Nature based solutions for
bank protection along estuarine waterways
Direct bank protection: Brushwood mattress
Data sheet (Version 2024)

Brushwood mattress to protect dike without foreland (WSA Weser-Jade-Nordsee)

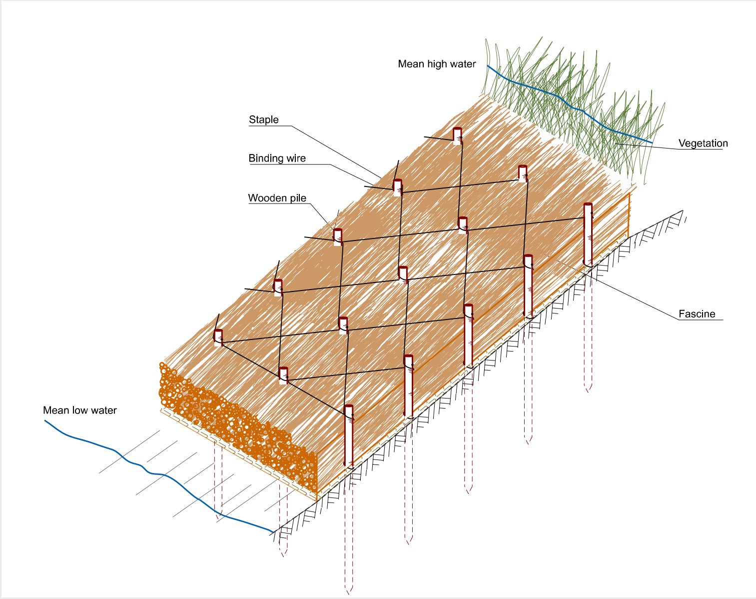

Diagram of a brushwood mattress (BAW)

OVERVIEW

Brief description

Brushwood mattresses consist of fascines made of live brushwood that does not need to be able to form shoots. The fascines are laid across the bank slope, all pointing in the same direction, and are fixed with wooden piles and wire.

The direct and complete bank protection prevents surface erosion and near-surface sliding.

Where unprotected banks are susceptible to erosion, brushwood mattresses can provide a biological alternative to protecting banks with conventional revetments, provided that the currents they are exposed to are not too strong [1]. If lasting siltation of the brushwood mattresses is possible, this can increase their durability. Exposure to air and UV radiation at low tide cause the mattresses to degrade over time, depending on the timber type and the thickness of the brushwood or piles.

Level of bank stability ensured

Direct protection against slope erosion caused by currents and waves

A complete layer of brushwood mattresses is an immediately effective slope protection against surface erosion caused by currents and waves due to tidal dynamics, sea state or ship traffic.

Filter stability is ensured by installing a complete layer of fascines flush with the ground. A base layer of degradable geotextiles or other filter material can be used if required.

Direct protection against near-surface sliding

The soil is protected against sliding by fixing it with piles and brushwood tied to the ground.

OVERVIEW

Advantages and disadvantages compared to a direct bank protection using riprap, concrete or steel	
Advantages and disadvantages compared to a direct bank protection using riprap, concrete or steel	**Advantages** • Use of renewable and native materials, ideally from own trees or bushes • Comparatively low cost of material • In small areas that are difficult to access, manual installation and maintenance is possible without a need for large or special machinery • No or negligible disposal costs • Easy to combine with other forms of bank protection (riprap, brushwood box, etc.) **Disadvantages** • May require more staff for construction, monitoring and maintenance (especially with large-scale measures), depending on boundary conditions. This can be reduced by, among other things, choosing alternative design variants so that the measure has a more sustainable and long-term effect and is still economical despite the need for more staff during construction.

