Ecological Indicators 11 (2011) 168–174

Contents lists available at ScienceDirect

Ecological Indicators

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

Ecosystem based modeling and indication of ecological integrity in the German North Sea—Case study offshore wind parks

Benjamin Burkhard [a,*], Silvia Opitz [b], Hermann Lenhart [c], Kai Ahrendt [d], Stefan Garthe [e], Bettina Mendel [e], Wilhelm Windhorst [a]

[a] Ecology Centre University of Kiel, Olshausenstr. 40, 24098 Kiel, Germany
[b] Leibniz Institute of Marine Sciences University of Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany
[c] Institute for Marine Research, Hamburg University, Bundesstr. 53, 20146 Hamburg, Germany
[d] Company for Environment & Coast, Steinstr. 25, 24118 Kiel, Germany
[e] Research and Technology Centre West Coast, Hafentörn 1, 25761 Büsum, Germany

ARTICLE INFO

Article history:
Received 6 June 2008
Received in revised form 16 March 2009
Accepted 10 July 2009

Keywords:
Marine ecosystems
Artificial reefs
Offshore wind power
Integrated Coastal Zone Management (ICZM)
Ecosystem dynamic

ABSTRACT

Human exploitation and use of marine and coastal areas are apparent and growing in many regions of the world. For instance, fishery, shipping, military, raw material exploitation, nature protection and the rapidly expanding offshore wind power technology are competing for limited resources and space. The development and implementation of Integrated Coastal Zone Management (ICZM) strategies could help to solve these problems. Therefore, suitable spatial assessment, modeling, planning and management tools are urgently needed. These tools have to deal with data that include complex information on different spatial and temporal scales. A systematic approach based on the development of future scenarios which are assessed by combining different simulation models, GIS methods and an integrating set of ecological integrity indicators, was applied in a case study in the German North Sea. Here, the installation of huge offshore wind parks within the near future is planned. The aim was to model environmental effects of altered sea-use patterns on marine biota. Indicators of ecological integrity were used to assess altering conditions and possible ecosystem shifts ranging from systems' degradations to the development of highly productive and diverse artificial reef systems. The results showed that some ecosystem processes and properties and related indicators are sensitive to changes generated by offshore wind park installations while others did not react as hypothesized.

1. Introduction

Coastal and marine regions have been of special interest for human activities due to their high potentials to provide ecosystem goods and services (UNEP, 2006; Peterson and Lubchenco, 1997). Besides more traditional uses like fishery or raw material exploitation, contemporary activities include rapidly growing shipping traffic and the implementation of offshore wind parks (OWPs) for electricity generation. The latter has become an issue in Germany due to its high demand for space and its political desire to mitigate the effects of climate change (POWER, 2005). Integrated Coastal Zone Management (ICZM) has the potential to aid in solving conflicts between competing forms of anthropogenic activities and their effects (Cicin-Sain and Knecht, 1998). In Germany, the Federal Maritime and Hydrographic Agency (BSH) has been authorized to carry out the planning and licensing of OWPs. Two reasons typically cited for refusal of respective approvals are: (a) the interference with shipping activities; and (b) possible threats to the marine environment. Until now, 16 applications for construction of OWPs have been approved in Germany's Exclusive Economic Zone (EEZ) of the North Sea and three in the Baltic Sea (www.bsh.de; December 2008) even though little is known about their environmental impacts so far. Two OWP applications in the Baltic Sea were declined due to nature conservation reasons. Appropriate tools and methods appear needed to assess potential impacts of OWPs on marine environments.

The framework and methodology presented in this paper link different models aiming to carry out a holistic assessment of diverse biotic and abiotic components and processes relevant for the functioning of marine ecosystems. Hypothetical installations of future OWPs were chosen as case study because they represent a new form of sea use likely to play a major role in future sea-use patterns. To date a huge number of methods for analyzing environmental impacts of human activities on coastal ecosystems are available (Bierman et al., 2011) and studies with special focus

* Corresponding author. Tel.: +49 431 880 1230; fax: +49 431 880 4083.
E-mail address: bburkhard@ecology.uni-kiel.de (B. Burkhard).

1470-160X/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecolind.2009.07.004

on offshore wind energy have been carried out (e.g. in Köller et al., 2006), but still there are many gaps in knowledge, especially with regard to long term and spatial effects and system dynamics. It is unclear if the insertion of new structures in the form of thousands of wind turbine foundations will cause a deterioration of marine ecosystems or the generation of new, artificial reef-like systems. To better characterize specific effects of human activities on coastal ecosystems a new approach was tested which combines theory with models that integrate best available data with scientific knowledge, as at 2008.

Two main questions arise from the issues mentioned above:

- Are the existing methodology, models and indicators suitable for the assessment of environmental components of ICZM? If "yes",
- will the construction of offshore wind parks cause a system shift towards a degradation of marine ecosystems, the development of artificial reef systems or will the system show a resilient behavior?

