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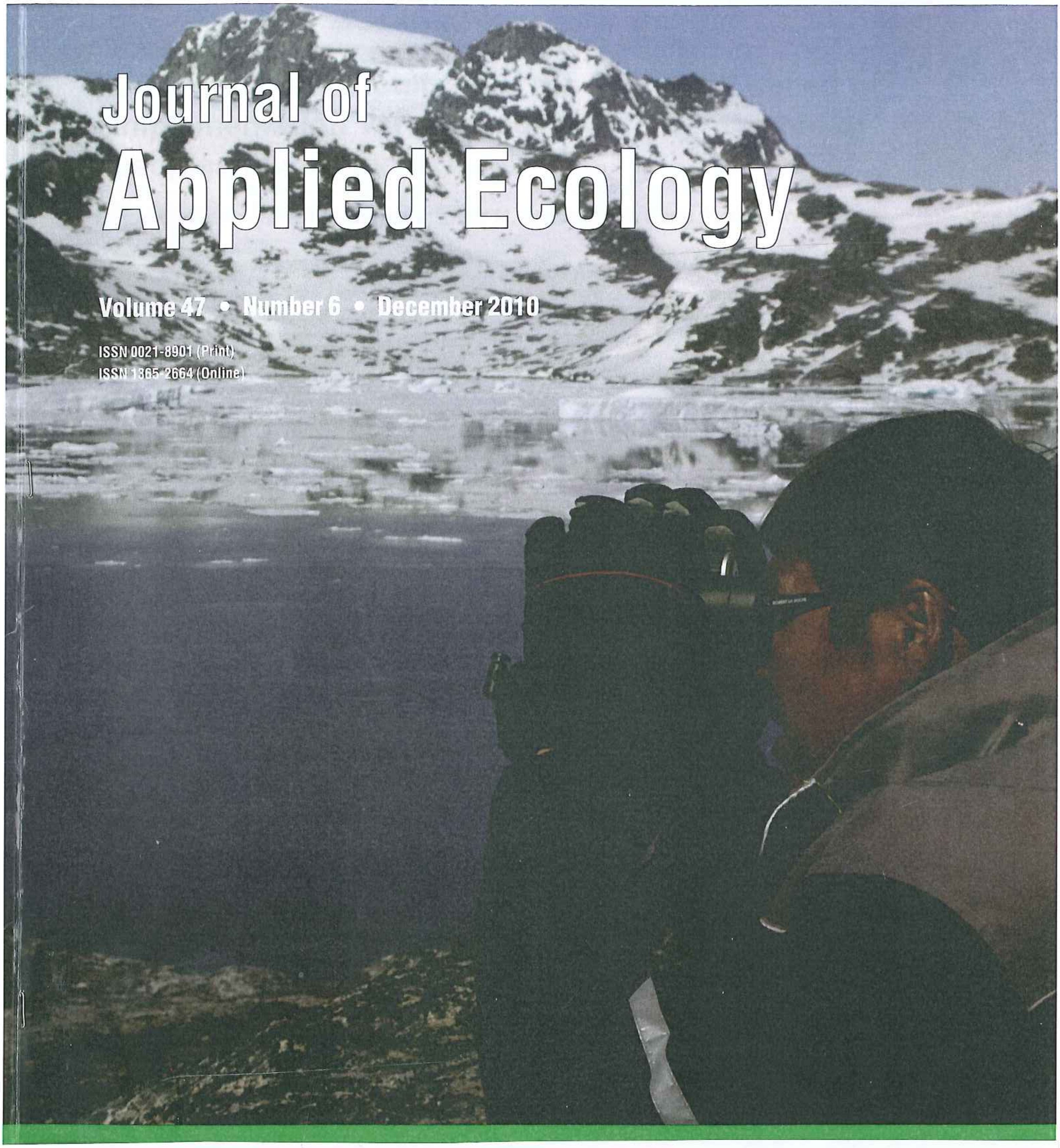

Cover image: The Government of Greenland is pilot-testing the use of locally based monitoring of living resources as a tool for improving Arctic resource management. New findings by Finn Danielsen and his colleagues (see p. 1166) suggest that involving local stakeholders in environmental monitoring enhances management responses at local spatial scales, and increases the speed of decision-making to tackle environmental challenges at operational levels of resource management. Locally based monitoring may be particularly useful in those areas where the government's role in influencing land-use is minimal and village decision makers are in practice the day-to-day managers of natural resources and make most of the management decisions. Photo by Elmer Topp-Jørgensen.