ECOLOGICAL BENEFIT

compared to direct bank protection using riprap, concrete or steel

Hydromorphology	Brushwood mattresses can favour sedimentation because of the gaps between the brushwood packages. They can contribute to the provision of habitats.
Habitats and their interconnectedness	Wood is a material that provides habitats to characteristic plants and animals and microorganisms colonising hard substrates. These natural habitats are found in tidal forested wetlands, which are now endangered. However, while this enlarges the range of available habitats in an estuary, natural rocky substrate is almost non-existent in the German Bight's estuaries, as the sediment layers containing rocky substrate were covered with marine sediments after the last ice age and this type of sediment contains no mineral deposits [2].
Vegetation	In the mean high water zone, vegetation can establish in the gaps created by wood decay processes. Reed develops frequently in these areas and above mean high water tall forbs also establish [1]. Depending on salinity and wave load, willows can grow here as well. Reeds, tall forbs and softwood forests are legally protected biotopes according to the German Federal Nature Conservation Act (Bundesnaturschutzgesetz, BNatSchG).
Fauna	Brushwood mattresses, concrete, riprap or sheet pile walls are all hard substrates and provide a surface suitable for colonisation by various groups of fauna, e.g. hard-substrate species such as small invertebrates (depending on salinity and elevation, e.g. mussels, barnacles) which are not characteristic of the habitat. However, as the wood rots over time, these bank protection structures are of a less permanent nature as e.g. riprap and therefore tend to promote the natural species composition of the estuarine macrobenthic fauna. If ecologically permeable filters are used or large quantities of sediment are trapped in the fascines, a large diversity of species can establish, depending on the salinity (fresh, brackish or salt water), such as worms (e.g. bristle worms), crustaceans (e.g. amphipods), clams (e.g. Asian clam, razor clam) and winkles (e.g. common periwinkle). They serve as an important source of food for breeding and resting birds.

ECOLOGICAL BENEFIT

compared to direct bank protection using riprap, concrete or steel

Ecosystem services

In contrast to sheet pile walls and concrete, the structures that develop during the wood decay process can promote the following ecosystem services with ecological benefit:

- Provision of habitats for riparian vegetation and fauna
- Carbon regulation and storage as a result of the development of riparian vegetation in the mean high water zone
- Additional protection against bank erosion as vegetation establishes in the mean high water zone
- Enhanced recreational functions because area is experienced as a more natural landscape

RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

Range of applications

Similarly to revetments, brushwood mattresses can be used as a protection against slope surface erosion and local geotechnical failure, provided that they have the appropriate dimensions.

However, their use on the tidally influenced federal waterways has been restricted so far to tributaries or banks not facing the fairway. Local empirical data are provided in, among others, the Collection of measures which is available at: https://ufersicherung-baw-bfg.baw.de/aestuarbereich/en/massnahmen.

Design and dimensioning

In the collection of existing measures, brushwood mattresses are mostly constructed in the zone between mean high water and mean low water. Below this zone, brushwood mattresses can only be used under favourable conditions when water levels are low.

Alternatively, fascine mattresses can be installed under water as sinking pieces using rubble stones as ballast.

Estimated pile length

DIN 19657 recommends to choose pile lengths and diameters based on experience, samples or geotechnical verification [4].

Based on mathematical estimations and the collection of measures referred to above, the following procedure is proposed for determining pile lengths and installation depths, taking into account soil conditions and slope inclination.

The following site-specific variables should be known:

- Slope profile including slope inclination
- Soil stratification with soil type, including consistency/bulk density if required, and horizon of soil strata with load-bearing capacity

As depicted in the cross-sectional drawing in *Annex 1*, the total pile length is the combined length of the packed fascine-work and the embedment depth of the piles in the load-bearing layers. It should be noted that because the fascines are fixed with wire, the upper edge of the fascine fill material is lower than the tops of the piles.

RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

Table 1: Calculated required pile length as a function of soil characteristics and design wave height

	Required pile length as calculated [m]	
H_{Design} [m]	Sand, loose (SE, SU)	Clay (TA, OU)
0.3	1.5	1.5
0.5	2.0	2.0
0.8	2.5	3.0
1.0	3.0	3.5

To determine the required pile embedment depths and pile lengths, geotechnical equilibrium analyses were conducted according to the Code of Practice GBB (2011), chapter 7 [3]. Soil characteristics were used based on DIN 1055-2 for loose sand (SE, SU) and clay (TA, OU) with soft or stiff consistency. Slopes with an inclination of 1:3 or flatter were considered. Based on these assumptions, the pile lengths indicated in Table 1 were obtained for the different design wave heights (or design drawdown heights) H_{Design}.

