HR Wallingford
Working with water

Agent-Based Modelling of fish collisions with tidal turbines

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Introduction

With growing developments in marine tidal energy, coupled with high densities of marine species in suitable installation locations, there is concern about marine wildlife colliding with underwater devices. Methods are needed to predict such collisions when assessing environmental impacts of underwater turbines.

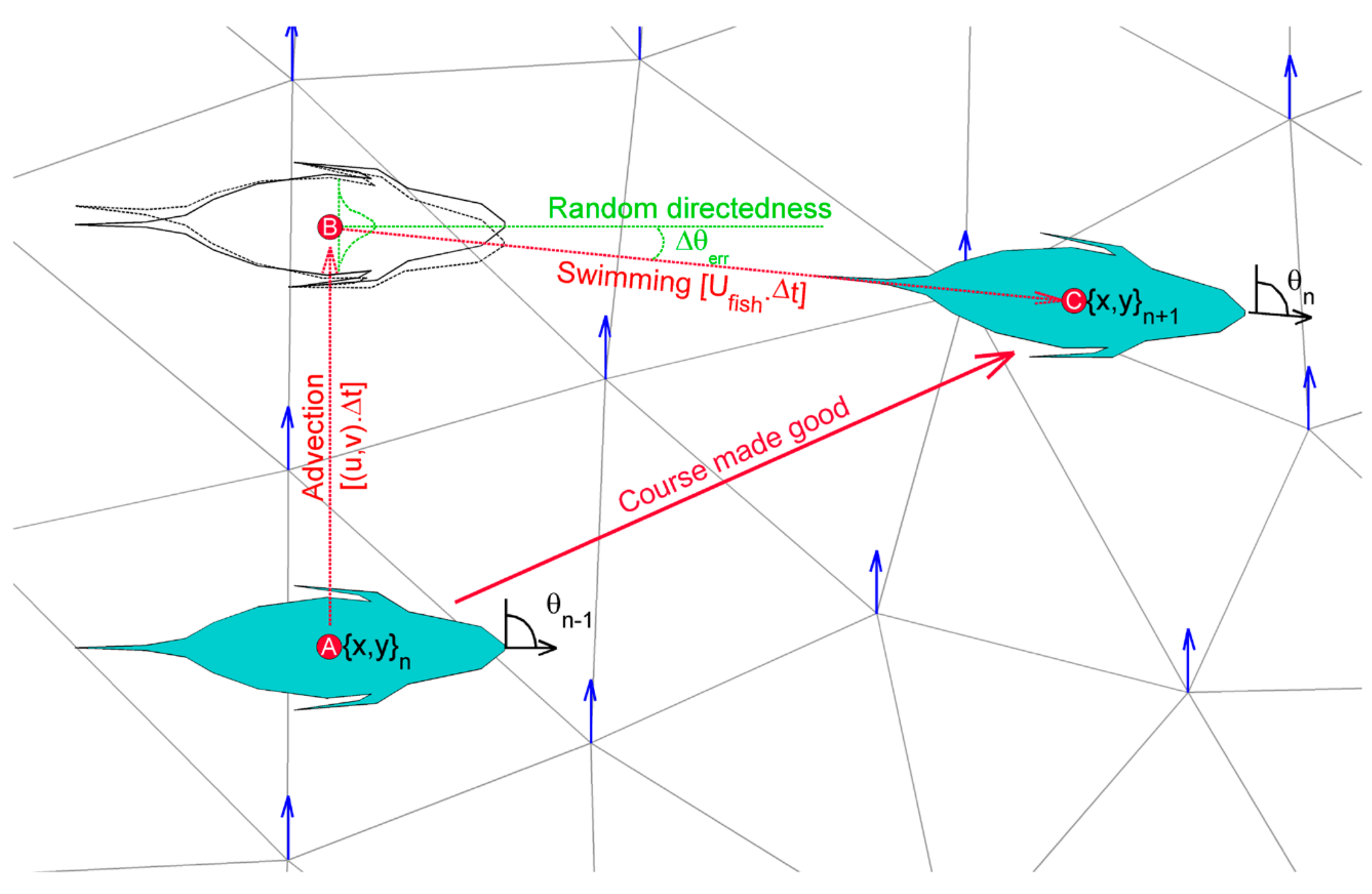
Agent-Based Models (ABMs) in the field of ecology:

> simulate interactions between organisms;
> assess how they live (i.e. grow, reproduce, function, adapt) and die in a dynamic physical environment;
> consider a population from the point of view of the individuals, or agents with population level behaviours emerging from the behaviour of the individuals;
> have individual within a system that are defined by traits (e.g. size, age or sensitivity to a stressor) and behaviours they can perform (e.g. migration or avoidance).

