*Brushwood box for stabilising an erosion edge (WSA Weser-Jade-Nordsee)*

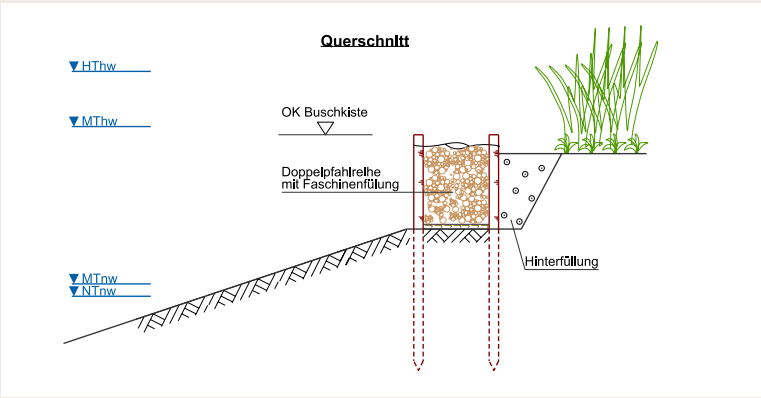


*Diagram of a brushwood box (BAW)*

## OVERVIEW

### Brief description

Brushwood boxes are double pile rows fixed with wire and preferably filled with fascines. Where brushwood boxes are used as direct bank protection, they are installed immediately in front of a steep or vertical slope, e.g. an erosion edge, or on a bank slope.

They protect banks by retaining sediments and soil and reducing current and wave loads. Fill material, dimensions, design or other aspects can vary according to site requirements. Depending on the elevation of the brushwood box, the immediate back area provides a habitat where riparian vegetation can establish or existing populations can be preserved or promoted. This has an additional stabilising effect on the banks.

Where environmental conditions and bank protection requirements permit, brushwood boxes should be installed as off-the-bank, indirect protection measures to achieve greater ecological benefit (see data sheet *Indirect bank protection in tidal areas*).

### Ensuring bank stability

#### Direct protection through support measures for slope breaks

Brushwood boxes are able to support the soil behind the box and can therefore replace low sea walls, pile walls, etc. At the same time, they can reduce or in some cases even prevent the removal of eroded soil material or new sediment.

#### Indirect protection through current and wave attenuation

The hydraulically permeable fill material (e.g. fascines, brushwood, stones) dampens the waves and currents close to the bank that are caused by tidal dynamics, sea state or ship traffic and thus reduces directly effective hydrodynamic loads. As a result, erosion is mitigated or, at best, stopped. The reduction in hydrodynamic load can create more favourable conditions for the establishment and spreading of riparian plants in the shelter of the brushwood box. This can initiate a natural bank protection based on vegetation.

### Advantages and disadvantages

compared to a direct bank protection using riprap, concrete or steel

#### Advantages

- (Improved) interconnectedness of habitats in front of and behind the protection measure
- Use of renewable and native materials, ideally from own trees or bushes
- Comparatively low cost of material

## OVERVIEW

- 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, brush mattress, 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 designs, so that the measure has a more sustainable and long-term effect and is still economical despite the need for more staff for construction.
- May turn out to be an animal trap. This can be prevented on the landside by backfilling the gap between the terrain and brushwood box with soil and, if required, sod (see explanations in the sections *Alternative designs* and *Installation instructions*). From the waterside, the barrier cannot be overcome by e.g. ducklings or hedgehogs.

## ECOLOGICAL BENEFIT

compared to direct bank protection using riprap, concrete or steel

### Hydromorphology

Brushwood boxes are dead wood structures with rough surfaces and many gaps in the filling material. As a result, they act as a sediment trap and sometimes provide habitats.

### Habitats and their interconnectedness

Wood is a material that provides habitats to characteristic plants and animals as well as microorganisms colonising hard substrates. These natural habitats are found in the now endangered tidal forested wetlands. 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 [1].

Where brushwood boxes are needed only temporarily, the decomposition of the wood promotes the colonisation of characteristic plants, animals and microorganisms. It also reduces the barrier effect. To ensure colonisation success in the long term, habitat connectivity is essential.

### Vegetation

The initiation and protection of developing riparian vegetation in the area behind the brushwood boxes is dependent on salt influence as well as the elevation of the boxes' location. Reed develops frequently in this area and above mean high water tall forbs also establish. Vegetation development is potentially possible, albeit limited because of the little surface area that is available behind a brushwood box installed as direct bank protection. For vegetation development potential, see the data sheet *Indirect bank protection in tidal areas*.

