Integrative Ecological Research: Case-Specific Validation of Ecological Knowledge for Environmental Problem Solving

Abstract
Taking ecology as an example, I discuss the contribution of a disciplinary natural science to environmental problem solving. Ecological theory has so far been of limited use for environmental management. I present an ecological research strategy that may be termed integrative ecological research. It seeks to explain the complexity of specific field or real-world situations. I argue that such research should be viewed as complementary to other types of ecological research, and that it may be of particular relevance for environmental management – for instance, the adaptive management of ecosystems. This analysis is illustrated with a bottom-up research collaboration combining plant-ecological research and ecosystem management in the Seychelles (Indian Ocean).

Keywords
adaptive management, bottom-up research collaborations, case study method, ecosystem management, integrative ecological research, invasive species

Mutual Learning in Ecology

Throughout its history, ecological science, or ecology, has developed in close interaction with particular management contexts (Bocking 1997). For instance, early British plant ecology was closely linked to the formation of The Nature Conservancy, a nature conservation body. Similarly, many ecological research programmes are rooted in practical problems in agriculture, forestry, or fisheries. Over the past twenty years, two divergent interaction zones between ecology and application have emerged: the adaptive management of species and ecosystems, and the science and policy of global environmental change.1 In this paper, I focus on the interactions between ecology and adaptive management.

Such interaction zones are characterised by a relatively well-established consensus among experts and stakeholders on how scientific uncertainties and conflicts of interests may be addressed. They therefore allow for a focused and interactive co-production of knowledge, or mutual learning, by actors from both science and management. Mutual learning is necessary when expert knowledge is tentative, incomplete, and uncertain, and a transfer of “frozen facts” is insufficient. It provides both users and producers of knowledge with a better understanding of the uncertainties and unknowns in the respective contexts of knowledge production and use, and facilitates the orientation of research according to management needs.

In order to allow mutual learning, both science and management have to “accommodate” each other’s inputs. In the following, I am particularly interested in the role of insights gained in a management context, particularly adaptive management, for ecological research.2 Hoffmann-Riem (2006) has discussed the complementary aspect of how ecological knowledge production can be integrated into recursive learning processes in ecological design.

1 Kwa (2005) reconstructed the emergence of the interaction zone between ecology and global change science.

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Adaptive Management of Ecosystems

The management of ecosystems is regarded as one of the greatest environmental challenges (MA 2005). Thereby management interventions often have unanticipated outcomes. Adaptive management of ecosystems supports the continuous adaptation of management practices in response to unanticipated outcomes, new scientific knowledge, and stakeholder interventions. It is commonly accepted that the management of real-world problems such as the protection of a species or an ecosystem calls for such a learning approach (e.g., Walters and Holling 1990, Hoffmann-Riem 2006).

There has been considerable discussion about the role of adaptive management in societal problem solving (Gross and Hoffmann-Riem 2005, Hoffmann-Riem 2006) and on the prerequisites for adaptive management to function effectively. These prerequisites include access to ecological research (e.g., Walters and Holling 1990, Hoffmann-Riem 2006) and appropriate institutional settings (Lee 1993, Folke et al. 2005). Much less understood is the way in which insight gained through adaptive management may feed back upon ecological research (e.g., Slobodkin 1988, Shrader-Fechette and McCoy 1993).

Adaptive management requires a transparent synthesis of the available ecological knowledge on the particular case under consideration. In the following, I argue that such case-specific or integrative ecological research plays also an important role in ecological research complementary to other research strategies. Then, I present a research methodology that facilitates learning between ecological research and adaptive management and that may be termed “case study research in ecology”. I illustrate some aspects of a concrete implementation of mutual learning between ecology and adaptive management with a research collaboration in the Seychelles in the Indian Ocean (see box).

Research Strategies in Ecology

Ecological research strategies may be categorised as hypothetico-deductive, inductive, or integrative (compare, e.g., Weiner 1995).

