Letter to the Editor

Fact, theory, test and evolution

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In the article, 'The Role of Climatic Change in the Evolution of Mammals', in the *Teaching Biology* section of *BioScience*, Barnosky & Kraatz (2007) make two claims: evolution is a fact, and fossils are the test evidence of evolutionary hypotheses. In the beginning sentence, the authors state, 'Despite all the arguments over semantics, evolution is a fact' (Barnosky & Kraatz 2007: 523), but later claim, 'Evolution is also a theory' (Barnosky & Kraatz 2007: 524). This conflation of fact and theory is extended to hypotheses in relation to testing: 'Over time, as predictions [*sic*] are repeatedly confirmed through multiple tests, hypotheses are transformed into scientific fact ...' (Barnosky & Kraatz 2007: 525, fig. 2 legend). Further on the matter of testing, Barnosky & Kraatz (2007: 524) claim this is 'provided by the fossils themselves, which are the primary data....' Consequently, Barnosky & Kraatz (2007: 525) conclude that 'it is important to note that through the same kind of iterative observation, prediction, and tests, evolution itself has proceeded from hypothesis in Charles Darwin's time to scientific fact in ours....' At a time when evolutionary biology, and science in general, is under attack from advocates of creationism and intelligent design, with the caveat that theirs is a 'scientific research program' (Dembski 1999: 13; Ross 2006; Wells 2006), it is incumbent upon evolutionary biologists to carefully and correctly outline the nature of scientific investigation. Two critical topics include the fact and hypothesis/theory distinction, and the proper mechanics of testing.

What are facts? Mahner & Bunge (1997: 34) provided what is probably the best definition of the term as it relates to biology: 'the being of a thing in a given state, or an event occurring in a thing.' By extension, they noted that 'there can be no "scientific facts"....' This should not be surprising, given the definition. Facts transcend all human activities, even those in science, such that no particular set of facts could be labelled scientific as opposed to non-scientific. Mahner's & Bunge (1997) definition is consistent with that cited by Barnosky & Kraatz (2007: 523), as '"something having real, demonstrable existence ... the quality of being real or actual" (Soukhanov *et al*. 1996).' But, Barnosky & Kraatz (2007) also accept that there can be scientific facts, citing the definition provided by Kennedy *et al*. (1998; see also Scott 2004: 12; Johnson 2007: 340): 'Fact: In science, an observation that has been repeatedly confirmed.' As we will see next, observation and confirmation are irrelevant to facts (but not vice versa). The status of something as a fact is not contingent upon what is mandated in science, which also has significant consequences for the relations between facts and hypotheses/theories.

We might consider the following example as a contrast to what was claimed by Barnosky & Kraatz (2007) regarding the status of facts and hypotheses. I perceive on the table in front of me a set of objects. From these perceptions, I infer the hypothesis, 'There is a glass of ice water on the table.' The hypothesis, as an observation statement, presents an explanatory account of the *facts*. In other words, my hypothesis provides at least initial understanding of the facts I have just encountered — my sense perceptions are effects caused by the existence of a particular set of facts in specifiable states of being. At a minimum, my ability to make the inference from my sense perceptions to the hypothesis was contingent upon my applying at least two theories to those perceptions: the theories of glass and water. The hypothesis, 'There is a glass of ice water on the table', is therefore not a fact. It is not an object that can be identified as being in a particular state of being. It is, instead, a statement that *refers to facts*.

Hypotheses, and theories for that matter, are human constructs inferred from the conjunctions of statements regarding specific facts and theories; a class of non-deductive reasoning known as abduction (Peirce 1878, 1931–35, 1958; Hanson 1958; Harman 1965; Fann 1970; Curd 1980; Thagard 1988; Lipton 1993; Josephson & Josephson 1994; Magnani 2001; Walton 2004; Fitzhugh *et al*. 2005a,b, 2006a,b; Atocha

