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D1.7 Scientific Papers from WP1: Driver parameterisations and model scenarios

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Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission)	
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D1.7 Scientific Papers from WP1: Driver parameterisations and model scenarios

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List compiled August 2011*

The overall objective of WP1 was to quantify the sensitivity of marine organisms and ecosystems to important ecosystem drivers (climate patterns, ocean circulation, ocean acidification, overfishing, invasion of alien species and pollution (including eutrophication) and develop new model parameterisations and perturbation scenarios for implementation in, and testing of, ecosystem models. Key sub objectives included collating existing information on the drivers and their impacts on the marine ecosystem, validation information for the regional models and experimentation to investigate the response of ecosystem components to multiple drivers. The ultimate goal of the exercise being to provide model parameterisations and scenario definitions for each driver on a regional scale. The final objective is to publish the advances in technical and scientific knowledge generated in the peer reviewed literature.

To date MEECE WP1 has published 15 papers in a variety of journals including one in Science, with a further six submitted. The published papers represent aspects of the diverse range of activities. Particular focal points of published activity thus far have been plankton and metabolic theory, alien invasive species, model validation, ecotoxicology and modelled plankton response to climate. It should be noted that while WP1 is now complete, the work of writing up the results and completing the publishing process is ongoing and this deliverable will be updated at the end of the project.

A. Published Papers

1. Allen JI, Polimene L, (2011). Linking physiology to ecology: Towards a new generation of plankton models. Journal of Plankton Research 33, 989-997. DOI: 10.1093/plankt/fbr032

<http://plankt.oxfordjournals.org/content/33/7/989.full.pdf+html>

Abstract: Understanding how plankton communities change under varying environmental conditions is crucial to assessing the effects of global change on marine ecosystems. Marine plankton community evolution is generated from the non-linear combination of biotic and abiotic ecosystem forcing and, therefore, is an emergent property and difficult to predict. The adequacy of current modelling approaches for generating emergent properties is discussed and suggestions are made for new directions that may better capture the emergent properties of marine ecosystems. It is suggested that more emphasis is placed on underlying mechanism of cell physiology and foodweb interactions and less on empirical or numerical parameter fitting. Biogeochemistry and ecology can be considered as generated by a

limited number of "physiological rules" (photosynthesis, respiration, antioxidant response, autophagy etc.) which are "prescribed" and common to all phytoplanktonic organisms. The challenge is to design a generic cell that captures the essence of key physiological activities (photosynthesis, nutrient and endocytotic uptake, ingestion, respiration, oxyradical defence mechanisms etc.). Once we have such a model cell, we can then define plankton functional types in terms of their capacity to implement each function (i.e. to allocate resources within cellular functions) and hence generate biogeochemical function and ecosystem structure as emergent properties in response to environmental changes. Ultimately, there is a need to think differently and more creatively about how marine ecosystems are modelled.

**2. Acuña, JL. Lopez-Urrutia A. and Colin S, (2011). Faking giants: the evolution of high prey clearance rates in jellyfish. Science. 333 1627-1629
DOI: 10.1126/science.1205134**

<http://www.sciencemag.org/content/333/6049/1627.full>

Abstract: Jellyfishes have functionally replaced several overexploited commercial stocks of planktivorous fishes. This is paradoxical, because they use a primitive prey capture mechanism requiring direct contact with the prey, whereas fishes use more efficient visual detection. We have compiled published data to show that, in spite of their primitive life-style, jellyfishes exhibit similar instantaneous prey clearance and respiration rates as their fish competitors and similar potential for growth and reproduction. To achieve this production, they have evolved large, water-laden bodies that increase prey contact rates. Although larger bodies are less efficient for swimming, optimization analysis reveals that large collectors are advantageous if they move through the water sufficiently slowly.

3. Dagnino A, Sforzini S, Boatti L, Capri F, Oliveri C, Negri A, Dondero F, Viarengo A, (2010). Sub-lethal effects of copper combined with temperature stress in the marine mussel *Mytilus galloprovincialis*. Comparative Biochemistry and Physiology, 157A (1 / Suppl.), S38:S39.

