

Supplementary Information for

Identifying controlling factors of delta morphology using a convolutional autoencoder

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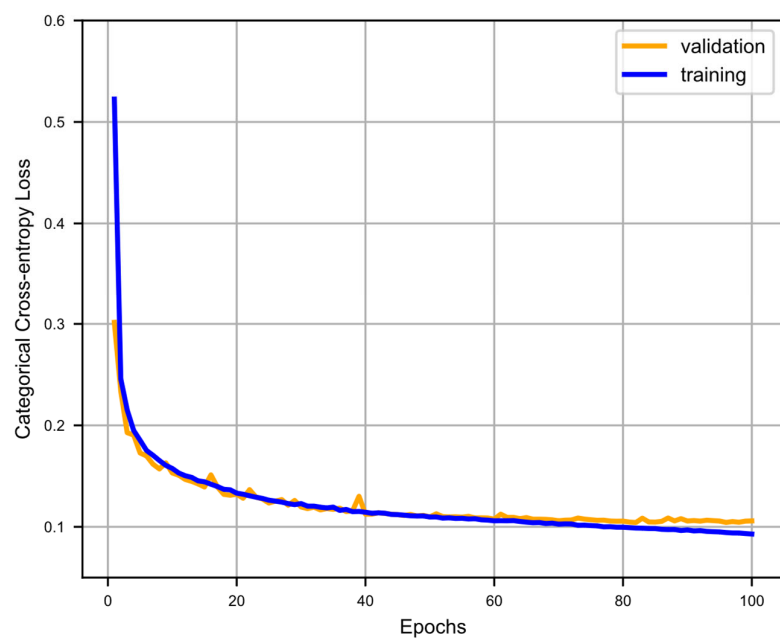
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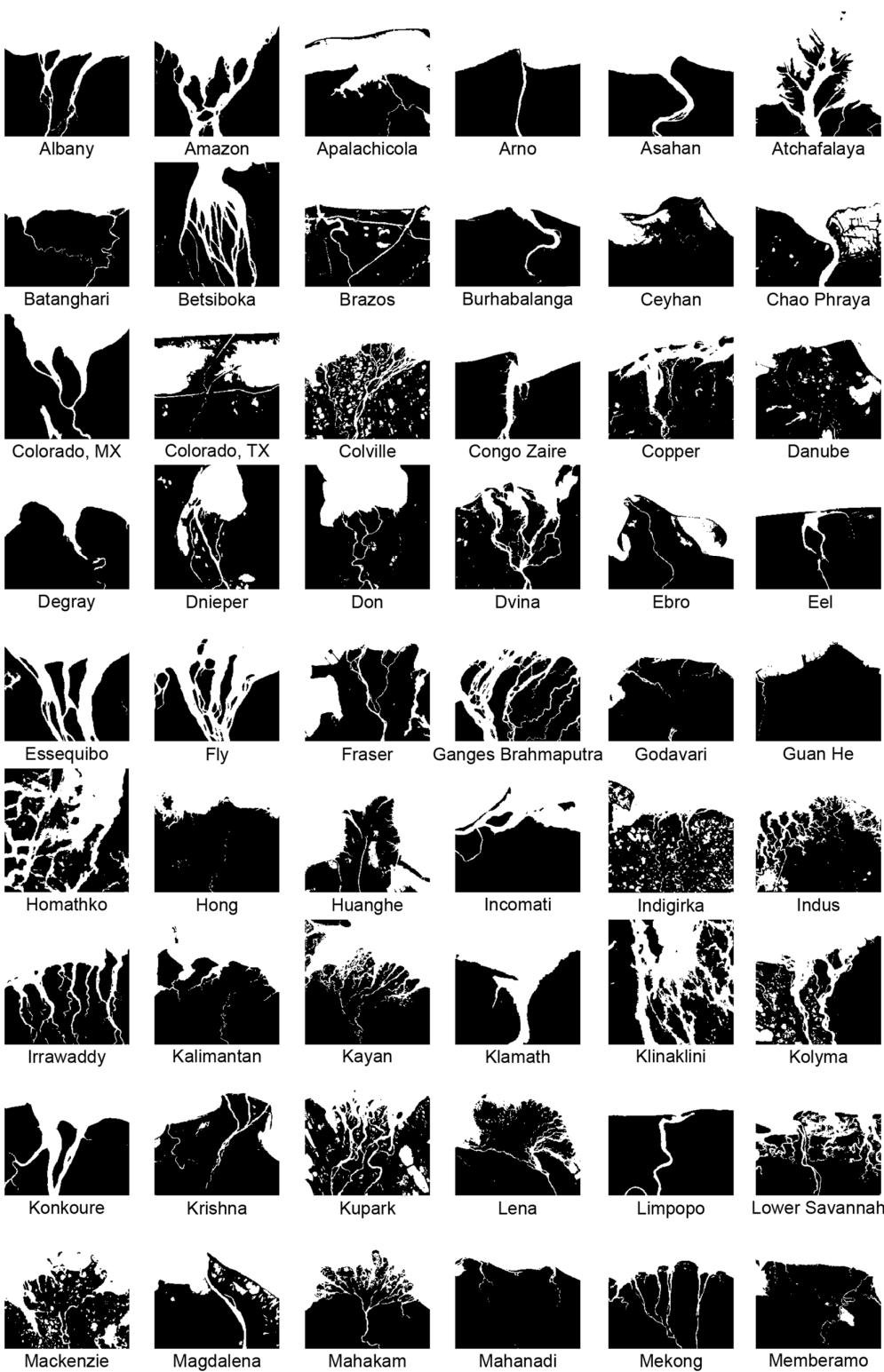
Supplementary Information Text