1. The hypothetico-deductive approach characterises much work in laboratory sciences such as physics (Murray 1992). According to this approach, experiments are designed under simplified conditions in order to test hypotheses derived from theory. In ecology, classical examples of this approach are provided by population ecology (e.g., Turchin 2001).

2. The inductive approach is data-driven. Inductive generalisations are gained through statistical modelling of large datasets and meta-analysis of published studies (e.g., Brown 1995). For instance, consistent empirical relations were found between leaf characteristics of plants such as longevity, nutrient concentrations, or thickness (Wright et al. 2004).

3. The integrative approach seeks to explain the complexity of specific field or real-world situations (Orians et al. 1986, Slobodkin 1988, Walters and Holling 1990, Peet 1991, Walters 2001, Shrader-Fechette and McCoy 1993, Haila and Taylor 2001, Carpenter 2002, Roe 2004, Ives and Agrawal 2005). Field research and simulation modelling are common methods. Long-term ecological research on a particular ecosystem often provides the basis for such integrative research (e.g., Vitousek 2004). Epithets used to characterise such integrative ecological research are “case-by-case analyses”, “just-in-time ecology for management” (Roe 2004); “heuristic”, “multiple working hypotheses”, “multiple types of evidence”, “wholistic” (Shrader-Fechette and McCoy 1993); or “multicausal, integrative explanations” (Carpenter 2002).

The three approaches differ as to how they deal with the tensions between scientific generalisation and real-world complexity. The hypothetico-deductive approach rests on the classical strategy of the laboratory sciences, which use artificial, enclosed systems to test theories. Inevitably, the question arises how the research results relate to the open systems in the real world. The inductive approach describes patterns that are sufficiently dominant so that other aspects of real-world complexity can be dismissed as contributing random noise. However, this approach is not particularly useful when the patterns described are either too trivial or too general to explain real-world phenomena. The integrative approach attempts to study real-world complexity directly, but it often remains unclear whether knowledge gained from one study can be applied to other cases. Therefore, validation across cases is needed.

It is an unresolved question to what extent ecological research can be designed in analogy to laboratory sciences such as physics. This debate has accompanied ecology since its birth at the beginning of the 20th century (e.g., Orians et al. 1986, Slobodkin 1988, Peet 1991, Haila and Taylor 2001, Kohler 2002). In my opinion, the integrative research strategy that seeks to understand the complexity of tangible real-world cases is necessary as a complement to the hypothetico-deductive and inductive research strategies. Scientific generalisations in ecology have to be sensitive to the contingencies of particular cases such as an ecosystem or a species (compare, e.g., Peet 1991). The relative importance of knowledge on specific local aspects versus generalised knowledge depends on the particular research question or management problem (e.g., Walters 1991).
Case Study Research in Ecology

Case study research has developed in many fields including environmental research (Scholz and Tietje 2001) and is in this paper reckoned an emerging methodology for integrative ecological research. According to Shrader-Frechette and McCoy (1993, 1994) who have discussed the epistemological and methodological implications of ecological case study research focusing on particular real-world management problems, the objective of case study research in ecology is the compilation and assessment of different forms of knowledge on a particular case in a structured and transparent way (figure 1). Often, case studies draw upon local, experience-based traditional or practitioner’s knowledge (e.g., Fry 2001, Sheil and Lawrence 2004). The approach can be characterised as comparing multiple working hypotheses. Shrader-Frechette and McCoy (1993, 1994) stress that it is important to balance reducing the risk of stating something as true that is in fact wrong (i.e., reducing type I statistical errors) with reducing the risk of neglecting something that is in fact true (i.e., reducing type II statistical errors).