Abstract: The intertidal bivalves *Mytilus* spp. have been used in biomonitoring of marine ecosystems for over 30 years. Water temperature fluctuations are typical of Mediterranean Sea environments and it might represent a confounding factor for the correct assessment of the mussel health status and the use of mussels as bioindicators. To date, very little is known about the interaction of heat with pollutants for what concern the cellular responses of mussels. With the aim to clarify some of these aspects, we carried out short term exposure of *Mytilus galloprovincialis* specimens to five copper concentrations (2.5–40 µg/L) within a temperature gradient ranging from 16°C to 24°C. Core biomarker responses, i.e. lysosomal membrane stability (LSM), neutral lipid (NP) and lipofuscin content, were examined in the digestive tissue along with a battery of molecular assays, including DNA-microarray and real time quantitative PCR. Our results showed significant lysosomal destabilization and accumulation of NP and lipofuscin along with the raise of pollutant concentration. However, in general effects of temperature were mostly confined to molecular changes and did not affect mussel physiological functions. These data seem to indicate that marine inter-tidal organisms such as mussels are suddenly able to adapt to temperature changes confirming their primary role in biomonitoring programs as robust bio indicators of chemical contaminations. The present research is carried out in the framework of EU FP7 MEECE.

4. de Kluijver AK, Soetaert K, Schulz G, Riebesell U, Bellerby R and Middelburg JJ, (2010). Phytoplankton-bacteria coupling under elevated CO₂ levels: a stable isotope labelling study *Biogeosciences*, 7, 3783-3797.

<http://www.biogeosciences.net/7/3783/2010/bg-7-3783-2010.pdf>

Abstract: The potential impact of rising carbon dioxide (CO₂) on carbon transfer from phytoplankton to bacteria was investigated during the 2005 PeECE III mesocosm study in Bergen, Norway. Sets of mesocosms, in which a phytoplankton bloom was induced by nutrient addition, were incubated under 1× (350 μatm), 2× (700 μatm), and 3× present day CO₂ (1050 μatm) initial seawater and sustained atmospheric CO₂ levels for 3 weeks. ¹³C labelled bicarbonate was added to all mesocosms to follow the transfer of carbon from dissolved inorganic carbon (DIC) into phytoplankton and subsequently heterotrophic bacteria, and settling particles. Isotope ratios of polar-lipid-derived fatty acids (PLFA) were used to infer the biomass and production of phytoplankton and bacteria. Phytoplankton PLFA were enriched within one day after label addition, whilst it took another 3 days before bacteria showed substantial enrichment. Group specific primary production measurements revealed that coccolithophores showed higher primary production than green algae and diatoms. Elevated CO₂ had a significant positive effect on post-bloom biomass of green algae, diatoms, and bacteria. A simple model based on measured isotope ratios of phytoplankton and bacteria revealed that CO₂ had no significant effect on the carbon transfer efficiency from phytoplankton to bacteria during the bloom. There was no indication of CO₂ effects on enhanced settling based on isotope mixing models during the phytoplankton bloom, but this could not be determined in the post-bloom phase. Our results suggest that CO₂ effects are most pronounced in the post-bloom phase, under nutrient limitation.

5. Frigstad H, Andersen T, Hessen DO, Naustvoll LJ, Johnsen TM and Bellerby R, (2011). Seasonal variations in C:N:P stoichiometry: can the composition of seston explain stable Redfield ratios? *Biogeosciences*, 8, 2917-2933, 2011

<http://www.biogeosciences-discuss.net/8/6227/2011/bgcd-8-6227-2011.pdf>

Abstract: Seston is suspended particulate organic matter, comprising a mixture of autotrophic, heterotrophic and detrital material. Despite variable proportions of these components, marine seston often exhibit relatively small deviations from the Redfield ratio (C:N:P = 106:16:1). Two time-series from the Norwegian shelf in Skagerrak are used to identify drivers of the seasonal variation in seston elemental ratios. An ordination identified water mass characteristics and bloom dynamics as the most important drivers for determining C:N, while changes in nutrient concentrations and biomass were most important for the C:P and N:P relationships. A generalized linear model was used to differentiate between the live autotrophic and non-autotrophic sestonic fractions, and for both stations the non-autotrophic fractions dominated with respective annual means of 24 and 45% live autotrophs. The autotrophic percentage calculated from the statistical model was compared with estimated phytoplankton carbon, and the two independent estimates of autotrophic percentage were comparable with similar seasonal cycles. The estimated C:nutrient ratios of live autotrophs were in general lower than Redfield, while the non-autotrophic C:nutrient ratios were higher than the live autotrophic ratios and above or close to the Redfield ratio. This is due to preferential remineralization of nutrients (especially phosphorus), while carbon gradually builds up in the detritus pool. Despite the seasonal variability in seston composition and the generally low contribution of autotrophic biomass, the variation observed in the total seston ratios was low compared to the variation found in dissolved and particulate pools. This study shows that sestonic Redfield ratios

