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A hierarchical approach to ecosystem assessment of restoration planning at regional, catchment and local scales in Japan

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Abstract A hierarchical approach to restoration planning at the regional, catchment and local scales is proposed and examined. Restoration projects limited to a local scale and focused on habitat improvement for individual species ended in failure, which has led to the recognition that there is a need for ecosystem-based management at the landscape level. The first landscape-level restoration in Japan is under way in the Kushiro and Shibetsu River Basins, in northern Japan. However, public consensus on these large-scale restoration projects has not yet matured and there are very few projects that have progressed even as far as mapping to classify intact and disturbed ecosystems. Classification of habitat quality using physical and biological indicators appears to be the core element of analysis of ecological degradation at the regional scale (100–1,000 km²). This mass-screening process is critical to identify areas in potential need of restoration. The causes and mechanisms of ecosystem degradation are then examined at the catchment scale (10–100 km²) by linking material flows and habitat conditions. Direct environmental gradient analysis is useful to determine cause and effect relationships between species and habitat quality. Finally, we recommend implementation of field experiments with a clear hypothesis at the local scale (0.01–1 km²). At this stage, key variables causing degradation of the target ecosystem are manipulated to verify the hypothesis. Based on the results of local-scale analyses, the possibility of restoration success can be evaluated, which directs us to practical schemes for future restoration projects at larger scales.

Keywords Ecosystem restoration · Landscape analysis · Resource management · Planning

Abbreviations DEGA: Direct Environmental Gradient Analysis · HSI: Habitat Suitability Index · NRC: National Research Council · IBI: Index of Biological Integrity · RHS: River Habitat Survey · CCA: Canonical Correspondence Analysis · BARCI: Before-After-Reference-Control-Impact

Introduction

Ecological restoration appears to be a popular arena of political, social and scientific investment in Europe and North America. In the past, restoration consisted of local-scale habitat improvement in favor of individual species, with little consideration paid to the ecosystem processes and functions (Minns et al. 1996; Jungwirth et al. 2002). For example, to restore salmonid habitats in the Pacific Northwest, the construction of in-stream structures using logs and wire gabions and other artificial materials was a common practice (Frissell and Ralph 1998). However, as understanding of other human-related limiting factors, such as degraded water quality and quantity and their relationships with riparian or watershed conditions, the effectiveness of local-scale restoration on the long-term sustenance of salmon populations was realized to be unclear (Roni et al. 2002). In the early 1990s, ecosystem-based management was proposed to protect biodiversity, which emphasized the maintenance of ecosystem processes at larger scales (e.g., disturbance regimes, forest succession, and climate; Franklin 1993). The state-of-the-art stream restoration projects in Europe and the USA share a common vision of the recovery of river and floodplain landscapes by rehabilitating the altered hydrologic connectivity among river system elements (e.g., secondary channels, alcoves, and wetlands) that is promoted by natural hydrogeomorphic disturbances as well as organisms depending upon these dynamic physical conditions (Buijse et al. 2002; Jungwirth et al. 2002; Nienhuis et al. 2002).

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Modern restoration acknowledges the importance of ecosystem patterns and processes occurring at landscape scales. The ecosystem processes of landscape development, such as disturbance regimes, succession and climate, are characteristic of different scales (Urban et al. 1987), which determine the spatial distribution of habitat availability. As a result, the biological patterns of the ecosystems (e.g., species composition and structure) also are characterized differently at different scales (Detenbeck et al. 1999). This scale dependence of ecosystem processes and patterns requires the use of appropriate scales for the assessment (Urban et al. 1987; REO 1995). For example, to determine the controlling factors on the water quality of a wetland, catchment scales are critical because of their close association with watershed management through hydrologic connectivity (Bedford 1999). Assessment at larger scales may be necessary when incorporating the influences of geology and climate. Moreover, wetland functions on the maintenance of habitat, biodiversity and water quality may be cumulative in space and detected by analyses at larger scales (Johnston et al. 1988; Detenbeck et al. 1999; Gwin et al. 1999; Nakamura et al. 2004).

In Japanese society, the ecological and aesthetic values of natural resources have been recognized only recently. The government has enacted or revised legislation pertaining to resource management, with greater consideration being given to conservation of species and their habitats (Nakamura 2003). In 1997, ecological perspectives were first embraced in river policy, followed by the declaration of the Environmental Assessment law. The New National Strategy of Japan on Biological Diversity, which recommends the implementation of restoration projects and government funding to these projects, was adopted in 2002. The ecological, social and institutional circumstances were aligned only lately to place greater emphasis on the needs of restoration at ecosystem levels. The Ministries of Environment, Land and Transportation, and Agriculture began ecosystem restoration programs or projects across the country.