To better predict collisions with underwater devices, HR Wallingford has developed an Agent-Based Model (ABM) to predict the probability of marine animals colliding with an underwater device.

Fish Tracking Model

HydroBoids is an ABM coupled to a particle tracker for predicting the movement of fish (or other mobile marine animals) in response to stimuli such as sound or chemical tracers (Rossington et al., 2013). Using a TELEMAC flow model to define the underwater world, individuals (e.g. fish) are represented as Lagrangian points which are advected by the hydrodynamic flows from the TELEMAC model.



2D fish movement using a correlated random walk and advection by hydrodynamic flows

In addition to advection by flows, modelled fish move under their own propulsion according to a correlated random walk (CRW) algorithm (Codling et al., 2008; Willis, 2011). A CRW is a pattern of movement where the direction of the fish at each model time step is dependent on the direction at the previous time step.

Modelled fish can perform a number of behaviours:

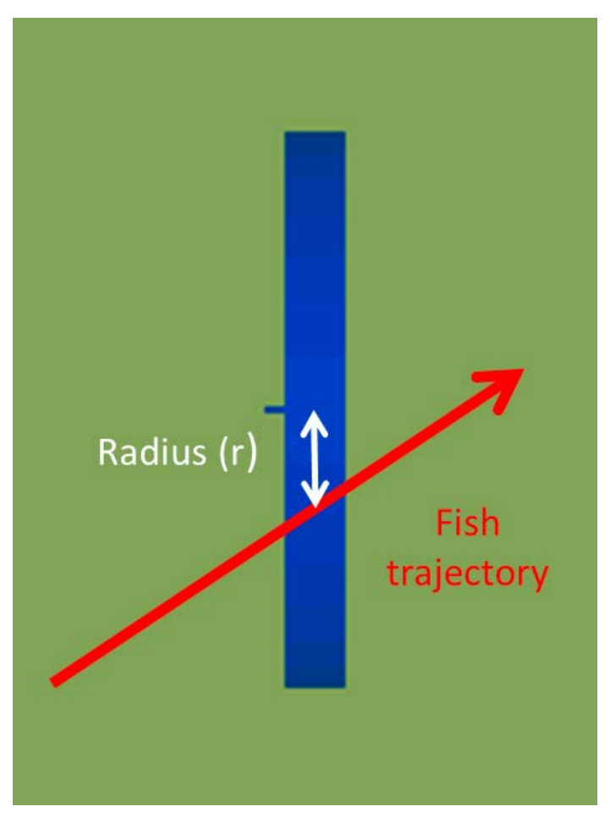
> Swimming
> Schooling
> Migration/navigation
> Flee predator or chase prey
> Respond to stimulus (e.g. flows, temperature, salinity, sound, light, food)
> Vertical migration.

Collision Modelling

The turbine occupies a 3D space within the underwater world defined by the TELEMAC model.

For each transit, the probability of collision is calculated based on Band et al's (2016) collision risk model:

$$p(r) = \frac{b\Omega}{2\pi v}\left(|\pm c\,sin\,y + \alpha\,cos\,y| + max\{L, W\alpha\}\right)$$