cannot automatically be interpreted as phytoplankton with “balanced growth”, but could instead reflect varying contributions of sestonic compartments that sum up to an elemental ratio close to Redfield.

6. Ojaveer H, Jaanus A, MacKenzie BR, Martin G, Olenin S, Telesh I, Zettler M, Zaiko A, (2010). Status of Biodiversity in the Baltic Sea. PLoS ONE Collection: Marine Biodiversity and Biogeography Regional Comparisons of Global Issues, 5(9): e12467 doi:10.1371/journal.pone.0012467 eISSN-1932-6203

<http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0012467>

Abstract: The brackish Baltic Sea hosts species of various origins and environmental tolerances. These immigrated to the sea 10,000 to 15,000 years ago or have been introduced to the area over the relatively recent history of the system. The Baltic Sea has only one known endemic species. While information on some abiotic parameters extends back as long as five centuries and first quantitative snapshot data on biota (on exploited fish populations) originate generally from the same time, international coordination of research began in the early twentieth century. Continuous, annual Baltic Sea-wide long-term datasets on several organism groups (plankton, benthos, fish) are generally available since the mid-1950s. Based on a variety of available data sources (published papers, reports, grey literature, unpublished data), the Baltic Sea, incl. Kattegat, hosts altogether at least 6,065 species, including at least 1,700 phytoplankton, 442 phytobenthos, at least 1,199 zooplankton, at least 569 meiozoobenthos, 1,476 macrozoobenthos, at least 380 vertebrate parasites, about 200 fish, 3 seal, and 83 bird species. In general, but not in all organism groups, high sub-regional total species richness is associated with elevated salinity. Although in comparison with fully marine areas the Baltic Sea supports fewer species, several facets of the system's diversity remain underexplored to this day, such as micro-organisms, foraminiferans, meiobenthos and parasites. In the future, climate change and its interactions with multiple anthropogenic forcings are likely to have major impacts on the Baltic biodiversity.

7. Peric L, Robotti E, Boatti L, Marsano F, Negri A, Marengo E and Viarengo A, (2010). Maldi TOF profile of *Mytilus galloprovincialis* haemolymph proteins. Comparative Biochemistry and Physiology, 157A (1/Suppl.), S46.

<http://www.sciencedirect.com/science/article/pii/S1095643309009015>

Abstract: Haemolymph represents the circulatory fluid of mollusks with an open circulatory system. The majority of studies of the mussels *Mytilus galloprovincialis* haemolymph have mainly been focused on the function of blood cellular component and humoral factors related to immune defense, while data on the protein composition has recently started to emerge. Thus, the goal of the present study was to investigate the mussel's haemolymph proteome, utilizing proteomics techniques such as two-dimensional electrophoresis (2DE) in combination with mass spectrometry. 2DE under denaturing conditions revealed the presence of several tightly closed and highly abundant protein bands of 30–45kDa and with pI values ranging from 4.0 to 6.0. With respect to the above characteristics, the dominant protein component matched histidine rich glycoprotein (HRG) previously isolated from haemolymph of *M. edulis* on the basis of its highly expressed metal binding properties. The protein spot was identified by ESI-QTOF MS/MS and the database search revealed its high homology with the extrapallial protein (EP) which was

isolated from extrapallial fluid of mussel *M. edulis* and could have a role in Ca^{2+} -transport and as a shell matrix protein. We also investigated the protein expression in *M. galloprovincialis* haemolymph, following *in vivo* exposure to sublethal concentrations of heavy metals known to induce the formation of reactive oxygen species (ROS), which can cause carbonylation of proteins. Quantization of carbonylated proteins in *M. galloprovincialis* haemolymph could provide further insight in the effects of oxidative stress on the proteome of this bivalve species.

