

Evaluating ecosystem services: Starting at the bottom of the food-chain?

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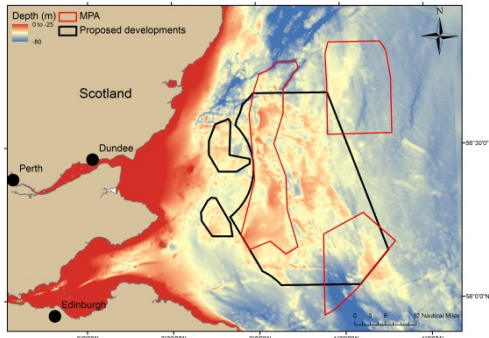
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Summary: Primary producers (phytoplankton) provide important provisioning and regulating ecosystem services. They form the basis of marine food-webs, supporting production of higher trophic levels (a provisioning ecosystem service), and act as a sink of CO₂ (a climate regulation service). We propose that, as phytoplankton are important to climate cycle and ecosystem functions, and as concentrations of phytoplankton are neither spatially nor temporally homogenous, consideration for the potential impact from human developments and activities on the service provision afforded by phytoplankton should be accounted for in marine planning processes. As a case study, we consider the impacts of marine renewable developments. Previous studies have looked at impacts of marine renewable structures on the physical environment, and at interactions with higher trophic levels (such as fish, birds and mammals). However, due to the tight coupling between physical and biological processes in the ocean, an effect on phytoplankton is predicted. In a preliminary study, the regional impact of proposed large scale offshore wind farms in the Firth of Forth, Scotland, on levels of primary production, through changes in physical processes, is investigated. The results are expected to inform the sectoral planning and licensing process for renewable energy developments.

Introduction: Effective Marine Spatial Management and Planning (MSP) provides us with clean, healthy, safe, productive and biologically diverse seas, and can be achieved by applying an ecosystem based management approach to MSP, as endorsed by the European Commission. Ecosystem service considerations must be based upon an ecologically sound framework. An understanding of the ecosystem at a mechanistic level, from bottom to top, is required to enable effective management and planning of related services, and to support the evolution of future legislation and policy. MSP in Scotland (under the Marine Spatial Planning Directive) will take into consideration previous Directives, but also allow consideration of a bigger economic, ecological and social picture, with scope to maintain or increase ecosystem service provisions. As marine ecosystems are founded upon primary producers, an understanding of the ecosystem services provided by phytoplankton is essential.

The marine environment is not homogenous in terms of primary productivity; it is subject to 'patchiness', temporally and spatially, driven by underlying physical processes. Generally, increased physical mixing within the marine environment leads to an associated increase in biological productivity. This can be large in scale, e.g. upwelling (e.g. *MacIsaac et al., 1985*), or along the continental shelf break (e.g. *Joint et al., 2001*), but relatively small spatial areas are also of disproportionate importance to total primary production; for example, tidal mixing fronts (e.g. *Videau 1987*), and, during summer, over submarine banks (e.g. *Horne et al., 1996; Sharples et al. 2013*). This variability in phytoplankton has consequential effects, e.g. spatial and temporal patchiness in CO₂ drawdown from the atmosphere (e.g. *Kavanaugh et al., 2014*), of great relevance to climate change and carbon balancing. Patchiness in phytoplankton can also be 'passed on' through the trophic levels (e.g. *Scott et al., 2010; Benoit-Bird & McManus 2010*).

Materials and Methods: An area off the east coast of Scotland has been chosen as a study site (see below). Three wind farms are proposed within the area, and a Marine Protected Area has been designated. The area contains a system of submarine banks, and previous research cruise data from the area suggested the presence of internal waves and mixing in the region. The region is subject to

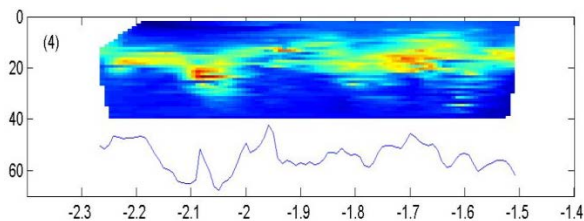


Map of study area, with coloured bathymetry.

patchiness in phytoplankton, and in higher trophic levels (Scott *et al.*, 2010). A cruise in July 2014 reaffirmed hydrographic and biological conditions in the region. Satellite data has also been used to establish temporal and spatial variability in temperature and Chl *a* concentrations (a proxy for phytoplankton concentrations). A 3-D FVCOM tidal model has been used to model the impact of wind turbines on the current velocities in the area, and a 1-D model (courtesy of J Sharples) used to look at the impact on primary production.

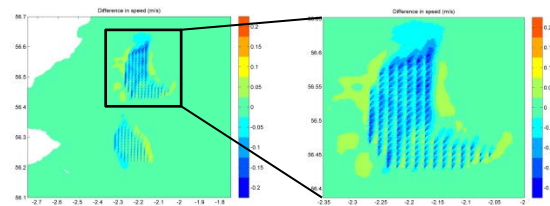
Results and Discussion:

In situ data:



Towed, undulating fluorometer and bathymetry data showing that the large banks in the area have patches of higher concentrations of phytoplankton over regions of sloping topography.

Model data:



Difference in current speed (m s^{-1}) with and without wind farms, using an FVCOM model. Preliminary results from the hydrodynamic model show that the presence of wind turbine arrays could have a significant impact on current speed.

Primary production was modelled throughout the year at one location within a proposed wind farm array. Net annual primary production is reduced by 32% (from 50 to 34 $\text{g C m}^{-2} \text{ yr}^{-1}$) by the presence of wind turbines, through changes in current speed influencing the mixing of nutrients into the summer thermocline. This has further ramifications on ecosystem services, such as CO_2 drawdown and food provision to higher trophic levels, and in the location of good foraging sites (Scott *et al.* 2010).

Human maritime activities *do* impact on phytoplankton, to positive or negative effect, and this will have an impact on the ecosystem services rendered by phytoplankton. Effective MSP will take account of these impacts; considering the impact of a marine development on primary production in siting such developments, or within assessments of the cumulative effects of such developments.

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