This document contains supplemental figures (Supplementary Figs. 1–5) and tables (Supplementary Table 1 and 2). Supplementary Fig. 1 shows the training history of the convolutional autoencoder (CAE) model developed in this study. Supplementary Fig. 2 shows 97 delta images (a part of the delta images generated in this study), which were selected as the dataset for the regression analysis. Supplementary Fig. 3 exhibits the delta images predicted by the trained CAE model, with the delta images shown in Supplementary Figure 2 as the input. Supplementary Fig. 4 shows the performance of the CAE model under different latent code dimensions (from 10 to 100). In Supplementary Fig. 5, the result of the principal component analysis accounted for over 80% of the cumulative explained variance from PC1 to PC19 scores, which were chosen as the candidates of the independent variables in the regression analysis.

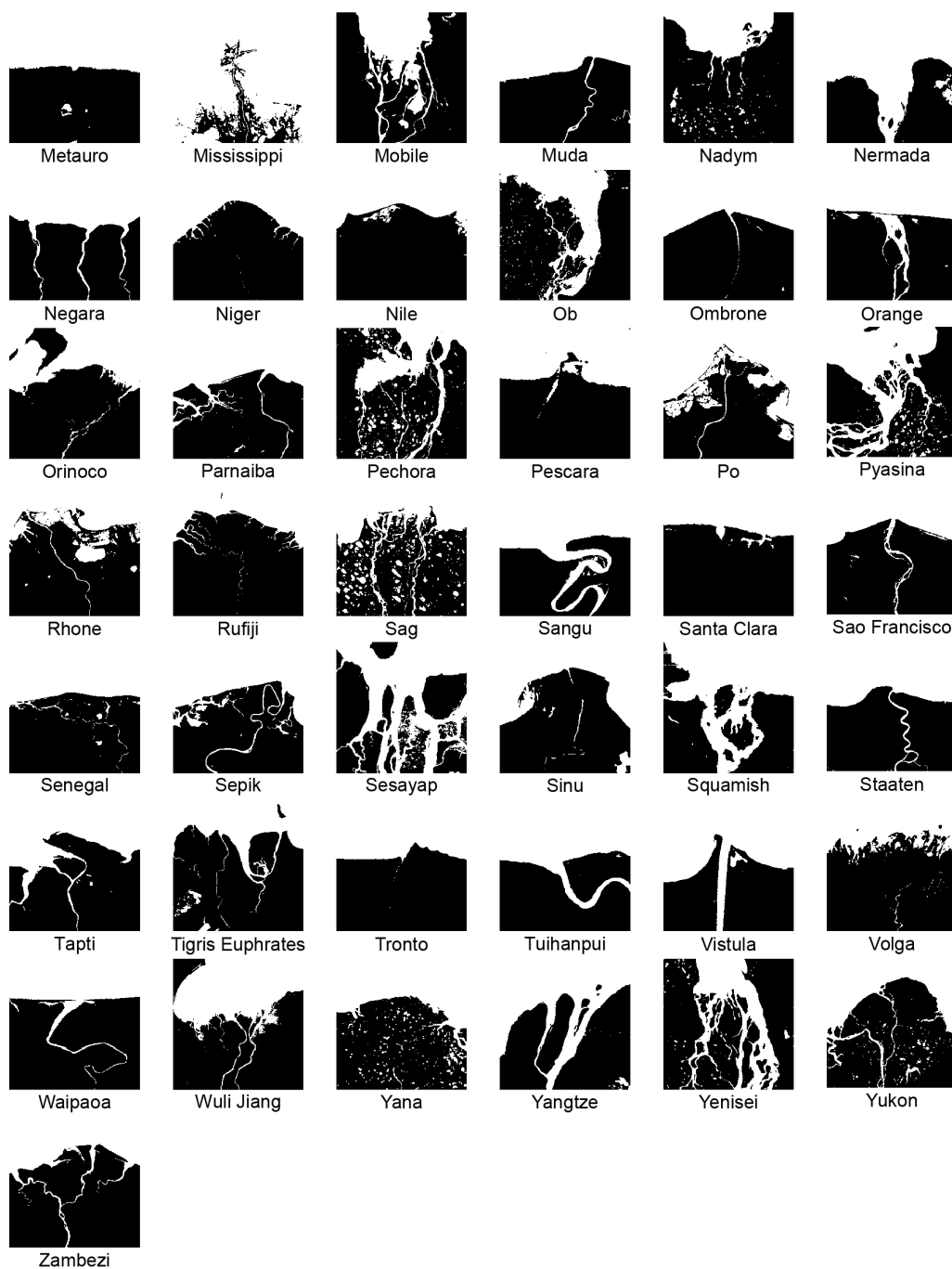
Supplementary Table 1 shows the sediment flux data sourced from previous literature, and morphotypes for the selected deltas resulting from the X-means clustering method. The best regression models based on the Akaike Information Criteria are provided in Supplementary Table 2.