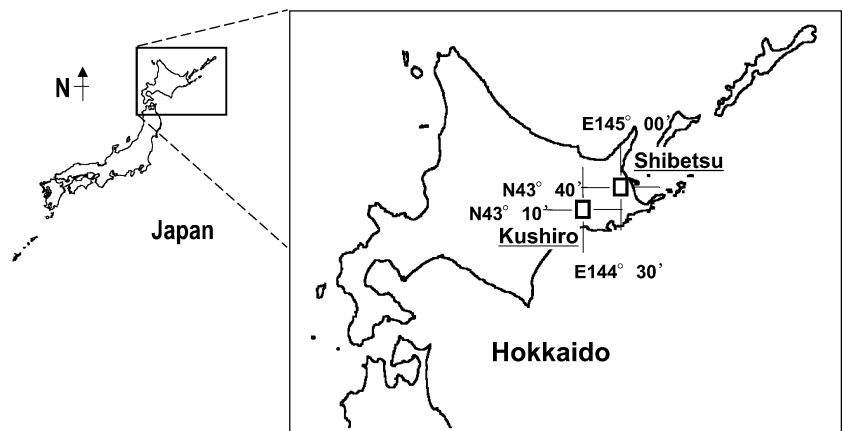
The first landscape-level restoration in Japan is under way in the Kushiro and Shibetsu river basins, in

northern Japan (Fig. 1). However, public consensus on these large-scale restoration projects seems to be immature, probably in part because of inconsistent policies between and within government agencies for the conservation of habitat and wildlife species. In contrast to the above-mentioned conservation and restoration policies, government-sponsored developments, such as timber harvesting, channelization, construction of impoundments and landfills, will concurrently continue to disturb the remaining habitat. This situation conflicts with a principle of ecological restoration, which assumes as a first priority the protection of existing intact ecosystems from further development (NRC 1992). This is because preserving intact ecosystems is often more effective and less costly than restoration. Intact ecosystems also assist restoration by providing vital references and sources of indigenous propagules.

Another source of skepticism toward ecosystem restoration in Japan may be the lack of clear exposition of where and how to implement restoration. Restoration projects in Japan typically do not have a defined process for site selection or development of restoration strategies, making the rationales for the entire restoration efforts uncertain (Nakamura 2004). The identification of rationales, as well as goals and expected results, of a restoration project comprises the major component of the planning process (REO 1995; Jungwirth et al. 2002). Without a clear rationale, the realization of successful cost-effective restoration is not credible.

In Japan, landscape perspectives are not generally considered subjects for restoration (Nakamura 2004). Water quality assessment using aquatic macroinvertebrate inventories and perturbation evaluation using vegetation have been conducted at regional scales. However, these assessments are not designed to explain ecosystem-level structures and processes and therefore are incapable of assisting restoration planning of the landscapes. Even classification of intact and disturbed ecosystems by mapping has been carried out in only a few instances. If location of the remaining intact ecosystems in the landscape has not been completed, the importance of these ecosystems may be overlooked and

Fig. 1 Locations of Kushiro and Shibetsu River Basins



subject to unintended alterations. Honnay et al. (2002) recommend, based on their study of forest restoration in Europe, selection of restoration sites within a distance of dispersal potential of reference communities; the location of restoration sites in relation to the reference sites becomes important for the success of restoration. Thus, there is a need to develop a framework for ecosystem assessment in the context of restoration planning, which integrates landscape perspectives and provides a defined process of site selection and development of restoration strategies.

In this paper, we consider how spatially hierarchical analyses at regional, catchment and local scales can be used to assess ecosystem patterns and processes in the context of restoration planning and to provide a clearly defined process of identifying rationales for, and measures of, restoration. The regional context is used to identify the ecosystem elements or functions needing preservation or restoration. The following catchment-scale analysis contributes to clarify the mechanism that deteriorates the target ecosystem conditions for restoration and to develop a hypothesis with a particular consideration on the ecosystem process. A hypothesis should be validated by a field experiment at a local-scale before launching full restoration actions because we are not able to predict a precise response of the target ecosystem to restoration impact. We discuss the benefits and features of assessment tools that can be used at three scales and apply their frameworks to case studies in Japan, to illustrate a few of the analytical approaches to be used.

Regional-scale analysis

As a first step in restoration planning, a regional analysis aims at constructing an overview of ecosystem conditions to identify altered areas in need of management action. This process is analogous to a mass-screening test in medicine, which evaluates the health of an entire human body. The analysis begins with the construction of a regional database that characterizes the patterns of biophysical conditions (e.g., biodiversity, vegetation, topography, geology, and land use). The analysis areas may be delineated by political boundaries (e.g., nationwide, provincial) or physiographic units that share similar climate and geology. The region is then classified in terms of the levels of alteration of target communities or systems. The alterations may be regional and not clearly visible at a first look, thereby requiring a special attention to the spatial configuration of the ecosystem patterns. Analyzing temporal trends of spatial patterns may be necessary to see the alterations.

