Compositional and multivariate statistical analyses for grain-size characterisation of intertidal sedimentary facies in an estuarine environment

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ABSTRACT
This study presents the characterisation of grain size dynamics within an estuarine environment through statistical summarisation of grain size distribution and multivariate statistics. A total of 44 samples were taken from seven (7) main locations to the depth of ~15 cm at the intertidal depositional environment of Camel Estuary, Southwest England. A wide range of grain size statistical parameters explored here shows that outer estuarine sediment is composed of coarse sand population mixed with fine/medium sand while mid-estuarine sediment composition is of fine/medium sand population. The inner sediment deposition is a total deviation from other sections of the estuary, suggesting that the decrease in transportation energy caused the deposition of very fine sediments at this sedimentary facies. The summarisation of grain size distributions and multivariate statistics have shown that these methods can be used to determine sediments with similar parameters and, therefore, are a good proxy in recognising sedimentary facies within an inter-tidal depositional environment.

1. Introduction
Description and understanding of the provenance, processes, pattern, and direction of sediment movements using grain-size parameters is well established in literature and this has now become a basic routine in sedimentology (e.g., Donohue et al., 2003; Fan et al., 2015; Flemming, 2007; McLaren, 1981; McLaren et al., 2007; Nugroho & Putra, 2017). Textural characteristics of grain size parameters (e.g., median, mean size, sorting, kurtosis, skewness) have been methodically used to describe sedimentary features and their depositional settings (e.g., Ashley, 1978; Francke et al., 2013; Friedman, 1961) and to infer sedimentary transport pathways (e.g., Anthony & Héquette, 2007; Oyedotun, 2016; Folk & Ward, 1957; Oyedotun et al., 2012, 2013). Many methods have been extensively developed and used to describe sedimentary environments (Fan et al., 2015) and, by extension, the grain-size distributions of these naturally occurring depositional environments (McLaren et al., 2007). Most common measures of quantifying composition and comparison of grain size distributions (GSDs) are mean, median, standard deviation, sorting, kurtosis and skewness statistics (Blott & Pye, 2001; Katra & Yizhaq, 2017). These are known to accommodate less message than the weight-percent histogram from which they have been derived (Chayes, 1971; Nugroho & Putra, 2017; Nugroho et al., 2018). To overcome these and other several limitations posed by the compositional data, several techniques and methods have been developed (e.g., Roberson & Weltje, 2014), the notable of which include development of a series of log-ratio transformation practices (e.g., Aitchison, 1986). However, statistical analyses and summarisation remain an effective technique in describing the GSDs, and Principal Component Analysis (PCA) remains a very vital multivariate statistic in reducing the compositional dimensionality of GSDs (e.g., Garzón et al., 2016; Katra & Yizhaq, 2017; Palazón & Navas, 2017; Flood et al., 2015; Tiecher et al., 2015).

The main aim of this paper is to provide statistical summarisation of GSDs and multivariate statistics (PCA) of the inter-tidal sedimentary facies of an estuarine environment, using an example from Camel Estuarine system of southwest England. The methods applied in this study entail: firstly, the decomposition of grain size variabilities into signals to establish the nature of the composition of the grain size data; and secondly, the reduction of data dimensionality to principal components (PCs) using hierarchical sequences without the loss of any information. In this paper, the results of characterising the GSDs in sediments through compositional data and multivariate statistical framework (specifically, PCA) are presented.

2. Materials and method

2.1. Study site: Padstow Bay and the Camel estuary
This study was conducted in Camel Estuary (Figure 1), a ria estuarine system located in the Padstow Bay of...
Southwest England. This macro-tidal (with mean spring tide range of 6.3 m at the outer section of the estuary which later decreases to 2.8 m at the inner section of the estuary) system is a product of post-glacial rise in sea-level with predominant sandy sediments (Brew & Gibberd, 2009; Oyedotun et al., 2013). The entire intertidal area of this system is approximately 6 km² with about 92% being tidal flat (Brew & Gibberd, 2009). This estuarine system can be differentiated into three sedimentary facies (Figure 1). The outer estuary, which is a subtidal channel that flows between Daymer Bay and Harbour Cove, is dominated by large intertidal sand flats at the mouth of the estuary and planar high intertidal beaches which merge with low intertidal flats (Sites A and B). The mid-estuarine environments are characterised by various types of bedforms which range from megaripples (c. 10–20 m wavelength) to wave-current ripples (c. 10–25 cm wavelength) (Sites C, D and E) (See Figures 1 and 2). The inner estuary environment at the landward section of this system is more sheltered, thereby enabling the system to function as a very vital sediment sink (Defra, 2002; Oyedotun et al., 2013). In the inner section of the estuary (Site F and G), the extensive sand flats give way to narrow muddier features that merge with relic gravel shoreline deposits (Figures 2 and 3). Previous studies of the estuarine systems in this region have focused primarily on impacts of mining on sediment supply rate, mineralogy and sedimentology (e.g., Pirrie et al., 2000). However, of recent, textural analyses of sediments are being used to understand the fundamental information of sediment dynamics of this estuarine systems (e.g., Brew & Gibberd, 2009; Oyedotun et al., 2013).