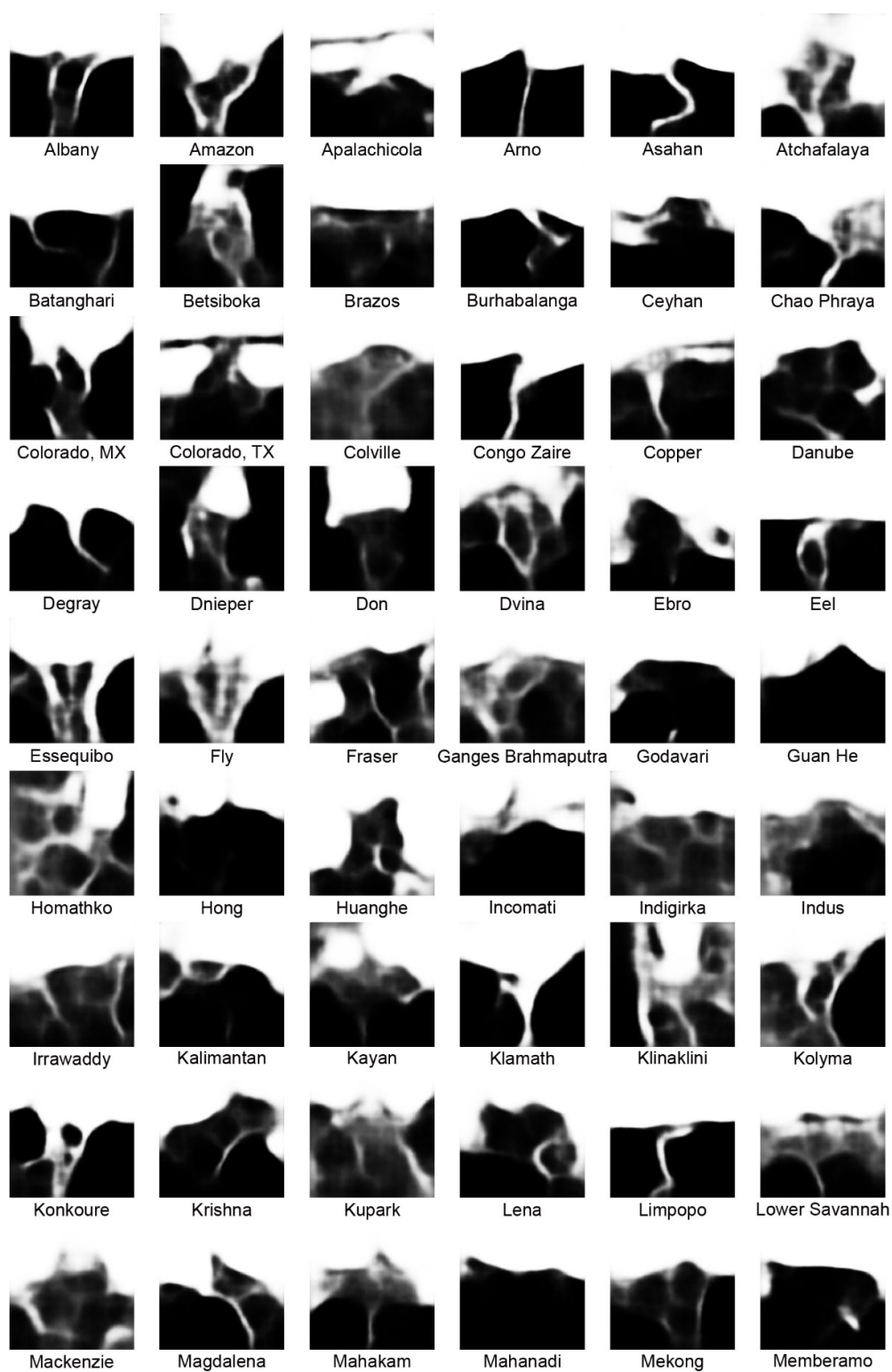
Supplementary Fig. 1. Training history of the convolutional autoencoder model. Loss function values are plotted for the training and validation datasets.



