

Consilience in Oceanographic and Fishery Research: A Concept and Some Digressions

D. Pauly

Abstract

The concept of *consilience*, describing the 'jumping together' of different scientific disciplines, and recently revived in a book of the same title, authored by E.O. Wilson, is presented, along with some of its implications for work conducted by oceanographers, marine biologists and fisheries and social scientists in the Gulf of Guinea area. It is suggested that maintenance and analysis of time series data, remote sensing of marine primary production, trophic mass balance modelling, and analysis of multi-sectoral coastal transects are eminently *consilient* in that they not only invite interdisciplinary co-operation, but also impose standards and provide common currencies that makes such co-operation meaningful.

Consilience

The text below is not an attempt to summarise the contributions to the Accra workshop documented in this volume. Rather, a few major threads - we would call them *lignes de force* in French - are brought together, showing the inherent coherence of the themes covered during our deliberations. To document this, however, I shall however, use a new, or rather newly revived concept, that of *consilience* (Wilson 1998). Most advances, within the various disciplines practised by the participants of this workshop, such as biology, or the environmental sciences have been the result of synthesis of previously unconnected data or ideas (Simonton 1988). Thus, the furious pace at which data continue to be collected and ideas continue to sprout guarantees that new knowledge will continue to be generated within our disciplines, if only by integrating these data and ideas into common explanatory frameworks.

In analogy to this, if perhaps at a grander scale, major scientific breakthroughs have often been the result of convergence among traditionally distinct disciplines. Herein, these disciplines usually articulate themselves in a hierarchy, with logic/mathematics (and the usual criterion of parsimony; Pauly 1994) providing the backbone of any given breakthrough, physics and chemistry providing the basic rules constraining the changes of its material substrate, and evolutionary biology providing the framework that constrains its living organisms (if any), including humans and their culture. Wilson (1998) called *consilience* (from 'jumping together') the explicit search for scientific explanations within the context of this hierarchy, and provided examples of research issues whose resolution, he felt, would occur faster if consilience were used as an explicit criterion - in addition to parsimony - for structuring the relevant research programmes.

My favourite examples (not Wilson's) of consilience are the Cretaceous/Tertiary (K/T) extinction of 65 million years ago, of dinosaur fame, and the origins of *Homo sapiens*, both of which made mutually compatible data and concepts from an enormous range of disciplines, previously not interacting with each other. A nuclear scientist, his geologist son, and two chemists colleagues proposed that the K/T extinction was caused by the impact of a large meteorite (Alvarez *et al.* 1980). This hypothesis, then based mainly on evidence from an Italian dig, was subsequently corroborated by petroleum geologists, who had previously identified, then ignored the Chicxulub impact crater, in Yucatan, Mexico. Other scientists, from astronomers to evolutionary biologists joined the fray (Raup 1986), and gradually, the 'Alvarez' hypothesis was accepted by the best of them. The results of this development has been extraordinarily fruitful, "provoking new observations that no one had thought of making under old views" (Gould 1995, p.152). This led among other things, to a resolution, in evolutionary biology, of the ancient, but still acrimonious debate between *catastrophists* (Sedgwick, Cuvier, etc.) and *uniformitarianists* (Lyell, Darwin, etc.). Even popular culture was impacted (see the movies *Meteor*, *Armageddon*, and *Deep Impact*).

Indeed, the eventual creation of an international system for tracking potentially dangerous meteorites is not unlikely. Similarly, the evidence for a recent African origin of *Homo sapiens*, with subsequent dispersal to West Asia, Eurasia, Australia, the Americas, and finally Oceania is supported by archaeological and genetic evidence, with linguistics providing the clincher: an evolutionary tree that closely matches that generated by the physical disciplines (Cavalli-Sforza *et al.* 1988). The latter example shows that the hierarchy of sciences implied in consilience does not mean that the specific results of a more fundamental discipline are inherently more reliable than those of a more derived discipline. Rather, it only implies that the different sets of results must be mutually compatible. Thus, the linguistic evidence is, in this example, no less important than the evidence based on genetics. Similarly, when the physicist Lord Kelvin pronounced the Earth to be only a few thousands years old, based on the time required for a large sphere of burning coal to cool off, and evolution by slow natural selection thus impossible, it was he who was wrong, not Charles Darwin (Tort 1996).

