POLICY PERSPECTIVE

Leak Plugging and Clog Removal: Useful Metaphors for Conservation and Restoration

James Aronson[1,2], Carolina Murcia[3,4], & Luis Balaguer[5]

[1] Centre d'Ecologie Fonctionnelle et Evolutive (CNRS-UMR 5175), 1919, Route de Mende, 34293 Montpellier, France
[2] Missouri Botanical Garden, St. Louis, Missouri, USA
[3] Department of Biology, University of Florida, Gainesville, FL 32611, USA
[4] Organization for Tropical Studies, Duke University, Durham, NC, USA
[5] Departamento de Biología Vegetal I, Facultad de Biología, Universidad Complutense de Madrid, José Antonio Novais, 2, 28040 Madrid, Spain

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Correspondance
James Aronson, Centre d'Ecologie Fonctionnelle et Evolutive (CNRS-UMR 5175), 1919, Route de Mende, 34293 Montpellier, France.
Tel: +33 (0) 467613218;
fax +33 (0) 467613336.
E-mail: james.aronson@cefe.cnrs.fr

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Abstract

Metaphors are common in our ecological and conservation language. They help us understand complex issues and communicate them to different audiences. We propose two new metaphors: ecosystem leaks and ecosystem clogs that can help us understand the role of flows among ecosystems (inflows and outflows), the impacts of anthropogenic perturbations of these flows within and beyond ecosystem boundaries. They help us grasp the need for a broader outlook in restoration and conservation that goes beyond the ecosystem level. We define an ecosystem leak as *any net loss of natural capital from any ecosystem with the potential of exerting a long-term transformative effect*. As its name implies, an ecosystem clog is the opposite of a leak, and we define it as *a total or partial obstruction in the flows of natural capital within an ecosystem, or between ecosystems*. Leaks can create clogs, and vice versa, and they can occur in cyclic succession causing cascading effects that affect not just the natural capital of an ecosystem, but its social and cultural capital as well. We focus on anthropogenic leaks and clogs as these are the ones for which society does not invest adequate attention and efforts.

The metaphor is not a matter of language but of thought and reason (Lakoff 1993)

Introduction

Metaphors are more than rhetorical flourishes and idioms (Lakoff 1993; Thibodeau & Boroditsky 2011); they are tools for communicating complex concepts, opening ideas up for discussion, and processing information in all areas of knowledge and in everyday life (Lakoff & Johnson 1980; Väliverronen 1998; Carpenter *et al*. 2001). Consequently, they affect how we think and act with respect to societal concerns (Pickett *et al*. 2004; Thibodeau & Boroditsky 2011). Metaphors are common in ecological theory, where they help us understand complex concepts such as "niche," "ecosystem," or "resilience" that can perhaps be better understood thanks to the judicious use of metaphors (Carpenter *et al*. 2001; Pickett & Cadenasso 2002). They have also been very useful in conservation particularly for communicating problems that are not immediately apparent or clear to a wider public, for example, greenhouse gases, or acid rain (Väliverronen & Hellsten 2002), and environmental sustainability (Larson 2011).

The purpose of this article is to present two complementary metaphors regarding ecosystem flows: *leaks* and *clogs,* and the terms describing the related actions: *leak plugging* and *clog removal*. These metaphors can help scientists and practitioners to understand and communicate in simple language and powerful imagery two crucial concepts: (1) the role of anthropogenic disturbances in altering flows among ecosystems, compromising not only one ecosystem but also its neighbors and (2) why ecological restoration needs to focus beyond specific and obvious