### Fauna

The brushwood box itself as well as the potentially developing structures and vegetation can provide habitats for various animal groups.

- Depending on its elevation, a brushwood box can provide a habitat for small invertebrates that colonise hard substrates (e.g. shells, barnacles, moss animals and cnidarians, depending on salinity conditions).

## ECOLOGICAL BENEFIT

compared to direct bank protection using riprap, concrete or steel

- In contrast to extensive bank protection measures, particularly revetments, the tidal flat is not covered when brushwood boxes are used. Depending on the salinity (fresh, brackish or salt water), a large diversity of species can therefore establish, such as worms (e.g. bristle worms), crustaceans (e.g. amphipods), shells (e.g. Asian clam, razor shell) and winkles (e.g. common periwinkle). They serve as an important source of feed for breeding and resting birds.

### Ecosystem services

Compared to direct technical bank protection measures, the potentially developing structures and vegetation associated with brushwood boxes can provide the following ecosystem services and benefits. Depending on the degree of riparian vegetation behind the brushwood box:

- Carbon storage
- Improved erosion protection through vegetation
- Habitats for riparian organisms in estuaries
- Enhanced recreational functions because area is experienced as a more natural landscape

## RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

### Range of applications

The design of brushwood boxes makes them suitable for bridging differences in elevation of up to approximately 1.2 m if conditions are favourable. They can therefore be used for the direct protection of erosion edges or steep banks above mean low water. They can also serve to protect the toes of banks with (almost) vertical slopes and large differences in elevation.

Brushwood boxes can be found both on tributaries and on the Lower Elbe and Lower Weser banks facing the fairway. This means that they are also suitable for very busy waterways. 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

Sophisticated calculation approaches for the design of brushwood boxes are not available. The material and dimensions are usually chosen based on local experience. This is why brushwood boxes are only used for situations with a limited potential for damage. However, DIN 19657 provides instructions e.g. for the design of brushwood boxes for land reclamation [2].

#### Estimated pile length

DIN 19657 recommends to choose pile lengths and diameters based on experience, samples or geotechnical verification [2]. Based on mathematical estimations and the Collection of measures referred to above, the following procedure is proposed for determining pile length and embedment depth, taking into account soil conditions, slope inclination and elevation of the backfill or steep bank.

The following site-specific variables need to be collected (see diagram below):

- Slope profile with slope inclination, including among others the heights of steep banks that may require protection
- Soil stratification with soil type, including consistency/bulk density if required, and horizon of soil strata with load-bearing capacity

## RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

### Estimated pile length

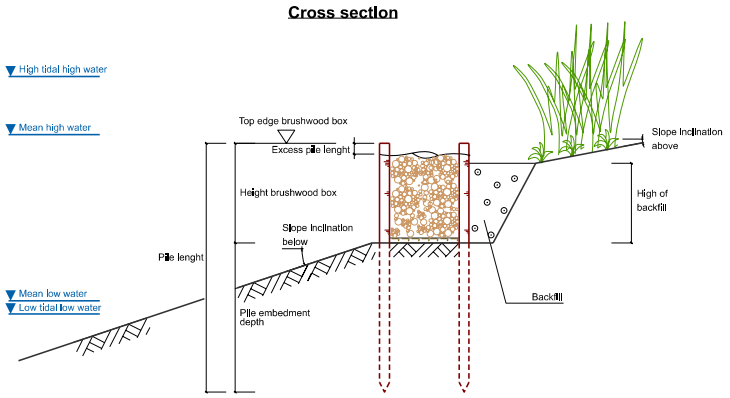


*Diagram: Variables required for choosing pile length (BAW)*

In the diagram above, the total pile length is the combined length of the brushwood box and the pile embedment depth. It should be noted that because the fascines are fixed to the ground with wire, the upper edge of the fascines is lower than the upper edge of the brushwood box and consequently the piles. As a result, the backfill has a slightly lower height than the brushwood box.

To determine the required pile embedment depths and pile lengths, geotechnical equilibrium analyses as applicable for soldier pile walls according to the Recommendations on Excavations (EAB) were conducted [3]. The analyses covered different potential cases that can occur in estuarine areas. Soil characteristics based on DIN 1055-2 [4] were determined for loose sand (groups SE, SU) and clay (groups TA, OU) with soft or stiff consistency. The resulting pile lengths are stated in the table.

