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GERMAN PALEONTOLOGY IN THE EARLY 21ST CENTURY

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SUMMARY

German paleontology has a long tradition and is still very active and innovative in many fields. Fields with the highest impacts are Neogene to Recent micropaleontology with paleoceanographic and climate focus as well as geobiology and paleoecology. Systematic paleontology is well represented in Germany and leading taxonomic expertise is present for many groups although the impact of this research is necessarily low. Conservation of this expertise is important but visibility should be enhanced by cooperation with researchers from other disciplines. Analytical paleobiology is too weak in Germany with a few exceptions, as is the deep-time perspective of evo-devo research and efforts should be made not to fall further behind here.

The greatest risk for German paleontology is the continued closure of university departments and the replacement of retired paleontologists by non-paleontologists. This threatens the future of our students in science and the paleontological research community may fall below a critical mass which is needed for innovative research. Some of these problems fall in the responsibility of the paleontologists themselves (e.g., lack of innovative approaches, apparent absence of practical/ economic applicability, tactical mistakes) but others are the result of administrative actions to save or shift resources independent of the quality of research and teaching.

INTRODUCTION

Germany is often envied for its richness of Fossil-Lagerstätten. Sites such as Bundenbach, Holzmaden, Solnhofen, or Messel are known to most paleontologists around the globe. The marine Muschelkalk Basin (Middle Triassic) and the small Miocene Steinheim crater serve as classical test tubes for studying endemic evolution after the immigration of founder species. Not only the field sites, but also the work that has been done have made Germany one of the big players in paleontology. Famous names associated with German paleontology include Ernst Friedrich von Schlotheim (1764-1832), Leopold von Buch (1774-1853), Karl Alfred von Zittel (1839-1904), Werner Janesch (1878-1969), Otto H. Schindewolf (1896-1971), Tilly Edinger (1897-1967), Dolf Seilacher (1925-), and Peter Wellnhofer (1936-).

However, paleontology as a scientific discipline is in decline, not only in Germany but worldwide. In this essay, we try to evaluate how this decline is manifested and what are its causes, using Germany as an example. We first lay out some facts on the recent history and current status of paleontology in Germany. We then ask who is to blame. We do this in a subjective manner combining experience from invertebrate and vertebrate paleontology. Finally we propose some ideas on how this situation could be improved.

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Because paleontology is traditionally highly interdisciplinary, its boundaries are volatile. We thus see the need to define the science of paleontology and its current boundaries to neighboring disciplines such as biology, geology, and archeology in order to provide constraints for assessing the current status of German paleontology.

In our opinion, two prerequisites that are already in the name of the discipline have to be fulfilled for a curriculum to be called paleontological: the study of *ancient life*. There is no restriction of the type of organisms being studied, but central is the idea that the organisms are treated as life forms and not just as objects carrying proxy data. Is then a project on the oxygen isotope study on planktonic foraminifers paleontological or something else? If the only purpose of the study is to trace temperature through time, we think it is something else. If the ecological and evolutionary response of the foraminifers (or other organisms) is studied simultaneously, it is paleontology. Can molecular studies on modern organisms or sedimentological studies on carbonate platforms still be regarded as paleontology? Yes, if fossils or the deep time perspective are also considered, no if molecular data are the only means to reconstruct phylogenies or if carbonate platforms are just being treated as geological structures. The definition of ancient is less clear, but here artificially defined as older than Holocene. A project on Holocene climatic variability is thus not paleontology.

RECENT HISTORY AND CURRENT STATUS

Representation of Paleontology at Research Institutions

As in most other countries, paleontology in Germany is usually embedded in geoscience departments of universities. Exceptions are some museums that are either independent or in the Leibniz Association (http://www.wgl.de/?nid=ubu&nidap=&print=0), institutes of the Max Planck Society (http://www.mpg.de/english/portal/index.html), and institutes in the Helmholtz Association (http://www.helmholtz.de/en/). The Museum für Naturkunde in Berlin is a special case in that it has stronger links to biology than to geosciences: paleontology is part of the biology department, largely because there is no geology at Humboldt University with which the museum is associated. In any case, virtually all professional German paleontologists studied geology/paleontology and, apart from some vertebrate paleontologists, regard themselves as geoscientists.