- **Managing invasive pests, weeds and diseases**
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FORUM

Environmental monitoring: the scale and speed of implementation varies according to the degree of peoples involvement

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Summary

1. Solutions to the global environmental crisis require scientific knowledge and responses spanning different spatial scales and levels of societal organization; yet understanding how to translate environmental knowledge into decision-making and action remains limited.
2. We examined 104 published environmental monitoring schemes to assess whether participation in data collection and analysis influences the speed and scale of decision-making and action.
3. Our results show that scientist-executed monitoring informs decisions within regions, nations and international conventions. However, decisions typically take 3–9 years to be implemented.
4. We also show that scientist-executed monitoring has little impact at the village scale, where many natural resource management decisions are made.
5. At the village scale, monitoring schemes that involve local people, and relate to resource utilization at the village level, are much more effective at influencing decisions; these decisions typically take 0–1 year to be implemented.
6. *Synthesis and applications:* Involving local stakeholders in monitoring enhances management responses at local spatial scales, and increases the speed of decision-making to tackle environmental challenges at operational levels of resource management.

Key-words: 2020 target, biodiversity monitoring, citizen science, climate change, decision-making, locally based monitoring, natural resource management, participatory monitoring, REDD, stakeholder participation

It is now clear that the world has failed to achieve the United Nations' 2010 target to stem biodiversity loss (Butchart *et al.* 2010; European Union 2010). Additionally, anthropogenic global changes continue to undermine the ecosystem services upon which society depends (United Nations 2005; CAFF 2010). Future attempts to reverse this multifaceted crisis need scientific information (Hobbs 2003) and responses spanning different spatial scales and levels of societal organization (United Nations 2005; Sandbrook *et al.* 2010), yet understanding how to translate environmental knowledge into decision-making and action is limited (Mooney & Mace 2009; Milner-Gulland *et al.* 2010).

Case studies suggest that collaboration between scientists and local stakeholders in producing knowledge on the status of the natural resources can lead to favourable outcomes for the environment (Sheil & Lawrence 2004; Lawrence 2010), but quantitative analysis is lacking. Here we use meta-analysis techniques to explore if public participation in environmental monitoring influences the speed and spatial scale of decision-making and resulting action to address environmental challenges.

We first established a database of 104 publications on environmental monitoring schemes where the role of scientists and local stakeholders in the monitoring was described (see Appendix S1 and Table S1, Supporting information). We then identified who made decisions based on the results of the monitoring, and assessed the minimum time from the start of

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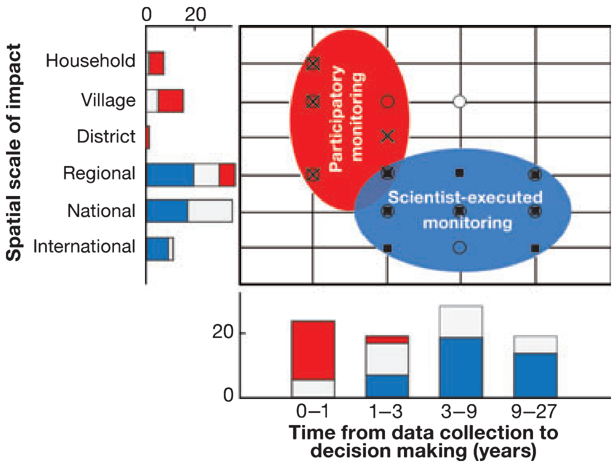

Fig. 1. Decision-making from environmental monitoring, based on data from published monitoring schemes 1989–2009 (n = 104). ■, scientist-executed monitoring schemes (n = 45); ○, monitoring schemes with local data collectors (n = 37); and ×, participatory monitoring schemes (n = 22). The circles comprise all the scientist-executed (blue) and all the participatory monitoring schemes (red). The bar chart indicates the number of scientist-executed monitoring schemes (blue bars), monitoring schemes with local data collectors (white bars) and participatory monitoring schemes (red bars) at each level of spatial scale and implementation time.

the data collection to the findings being used for decision-making.

The degree of involvement by local stakeholders in environmental monitoring profoundly influences the spatial scale and speed of decision-making based on the monitoring data (Fig. 1; Table S2). Scientist-executed monitoring informs decisions in regions (44%), nations (38%) and international conventions (18%) (n = 45 scientist-executed schemes). However, in many areas, particularly in the developing world, the government's role in influencing land-use is minimal and village decision makers are in practice the day-to-day managers of natural resources and make most of the management decisions (Getz *et al.* 1999). Scientist-executed monitoring has little impact at this scale (Fig. 1). Instead, the monitoring schemes that inform decision-making and resource utilization at the village level are those that engage people in the participatory collection, analysis and interpretation of the environmental data (Fig. 1). The greater the involvement by local people in monitoring activities the shorter time it takes from data collection to decision-making following monitoring (P < 0·001; see Appendix S1, Fig. 1 and Table S2b). Two types of participatory monitoring are recognized; one where local people collect data but the analysis is done by someone else, and another where local people collect and analyse the data themselves. The most locally based and participatory of these two options leads to management decisions, which are typically taken at least three to nine times more quickly than scientist-executed monitoring, although they operate at much smaller spatial scales (P < 0·001; see Appendix S1, Fig. 1 and Table S2a).