*Table: Pile length as a function of soil, slope inclination and backfill height.*

| Soil type | Slope inclination above and below up to | Backfill height Break of slope up to | Required pile length |
|---|---|---|---|
| Sand, loose (SE, SU) | max. 1:3 | 0.3 m | 1.5 m |
| | | 0.7 m | 1.7 m |
| | | 1.0 m | 2.0 m |
| | | 1.2 m | 2.5 m |
| Clay, soft to stiff (TA, OU) | max. 1:4 | 0.3 m | 1.7 m |
| | | 0.4 m | 2.0 m |
| | | 0.6 m | 2.5 m |
| | | 0.8 m | 3.0 m |
| | | 1.0 m | 3.5 m |

### Additional measurements

Experience has shown so far that brushwood boxes ideally have a width that is almost identical to their height. Accordingly, the widths of the brushwood boxes range between 0.4 m and 1 m.

The piles hold the fill material together and prevent the loss of material or breaking of the fascines under external load. A maximum distance of 1 m between the piles is therefore recommended; depending on the fill material, a shorter distance may be necessary.

## RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

### Tolerance of hydrodynamic loads

Brushwood boxes can withstand the hydrodynamic loads on highly frequented waterways, provided that they have the appropriate dimensions. To fulfil durability requirements, the brushwood boxes need to be adapted, e.g. with respect to the fill material used (see section *Alternative designs*).

Specific measurements of the hydrodynamic loads acting on brushwood boxes 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 boxes.

### Alternative designs

#### Brushwood boxes with stone filling

(For more information refer to [2])

Stone gabions or loose armour stones as fill material have been proven to be a suitable alternative to fascines or brushwood on waterway sections with high hydrodynamic loads. A higher durability of the structures is likely, as scarcely any loss of material has to be expected. The lower conductivity of a stone filling compared to brushwood can result in increased wave reflection and, consequently, a higher scour risk. A scour protection may therefore need to be installed on the waterside of the brushwood box. Alternatively, a stone cover on the brushwood filling or the placing of loose stones can increase the durability and stability of brushwood boxes. From an ecological viewpoint, designs with biodegradable materials (driftwood, brushwood, live willow rods) are preferable as they provide habitats and feed for riparian plants and animals and foster habitat interconnectivity. Moreover, natural wood structures are rare on tidal flats since floodplain forests belong to the group of habitats with deficits.

#### Live brushwood box

Dormant willow rods or piles can develop shoots at a level of approximately 1 m above mean high water and are therefore suitable as bank protection, e.g. as fill material for live brushwood boxes. In lower-lying areas, reed rolls are a suitable alternative fill material. From an ecological perspective, this design has the potential to promote biotopes such as softwood forests which are legally protected biotopes.

#### Brushwood boxes with soil backfill

The space between the open terrain and the brushwood box should be backfilled with soil and, if necessary, with sod to restore the bank line and prevent animals from being trapped in this area (see *Annex 1*). Filter stability of the structure against the backfilled soil should be ensured as far as possible. This design alternative is preferable from an ecological viewpoint as it minimises the risk of fish traps between the brushwood box and the ground surface.

#### Additional perpendicularly placed fascines

To increase ecological benefit, brushwood boxes can be additionally filled with fascines placed at regular distances in a perpendicular position so that they protrude from the brushwood box on the waterside. This adaptation adds structure and, depending on the elevation of the brushwood box, can serve as refuge for juvenile fish during tidal high water. A high proportion of dead wood structures also has a positive effect on the area potentially available for colonisation by hard-substrate macrobenthic organisms.

Fascines installed as ramps can provide a means of escape for land animals with limited climbing abilities, such as hedgehogs, sheep or fledglings.

## RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

### Fascine rolls

Fascine rolls are a suitable alternative in bank sections where the difference in elevation is small and loads are insignificant. With their smaller dimensions (compared to brushwood boxes) they act less as a barrier between habitats in the intertidal zone and are therefore preferable from an ecological perspective.

### Design with scour protection

In areas with a scour risk in front of the brushwood box, a scour protection is required, using either a dead wood brush mattress (more ecological [5]) or armour stones.

## COMPONENTS AND INSTALLATION

### Components

For the usual dimensions of a brushwood box with a thickness of 0.4–1 m and a height of 1 m the following average quantity of material per 10 m length of the structure are required:

- 10–20 wooden piles
- 4–10 m³ of fascines (compressed, after installation)
- Approx. 10 m² of degradable geotextile or other filter material if required
- backfill if required
- approximately 50 m binding wire
- 10–20 staples

The exact design and material requirements can vary between projects. Components with the following properties have proved 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 ends should be 2–4 times larger than the pile diameter.

