TOOLBOX AQUACULTURE

UNIVERSITÉ DE NANTES

PML Plymouth Marine Laboratory

POLCOMS-ERSEM driven Dynamic Energy Budget (DEB) modelling of offshore Pacific oyster growth: indicators, regional comparison & identification of potential Allocated Zones for Aquaculture

SUGGESTED USERS	PLANNING PROCESS	TYPE OF AQUACULTURE
Aquaculture producers Spatial planners	Location Decision	Shellfish: Pacific oyster (Crassostrea gigas); could be adapted to other species

SUMMARY

Dynamic Energy Budget-modelled offshore Pacific oyster growth throughout western Europe and northwestern Africa, based on POLCOMS-ERSEM modelled environmental data (water temperature, chlorophyll-a), for an early-century reference period (2000-04) and two late-century future scenarios (2090-99; RCP 4.5, 8.5), digested into industry-relevant indicators for regional comparison and identification of potential Allocated Zones for Aquaculture by aquaculture producers and planners.

DESCRIPTION

Dynamic Energy Budget (DEB) theory, applied here to Pacific oyster (Crassostrea gigas), provides a generic (i.e., non-species-specific) approach to mechanistically model the flow of energy through individual organisms, from the ingestion and assimilation of food, through somatic maintenance and growth, to reproduction. It was driven using broad-scale (0.1°; pan-European), daily spatial water temperature and chlorophyll-a data (POLCOMS-ERSEM model output) to allow regions of good potential growth, now and under two future climate change scenarios, to be identified through mapping.

The approach described here provides a large, macro-scale perspective toward identifying areas within which future Allocated Zones for Aquaculture might most beneficially be designated and offshore oyster farms could be situated, in terms of various constraints and focusing on growth potential. Through quantitative mapping and analysis, areas warranting further investigation on a finer spatial scale are highlighted. Areas for which growth is expected to be more robust under variable climate conditions are also highlighted and should be paid special attention in planning and development, as should emerging areas, where oyster cultivation may not currently be present, but may be feasible and worthy of investment now and/or into the future. Such quantitative mapping of potential growth and related indicators can be included as part of more comprehensive spatial multi-criteria evaluation (SMCE) to further explore and integrate the social, economic, environmental, and biological suitability of a given site or area in aquaculture site selection and planning.

THE ISSUE BEING ADDRESSED

For aquaculture to develop as planned as part of the European Blue Growth strategy, several factors inhibiting the growth of this sector in the near-coastal zone, where cultivation conventionally takes place, need to be addressed. Namely, the lack of space in this densely-occupied area, for which offshore production is increasingly considered as a solution, and the lack of clear priorities and planning at the European and often country scales. To support both of these, broad-scale spatial data are needed for spatial planning and to inform site selection.

THE APPROACH

Dynamic Energy Budget (DEB) modelling of offshore Pacific oyster (Crassostrea gigas) growth was carried out at the regional scale using daily 0.1°-resolution surface layer water temperature and chlorophyll-a data (phytoplankton excluding picoplankton) outputs from POLCOMS-ERSEM modelling provided by the Plymouth Marine Laboratory (PML) for an early-century and two late-century climate change scenarios, and applied to the northeastern Atlantic, extending south to northwestern Africa, North Sea, and Mediterranean Sea. Future climate change scenarios are based on representative concentration pathway (RCP) 4.5, corresponding to a peak in greenhouse gas emissions at approximately 2040 and subsequent decline, and RCP 8.5, associated with continuously increasing emissions over the next century, were also used in growth modelling. In situ oyster growth data from collaborators and the literature were used to corroborate model results.

Spatial "hotspots" and changes in projected oyster growth over time under the different scenarios were considered in combination with chlorophyll-a, temperature, salinity, current speed, and bathymetric thresholds within which production is feasible, to identify areas that may sustain or increase in productivity in the future, as well as areas of existing cultivation that may become less productive or inappropriate. Differences between results from the early-century reference period and future RCP 4.5 and RCP 8.5 scenarios are intended to inform climate-adaptive aquaculture planning and policy. Daily time-step growth data were further digested into industry-relevant growth-related indicators (e.g., time to achieve minimum market weight) to aid in the interpretation of this tool by producers and planners alike, with both spat and grow-out scenarios considered.

