Journal of Marine Systems 152 (2015) 51–63

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

Modelling the combined impacts of climate change and direct anthropogenic drivers on the ecosystem of the northwest European continental shelf

Sarah L. Wakelin [a,*], Yuri Artioli [b], Momme Butenschön [b], J. Icarus Allen [b], Jason T. Holt [a]

[a] National Oceanography Centre, Joseph Proudman Building, 6 Brownlow Street, Liverpool, L3 5DA, UK
[b] Plymouth Marine Laboratory, Prospect Place, Plymouth, PL1 3DF, UK

ARTICLE INFO

Article history:
Received 16 February 2015
Received in revised form 14 July 2015
Accepted 19 July 2015
Available online 29 July 2015

Keywords:
Climatic changes
Man-induced effects
Modelling
Ecosystems
Northwest European continental shelf
POLCOMS-ERSEM

ABSTRACT

The potential response of the marine ecosystem of the northwest European continental shelf to climate change under a medium emissions scenario (SRES A1B) is investigated using the coupled hydrodynamics-ecosystem model POLCOMS-ERSEM. Changes in the near future (2030–2040) and the far future (2082–2099) are compared to the recent past (1983–2000). The sensitivity of the ecosystem to potential changes in multiple anthropogenic drivers (river nutrient loads and benthic trawling) in the near future is compared to the impact of changes in climate. With the exception of the biomass of benthic organisms, the influence of the anthropogenic drivers only exceeds the impact of climate change in coastal regions. Increasing river nitrogen loads has a limited impact on the ecosystem whilst reducing river nitrogen and phosphate concentrations affects net primary production (netPP) and phytoplankton and zooplankton biomass. Direct anthropogenic forcing is seen to mitigate/amplify the effects of climate change. Increasing river nitrogen has the potential to amplify the effects of climate change at the coast by increasing netPP. Reducing river nitrogen and phosphate mitigates the effects of climate change for netPP and the biomass of small phytoplankton and large zooplankton species but amplifies changes in the biomass of large phytoplankton and small zooplankton.

1. Introduction

Marine ecosystems are in continual adjustment responding to changes in the climate, both from natural variability and long term anthropogenic climate change. Global climate change may impact on ecosystems through large scale changes in temperature, stratification and circulation (e.g. Bopp et al., 2001; Chust et al., 2014; Holt et al., 2012; Sarmiento et al., 2004). Additionally, there is a direct impact from human activities, such as fishing, waste water discharge, dredging, leisure, fossil fuel extraction and off-shore energy generation (e.g. UKMMAS, 2010; Ducrotoy and Elliott, 2008; Halpern et al., 2008). These direct effects tend to be largest in coastal and shelf seas, where changes in the ecosystem are also likely to impact most directly on humans.

The physical climate influences the ecosystem through temperature, which affects chemical and physiological rates (Boyd et al., 2013), and by controlling the availability of nutrients (Holt et al., 2012) through horizontal transport and vertical mixing (which is inhibited by stratification). The nutrient supply, and particularly its vertical distribution, combines with the light climate (light diminishes with depth and the presence of organic and non-organic matter) to control the productivity of the lower trophic level (LTL) marine ecosystem. Carbon is taken up through photosynthesis by phytoplankton, which are grazed by zooplankton; the plankton are transported by physical processes and also sink under gravity through the water column; bacteria act to decompose dead plankton and nutrients are released through remineralisation. The LTL ecosystem has a direct effect on the environment (e.g. through the development of harmful algal blooms (Anderson et al., 2002)) and supplies food for higher trophic levels (e.g. fish) used for human consumption or industry.