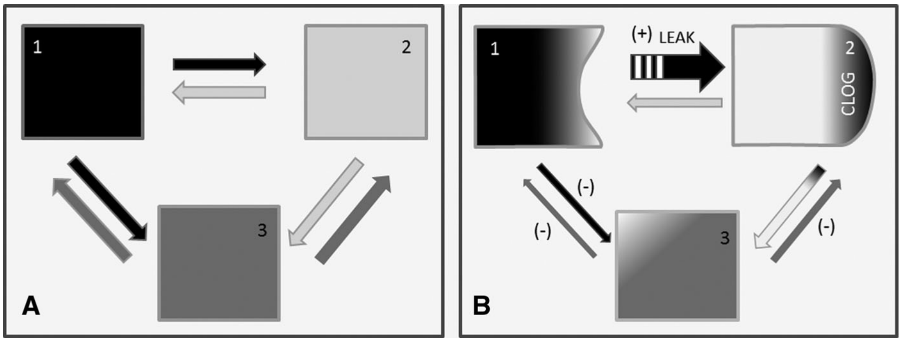

Figure 1 Leaks and clogs among interacting ecosystems illustrated schematically. Panel A shows a landscape with balanced inflows and outflows among ecosystems 1, 2, and 3. Panel B shows changes in ecosystem flows and state with relative size of arrows representing relative changes in the amounts of material in transit; (+) or (–) signs indicate increased or decreased flow rates relative to initial conditions (Panel A). The black ecosystem (1) is "leaking" materials or energy toward the gray ecosystem (2), causing a clog (represented by the enlarged bulge on the right and accumulation of black): the clog in (2) changes the nature of the flow from (2) to a third (3) ecosystem (represented by a mixed colored arrow. The leak of materials from (1) can also affect (3) by the reduced availability of materials that now accumulate in (2). Hence, transfers between (1) and (3) and from (3) back to (2) may also be affected. Effects of a leak can be reciprocal or operate in a more complex fashion at the level of an ecosystem network, though cascading effects.

disturbances and consider also the degraded ecosystems in its landscape or seascape context.

Humanity's natural capital (Costanza *et al*. 1997; Blignaut & Aronson 2008), represented as stocks of matter, energy, information, and species within ecosystems, is not uniformly distributed in space, indeed, it flows across ecosystem boundaries. Ecosystems' equilibria—or metastability—depend on a relatively balanced net flow of inputs and outputs. This is, of course, not a static balance; it is often disrupted by natural disturbances that interfere with the rate of inflows and outflows. This may cause loss or accumulation of any element, sometimes dramatically so when the disturbance is "catastrophic." Typically, however, ecosystems are resilient, and after temporary upsets the flows usually return to a net exchange of zero, at least within the timeframe of the Holocene.

Anthropogenic disturbances, in contrast, can drastically affect these natural flows between an ecosystem and its surroundings, causing a permanent loss or accumulation of any element that will have a transformative effect on the ecosystem. We call these significant alterations in flow leaks, and clogs, respectively, and advocate the need to restore both. We limit our discussion to anthropogenic leaks and clogs because these are the ones most likely to cause significant and recurrent alterations and loss of natural capital, and to which society should devote much more attention and resources in efforts to restore and transition toward sustainability.

In the environmental sciences, the concept of "leakiness" has been sparsely used, and always in the context of anthropogenic disturbance. It was first used in the terrestrial ecosystems ecological literature in the context of nutrient loss and its relation to functional complexity (Van Voris *et al*. 1980; Lamont 1982). Recently, the term leakiness was introduced in the restoration ecology literature in two different and specific ways: (1) to refer to species loss (Aronson & Le Floc´h 1996) and (2) to name an index of landscape health that measures lack or loss of soil retention by vegetation clumps in arid and semiarid environments (Ludwig *et al*. 2002; Bautista *et al*. 2007; Ludwig *et al*. 2007). In all cases, the metaphor refers to a condition of an ecosystem, but does not refer to the process that alters the overall state of the ecosystem. Perhaps due to the very specific contexts in which it has been defined and used, this metaphor has not caught on or been developed in the various relevant literatures. Here, we refine and expand its definition and application, and introduce the complementary (converse) concept of accumulation, due to clogs, to generate a more powerful and more broadly applicable set of metaphors.

Ecosystem leaks and clogs: redefining and expanding the concept of leakiness

We propose a broad definition for ecosystem leaks that refers to *any net loss of natural capital from any ecosystem with the potential of exerting a long-term transformative effect*. This can refer to losses of matter in general (e.g., soil, litter, nutrients, or water), energy, information, or species. Severe leaks negatively affect ecosystem functionality, structure, and composition, as well as interactions among ecosystems (Figure 1). Consequently, there are adverse effects on the flow of ecosystem services to society (see below).