The results from the mathematical model shown in *Table 1* have not yet been verified. Up to now, blanket values of 3–3.5 m have been used in practice to define pile length.

Tolerance of hydrodynamic loads

Specific measurements of the hydrodynamic loads acting on brushwood mattresses due to ship traffic in the tidal area have to date only been available for the Wümme river, which is exclusively navigated by recreational craft. In this case maximum flow velocities of 0.9 m/s measured near the banks do not affect the stability of the brushwood mattresses.

For willow brush mattresses in their critical initial state, which is similar to that of a brushwood mattress, a capacity to absorb flow velocities close to the bank of up to 2.0 m/s has been derived from these measurements (cf. data sheet *Living brush mattresses – inland waterways*, https://ufersicherung-baw-bfg.baw.de/binnenbereich/en/arbeitshilfen/kennblaetter).

Alternative designs

Brushwood mattress

Brushwood mattress with fascines arranged in a cross pattern [4]

Brushwood layer

Design with loose branches (brushwood) not bundled into fascines [4]

Willow brush mattress

Dormant willow rods or stakes can develop shoots e.g. at a level of around 1 m above mean high water and are therefore suitable as willow brush mattresses for protecting the bank in this zone (cf. data sheet *Living brush mattresses – inland waterways*, https://ufersicherung-baw-bfg.baw.de/binnenbereich/en/arbeitshilfen/kennblaetter). From an ecological perspective, this design has the potential to promote biotopes such as softwood forests which are legally protected biotopes.

Brushwood mattress with stone cover

In sections with high hydrodynamic loads a stone cover can be added to increase the durability of the brushwood mattresses. From an ecological perspective, the designs with degradable materials (driftwood, brushwood, live willow rods) provide an additional habitat for animals.

RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

Design as scour protection

In areas susceptible to scour, brushwood mattresses can be used as scour protection in addition to other bank protection measures, e.g. brushwood boxes.

Design with head and/or toe protection

In areas with higher loads a head and/or toe protection may be necessary, which can be provided e.g. by riprap or a brushwood box [1].

COMPONENTS AND INSTALLATION

Components

For the usual dimensions of a brushwood mattress with a fascine thickness of up to 0.5 m, the following mean quantity of material per 100 m² slope surface is required:

- 100–250 wooden piles
- approx. 50 m³ of fascines or brushwood (after installation)
- > 100 m² of degradable geotextile or other filter material if required
- > 200 m of binding wire
- 100–250 staples

The exact design and material requirements can vary between projects. Components with the following properties have proven to be suitable for the conditions prevailing in estuaries.

Wooden piles

Natural piles with their bark stripped, or round milled piles of best quality, made from straight-grown fir, spruce or larch timber; the piles should be rounded or cut square at their pointed ends. The length of the pointed end should be 2–4 times larger than the pile diameter [4].

Diameter (bottom): 0.09–0.13 m

Length: 1.5–3.5 m

Among native timber types, larch shows the highest resistance to weathering [5].

Fascine material

Fascines

Fascines are bundled brushwood. They must be supplied when freshly cut and installed without delay. In intertidal areas their capacity to form shoots is limited by flood duration. As a result, it is generally not required to use dormant wood for the mattresses.

Generally, unbundled brushwood can also be used. In this case, the savings on the costs of unbundled brushwood material must be weighed against the higher installation costs.

Fascine dimensions and properties

Length: 1.8–2.3 m

Proportion of the bundles: 0.6–0.9 m (corresponding to a diameter of 0.2–0.3 m)

The fascines must be tied with three galvanised and annealed steel wires, 1.2–2.0 mm in diameter. A strand of wire must consist of at least three wires. It must be pulled tight so that it is impossible to pull single branches from the bundle or strongly squeeze the bundle when holding it in two hands. Alternatively, fascine mattresses can be tied with twine made of natural fibre. While this is the ecologically preferable solution, the shorter material durability should be taken into consideration.