Figure 1. The Padstow Bay – Camel Estuary sites sampled for sediment analysis. (Inset: Southwest England showing the location of Camel Estuary. Map Data Sources: National Geographic, ESRI, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCan, GEBCO, NOAA, Increment P Corp. Credit: Content may not reflect National Geographic’s current map policy).

Figure 2. Padstow – Camel photographs showing surface conditions in the seven main sedimentary environments surveyed. Sites are: the outer estuary (a – Harbour Cove/Hawker’s Cove, b – Daymer Bay), mid-estuary (c – Porthilly Cove, d – near Padstow, e), and inner estuary (f and g). See Figure 1 for location.

Figure 3. Surface and sub-surface sediment characteristics in the Padstow Bay – Camel estuary system. Grain size distributions are shown for all samples obtained within the depth range 0–15 cm at locations in the 3 main sedimentary facies examined. (a) – The average particle size or median diameter (D₅₀); (b)– Sorting and (c) – Skewness. Outer estuary is Sites (a) – Harbour Cove/Hawker’s Cove, (b) – Daymer Bay, (c) – Porthilly Cove, (d) – near Padstow, (e) – mid-estuary, (f and g) – inner-estuary.
2.2. Materials

Short core (length ~<15 cm) surface sediment deposited within the Camel estuarine system was sampled using a 65-mm-diameter tube at approximately 44 locations (Figure 1) at the outer, mid and inner sections of this system, covering seven (7) separate intertidal sedimentary sites. The sample positions were recorded using a hand-held Global Positioning System (GPS, ±3 m rms error) and these were collected during the PhD research programme of Oyedotun (2015). The surface conditions of these surveyed sedimentary environments are presented in Figure 2.

2.3. Methods

Short (15 cm) cores were sliced at 1 cm interval and their GSDs were obtained using the optical laser method (after Flood et al., 2015) of Malvern MasterSizer 2000 instruments (Malvern, 1999). Following the collection of measurements from the instrument, the data were aggregated across the range 0.002–2000 μm (Malvern, 1999). Sediments coarser than sand (>2000 μm) were not considered in this analysis. Here, the GSDs were processed for a range of Folk and Ward (1957) grain size statistics (e.g., median, D50; Skewness, Sk; sorting, σ, and Kurtosis, K) through GRADISTAT (Blott & Pye, 2001).

The compositional distribution of the grain size and the grain size classification (defined by Udden, 1914; Wentworth, 1922) along with the multivariate statistics calculations (specifically, PCA) were processed in MATLAB. Principal Component Analysis (PCA), using Euclidean distance and average link in the Hierarchical cluster, was used to reduce the grain size distributions across all samples into groups with similar sedimentological characteristics. Based on the recommendations by several authors, Euclidean distance is used, here, for PCA (e.g., Nugroho et al., 2018; Flood et al., 2016; Flood et al., 2015; Todde et al., 2016).

3. Results and discussion

3.1. Grain size distribution

In this study, 44 short bulk (core) samples were examined across the sites to provide opportunity to understand spatial distribution and characterisation of sediment grain size populations and mixing. The statistical results of median (D50, μm), sorting (σ, μm) and Skewness (Sk) of the grain size distribution for each of the sedimentary environments with their correlation with depth of sampling are summarised and presented in Figure 3. The median (D50) grain size of sediments of Camel Estuary sub-environments ranges from coarse/medium sand (250–500 μm) to fine/very fine sand (125–250 μm) at the seaward outer section of the estuary to the middle section of the estuary, respectively (Figure 3(a)). Bulk of sediments in the range of 160–500 μm constitute the dominant sediment makeup in this entire system, except at the inner estuary where sediment population, are principally broad silt/clay/very fine sand (range of <63 μm). Mid-estuary sediments (sites C, D, and E) are also mixed with a distinct finer (silt and clay) population. In terms of depth, the sediment content did not vary significantly as the outer estuary sediment population is composed of coarse/very coarse sand mixed with core fine-medium sand population at 0–5 cm/5–10 cm and 10–15 cm, respectively. Similarly, the pattern of grain size distribution from the surface of the mid-estuary to the depth of 15 cm did not illustrate any form of diversity as these show sediment population composed of a mixture of medium/fine sand at 0–5/5–10 and 10–15 cm, respectively. Clay and silt population also dominate below the surface sedimentary environment (to the depth of 15 cm) of the inner section of Camel Estuary.