2006).[1] A consequence is that they do not have deductive certainty. Hypotheses and theories are fallible, theory-laden constructs. Such fallibility does not, however, apply to facts, since facts merely exist regardless of their being perceived. The basis for testing is to evaluate the veracity of our claims regarding facts. But, do hypotheses and theories have the potential to be 'transformed into scientific fact' subsequent to successfully passing any number of tests, as claimed by Barnosky & Kraatz (2007)? Of course not. Regardless of how many tests confirm the hypothesis, 'There is a glass of ice water on the table', it will always remain a hypothesis. The statement will always stand as an explanation of why I perceive a set of facts. The greater certainty one holds for a hypothesis or theory subsequent to testing is nothing more than an indication of the ever-increasing understanding afforded by that hypothesis or theory of the facts we perceive or anticipate perceiving. Referring to hypotheses and theories as 'facts' is contrary to the explanatory nature of those concepts, and is a corruption of the intent to accurately represent the nature of acquiring understanding in the realm of science. Bock (2007: 89) summarized the situation nicely,

> Over the decades as more and more was learned about evolution, many evolutionists stated that Biological Evolution was no longer a theory, but was factual or a fact (= an objective empirical observation) which confused the issue even more as a sharp difference exists between scientific theories and objective empirical observations.... Facts, as used in science, are quite different from theories and the two are best kept strictly separated.

'Evolution' cannot be both a theory and a fact. Theories are concepts stating cause–effect relations (Cohen & Nagel 1937; Nagel 1961; Hempel 1965; Harré 1970; Fetzer & Almeder 1993). Regardless of one's certainty as to the utility of a theory to provide understanding, it would be epistemically incorrect to assert any theory as also being a fact, given that theories are not objects to be discerned by their state of being. But, is there a proper context in which we might speak of evolution as a fact? One might argue that it is conceivable to speak of 'evolution' as a fact by way of it being the subject of reference in explanatory hypotheses. This is not to say that

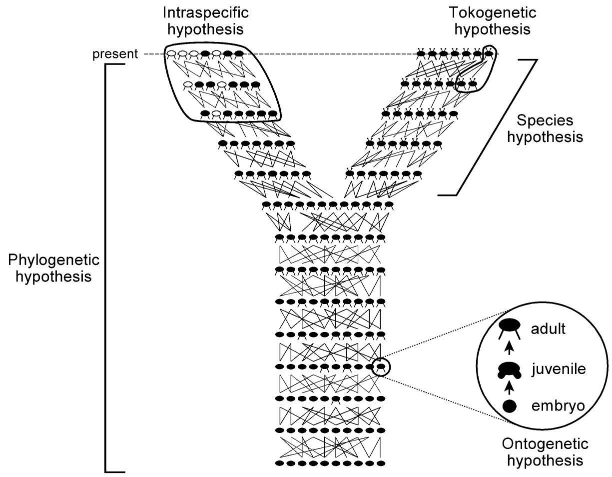

Fig. 1 Relations between ontogenetic, tokogenetic, intraspecific, specific and phylogenetic hypotheses (adapted in part from Hennig 1966: fig. 6; Fitzhugh 2005b: fig. 1; 2006b: fig. 1).

evolution can be equated with 'change through time.' Ontologically, change is 'the transition of a being from one state to another' (Coffey 1938: 61). The term evolution does not apply to a single object, but to a multitude of objects over time, that is, organisms. 'Change' is not the pertinent quality of interest in evolution, but rather explanations of the *differences* between organisms. Different properties among organisms cannot then be explained via any notion of change: 'When one thing is put in the place of another, each ... undergoes a change of place, but neither is changed into the other' (Coffey 1938: 61). Thus, if we can speak of evolution being a fact, it must be by way of some connotation other than 'change'.

As noted above, hypotheses are the inferential products of the conjunctions of theories and observed effects, that is, facts. But, there also are facts beyond those being explained to which an 'evolutionary' hypothesis refers, in the form of past organisms involved in the events that are the subjects of evolutionary biology. Consider the hypotheses diagrammatically represented in Fig. 1. Five classes of explanatory hypotheses are shown: ontogenetic, tokogenetic, intraspecific, specific and phylogenetic (cf. Hennig 1966; Fitzhugh 2005b, 2006a,b).[2] What will be noticed is that in each instance, the facts referred to are individual organisms. The hypotheses provide causal accounts for the facts observed in the present, which