Paleontology was, until German reunification in 1990, represented in almost all larger universities, that is, in all larger cities in West Germany (58 professorships, not including assistant professors who did not have professor status then). In former East Germany, paleontology was represented in only three cities: Berlin, Greifswald and Freiberg. With represented, we mean that at least one professorship was devoted to the field. After reunification, there was a short-term expansion of paleontology in the east, but this is now almost back to the previous state. In the west, there has been a loss of about 30% of paleontological representation at institutions that formerly had paleontology: Examples are Aachen, Darmstadt, Gießen, Hannover, Karlsruhe, Marburg, Stuttgart, Würzburg, and the Technical University at Berlin. The number of professional paleontologists is usually declining at those universities that still have paleontology (e.g., Mainz).

Universities in the east, with newly established geoscience departments, often do not have a paleontology professor and sometimes not even paleontology in their curriculum. Examples are the universities of Jena and Potsdam. Even where paleontology is still taught, the number of professors is declining. There are still 54 paleontology professors in Germany, including so-called junior professors. Although not all are active in (paleontological) research, this looks like a healthy number for a medium sized country. But considering the population of Germany (81 Million) this number is probably too small to maintain or build an active, sustainable research curriculum. The USA, with a population 3.7 times the one of Germany, has 10 times the number of professors (541 in 2007, Plotnick 2007). On the other hand, more paleontologists than ever are now involved in science policy: of the seven large museums in natural sciences, three are led by paleontologists (Berlin, Frankfurt, Stuttgart). Several paleontologists are active in policy working committees such as the Joint Science Conference of Germany, the UN and the OECD (Leinfelder 2009). While this might indicate that German paleontology is moving forward, an alternative explanation would be that the most ambitious paleontologists are leaving the field towards science management, because they see no future for research (Leinfelder 2009). The representation of paleontologists in political decision making has probably accelerated the shift of German paleontology away from evolutionary questions toward climate change.

Research Themes and Funding

The major research themes, determined by the number of projects funded by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG, see http://gepris.dfg.de/gepris/), are climate change (28% of projects), phylogeny (20%), and ecology (17%). Climate change studies are strongly focused on Pleistocene and Holocene dynamics, often without considering organismic responses. When those are excluded, the rank-order distribution changes to (1) phylogeny (23%), (2) ecology (20%), and (3) climate (16%). Under phylogeny are summarized all studies that are systematic-taxonomic and which are usually concerned with the evolution of particular groups of organisms. Ecology is strongly dominated by projects within the new research unit 533 that is assessing the causes of gigantism in sauropod dinosaurs. Macroevolution and biodiversity that are so eminent in US paleontology are strongly underrepresented, targeted in only 7% of DFG projects. We will return to this point blow (see: Who is to Blame).

The general funding situation for paleontological projects has remained fairly constant at medium levels. The success rate in DFG proposals has dropped slightly in the last few years, but is still much higher than with NSF in the United States. About 120 paleontological projects in the broad sense are currently funded, among them project bundles such as the IODP (DFG), the above mentioned sauropod project (DFG), a research unit on the Precambrian-Cambrian biosphere (r)evolution (DFG), a research unit on function and performance enhancement in the mammalian dentition (DFG), a Lichtenberg professorship on reef evolution (VolkswagenStiftung), and an Emmy-Noether fellowship on the phylogeny and palaeobiology of early reptilians (DFG). Really big projects in the earth sciences are unfortunately running without much involvement of paleontology. Examples are the clusters of excellence on the Future Ocean (Kiel) and on the Ocean in the Earth System (Bremen), and the international graduate school on Global Change in the Marine Realm (Bremen). Marine microfossils are treated as proxy data, but neither evolution nor ecological aspects of ancient life are considered. Likewise paleontology is not involved in the big life science projects. There are big EU projects (HERMES) supporting integrated studies on modern cold and deep-water reefs, but to our knowledge there is not much effort on tracing these important ecosystems and their biota through time.