The sorting (σ) results of the sedimentary facies ranged from 1.41–1.62 μm (moderately well sorted) at outer estuary to 1.62–2.00 μm (moderately sorted) at the mid-estuary (Figure 3(b)) but those at the inner section of the estuary are poorly sorted (2.00–4.00 μm). Similarly, there is a significant difference in sorting at the different depths of the inner section of the estuarine environment where the 0–5 cm of the sediments (the near surface sediments) are far more poorly sorted than those found at 5–10 cm and 10–15 cm, respectively. At mid-estuary, the short stratigraphic distribution of sorting shows the grain size between 5 and 10 cm exhibiting significant differences (but less pronounced) than the sediments at the near surface (0–5 cm) and at deeper surface (10–15 cm). As can be seen at the outer estuary, there is consistency in sediment sorting with depth variation (Figure 3(b)).

The skewness (Sk) values of the sediments ranged from symmetrical (±0.43) at the outer and mid-estuarine environment to negatively skewed (< –0.43) sediments at the inner estuary. These values of sediments indicate a positive skewed sediment distribution at the outer/seaward section of the estuary, while negative symmetrical distribution dominated the mid-estuarine distribution and a very negatively skewed distribution at the inner-estuarine distribution, respectively (Figure 3(c)). Of all the three sedimentary facies, the mid-estuarine sediment facie revealed variation in skewness values with depths with pronounced negatively skewed distributions at 5–10 cm depth. However, what the sedimentary condition here suggests is that fine grain size distributional patterns were within the negatively skewed and poorly sorted sediments at the mid and inner section of this environment, indicating a possibility of decreasing transport
energy in the inward (landward) direction of estuary head.

3.2. Exploratory sediment statistics

The exploratory sediment analysis of grain size statistics – mean vs. sorting, mean vs. skewness, median vs. sorting, and median vs. skewness are presented in Figure 4. The sedimentary environments of the systems investigated here are characterised mostly by sand flats. However, the differences in sediment patterns are evident based on the grain size distributions from the different depositional environments. There is evidence that the open coast and beach/dune (outer estuary) system are composed of the coarse/very coarse (CS/VCS) and medium sand (MS) grain sizes with small contributions of finer material to the distributions (Figure 4). A closer look at the distribution of the sediment shows that about 89% of the sediment composition is dominated by medium sand (MS) part of the distribution, and to a lesser extent coarse/very coarse sand (CS/VCS) and some fine sand (FS). The components of the sand at the beaches and the outer section of this estuarine system are predominantly characterised by a mixture of medium – coarse sand while the mid-estuarine sediment population is mainly a mixture of medium – finer sand and finer materials. Although silts and clays are present in the inner environment of the estuaries, they are however absent in the open coast/beaches/outter section of this system. This ubiquitous pattern of arrangement shows that grain size diameter varies spatially in response to the local hydrodynamic forces and conditions. In terms of sorting and skewness, the sediments along the coastlines of the estuaries in the region, are largely moderately well sorted (MWSo) with near-symmetrical/positive skewness while those found in the inner estuaries are less well-sorted and some, negatively skewed (Figure 4).

The sediments sampled along the outer estuary seaward indicate that the mixture of fine medium and coarse sand population likely reflects the combination of marine sediment source and higher energy processes. Within the estuaries, the silt and clay population combined with the fine-medium sand, suggests mixing with fluvially-sourced material. The coarse sediments found in some points within the estuarine environments may have constitute “lag” deposits which may be too heavy to be transported during the flow processes, thereby left “in situ” as other materials are being sorted and transported. From the grain size composition/distribution perspective, the sand population in the outer estuary is probably derived from a seaward source (possibly from the Celtic sea where Padstow Bay is exposed) and the river borne sediments. However, there is no significant difference in sedimentological depth (<15 cm below the surface) at each of the sedimentary facies (Table 1).