[1] *Barnosky & Kraatz (2007: fig. 2) indicate that the 'scientific method' is an interplay only between induction* (sensu lato) *and deduction, where hypothesis formation occurs in the former, and testing in the latter. It is more appropriate to acknowledge three classes of reasoning typically involved in science: abduction, deduction, and induction [*sensu stricto; *'inferences from particular observations in support of generalizations' (Godfrey-Smith 2003: 42)] (Fitzhugh 2005a,b, 2006a: fig. 5, b). Hypothesis formation is a matter of abductive inference, not induction. Deduction only characterizes the act of deducing potential tests, while induction is the act of testing.*

[2] *Not all biologists (or philosophers) will agree that the events presented in Fig. 1 should be characterized as hypotheses, much less labelled in the manner shown — for example, the treatment of species as explanatory hypotheses (Fitzhugh 2005b) as opposed to individuals. Regardless, the intent of the example is to highlight that 'evolution' is not the 'fact' to which hypotheses refer.*

are individual organisms in different states of being, by way of references to facts hypothesized to have existed in the past. For instance, regarding what is demarcated as a phylogenetic hypothesis in Fig. 1, this could be written as follows:

> Ventral appendages originated by some unspecified mechanism(s) within a reproductively isolated population with a convex ventrum, and the appendage condition became fixed in the population by some unspecified mechanism(s), followed by an unspecified event(s) that subsequently resulted in two reproductively isolated populations.

Similarly, the species hypothesis indicated in Fig. 1 would have the form:

> Antennae originated by some unspecified mechanism(s) within a reproductively isolated population with convex dorsal margins, and antennae subsequently became fixed, such that individuals observed in the present are products of past tokogenetic events involving individuals with that character.

One might, however, be compelled to speak of the phylogenetic hypothesis as showing the 'fact of evolution of appendages', or the species hypothesis the 'fact of evolution of antennae.' In either instance, and regardless of the amount of test evidence confirming either hypothesis, it would be incorrect to claim that 'it is a *fact* that appendages evolved' or that 'it is a *fact* that antennae evolved.' Confirming evidence cannot change the status of a hypothesis to a fact. Rather, what we see in the diagrammatic representations and written forms of each hypothesis are what are referred to as the facts, in the form of past individual organisms and events involving those organisms. In the strictest sense then, 'evolution' cannot be regarded as a fact even in the context of hypotheses since the causal points of reference continue to be organisms, and no amount of confirming instances for those hypotheses will transform them into facts. To say 'evolution is a fact' is just an inexact reference to what is thought to have existed, which are organisms and the events in which they were involved. While evolution is not a fact, it is also not a single theory, but a set of theories applied to a variety of causal questions. Answers to five of those questions are represented in Fig. 1. For the sake of accurately communicating the nature of science, we would do well to avoid misconstruing the notion of fact with hypothesis or theory.

The claim by Barnosky & Kraatz (2007) that hypotheses are tested by fossils is consistent with the long-standing misconception that the class of effects being accounted for by a hypothesis can also serve as test evidence confirming or disconfirming the causal claims in that hypothesis. This error is not only prevalent in evolutionary biology (cf. Fitzhugh 2006a) but also among advocates of creationism and intelligent design (Bird 1991; Dembski 1999; Meyer 2003, 2004; Ross 2006). Let's refer back to Fig. 1, which presents a series of hypotheses to explain the properties of some set of individuals, *qua* facts, observed in the present. It makes no difference if what are observed are fossils or living/preserved organisms. Can fossils observed in the present, of individuals thought to have lived prior to observed individuals, serve as legitimate evidence to test any of the hypotheses in Fig. 1? No. Any predictions of what might be found in the way of fossils are not legitimate tests of a hypothesis for the fact that it is not possible to deduce such occurrences as consequences from the conjunction of a theory and the hypothesis. Moreover, such predictions do not provide the relevant evidence regarding the causal claims made in the hypothesis. Each of the hypotheses in Fig. 1 is an assertion regarding specific, past causal events. The phylogenetic hypothesis in this figure states that a minimum of two classes of causal events occurred: the origin/fixation of ventral appendages, and subsequent formation of two reproductively isolated populations. The formal deductive structure from which potential test evidence can be derived is as follows (cf. Fitzhugh 2006a):

Phylogenetic theory: If character α exists among individuals of a reproductively isolated, gonochoristic or cross-fertilizing hermaphroditic population and character β originates by mechanisms *a*, *b*, *c* ... *n*, and becomes fixed within the population by mechanisms *d*, *e*, *f* ... *n* [= ancestral species hypothesis], followed by event or events *g*, *h*, *i* ... *n*, wherein the population is divided into two or more reproductively isolated populations, then individuals to which descendant species hypotheses refer would exhibit β.

