Rendiconti Lincei. Scienze Fisiche e Naturali (2022) 33:213–216
https://doi.org/10.1007/s12210-022-01072-x

THE INTRUSION OF ECOLOGY INTO HYDROLOGY AND MORPHODYNAMICS

The intrusion of ecology into hydrology and morphodynamics

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Published online: 10 May 2022

The topical collection "The Intrusion of Ecology into Hydrology and Morphodynamics" offers a selection of contributions presented at the meeting "Acqua, vegetazione, clima: l'avvento dell'ecoidrologia" held at the Accademia Nazionale dei Lincei on 22 marzo 2021 to celebrate the 2021 Water Day.

The title of this collection has been purposedly chosen in analogy with the title ("The intrusion of fluid mechanics into geology") of a cornerstone paper that Herbert Huppert published in the Journal of Fluid Mechanics (Huppert 1986). That paper was 'historical' in the sense that it opened a whole new line of research, arising from the cross-fertilization of two apparently distant disciplines: Fluid Mechanics is enriched by the stimulus to investigate a bunch of new phenomena observed and described by geologists, geology benefits from the insight that Fluid Mechanics can provide into the physical mechanisms from which those phenomena originate. In some sense, the field of science and engineering of natural water bodies has undergone a similar process of cross-fertilization.

The first change of paradigm started about half a century ago, when the communities of geophysicists and hydraulic engineers became increasingly aware that the study of natural water bodies (rivers, estuaries, lagoons, coasts, submarine environments) cannot be satisfactorily pursued ignoring the mechanical interactions between the water and its container. Indeed, the latter invariably consists of an erodible material, either cohesionless (e.g., sandy or gravel river beds and coastal bottoms) or cohesive (e.g., clayey banks, rocky channels). Whatever the degree of boundary erodibility, the interaction between the water motion and the boundaries of the water bodies is the cause of the development of the variety of beautiful sedimentary patterns observed in nature (Fig. 1).

Investigating the mechanisms that control the formation of patterns in sedimentary environments is the core of a new discipline, the Morphodynamics, whose relevance for Science and Engineering is well described by Levin (1992) in a different context: "*Understanding patterns in terms of the processes that produce them is the essence of science, and is the key to the development of principles for management*".

From the conceptual and mathematical viewpoint, Morphodynamics ultimately consists of solving a free boundary problem where, unlike in classical open channel hydrodynamics, the 'free' boundary consists not only of the water–air interface (the free surface) but also of the interface between the water and its solid container. The 'free' character of the latter is now brought up by the container erodibility and is distinct from the former as erosion occurs through a fairly complex process whereby sediment transported by the fluid is exchanged with the boundary. The first seeds of Morphodynamics were laid in the pioneering contribution of J.F. Kennedy (Kennedy 1969) (Fig. 2a), who was the first to pick up a major feature of sedimentary patterns, namely that most of them originate from an instability of the cohesionless bed interface. This idea was initially investigated to understand the formation of small-scale river bedforms (ripples and dunes) and was later extended to large-scale processes (river bars, meandering and braiding) as the interest for Morphodynamics spread across several academic schools (Fig. 2b). More recently, the subject has widened considerably, extending ideas and techniques to the analysis of virtually all sedimentary environments (estuaries, lagoons, coasts and continental shelves) on the Earth and other planets. Brief introductions to the subject are contained in the review paper of Seminara (2010) as well as in the first published