8. Sal S, Lopez-Urrutia A, (2011). Temperature, nutrients, and the size-scaling of phytoplankton growth in the sea. *Limnology And Oceanography* Volume: 56 Issue: 5 Pages: 1952-1955 DOI: 10.4319/lo.2011.56.5.1952

http://www.aslo.org/lo/toc/vol_56/issue_5/1952.pdf

Comments in *Limnology and Oceanography* don't have an abstract.

9. Shutler J, Smyth TJ, Saux-Picart S, Wakelin SL, Hyder P, Orekhov P, Grant MG, Tilstone GH and Allen JI, (2011). Evaluating the ability of a hydrodynamic ecosystem model to capture inter- and intra-annual spatial characteristics of chlorophyll-a in the north east Atlantic *Journal of Marine Systems*, 88 , 169-182 DOI: 10.1016/j.jmarsys.2011.03.013

<http://www.sciencedirect.com/science/article/pii/S0924796311000777>

Abstract: As our reliance upon numerical models for forecasting environmental conditions increases, so does our need to quantitatively analyse their performance. Often, a single metric approach is adopted, the choice of which is dependent upon the application for which the model output are to be used. Here we present a multi-metric verification approach to analyse the spatial and temporal performance of a hydrodynamic ecosystem model. The metrics allow us to investigate the model's ability to predict the inter- and intra-annual spatial variations and are used to evaluate surface chlorophyll-a estimates from the POLCOMS-ERSEM model, using satellite Earth observation data from NASA's MODIS-Aqua sensor. The study focuses on a region of the north east Atlantic which encompasses both open ocean and shelf seas, presenting a sizeable challenge for any model. The metrics reveal that the model is able to capture the mean annual chlorophyll-a signal (as exhibited in the Earth observational data) and has the capability to describe medium scale spatial variations. The seasonal signal exhibited in the Earth observation data is not apparent in the model fields. Possible reasons for the mis-match between the Earth observation and model data are discussed. Notwithstanding these issues, the model exhibits predictive skill during the northern hemisphere summer months for a range of chlorophyll-a concentrations. This multi-metric evaluation approach provides a method for the rigorous evaluation of the spatial and temporal accuracy of the hydrodynamic ecosystem model.

10. Steinacher M, Joos F, Frölicher TL, Bopp L, Cadule P, Cocco V, Doney SC, Gehlen M, Lindsay K, Moore JK, Schneider B and Segschneider J, (2010). "Projected 21st century decrease in marine productivity: a multi-model analysis", *Biogeosciences*, 7/3, 979-1005.

<http://www.biogeosciences.net/7/979/2010/bg-7-979-2010.pdf>

Abstract: Changes in marine net primary productivity (PP) and export of particulate organic carbon (EP) are projected over the 21st century with four global coupled carbon cycle-climate models. These include representations of marine ecosystems

and the carbon cycle of different structure and complexity. All four models show a decrease in global mean PP and EP between 2 and 20% by 2100 relative to preindustrial conditions, for the SRES A2 emission scenario. Two different regimes for productivity changes are consistently identified in all models. The first chain of mechanisms is dominant in the low- and mid-latitude ocean and in the North Atlantic: reduced input of macro-nutrients into the euphotic zone related to enhanced stratification, reduced mixed layer depth, and slowed circulation causes a decrease in macro-nutrient concentrations and in PP and EP. The second regime is projected for parts of the Southern Ocean: an alleviation of light and/or temperature limitation leads to an increase in PP and EP as productivity is fuelled by a sustained nutrient input. A region of disagreement among the models is the Arctic, where three models project an increase in PP while one model projects a decrease. Projected changes in seasonal and interannual variability are modest in most regions. Regional model skill metrics are proposed to generate multi-model mean fields that show an improved skill in representing observation-based estimates compared to a simple multi-model average. Model results are compared to recent productivity projections with three different algorithms, usually applied to infer net primary production from satellite observations.