COMPONENTS AND INSTALLATION

Hardwood fascines

Fascines made from fresh hardwood that is not dormant, as straight-grown as possible, pliable and not unwieldy, e.g. oak, willow, rowan, ash, hazel, birch or beech. Free from thorny twigs, such as those found on hawthorn, blackthorn or roses. At the end of the stems, the diameter of the twigs should not be more than 4 cm.

Softwood fascines

Fascines made from softwood (spruce, fir) have proved suitable for brushwood box construction for land reclamation purposes. They are less wieldy; the needles come off quickly and the resulting loss in volume can have a negative impact on the long-term packing thickness of the fascine work.

The fascines can be made by recycling Christmas trees [6]. However, due its content of tannins, softwood has a smaller ecological potential for colonisation [7].

Filter

In cases of a risk of soil loss, a suitable filter can be installed between the fascines and the in-situ soil. However, no conclusive empirical values exist as yet on the use of filters. By way of experiment, degradable geotextiles could be installed to prevent the fill material from being washed away through the brushwood structure. The design of the geotextiles would need to be based on the relevant Codes of Practice (MMB (2013) [8], MAK (2013) [9] and MAG (1993) [10]). Geotextiles that are rootable, fully biodegradable and whose durability as a filter corresponds to that of the fascine material seem to be the optimal type of filter material.

If a base layer of straw, heather or floating debris is used, as is recommended in textbooks [11], it should be taken into account that these materials may have a lower durability. The same applies to coir or sheep wool geotextiles. Another alternative would be to use mineral grain filters.

Other construction materials

Binding wire

Annealed or galvanised, corrosion-resistant wire with a minimum thickness of 3 mm

Staples

Annealed or galvanised, corrosion-resistant staples

Work steps

Generally, the following work steps can be distinguished.

1. Preparing the subgrade; clearing the construction area of any obstacles (armour stones, geotextiles, vegetation cover, etc.)
2. If required, placing overlapping layers of a geotextile on the slope; the geotextile must be cut crosswise at the place where the piles are driven into the ground
4. Driving or pressing the piles into the ground while maintaining a defined horizontal and longitudinal distance up to a height double the target height of the fascine work
5. Complete coverage of the area between the piles by at least two layers of fascines
6. Tensioning the wire between the piles without kinks; the wire must be placed as a loop around the piles and fixed with staples
7. Driving or pressing the piles deeper into the ground until target depth is reached; as a result, the fascines are compressed by the wire and pressed onto the ground

COMPONENTS AND INSTALLATION

Reworking

E.g. shortening of piles or wire in case of excess length

Installation instructions

General

Nature conservation and occupational safety regulations must be observed.

Working in intertidal areas

The daily tidal dynamics act as limiting factor for the time available for construction activities. Depending on the elevation of the location where the brush mattress is installed, construction is only possible during tidal low water period. Frequently, construction sites are located on stretches of the bank that are difficult to access from water or land.

Personnel and equipment requirements

The working conditions are very demanding and require skilled staff with the relevant technical expertise and experience in working in tidal areas. We recommend to deploy trained hydraulic technicians.

Hydraulic dredges that can be used both on land and water often save time and work. For small-scale measures in particular, portable manual or power post drivers can also be used.

Obstacles

Obstacles such as stones in the ground may pose problems when the piles are driven or pressed into the ground. Even when the work is carried out very carefully, breaking of the piles may occur.

MAINTENANCE

The required maintenance effort depends on the local conditions and is influenced, among others, by the intensity of wave- and flow-induced loads. Experience gained from measures implemented by the German Federal Waterways and Shipping Administration (WSV) has shown that the mean maintenance intervals for brushwood mattresses are in the range of 6–10 years. In some cases, it was possible to increase the measure’s durability to over 10 years. Ideally, regular inspections are carried out to assess the condition and replace fascine material as required.