To qualify ecological degradation, classifying assessment units in the region using ecological indicators appears to be the core element of regional analyses. Scoring each class may follow to quantify the degradation. The assessment units can be forest stands, stream

reaches, watersheds, or other functional habitats, all which play important roles in the conservation of target communities or the maintenance of ecological integrity of the landscape as a whole (e.g., Detenbeck et al. 1999; Karr 1991; Raven et al. 1998; Jungwirth et al. 2002). Ecological indicators may be biological (e.g., species composition or structure) or physical (e.g., water quality, land use), combinations of which can be chosen to infer the cause and effect relationships as the response (i.e., target communities) and explanatory (i.e., environment) variables (e.g., Rathert et al. 1999; Chu et al. 2003). Environmental variables can be narrowed down to smaller variable sets using statistical tools, such as analyses of principal component, regression trees and multiple regression.

Classification of assessment units directly assists resource management, including restoration. For example, Chu et al. (2003) classified watersheds throughout Canada based on fish biodiversity in relation to climate and human stresses. Their result generated three levels of ranked conservation priorities across Canada. Likewise, Gwin et al. (1999) classified 96 wetlands distributed in the metropolitan areas of approximately 3,900 km² in Oregon, USA. The classification was accomplished based upon the wetland's geomorphic setting, water source and hydrodynamics in the wetland using a hydrogeomorphic (HGM) classification (Brinson 1993; Smith et al. 1995). This regional wetland classification indicated the dominance of a certain type of wetlands in the landscape. This trend may lead to a homogeneous landscape of wetland habitats, suggesting an opportunity to restore the diversity of wetland habitats across the landscape (Bedford 1999).

Classification provides a valuable tool for restoration planning because it allows us to identify reference sites and therefore to evaluate the ecological status of ecosystems (Buijse et al. 2002) and the effectiveness of restoration measures after implementation (Jungwirth et al. 2002). Buijse et al. (2002) reviewed the assessments of the Danube delta lakes and the Lower Rhine, and asserted that the classification of floodplain elements, such as lakes and wetlands, assisted in developing reference sites for the rehabilitation of river-floodplain systems in Europe.

Habitat classification can also be achieved in conjunction with scoring systems (Raven et al. 1998). One scoring system that uses biological indicators is the Index of Biological Integrity (IBI, Karr 2001), which has been widely applied to the assessment of stream ecosystems (Karr 1991). Since IBI uses ecological guilds for ranking habitat quality, such as native, benthic, and omnivores, the indicators can be modified to apply to representative communities of a given region. In practice, the framework of the IBI has been applied worldwide (e.g., Ganasan and Hughes 1998; Harris and Silveira 1999; Belpaire et al. 2000; Dauwalter and Jackson 2004) and used to develop modified IBI for different taxa (Kerans and Karr 1994; Simon et al. 2000). Another assessment framework, the River

Habitat Survey (RHS) system uses two types of indices, a habitat quality assessment and habitat modification score (Raven et al. 1998). The RHS system focuses on the physical conditions of a river corridor (both in-stream and riparian) to score the quality of habitat features for target communities. The identification of reference conditions is critical for both IBI and RHS.

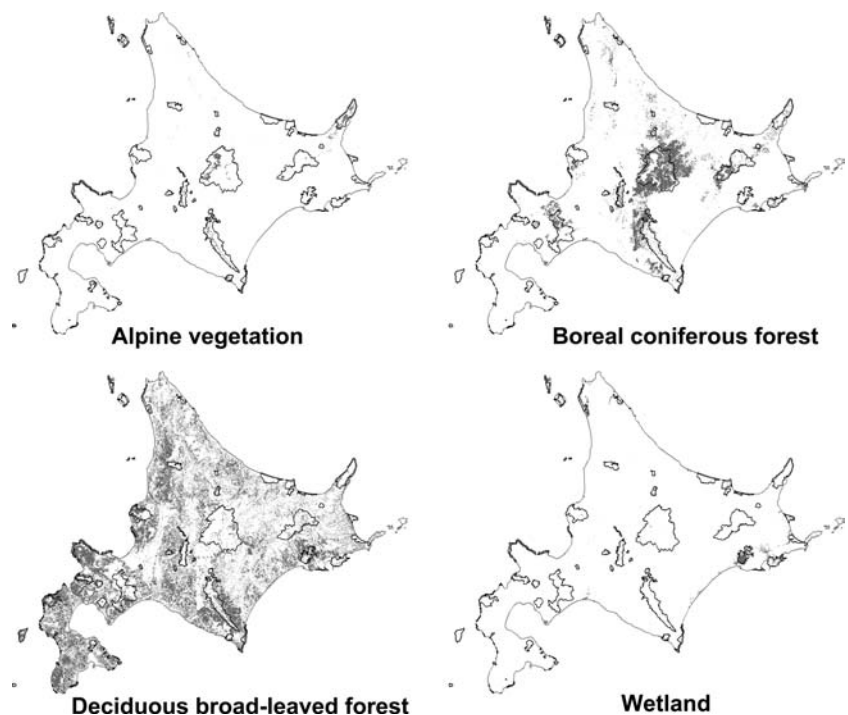
Another important role of regional analyses is to profile regional abundances and configurations of wildlife habitat, because small local alterations may be cumulative across the region (e.g., Bedford 1999). The regional habitat profile can be manifested as heterogeneity, connectivity, and isolation, all which can change the pattern of plant and animal colonization and therefore influence biodiversity (Harris 1988). For example, Naugle et al. (2001) found that small wetlands interspersed across the landscape, with each wetland connected by upland habitat, were beneficial for the conservation of migratory waterfowls. This suggests that habitat connectivity plays an important role in the maintenance of biodiversity. A similar conclusion has been drawn for the cases of stream fish (Rathert et al. 1999), forest plant communities (Honnay et al. 2002), and the ecological integrity of large river floodplain systems (Jungwirth et al. 2002). Thus, when the regional analysis finds alterations across the region, it is necessary to develop restoration schemes in the regional context.