The northwest European continental shelf is part of the northeast Atlantic and is exposed to changes in the global atmospheric and oceanic climates. It also experiences direct anthropogenic pressure from close proximity to the highly populated industrial regions of northern Europe. Fishing activity (demersal trawling) and riverine nutrient input to the ocean are two such direct anthropogenic processes that combine with changes in the climate to impact on the shelf sea ecosystem. Demersal trawling acts to disturb the seabed and induces mortality in benthic fauna, leading to disruptions of food webs and biogeochemical cycles in the vicinity of the disturbance (Kaiser et al., 2006). Changes to nutrient loads impact the primary production and community composition, particularly in hydrodynamic regimes directly connected to the riverine sources. In particular high nutrient loads or imbalance in the ratio of nutrients may lead to deleterious eutrophication impacts such as high

* Corresponding author. Tel.: +44 151 7954809.
E-mail address: slwa@noc.ac.uk (S.L. Wakelin).

http://dx.doi.org/10.1016/j.jmarsys.2015.07.006
0924-7963/

biomass (Cadée and Hegeman, 2002), toxic algal blooms (Anderson et al., 2002) and near bed hypoxia (Dethlefsen and Von Westernhagen, 1983).

The policy driver behind this work is the Marine Strategy Framework Directive (MSFD: Directive 2008/56/EC[1]) of the European Commission, which requires member states to develop strategies to achieve a healthy marine environment and make ecosystems more resilient to climate change in all European marine waters by 2020 at the latest. The MSFD identifies 11 high level descriptors, 5 of which are considered here (D1 Biodiversity, D4 Food webs, D5 Eutrophication, D6 Sea floor integrity and D7 Hydrography). Each descriptor comprises a set of indicators which characterise marine ecosystems and requires an understanding of the possible pressures and impacts on them. For instance, Good Environmental Status (GES) is achieved when biodiversity is maintained (D1); the food web ensures long-term abundance of species (D4); eutrophication is minimised (D5); benthic ecosystems are not adversely affected by changes in the sea floor (D6) and the ecosystem is not adversely affected by changes in hydrographical conditions (D7). Numerical models such as those applied here provide a valuable tool to improve the knowledge base on marine ecosystems and input to the development of innovative tools for understanding and assessing GES in marine waters in European regional seas to inform the implementation of the MSFD. For examples, see decision support tools developed from numerical model simulations during the Marine Ecosystem Evolution in a Changing Environment (MEECE) project.[2]

Here we investigate the relative and combined effects of climate change and changes in the direct anthropogenic drivers of benthic fishing and river nutrients, and study the impacts on the LTL ecosystem over the northwest European shelf. A key question is the relative balance between climate change and direct drivers, whether they act synergistically or antagonistically, and whether management measures leading to changes in direct drivers can mitigate the effects of climate change.

A major driver of primary production is the availability of nutrients, particularly nitrogen and phosphate. Origins of these nutrients include natural (e.g. the open ocean) as well as anthropogenic sources such as the release from industry, urban waste water treatment and agriculture, through rivers and groundwater, to the ocean. For the European shelf as a whole, the largest source of nutrients is the open ocean, although regionally, such as in the English Channel and Irish Sea, river sources are significant (Huthnance, 2010). For the North Sea, Thomas et al. (2010) estimated that ~80% of nitrogen input comes through the northern boundary, ~4% from the Baltic outflow, ~9% from rivers and ~6% from the atmosphere. In coastal regions of the North Sea for a contemporary period (2000 onwards), Artioli et al. (2008) calculated the contribution of nitrogen from rivers to be 16%, with 26% coming from horizontal transport, 5% from atmospheric deposition and 53% from sediments (mainly through resuspension). Elevated nutrient concentrations imply that some coastal areas of the North Sea are at risk of eutrophication, giving rise to increases in biomass and the potential for detrimental effects such as oxygen depletion near the sea bed. During ~1950–1990, coastal waters of the North Sea experienced increases in nutrient loads of ~62% for nitrogen and ~45% for phosphate (Vermaat et al., 2008). Management action to reduce riverine nutrient sources to the North Sea started in the 1980s. The OSPAR Convention for the protection of the marine environment in the North-East Atlantic (http://www.ospar.org) is supported by 15 European governments and came into force in 1998; one of its aims is to tackle all sources of pollution affecting the maritime area, including the release of nutrients leading to eutrophication in the North Sea. The Paris Commission (PARCOM) made recommendations in 1988, 1989 and 1992 on reducing nutrient inputs to the North Sea (OSPAR, 1988, 1989, 1992).