11. Smyth T and Artioli Y, (2010). Global inherent optical properties from SeaWiFS data. Plymouth Marine Laboratory, doi:10.1594/PANGAEA.741913

<http://doi.pangaea.de/10.1594/PANGAEA.741897>

Coverage: Date/Time Start: 1998-01-01T00:00:00 * *Date/Time End:* 2009-12-31T00:00:00

Comment:

The PML IOP model is a fully analytical approach based on simultaneously solving the remote sensing reflectance equation at two neighbouring wavelengths. For the SeaWiFS sensor these wavelengths are 490 and 510 nm. The only empirical information required is the spectral slope in both backscatter and total absorption for determining the primary measurements of total backscatter and total absorption. These were derived using the COLORS dataset and details can be found in Smyth et al. (2006, doi:10.1364/AO.45.008116). The model assumes a spectral shape for the backscatter and uses this information to extrapolate to the other wavelengths. The bio-geochemical parameters of absorption due to phytoplankton and absorption due to yellow substance and detritus are derived in a similar manner, but this time simultaneously solving for the wavelength pair 412: 443 nm. Again empirical data from the COLORS dataset is used to solve the equations. The surface interface term has been determined using look-up-tables generated from the HYDROLIGHT radiative transfer scheme and a solution is iteratively arrived at. Again, for full details see Smyth et al., (2006). The input data are the SeaWiFS global normalised water leaving radiance at wavelengths 412, 443, 490, 510 and 555 nm. The nominal resolution of the images is 18 km on an equal angle projection.

12. Vichi M, Allen JI, Masina S and Hardman-Mountford NJ, (2011). The emergence of ocean biogeochemical provinces: a quantitative assessment and a diagnostic for model evaluation, Global Biogeochem. Cycles, doi:10.1029/2010GB003867

<http://europa.agu.org/?view=article&uri=/journals/gb/gb1102/2010GB003867/2010GB003867.xml&t=2010GB003867>

Abstract: The concept of ocean biogeochemical provinces is based on the observation that large ocean regions are characterized by coherent physical forcing and environmental conditions, which are eventually representative of macroscale ocean ecosystems. Biogeochemical models of the global ocean focus on simulating the coupling between prevalent physical conditions and the biogeochemical processes with the assumption that biological properties respond coherently to physics and therefore should produce such provinces as an emergent property. In this paper, we quantitatively assess the emergence of a reference set of predefined biogeochemical provinces in the available global data sets and propose a province-based approach to the evaluation of one of the most comprehensive models of ocean biogeochemistry. Multivariate statistical tools were applied to model and observation data, verifying the existence, distinctiveness and reliability of the predefined provinces and quantifying the correlation of model results with observations at the global scale. The analysis of similarity between provinces shows that they are statistically separable in data and model output and therefore can be used as reliable metrics. The analyses indicate that provinces can be more easily distinguished in terms of their environmental features rather than using chlorophyll concentration. The characterization of provinces by means of chlorophyll values shows a significant overlap in both the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data and the model. It is likely this is related to the choice of province boundaries based on coarse-resolution mapped data, which are not necessarily the same as those derivable from high-resolution satellite data. We also demonstrated through cluster analysis that the long-term time series data collected at Joint Global Ocean Flux Study (JGOFS) stations are representative of environmental conditions of the respective province and can thus be used to evaluate model results extracted from that province. The method shows promise for helping to overcome problems with model verification due to under sampling of most ocean biogeochemical variables but also gives indications that unsupervised clustering may be required when more spatially resolved data and models are available.

13. Morán XAG, López-Urrutia A, Calvo-Díaz A and Li W, (2010). Increasing importance of small phytoplankton in a warmer ocean. *Global Change Biology* 2010 Volume: 16, Issue: 3, Pages: 1137-1144

<http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2009.01960.x/pdf>

Abstract: The macroecological relationships among marine phytoplankton total cell density, community size structure and temperature have lacked a theoretical explanation. The tiniest members of this planktonic group comprise cyanobacteria and eukaryotic algae smaller than 2 μ m in diameter, collectively known as picophytoplankton. We combine here two ecological rules, the temperature-size relationship with the allometric size-scaling of population abundance to explain a remarkably consistent pattern of increasing picophytoplankton biomass with temperature over the -0.6 to 22 degrees C range in a merged dataset obtained in the eastern and western temperate North Atlantic Ocean across a diverse range of environmental conditions. Our results show that temperature alone was able to explain 73% of the variance in the relative contribution of small cells to total phytoplankton biomass regardless of differences in trophic status or inorganic nutrient loading. Our analysis predicts a gradual shift toward smaller primary producers in a warmer ocean. Because the fate of photosynthesized organic carbon largely depends on phytoplankton size, we anticipate future alterations in the functioning of oceanic ecosystems.