Considering that there is virtually no regional assessment of restoration needs in Japan, a straightforward ranking of restoration and conservation priorities should greatly assist restoration planning. We consider that regional analyses in Japan are conducted over scales of the order of 100–1,000 km². Using readily available

data, such as species distribution, land use, climate and topography, the areas of degradation and their reference systems can be located and then scored from most disturbed to most intact. The deviations of degraded systems from the reference sites can be quantified. For further analyses, environmental (e.g., climate, geology, topography) and anthropogenic attributes (e.g., land use, population, road density) can be overlaid onto the species profile to develop management strategies. The regional structure and composition of ranked systems may provide important insights for alterations that depend upon the regional scales but that could not be discerned by the smaller scale analyses.

Figure 2 shows four zones of a vegetation classification of Hokkaido Island (78,000 km²) based upon climate and dominant vegetation communities: the alpine zone where *Pinus pumila* Regel and alpine plants are dominant, a boreal forest zone of *Picea jezoensis* Carr and *Abies sachalinensis* Masters, a cool temperate zone of deciduous broad-leaved species, *Acer mono* Maxim., *Tilia japonica* Simonkai, and *Quercus crispula* Blume, and wetlands dominated by reed and sedge species. Each zone represents a wide variety of habitat types such as feeding grounds, refugia, resting and wintering habitats and migration corridors for a characteristic wildlife community (Hokkaido Gap Analysis Group 2002). Therefore, habitat diversity in each zone is warranted for wildlife conservation. However, protected areas such as national parks, quasi-national parks, and the Hokkaido prefectural natural parks do not cover the various habitat types (Fig. 2). The proportion of protected zones is highest for alpine (85.0%), intermediate for wetlands (37.4%) and boreal forest (34.5%), and lowest for

Fig. 2 Distribution of four dominant vegetation communities and the protected areas (national park, quasi-national park, and prefectural natural park) delineated by solid lines in Hokkaido



deciduous broad-leaved forest (7.8%). Most of the alpine zone is protected by the national park, where human activities are strictly prohibited, whereas deciduous broad-leaved forest resides within urban and agricultural areas. The Ministry of the Environment has divided deciduous broad-leaved forests into primary (natural) and secondary forests. The former occupies 79.0% and the latter only 21.0% of the corresponding area in Hokkaido. However, primary forests that are within protected areas account for only 8.2%. Further, about 60% of wetlands in Hokkaido have disappeared in association with agricultural and urban developments since 1960s and only one third of remaining wetlands are protected within park areas.

This preliminary GAP analysis (Scott et al. 1993) with readily available data suggests the need of further investigation on potential habitat fragmentation in deciduous broad-leaved forest, assisting site selection for restoration and the development of restoration strategies.

Catchment-scale analysis

When finding an illness (i.e., ecological alteration) in the mass-screening test (i.e., regional analysis in ecosystem assessment), the practitioner moves to a closer inspection to determine the cause and mechanisms of the illness, using more sophisticated technologies such as CT scans and endoscopy. For finer-scale examination in ecosystem assessment, we propose that catchment scales should be the first choice, because of important roles of hydrogeomorphic processes on various ecosystem functions. The size of the catchment scales is 10–100 km² in Japan.

As with in many other industrial countries, past studies in Japan have demonstrated the relationships between habitat alteration, land-use development and water resource management, including timber harvesting, pasture development, stream flow manipulation, sediment and chemical inputs into ground and surface water (e.g., Nagasaka et al. 2000; Kamada et al. 2002; Nakamura et al. 2002). These studies ascertained that material yields and flows were the major mechanisms of these cause and effect relationships, and therefore are essential factors of the catchment analyses. With knowledge of physical processes at the catchment scales, land use activity data (type, intensity and distribution) and the collective influences of these activities across the catchment are also important matters for consideration.

Although the direct environmental gradient analysis (DEGA) is a popular approach across both small and large scales, it is very effective at the catchment scale in order to determine cause and effect relationships. While many regional assessments have aimed at evaluation at the population, community or ecosystem levels, DEGA may be useful at species levels. Examples of assessment systems using DEGA include Habitat Suitability Index,

which has been applied to the Physical Habitat Simulation System for river assessment (e.g., US Fish and Wildlife Service Ecological Services 1983; Stalnaker et al. 1995).