There are two main phases in a case study: the building of plausible hypotheses, and the gathering and assessment of evidence to support or refute them. In the first phase, it is essential to represent all relevant hypotheses, for instance by expert workshops, Delphi surveys (Hess and King 2002), re-analysis of existing datasets through exploratory statistics or retrospective analysis (Sit and Taylor 1998), or collaborative simulation modelling (Costanza and Ruth 1998). The nub of the second phase is to present the relevant evidence in a transparent way and to assess the uncertainties and risks (of management options) that are attached to each hypothesis. Typical methods include qualitative weight-of-evidence methods (Marmorek and Peters 2001), extended peer-review systems (Marmorek and Peters 2001), decision analysis (Sit and Taylor 1998), scenario technique, and simulation modelling including sensitivity analysis and model evaluation (Prisley and Mortimer 2004).

Conclusions

Integrative ecological research seeks to explain the complexity of specific field or real-world situations and benefits from the co-production of knowledge by experts from science and management (mutual learning, see box). Such case-specific research is valuable to both ecological research and environmental management – particularly the adaptive management of ecosystems.

Ecological theory has so far been of limited use for environmental management (e.g., Shrader-Frechette and McCoy 1993). Nevertheless, applied research and management that are not well grounded in ecological science risk to neglect important processes. Integrative ecological research has the potential to build a bridge between ecological science and practical management. It thereby facilitates the production of case-specific and validated ecological knowledge that is particularly suited to assist environmental decision making.

In ecology, the need for integrative research on particular real-world cases has been recognised throughout the history of the discipline (e.g., Peet 1991, Kohler 2002, Ives and Agrawal 2005). However, often integrative ecological research and other research strategies have been perceived as competing or even mutually exclusive alternatives; or case-specific research (often termed “natural history”) has been judged as an inferior research practice. I argue that the various ecological research strategies are complementary, and that the special contribution of integrative research, both methodologically and theoretically, deserves to be better appreciated. Acknowledging the value of pluralistic research in ecology will facilitate integration of conceptual and methodological innovations from applied ecological research and from other environmental natural sciences (as exemplified by the chapter “case study research in ecology”). Interestingly, the complementarity of “empirical-inductive, hypothesis-deductive, and complex system modelling styles of conducting scientific research” was pivotal in the historical development of modern meteorology (Davies 2005).

![Figure 1](image-url) Integrative ecological research may be seen as complementary to other ecological research strategies. In ecological case study research – an emerging methodology for integrative ecological research – several hypotheses are tested and integrated based on multiple evidence for a particular case. Such research combines qualitative knowledge (e.g., experience-based practitioner’s knowledge or theoretical reasoning) and quantitative data.
In bottom-up research collaborations between scientists and practitioners, new research questions may evolve and new management problems may be recognised underway in response to each other. A contrasting approach is top-down oriented research, following rigid scientific and management goals defined at the beginning (e.g., Troumbis et al. 2001).

Research Collaboration in the Seychelles

The 14-year research project carried out by the Geobotanical Institute of the Swiss Federal Institute of Technology (ETH) Zurich in the Seychelles in the Indian Ocean exemplifies a long-term bottom-up research collaboration between scientists and practitioners (figures 2 and 3). The research collaboration with the local Ministry of Environment and several non-governmental organisations encompasses both applied research – related to vegetation mapping, red listing of rare plants, habitat restoration, and sustainable use of forest products – and ecological research on the evolution and ecology of invasive (non-native) plants, island floras and tropical forests. Also, the Geobotanical Institute is a lead organisation in the setting up of a national and regional network for invasive species management, the development of a National Strategy for Plant Conservation, capacity and public awareness building, and the publication of the plant conservation newsletter Kapisen.

The collaboration is situated in the context of the management of protected areas. It is confined to a well-defined group of nature conservation practitioners and decision makers. However, in several instances we have transgressed these boundaries: The national strategies for invasive species management and plant conservation involve actors from agriculture, horticulture, customs, tourism, education, and the media. We also conducted a project on sustainable exploitation of the invasive cinnamon (Cinnamomum verum) together with the spice industry. In collaboration with seed sustainability, a further initiative was a research project on sustainable ecotourism involving scientists from the fields of marketing, economics, geography, and environmental sciences.