Impact of Research

To estimate the impact of German paleontology, we extracted the *h*-index (Hirsch 2005) of 210 professional paleontologists (that is, those holding a PhD and currently work at a German research institution) from ISI (accessed November 2009). The h-index is a measure of an individual's research output, where *h* refers to the number (*n*) of papers that have been cited n times. For example a scientist with h=10 has published at least ten papers each of which has been cited at least ten times. We are aware of the short-comings of ISI-mania but see no other way to quantify the impact at the moment. It should also be pointed out that paleontology is a small discipline and this should lower the expected *h* values; thus typical values for tenure positions at major research institutions should certainly be lower than the $h \approx 12$ suggested by Hirsch (2005).

Retired professors were included if they are still active in research, that is they published in 2009. Although some paleontologists may still be missing, our list is comprehensive in that we listed all colleagues we know and checked the web pages of many universities and museums. The results (Figure 1) show a right-skewed distribution, which is log-normal. This is to be expected for a healthy field with many young researchers (with low *h*) and a pyramid of experienced scientists with some global players. A whisker plot of all data (Fig. 1) demonstrates that an $h > 18$ is outstanding for German paleontology. It is also good to notice that the high-impact paleontologists (those in the upper quartile) are mostly professors and stem from a variety of subdisciplines such as micropaleontology, geobiology, invertebrate paleontology, paleobotany, vertebrate paleontology, and macroevolution.

In general, we recognize that applied micropaleontology is a clear winner, although one must also state that the high-impact papers of micropaleontologists rarely deal with fossils of any kind. Micropaleontologists have successfully transformed from oil industry biostratigraphers to oceanographers with a high influence in climate change debates. This is a positive development but it would be great if more evolutionary aspects would be included in this research. On the lower end of the *h* spectrum are those taxonomists who publish almost exclusively descriptive papers. Systematists who also report records (e.g., the oldest, biggest, smallest), or use their data for larger-scale analyses (phylogeny, diversity) are commonly in the middle field of the spectrum. The low impact

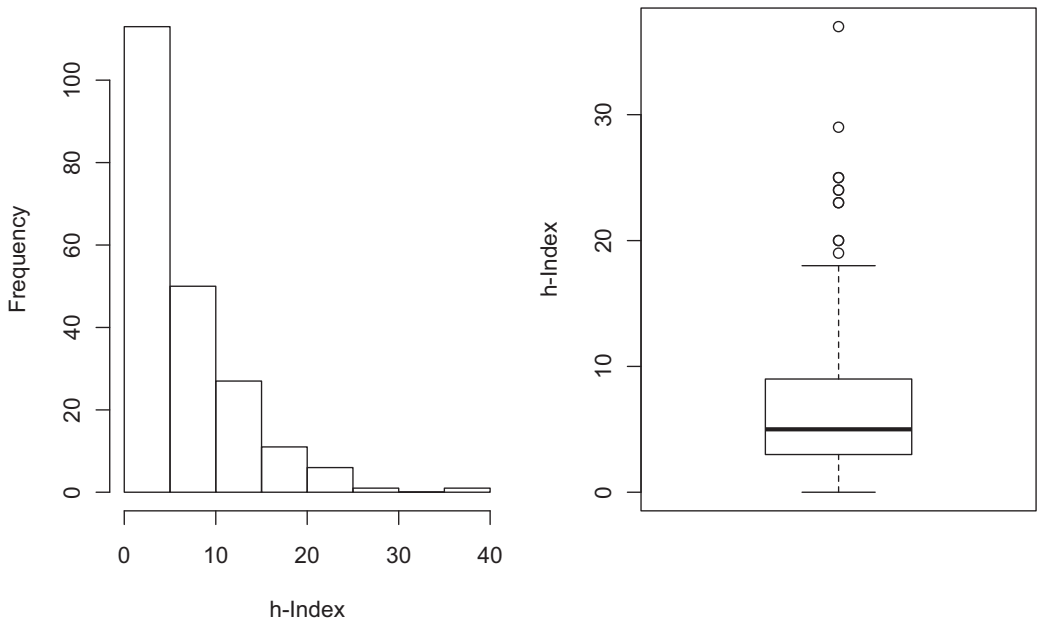

FIGURE. 1. Distribution of Hirsch factor among 210 active, professional paleontologists in Germany. Left panel: A histogram of the data showing the number of paleontologists (frequency) per bin of h-factor. Right panel: a whisker plot showing the median at 5 and outliers at > 18.