In the Kushiro Mire, Hokkaido (Fig. 1), DEGA has also been used to examine the relationships between land-use history, material flows and wetland vegetation. Protected under the Ramsar Convention and as a National Park, the Kushiro Mire is the largest (19,000 ha) wetland complex in Japan, consisting of sedge fens, bogs, forest swamps and lakes, and provides important wetland habitats for a variety of wildlife. Located at the downstream end of the Kushiro River Basin, the Kushiro Mire has been impacted by the watershed's land use (logging, agricultural land conversion and drainage activities) and through the inputs of pollutants in surface water. In particular, an excessive amount of sediment load has been causing riverbed aggradation, of approximately 2 m, and reducing the channel capacity of the Kuchoro, one of the tributaries of Kushiro River (Nakamura et al. 1997). Turbid stream water carrying a fine sediment load overflows during large-scale flooding and accumulates fine sediment in the wetland. This has likely changed wetland's edaphic conditions, reducing groundwater tables and increasing nutrient fluxes in the wetland. Results of DEGA, including a canonical correspondence analysis (CCA), has indicated that the nutrient conditions of the Kushiro Mire has shifted from oligotrophic (nutrient poor) toward eutrophic (nutrient rich). The increased area of dry land and nutrient enrichment likely affect wetland vegetation, which has been evidenced by the transition of dominant communities from sedge or reed marshes to alder and willow forests (Nakamura et al. 2002). In agreement with the DEGA results, remote sensing analyses have shown the concurrent expansion of turbid-water areas and forest into the wetland (Kameyama et al. 2001; Nakamura et al. 2004). Thus, following determination of the causes of wetland degradation and mechanisms at the catchment scale, specific restoration actions for the Kushiro Mire restoration have been designed in the catchment context (Nakamura et al. 2003).

In order to link between material flow, habitat conditions and organisms at catchment scales, examination of the spatial distribution of materials and the material flux are necessary. Material flows in a stream reach may occur by several pathways: (1) energy and material inputs from sunlight and precipitation, (2) stream flow from upstream to downstream, (3) lateral flows between floodplains and channel water, and (4) between floodplains and adjacent hill slopes. For example, when nutrient fluxes at the most upstream and downstream points of a reach are known, by determining the material flows in these pathways, nutrient storage in the stream reach can be quantified as the difference, ΔS . The change in nutrient flux (i.e., nutrient excess or deficit) in the reach and its location in the pathways may explain habitat conditions and plant and animal distributions in the reach. If nutrient loading into the reach is greater

than the amount of output, nutrient excess (i.e., accumulation or deposition expressed as $+\Delta S$ value) becomes dominant in the reach. Supposing that nutrient excess favors the growth of species *b* whereas deficit (i.e., outflow or erosion, expressed as $-\Delta S$) favors species *a* (Fig. 3), the outcome can be easily expected as the dominance of species *b* at the expense of species *a*. The forest invasion into the marsh in the Kushiro Mire follows this scenario. Sediment and nutrient produced in upstream forest and hay fields have been accumulated in the wetland to cause sediment and nutrient excess within the wetland, which likely favors the growth of willow and alder trees. Similar examples were found in the restoration sites in the Kinu and Tama Rivers, where a native herb, *Aster kantoensis* Kitamura (Asteraceae), has been extirpated by nonnative species (Murakami and Washitani 2001; Washitani 2001). Both rivers are short of cobble-size sediment input but have excessive fine sediment input due in part to flow regulation, which has been inferred to be the cause of alterations in species composition (Inoue et al. 1998; Washitani 2001).

Thus, the rehabilitation of material flows at catchment scales are of importance for species conservation and restoration, since otherwise its persistence cannot be

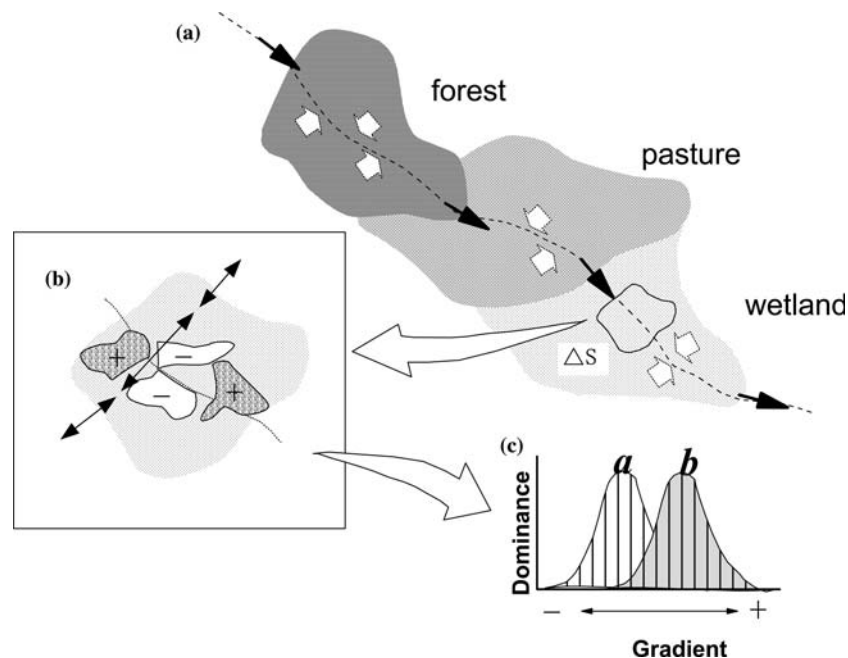
realized. Catchment-scale analysis, particularly understanding of the material budget, plays a crucial role in the planning process of ecosystem restoration. Identification of issues causing ecosystem degradation and their mechanisms in the catchment context directs ecosystem analysis in the design of specific restoration measures.