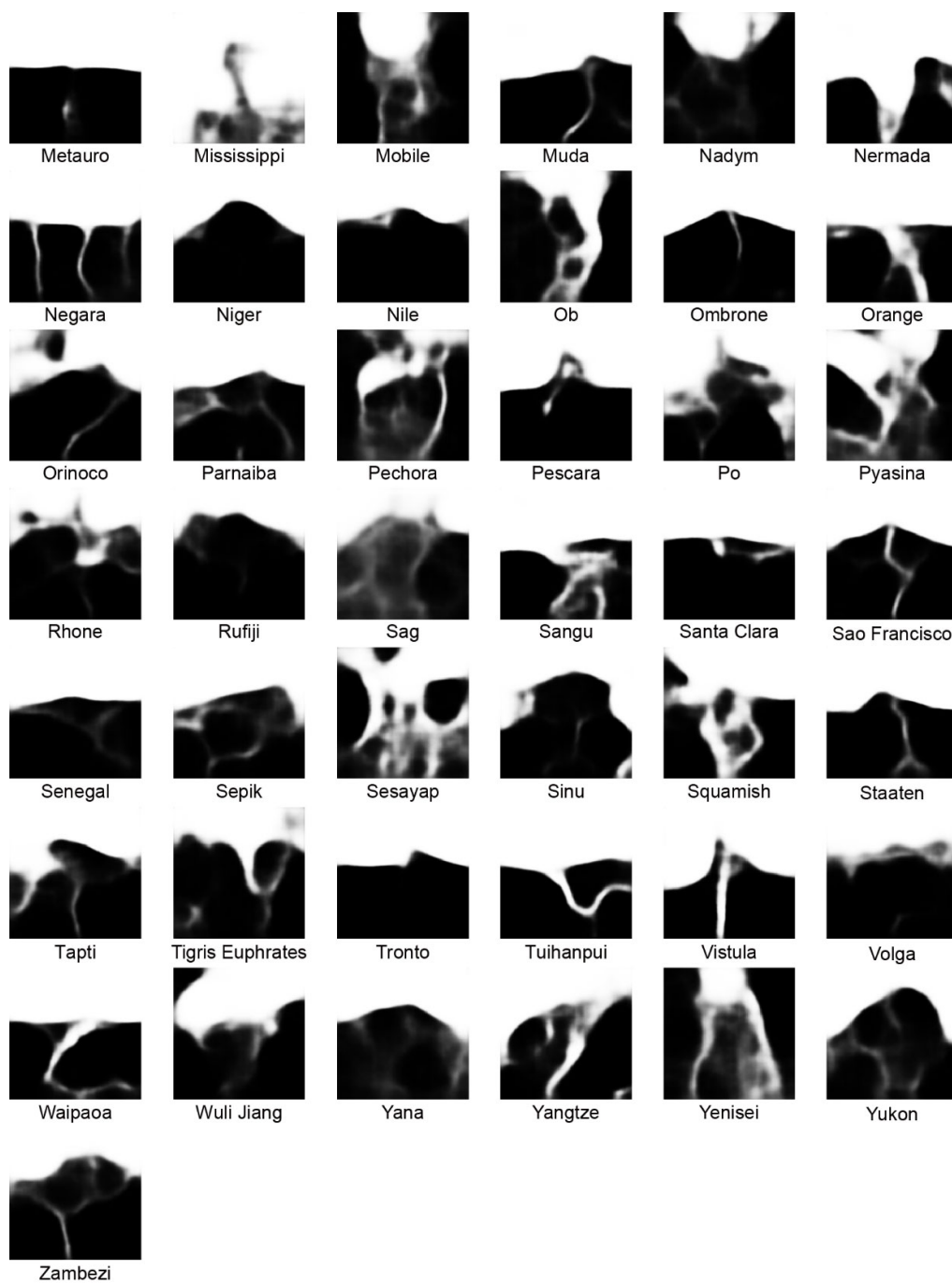
Supplementary Fig. 2. 97 delta images obtained from the surface water distribution dataset (Pekel et al., 2016). The images were processed into 224×224 pixels and converted to binary format. These deltas are the dataset for the regression analysis.