14. Zaiko A, Paškauskas R and Krevš A, (2010). Biogeochemical alteration of benthic environment by zebra mussel *Dreissena polymorpha* (Pallas). OCEANOLOGIA, 52 (4), 649-667.

<http://www.iopan.gda.pl/oceanologia/524zaiko.pdf>

Abstract: The aim of this study was to verify whether the biogeochemical features (e.g. concentration of nutrients, oxygen consumption, mineralization rate, Eh) of sediments changed by the zebra mussel or its shell deposits differ from those in the ambient soft bottom, and how these differences are related to the structure of benthic macroinvertebrates. In 2006 three sampling sessions were carried out in the Curonian Lagoon, SE Baltic Sea, at three pre-defined sites, corresponding to different bottom types: zebra mussel bed, zebra mussel shell deposits and bare soft sediments. Similarity analysis of biogeochemical parameters indicated that bottom sediments covered with zebra mussel shell deposits were rather distinct from the other bottom types because of the lowest total organic matter mineralization rate and highest organic carbon, total phosphorus and total nitrogen content. The parameters measured in the zebra mussel bed did not deviate conspicuously from the values observed in bare bottoms, except for the higher rate of oxygen consumption in the upper sediment layer. Unsuitable anoxic conditions on the one hand and the 'attractive' shelters provided by zebra mussels on the other hand may promote the epifaunal life style in the habitats formed by dense zebra mussel clumps

15. Zaiko A, Lehtiniemi M, Narščius A and Olenin S, (2011). Assessment of bioinvasion impacts on a regional scale: a comparative approach. Biological Invasions. DOI 10.1007/s10530-010-9928-

<http://www.springerlink.com/content/a644577r5047jv83/>

Abstract: This paper presents an overall bioinvasion impact assessment on the scale of a large marine region-the Baltic Sea, as defined by the Helsinki Commission. The methodology is based on a classification of the abundance and distribution range of alien species and the magnitude of their impacts on native communities, habitats and ecosystem functioning aggregated in a "Biopollution Level" index (BPL) which ranges from 'no impact' (BPL = 0) to 'massive impact' (BPL = 4). The assessment performed for nine Baltic sub-regions revealed that documented ecological impact is only known for 43 alien species out of 119 registered in the Sea. The highest biopollution (BPL = 3, strong impact) occurs in coastal lagoons, inlets and gulfs, and the moderate biopollution (BPL = 2)-in the open sea areas. The methodology was also used to classify species into alien (BPL = 0) versus 'impacting' species (BPL > 0), which can be divided into 'potentially invasive' (BPL = 1) and 'invasive' (BPL > 1) ones. No clear correlation between the number of established alien and impacting species was found in the sub-regions of the Baltic Sea. The methodology, although requiring a substantial research effort, proved to be useful for interregional comparisons and evaluating the bioinvasion effects of individual alien species.

B. Submitted for Publication

1. Årthun M, Bellerby RGJ, Omar AM, Schrum C. Air-sea CO₂ fluxes in the Barents Sea as determined from empirical relationships. Submitted to Journal of Marine Systems.

2. Artioli Y, Blackford JC, Butenschön M, Holt JT, Wakelin SL and Allen I. The carbonate system of the NW European shelf: sensitivity and model validation. Submitted to *Journal of Marine Systems*
3. Bueno, J. and Lopez-Urrutia A (under review). Merging life-history and metabolic scaling theories for developmental time
4. Hessen DO, Frigstad H, Færevig PJ, Wojewodzic MW and Leu E. UV radiation and its effect on P-uptake in arctic diatoms. In revision for *J. Exp. Marine Biol. Ecol.*
5. Llope M, Licandro P, Stige LC, Chanc K-S, John AWG, Lindley JA, Stenseth NC. Spatio-temporal dynamics of the North Sea plankton functional groups over the last 50 years. Submitted to *Limnology & Oceanography*.
6. Olenin S and Minchin D, (in press). Introductions of non-indigenous species to coastal and estuarine systems: pathways and implications for environmental quality. In: *Treatise on Estuarine and Coastal Science. Volume 8: Human-induced Changes in Coastal and Estuarine Regions.* (Elsevier).