but simultaneously outstanding importance of alpha-taxonomic work – it forms the foundation of our whole discipline – continues to be an unresolved problem, not only for Germany but globally.

The view of a healthy field is compromised when we limit the analysis to professors (Figure 2). Although the median is substantially greater than in the whole community (10.5 versus 5), the indices still cover the entire range. As the upper quartile of professional paleontologists starts at h = 9, we suggest that this value could serve as a rough guideline for paleontological tenure professorships in Germany. We also examined whether there was a relationship between individual age and *h* for professors. To test this, we divided active professors into three categories: junior (< 42 years), middle (42-52) and senior (> 52), and ran a rank-order correlation test achieving: R = -0.071, p = 0.61. This result is surprising because *h* can only increase with an individual's age. We explain this paradox by a generational change in paleontology. The younger generation is specifically targeting high-visibility journals, much more than the older generation used to do.

Journals

Five ISI journals with a paleontological focus are published in Germany: *Paläontologische Zeitschrift*, *Facies*, *Fossil Record*, *Neues Jahrbuch für Geologie und Paläontologie*, and *Palaeontographica*. None is ranked in the top ten, but *Facies* is ranked 13 out of 41 in paleontology (2008). This situation is not necessarily due to quality issues. This point becomes clear when comparing two society journals. The *Paläontologische Zeitschrift* was founded 1914 and the earliest articles listed by ISI are from 2006. The *Journal of Paleontology* (founded 1927), in contrast, has been listed since 1955. Both journals have basically the same function, i.e. they turn out specimen based research and are outlets of paleontological societies. The ISI discrimination of non-Anglophone journals leads to a vicious circle in that most German paleontologists target American or British journals to increase their visibility and the German journals stay at relatively low levels.

Paleontological Collections

Germany hosts a large number of important paleontological collections. We counted 42 German institutions holding more than 10,000 fossil specimens in their collections. The biggest collections are in natural history museums in Berlin, Frankfurt, Stuttgart, and Munich. In addition there are several large collections at universities. Generally these institutions are poorly funded and do not have enough staff. As a consequence, curators commonly have multiple tasks: They are researchers, collection managers, and administrators in one person, which often limits scientific productivity or collection development. The two museums in the Leibniz Association, the Museum für Naturkunde in