The question now is whether we can make use of consilience in our work as oceanographers, marine biologists and fisheries scientists, i.e., in fields perhaps less glamorous than those in the above examples. Various concepts we may call consilient come to mind here, related to presentations at the workshop documented in this volume. The first of these is the mass-balance concept, i.e., the notion that, in a given system, mass must be conserved, irrespective of its movements and transformations. This principle is related to the First Law of Thermodynamics, which states that energy can be neither destroyed nor created (Gilmont 1959). For chemical reactions, this implies for example that "the sum of the masses of the reactants must equal the sum of the masses of the products" (Gilmont 1959, p. 146). Physical oceanographers also rely on mass-balance when calculating geostrophic flows from density fields (Sverdrup *et al.* 1942), or when calculating upwelling intensity from coastal wind stress, which implies water masses welling up to replace water blown off the coast (Bakun 1996).

On the other hand, one rarely hears biologists, or even ecosystem modellers explicitly invoke the principle of mass-balance, though it is also an absolute requirement for living things (Schrödinger 1992). An exception to this is the ecosystem modelling work of T. Laevastu and colleagues, in which mass-balance was used as a key structuring element for trophic interactions and migrations (Laevastu and Favorite 1977; Laevastu and Larkins

1981). J.J. Polovina emphasized this feature when he simplified Laevastu's model and formulated the Ecopath approach (Polovina 1984, 1985), thus giving it the feature which made it applicable to a wide range of system types (Christensen and Pauly 1993; Pauly, this volume). Ecopath uses the mass-balance approach to verify that the estimated production of the functional groups (exploited or not) of a given ecosystem matches the estimated consumption by their predators. Such verification is not ensured by the publication of individual estimates, however precise, even in the best journals catering to the different sub-disciplines of marine biology.

Rather, it is by incorporating such estimates into a mass balance ecosystem model that we render such estimates mutually compatible, and hence assure ourselves of their reliability and usefulness. This should have a beneficial impact on marine biology, whose work on different processes in an extremely wide variety of organisms is sometime perceived as lacking 'relevance'. Moreover, ecosystem and mass-balance considerations should help renew fishery science as well, given that it has been too narrowly focused on the study of single species, and on industrial fisheries, usually overlooking by-catch discarding practices, non-commercial species, and other fisheries (artisanal, sport, etc.) as well.

The relation of these points to Wilsonian consilience should be obvious. Consilience also implies developing protocols for integrating the results of remote sensing studies (as illustrated here by Hardman-Mountford and McGlade or Roy *et al.*, this volume) into mass-balance trophic models of ecosystems. The key results relevant here are: (1) definition of geographic system boundaries, as in the case of the biochemical provinces of Longhurst (1998); and (2) synoptic estimates of primary production (Longhurst *et al.* 1995), i.e., of that which determines the boundaries of marine ecosystems in terms of the size of their biomass fluxes. Here, by constraining model size, remote sensing can link with ecosystem modelling, and thus work in consilient mode. Note also that both remote sensing and trophic modelling may be accused of being 'superficial': remote sensing because, quite literally, it cannot look deeper than a few decimetres into the sea, and trophic modelling because it does not consider interactions other than those generated by grazing and predation. Yet, when data from the two approaches are analyzed jointly, inferences can be drawn which go well beyond those based on more conventional approaches (see e.g., Pauly and Christensen 1995; Trites *et al.* 1997).

Perhaps we may infer from this issue of apparent superficiality that consilient work may suffer, at least for a while, from analogies with multidisciplinary work, wherein the methods of different disciplines are brought to bear on a given topic (e.g., as chapters in a book), without any of these methods being made to relate to each other. Such unconnected work is all too frequent, e.g., in that discipline called coastal area management, a theme to which we shall return. The concept of consilience, it seems to me, should also apply to the strengthening of inferences that results when the past is related to the present. This is what occurs when we use knowledge gathered by historians, or by scientists of past centuries, and often perceived as anecdotal, to establish stable baselines for biodiversity (Pauly 1995, 1996).

This is also what occurs when we draw inferences from time series, whose increasing length increases their contrast, and hence their usefulness for various analyses (Hilborn and Walters 1992). Thus, it is important that the physical and biological time series generated and/or used by the participants in this book be continued, and every effort should be made to ensure that this occurs. The last aspect of consilience to be covered here refers to its implications for the languages we use. Trivially, this means that we must speak the same vernacular language (English, as it mostly turns out), and only a bit less trivially, translate concepts in and out of our various discipline-specific jargons. Also, and this is where things

start getting really complicated, we must identify concepts that cut across disciplines, and a multidisciplinary currency allowing for transactions between disciplines.