2. Materials and methods

The study is part of the research and development project *Zukunft Küste—Coastal Futures* which deals with aspects of ICZM in the German North Sea. In this interdisciplinary project, various future scenarios were developed following a systematic framework (Burkhard, 2006). Within these scenarios, characteristic patterns of anthropogenic use evolve according to certain combinations of socio-ecological driving forces. The individual patterns are dominated by one form of use (e.g. shipping, recreation, nature conservation, energy conversion), and are linked to distinctive intensities, areas and time steps of OWP installations in the German North Sea. For the purposes of modeling we assumed in the maximum OWP scenario, that in 2055 Germany will have installed 10,000 wind turbines in the North Sea with the capacity to generate 90,000 MW of electricity. This would be a massive increase over 2005 levels when no offshore turbines existed in Germany. An area covering almost one fourth of the German EEZ would be used by OWPs then. Time steps and single events like successive construction and operation of individual wind parks at particular sites were defined within the different scenarios. The conceptual framework, methods and results of the ecologically oriented sub-projects in *Zukunft Küste—Coastal Futures* for the assessment of environmental impacts of the different OWP scenarios are presented in this paper.

2.1. Ecological integrity—indicators and system dynamics

The concept of ecological integrity refers to the necessity to safeguard the self-organizing capacity of ecosystems (Barkmann et al., 2001). Such self-organized systems receiving a flow through of energy (e.g. sunlight) have the capacity to build up structures and gradients based upon spontaneously occurring processes (Bossel, 2000). It follows that the concept of ecological integrity does not focus on single species or parameters but rather on processes and structures. Consequently, significant processes like cycling and transformation of exergy (usable energy; Jørgensen et al., 2005) and matter, and the preservation of specific biotic structures and abiotic components have to be maintained to secure ecosystem functioning (Müller and Burkhard, 2007). Indicators for the assessment of ecological integrity have to reflect these processes and structures. The systematic derivations of ecological integrity indicators as they are used in this study also are described in detail by Müller (2005). Their applications in different case studies in terrestrial ecosystems are illustrated for example in Burkhard and Müller (2008) and in Müller and Burkhard (2006, 2007). Hence, this study about effects of offshore wind parks and the combination with different models is a new challenge to assess impacts of human action on the state of ecosystems. Table 1 gives an overview of the applied indicators, respective parameters for their quantification, and data sources and models that were applied for their quantification. Descriptions of the individual models are given below.

Different system dynamics can be hypothesized to be impacted as a consequence of the installation of offshore wind parks. During the erection phase of the turbines, existing processes and structures will be disturbed. This will result in alterations of integrity components and respective indicators. In particular the insertion of turbine fundaments into the seabed and associated scour protections in a previously rather homogeneous sandy and muddy sea bottom environment may have the potential to initiate remarkable system dynamics. How the system might react after disturbance during this construction phase is still unclear. First results of monitoring at Danish offshore wind parks showed that epifaunal communities establish relatively quickly following construction (DONG Energy et al., 2006; ELSAM Engineering & Energy E2, 2004). On the one hand, these findings support the hypothesis, that insertion of hard structures in sea bottom areas will provide substrate suitable for the emergence of artificial reef-like ecosystems. These systems have the potential to be more productive, more efficient regarding energy and matter cycling and they could maintain a high biodiversity. This would raise the self-organizing capacity of the system and thereby, increase its integrity. Of course this would mean a fundamental change in the state of marine ecosystems, but it is important to recognize that hard substrate communities were typical of marine environments into the 1970s, being substantially reduced by the stone fishing activities that were carried out in German coastal waters.

On the other hand, disturbances during construction phases could be so severe that essential ecosystem processes and structures are interrupted, leading to irreversible system degradation or even a continuation of degradation after the construction is finished. A third hypothesis would suggest a resilient behavior of the system. This would mean that following the disturbance, main attributes, structures and functions will be restored to their earlier states (Walker and Salt, 2006) (Fig. 1).

To test these hypotheses, different simulation models and existing monitoring data were linked and used to quantify the

Table 1
Ecological integrity groups and indicators, parameters and data sources applied for their quantification.

Orientor groups	Indicator	Parameter	Data source/model
Energy budget	Exergy capture	Net primary production	ERSEM
	Entropy production	C/year from respiration	Ecopath
Matter budget	Storage capacity	C stored in biomass	Ecopath
	Nutrient cycling	Winter turnover of nutrients	ERSEM
	Nutrient loss	Transport loss of nutrients	ERSEM
Structures	Biotic diversity	Diversity seabirds	GIS data
	Abiotic heterogeneity	Turbidity, sediment parameters	MIKE21
	Organization	Ascendancy	Ecopath