Marine Pollution Bulletin 75 (2013) 224–234

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Impact of secondary hard substrate on the distribution and abundance of *Aurelia aurita* in the western Baltic Sea

H. Janßen [a,*], C.B. Augustin [a,b], H.H. Hinrichsen [c], S. Kube [d]

[a] Leibniz Institute for Baltic Sea Research Warnemuende (IOW), Seestrasse 15, 18119 Rostock-Warnemuende, Germany
[b] University of Rostock, Aquaculture and Sea-Ranching, Faculty of Agricultural and Environmental Sciences, Justus-von-Liebig-Weg 6, 18059 Rostock, Germany
[c] GEOMAR – Helmholtz Center for Ocean Research Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany
[d] University of Rostock, Institute of Biosciences, Aquatic Ecology, Albert-Einstein-Str. 3, 18059 Rostock, Germany

ARTICLE INFO

Keywords:
Wind farm
Artificial reef
Secondary hard substrate
Jellyfish
Europe
Marine spatial planning

ABSTRACT

This study assessed the impact of secondary hard substrate, as being introduced into marine ecosystems by the establishment of wind farm pillars, on the occurrence and distribution of the moon jelly *Aurelia aurita* in the southwestern Baltic Sea. A two-year data sampling was conducted with removable settlement plates to assess the distribution and population development of the scyphozoan polyps. The data collected from these samples were used to set up a model with Lagrangian particle technique. The results confirm that anthropogenic created hard substrate (e.g. offshore wind farms) has the potential to increase the abundance of the *A. aurita* population. The distribution of wind farm borne jellyfish along Danish, German and Polish coasts indicates conflicts with further sectors, mainly energy and tourism.

1. Introduction

The generation of renewable energy by offshore wind farms is likely to increase significantly in the western Baltic Sea despite of current delays in the implementation of already approved wind farms. In March 2012 Denmark passed a new Energy Agreement with the target of 100% renewable energy in 2050 (ENS, 2012). Already in 2020 half of the energy consumption shall be covered by wind farms. The energy concept of the German Government aims at a share of 50% for offshore wind farms in the national energy production by 2050 (BMU, 2011). A capacity of 25 GW shall be installed offshore until 2030. Sweden's energy policy foresees a 50% share of renewable energies with 10 TWh offshore wind energy production in 2020 (Regeringskansliet, 2009). This will lead to a considerable expansion of today's offshore wind farms in the western Baltic Sea, where single wind farms have already been built in Danish and German waters during recent years.

A number of studies researched local impacts of wind farms on benthic communities in the region (e.g. Birklund and Petersen, 2004; DHI, 2000, 2006a,b; Petersen and Malm, 2006). Wind farms as well as other fixed offshore installations such as platforms, piles and pillars act as artificial reefs (Petersen and Malm, 2006; Maar et al., 2009; Wilhelmsson et al., 2006; Wilhelmsson and Malm, 2008). These provide substrate for organisms which would not be able to settle on the original soft sediments (Svane and Petersen, 2001). This issue is of high relevance in the western Baltic Sea where predominant soft-sediments (Emeljanov et al., 1993; Hermansen and Jensen, 2000) limit the spectrum of organisms. An organism that might benefit from this additional secondary hard substrate is the moon jellyfish *Aurelia aurita*. Scyphozoans like *A. aurita* have a life cycle consisting of planktonic sexually-reproducing medusae and benthic asexually-reproducing polyps (Möller, 1979; Gröndahl, 1988; Lucas, 2001). The benthic polyps need hard substrate to settle on. From these polyps ephyrae are released by strobilation and further develop into medusae. The medusae in turn reproduce by the release of planula larvae which develop again into polyps. In accordance with these development stages *A. aurita* populations are found predominantly in those areas where suitable hard substrata are available for the benthic scyphistoma (Lucas, 2001).

Several studies suggest that anthropogenic installations might favor problematic occurrence of massive numbers of jellyfish (Duarte et al., 2013). These so called jellyfish blooms were related to factors such as climate warming, eutrophication, overfishing, aquaculture, invasion of non-native species by marine traffic and maritime constructions (Purcell et al., 2007). The increasing amount of artificial underwater hard substrate by maritime constructions is expected to provide new habitats especially for the settlement and reproduction of benthic stages of scyphozoan jellyfish such as *A. aurita*. Considering rising numbers of marinas, harbor expansions, wind farms, which are located in the western Baltic Sea (Janßen et al., 2013), increased benthic polyp colonies and subsequently increased medusa blooms are likely for the Baltic Sea.

* Corresponding author. Tel.: +49 381 5197 469.
E-mail address: holger.janssen@io-warnemuende.de (H. Janßen).

0025-326X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2013.07.027

Jellyfish species are of high ecological importance by its functional value in the marine pelagic ecosystem acting as predator for native zooplankton and competitor for commercially important planktivorous fish species. If scyphomedusae occur with high abundance they have impacts on zooplankton communities (Barz and Hirche, 2005). A reduction of zooplankton and herring larvae populations caused by *A. aurita* in the western Baltic is documented e.g. by Möller (1980a) and Schneider and Behrends (1998). Experiments showed also predation on cod larvae (Baily and Batty, 1984; Titelman and Hansson, 2006). This is of importance for the southwestern Baltic as it is characterized by various Marine Protected Areas (MPA) administered under European Natura 2000 legislation. As shown by Barz et al. (2006) also remote areas might be affected by the occurrence of *A. aurita* due to drift over larger distances.