The siltation of the brushwood mattresses increases their durability as the fascine decomposition due to biochemical processes or hydrodynamic attack is slowed down. Nevertheless, after a period of 6–10 years a complete repair, including the piles, is required as a rule if the effect of the measure is intended to continue. Before carrying out repairs, it should be assessed whether direct bank protection is still required or whether further maintenance and replacement of the brushwood mattress is not necessary.

EXAMPLES

Examples on Germany's federal waterways

Protection of dikes without foreland on the Pinnau river

Pinnau-km 6.75–7.00, left bank

https://izw.baw.de/publikationen/alu-aestuare-massnahmen/0/Pin-007li_01_01.pdf

Brushwood mattress on the Wümme river

Wümme-km 17.0–17.08, right bank

https://izw.baw.de/publikationen/alu-aestuare-massnahmen/0/Wue-017re_01_01.pdf

REFERENCES

[1] BfG, WSA Weser-Jade-Nordsee, WWK (2019): Technisch-biologische Ufersicherungen an drei Versuchsstrecken an der Wümme. Bundesanstalt für Gewässerkunde, Koblenz, BfG-1997

[2] Wetzel, M.A., Scholle, J., Teschke, K., 2014. Artificial structures in sediment-dominated estuaries and their possible influences on the ecosystem. Marine Environmental Research 99, 125–135. https://doi.org/10.1016/j.marenvres.2014.04.008.

[3] Bundesanstalt für Wasserbau (2011): Grundlagen zur Bemessung von Böschungs- und Sohlensicherungen an Binnenwasserstraßen (GBB), Bundesanstalt für Wasserbau, Karlsruhe.

[4] DIN 19657:2023-12: Sicherung von Gewässern, Deichen und Küsten

[5] DIN EN 350:2016-12 Dauerhaftigkeit von Holz und Holzprodukten - Prüfung und Klassifizierung der Dauerhaftigkeit von Holz und Holzprodukten gegen biologischen Angriff; Deutsche Fassung EN 350:2016.

[6] Müller, C.(2022): Wie Weihnachtsbäume nützlich werden, Kieler-Nachrichten am 06.01.2022, online unter: https://www.kn-online.de/Region/Rendsburg-Eckernfoerde/Eckernfoerde-Wie-alte-Tannenbaeume-nuetzlich-werden (zuletzt geprüft: 08.02.2023).

[7] Pérez, M., García, M., Blustein, G., Stupak, M. (2007): Tannin and tannate from the quebracho tree: an eco-friendly alternative for controlling marine biofouling, Biofouling, 23:3, 151-159, https://doi.org/10.1080/08927010701189484

[8] Bundesanstalt für Wasserbau (2013): BAWMerkblatt Materialtransport im Boden (MBB), Bundesanstalt für Wasserbau, Karlsruhe (BAW-Merkblätter, -Empfehlungen und -Richtlinien).

[9] Bundesanstalt für Wasserbau (2013): BAWMerkblatt Anwendung von Kornfiltern an Bundeswasserstraßen (MAK), Bundesanstalt für Wasserbau, Karlsruhe (BAW-Merkblätter, -Empfehlungen und -Richtlinien).

[10] Bundesanstalt für Wasserbau (1993): BAWMerkblatt Anwendung von geotextilen Filtern an Wasserstraßen (MAG) (Ausgabe 1993), Bundesanstalt für Wasserbau, Karlsruhe (BAW-Merkblätter, -Empfehlungen und -Richtlinien).

[11] Nakoinz, H. (2019): Handbuch für den Beruf Wasserbauerin/ Wasserbauer, Wasserstraße – Schifffahrt – Umwelt, Generaldirektion Wasserstraßen und Schifffahrt, Berufsbildungszentrum Koblenz.

INSTITUTIONEN / LINK	
Editor	Federal Waterways Engineering and Research Institute, Hamburg Federal Institute of Hydrology, Koblenz
Link	https://ufersicherung-baw-bfg.baw.de/
Citation	BAW and BfG (2024): Data sheet Direct bank protection: Brushwood mattress. Nature-based solutions for bank protection along estuarine waterways

Annex:
1. Technical drawings

Annex 1 Technical drawings

The drawings shown here must be adapted to local conditions.