3.3. Principal component analysis (PCA)

In Camel Estuary, the principal component analysis of the grain size distribution account for approximately 96% of the variance (Figure 5). The PC1 indicates 89% of the variance is dominated by the medium sand (MS) part of the distribution, and to a lesser extent coarse/very coarse sand (CS/VCS) and some fine sand (FS), but a distinct lack of material smaller than fine sand. PC2, accounting for 7% of the variance, relates to a coarse component, specifically the presence of coarse and very coarse sand (VCS) and the lack of a fine-medium sand (FS/MS) component.

Combined plots of PCA and cluster analysis of the grain size distribution presented in Figure 6 compare the principal components of the relative sub-environment (B) and relative stratigraphic depth (C). This comparison shows that the main sub-environments

![Figure 4](image-url)

**Figure 4.** Exploratory sediment analysis – grain-size statistics – (a) Mean vs. Skewness (b) Mean vs. Sorting (c) Median vs. Skewness and, (d) Median vs. Sorting.

**Table 1.** Results (p-value) of one-way analysis of variance of selected sediment statistics, considering groupings based on sample site and depth, using the Kruskal Wallis non-parametric method.

| Group         | Depth | Site A & Depth | Site B & Depth | Site C & Depth | Site D & Depth | Site E & Depth | Site F & Depth | Site G & Depth |
|---------------|-------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|               | 0–5 cm & Site | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
|               | 5–10 cm & Site | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
|               | 10–15 cm & Site | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
(outer-estuary, mid-estuary or the inner-estuary) are the clear discriminator of sediment characteristics (Figure 6(a,b)), whilst stratigraphic depth is not (Figure 6(c)). Separation of samples identified in the PCA is clarified in the clustering of samples into four groups. All but two (2) samples (both mid-depth, estuarine samples) are within clusters 1, 2, and 4, which can be described as environment-specific groupings (Figure 6(a)). Cluster 1 refers to medium to high values on both PC1 and PC2, indicating a dominance of the coarser grain sizes and small contribution of finer material to these distributions. This cluster generally characterises the outer-estuary and mid-estuary environment. Cluster 2 refers to high PC1 and low PC2 values, which correspond to a dominance of fine and medium sand in the grain size distribution. This cluster largely represents mid – estuarine sediments. Cluster 4 refers specifically to low PC1 and PC2 values, representing those samples containing a mix of fine material (silt and very fine sand) and limited coarser component. Cluster 4 comprises entirely inner estuarine samples.

The study of any grain size trend should take into the account the sampling depth. Gao and Collins (1992) stated that sampling depth must not be too great so as to avoid mixing “ancient” and “modern” net transport, if the grain-size trend is aimed at identifying the local dynamic forces determining the transport of sediment. This section provides a generalised indication of down core (length <15 cm) changes in sediment textures in the estuaries. The stratigraphic investigation of the texture can provide information or important insights into depositional processes and probably the environmental condition driving the depositional processes.

The principal component and cluster analyses of the sediments in the estuaries have been used to decompose the grain-size distributions into four main clusters of sediments compositions. Figure 6(c) presents the stratigraphy of sediment distribution from the surface through to 15 cm depth. In Padstow-Camel system, the variation in depth of sediment composition is pronounced at the inner section of the Estuary. Sites F and G where silt (Site F) and combination of silt and clay sediments (Site G) provide the variation in sediment consistency. Stratigraphically, there appears to be a high degree of consistency in the principal component-based sample clustering from surface through the 15 cm depth. Despite the lack of overall significance difference, there are minor occurrences of clay-silt peaks sub-surface in several cores. This observation does support the inference that both the compartmentalisation and partial exchange between the beach/coastal sediments and estuarine sub-environments can be attributed to the contemporary processes in the region. These findings also suggest that sediment characterisation in this physical context is relatively insensitive to the sampling depth within the near-surface zone.

