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Review

Guidelines for seagrass restoration: Importance of habitat selection and donor population, spreading of risks, and ecosystem engineering effects

M.M. van Katwijk [a,*], A.R. Bos [a,b], V.N. de Jonge [c], L.S.A.M. Hanssen [d], D.C.R. Hermus [a], D.J. de Jong [e]

[a] Department of Environmental Science, Radboud University Nijmegen, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands
[b] Davao del Norte State College, New Visayas, 8105 Panabo City, Philippines
[c] Department of Marine Biology, University of Groningen, P.O. Box 14, 9750 AA Haren, The Netherlands
[d] Deining Societal Communication, Peter Scheersstraat 26, 6525 DE Nijmegen, The Netherlands
[e] Ministry of Transport, Public Works and Water Management, P.O. Box 8039, 4330 EA Middelburg, The Netherlands

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ABSTRACT

Large-scale losses of seagrass beds have been reported for decades and lead to numerous restoration programs. From worldwide scientific literature and 20 years of seagrass restoration research in the Wadden Sea, we review and evaluate the traditional guidelines and propose new guidelines for seagrass restoration.

Habitat and donor selection are crucial: large differences in survival were found among habitats and among donor populations. The need to preferably transplant in historically confirmed seagrass habitats, and to collect donor material from comparable habitats, were underlined by our results. The importance of sufficient genetic variation of donor material and prevention of genetic isolation by distance was reviewed. The spreading of risks among transplantation sites, which differed in habitat characteristics (or among replicate sites), was positively evaluated. The importance of ecosystem engineering was shown in two ways: seagrass self-facilitation and facilitation by shellfish reefs. Seagrass self-facilitative properties may require a large transplantation scale or additional measures.

1. Introduction

Seagrass beds are among the most valuable ecosystems in the world (Costanza et al., 1997). Yet, these systems are relatively unknown and therefore often underappreciated by the general public (Orth et al., 2006). Large-scale losses have been reported for decades. For instance, worldwide seagrass loss between the mid-1980s and mid-1990s was estimated to be 12,000 km^2 (Short and Wyllie-Echeverria, 2000). This has led to numerous restoration programs (e.g., Paling et al., 2009).

Traditional guidelines in restoration literature suggest that it is necessary to reverse habitat degradation, to select transplantation habitats carefully, and to optimise the transplantation techniques (Hobbs and Norton, 1996; den Hartog, 2000; Calumpong and Fonseca, 2001; Campbell, 2002; Short et al., 2002; McKay et al., 2005). An unwritten rule is to spread risks in space and/or time. Recently, the importance of ecosystem engineering for seagrass beds was studied and described (Bouma et al., 2005; Bos and van Katwijk, 2007; Bos et al., 2007; van der Heide et al. 2007), and, as a new guideline, these studies should be accounted for in restoration projects (Byers et al., 2006). In this paper, we evaluate the traditional, and formulate new, guidelines by reviewing literature and 20 years of research from the Wadden Sea.

2. Study site: Wadden Sea and historical records of seagrass vegetation

The Wadden Sea is one of the world's largest international marine wetland reserves. The area covers circa 6000 km^2 and borders the coasts of The Netherlands, Germany, and Denmark (Fig. 1). The western Wadden Sea was inhabited by seagrasses since ancient times. The first record dates back to 1329 (den Hartog and Polderman, 1975). A treatise in the 18th century (Martinet, 1782), and a detailed mapping in the 19th century (Oudemans et al., 1870) are also early studies of its perceived importance, indeed providing hundreds of families with an income thanks to its economic value as isolating and filling material. Furthermore, seagrass was used to enforce the internal structure of the main dikes (to protect the polders against flooding) until the 18th century. The economic interest focused on the robust form of *Zostera marina* (eelgrass) that grew around the low tide level and deeper. The flexible, annual form of *Z. marina* as well as *Zostera noltii* (dwarf eelgrass) – both growing in the inter-tidal area that is around or

* Corresponding author. Tel.: +31 24 3652478; fax: +31 24 3653030.
E-mail addresses: m.vankatwijk@science.ru.nl (M.M. van Katwijk), arthurrbos@yahoo.com (A.R. Bos), v.n.de.jonge@rug.nl (V.N. de Jonge), deining@wxs.nl (L.S.A.M. Hanssen), dick.j.de.jong@rws.nl (D.J. de Jong).