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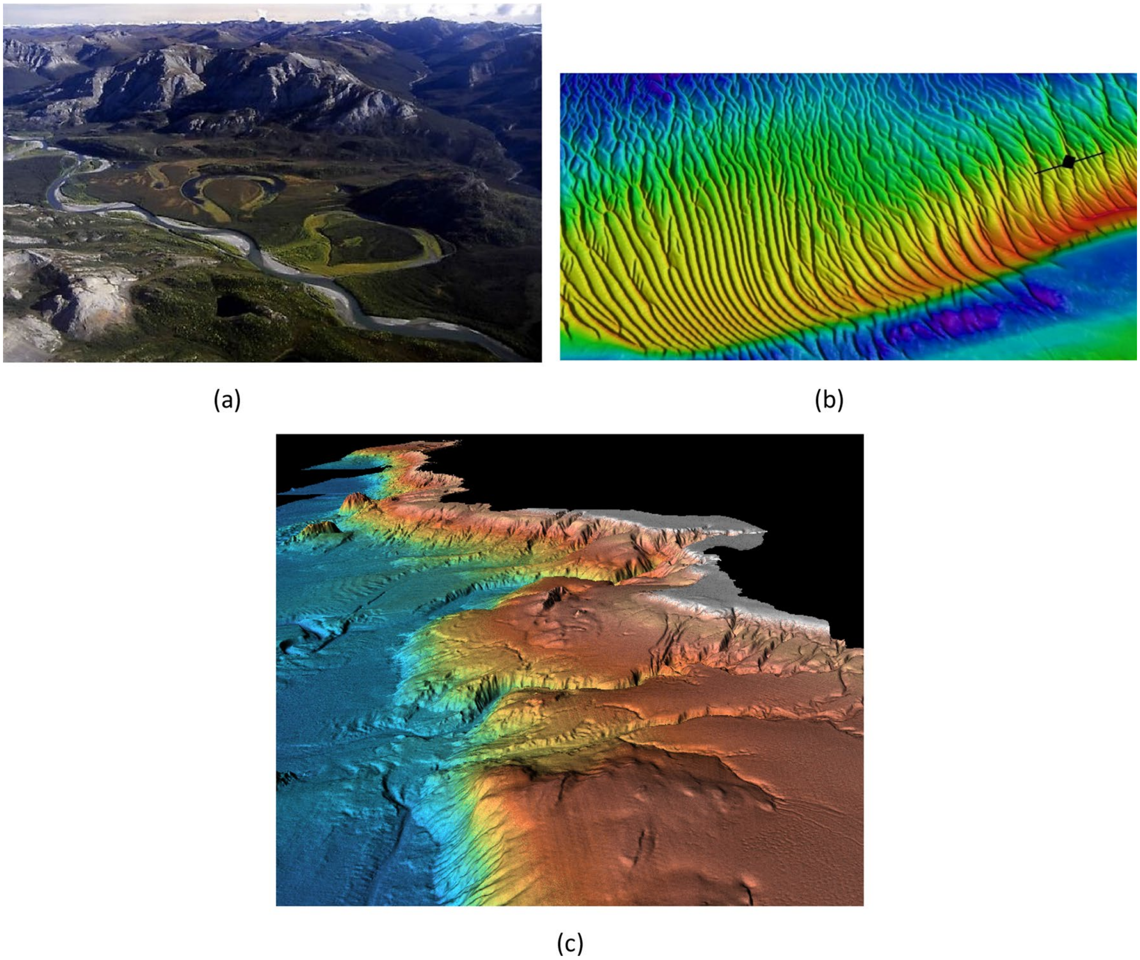

Fig. 1 Sedimentary patterns in nature. **a** Meanders of the Alatna River (Alaska) that have 'recently' undergone neck cutoffs (Source: https://www.terragalleria.com/images/np-alaska/gaar0023.jpeg). **b** Submarine wave fields off the Belgian coast (courtesy of Vera Van Lanker). **c** Canyons incised by turbidity currents in the continental shelf of the Californian coast (courtesy of Lincoln Pratson)

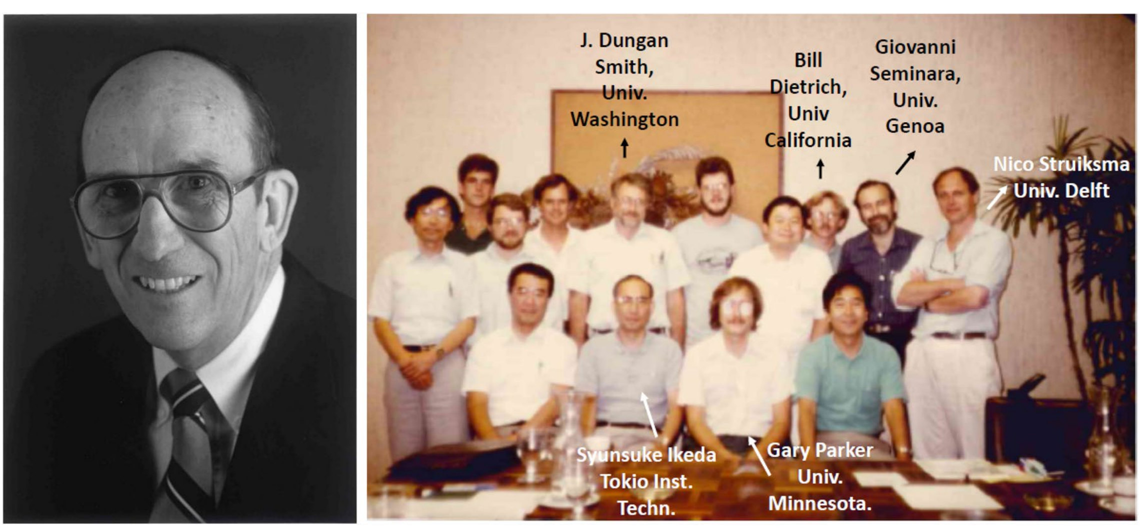

Fig. 2 **a** Prof. J. F. Kennedy; **b** some major scientists in the field of Morphodynamics, gathered in 1988 in a cornerstone meeting on River Meandering at Kauai Island (modified from Ikeda and Parker 1989)

Monograph (Blondeaux et al. 2018) of a forthcoming series which will hopefully encompass the whole subject.

More recently, the field has undergone a second major change in paradigm, widening the notion of water bodies, treated as systems which evolve also in response to a further fundamental ingredient of their composition, namely their biotic component. This led to the 'intrusion' of ecology into hydrodynamics and hydrology.