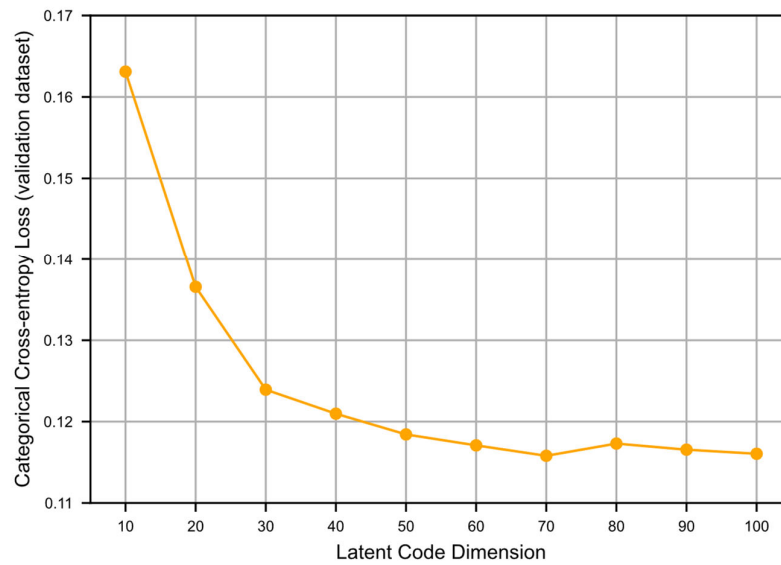
Supplementary Fig. 2. (continued).



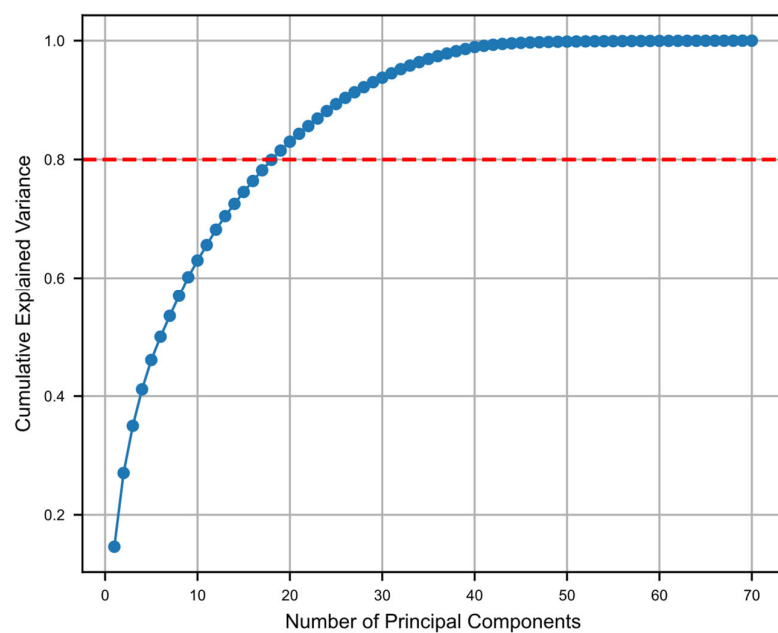
Supplementary Fig. 3. Output of the trained convolutional autoencoder model with the 97 delta images (Fig. S2) as the input. The darker color indicates a higher probability that the pixels are classified into land regions.



Supplementary Fig. 3. (continued).



Supplementary Fig. 4. Values of categorical entropy loss for the validation dataset under different latent code dimensions in the convolutional autoencoder model. Each loss value results from 50 epochs of training, with hyperparameters optimized using Optuna (Akiba et al., 2019) under each condition. The latent code dimension was set to 70, as the loss values decreased well up to a latent code dimension of 70 and became stable after that.