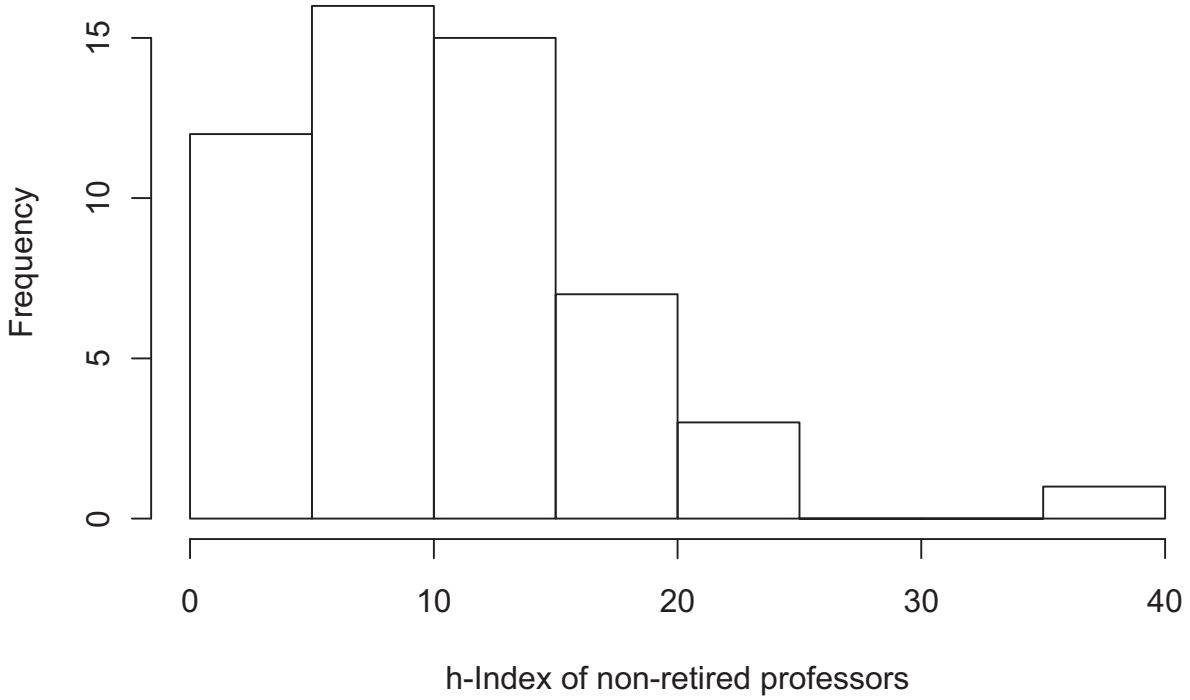

FIGURE 2. Hirsch factor of German university professors.

Berlin and the Senckenberg Museum in Frankfurt, are better funded, but the multiple responsibilities of curators are the same.

Major German museums are currently following two strategies to increase their influence and visibility. The Senckenberg Institution is expanding by incorporating other museums, whereas museums in Berlin, Bonn, Munich, Stuttgart, and Karlsruhe have recently founded a new trust, the Humboldt-Ring.

Paleontological Society

The Paläontologische Gesellschaft is one of the biggest Paleontological Societies in the world. There is no separation into invertebrate and vertebrate paleontology. The Paläontologische Gesellschaft has 1064 members (September 2009), both professionals and amateurs. It holds an annual meeting with usually 200-300 abstracts and publishes the *Paläontologische Zeitschrift*. Although the Paläontologische Gesellschaft is principally open for paleontologists from foreign countries, the number of international members is relatively low. Unlike the Palaeontological Association and Paleontological Society, the Paläontologische Gesellschaft has not yet managed to become fully international.

Germany has a very high number of amateur paleontologists and private collectors. They run own homepages like the Steinkern, journals and even museums, such as the Muschelkalkmuseum in Ingelfingen. Collaboration between amateurs and professionals is usually good and amateurs are included in research projects. The high number of amateurs as well as museum visitors reflects a strong interest of the German public in Paleontology. There are also associations of supporters of museums such as for the Berlin, Frankfurt and Munich.

WHO IS TO BLAME?

The decline of paleontology is largely manifested in decreasing numbers of academic positions, whereas funding remained roughly stable and research output and impact per person is increasing. Intuitive reasons for the loss of positions could be historical factors, lack of applied aspects, limited visibility of research, and lack of innovative approaches.

Historical Factors

German universities have experienced drastic changes since the late 1990s. Political reforms created market-like competition among universities and internal quality-assessment structures. A differentiation and profiling was desired that was borrowed from product and service specifications of companies. As a result the universities strength-

ened their profiles in focusing on international top science. As paleontology was usually closely tied with geology, the reorganization of that science caused major problems. Teaching students "Introduction of Paleontology" must fit into the new service specification of the university, and it seems that it often fails to do so. The 20th century model of joined geological/paleontological institutes is a phase-out model, but alternative interactions, such as with ecology departments and evolutionary biology are still poorly developed.