Hypothesis (Fig. 1): Ventral appendages originated by some unspecified mechanism(s) within a reproductively isolated population with a convex ventrum, and the appendage condition became fixed in the population by some unspecified mechanism(s), followed by an unspecified event(s) that resulted in two reproductively isolated populations.

Observed effects: Individuals to which species hypotheses *B-us b-us* and *B-us c-us* refer have ventral appendages in contrast to a convex ventrum as seen among individuals to which other species hypotheses refer.

***Potential tests*:** Effects of type δ and γ should be observed, respectively, indicating that the specific causal events of (i) appendage fixation in the ancestral population and (ii) splitting of that population into separate, reproductively isolated populations occurred, as stated in the hypothesis.

Notice that what is deduced as potential tests of this hypothesis must be effects extending to the present that are related as closely as possible to the causal events claimed in the hypothesis. In other words, what we would have to seek would be evidence confirming that the events themselves actually occurred. Critical tests are those that seek evidence, as effects, with the lowest probability of being witnessed if the events did not occur (Fitzhugh 2006a). Simply finding fossils would not suffice, as these are not deducible effects that trace back to the causal events claimed by the hypothesis. Fossils are individuals that become part of the collection of effects also in need of being explained in the context of the hypothesis. Thus, the class of effects that serve as test evidence for or against a hypothesis will always be entirely different from the class of effects being explained by the hypothesis.

Ironically, in contrast to what was suggested by Barnosky & Kraatz (2007), what has been discussed here is largely a matter of semantics. An emphasis on associating 'evolution' with 'fact' presents the misguided connotation that science seeks certainty. Acknowledging that the statement, 'evolution is a fact', is an incorrect assertion has the benefit of focusing our attention back on the goal of science, which is to continually acquire causal understanding through the critical evaluation of our theories and hypotheses. Certainty provides no basis for elevating any evolutionary theory or hypothesis to the level of fact. The characterization and practice of science should be burdened as little as possible with catch phrases that promote misunderstanding.

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References

Atocha, A. (2006). *Abductive Reasoning: Logical Investigations Into Discovery and Explanation*. Dordrecht: Springer.

Barnosky, A. D. & Kraatz, B. R. (2007). The role of climatic change in the evolution of mammals. *Bioscience*, *57*, 523–532.

Bird, W. R. (1991). *The Origin of Species Revisited: The Theories of Evolution and Abrupt Appearance, Vol. II: Philosophy of Science, Philosophy of Religion, History, Education, and Constitutional Issues*. Nashville: Regency.

Bock, W. J. (2007). Explanations in evolutionary biology. *Journal of Zoological Systematics and Evolutionary Research*, *45*, 89–103.

Coffey, P. (1938). *Ontology or the Theory of Being: An Introduction to General Metaphysics*. New York: Peter Smith.

Cohen, M. R. & Nagel, E. (1937). *An Introduction to Logic and Scientific Method*. New York: Harcourt, Brace.

Curd, M. V. (1980). The logic of discovery: an analysis of three approaches. In T. Nickles (Ed.) *Scientific Discovery, Logic and Rationality* (pp. 201–219). Dordrecht: D. Reidel Publishing Co.

Dembski, W. A. (1999). *Intelligent Design: The Bridge Between Science and Theology*. Downers Grove: InterVarsity Press.

Fann, K. T. (1970). *Peirce's Theory of Abduction*. The Hague: Martinus-Nijhoff.

Fetzer, J. H. & Almeder, R. F. (1993). *Glossary of Epistemology/ Philosophy of Science*. New York: Paragon House.

Fitzhugh, K. (2005a). Les bases philosophiques de l'inférence phylogénétique: une vue d'ensemble. In P. Deleporte & G. Lecointre (Eds) *Philosophie de la systématique. Biosystema*, *24*, 83–105.