THE RESULTS

Outputs are maps of modelled oyster growth (shell length, transformed empirically to total weight, and dry flesh mass) at the same temporal and spatial resolution as the input data for the simulated period (i.e., daily time-step between April 1 and December 1, and 0.1° respectively; Fig. 1). From an industry standpoint, most criteria of interest are related to total weight, which underlies the definition of oyster calibre and therefore demand and price. Several example indicators were therefore defined and implemented as a function of these. Key market timings and market weight thresholds were identified through consultation of producers and professionals from one of the main oyster-producing regions in France and examples of these are integrated into indicators mapped for the early-century reference period in Fig. 2: (a) days until the smallest spat size reach target sale size (T25; approximately 14g); (b) days until minimum adult market size (30g) is reached; and (c) weight (g) obtained by adults for the (main) December market.

Indicators are relevant to specialization in the production of various life stages (spat production, growing adults), and could easily be adapted to other user-defined criteria (e.g., the timing the weight of a certain calibre of oyster is achieved; growth for secondary summer market or another target date), by altering threshold values or dates. Areas for which growth is expected to be more robust under variable climate conditions are particularly highlighted and should be paid special attention in planning and development, as should emerging areas, where oyster cultivation may not currently be present, but may be feasible and worthy of investment now and/or into the future. Broad areas highlighting exceptional and climate-robust growth can be used as part of spatial multi-criteria analysis to determine Allocated Zones for Aquaculture, within which more detailed, local studies can be carried out for farm site selection.

THE BROADER APPLICABILITY

Although applied here for Pacific oyster, DEB theory has also been used to investigate the growth of other species under variable environmental conditions, and a similar exercise could foreseeably be used to model growth-related indicators other species of interest (e.g. blue mussel (*Mytilus edulis*), Mediterranean mussel (*Mytilus galloprovincialis*), and great scallop (Pecten maximus)). In situ growth data should be used to corroborate model results. Likewise, based on current industry standards and preferences, and in consultation with industry professionals, we have selected and mapped a suite of growth-related indicators to enhance the relevance of the model output data, but growth data could also be transformed into other user-defined indicators, using the mapped time series provided here, and model initialization criteria (e.g., oyster size, start date) can also be adapted to user requirements.

Pacific oyster growth indicator maps:

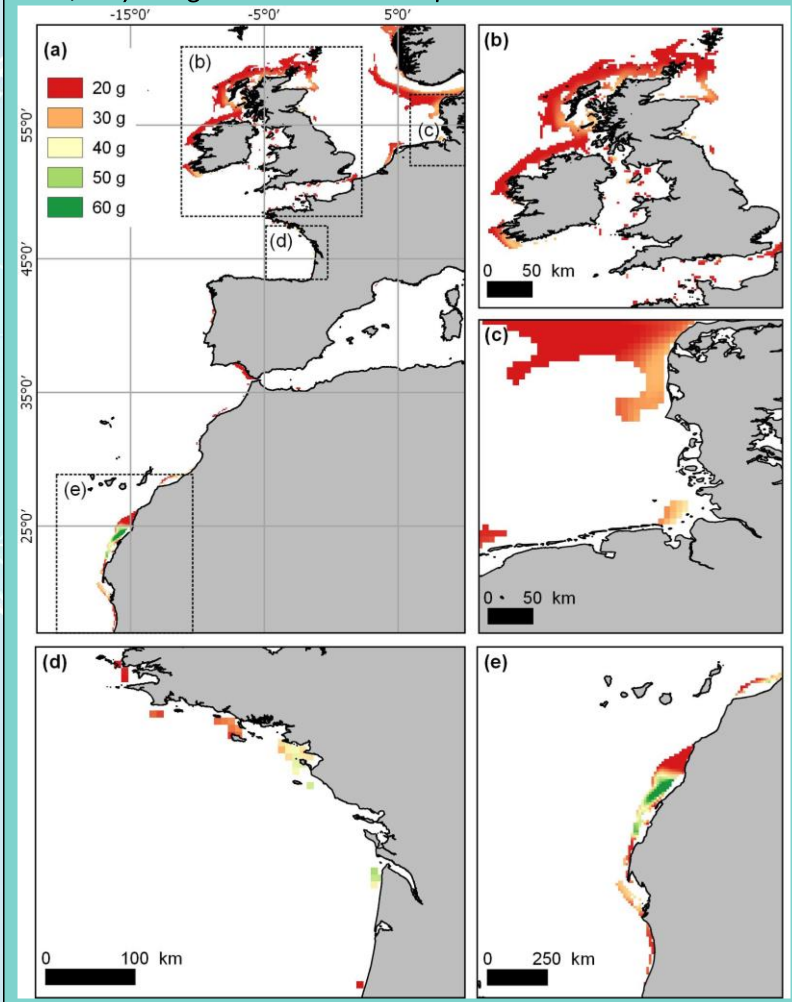

Figure 1. Total adult weight obtained by Dec. 1 (from an initial weight of 14 g on April 1) for the early-century reference period, for the full model domain (a), and indicated close-ups; (b) the United Kingdom, (b) the southeastern North Sea, (c) the Bay of Biscay, and (d) the west coast of Western Sahara and Mauritania.