4. Conclusion

In this study, the grain size sedimentological parameters have been demonstrated to be a good index for characterisation of depositional environments and indicator of hydro-transport energy. Here, the statistical summarisation of grain size distributions (GSDs) and multivariate statistics (PCA) were used to infer the sediment composition and connectivity of the inter-tidal sedimentary facies of the Camel estuarine environment. These two methods (statistical summarisation and multivariate statistics) used in this study were effective in the determination of sedimentary facies. The pattern of sediment composition at the outer estuary is composed of coarse sand population mixed with fine/medium sand.
population, the mid-estuary composed of fine/medium sand population mixed silt/clay, and the inner estuary principally composed of very fine sediments suggest that the processes here decrease in energy as the sediments are transported from outer to inner section of the system. With GSDs statistical summation and the multivariate statistics, the main three sedimentary facies (outer, mid, and inner) can be distinguished and determined in an estuarine environment like Camel Estuary.

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No potential conflict of interest was reported by the author.

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References

Aitchison, J. (1986). The statistical analysis of compositional data. Chapman and Hall.

Anthony, E. J., & Héquette, A. (2007). The grain-size characterisation of coastal sand from the Somme estuary to Belgium: Sediment sorting processes and mixing in a tide- and storm-dominated setting. Sedimentary Geology, 202(3), 369–382. https://doi.org/10.1016/j.sedgeo.2007.03.022

Ashley, G. M. (1978). Interpretation of polymodal sediments. The Journal of Geology, 86(4), 411–421. https://doi.org/10.1086/649710

Blott, S. J., & Pye, K. (2001). GRADISTAT: A grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms, 26(11), 1237–1248. https://doi.org/10.1002/esp.261

Brew, D. S., & Gibberd, B. B. (2009). Geomorphical change and its impact on habitats in the Camel Estuary, Cornwall, UK. Geoscience in South-West England, 12 (2), 95–100.

Chayes, F. (1971). Ratio correlation: A manual for students of petrology and geochemistry. University of Chicago Press.

Defra. (2002). Futurecoast.

Donohue, I., Duck, R. W., & Irvine, K. (2003). Land use, sediment loads and dispersal pathways from two catchments at the southern end of Lake Tanganyika, Africa: Implications for lake management. Environmental Geology, 44(4), 448–455. https://doi.org/10.1007/s00254-003-0779-0

Fan, D., Shang, S., Cai, G., & Tu, J. (2015). Distinction and grain-size characteristics of intertidal heterolithic deposits in the middle Qiantang Estuary (East ChinaSea), Geo-Marine Letters, 35(3), 161–174. https://doi.org/10.1007/s00367-015-0398-2

Flemming, B. W. (2007). The influence of grain-size analysis methods and sediment mixing on curve shapes and textural parameters: Implications for sediment trend analysis. Sedimentary Geology, 202(3), 425–435. https://doi.org/10.1016/j.sedgeo.2007.03.018

Flood, R. P., Bloemsmia, M. R., Weltje, G. I., Barr, I. D., O’Rourke, S. M., Turner, J. N., & Orford, J. D. (2016). Compositional data analysis of Holocene sediments from the West Bengal Sundarbans, India: Geochemical proxies for grain-size variability in a delta environment. Applied Geochemistry, 75, 222–235. https://doi.org/10.1016/j.apgeochem.2016.06.006

Flood, R. P., Orford, J. D., McKinley, J. M., & Roberson, S. (2015). Effective grain-size Distribution analysis for interpretation of tidallyeltaic facies: West Bengal Sundarbans. Sedimentary Geology, 318, 58–74. https://doi.org/10.1016/j.sedgeo.2014.12.007

Folk, R. L., & Ward, W. C. (1957). Brazos River bar: A study in the significance of grain size parameters. Journal of Sedimentary Petrology, 27(1), 3–26. https://doi.org/10.1306/74D70646-2B21-11D7-8648000102C1865D

Francke, A., Wennrich, V., Saurbrey, M., Juschus, O., Melles, M., & Brigham-Grette, J. (2013). Multivariate statistic and time series analyses of grain-size data in quaternary sediments of Lake El'gygytgyn, NE Russia. Climate of the Past, 9(6), 2459–2470. https://doi.org/10.5194/cp-9-2459-2013

Friedman, G. M. (1961). Distinction between dune, beach, and river sands from their textural characteristics. Journal of Sedimentary Petrology, 31 (4), 514–529. https://doi.org/10.1306/74D70646-2B21-11D7-8648000102C1865D

Gao, S., & Collins, M. (1992). Net sediment transport patterns inferred from grain-size trends, based upon definition of “transport vectors”. Sedimentary Geology, 81(1–2), 47–60. https://doi.org/10.1016/0037-0738(92)90055-V

Garzón, E., Romero, E., & Sánchez-Soto, P. J. (2016). Correlation between chemical and mineralogical characteristics and permeability of phylite clays using multivariate statistical analysis. Applied Clay Science, 129, 92–101. https://doi.org/10.1016/j.clay.2016.05.008

Katra, I., & Yizhaq, H. (2017). Intensity and degree of segregation in bimodal and multimodal grain size distributions. Aeolian Research, 27, 23–34. https://doi.org/10.1016/j.aeolia.2017.05.002

Malvern. (1999). Operators guide Worcesterhire, UK.