Ecosystem leaks occur when—among other causes—human activities intensify outflows of a given element, causing a significant and continued net deficit in its stocks. In terrestrial Mediterranean Basin ecosystems, for example, volatilization of soil-borne nitrogen triggered by natural wildfires represent recurrent natural ecosystem outflows that occur at intervals of years or decades, yet nitrification is sufficient to compensate for these outflow pulses (Blondel *et al.* 2010). However, anthropogenic activities in this region increase fire frequency at least 16-fold (Jiménez-Bermúdez 2006), turning an average nitrogen outflow into a "leak." Similarly, anthropogenic underground peat fires in Kalimantan, Indonesia, that have run for at least a decade (Brown 1998), result in carbon leaks in the order of 3–8% of the carbon stocks per year (Page *et al.* 2002).

A leak also entails the loss of ecological "memory" essential to an ecosystem's capacity to recover from profound disturbance. A topsoil leak, for example, often leads to ecologically detrimental outflows of water, sediments, nutrients, or seeds, and even the loss of drainage networks, soil profile, microbial and microarthropod communities, and soil banks. All these ecosystem components are the outcomes of historical and largely unrepeatable sequences of past and ongoing events and interactions. Beyond a certain threshold, loss of these abiotic and biotic legacies compromises the resources required for ecosystem reorganization after profound disturbance. This loss of "ecological memory" (Bengtsson *et al.* 2003) jeopardizes the historical continuity and resilience in ecosystems—both of which are necessary for the maintenance of natural capital (Brand 2009) and, ultimately, for the sustainable delivery of ecosystem services (Ekins *et al.* 2003).

Whereas a leak refers to outflows or losses, a clog refers to accumulation. We define an ecosystem clog as *a total or partial obstruction in the natural flows of natural capital within an ecosystem*. A clog blocks, or otherwise impairs, the flow of one or more ecosystem element or service. Clogging occurs when human activities interfere with an ecosystem in such a way that the inputs become excessive with regard to the outputs, either because the outflows are blocked or because the inputs are in excess (Figure 1). For example, a dam reduces or blocks the regular outflows of water from a basin, causing water accumulation and, consequently soil water logging and flooding. The short-term consequence of this is often the death of most terrestrial organisms, and a pulse of decomposition and accumulation of organic matter, causing the natural ecosystem to dysfunction, or destroying it altogether.

Clogging can also occur when an ecosystem receives inordinate amounts of materials for an adjacent ecosystem, in amounts or rates beyond the recipient ecosystem's capacity to eliminate it effectively and quickly. For example, sediments leaked from a quarry may result in a silt discharge too large to be washed away from the gravel bed of an adjacent river, with severe impacts on aquatic species that rely on such beds for spawning (FISRWG 1998). Another example of a clog caused by a leak is when a river dumps large amounts of silt into a lagoon, where it behaves as an immiscible fluid that interferes with the functioning, structure, and composition of that wetland system (Aronson *et al.* 2012).

Leaks and clogs are often related and can have cascading effects

The fact that leaks in one ecosystem can cause a clog in another (Figure 1), and vice versa, invites us to expand our vision of how restoration should be done. If a clog is identified in an ecological system, we should not only think about fixing the clog but also about identifying and repairing the leak that caused the clog in the first place. Similarly, we should be aware that a leak can lead to clogs in an adjacent ecosystem, an additional reason for it to be addressed quickly and effectively. This forces scientists, practitioners—and the general public—to look beyond the target ecosystem. Permanent solutions to conservation and restoration problems require looking beyond the immediate leak or clog.

Although a leak can be fixed and leave no apparent trace of its occurrence, there is the additional challenge of dealing with the unintended or unforeseen consequences of the leaked materials in the adjacent ecosystem. Disturbances that warrant active investment in restoration rarely affect a single ecosystem but rather tend to create cascading events that affect adjacent ones as well (Figure 1). For example, a leak of nutrients from a fertilized cropland may result in the eutrophication of an adjacent lake and the load of silt, fresh water, or nutrients generates severe clogs. Similarly, a mudslide "leaking" down a mountain slope will often cause a "clog" in the riverbed downslope (Figure 2). In some cases, the resulting clog can cause even more harm than the leak it originated from. For example, the Deep Water Horizon oil spill in 2010 leaked an estimated 4.5 million barrels of crude oil that contained 40% methane, from deep in the sea floor into the waters and beaches of the Gulf of Mexico where these materials never occur and there are no mechanisms for their transformation, incorporation, or elimination. And so they clogged these ecosystems (Kessler *et al.* 2011). The result of this clogging was toxicity and interference with the food chain and reproduction, and the concomitant loss of life (Mishra *et al.* 2012), productivity (McCrea-Strub *et al.* 2011), and species richness (Campagna *et al.* 2011).