Supplementary Fig. 5. Cumulative explained variance resulted from the principal component analysis. The cumulative variance from PC1 to PC 19 exceeds 80%.

Delta Name	Q_{river}	Q_{tide}	Q_{wave}	Morphotype	Source
Albany	4.09E+01	1.57E+00	1.39E+00	Distributary	Nienhuis et al. (2020)
Amazon	3.11E+04	3.09E+04	6.56E+01	Bayhead	Broaddus et al. (2022)
Apalachicola	2.07E+02	2.74E+01	1.35E+02	Elongate	Vulis et al. (2023)
Arno	7.99E+01	7.83E-01	5.29E+02	Flat I	Broaddus et al. (2022)
Asahan	9.21E+01	5.16E+01	5.04E+01	Flat I	Broaddus et al. (2022)
Atchafalaya	1.03E+01	1.73E+00	1.07E-01	Elongate	Vulis et al. (2023)
Batanghari	1.07E+03	2.14E+02	1.41E+02	Flat III	Broaddus et al. (2022)
Betsiboka	2.14E+01	4.27E+01	1.79E+01	Bayhead	Nienhuis et al. (2020)
Brazos	7.29E+02	2.72E+00	6.78E+02	Distributary	Broaddus et al. (2022)
Burhabalanga	1.47E+02	1.46E+02	4.97E+02	Flat I	Broaddus et al. (2022)
Ceyhan	3.15E+02	6.14E+00	2.05E+02	Elongate	Broaddus et al. (2022)
Chao Phraya	8.91E+02	1.42E+03	4.75E+00	Distributary	Broaddus et al. (2022)
Colorado, MX	7.72E+03	4.50E+02	1.20E+02	Bayhead	Broaddus et al. (2022)
Colorado, TX	3.32E+02	1.54E+00	7.14E+02	Elongate	Broaddus et al. (2022)
Colville	1.51E+02	6.01E+00	4.73E+02	Distributary	Vulis et al. (2023)
Congo Zaire	1.60E+04	5.31E+03	3.40E+03	Flat I	Nienhuis et al. (2020)
Copper	3.43E+02	1.39E+02	3.68E+03	Distributary	Broaddus et al. (2022)
Danube	4.29E+03	3.27E+01	2.04E+02	Arcuate	Broaddus et al. (2022)
De Grey	5.31E+01	1.31E+02	1.59E+02	Flat III	Broaddus et al. (2022)
Dnieper	6.39E+02	9.83E+00	3.04E+00	Bayhead	Vulis et al. (2023)
Don	1.08E+03	8.63E-01	4.26E+00	Bayhead	Vulis et al. (2023)

Dvina	2.03E+02	2.25E+01	3.65E+00	Bayhead	Vulis et al. (2023)
Ebro	7.03E+02	1.98E+00	2.59E+02	Elongate	Broaddus et al. (2022)
Eel	7.62E+01	1.70E+01	8.33E+03	Flat I	Broaddus et al. (2022)
Essequibo	7.58E+02	3.17E+03	1.14E+03	Distributary	Broaddus et al. (2022)
Fly	2.59E+03	2.19E+03	6.89E+02	Distributary	Broaddus et al. (2022)
Fraser	1.30E+03	1.10E+03	2.58E-01	Elongate	Broaddus et al. (2022)
Ganges Brahmaputra	5.35E+04	8.47E+04	1.81E+02	Distributary	Broaddus et al. (2022)
Godavari	3.34E+03	7.10E+01	1.78E+03	Arcuate	Broaddus et al. (2022)
Guan He	1.67E+02	7.85E+02	2.02E+02	Arcuate	Broaddus et al. (2022)
Homathko	4.73E+01	2.02E+02	1.82E+00	Bayhead	Broaddus et al. (2022)
Hong	2.59E+03	1.98E+03	4.66E+02	Arcuate	Vulis et al. (2023)
Huanghe	7.28E+03	6.09E+02	3.07E+02	Elongate	Vulis et al. (2023)
Incomati	1.72E+02	4.86E+01	1.94E+03	Elongate	Broaddus et al. (2022)
Indigirka	1.91E+03	2.15E+00	7.79E+01	Distributary	Broaddus et al. (2022)
Indus	2.41E+04	2.55E+03	3.41E+03	Distributary	Broaddus et al. (2022)
Irrawaddy	1.00E+04	3.65E+04	2.90E+03	Distributary	Broaddus et al. (2022)
Kalimantan	1.29E+03	2.36E+02	5.79E+01	Arcuate	Broaddus et al. (2022)
Kayan	4.76E+02	6.71E+01	1.44E+02	Distributary	Broaddus et al. (2022)
Klamath	1.71E+02	1.51E+02	7.45E+03	Flat I	Broaddus et al. (2022)
Klinaklini	1.91E+01	4.15E+01	1.38E+00	Bayhead	Broaddus et al. (2022)
Kolyma	2.59E+03	1.51E+01	1.14E+02	Bayhead	Broaddus et al. (2022)
Konkoure	2.53E+02	7.35E+01	3.74E+02	Distributary	Broaddus et al. (2022)

