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<td>Summary:</td>
<td>The Bathymetric Position Index (BPI) is a measure which allows calculating where a certain location with a defined elevation is relative to the overall landscape. Examples of BPI applications both on a fine and a broad scale are shown on datasets on the Belgian continental shelf, the Dutch continental shelf, Hemptons Turbot Bank (Ireland) and North Maidens Peak (Irish Sea), encompassing a range of sedimentary and bedrock environments.</td>
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The bathymetric position index (BPI) as a support tool for habitat mapping

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1. Introduction

The bathymetric position index or BPI is a second order derivative of the surface. It is a calculated metric, which defines the elevation of locations with reference to the overall landscape. The result is a map with geomorphological features like slopes, depressions, crest lines and flat areas. It was originally derived for geomorphological purposes on land and was called topographic position index (TPI) (Weiss, 2001). The TPI was used for benthic habitat mapping by Iampietro & Kvitak (2002) and Iampietro et al. (2005). Specific for the marine context, the name changed towards bathymetric position index (Lundblad et al., 2006). A GIS tool called the Benthic Terrain Modeler (BTM) was built (Wright et al., 2005) allowing user friendly calculation of the BPI, as well as the rugosity index. The rugosity is the ratio of the surface area to the planar area. It gives an indication of the "bumpiness" of the terrain.

The BPI is calculated from bathymetrical digital elevation models (DEMs), such as multi beam or single beam echosounder data. It can be both calculated on a broad scale (B-BPI) and a fine
scale (F-BPI). The BPI algorithm compares each cell’s elevation to the mean elevation of the surrounding cells within a user defined rectangle, annulus (donut shape) or circle (Figure 1). Using negative bathymetry data results in a negative BPI value for depressions (a cell is lower than its neighbouring cells), a positive BPI for crests (a cell is higher than its neighbouring cells) and a zero BPI for constant slopes or flat areas (Figure 2) (Lundblad et al., 2006).

Wright (2005) (being the Help function of the BTM) explains the standardization of the BPI’s. Both B-BPI and F-BPI have to be converted into standardized values because bathymetric data tend to be spatially autocorrelated (i.e. locations that are closer together are more related than locations that are farther apart) (Weiss, 2001). Therefore, the range of BPI values increases with scale. For example, broad scale BPI data sets would have smaller BPI values because a larger analysis neighborhood is used. This would have the effect of averaging out small variations in the terrain. Fine scale BPI data sets would have larger BPI values because of the smaller neighborhood that is used. This smaller analysis neighborhood would result in the detection of smaller, localized variations in the terrain. Standardization of the raw BPI values allows for the classification of BPI data sets at almost any scale (Weiss 2001). This way, standardized BPI’s are comparable. A BPI value of 100 corresponds to one standard deviation. BPI’s are then classified against a defined dictionary of fine and broad scale BPI values, slopes and depths (Figure 3).

Figure 2: Top: with a small scale factor, subtle topographic features show up. Bottom: a large scale factor results in broad scale topographic features (from Weiss, 2001).
2. Examples of BPI

2.1. BPI on the scale of the Belgian Continental Shelf

The DEM of the Belgian Continental Shelf (BCS) is based on single beam echosounder data from the IVA Maritime Services and Coast, Flemish Hydrography and completed with data from the Hydrographic Office of the Netherlands and the United Kingdom. This dataset was interpolated using a simple inverse distance algorithm to a DEM with a resolution of 80 m (Figure 4).

Figure 3: Example of a classification dictionary where 5 classes result from F-BPI, B-BPI and a slope map.

Figure 4: The digital elevation model of the Belgian Continental Shelf, based on single beam echosounder data and with a resolution of 80 m.
Different BPI scale factors were tested and compared. A B-BPI was made with a scale factor of 1600 (outer radius 20 and resolution of 80 m) and a F-BPI with a scale factor of 240 (outer radius 3). The F-BPI was used to separate the small scale crests from the broad scale features, determined by the B-BPI (depressions, crests, flats and slopes). For distinction between flats and slopes a threshold slope value of 0.65 was used. This value is equal to the mean slope value of the slope map of the BCS multiplied by 0.6 standard deviation (slope classification from Burrough & McDonnell, 1999). The classification decision tree shows how the different classes were defined (Figure 5). Figure 6 gives an overview of the methodology followed to come to the final map.

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**Figure 5**: Classification decision tree developed for the Belgian Continental Shelf of a B-BPI and a F-BPI classification, resulting in 5 classes: depressions, crests, flats, slopes and small-scale crests.

**Figure 6**: The final map of the 5 BPI classes is the result from 3 maps derived from the bathymetry: slope, F-BPI (scale factor 240) and B-BPI (scale factor 1600). The classification dictionary is used to combine and query the different maps.
Finally a map of the BCS was created with 5 classes, resulting from the B-BPI, the F-BPI and the slope map. The 5 BPI classes are small scale crests, crests, depressions, flats and slopes (Figure 7). Most of the sandbanks and their swales show up clearly. In the northern part of the BCS the sandwave field comes out very well. The southern part of the BCS shows the artificially dredged shipping lane and the quasi flat areas around it.