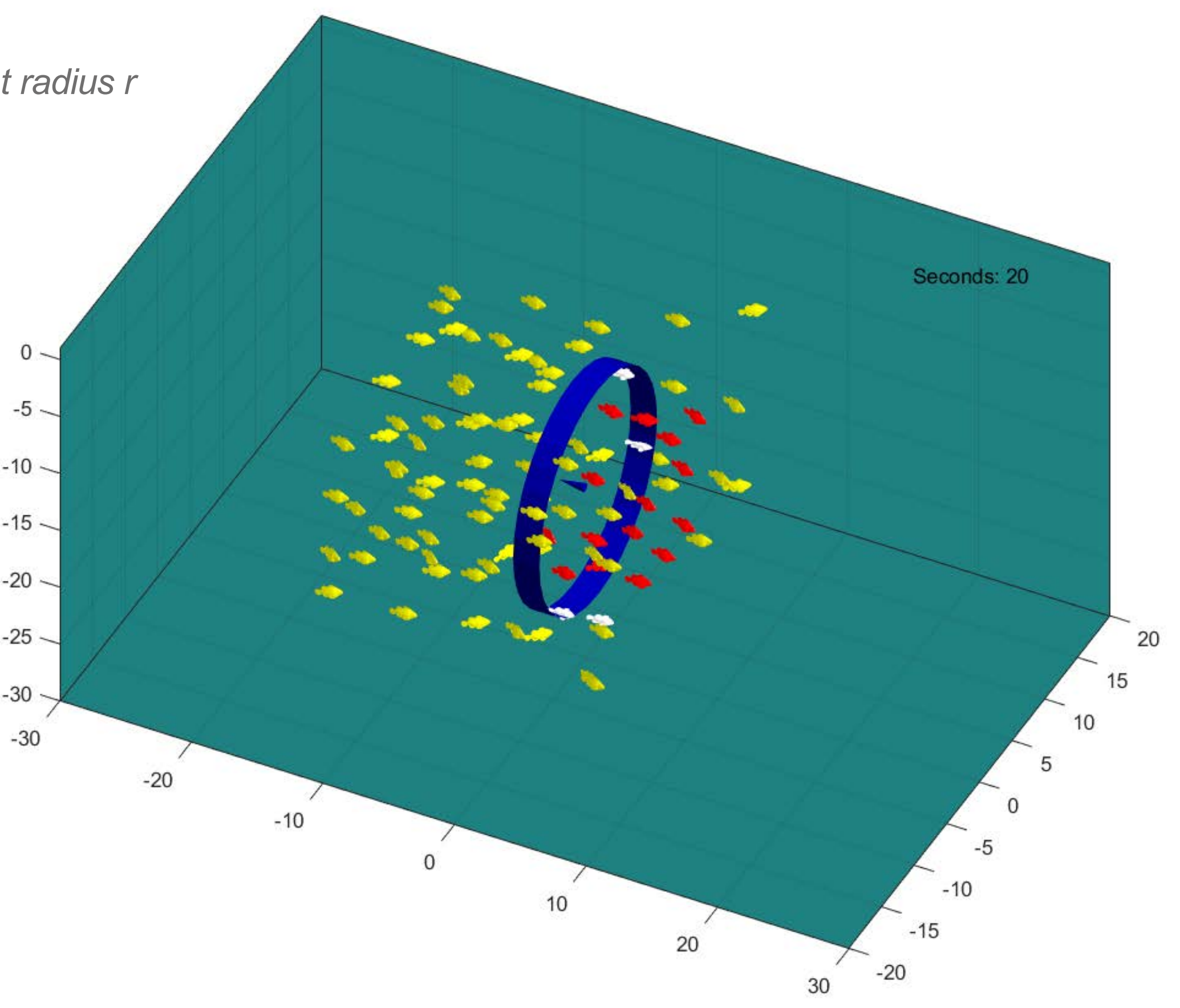


For fish transiting the turbine rotor, the probability of collision is calculated

p(r) - probability of collision as a function of radius
b - number of blades in the rotor
Ω - angular velocity
c and y are the chord and pitch of the blade at radius r
v - velocity of the marine animal
L - body length of the animal
W - animal's body width
α = v/rΩ

To determine whether a collision took place, the probability of collision is compared with a random decimal number between 0 and 1. If the random number is less than the probability then a collision has occurred.

Combined collision speeds greater than 5 m/s are assumed to be fatal.