Paleontologists themselves may have contributed to a situation that ultimately led to the closure of departments. They did not pay sufficient attention to the changing political situation. Moreover, there was great reluctance of senior professors to publish in English. Until the mid-1990s they even advised students to foster the German language by doing the same, especially when it came to writing a thesis. ("if your research is good, it will be read in any language"). New methods were confronted with suspicion rather than excitement. For example, the phylogenetic method developed in Germany (Hennig 1950) was embraced by US paleontologists, but it took rather long to become standard in German paleontology. Analytical paleobiology is almost non-existent in German universities, due to a lack of training in quantitative methods, a great skepticism against database approaches, and an ignorance of the power of analytical methods to address big questions.

Perhaps due to the influential work of Otto Schindewolf, who developed the concept of typostrophism (Schindewolf 1950), German evolutionary paleontology was on a *Sonderweg* (separate path) until the 1970s (Reif 1993). Although some research groups, especially in vertebrate paleontology, are rapidly catching up, this *Sonderweg* is probably responsible for the still poor interactions between paleontologists and evolutionary biologists.

The use of the typological concept may also have contributed to low appreciation of evolutionary questions in paleontology. In German vertebrate paleontology, for example, a large portion of scientists devoted their career to (mostly regional) biostratigraphic issues and alpha-taxonomic questions. This long-lasting non-phylogenetic approach was coupled with a focus on publishing in Central European non-ISI, and often non peer-reviewed research journals. Students were sometimes even recommended not to publish their research in international journals. As a result, vertebrate paleontology no longer came across as a cutting-edge field to many German university administrators and colleagues from neighboring disciplines, which weakened its status when positions needed to be replaced or departmental structures became reorganized.

Perceived Lack of Applied Aspects

One classical justification for paleontological research was biostratigraphy, which nowadays plays only a minor role. The exploration for hydrocarbons, coal, and ores no longer requires paleontological expertise. Other applied aspects such as contributions to conservation biology and climate change studies are still poorly developed, except for micropaleontology. Paleontology is then increasingly seen as a beautiful but useless discipline (we use the term *Orchideenfach* = "orchid subject"), with few applied aspects and no major impact, besides discoveries of new dinosaurs and other sensational fossils.

Limited Scientific Visibility

Visibility in the public is not an issue, as paleontology is very well represented in the media, especially when it comes to the discovery of new dinosaurs. A problem for German paleontology is scientific visibility, evidenced by the moderate impact factor of individual researchers, the absence of expensive and visible equipment, the apparent lack of big questions to be solved, and perhaps the public visibility itself, leaving the impression of paleontologists as people who dig for bones in remote areas but otherwise contribute little to the advancement of science.

Specimen-based research including systematics and taxonomy is still well represented in Germany and there are leading experts on many fossil groups. The impact of most papers is limited because only the few other specialists in a group are usually interested in the specialist's work. This also limits the capacity for fund raising and as a consequence taxonomists and systematists are not considered for top jobs any longer. Natural history museums serve as the most important refuge for this kind of research whereas it is doomed at university departments. It is no surprise that by far the strongest support in Germany for the discipline-wide Paleobiology Database (http://paleodb.org) comes from the Museum für Naturkunde in Berlin.

Paleontology is "cheap", i.e., the most costly items in a typical paleontology project are a position for a PhD student or a post-doc and some travel money. Compared to related disciplines such as geophysics or oceanography, let alone particle

physics, this is peanuts. Now, if universities hire people for top positions, they prefer researchers with large grants, meaning substantial overhead for them. This is, by the way, not only a German problem (Plotnick 2007).

Small Constituencies

The case of the closure of paleontology in Würzburg suggests that the small size of our discipline represents another problem. The University of Würzburg decided to save money or shift resources to other more prestigious departments. There are two ways to do that: 1) Try to save money across the board in all departments. This would need time and would cause multiple conflicts. 2) Shut down one of the smaller departments, such as geosciences. This is a quick and easy way to save money and there would only be a small group of complaining people. This has nothing to do with the quality of research; Würzburg was a working place with one of the best performing paleontologists in Germany.