Diameter (bottom): 0.09–0.13 m

Length: 1.50–3.50 m

Among native timber types, larch shows the highest resistance to weathering [6].

### Fascine material

#### Fascines

Fascines are bundled brushwood. They must be supplied when freshly cut and installed without delay. In intertidal zones their capacity to form shoots is limited by the duration of the inundation period. As a result, it is generally not required to use dormant brushwood as material for the brushwood boxes.

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

#### Fascine dimensions

Length: 1.8–2.3 m

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

## COMPONENTS AND INSTALLATION

The fascines must be tied with three galvanised and annealed steel wires, 1.2–2.0 mm in diameter. At least three wires must be used for a strand which 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, fascines 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.

### Hardwood fascines

Fascines made from fresh hardwood, 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 [2].

### Softwood fascines

Fascines made from softwood (spruce, fir) have proved suitable for brushwood box construction in coastal protection. They are more unwieldy as a rule; the needles come off quickly and the resulting loss in volume can have a negative impact on the long-term packing thickness of the brushwood box.

Softwood fascines can be made by recycling Christmas trees [7]. However, because of its content of tannins, softwood has a smaller ecological potential for colonisation [8].

**Filter**

In cases of a risk of soil loss, a suitable filter can be installed between the brushwood box and the 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 box. The design of the geotextiles would need to be based on the relevant Codes of Practice (MMB (2013) [9], MAK (2013) [10] and MAG (1993) [11]). 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.

When using a base layer of straw, heather or floating debris, as is recommended by various textbooks [12], 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**

An example of how to build a brushwood box is available at: https://izw.baw.de/publikationen/alu-aestuare/0/vortrag_instandsetzungsarbeiten-Wuemme_schreiber-popp_2020-02.pdf

Generally, the following work steps are distinguished:

1. Preparing the subgrade; clearing the construction area of any obstacles (armour stones, geotextiles, vegetation cover, etc.)
2. Driving or pressing the piles into the ground while maintaining a defined horizontal and longitudinal distance up to a height that is double the target height of the brushwood box

## COMPONENTS AND INSTALLATION

3. Filling the space between the pile rows with fascines (laying of a filter layer below the fascines if required)
4. Tensioning the wire between the piles; the wire must be placed as a loop around the piles and fixed with staples
5. 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
6. Laying of geotextile or alternative filter material behind the brushwood box if required
7. Backfilling of the space behind the brushwood box if required

**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 zones**

The daily tidal dynamics act as limiting factor for the time available for construction activities. Depending on the elevation of the location where the brushwood box 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.

**Backfilling of the space behind the brushwood box**

The risk of potential fish traps behind the brushwood box should be minimised by completely filling up the gap between the brushwood box and the ground surface. Alternatively, it would be possible to maintain or create residual water bodies (tidal pools) that are safe for fish.

## MAINTENANCE

The required maintenance effort depends on the on-site 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) shows that brushwood boxes require maintenance intervals of 3–5 years and in some cases up to 10 years. The durability of the fascine material is crucial here; the material needs to be refilled or replaced regularly, on average every 3–5 years. Ideally, regular inspections are carried out to assess the condition and replace the fascine material if required.

## MAINTENANCE

In areas with very high dynamic loads it may be necessary to refill the brushwood box on a yearly basis.

The piles are more durable than the fascine material as a rule. Nevertheless, after a period of 6–10 years, a complete repair including the piles is required in most cases 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 box is not necessary.

## EXAMPLES

**Examples of brushwood boxes on German federal waterways**

### Brushwood box Kleinensieler Plate

Lower Weser, km 54.600–54.850, left bank

https://izw.baw.de/publikationen/alu-aestuare-massnahmen/0/Uwe-055li_01_01_EN.pdf

### Test stretch 1 for NBS for bank protection on the Wümme river

Wümme-km 17.310–17.390, left bank

https://izw.baw.de/publikationen/alu-aestuare-massnahmen/0/Wue-017li_01_01_EN.pdf