I shall illustrate this with reference to coastal area management (CAM), a discipline with many practitioners and applications, but whose defining tenet(s), topic(s) and technique(s) remain elusive. Indeed, some practitioners give the impression that anything that happens anywhere on or close to on any coastline is within the purview of CAM, and that any method ever used to investigate any of these things is appropriate for CAM. (The reader will understand that I could not provide references to back these claims without antagonizing people whose technical work I respect, in spite of the disorganisation of their discipline). Thus for CAM, as perhaps everywhere in science (Medawar 1967), the challenge is to identify tractable problems, related to its defining objects: coastlines.

Coastlines differ from other geographic features in that most of their different characteristics are arrayed in a single dimension, i.e., in the form of transects that are perpendicular to the coastline, and stretch from upland to the sea. On the other hand, fewer differences occur parallel to a coastline. Alexander von Humboldt, a founder of physical geography, may have been the first to use transects to document geographical variations along strong gradients (Gayet 1996). Conway (1985), on the other hand, introduced transects to agro-ecosystem analysis, as a tool to express in simplified manner the complex interactions within highly integrated farming systems. [Note, incidentally that such systems can also be described by trophic mass-balance models; Dalsgaard and Oficial 1997]. From this, it is straightforward to propose that multi-sectoral coastal transects should become a key concept in CAM, and that, suitably formalized, such transects could lead to the common currency required for comparison of coastal systems, and for comparative evaluation of various injuries to such systems (Pauly and Lightfoot 1992).

SimCoast™ (McGlade 1999; 2001) which was used in the EU Gulf of Guinea implements this coastal transect approach, and provides, via fuzzy logic, the currency that CAM had been lacking so far, enabling quantitative comparisons of impacts due to different, otherwise incommensurable agents (Nauen, this volume), ranging from upland erosion to fisheries policy. That this should lead to consilience among, and progress for, the different disciplines so far fruitlessly engaged in CAM needs little emphasis.

Another example of consilience requiring a common currency is FishBase, the electronic encyclopaedia of fishes (see www.fishbase.com), which works only because a standardised nomenclature (Eschmeyer 1998) is used to establish the links between the widely different data types included in FishBase (Froese and Pauly 1998). This is what enables FishBase to provide, among other things, a comprehensive coverage of the fishes of the Gulf of Guinea, and of their biology. As might have be noted, several of my examples (Ecopath, SimCoast, FishBase) are products of projects supported by the European Commission, particularly by its Directorate General concerned with development (i.e. VIII and XII INCO/DC), but not run by committees, or university consortia. Perhaps this indicates that such projects, providing support to participants only if they buy in the strong concept underlying such ventures, are more effective than the usual collaborative projects, where the partners agree only to share the available funds.

The ventures given as example here certainly have shown that participants from a variety of countries, both developed and developing, can contribute. And this is probably the neatest thing about consilience: it implies that we can all contribute, given some self-discipline.

Acknowledgements

I thank Dr. Cornelia Nauen, for useful discussions, and for all the support.

References

- Alvarez, L. W. Alvarez, F. Asaro and H.V. Michel 1980 Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science* 208: 1095-1106.
- Bakun, A. 1996 Patterns in the Ocean: ocean processes and marine population dynamics. California Sea Grant, La Jolla, CA, and Centro de Investigaciones Biologicas del Noroeste, La Paz, BCS. 323p.
- Cavalli-Sforza, L.L., A. Piazza, P. Menozzi, and J. Mountain 1988 Reconstruction of human evolution: bringing together genetic, archaeological and linguistic data. *Proc. Acad. Sci.* 85(16): 6002-6006.
- Christensen, V. and D. Pauly (eds) 1993 Trophic models of aquatic ecosystems. ICLARM Conf. Proc. 26. 390p.
- Conway, G.R. 1985 Agroecosystem analysis. *Agric. Admin.* 20:31-55.
- Dalsgaard, J.P.T. and R.T. Oficial 1997 A quantitative approach for assessing the productive performance and ecological contribution of smallholder farms. *Agricultural Systems* 55(4): 503-533.
- Eschmeyer, W.N. (ed.) 1998 *Catalog of fishes*. Special Publication, California Academy of Sciences, San Francisco, 3 volumes, 2905p.
- Froese, R. and D. Pauly (eds) 1998 FishBase 98: concepts, design and data sources. ICLARM. 293 p. [distributed with 2 CD-ROMs]
- Gayet, M. 1996 Humboldt, Friedrich Wilhelm Heinrich, Alexander von, 1769-1859. pp2284-2287. *In: P. Tort (ed.) Dictionnaire du Darwinisme et de l'Evolution*. Presse Universitaire de France. Paris.
- Gilmon, R. 1959 *Thermodynamic principles for chemical engineers*. Prentice Hall, New York. 339p.
- Gould, S.J. 1995 *Dinosaurs in a haystack: reflection in natural history*. Harmony Books, New York. 480p.
- Hardman-Mountford, N.J. and J.M. McGlade (this volume, chapter 5) Variability of physical processes in the Gulf of Guinea and implications for fisheries recruitment. An investigation using remotely sensed sea surface temperature.
- Hardman-Mountford, N. J. and J.M. McGlade (this volume, chapter 6) Defining ecosystem structure from natural resource variability: application of principal components analysis to remotely sensed sea surface temperatures.
- Hilborn, R. and C.J. Walters 1992 *Quantitative fisheries stock assessment: choice, dynamics and uncertainty*. Chapman & Hall, New York. 570p.
- Laevastu, T. and F. Favorite 1977 Preliminary report on a dynamic numerical marine ecosystem model (DYNUMES) for the Eastern Bering Sea. U.S. Natl. Mar. Fish./Northwest and Alaska Fisheries Center, Seattle. 81p.
- Laevastu, T. and H.L. Larkins 1981 *Marine Fisheries Ecosystems: quantitative evaluation and management*. Fishing News Books, Farnham, Surrey. 162p.
- Longhurst, A.R. 1998 *Ecological geography of the sea*. Academic Press, San Diego. 398p.