PROPOSALS FOR A BETTER FUTURE

Modern ecology is no longer a subdiscipline of biology but has become a separate discipline (Odum 1992). Similarly, modern paleontology is neither a subdiscipline of biology nor of geology but represents an independent, albeit highly integrative discipline (Jablonski 1999) in earth system research. Only, if this can be demonstrated to a wide audience (general and scientific) will paleontology survive. Decision makers, such as the newly strengthened university administrations and external consultants will continue to eliminate paleontology positions if paleontologists do not manage to find partners, accentuate their necessity and excellence in the context of newly evolving fields.

"Either study the past or study slime". This quote of Jeremy Jackson at NAPC 2009 in Cincinnati summarizes nicely the great strength of paleontology as a discipline. Only we have the ability to study ecosystems undamaged by human activities and their response to natural physicochemical perturbations. The incompleteness of the fossil record is of course a major drawback, but this should be seen as a challenge rather than a cause of depression (Erwin 2009). However, many colleagues have chosen to either study ancient slime, to move away from treating fossils as organisms but rather as archives of isotopic data, or to become science managers.

We propose some actions that should improve the situation of German paleontology:

1. **Lobbies.** Paleontology has to find new allies in administration and sciences politics. We must convince university administration and politicians that cheap science can be good science. Make clear that few other disciplines have such a high impact using relatively few resources. The community must observe which places are endangered and take action, before it is too late. This could be done by taking advantage of the many colleagues in top positions. A symposium, organized by the Paläontologische Gesellschaft with invited speakers would be a first important step in this direction.
2. **Integration and collaboration.** As the integration into geology is continuously eroding, paleontology has to be integrated into other larger disciplines and departments. Micropaleontology has successfully managed to grant its long-term survival and to enhance its research impact by joining large oceanographic institutions. Similarly the visibility of geobiology is fine by close collaboration with molecular and geochemical labs. Integration of other paleontological branches should be possible in highly interdisciplinary departments of evolutionary biology, ecology and climate research. The USA and the UK are far more advanced in this direction, much to the intellectual benefit of paleontology. Discipline-wide endeavors such as the Paleobiology Database can help taxonomists to find partners for analytical papers on ecology and evolution, which should enhance their scientific impact.
3. **New fields of research.** German paleontology must be more adaptive to new methods and creative in addressing new questions and establishing new approaches to them. Evo-Devo and analytical paleobiology are just two relatively new fields that are strongly underrepresented in German Paleontology. Theoretical approaches applying numerical simulations are needed to sharpen our questions and to enhance sensibility for randomness. Because stochastically generated data can easily be interpreted as biological pattern (Maynard Smith 1989), the mental walls against theory in paleontology have to fall.
4. **No subdivision of the discipline.** Paleontology is so small that any subdivision of the discipline might be hazardous. You may be interested in Pliocene coccoliths and climate change, in the stomata of Cretaceous leaves,

in biomarkers of Proterozoic stromatolites, in deep time diversity, in the diet of Jurassic sauropods, or in deep time phylogeny including molecular techniques. Call yourself proudly a paleontologist and the whole discipline will benefit.

5. **Systematics/Taxonomy.** It is an asset of German Paleontology that there is still a lot of systematic and taxonomic expertise for various groups. It is important to conserve this expertise, in spite of its apparently low short-term impact. Besides collaboration (see point 2), colleagues can help by actively citing important taxonomic data sources of their big-picture papers.
6. **Publicity.** One of the greatest strengths of paleontology is the enthusiasm of the public. We must continue to bring our results to the public but we should try to attract public interest with more than big dinosaur bones.
7. **Teaching.** Education of young scientists in modern and innovative, multidisciplinary methods should be enhanced. Bring your students in contact with the most innovative methods even though you may not feel fully competent; they are young and will find their way to do it properly. Very often there are summer courses where talented students can be delegated to learn the details. Students must also learn, just as in the Anglophone countries, to target high-ranked journals early in their career.
8. **Publishing.** Renowned scientists should be solicited by editors of German journals to submit outstanding research or review papers. Journals that already are in the ISI and those who try should raise their publication standards with their impact factor.

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