Up to 21 wind farms are planned in the study area, of which three are already build and four recently received an approval. The present study modeled the impact of secondary hard substrate on the occurrence and distribution of juvenile *A. aurita* on a regional scale by using a hydrodynamic model with particle tracking technique. The study is structured into four steps. First, data on the spatial and temporal patterns of *A. aurita* occurrence were collected by in situ experiments in the southwestern Baltic Sea. Secondly, to assess the spatial movement of *A. aurita* towards and also from secondary hard substrate at wind farms, a drift model with particle tracking technic was set up on the basis of this these sampling data. Thirdly, the potential abundance of *A. aurita* released from wind farms was estimated on the basis of current wind farm construction plans. Finally the drift simulation results have been analyzed to further identify affected areas and possible conflicts.

2. Materials and methods

2.1. Data sampling

The seasonal and temporal distribution of benthic developmental stages (polyps) and pelagic developmental stages (ephyrae and medusae) of *A. aurita* were studied in 2009 and 2010 in the southwestern Baltic Sea.

To assess the distribution and population development of the scyphozoan polyps, off-shore polyp settlement experiments were carried out in Fehmarnbelt and in Mecklenburg Bight. Mooring systems with removable settlement plates were installed at 4 stations in the southwestern Baltic Sea in Mecklenburg Bight in July 2009 (Fig. 1).

Areas with a water depth more than 15 m allowed polyp sampling at two different water layers (above and below the halocline). At these stations, two settlement frames, were installed above each other on the same mooring (Fig. 2). Each settlement frame had about 1 m diameter and consisted of 12 removable settlement plates, attached to three horizontal arms (Fig. 2). The rectangular settlement plates were made of concrete and had a total settling area of 190 cm^2 (horizontal settling area on the upper and bottom side each 75 cm^2, vertical settling area 40 cm^2).

Planula larvae released in summer and autumn were expected to attach on the plates and develop into polyps during autumn and winter. Concrete was chosen as material because wind farm foundations and piles in the southwestern Baltic with typical water depths below 40 m may partly or fully be made out of concrete (Larsen et al., 2005; Strabag, 2013). Such an example is the existing Lillgrund wind farm southeast of Sweden (Vattenfall, 2008). Another common material for the construction of wind farm piles in the case study region is steel with epoxy or polymer coatings. *A. aurita* polyps are able to settle also on this substrate (Ishii and Katsukoshi, 2010) and their abundance on polymeric materials may be higher than on concrete (Holst and Jarms, 2007). Sampling of settlement plates and counting of polyps was carried out monthly during the annual polyp growth and strobilation period in two successive years (October 2009–April 2010, November 2010–April 2011). In this study we only present the polyp abundances for the second measured settling season (November 2010–April 2011) after 1.5 years of mooring deployment. This means that the moorings were exposed to planula larvae settling for two seasons (summer 2009 and summer 2010) before sampling.

Settling plates were collected either by craning the whole mooring out of the water on a research vessel or by scientific scuba diving. In case of craning, the settling frames were submersed in habitat water tanks on board of the vessel during removing the settling plates. For transport to the laboratory the removed plates were placed in habitat water containers and stored at habitat temperature. Polyps were counted and measured alive at each settling side of the plate under a stereomicroscope within 1 day after sampling. The abundance of polyps attached upright at the upper side of the plate, upside down on the bottom side of the plate and horizontally positioned on the vertical edge was calculated separately and was expressed as polyps cm^{-2}.

To assess the abundance of pelagic developmental stages of *A. aurita*, monthly samples were taken at 12 stations in the southwestern Baltic Sea between June 2009 and December 2010 (Fig. 1). The medusae field survey in the southwestern Baltic Sea covered an area between Kiel Bight in the West and Darss Sill in the East. Samples were taken by using a MultiPlanktonSampler (MPS, opening area 0.25 m^2, mesh size 500 μm), which was towed horizontally with a maximum inflow speed of about 1 m s^{-1}. Two electronic flow-meters measured the filtrated water volume (100–200 m^3). Collected ephyrae and medusae of *A. aurita* were counted alive directly after sampling and the bell size (diameter) of each individual was determined. Specimens <0.5 cm were considered as ephyrae. The abundance of ephyrae and medusae was calculated (individuals m^{-3}) from the number of counted specimens and the filtrated volume of water.

2.2. Hydrodynamic model and particle tracking technique

To assess the distribution of *A. aurita*, both from today's potential habitats and from additional settlement areas provided by offshore wind farms, a hydrodynamic model and Lagrangian particle technique was used. A comprehensive description of those methods was published by Lehmann (1995) and Hinrichsen et al. (1997). The hydrodynamic model used in this study is based on the free surface Bryan–Cox–Semtner model (Killworth et al., 1991) which is a special version of the Cox numerical ocean general circulation model (Bryan, 1969; Semtner, 1974). The Baltic Sea model domain comprises the entire Baltic Sea. The horizontal resolution is 2.5 km, with 60 vertical levels specified. The Baltic Sea model is driven by atmospheric data provided by the Swedish Meteorological and Hydrological Institute (SMHI: Norrköping, Sweden) and river runoff taken from a monthly mean runoff database (Bergstrøm and Carlsson, 1994). Prognostic variables of the model are the baroclinic current field, the 3-D temperature, salinity and oxygen distributions, the 2-D surface elevations and the barotropic transport, all of them available at 6 h intervals. Physical properties simulated by the hydrodynamic model agree well with known circulation features and observed physical conditions in the Baltic. A detailed description of the equations and modifications made, necessary to adapt the model to the Baltic Sea can be found in Lehmann (1995) and Lehmann and Hinrichsen (2000a). A detailed analysis of the Baltic Sea circulation has been performed by Lehmann and Hinrichsen (2000b) and by Lehmann et al.