application to coastal ocean and estuaries. Journal of Atmospheric and Oceanic Technology 20(1): 159-186.
Langhamer, O., Haikonen, K., Sundberg, J. (2010). Wave power – sustainable energy or environmentally costly? A review with special emphasis on linear wave energy converters. Renewable and Sustainable Energy Reviews 14: 1329-1335.
Macleod, A.K. (2013). The role of marine renewable energy structures and biofouling communities in promoting self-sustaining populations of non-native species. Ph.D. Thesis, University of Aberdeen.
Miller, R.G., Hutchison, Z.L., Macleod, A.K., Burrows, M.T., Cook, E.J., Last, K.S., Wilson, B. (2013). Marine renewable energy development: assessing the benthic footprint at mulitple scales. Frontiers in Ecology and the Environment 11(8): 433-440.
Petersen , J.K., and Malm, T. (2006). Offshore windmill farms: threats to or possibilities for the marine environment. AMBIO 35(2): 75-80.
Shanks, A.L. (2009). Pelagic larval duration and dispersal distance revisited. Biological Bulletin 216(3): 373-385.
Shields, M.A., Woolf, D.K., Grist, E.P.M., Kerr, S.A., Jackson, A.C., Harris, Robert E., Bell, Michael C., Beharie, R., Want, A., Osalusi, E., Gibb, S.W., Side, J. (2011). Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment. Ocean & Coastal Management 54(1): 2-9.
Wolanski, E. (1994). Physical oceanographic processes of the Great Barrier Reef. CRC Press, Boca Raton, FL, USA. 194 pp.