Fitzhugh, K. (2005b). The inferential basis of species hypotheses: the solution to defining the term 'species.' *Marine Ecology*, *26*, 155–165.

Fitzhugh, K. (2006a). The abduction of phylogenetic hypotheses. *Zootaxa*, *1145*, 1–110.

Fitzhugh, K. (2006b). The 'requirement of total evidence' and its role in phylogenetic systematics. *Biology and Philosophy*, *21*, 309–351.

Godfrey-Smith, P. (2003). *Theory and Reality: An Introduction to the Philosophy of Science*. Chicago: The University of Chicago Press.

Hanson, N. R. (1958). *Patterns of Discovery: An Inquiry into the Conceptual Foundations of Science*. New York: Cambridge University Press.

Harman, G. (1965). The inference to the best explanation. *Philosophical Review*, *74*, 88–95.

Harré, R. (1970). *The Principles of Scientific Thinking*. Chicago: The University of Chicago Press.

Hempel, C. G. (1965). *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science*. New York: The Free Press.

Hennig, W. (1966). *Phylogenetic Systematics*. Urbana: University of Illinois Press.

Johnson, N. A. (2007). Is evolution 'only a theory'? Scientific methodologies and evolutionary biology. In A. J. Petto & L. R. Godfrey (Eds) *Scientists Confront Intelligent Design and Creationism* (pp. 339–360). New York: W.W. Norton Co.

Josephson, J. R. & Josephson, S. G. (Eds) (1994). *Abductive Inference: Computation, Philosophy, Technology*. New York: Cambridge University Press.

Kennedy, D., Alberts, B., Ezell, D., Goldsmith, T., Hazen, R., Lederman, N., McInerney, J., Moore, J., Scott, E., Singer, M., Smith, M., Suiter, M. & Wood, R. (1998). *Teaching About Evolution and the Nature of Science*. Washington D.C.: National Academy Press, Available via http://www.nap.edu/readingroom/books/evolution98.

Lipton, P. (1993). *Inference to the Best Explanation*. New York: Routledge.

Magnani, L. (2001). *Abduction, Reason, and Science: Processes of Discovery and Explanation*. New York: Kluwer Academic.

Mahner, M. & Bunge, M. (1997). *Foundations of Biophilosophy*. New York: Springer-Verlag.

Meyer, S. C. (2003). DNA and the origin of life: information, specification, and explanation. In J. A. Campbell & S. A. Meyer (Eds) *Darwinism, Design, and Public Education* (pp. 223–285). East Lansing: Michigan State University Press.

Meyer, S. C. (2004). The Cambrian information explosion: evidence for intelligent design. In W. A. Dembski & M. Ruse (Eds) *Debating Design: From Darwin to DNA* (pp. 371–391). Cambridge: Cambridge University Press.

Nagel, E. (1961). *The Structure of Science: Problems in the Logic of Scientific Explanation*. New York: Harcourt, Brace & World.

Peirce, C. S. (1878). Illustrations of the logic of science. Sixth paper. — Deduction, induction, and hypothesis. *Popular Science Monthly*, *13*, 470–482.

Peirce, C. S. (1931–35). In C. Hartshorne, P. Weiss & A. Burks (Eds) *Collected Papers of Charles Sanders Peirce*, *1–6*. Cambridge: Harvard University Press.

Peirce, C. S. (1958). In A. Burks (Ed.) *Collected Papers of Charles Sanders Peirce*, *7–8*. Cambridge: Harvard University Press.
Ross, H. (2006). *Creation as Science: A Testable Model Approach to End the Creation/Evolution Wars*. Colorado Springs: NavPressPublishing.
Scott, E. C. (2004). *Evolution vs. Creationism: An Introduction*. Los Angeles: University of California Press.
Thagard, P. (1988). *Computational Philosophy of Science*. Cambridge: The MIT Press.
Walton, D. (2004). *Abductive Reasoning*. Tuscaloosa: The University of Alabama Press.
Wells, J. (2006). *The Politically Incorrect Guide to Darwinism and Intelligent Design*. Washington D.C.: Regnery Publishing, Inc.