Krishna	2.42E+03	6.57E+01	1.19E+03	Arcuate	Broaddus et al. (2022)
Kuparuk	1.88E+01	2.38E-01	3.78E+02	Distributary	Vulis et al. (2023)
Lena	5.44E+03	5.50E+02	9.28E+01	Arcuate	Broaddus et al. (2022)
Limpopo	8.79E+02	1.79E+01	2.38E+03	Flat I	Broaddus et al. (2022)
Lower Savannah	2.16E+02	1.90E+02	8.96E+02	Distributary	Broaddus et al. (2022)
Mackenzie	4.32E+03	2.44E+02	3.04E+02	Elongate	Broaddus et al. (2022)
Magdalena	8.13E+03	1.12E+02	8.31E+03	Elongate	Broaddus et al. (2022)
Mahakam	1.30E+03	2.10E+03	1.06E+02	Elongate	Vulis et al. (2023)
Mahanadi	1.38E+03	4.29E+02	3.31E+03	Flat III	Broaddus et al. (2022)
Mekong	1.57E+04	9.08E+04	2.63E+03	Distributary	Broaddus et al. (2022)
Memberamo	3.71E+03	5.57E+02	1.02E+03	Arcuate	Broaddus et al. (2022)
Metauro	5.74E+00	3.81E-02	1.64E+02	Flat I	Nienhuis et al. (2020)
Mississippi	2.73E+04	7.13E+02	3.15E+02	Elongate	Broaddus et al. (2022)
Mobile	4.54E+02	3.34E+01	3.04E+00	Bayhead	Nienhuis et al. (2020)
Muda	5.39E+01	9.52E+00	1.20E+02	Flat II	Broaddus et al. (2022)
Nadym	1.38E+01	1.86E-03	3.35E+00	Bayhead	Vulis et al. (2023)
Narmada	9.73E+02	7.94E+02	4.20E+01	Flat I	Broaddus et al. (2022)
Negara	1.48E+02	1.72E+02	4.24E+00	Flat III	Nienhuis et al. (2020)
Niger	1.37E+04	2.48E+03	2.31E+03	Arcuate	Broaddus et al. (2022)
Nile	3.36E+04	1.63E+02	1.25E+03	Cuspate	Broaddus et al. (2022)
Ob	3.95E+03	4.12E+00	3.40E+00	Bayhead	Nienhuis et al. (2020)
Ombrone	2.30E+01	2.83E-01	1.65E+02	Cuspate	Broaddus et al. (2022)