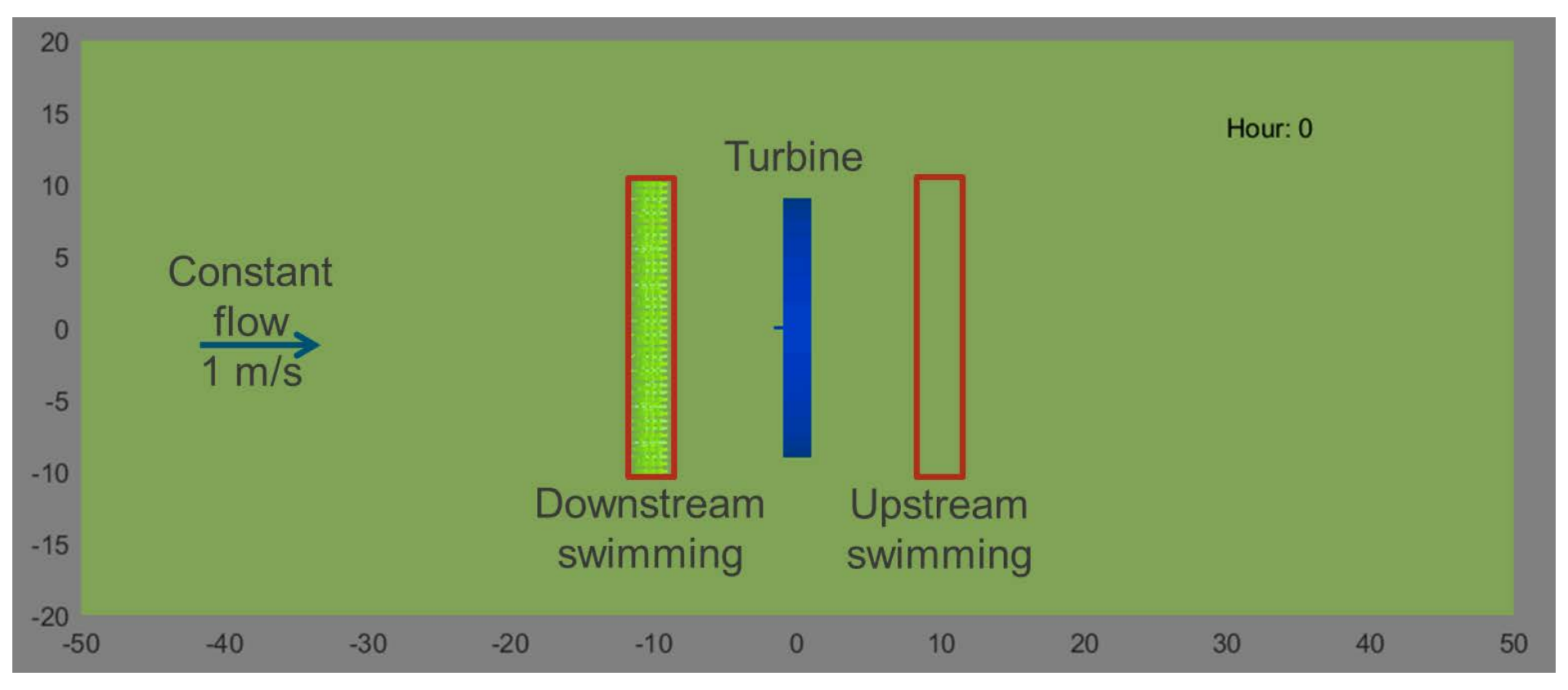
Modelled fish swimming through a rotor. Yellow fish have not collided; Red have collided and white have been killed by a collision.

Benchmark Tests

A HydroBoids model was set up using a rectangular flume with a constant flow from left to right. The front face of the turbine faces into the flow. Fish were either release directly upstream or downstream of the turbines. Three different test cases were simulated:

> Downstream v upstream releases;
> Different body length;
> Different swim speeds.

For each test case, average collision rates were compared with the disk averaged collision probability of Band et al (2016).



Model set up for benchmark tests

Results

> More collisions for fish swimming upstream (against the flow);
> Collision risk decreased the faster the fish swam;
> Collision risk increased with longer body lengths;
> Results from HydroBoids were almost identical to CRM.