Leaks and clogs can succeed one another in a cascade of effects and reinforcing feedbacks. For example, when

Figure 2 Illustration of an anthropogenic leak in a tropical watershed of SE Brazil. A major "leak" in topsoil and vegetation was caused by inappropriate roadwork in this mountainous region, causing a "clog" in the river downslope (not shown). A tunnel would have been a better solution. Photo reproduced with permission of André Nave.

a dam clogs a retention basin, a significant amount of nutrients and fine-grained sediments become deposited (Baxter 1977). This triggers numerous leaks and clogs. As the suspended sediment load is reduced downstream, scouring lowers the streambed and erodes the stream banks, which often results in soil loss and incised stream channels (FISRWG 1998).

The High Dam of Aswan (Egypt) provides a specific case that illustrates interrelated clog and leak effects. In addition to the obvious clogging of water that reduces water availability downstream, the newly erected dam retained a significant amount of dissolved silt that for decades was used in a nearby brick industry. To make up for this reduction and obtain the necessary materials, brick manufacturers excavated over 1,000 Km^2 to the depth of the groundwater table, and exported (leaked) that material (White 1988). In addition to this "leak," the dam causes a loss of ca. 20 million cubic meters of water per year (to evaporation and seepage), which otherwise would have transited downstream (Waterbury 1979). Finally, the list of dam-induced "clogs" at Aswan also includes the invasion of water hyacinth (*Eichornia crassipes* [Mart.] Solms.), water pollution, salinization, and water logging of soils that, in turn, have triggered a "cascade" of further "leaks" in cultural heritage, and also biodiversity and losses of millions of hectares of highly productive cultivated land (Benedick 1979).

The cascading repercussions of leaks and plugs can extend beyond the realm of ecological systems to affect the human world directly. Because the various forms of capital (natural, social, economic) are interlinked (De Groot *et al.* 2010), leaks in one kind of capital will most likely affect the others. A species leak from an ecosystem, for example, is likely to negatively affect ecosystem services, income, traditions, and cultural beliefs in those human communities that depend in part on those vulnerable and vanishing species. Similarly, clogs can cause serious harm to social well-being if they cause the redistribution of materials in a way that hinders access to ecosystem goods and services for some and allow excesses of these goods and services to others (Myers & Kent 2001; Boardman *et al.* 2003). These further implications reinforce the notion that ecological restoration should involve a broader long-term view and a landscape perspective that goes beyond treating the symptoms or specific disturbances.

"Leaks" and "clogs" as didactical metaphors for conservation and restoration practice

Metaphors help us understand what is happening through powerful images and prompt us into action by evoking emotions (Väliverronen 1998; Väliverronen & Hellsten 2002; Larson 2011). Hence, they can be very powerful didactic tools in discussing environmental and ecological issues (Larson 2011). In the broad context we address here, leaks, leakiness, and leak plugging (and their counterparts—clogs, clogging, and clog removal) have great potential as metaphors for communication, education, consensus building, transdisciplinary research, and problem solving among people engaged in conservation, restoration, and related disciplines (Pickett *et al.* 2004). This is language that anyone can understand and respond to, particularly if it is accompanied by illustrations (Figure 1) and examples (Figure 2) that help convey the message.

Because the terms leaks and clogs are simple, everyday words that convey common images, they are particularly useful in explaining these concepts to local communities and other stakeholders. Furthermore, they translate well to other languages (e.g., "fugas" and "atascos" in Spanish; "fuites" and "bouchons" or "caillots" in French), a precondition to make these concepts universal, and cause little meaning loss in translation (Dobrzyńska 1995; Schäffner 2004; Meifang 2005). Thus, they can also help convey messages beyond scientific circles to the wider public, including corporate, international and national legislative audiences where clear concepts and practical tools for sustainability and conservation science need to be heard and integrated in policy debates.