Orange	7.10E+02	3.71E+00	9.65E+03	Flat I	Broaddus et al. (2022)
Orinoco	1.96E+04	3.65E+04	3.80E+03	Arcuate	Broaddus et al. (2022)
Parnaiba	2.63E+03	1.51E+03	1.19E+03	Distributary	Broaddus et al. (2022)
Pechora	6.13E+02	2.25E+02	3.69E+01	Bayhead	Broaddus et al. (2022)
Pescara	4.10E+01	1.21E-01	1.19E+02	Cuspate	Broaddus et al. (2022)
Po	9.60E+02	1.20E+02	1.77E+02	Elongate	Broaddus et al. (2022)
Pyasina	5.26E+02	4.62E+00	4.13E+00	Bayhead	Nienhuis et al. (2020)
Rhone	1.61E+03	2.73E+01	1.25E+02	Arcuate	Broaddus et al. (2022)
Rufiji	9.20E+02	5.23E+02	1.60E+03	Arcuate	Vulis et al. (2023)
Sag	4.92E+01	3.63E-01	5.44E+02	Distributary	Nienhuis et al. (2020)
Sangu	2.46E+01	1.83E+01	9.01E+01	Flat I	Broaddus et al. (2022)
Santa Clara	2.67E+02	1.69E+00	1.07E+03	Flat III	Nienhuis et al. (2020)
Sao Francisco	2.54E+03	2.58E+03	2.22E+03	Flat I	Vulis et al. (2023)
Senegal	5.61E+02	6.08E+02	2.36E+03	Flat III	Broaddus et al. (2022)
Sepik	3.23E+03	4.20E+02	4.60E+02	Distributary	Broaddus et al. (2022)
Sesayap	2.86E+02	1.18E+02	1.54E+00	Distributary	Broaddus et al. (2022)
Sinu	3.19E+02	9.34E+00	1.41E+03	Arcuate	Nienhuis et al. (2020)
Squamish	3.80E+01	2.04E+02	1.89E+00	Distributary	Broaddus et al. (2022)
Staaten	7.46E+01	1.90E+01	5.04E+01	Flat I	Broaddus et al. (2022)
Tapti	5.15E+02	6.84E+02	2.19E+02	Distributary	Broaddus et al. (2022)
Tigris Euphrates	1.84E+04	4.69E+02	7.92E+01	Distributary	Broaddus et al. (2022)
Tronto	1.41E+01	5.16E-02	1.73E+02	Flat III	Nienhuis et al. (2020)

Tuihanpui	1.61E+02	1.30E+02	3.06E+02	Flat II	Broaddus et al. (2022)
Vistula	7.21E+02	1.01E+00	8.25E+02	Elongate	Broaddus et al. (2022)
Volga	4.68E+03	1.27E+01	4.89E+00	Arcuate	Broaddus et al. (2022)
Waipaoa	6.13E+00	8.83E-02	1.19E+03	Flat I	Broaddus et al. (2022)
Wuli Jiang	6.18E+01	3.44E+01	3.95E+01	Bayhead	Broaddus et al. (2022)
Yana	9.26E+02	4.24E+00	2.32E+03	Arcuate	Broaddus et al. (2022)
Yangtze	6.10E+03	7.65E+02	6.50E+01	Distributary	Broaddus et al. (2022)
Yenisei	3.42E+03	1.57E+01	1.52E+00	Bayhead	Vulis et al. (2023)
Yukon	3.31E+03	5.27E+02	9.26E+01	Arcuate	Broaddus et al. (2022)
Zambezi	6.94E+03	2.19E+03	1.96E+03	Arcuate	Broaddus et al. (2022)

Supplementary Table 1. The relative sediment fluxes of rivers, tides and waves labeled with the classes resulted from the x-means clustering. The sediment flux data are sourced from Nienhuis et al. (2020), Broaddus et al. (2022), and Vulis et al. (2023).

Objective variable	R^2		Independent Variable					
$\hat{Q}_{river}$	0.377		PC2	PC4	PC7	PC9	PC14	PC15
		Partial Regression Coefficient	-0.442	0.180	0.216	-0.155	0.133	0.134
		Upper Confidence Interval	-0.257	0.363	0.386	0.014	0.309	0.304
		Lower Confidence Interval	-0.629	-0.003	-0.047	-0.324	-0.043	-0.036
		p-value	6.69E-06	5.08E-02	1.20E-02	6.83E-02	1.32E-01	1.15E-01
$\hat{Q}_{tide}$	0.203		PC1	PC2	PC6	PC8	PC13	PC17
		Partial Regression Coefficient	0.169	-0.170	0.222	0.204	0.222	-0.145
		Upper Confidence Interval	0.362	0.023	0.414	0.397	0.412	0.045
		Lower Confidence Interval	-0.023	-0.362	0.030	0.011	0.031	-0.335
		p-value	8.00E-02	7.99E-02	2.25E-02	3.60E-02	2.15E-02	1.28E-01
$\hat{Q}_{wave}$	0.426		PC1	PC2	PC5	PC6	PC7	PC9
		Partial Regression Coefficient	-0.159	0.534	-0.155	-0.114	-0.209	0.169
		Upper Confidence Interval	0.007	0.697	0.006	0.050	-0.046	0.332
		Lower Confidence Interval	-0.325	0.371	-0.317	-0.277	-0.373	0.005
		p-value	5.68E-02	2.78E-09	5.56E-02	1.65E-01	1.17E-02	4.08E-02

Supplementary Table 2. Multiple regression models for predicting $\hat{Q}_{river}$, $\hat{Q}_{tide}$, and $\hat{Q}_{wave}$ with the minimum Akaike Information Criterion scores.

Supplementary References

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