- Longhurst, A.R.S. Sathyendranath, T. Platt, and C.M. Caverhill 1995 An estimate of global primary production in the ocean from satellite radiometer data. *J. Plankton Research* 17: 1245-1271.
- McGlade, J.M. 1999 Ecosystem analysis and the governance of natural resources. pp309-342. *In: J.McGlade (ed.) Advanced Ecological Theory. Principles and Applications.* Blackwell Science, Oxford.
- McGlade, J.M. 2001 SimCoast™. A Fuzzy Logic Rule-Based Expert System. View the World, UK [distributed as CD-ROM]
- Pauly, D. 1994 Resharpener Ockhams' Razor. *Naga, the ICLARM Quarterly* 17(2):7-8.
- Pauly, D. 1995 Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology and Evolution* 10(10):430.
- Pauly, D. 1996 Biodiversity and the retrospective analysis of demersal trawl surveys: a programmatic approach, pp1-6. *In: D. Pauly and M. Martosuborto (eds). Baseline studies in biodiversity: the fish resources of Western Indonesia.* ICLARM Studies and Reviews 23.
- Pauly, D. (this volume, chapter 21) Spatial modelling of trophic interactions and fisheries impacts in coastal ecosystems: a case study of Sakumo Lagoon, Ghana.
- Pauly, D. and V. Christensen 1995 Primary production required to sustain global fisheries. *Nature* 374:255-257.
- Pauly, D. and C. Lightfoot 1992 A new approach for analyzing and comparing coastal resource systems. *Naga, the ICLARM Quarterly* 15(3):7-10.
- Polovina, J.J. 1984 Model of a coral reef ecosystem I. The ECOPATH model and its application to French Frigate Shoals. *Coral Reefs* 3:1-11.
- Polovina, J.J. 1985 An approach to estimating an ecosystem box model. *U.S. Fish. Bull.* 83(3): 457-460.
- Raup, D.M. 1986 *The Nemesis affair: a story of the death of Dinosaurs and the Ways of Science.* W.W. Norton, New York. 219p.
- Roy, C. P. Cury, P. Fréon and H. Demarq (this volume, chapter 10) Environmental and resource variability off northwest Africa.
- Schrödinger, E. 1992 *What is Life?* Cambridge University Press, Cambridge. 184p.
- Simonton, D.K. 1988 *Scientific genius: a psychology of science.* Cambridge University Press. Cambridge, 229p.
- Sverdrup, H.U., M.W. Johnson and R.H. Fleming 1942 *The oceans: their physics, chemistry and general biology.* Prentice Hall, New York. 1087p.
- Tort, P. 1996 Thompson, Sir William, Lord Kelvin, 1824-1907. pp4281-4283 *In: P. Tort (ed.) Dictionnaire du Darwinisme et de l'Evolution.* Presse Universitaire de France. Paris.
- Trites, A., V. Christensen and D. Pauly 1997 Competition between fisheries and marine mammals for prey and primary production in the Pacific Ocean. *J. Northw. Atl. Fish. Sci.* 22: 173-187.
- Wilson, E.O. 1998 *Consilience: the unity of knowledge.* Alfred A. Knopf. New York. 332p.