Local-scale analysis

To refine restoration strategies and validate the feasibility suggested by analysis at larger scales, local-scale analysis at orders of 0.01–1 km² is conducted. Field examination should be designed carefully in an experimental framework. Although experimental design may vary in specific studies, in part because of the available budget, Before-After-Reference-Control-Impact (BARCI) design is recommended (Fig. 4, Nakamura 2003). This allows us to evaluate the effectiveness of restoration in achieving its goal on both temporal and spatial scales. Researchers can compare ecosystem responses before and after implementing restoration actions and across intact (reference), control (disturbed) and impacted (disturbed but restored) sites. Moreover, it is recommended to establish as many replications as possible. When increasing the number of replication is too costly, repeated measurements over time using the same sites may be possible to test statistical significance.

An example of local-scale analysis was conducted to examine the influence of flood control structures on benthic fish communities in the Makomanai River, Hokkaido (Table 1, Watanabe et al. 2001). Preliminary catchment-scale analyses, by comparison of a natural reach and reaches with channelization and bank-protection works, indicated that the abundance of sculpin (*Cottus nozawae* Snyder) was greatly reduced by channelization works and

Fig. 3 Material flow influences community structure through the alteration of habitat conditions. Arrows indicate the flows of material flux. **a** A landscape consisting of forest, pasture and wetlands (e.g., Kushiro River Basin), material flux into and out of an ecosystem should vary by the material flows. **b** A difference in material flows between upstream and downstream ends in a given reach represents material storage, ΔS . The spatial distribution of material accumulation (expressed as + value) or erosion (– value) alters the habitat conditions in the reach. **c** Suppose that material accumulation provides favorable habitat for a species *b* whereas deficit is favored by a species *a*, we can predict a shift of dominant species along the gradient of material flux



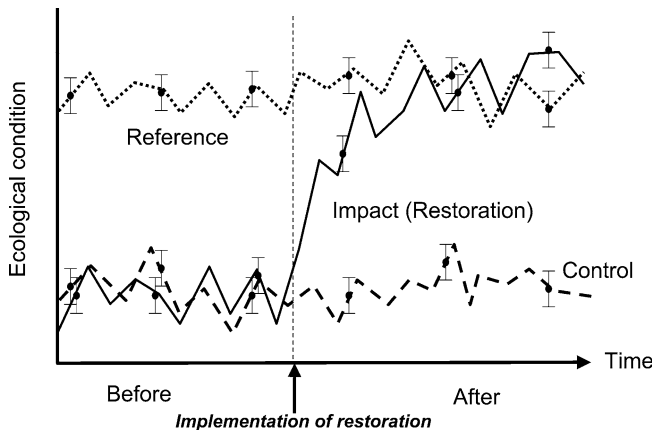


Fig. 4 BARCI sampling design with replicated temporal samples at reference, control and impact sites (from Nakamura 2003)

that this was associated with accumulation of fine sediment on the river bottom. The density of sculpins was positively correlated with the abundance of boulders and loose stones (Table 1), probably because interstitial spaces on the riverbed provide refuge and critical habitat components for living and spawning. By contrast, the number of stone loach (*Noemacheilus barbatulus toni* Dybowski) did not change, suggesting that sculpins were sensitive to the loss of interstitial habitat in pebbles and loose stones due to filling with fine sediment.

The source of fine sediment appeared to be upstream gravel mining. In addition, altered flow conditions in the concrete reach might reduce flushing of sediment from the river bed. Although sediment input from the mining should be controlled, this site-scale experiment attempted the restoration of loose stone habitat by manipulating flow conditions within the reach. The experiment began in July 2000 and was monitored for 1 year. In the experimental reach, the channel width was partly narrowed to create strong turbulent flow. This alteration of flow regime promoted the creation of riffles and loose stones. Figure 5 shows the distribution of loose stones and number and density of sculpins before

and 1 year after the channel restoration. In the narrowed channel, loose stones were abundant, and this was followed by increased density of sculpins. Although this experiment was not formulated in BARCI design that would have enabled testing its statistical significance, the result can be interpreted incorporating the effect of time. Figure 6 indicates that physical and biological responses to the restoration differ in time; loose stone habitat as a physical condition was created first after several flood disturbances while the recovery of fish abundance was delayed but finally reached levels of abundance close to the undisturbed reach within a year.

Thus, controlled experimentation at local scales can provide evidence of degradation, its cause and mechanism. It also provides a means of evaluating whether the planned restoration measure is appropriate and effective in achieving its desired goal. In accordance with the results of the experiments, the restoration measure is subject to further refinement or reconsideration. Issues may be evaluated again at regional or catchment scales. This is the principle of adaptive management, which should be adopted in any restoration program. As with state-of-the-art medicine, such as radiation therapy, bidirectional feedback between scientific evaluation and management should be emphasized in ecosystem assessment. When planning or conducting the experiments, it is recommended that we consider various possibilities for restoration strategies (Minns et al. 1996). This allows us to choose the best action from as many options as possible.

Synthesis

This study illustrates how the hierarchical assessment at regional, catchment, and local scales can benefit ecological restoration. Regional-scale analysis begins with the construction of a broad overview of ecological conditions. Classification of habitat quality is the key component of regional analyses, identifying potential needs of restoration. As mass-screening in medicine is

Table 1 Nested ANOVA test for differences in habitat variables and densities of *C. nozawae* and *N. barbatulus toni* among reaches and channel units (from Watanabe et al. 2001)

	Reach		Channel unit (Reach)	
	<i>F</i> (<i>df</i> = 2,24)	<i>P</i>	<i>F</i> (<i>df</i> = 3,24)	<i>P</i>
<i>Cottus nozawae</i> (<i>n</i> /100 m ²)	15.76	< 0.001	7.28	0.001
<i>Noemacheilus barbatulus toni</i> (<i>n</i> /100 m ²)	1.48	0.247	2.30	0.103
Stream width (m)	5.95	0.008	1.31	0.295
Stream depth (cm)	1.81	0.185	22.11	< 0.001
Velocity (m/s)	4.33	0.025	19.21	< 0.001
Bedrock (%)	1.91	0.170	0.42	0.738
Sand (%)	0.01	0.987	8.86	< 0.001
Gravel (%)	7.03	0.004	7.36	0.001
Pebble (%)	5.79	0.009	2.49	0.084
Cobble (%)	1.28	0.297	3.77	0.024
Boulder (%)	7.62	0.003	10.65	< 0.001
Loose stones (%)	11.81	< 0.001	14.87	< 0.001
Fine sediment (%)	8.08	0.002	12.61	< 0.001
Macroinvertebrate abundance (<i>n</i>)	2.26	0.126	10.86	< 0.001