The European shelf is also an important fishing region used by major international fishing fleets, with reported catches in the range of 2.5–3.1 million tonnes/year for 2006–2012 (ICES, 2014). For 1993–1996, Rijnsdorp et al. (1998) estimated that, in the most heavily fished regions in the southern North Sea, the Dutch beam trawler fleet covered 47%–71% of the surface area up to five times per year. There is significant effort in regulating fishing effort through the Common Fisheries Policy (CFP) (European Commission, 2011), regulations for managing European fishing fleets and for conserving fish stocks, first introduced in the 1970s. Recent regulations (European Commission, 2014) are aimed at reducing the wasteful practice of discarding catch in the North Sea.

The effects of climate change on the ecosystem are difficult to predict due to uncertainties in emission scenarios, climate forcing and models. Sources of uncertainty in atmospheric climate forcing include the trajectory of greenhouse gas emissions, their conversion into atmospheric concentrations and the responses of the global climate system to this radiative forcing (IPCC, 2001). In studying the impact of climate change on ecosystems the additional impact of direct anthropogenic drivers, such as those controlled by government policies, can also be considered. Foreseen and unforeseen events (e.g. changes in governments, demographics, economic recession and war) make long-term (>~50 years) projections of direct drivers highly uncertain. However, in some circumstances, the sign of change in a direct driver can be estimated: e.g., under environmental policies nutrient emissions from agriculture, waste water and industry might be restricted. The time frame considered by governments is typically ~5–6 years (e.g. duration of the European parliament). However, a time horizon of ~20–30 years is more useful for policymakers to legislate for climate change adaptation.

Models are a useful tool to study potential conditions under possible future climate, and are particularly suited to sensitivity experiments where the response of the system to changes in forcing can be assessed. There have been several recent studies downscaling global climate change projections to the ecosystem of European regional seas. Skogen et al. (2014) investigated eutrophication in the North Sea, Skagerrak, Kattegat and the Baltic Sea under a medium emissions scenario (A1B) and found little change in the North Sea eutrophication status due to changes in climate; river nutrients were kept at present day values. Also using a medium emissions scenario, Holt et al. (2012) demonstrated that the supply of nutrients from the open ocean is an important control of primary production on the northwest European shelf, particularly for the Irish shelf and the central and northern North Sea, which are exposed to exchange with the open ocean. Using a 1D water column model at three contrasting locations in the North Sea, Van der Molen et al. (2013) found that gross primary production increased and zoobenthos biomass and sea-bed oxygen decreased under climate change conditions; there was little interaction between the climate signal and the addition of demersal trawling indicating that reducing demersal trawling might mitigate the effects of climate change on benthic biomass.

Nutrient inputs from rivers and their relationship to eutrophication has substantial policy interest in this region owing to uncertainties in whether undesirable effects arise (e.g. Gowen et al., 2008), costs of amelioration and the transnational nature of the problem. There have been several modelling studies on the effects of reducing concentrations of nutrients released from rivers into the North Sea under present day and recent past conditions. Using a coupled river and multi-box model of the Southern Bight of the North Sea and eastern English Channel over the last 50 years, Lancelot et al. (2007) showed increases in *Phaeocystis* and diatom production with increasing river nitrogen and phosphate, and decreasing production when river phosphate loads fell. Lacroix et al. (2007) used a 3D model of the southern North Sea and showed that reducing river nitrogen loads led to an increase in diatom biomass, whereas decreasing river phosphate reduced both diatom and *Phaeocystis* biomass; in addition, changes in open-ocean nutrient concentrations transported eastwards through the English Channel

[1] http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm.

[2] http://meece.eu/.