These metaphors are also effective for training undergraduate and master students in the analysis of ecosystem impairment. Humans are not particularly gifted in the conceptualization and envisioning of dynamic processes. For most students, the descriptors of ecosystem structure, such as species richness, tree density, or stream hydraulic geometry, are far more tangible than ecosystem processes, such as surface runoff, nutrient cycling, or seed dispersion. In this context, the leak and clog metaphors are useful conceptual tools that allow description of dysfunctional systems, not in terms of missing elements (e.g., water availability, scarcity of nutrients, or deforestation), but in terms of processes, from a dynamic perspective (e.g., leaks of water, sediments, or species, and clogs of organic matter or algal blooms).

Conclusion

We propose that, in a metaphorical sense, restoration and conservation scientists and practitioners are often confronted with the need to repair or plug "leaks" in stocks of natural capital, and to repair or remove "clogs" to the flow of ecosystem goods and services. However, this synthetic view of the disciplines has not often been elicited, possibly for lack of a good image or metaphor. While we do not claim universal applicability, these metaphors can help clarify, refine, and galvanize effective and long-lasting efforts in landscape scale conservation, management, and restoration.

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References

Aronson, J., Claeys, F., Westerberg, V. *et al.* (2012) Steps towards sustainability and tools for restoring natural capital: Etang de Berre (Southern France) Case Study. Pages 111–138 in M.P. Weinstein, R.E. Turner, editors. *Sustainability science – the emerging paradigm and the urban environment*. Springer, New York.

Aronson, J. & Le Floc´h, E. (1996) Vital landscape attributes: missing tools for restoration ecology. *Restor. Ecol.*, **4**, 377-387.

Bautista, S., Mayor, A.G., Bourakhouadar, J. & Bellot, J. (2007) Plant spatial pattern predicts hillslope runoff and erosion in a semiarid Mediterranean landscape. *Ecosystems*, **10**, 987-998.

Baxter, R. (1977) Environmental effects of dams and impoundments. *Ann. Rev. Ecol. Syst.*, **8**, 255-283.

Benedick, R.E. (1979) The High Dam and the transformation of the Nile. *Middle East J.*, **33**, 119-144.

Bengtsson, J., Angelstam, P., Elmqvist, T. *et al.* (2003) Reserves, resilience and dynamic landscapes. *AMBIO*, **32**, 389-396.

Blignaut, J. & Aronson, J. (2008) Getting serious about maintaining biodiversity. *Conserv. Lett.*, **1**, 12-17.

Blondel, J., Aronson, J., Bodiou, J.Y. & Boeuf, G. (2010) *The Mediterranean region: biological diversity in space and time*. Oxford University Press, New York.

Boardman, J., Poesen, J. & Evans, R. (2003) Socio-economic factors in soil erosion and conservation. *Environ. Sci. Policy*, **6**, 1-6.

Brand, F. (2009) Critical natural capital revisited: ecological resilience and sustainable development. *Ecol. Econ.*, **68**, 605-612.

Brown, N. (1998) Out of control: fires and forestry in Indonesia. *TREE*, **13**, 41.

Campagna, C., Short, F.T., Polidoro, B.A. *et al.* (2011) Gulf of Mexico oil blowout increases risks to globally threatened species. *BioScience*, **61**, 393-397.

Carpenter, S., Walker, B., Anderies, J.M. & Abel, N. (2001) From metaphor to measurement: resilience of what to what? *Ecosystems*, **4**, 765-781.

Costanza, R., d'Arge, R., De Groot, R. *et al.* (1997) The value of the world's ecosystem services and natural capital. *Nature*, **387**, 253-260.

De Groot, R., Fisher, B., Christie, M. *et al.* (2010) Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. Pages 9–40 in P. Kumar, editor. *TEEB (The Economics of Ecosystems and Biodiversity) ecological and economics foundations*. Earthscan, London, UK.

Dobrzyńska, T. (1995) Translating metaphor: problems of meaning. *J. Pragmatics.*, **24**, 595-604.

Ekins, P., Simon, S., Deutsch, L., Folke, C. & De Groot, R. (2003) A framework for the practical application of the concepts of critical natural capital and strong sustainability. *Ecol. Econ.*, **44**, 165-185.