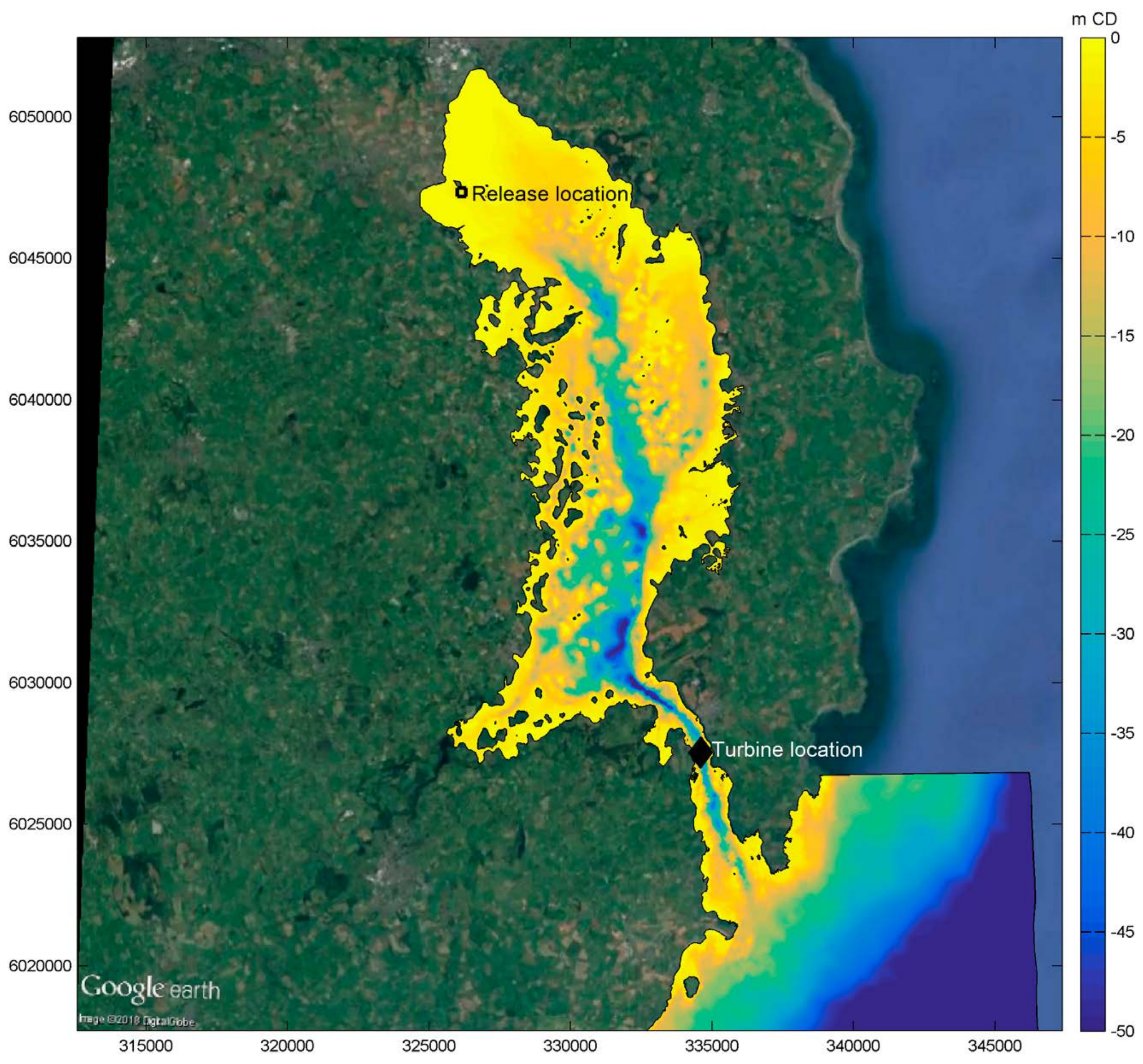
Comparison of average collision rates predicted using the ABM and the collision probability from the CRM (Band et al, 2016; SNH, 2016).

Scenario	Initial direction	Travel velocity of fish (v) (m/s)	Body length (m)	Average collision rate from HydroBoids	Disk averaged collision rate (CRM)
1	Downstream	1.5	0.5	16 %	16 %
	Upstream	1.5	0.5	23 %	23 %
2	Downstream	1	0.5	20 %	20 %
	Downstream	1.5	0.5	16 %	16 %
	Downstream	2	0.5	15 %	15 %
3	Downstream	1.5	0.2	11 %	10 %
	Downstream	1.5	0.5	16 %	16 %
	Downstream	1.5	0.8	22 %	22 %

Case Study: Strangford Lough

Aim: to investigate how different swimming behaviours impact collision rates.

Using a TELEMAC model of Strangford Lough, eels with different vertical swimming behaviours were modelled, following a salinity gradient from an upstream location to the open sea.



Flow model bathymetry, showing eel release location and turbine position

Cohort 1:	> Swim to bed during daylight; > Swim to bed if swimming against flow; > Otherwise swim near surface.
Cohort 2:	> Swim to bed during daylight; > Swim to bed if swimming against flow; > Otherwise no depth preference.
Cohort 3:	> No depth preference.

Summary of rotor transits and collisions for all eels passing through the channel to the mouth of Strangford Lough

	Cohort 1	Cohort 2	Cohort 3
Eels passing through channel	40 %	28 %	38 %
Of total eels passing through channel:			
% turbine transits	1.4 %	5.3 %	6.1 %
% collided	0.3 %	1.0 %	1.1 %
% killed	0.2 %	0.7 %	0.7 %

The vertical migration behaviours of the eels affected the number leaving the estuary and therefore the number passing the turbine in Strangford Narrows.

> Cohort 1 were least likely to transit the turbine and had low collision rates because they tended to be at the bed or the surface;
> Cohorts 2 and 3 were more likely to transit the turbine and to collide.

Conclusions

> Agent-Based Models can be used to predict the movements of marine animals in response to stimuli;
> Benchmark tests show that the HydroBoids collision probability is very comparable to the CRM disk averaged collision probability;
> Collisions rates were predicted to be low in the case study and were influenced by the swimming behaviours of the individuals;
> Further work could include modifying swimming behaviours to include active turbine avoidance.

References

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