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| **Editor** | Federal Waterways Engineering and Research Institute, Hamburg<br>Federal Institute of Hydrology, Koblenz |
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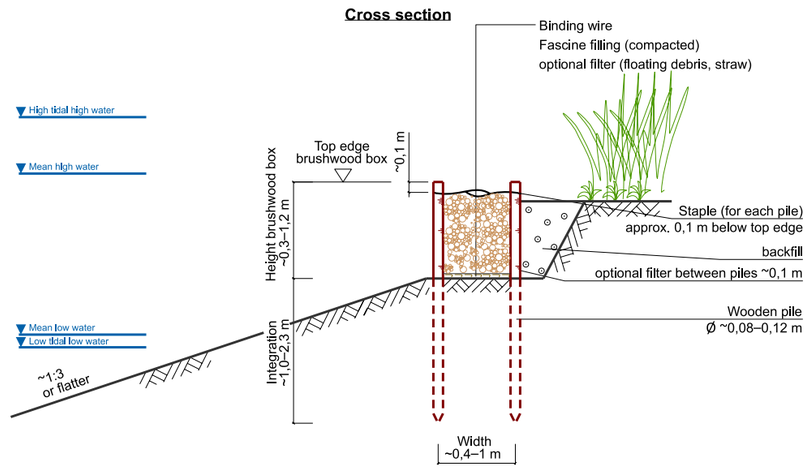
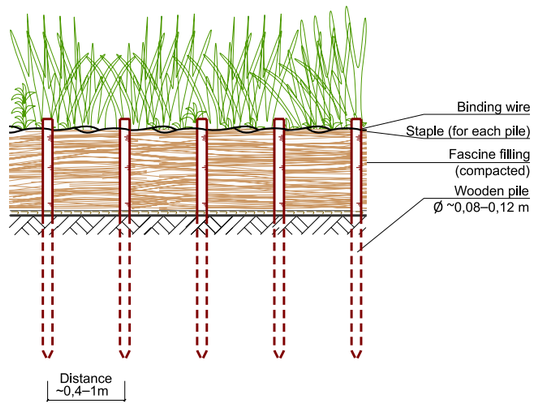
| **Citation** | BAW and BfG (2024): Data sheet Direct bank protection: Brushwood box. Nature-based solutions for bank protection along estuarine waterways |

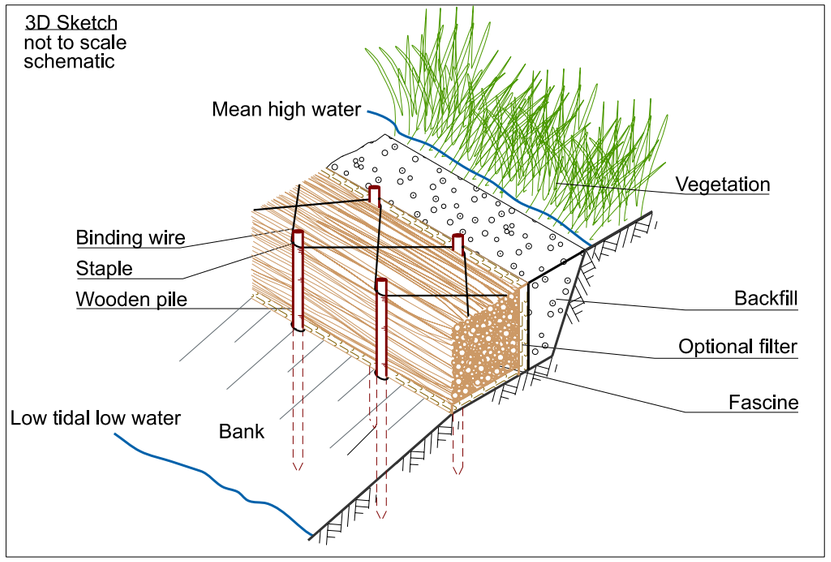
Annex:
1. Technical drawings

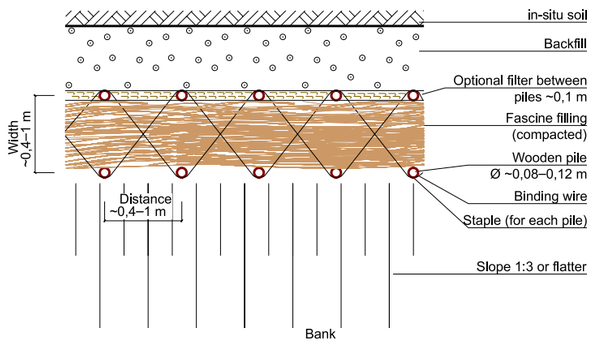
## Annex 1 Technical drawings

The drawings shown here must be adapted to local conditions.




The diagrams are only examples; all dimensions need to be adapted to on-site conditions.

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Technical biological bank protection in estuaries
direct bank protection:
brushwood box

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