The intrusion of ecology into hydrology moved its early steps more or less in the same years. It was prompted by the (joint and disjoint) work of two major figures of contemporary Hydrology, Peter S. Eagleson and Ignacio Rodriguez-Iturbe (Fig. 3).

Over 20 years ago, Eagleson foresaw the new and exciting avenues open to the hydrologic sciences (Eagleson 2000). Therein, he explicitly mentioned that hydrology should have then distanced itself from being a physical science 'alone' by embedding in full—no less—life on Earth as a fundamental part of the discipline. His main focus was on water-controlled vegetation and its powerful interactions with the atmosphere at all scales, from local to global. He specifically defined the defining feature of attempting to get the full picture expressing the role of plants in 'our' (i.e., the hydrologists') mathematical equations without fear. Around the same time, Rodriguez-Iturbe defined ecohydrology as fundamentally concerned with the hydrologic mechanisms underlying the climate–soil–vegetation dynamics and thus controlling the most basic ecological patterns and processes (Rodriguez-Iturbe et al. 1999; Rodriguez-Iturbe and Porporato 2004). As noted in this volume, the nascent disciplinary reformulation of hydrology was propelled into a new intellectual frontier for environmental sciences.

Fig. 3 (Left) A portrait of Peter S. Eagleson ca. 1980; (right) a recent image of Ignacio Rodriguez-Iturbe. It is a fitting tribute to two founders and key players of the field of Ecohydrology to place their portraits together, because of their lifetime friendship, joint work and affiliation at MIT's Parsons Lab for several years. Their seminal work has been foundational to the establishment of Ecohydrology as a field in its own right

This frontier has been fundamentally widened in recent years. In ecohydrology, we now focus not only in vegetation but rather in all aspects of life, however, related to hydrological processes. This new focus is rapidly transforming our understanding of the basic processes that control the stability and the sustainability of natural environmental systems, with radical implications on the way in which human impacts on the health of ecosystems are predicted and managed. A paradigm-shifting change of perspective came with a different choice of control volume for mass and energy balance. From the original focus on the critical zone sensu Grant and Dietrich (2017), i.e., from 'bedrock to treetop' to describe processes characterized stochastically—capitalizing on decades of hydrological work—yet essentially resolved only in the (sub-)vertical direction, a separate field of studies was heralded by work centered on the fundamental control volumes of hydrology—the catchment (Rinaldo et al. 2020). The catchment brings to the fore much more complexity largely induced by the interplay of channeled and unchanneled domains, and by the inherent scaling nature of fluvial patterns (Rodriguez-Iturbe and Rinaldo 2001). Catchments foster applications involving the properties of their embedded drainage networks (a byproduct of the landscape-forming processes that generate the catchment delimitation) providing controls and drivers to ecological processes. River basins are geomorphological entities of particular importance for life on earth which have been for years the focus of hydrologic and geomorphologic research. Their study poses significant methodological challenges precisely because of the synthesis that proves necessary.

The topical collection includes three review papers focusing on the various mechanisms whereby the presence of vegetation affects either the water and carbon cycles (ecohydrology) or the morphodynamic evolution of water bodies (eco-morphodynamics).

The paper by Tambroni et al (2022) tackles a major problem, threatening the future of coastal environments rich in biodiversity: the response of wetlands to an accelerated sea level rise, which is one of the major expressions of climate change. The review examines, in particular, the fate of Venice lagoon, one of the most carefully monitored wetlands in the world, whose morphodynamic evolution has also been affected by a variety of anthropogenic factors typically present in many coastal wetlands. The paper devotes special attention to answering the fundamental question of whether a coastal lagoon can reach an equilibrium state, depending on the rate of sea level rise.

The paper by Rinaldo and Rodriguez-Iturbe (2022) explores the new dimensions of contemporary ecohydrology where water controls on the biota are exerted at whole-catchment scales. The specific role of rivers as ecological corridors for species, populations and pathogens lends itself to studies of biodiversity, biological invasions or the spread of water-borne diseases (those where at least a part of the life cycle of the pathogen takes place in the water). The paper places a special attention on what are perceived as hotspots of forthcoming ecohydrologic research.

The contribution of Caferri and Bassi (2022) tackles a major issue: the impact that the desired reduction of CO_2 emissions would have on ecosystems stability and agricultural productivity. Noting that the desirable output of a reduction of global warming would be accompanied by unwanted consequences that should be duly considered when implementing policies aiming at the mitigation of global environmental changes. Indeed, a reduced CO_2 availability is expected to enhance transpiration rate in plants, decreasing their water use efficiency and imposing an increased water demand for both agricultural and wild ecosystems. Such effect would disrupt sustainable agricultural practices, decrease biodiversity through a reduction of biomass production and oxidation of soil organic component with release of CO_2. Modern biotechnology has developed solutions for tackling these global challenges and could significantly contribute to environmental sustainability, provided genome editing and transgenesis applied to crop species would become acceptable to the public opinion before environment unbalance will proceed too far towards the desertification and reduction of fertile soils.

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