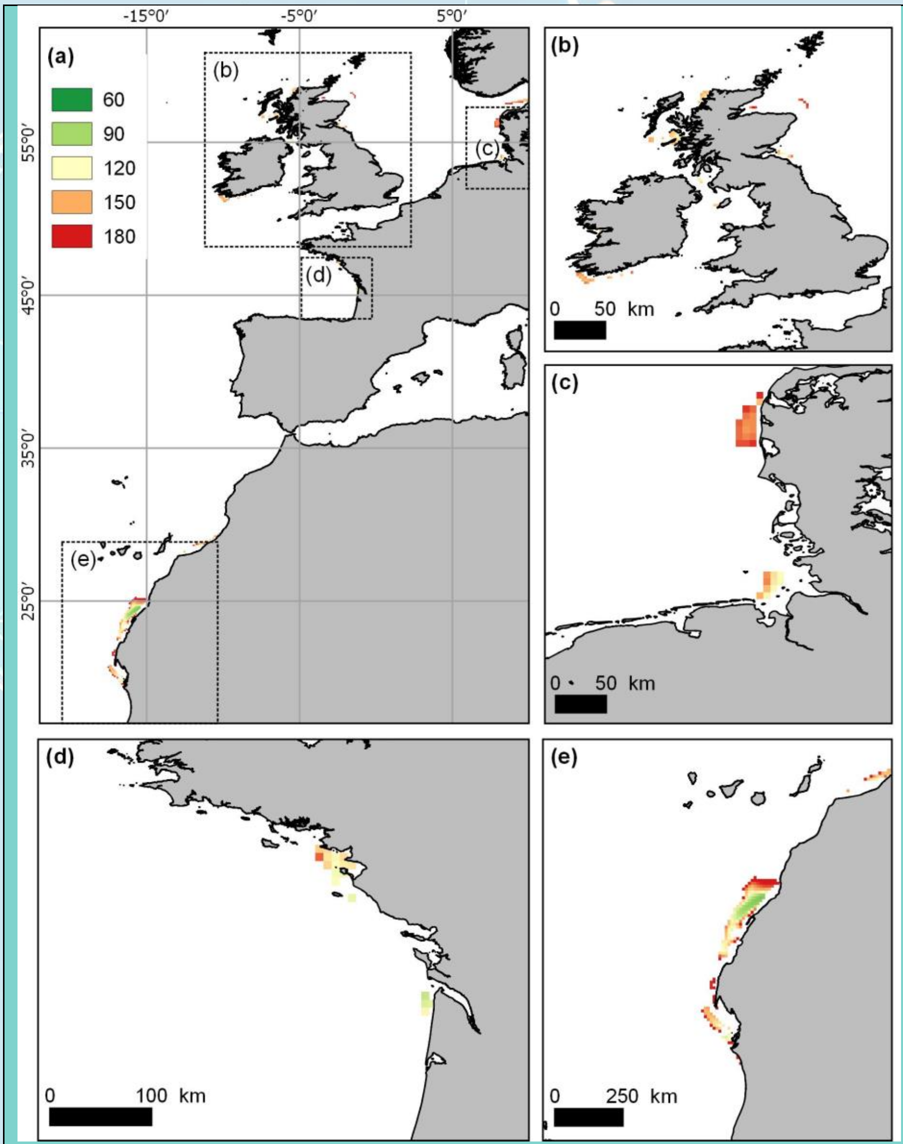

Figure 2. Days until 30 g total adult weight (i.e., minimum market weight) is reached (from April 1) for the early-century reference period, for the full model domain (a), and indicated close-ups; (b) the United Kingdom, (b) the southeastern North Sea, (c) the Bay of Biscay, and (d) the west coast of Western Sahara and Mauritania.