![Figure 7: BPI classes on the Belgian Continental Shelf. The morphology of the sandbanks, swales, bedforms and flat areas shows up very clearly.](image)

### 2.2. BPI in the Hinderbanken area

The Hinderbanken is an area of sandbanks about 35 – 60 km offshore. The same methodology was followed in the southern part of the Hinderbanken area, where a multi beam echosounder dataset was available with a resolution of 2 m. Figure 8 gives the resulting map of the 5 classes in this area. The threshold slope value is 4.01 in this area, defined in the same way as described above (classification from Burrough et al. (1999)). In the worked example ‘Analysis of bathymetrical derived features on the Belgian Continental Shelf as a support for marine habitat mapping’ (Verfaillie et al., 2006) the BPI methodology compared to another methodology based on unsupervised classification is described.
Figure 8: BPI classification applied to a multi beam bathymetric dataset (resolution 2 m) of southern Hinderbanken area with a clear distinction between bedforms on the sandbanks and the swales. The patchy pattern in the swales is a possible indicator of gravel.
2.3. BPI on the Dutch Continental Shelf (the Netherlands)

For the BPI classification on the Dutch Continental Shelf (DCS), the same classification was used as described in Section 2.1 (see Figure 5 for the classification decision tree). With a resolution of 200 m, a B-BPI was made with an inner radius of 1 m and an outer radius of 6 m, resulting in a scale factor of 1200 m. A F-BPI was made with an inner radius of 1 m and an outer radius of 2 m, giving a scale factor of 400 m. Figure 9 gives the resulting map of the 5 classes in this area.

**Figure 9**: BPI classes on the Dutch Continental Shelf: small scale crests, large scale crests, slopes >0.65°, valleys and flats.
2.4. BPI on the Hemptons Turbot Bank (Ireland)

The fourth example is Hemptons Turbot Bank, an area of sand waves sitting off the north coast of Ireland, west of Malin Head (55°28’00”N: 006°52’00”W to 55°24’00”N: 007°4’00”W) was surveyed by the Marine Institute and the Geological Survey of Ireland as part of the Irish National Seabed Survey, and subsequently identified as a site of relevance to MESH and resurveyed, by the North Western Shelf Consortium mapping effort (the Marine Institute, British Geological Survey, and Agri-food and Biosciences Institute, Northern Ireland). Depths of sand waves range from peaks at 19 m to troughs going down to 50 m. This case study is described in detail in ‘Survey Data Analysis for Hemptons Turbot Bank’ (link). With a resolution of 2 m, a B-BPI was made with an inner radius of 3 m and an outer radius of 15 m, resulting in a scale factor of 30 m. A F-BPI was made with an inner radius of 1 m and an outer radius of 5 m, giving a scale factor of 10 m. Figure 10 gives the resulting map of the 4 classes in this area.

Figure 10: Top: Multi beam bathymetry image of Hemptons Turbot Bank (resolution of 2 m), bottom: BPI classification with 4 classes (source: Survey Data Analysis for Hemptons Turbot Bank)

2.5. BPI on the North Maidens Peak (Irish Sea)

North Maidens Peak is located with its centre point at 54°59.89’ N, 5°43.32’ W, approximately 13 km east of the Northern Irish coastline in the North Channel of the Irish Sea. The site extends approximately 4.4 x 4k m and encompasses a bedrock intrusion and surrounding sedimentary region, ranging from –30 m to –166 m in depth. It has been surveyed as part of the MESH North Western Shelf Consortium mapping effort, and by the Agri-Food & Biosciences
Institute (AFBI) as part of their ongoing research into the sensitivity of Northern Irish benthic habitats.

With a resolution of 4 m, a B-BPI was made with an inner radius of 8 m and an outer radius of 40 m, resulting in a scale factor of 160 m. B-BPI was combined with depth for the final classification. The original multi beam echosounder bathymetric data is presented in Figure 11. Figure 12 gives the resulting zone map with 7 classes:

- sedimentary plain (close to flat / constant slope; depth limited to –166 to -68 m),
- low relief features (small crests/hummocks; depths unrestricted),
- ridges/slopes 1 (features/regions that are higher than their surroundings, with a BPI greater than zone 2; depths unrestricted),
- valleys/slopes 2 (features/regions that are lower than their surroundings; depths unrestricted),
- steep/high relief ridges (steep/high relief regions that are significantly higher than their surroundings, with a BPI greater than zone 3; depths unrestricted),
- steep/high relief valleys – cliff walls (steep/high relief regions that are significantly lower than their surroundings, with a BPI lower than zone 4; depths unrestricted),
- rock plateau/flat (close to flat / constant slope; depth limited to –68 to -31 m)
Figure 11: Multi beam echosounder bathymetric data for the North Maidens Peak (DEM)
Figure 12: Potential habitats defined using Benthic Terrain Modeller, based upon bathymetric position index and depth ranges from multi beam sonar survey. Ground truthing to test applicability of zones classification to habitat mapping will be provided from drop-down video survey and grab sampling.

3. Applications of BPI in habitat mapping

The derivation of B-BPI, F-BPI and use of the rule-based classification system based upon these datasets, along with, where applicable, slope angle and depth ranges, to provide a classified map of bathymetric ‘zones’ may prove an extremely valuable step in data analysis for benthic habitat mapping.
The generation of BPI and classified maps based upon BPI may yield features that were otherwise difficult to discern by eye from bathymetric data or backscatter data. The resulting map should be compared with an expert visual interpretation of the data to ensure consistency and rule out any artefacts that may be propagated by the BPI zone classification method.

Use of BPI and rule-based classification provides an objective approach to unsupervised classification of broad scale, remotely sensed data, and complements other methods of unsupervised classification. However, until ground truthing data is incorporated, such maps should be treated as potentially indicative of habitats through identifying distinct seabed zones. The zones, or ‘ground-types’, may not necessarily relate to biologically meaningful habitats as these have been generated through the use of artificial thresholds that may not be biologically relevant. The hypothesis that ground types/zones identified by BPI classification may correspond to habitats requires testing through appropriate ground truthing (for a worked example see Mitchell et al., 2007). Based upon thorough analysis of ground truthing data, the ground types/zones, their distribution and extent, should be re-evaluated to see if these can be translated into habitats, and whether they require modification to become biologically relevant.

4. References