Federal Interagency Stream Restoration Working Group (FISRWG). (1998) *Stream corridor restoration: principles, processes, and practices*. USDA – Natural Resources Conservation Service, Washington, D.C.

Jiménez-Bermúdez, J.I. (2006) La otra cara de la lucha contra el fuego. *Guardia Civil*, **747**, 62-65.

Kessler, J.D., Valentine, D.L., Redmond, M.C. *et al.* (2011) A persistent oxygen anomaly reveals the fate of spilled methane in the deep Gulf of Mexico. *Science*, **331**, 312-315.

Lakoff, G. (1993) The contemporary theory of metaphor. Pages 202–251 in A. Ortony, editor. *Metaphor and thought*. Cambridge University Press, Cambridge, UK.

Lakoff, G. & Johnson, M. (1980) *Metaphors we live by*. University of Chicago Press, Chicago, IL.

Lamont, B. (1982) Mechanisms for enhancing nutrient uptake in plants, with particular reference to Mediterranean South Africa and Western Australia. *Bot. Rev.*, **48**, 597-689.

Larson, B. (2011) *Metaphors for environmental sustainability: redefining our relationship with nature*. Yale University Press, New Haven, CN.

Ludwig, J.A., Bastin, G.N., Chewings, V.H., Eager, R.W. & Liedloff, A.C. (2007) Leakiness: a new index for monitoring the health of arid and semiarid landscapes using remotely sensed vegetation cover and elevation data. *Ecol. Indic.*, **7**, 442-454.

Ludwig, J.A., Eager, R.W., Bastin, G.N., Chewings, V.H. & Liedloff, A.C. (2002) A leakiness index for assessing landscape function using remote sensing. *Landsc. Ecol.*, **17**, 157-171.

McCrea-Strub, A., Kleisner, K., Sumaila, U. *et al.* (2011) Potential impact of the Deepwater Horizon oil spill on commercial fisheries in the Gulf of Mexico. *Fisheries*, **36**, 332-336.

Meifang, Z. (2005) A schematic analysis of the cognitive process of metaphor translation. *Foreign Lang Teach.*, **5**, 43-46.

Mishra, D.R., Cho, H.J., Ghosh, S. *et al.* (2012) Post-spill state of the marsh: remote estimation of the ecological impact of the Gulf of Mexico oil spill on Louisiana Salt Marshes. *Remote Sens. Environ.*, **118**, 176-185.

Myers, N. & Kent, J. (2001) *Perverse subsidies: how misused tax dollars harm the environment and the economy*. Island Press, Washington, D.C.

Page, S.E., Siegert, F., Rieley, J.O., Boehm, H.D.V., Jaya, A. & Limin, S. (2002) The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*, **420**, 61-65.

Pickett, S.T.A. & Cadenasso, M. (2002) The ecosystem as a multidimensional concept: meaning, model, and metaphor. *Ecosystems*, **5**, 1-10.

Pickett, S.T.A., Cadenasso, M.L. & Grove, J.M. (2004) Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. *Landsc. Urban Plan*, **69**, 369-384.

Schäffner, C. (2004) Metaphor and translation: some implications of a cognitive approach. *J. Pragmatics*, **36**, 1253-1269.

Thibodeau, P.H. & Boroditsky, L. (2011) Metaphors we think with: the role of metaphor in reasoning. *PLoS ONE*, **6**, e16782. doi: 10.1371/journal.pone.0016782.

Väliverronen, E. (1998) Biodiversity and the power of metaphor in environmental discourse. *Sci. Studies*, **11**, 19-34.

Väliverronen, E. & Hellsten, I. (2002) From “Burning Library” to “Green Medicine” the role of metaphors in communicating biodiversity. *Sci. Commun.*, **24**, 229-245.

Van Voris, P., O’Neill, R.V., Emanuel, W.R. & Shugart, Jr. H.H. (1980) Functional complexity and ecosystem stability. *Ecology*, **61**, 1352-1360.

Waterbury, J. (1979) *Hydropolitics of the Nile valley*. Syracuse University Press, Syracuse, NY.

White, G.F. (1998) The environmental effects of the high dam at Aswan. *Environment*, **30**, 4-11, 34-39.