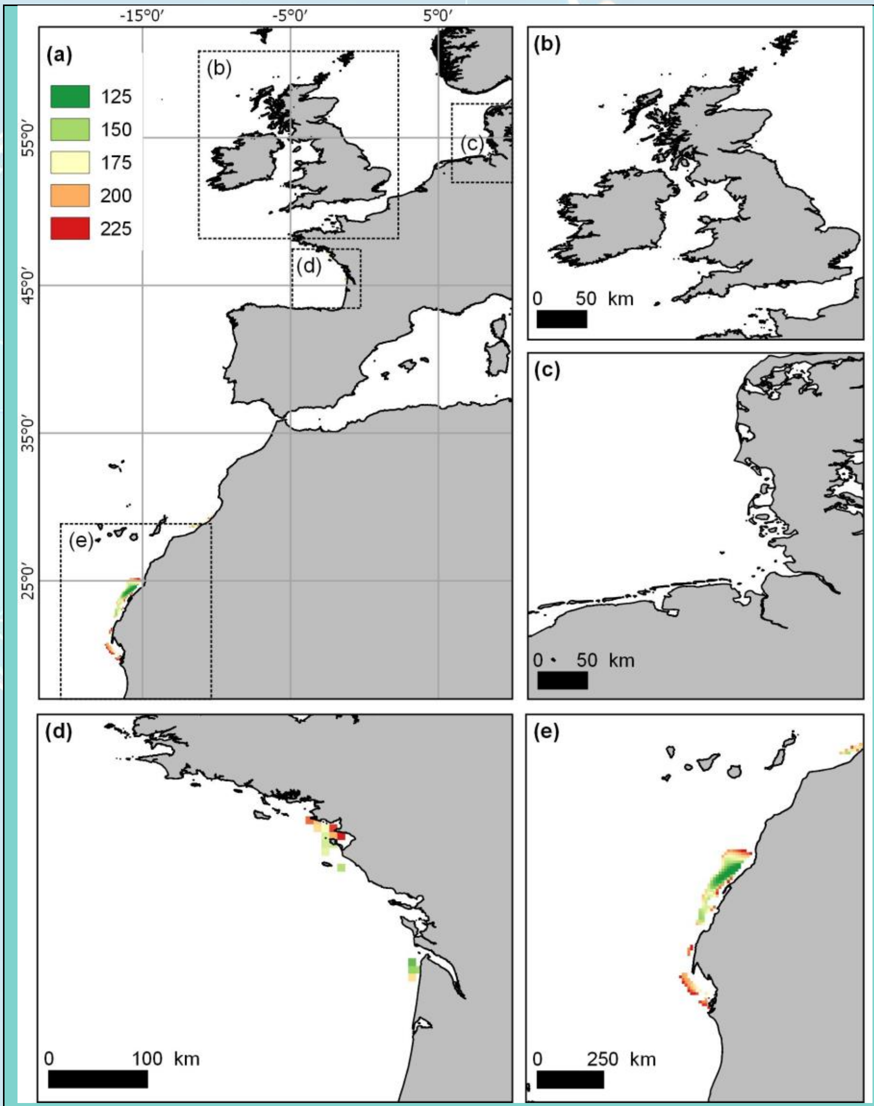

Figure 3. Days until 14 g total spat weight (i.e., T20/T25 industrial weight) is reached (from April 1) for the early-century reference period, for the full model domain (a), and indicated close-ups; (b) the United Kingdom, (b) the southeastern North Sea, (c) the Bay of Biscay, and (d) the west coast of Western Sahara and Mauritania.

SWOT ANALYSIS	
STRENGTHS	DEB modelling is broadly adaptable geographically and to many farmed species; various input data and scenarios can be used and compared Can provide macro- (as here) and local-scale assessment, depending upon the input data used
WEAKNESSES	Requires empirical calibration, and therefore in situ data Model in its current form is not user-friendly/easily transferable

OPPORTUNITIES	Macro-siting; identification of potential AZAs and/or regions for more detailed analysis
THREATS	Lack of in situ data for more extensive calibration and to transfer to other areas/eligible species

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LINK	The DEB wiki contains more extensive description of DEB theory and tools, and provides links to additional resources and research in the community, including for other species: http://www.debtheory.org/wiki/index.php?title=Main_Page The ERSEM website provides more detail on the biogepchemical model data used in this work, as well as model code: https://www.pml.ac.uk/Modelling_at_PML/Models/ERSEM