Seeding of Gymnodinium catenatum blooms in Iberian shelf waters

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Summary
Gymnodinium catenatum blooms in the Iberian upwelling system are highly variable at the decadal, annual and event scales. Species-specific life-cycle transitions are probably one of the key factors determining this variability. We investigated the presence of *G. catenatum* cysts in sediments from the Iberian shelf and their viability and physiology under laboratory conditions. Results were included in a Lagrangian model to test if cysts re-suspended near the bottom could be transported to pelagic conditions compatible with their germination. Particle-tracking experiments were performed using the solutions of a 3D hydrodynamic model configured to realistically reproduce shelf circulation off the study region. Predictions of the model suggest hypotheses about spatial and temporal patterns of cyst transport and coupling with pelagic blooms. There is a high intra- and inter-annual variability on cyst re-suspension probability. Cysts released at mid-shelf are frequently transported to the photic zone in less than 10 days contrasting with periods when this probability is null. The early-summer conditions are the most favorable for seeding of pelagic blooms. Shelf seed-beds may inoculate coastal blooms.

Introduction
Blooms of the toxic dinoflagellate *Gymnodinium catenatum* are a recurrent phenomenon in the Iberian upwelling system albeit highly variable at the decadal, annual and event scales. In this area the bloom dynamics of *G. catenatum* is usually interpreted as being more dependent on constraints in the planktonic stage than on the build up of a benthic seed population (e.g. Figueroa *et al*. 2008). This hypothesis is based both in field and laboratory results, namely: (1) very low concentration of cysts with viable cell contents, at any given time, in coastal and shelf sediments; (2) very short mandatory dormancy period (4-11 days); (3) no environmental pre-conditioning; (4) high cyst viability. But, the question remains, where does the seeding inoculum come from? In the present work we revisited the cyst bed-hypothesis using a Lagrangian model approach coupled to the Regional Oceanic Modelling System (ROMS). The model was constraint to consider environmental thresholds known to influence cyst germination, namely light, temperature and persistence of favorable germination conditions.

Materials and Methods
The study area is located in the NW Iberian shelf between 40°- 41°N. Sediment samples were collected from mid-shelf mud patches. Cyst concentrations were determined using standard methods. When concentrations were below the detection limit, the step gradient method was used (Bolch, 1995). Cyst germination rate, G50 (time needed for the germination of 50% of cysts isolated in a given day) and progeny viability were estimated following Figueroa et al. (2005). Temperature and *G. catenatum* cell counts (2004-2012) were obtained from a monitoring coastal site in the study area (40°38’43”N, 8°44’22”W). A Lagrangian model was coupled to the Regional Oceanic Modelling System (ROMS) using ROFF, a drifter-tracking code that simulates particle trajectories from stored ROMS velocity and hydrological fields (Carr *et al.,* 2008, Domingues et al., 2012). The simulations were run for 2010 and 2011. Based on results from the cyst studies, the following external factors were included in the model: (1) cyst re-suspension and transport to the photic zone (Z<20m), (2) and retention at least for 5 days, (3) at

temperatures above 15°C, presumably compatible with vegetative growth. The model was also run considering 17°C as the threshold. Particles were released every 2 days from 2 shelf mud patches. This work was funded by projects PTDC/MAR/100348/2008, PEst-OE/Mar/UI0199/2011 and EU FP7/2007-2013 under grant agreement N° 607325.

Results and Discussion

Results from the cyst survey (2010 and 2011) allowed identification of 2 mud patches located at mid-shelf, around 100m depth, with *G. catenatum* cysts with cell contents. Concentrations of these cysts never exceeded 25cystscm^{-3}. The location of these patches determined where particle release simulation. In the lab cysts showed high germination rates (35-82%), low G50 (0-6 days) and high progeny viability (50-95%). Analysis of the *G. catenatum* time series data and temperature indicated blooms were always recorded at temperatures above 15ºC, suggesting this as the lower limit for optimal vegetative growth. This value was thus used to constraint the model. The predictions of the model are exemplified for 2010 in Figure 1. Comparison with predictions of the model for 2011 showed high inter-anual variability (data not shown). For instance, August and October were months of null probability of seeding. However, the following general considerations may be made: (1) there are periods when the probability of transport of suspended cysts to the photic layer, reaching temperatures compatible to vegetative growth, are null; (2) the early-summer conditions are the most favorable for seeding pelagic blooms from benthic cyst beds; (3) average along-shore cyst transport is southeast towards the coast: shelf seed-beds may seed coastal blooms; (4) the site of the benthic seed-bed is geographically distinct from where the pelagic bloom may be initiated. These results look promising and suggest that in Iberia the cyst bed hypothesis for the initiation of *G. catenatum* blooms cannot be discarded yet.

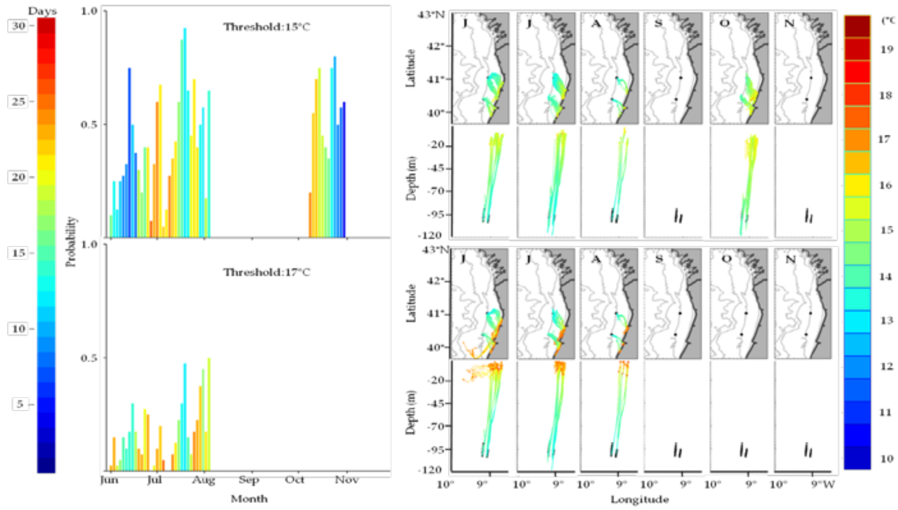

Figure 1 – Example of model results for 2010, 15°C and 17°C threshold To the left: time series plots represent the percentage of released tracers that satisfy the conditions included in the model (color code: mean number of days needed to arrive at the specified environmental conditions). To the right: trajectories of passive tracers released at mid-shelf satisfying specified conditions (color code: temperature during particle transport).

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