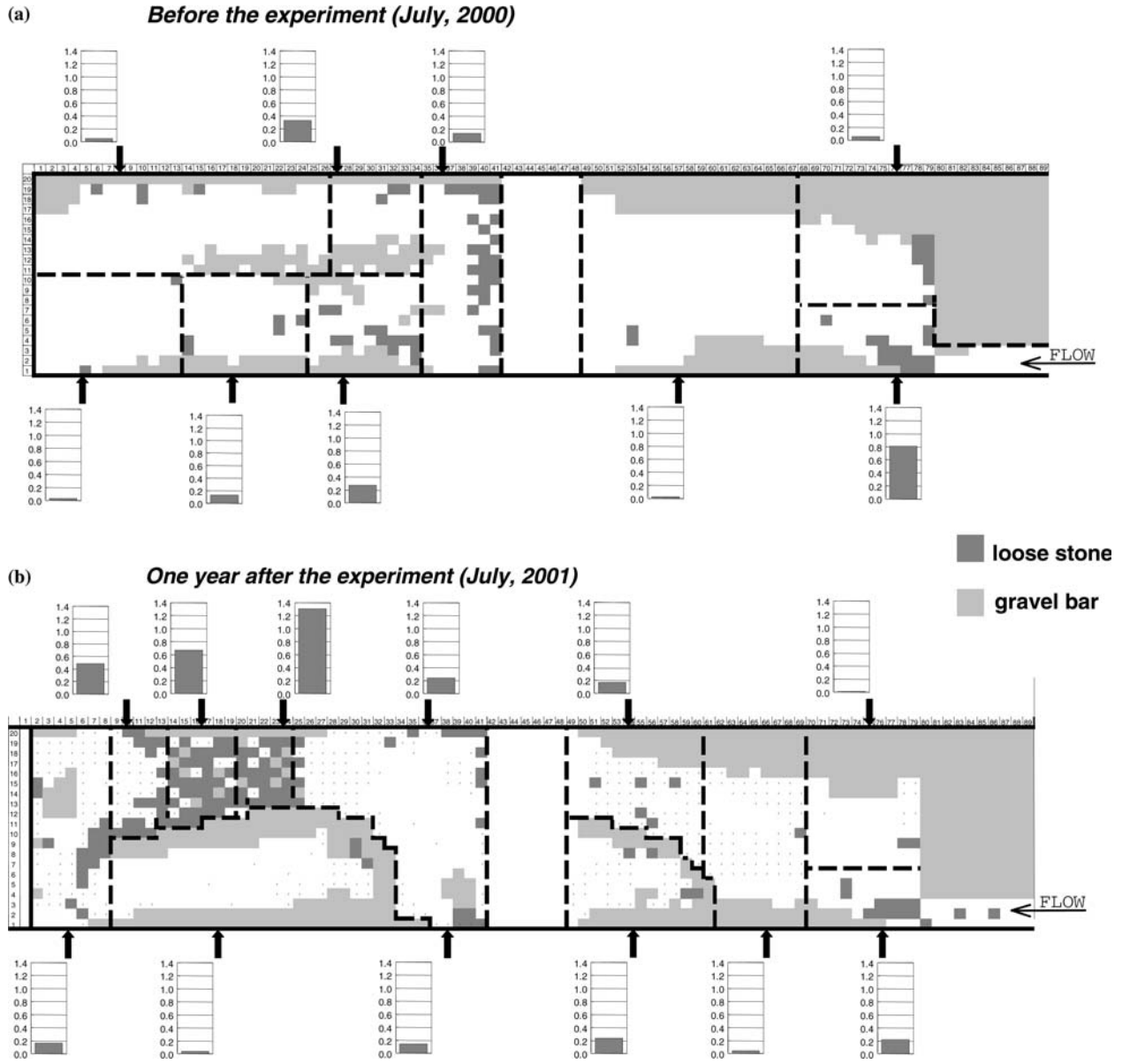
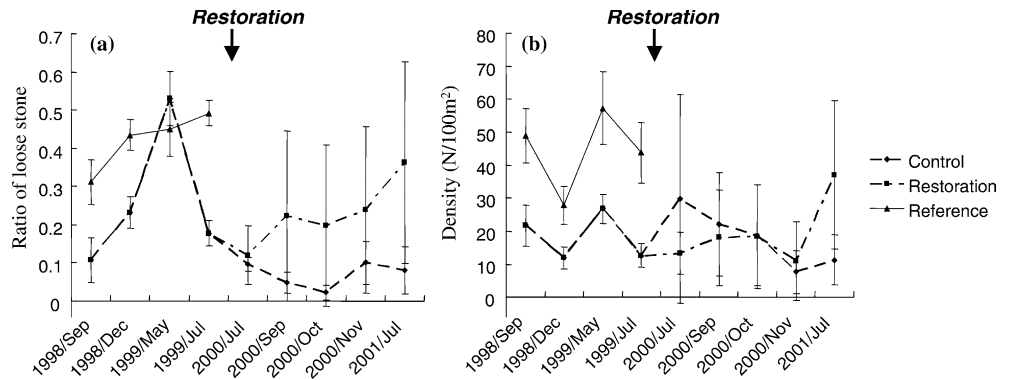


Fig. 5 The distribution of loose stones and density of sculpin **a** before and **b** 1 year after the experimental restoration. Restoration by narrowing the channel width was carried out at the downstream reach (*left side*)

Fig. 6 The abundance of **a** loose stone and **b** sculpin before and after the experimental restoration, compared between control, restoration and reference sites



critical to identify the need for treatment, regional-scale analysis plays a crucial role in restoration planning to provide opportunities for future restoration. Ecosystem patterns and processes are examined at catchment scales to determine potential cause of degradation. Understanding watershed processes and their relationships with the degradation is extremely important in identifying the best restoration strategy. In order to restore the degraded ecosystem, we should implement field experiments with a clear hypothesis at local scales. Using the experiment as a management strategy is an idea from adaptive management. Here, key variables identified in catchment scales are manipulated and the cause of degradation should be verified. From the experiment results, we can anticipate the possibility of restoration success and may conceive technical schemes for future restoration projects at larger scales.

The hierarchical assessment at regional, catchment and local scales provides a valuable framework to organize ecosystem information so it can be used to assist the development of restoration schemes. Through a sequence of analyses nested in spatial scales and controlled experimentation, various spatial data and field assessment can be integrated to lead to an understanding of biophysical processes and patterns that impose on target ecosystems or communities. This systematic procedure can provide a logical explanation for site selection and restoration actions. Thus, rationales behind the restoration activities become more certain, thereby facilitating social understanding on the needs of restoration projects. Frissell and Ralph (1998) pointed out the importance of documentation on restoration projects, to be subject to public evaluation and also to benefit future restoration efforts. A systematic means of ecosystem assessment in restoration planning should provide useful information for the future.

Furthermore, analyses at different scales are complementary. The landscape approach, as a top-down assessment tool, can provide a wider context to the assessment but with limited ability to specify the cause and effect relationship (Chu et al. 2003). In contrast, local-scale analysis is bottom up and constrained to the smaller scales, but it is more defensible on a basis of hypothesis testing. Catchment-scale analysis is situated between these two ends, and is the key to determining the watershed processes controlled by hydrology and geomorphology in order to explain the mechanism of ecosystem degradation. We believe that the sequence of multiple scale analyses from regional, catchment, to local analyses is essential and strongly recommended for ecosystem assessment in restoration planning.

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