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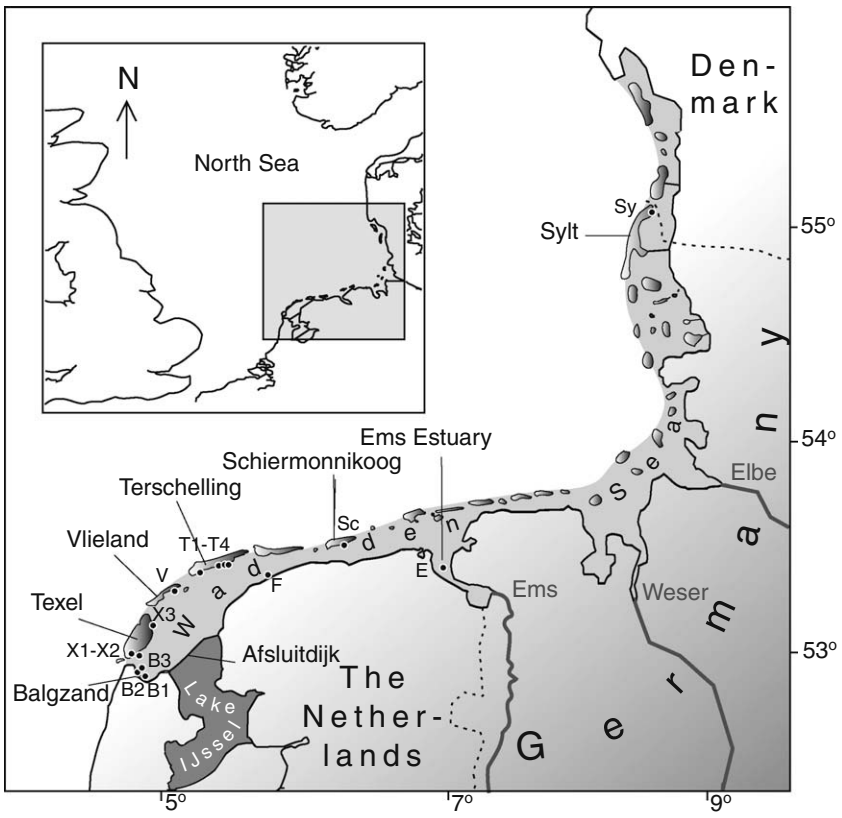

Fig. 1. Map of the Wadden Sea, NW Europe with transplantation locations.

above mean sea level – received no interest until the 20th century (Nienburg, 1927; Harmsen, 1936; den Hartog and Polderman, 1975; van Katwijk et al., 2000a, Fig. 2). The robust form of *Z. marina* completely disappeared during the early 1930s, due to a combination of factors, and never recovered (Reise et al., 1989; Giesen et al., 1990a, b). The flexible type of *Z. marina*, as well as *Z. noltii*, disappeared during the 1970s, shortly after they had been mapped (den Hartog and Polderman, 1975). Both species still occur in the inter-tidal zone in the middle, eastern, and northern parts of the Wadden Sea (Reise et al., 2005).

In 1987, a seagrass restoration program was started for *Z. noltii* and the flexible form of *Z. marina*, as a preamble on measures that should be taken to improve water quality and habitat-providing conditions (Anonymous, 1989; de Jonge et al., 2000). Natural recovery was not conceivable in the western part of the Wadden Sea because the potential donor populations were located leeward of the predominantly western winds. It was decided not to focus on the sub-tidal, robust form because it had already disappeared in the 1930s, and environmental changes had been tremendous since that time (de Jonge and de Jong, 1992). In particular, the turbidity of the water increased (van den Hoek et al., 1979; Giesen et al., 1990a; van der Heide et al., 2007). However, light does not limit seagrass growth in the inter-tidal belts around mean sea level (van Katwijk et al., 1998; van Katwijk and Hermus, 2000).

3. Transplantations

Between 1991 and 2004, 42 seagrass transplantations were carried out at four locations in the Wadden Sea, using approximately 10,000 *Z. noltii* shoots, and 23 000 *Z. marina* plants (Table 1). Four out of the 42 seagrass transplantations were carried out at presently vegetated sites as a control. Twenty-six were carried out at sites where vegetation had disappeared during the 1970s, eight were carried out at sites where vegetation had disappeared before

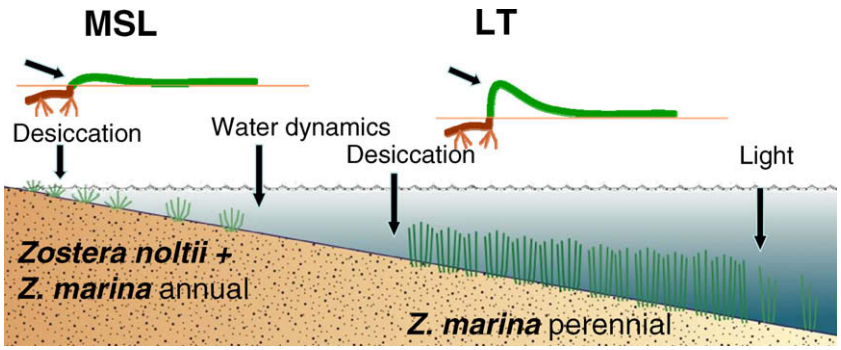

Fig. 2. *Zostera* zonation in the Wadden Sea. The perennial type of *Z. marina* went extinct in the 1930s.