A limitation in our approach is that many environmental monitoring schemes are not published in the peer-reviewed literature. By using electronic databases for locating examples of monitoring schemes, we probably have disproportionally included schemes from large, well-funded programmes where academic publication has been a primary, or main, goal. We do not know if the spatial and temporal scale of decision-making in the published schemes is representative of the environment monitoring schemes that are being used in practice, but we believe that they represent the range of variation. Further studies aimed at providing more accurate assessments of environmental monitoring schemes could use questionnaires to natural resource managers and investigate those schemes they use. Another limitation is that management decisions might have gone unreported or might only have taken place beyond the period reported in the papers. Also, we don't know if the natural resource management decisions emanating from the monitoring are implemented successfully or not. We could have overcome uncertainties in data interpretation by validating and cross-checking our records with the authors of the papers on the 104 monitoring schemes in our sample. However, this could have introduced methodological differences between studies for which confirmation was available and studies which could not be validated. As the frequency of validation would be likely to vary across the type of monitoring, possible added accuracy would be associated with increased across-scheme bias. Overall, we consider the magnitude of our estimates and their relative proportions acceptable for the purposes of this paper, although figures from individual schemes are subject to uncertainty.

Our findings suggest that the type of monitoring undertaken in an area can have dramatic impacts on the solution chosen for different environmental challenges. By using scientists to undertake monitoring, there is a strong chance that decisions will only be taken at the large scale and will take years to implement. As such, this kind of monitoring is useful to influence national and international policy and to track the implementation of global conventions. At more operational scales of management, at the local level and involving people who face the daily consequences of environmental changes, scientist implemented monitoring generally has little impact. At these scales it is often more beneficial to involve local resource managers directly in the monitoring work; this allows them to assess trends in resources of value to them, and facilitates a rapid response in terms of decisions that directly impact environmental trends at the local scale.

Participation of community members in environmental monitoring may also have other benefits than aiding decision-making and management action (Danielsen, Burgess & Balmford 2005). For instance, even in scientist-led monitoring schemes (Janzen 2004), involvement of community members as paid staff in field-based inventories can help develop a change in attitude towards environmentally sustainable natural resource management among the local participants (Gardner 2010).

A consequence of our findings is that unless governments and non-governmental organizations involve local stakeholders, in many areas, environmental monitoring will tend to remain an isolated academic exercise that is primarily undertaken for the benefit of national and international stakeholders. Involving the locally based stakeholders in monitoring will both enhance management responses across spatial scales, and improve the speed of decision-making to tackle current negative environmental trends at operational levels of resource management.

References

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. The materials and methods, and the results of the statistical tests.

Table S1. Summary of the dataset of published environmental monitoring schemes.

Table S2. Decision-making from published environmental monitoring schemes.

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Appendix S1. The materials and methods, and the results of the statistical tests.

In this supplement, we first describe how we obtained and examined data on published environmental monitoring schemes. We then present the results of the statistical tests.

Materials

To locate example of published environmental monitoring schemes, we used the programme WebSPIRS 5.0 (June 2009) and searched for publications in the databases BIOSIS PreViews (2004-2009), Biological Abstracts (1990-2000) and Biological Abstracts Reports, Reviews and Meetings (1989-2003).

We used the search terms "monitoring and conservation" and "traditional ecological knowledge" and obtained 7757 and 104 publication records, respectively. For the search term "monitoring and conservation", we viewed all 1077 publications since 2007 and 2350 of the 6680 publications before 2007 as the relevance of these publications to the search term rapidly diminished.

Out of the above sample, we located publications that described 104 schemes on monitoring of species or populations, habitats or ecosystems, or resource use, where the role of scientists and local stakeholders was described. We defined 'monitoring' as data sampling which is repeated at certain intervals of time for management purposes; we distinguished this from surveys by the emphasis on repeated and replicable measurements and the focus on rates and magnitudes of change (modified from World Bank 1992).