McLaren, P. (1981). Interpretation of trends in grain-size measures. Journal of Sedimentary Petrology, 51(2), 611–624. h https://doi.org/10.1306/212F7CF2-2B24-11D7-8648000102C1865D

McLaren, P., Hill, S. H., & Bowles, D. (2007). Deriving transport pathways in a sediment trend analysis (STA). Sedimentary Geology, 202(3), 489–498. https://doi.org/10.1016/j.sedgeo.2007.03.011

Nugroho, S. H., & Putra, P. S. (2017). Spatial distribution of grain size and depositional process in tidal area along Waikelo Beach, Sumba. Marine Georesources & Geotechnology, 36(3), 299 - 307. https://doi.org/10.1080/10664119.2017.1312649

Nugroho, S. H., Putra, P. S., Yulianto, E., & Noeradi, D. (2018). Multivariate statistical analysis for characterization of sedimentary facies of Tarakan sub-basin, North Kalimantan. Marine Georesources & Geotechnology, 36 (8), 907–917. https://doi.org/10.1080/10664119X.2017.1399178

Oyedotun, T. D. T. (2015). Estuary – coast interaction and morphodynamic evolution: A comparative analysis of three Estuaries in Southwest England. [unpublished PhD
Oyedotun, T. D. T. (2016). Sediment characterisation in Estuarine – coastal systems. Journal of Coastal Zone Management, 19(3), 433. https://doi.org/10.4172/2473-3350.1000433

Oyedotun, T. D. T., Burningham, H., & French, J. R. (2012). Characterisation of estuary and adjacent beach sediments in the Gannel Estuary, south-west England. Geoscience in South-west England, 13(1), 70–76.http://www.ussher.org.uk/journal/00s/2012/Full/07%20Oyedotun%20Gannel%20Estuary%202012%20full.pdf

Oyedotun, T. D. T., Burningham, H., & French, J. R. (2013). Sediment sorting and mixing in the Camel Estuary, UK. In D. C. Conley, G. Masserlink, P. E. Russell, & T. J. O’Hare (eds), Proceedings 12th International Coastal Symposium (held at Plymouth, England, UK), Journal of Coastal Research, [Special Issue No 65]. (pp. 1563–1568). https://doi.org/10.2112/S165-264.1

Palazón, L., & Navas, A. (2017). Variability in source sediment contributions by applying different statistic test for a Pyrenean catchment. Journal of Environmental Management, 194, 42–53. https://doi.org/10.1016/j.jenvman.2016.07.058

Pirrie, D., Power, M. R., Payne, A., Cammi, G. S., & Wheeler, P. D. (2000). Impacts of mining on sedimentation: The Camel and Gannel estuaries, Cornwall. Geoscience in Southwest England, 10(1), 021–028.http://www.ussher.org.uk/journal/00s/2000/documents/Pirrie-et_al_2000b.pdf

Roberson, S., & Weltje, G. J. (2014). Inter-instrument comparison of particle-size analysers. Sedimentology, 61(4), 1157–1174. https://doi.org/10.1111/sed.12093

Tiecher, T., Caner, L., Minella, J. P. G., & Dos Santos, D. R. (2015). Combining visible-based color parameters and geochemical tracers to improve sediment source discrimination and apportionment. Science of the Total Environment, 527-528, 135–149. https://doi.org/10.1016/j.scitotenv.2015.04.103

Todde, G., Murgia, L., Caria, M., & Pazzona, A. (2016). A multivariate statistical analysis approach to characterize mechanization, structural and energy profile in Italian dairy farms. Energy Reports, 2, 129–134. https://doi.org/10.1016/j.egyr.2016.05.006

Udden, J. A. (1914). Mechanical composition of clastic sediments. Bulletin of the Geological Society of America, 25(1), 655–744. https://doi.org/10.1130/GSAB-25-655

Wentworth, C. K. (1922). A scale of grade and class terms for clastic sediments. The Journal of Geology, 30(S), 377–392. https://doi.org/10.1086/622910