Integrative Ecological Research

Our long-term research project integrates studies on vegetation composition and dynamics, impacts of native and invasive plants on nutrient cycling through mechanisms such as litter decomposition or root competition, the physiology of native and invasive juvenile trees, seed dispersal by birds, and herbivory. This comprehensive approach allows comparing the data with extensive case studies in Hawaii or Puerto Rico (Lugo and Vitousek 2004). Regarding the invasive cinnamon tree, for instance, an integrative picture – widespread seed dispersal by birds, strong root competition, eco-physiological difference between native and invasive species, as well as regeneration patterns of native and invasive juveniles in forests dominated by cinnamon – may lead to a re-assessment of the role of cinnamon for nature conservation and to new practices in ecological restoration (Kueffer 2003). Cinnamon is generally considered problematic because it is the most abundant invasive plant species in the Seychelles. However, these new results may indicate that cinnamon is an effective barrier against other invasive species and may facilitate the regeneration of native species. In a pilot project, small patches of native vegetation have therefore been replanted scattered in cinnamon forests (figure 2). If, as is hoped, birds disperse seeds of native species from these patches, cinnamon forests may serve as a nursery habitat for native species.

Close interaction between scientists and practitioners facilitated the immediate interpretation of tentative scientific results for management and the setting up of pilot projects to validate research results. In return, local knowledge of the practitioners improved the research process: for instance, it provided support for formulating hypotheses, choosing appropriate sites and species for experiments, identifying species in the juvenile stage, interpreting unexpected outcomes of field experiments, or growing juveniles for laboratory experiments.

We made a special effort to increase the accessibility of local knowledge: Previously unpublished practitioners’ knowledge was documented in a regional study on invasive species management and habitat restoration in the Western Indian Ocean (e.g., Kueffer et al. 2004). The plant conservation newsletter Kapisen encourages local and visiting biologists to publish personal field observations that may not fit in a scientific paper.

Implications for Management

Empirical surveys have shown that research results are rarely used in nature conservation management except through direct interaction with scientists (Pullin and Knight 2005). Thanks to the close collaboration in the Seychelles project, research results of the project as well as international scientific results entered directly into management planning and action, e.g., the zoning of a national park or the management plan of an invasive species. Applied research questions were defined according to both management priorities and feasibility of research. Recent projects such as the red listing project were initiated because they were identified as a priority by the National Strategy for Plant Conservation. Ecological research, applied research, and actual management projects were developed in parallel, for instance for habitat restoration (see above and figure 2). This process let arise trust and a common language, which is essential for a transparent discussion of the validity and limitations of the scientific results for management.

Reliable knowledge about the relevant natural processes is a necessary but not a sufficient condition for sound environmental management. Environmental problems are first and foremost social, political, and cultural issues (e.g., Ludwig et al. 2001). Hence there is also a need for stakeholder processes in order to negotiate the particular interests and values involved and to find a consensus on the framing of environmental problems. Very often, these interests and values become entangled with scientific interpretations (e.g., Wallington and Moore 2005, and references therein), particularly when the scientific information is uncertain. Nevertheless, it is important to be clear whether in a particular process the main debate is about expertise or about negotiating conflicting interests and values (compare Collins and Evans 2002).

In transdisciplinary research a rich methodology is developing for negotiating and framing issues where values and facts are entangled (e.g., Pohl and Hirsch Hadorn 2006). Thereby transdisciplinary research may partly disentangle debates about facts and values and thus allow for mutual learning between disciplin-
Bottom-up research collaborations facilitate mutual learning, which is necessary when expert knowledge is tentative, incomplete, and uncertain. The picture shows scientists and practitioners working together in artificially created forest gaps of a research project between the Swiss Federal Institute of Technology Zurich and the Seychelles Ministry of Environment. The project combines studies on the plant physiology of light use and on habitat restoration.

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References


In bottom-up research collaborations new research questions and the recognition of new management problems evolve over time in response to each other. The picture shows a workshop held in the Seychelles to develop a consensus among experts and stakeholders on priorities in plant conservation and applied ecological research.


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