A single entry was made in our dataset for each monitoring scheme (Table S1). When two or more clearly distinct schemes were found in the same geographical area, they were retained as separate entries in the database. Sometimes monitoring schemes in different geographical areas used the same monitoring methods; they were also included as separate schemes. When we were in doubt on whether different papers described the same schemes, only one of the scheme descriptions was used.

Methods

We divided the environmental monitoring schemes into three categories defined by their degree of local participation:

1) Scientist-executed monitoring schemes; which did not involve local stakeholders;
2) Monitoring where local stakeholders are involved in data collection (and sometimes also in decision-making for management on the basis of the monitoring) but the data analysis is undertaken by professional scientists; and
3) Participatory monitoring; where local stakeholders collect, process and interpret the data and present the findings from the monitoring to decision-makers.

We defined 'local stakeholders' as community members, volunteers, or locally employed staff such as rangers. If a monitoring scheme comprised components with different degrees of local participation, the category judged to be the most important to that particular scheme was selected.

We assessed two parameters, the first on spatial scale of impact and the second on implementation time, for each monitoring scheme:

> 1) Spatial scale of impact: We assessed who made (or was expected to make) decisions on the basis of the findings from the monitoring. Options were: household, village, district, regional, national, international; these were ranked from 1 to 6 for statistical analysis. We used these six categories as proxies for the area covered by decisions made (or expected to be made) using results from the monitoring. We defined 'household' as an area covered by one family; 'village' as an area covered by a group of houses; 'district' as a division of a region, larger than a village; 'regional' as a division of a country, larger than a district; 'national' as one country; and 'international' as several countries. If decisions are made (or expected to be made) at several scales, the principal scale of decision-making for that particular scheme was selected. When a monitoring scheme is leading to decisions at protected area level, we assigned that scheme to the "regional" scale of impact.

2) Implementation time: What was (or what is likely to be) the minimum time from the start of the monitoring data collection to the findings being ready for decision-making. Options: 0-1, 1-3, 3-9, 9-27 years; these were ranked 1 to 4 for statistical analysis.

The same person scrutinized and evaluated all 104 monitoring schemes. A second person used the same criteria and independently evaluated a random selection of 20% of the schemes and she obtained the same results.

The results are presented in Table S2 and Fig. 1. Based on the data in Table S1, we used SigmaPlot to prepare Fig. 1. The circles were added by hand to encompass all participatory monitoring schemes (red circle in Fig. 1) and all scientist-executed monitoring schemes (blue circle in Fig. 1).

Differences in spatial impact scale and implementation time for the three monitoring categories were evaluated by Kruskal-Wallis test (PROC NPAR1WAY, SAS, SAS statistics). The correlation between spatial impact scale and implementation time was evaluated by Spearman correlation (PROC CORR SPEARMAN, SAS).

Results of the Statistical Tests

Spatial impact scale decreased from a mean of 4.7 and 4.2 to 2.2 for categories 1, 2 and 3 respectively (Kruskal-Wallis test: Chisq: 40.5, $P<0.001$, n=104). Similarly, implementation time was reduced from typically 3-9 years in category 1 to 0-1 years in category 3, while category 2 had intermediate implementation time (Kruskal-Wallis test: Chisq: 48.1, $P<0.001$, n=91). The spatial impact scale and time for implementation was significantly positively correlated (Spearman rank: 0.61, $P<0.001$, n=91), indicating that time for implementation and spatial scale of impact increased correspondingly from participatory monitoring to scientist-executed schemes.

Reference

World Bank (1992) *Guidelines for Monitoring and Evaluation of GEF Biodiversity Projects*. The World Bank, Washington.

Table S1. Summary of the dataset of published environmental monitoring schemes. List of schemes where the role of scientists and local stakeholders was described, showing the reference, short summary, category, the spatial scale of impact and the minimum time from the start of the monitoring data collection to the findings being ready for decision-making of each monitoring scheme.

Reference	**Short summary**	**Category**	**Spatial impact scale**	**Time**
Agnew, D.J. (1997) *Antarctic Science* **9,** 235-242.	Monitoring of marine ecosystems in the Antarctic.	1	6	9-27
Alcaraz-Segura, D., Cabello, J., Paruelo, J. & Delibes, M. (2009) *Environmental Management* **43,** 38-48.	Remote sensing of ecosystem functions in Spanish national parks.	1	5	1-3
Barlow, A.C.D., Ahmed, M.I.U., Rahman, M.M., Howladerc, A., Smith, A.C. & Smith, J.L.D. (2008) *Biological Conservation* **141,** 2032-2040.	Monitoring the management of tiger, *Panthera tigris,* in the Sundarbans of Bangladesh.	1	5	1-3
Boyes, S.J. & Allen, J.H. (2007) *Marine Pollution Bulletin* **55,** 543-554.	Topographic monitoring of a middle estuary mudflat, Humber Estuary, UK.	1	4	9-27
Caro, T. (2008) *African Zoology* **43,** 99-116.	Aerial censuses of large mammals in the Katavi-Rukwa ecosystem of western Tanzania.	1	4	9-27
Chen, Q.L., Zhang, Y.Z. & Hallikainen, M. (2007) *Environmental Monitoring and Assessment* **124,** 157-166.	Water quality monitoring in the Gulf of Finland.	1	5	n.a.
Cheng, I.J., Huang, C.T., Hung, P.Y., Ke, B.Z., Kuo, C.W. & Fong, C.L. (2009) *Zoological Studies* **48,** 83-94.	Monitoring the nesting ecology of green turtle, *Chelonia mydas*, on Lanyu (Orchid Island), Taiwan.	1	4	3-9
Cowx, I.G., Harvey, J.P., Noble, R.A. &	Survey and monitoring of fish	1	4	3-9

Nunn, A.D. (2009) *Aquatic Conservation-Marine and Freshwater Ecosystems* **19,** 96-103.	populations in river Special Areas of Conservation in the UK.			
Creuwels, J.C.S., Stark, J.S., Woehler, E.J., van Franeker, J.A. & Ribic, C.A. (2005) *Polar Biology* **28,** 483-493.	Monitoring of a population of southern giant petrel, *Macronectes giganteus*, in the Frazier Islands, Wilkes Land, Antarctica.	1	4	3-9
Critchley, C.N.R., Burke, M.J.W. & Stevens, D.P. (2003) *Biological Conservation* **115,** 263-278.	Botanical monitoring of lowland semi-natural grasslands in agri-environment schemes in the UK.	1	5	3-9
Doran, N.E., Balmer, J., Driessen, M., Bashford, R., Grove, S., Richardson, A.M.M., Griggs, J. & Ziegeler, D. (2003) *Organisms Diversity & Evolution* **3,** 127-149.	Monitoring of vegetation and faunal assemblages in Tasmania, Australia.	1	5	9-27
Fancy, S.G., Gross, J.E. & Carter, S.L. (2009) *Environmental Monitoring and Assessment* **151,** 161-174.	Monitoring the status of natural resources in U.S. national parks.	1	4	n.a.
Hansen, M.C., Stehman, S.V., Potapov, P.V., Loveland, T.R., Townshend, J.R.G., DeFries, R.S., Pittman, K.W., Arunarwati, B., Stolle, F., Steininger, M.K., Carroll, M. & DiMiceli, C. (2008) *Proceedings of the National Academy of Sciences of the United States of America* **105,** 9439-9444.	Remote sensing of humid tropical forest clearing.	1	6	1-3
Harper, G.J., Steininger, M.K., Tucker, C.J., Juhn, D. & Hawkins, F. (2007) Fifty years of deforestation and forest fragmentation in Madagascar. *Environmental Conservation* **34,** 325-333.	Monitoring deforestation and forest fragmentation in Madagascar.	1	5	3-9
Hart, C.R., White, L.D., McDonald, A. &	Monitoring related to ecosystem	1	4	3-9

Sheng, Z.P. (2005) *Journal of Environmental Management* **75,** 399-409.	restoration on the Pecos River in western Texas, U.S., to regulate populations of salt cedar, *Tamarix* spp., and water resources.			
Kingsford, R.T. & Porter, J.L. (2009) *Wildlife Research* **36,** 29-40.	Aerial surveys of waterbird populations in eastern Australia.	1	5	3-9
Kleinod K., Wissen M. & Bock M. (2005) *Journal for Nature Conservation* **13,** 115-125.	Monitoring of vegetation changes in a wetland in northern Germany using earth observations and geo-data.	1	4	n.a.
Kruger, J.M., Reilly, B.K. & Whyte, I.J. (2008) *Wildlife Research* **35,** 371-376.	Assessments of population densities of large herbivores in Kruger National Park, South Africa.	1	4	3-9
Labau, V.J. (1993) *Environmental Monitoring and Assessment* **26,** 283-294.	National forest health detection monitoring programme in the United States.	1	5	n.a.
Lambin, E.F. & Ehrlich, D. (1997) *Remote Sensing of Environment* **61,** 181-200.	Monitoring of land-cover changes in sub-Saharan Africa by remote sensing.	1	6	9-27
Large, A.R.G., Mayes, W.M., Newson, M.D. & