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Kurt Jax
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1 · *Introduction*

Concern about the functioning of the world's ecosystems has become commonplace, in the scientific literature as well as in everyday parlance. Climate change, loss of biological diversity, chemical pollution, land use changes, and the spread of exotic species are all discussed in connection with the perceived or anticipated degradation or destruction of ecosystems, or at least with an impairment of their functioning. While attention has been focused in the past mostly on the fate of specific processes relevant to human life (such as clean water or the maintenance of food production) or specific valued species, the emphasis has shifted increasingly towards a broader perspective, namely that of the whole ecosystem. Since about the early 1990s, ecosystems and their functioning have become major targets of conservation and management, accompanied by biodiversity as the other major broad-scale conservation focus. Today, both conservation aims are embodied in national and international management strategies, such as the variety of ecosystem management approaches (e.g. Yaffee *et al.*, 1996; Boyce and Haney, 1997) or the Convention on Biological Diversity (including also an 'Ecosystem Approach' as a cross-cutting issue), and the various regional and national strategies that are still newly developed. These trends have also triggered a large amount of scientific research related to these fields, which vice versa reinforced the political processes. The concept (or at least the term) 'ecosystem functioning' (also 'ecosystem function') has thus become a major topic of ecological research during the last decades, especially in connection with biodiversity research.

The notion of focusing not on single ('sectoral') aspects of the environment and/or ecological systems but rather on the performance of whole ecosystems appears to be a useful approach. In the face of limited resources for research and management measures and under the conditions of accelerating global changes, it seems a wise decision to concentrate our efforts on understanding and maintaining whole systems – and hopefully at the same time saving the maximum components of these systems (especially the species which constitute them) (Walker, 1992, 1995), as well as the services they provide for human wellbeing (Daily, 1997; Millennium Ecosystem Assessment, 2003, 2005). If there is something like ecosystems, and not just a happenstance or loose collection of relations between organisms and their environment, we should be able to speak of these systems as either functioning or not functioning, or about different degrees of functioning – as is the common parlance in ecology and conservation biology. We consider ecosystems as collapsing (e.g. when forests die off, lakes turn to hypertrophic states, or coral reefs bleach), we speak of degraded ecosystems, whose functioning is impaired (e.g. when leaching or soil erosion take place, when exotic species begin to dominate an ecosystem, or when some populations of fish become extinct), and we talk about intact, complete, and functioning systems (e.g. talking about the Greater Yellowstone Ecosystem as 'one of the largest, relatively intact temperate zone ecosystems left on earth' (Glick *et al.*, 1991, p. 9)).

Measuring and managing ecosystem functioning should thus provide a powerful and far-reaching tool for the management of nature (and its services). At the same time it should greatly contribute to our understanding of the ecological theatre (to use a term of the late G. E. Hutchinson), both through the basic research initiated by these practical concerns (see Srivastava and Vellend, 2005) and by the practical experiences gained from monitoring management results.

While the idea of ecosystem functioning is intuitively highly appealing to most people – including myself – implementing the conservation of ecosystems and their functioning is far from trivial. Some people would even argue that the concept of ecosystem functioning is not a useful concept at all, because it might rest on an unscientific view of goals inherent in nature (or ecosystems specifically). In any case, questions must begin with the understanding of the concept itself: do we all mean the same thing when we talk about ecosystem functioning or about a functioning ecosystem? Are we addressing the same object when we look at 'the' ecosystem? How can we measure ecosystem functioning? What (and who) decides if an ecosystem is functioning? When is an ecosystem destroyed? How do we evaluate different states of ecosystems? How do we arrive at reference states for functioning ecosystems? How do other concepts (such as ecosystem integrity or ecosystem health) relate to the notion of ecosystem functioning? To what degree is ecosystem functioning a descriptive concept and to what degree a normative concept?

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These are the questions this book will follow. It is thus a book on the concept of ecosystem functioning and the way this concept is or can be put into practice. As we will see, this will carry us far beyond the boundaries of empirical studies of ecology and conservation biology, into questions about the theory of ecosystems and about the interface between ecology, philosophy, and the social sciences. Although great emphasis will be laid on what we know about the functioning of ecosystems (and this functioning's relations to biodiversity), this is not a textbook on ecosystems as such. But neither is it a book on the philosophy of ecosystems and ecosystem functioning. Instead, it attempts to build a bridge between theoretical and practical issues, the latter ranging from field research through management. The book is thus, in the first place, targeted at ecologists and conservation biologists.

The structure of the book

Investigating ecosystem functioning is commonly considered an issue of ecosystem research and thus of the natural sciences. A second look at the topic, however, reveals that it is not only about ecology, but also requires taking into account some ideas and tools that are normally seen as belonging to the humanities. While thinking about ecosystem functioning, questions about epistemology, teleology, and norms pop up. As I will show, such tools are not just supplemental for when all the science is done, they are essential for conceptualising and operationalising ecosystem functioning. Thus, the arguments in this book will oscillate between the natural sciences and the humanities. Being a biologist, I see my own role not in purely analysing the process of doing science nor in developing new philosophical tools. I see myself more as *applying* philosophical tools to a new and specific subject – the issue of ecosystem functioning. By these means I hope to sharpen our ecological concepts and methods (and tools as well), and with it our understanding of the living world and how it may be preserved. I thus feel (surprisingly for myself) in the line of my own family tradition – that is, more a craftsman of philosophy than an artist in this field.

The first chapters of this book are devoted to an analysis of the different uses and various meanings of ecosystem functioning, and to the conceptual and practical issues related to them. The later chapters will then try to synthesise the ideas described. By means of an array of different conceptual tools, the chapters describe the necessary steps (as I see them) towards putting the concept of ecosystem functioning into practice. To aid the understanding of the conceptual intricacies of the notion, I will draw heavily on case studies, which can exemplify the difficulties and requirements of implementing ecosystem functioning.

This is what Chapter 2 starts with. A case study dealing with research conducted on the impact of the introduced Canadian beaver on the ecosystems of Navarino Island (southern Chile) (Section 2.1) will be used to introduce some of the major contexts of the use of ecosystem functioning concepts. Section 2.2 will then further broaden the context, describing in brief some other major fields in which the concept is of importance, such as restoration ecology or ecosystem management. Chapter 3 is devoted to the relationship between biodiversity and ecosystem functioning. This is the area where the issue is currently discussed most intensively, at least with respect to using the *term* 'ecosystem functioning'. As we will see, there are two fundamentally different ways in which the term is used. 'Ecosystem functioning' either refers to selected processes and properties at the ecosystem level, or to the overall performance (or operation) of the whole system. I will investigate the scientific discourse on biodiversity and ecosystem functioning in some more detail and analyse which variables are selected here as measures for ecosystem functioning. One basic question will be to what degree these variables are and can be considered as proxies for the notion of overall ecosystem performance – as is often implied, or at least alluded to. Or, are these variables and the processes or properties to which they relate of interest on their own?

It will become evident that there is some sort of terminological and conceptual confusion when talking about ecosystem functioning. This is only in part a matter of terminological convention. More than that, some philosophical problems hover in the background of the implicit mixing of different meanings of ecosystem functioning. These problems – and how they can be resolved – are dealt with in Chapter 4. I will start with an elaboration of the different meanings of 'function' in the environmental sciences – as the root of the word 'functioning' – and differentiate at least four different meanings of the term (Section 4.1). Although most of the following text will focus on the meaning of ecosystem function(ing) as the 'overall performance of ecosystems' (ecosystem functioning proper, or ecosystem functioning in the narrow sense), all of the other major meanings (function as process, function as services, function as roles) will nevertheless play important roles in understanding and implementing ecosystem functioning. Talking about function and functioning in biology is always subject to critical questions as to whether it implies teleological thinking, i.e. thinking in terms of goals within nature (or ecosystems in our case). At least some modes of teleological descriptions are seen as highly problematic within science. A huge literature exists with respect to the relation between function concepts and teleological thinking, mostly related to the concepts of the organism, the gene, or (human) society. To avoid pitfalls and unnecessary controversies in the application of ecosystem functioning concepts, it is necessary to ponder the implications of these discussions for our topic. This will be done in Section 4.2. As I will show, not every use of seemingly teleological assumptions within concepts of ecosystem functioning is really problematic. Some, however, are, and I will sketch ways to avoid them.

We then have to proceed to the other part of the expression 'ecosystem functioning', namely to the 'ecosystem' (Section 4.3). There is an even greater variety of meanings here than we find when analysing 'function'. This variety has important implications for our ability to agree on a measure of what ecosystem functioning is and – in applying the concept – what constitutes a functioning ecosystem. Far from analysing the many conceptual differences of the ecosystem concept, which has been done in other places (see Jax, 2006), I will first demonstrate the causes and consequences of different ecosystem concepts for implementing ecosystem management. The long and fascinating history of ecosystem management in Yellowstone National Park will serve as a very telling example. In connection with this case study, I will introduce a conceptual model (called the SIC model, explained in Chapter 4) to communicate and clarify the many possible definitions of an ecosystem. This model will be used later (Chapter 7) as one possible tool for operationalising ecosystem functioning.

The Yellowstone example also demonstrates how scientific and non-scientific ideas (such as our ideas of what nature is) intermingle in ecology and conservation biology. With this, it becomes clear that another (sometimes implicit) part of most of the uses of the ecosystem functioning concept is the notion of functioning as *proper* functioning. This means that describing ecosystem functioning not only requires clarification of the concept of the ecosystem implied, but also of a reference state for a functioning ecosystem, in comparison to which it is judged as either functioning (properly) or not functioning.

Having assembled the parts of a definition of ecosystem functioning so far as 'the overall performance of an ecosystem as compared to a reference state or dynamic', we can finally open up our view to include a variety of related concepts, which form together what I call a conceptual cluster. That is, we are not dealing with the *term* 'ecosystem functioning', but with the *concept* as coarsely defined above. Related concepts thus are: ecosystem resilience, ecosystem integrity, ecosystem health; but also ecosystem collapse, ecosystem reliability, etc.

The results of what is discussed in Chapter 4 raise new questions, which refer to the relationship between science and society when defining and assessing ecosystem functioning. This is the topic of Chapter 5. First, if there are many different possibilities for conceptualising ecosystems, are ecosystems mere mental constructs and not 'real'? Are they – to refer to a very heated controversy about the status of science and nature – only socially constructed? Would, then, ecosystem functioning also be merely a social construct and thus be completely relative? I will argue in Section 5.1 for a moderate realism, acknowledging the necessary social dimensions of all concept and theory formation while nevertheless not denying the existence of something 'out there' which resists a completely deliberate and artificial definition of ecosystems and ecosystem functioning, at least when these concepts are applied in practice. As one classical example of discontinuities in the overall performance of ecosystems, I will describe the discussion about alternative stable states in shallow lakes. Nevertheless, many different and (for specific purposes) appropriate ways of defining ecosystem functioning remain, and with them the question of who determines what a functioning ecosystem is. For this reason, part of the chapter will also deal with (and refute) the argument that acknowledging the partial epistemological relativity of defining ecosystems (and thus ecosystem functioning) would imply or foster *moral* relativity towards environmental problems.

In order to better understand the character of the social dimension in the definition of ecosystem functioning, I will, in Section 5.2, describe the various types of value decisions the selection of an (appropriate) concept of ecosystem functioning involves. This leads to the important question of normative dimensions of concepts like ecosystem functioning. When we change – as is frequently done – the order of words from 'ecosystem functioning' to 'functioning ecosystem', the normative dimensions (in terms of a *proper* functioning implied) of the concept come to the fore still stronger. Science, however, by its definition and its modern self-image, should be value-neutral and, as such, should keep clear of normative aspects. This image, however, has been challenged time and again and is not congruent with the practice of science. Particularly in conservation biology, many concepts (and the discipline as such) are highly value-laden. The question is more, which kind of norms and values enter our concepts in which way and how can they be made explicit? Acknowledging and explicating the different normative dimensions of ecosystem functioning is, in fact, less of a problem than it can be a solution to adequately defining and implementing the concept. In another case study (Section 5.3) I will analyse the complex relations between concepts of ecosystem functioning and societal choices in the context of ecosystem management strategies, focusing especially on the Ecosystem Approach of the Convention on Biological Diversity. Section 5.4 will draw some general conclusions on the roles of science and society in assessing ecosystem functioning.

In Chapter 6 I will proceed towards a synthesis. After a summary of the analysis elaborated in the preceding chapters (Section 6.1), some of the more prominent approaches of conceptualising and measuring ecosystem functioning (*sensu stricto*) will be discussed in Section 6.2. These are, especially, ecosystem integrity and ecosystem health, and ecosystem stability and resilience. They will be scrutinised by means of the tools and critical questions developed previously. The major questions applied to all of these approaches are: (a) which definition(s) of an ecosystem they follow; (b) which reference conditions they envisage; and (c) in which way societal choices are included in their definition and implementation. As a case study for the use of an ecosystem integrity concept, I will discuss the European Water Framework Directive and its goal of reaching 'good ecological status' in European surface waters.

While the approaches described in Chapter 6 all have some merits, I do not think they encompass the whole breadth and intuitive understanding of ecosystem functioning. At the beginning of the final chapter I will therefore use the SIC model, introduced in Chapter 4, to set out the possible definitions of ecosystem functioning. The four most common meanings of ecosystem functioning in an empirical setting (as I see them), will be described in more detail (Section 7.1). I will emphasise, in particular, how these meanings can be put into practice, i.e. how ecosystem functioning can be assessed. Determination of whether an ecosystem is functioning, or to what degree it is a functioning ecosystem, will, however, not always coincide. That is, applied to the same chunk of nature (e.g. the Greater Yellowstone Ecosystem or the ecosystem(s) of Navarino Island), an ecosystem will be considered as functioning under one definition but destroyed or 'malfunctioning' under another. As there is no use in searching for 'the' proper definition of ecosystem functioning, this brings us back to the crucial question of how to select an appropriate definition for specific purposes. To this end, Section 7.2 presents some guidelines for conceptualising and assessing ecosystem functioning in conservation practices, as a kind of checklist of necessary choices and procedures. The guidelines are followed by a final case study that illustrates the use of ecosystem functioning concepts in ecological restoration, building on an empirical example from strip mining rehabilitation in Lower Lusatia (Germany). The overall conclusions of the book and an outlook are given in Section 7.4. This final section very briefly draws together the most important results of this book. I then describe what the results mean for research on ecosystem functioning, as well as for the application of the concept, emphasising not least its ethical implications.

There is no unified theory or unified concept of ecosystem functioning. There will be none at the end of this book. But I hope there will be some more clarity about how to formulate and apply unambiguous concepts of ecosystem functioning and how to proceed in building more refined and restricted theories about it.

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2 · *Setting the scene*

The context of investigating ecosystem functioning

The issue of ecosystem functioning has been addressed in a variety of different contexts. In this chapter, I will introduce the most important of these contexts. First, however, I will open up a number of questions with respect to the meaning of the term 'ecosystem functioning' and the ways the concept is assessed in practice. To do so, I will start with a case study illustrating the many facets of the current discourse on ecosystem functioning.

2.1 Case study: exotic species and ecosystem functioning on Navarino Island

The Chilean island of Navarino is a remote and beautiful place, and an outstanding site of nature. I first visited the island in 2000, invited by my colleague and friend Ricardo Rozzi, who had started to study the biological and cultural diversity of the island a few years before. Military issues – tensions between Chile and its neighbour Argentina – meant access was largely restricted until the 1990s. Located in the XII Region of Chile, Navarino is one of the numerous islands which, at the southernmost tip of the American continent, form the archipelago of Tierra del Fuego. Being situated south of the Beagle Channel and only around 150 km north of Cape Horn (54° south), it is also a rather cold place. It harbours only a small human population of about 2300 people. Nevertheless, the island and its surroundings have been inhabited for at least 6500 years by the southernmost ethnic group of the world, the Yaghan or Yamana (Gusinde, 1937; Borrero, 1997; Martinic, 2002). Today the descendants of the indigenous Yaghan people, a small group of approximately 70 persons, form the Comunidad Yaghan. The majority of the population is comprised of European/Chilean settlers, the first of which arrived during the late nineteenth and early twentieth centuries, and by soldiers of the Chilean navy and their families. Puerto Williams, the only larger settlement on the island, was founded as a strategic naval

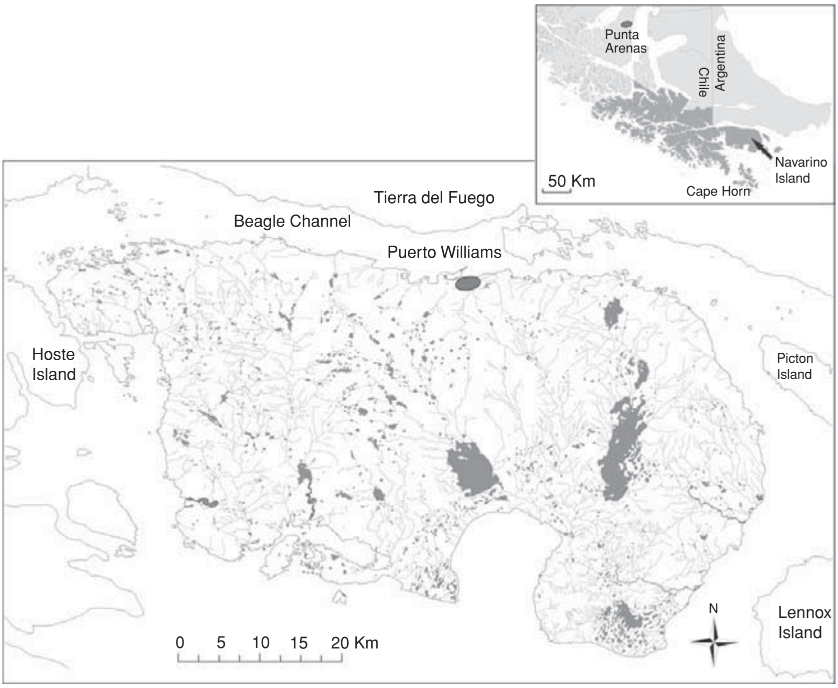

Fig. 2.1. Navarino Island, Chile and its location at the southern tip of South America. The dark-shaded area on the smaller map designates the extension of the Cape Horn Biosphere Reserve. Map courtesy of Elke Schüttler, Puerto Williams.

base in 1953, and is the southernmost permanent settlement in the world. The inhabited area of the island is limited to the coastline, especially the northern coast (Rozzi *et al.*, 2006), where only one (unpaved) road leads along most of the coastline.

Navarino (Fig. 2.1) covers an area of approximately 2500 km^2. Characteristic of the landscape is the mountain ridge of the 'Dientes de Navarino' ('teeth of Navarino'), whose highest peaks rise to well over 1000 m above sea level. The northern coast is sheltered from southerly storms by the mountain range and large extents of forest have developed there. The larger southern half of Navarino Island is an open expanse of sub-Antarctic tundra, interspersed with occasional patches of trees. Hundreds of small moor ponds and a number of larger, relatively shallow lakes are scattered across this marshy region (Sielfeld and Venegas, 1980).

Due to the insular conditions and the Arctic influence, a subhumid to humid climate has developed in the Tierra del Fuego archipelago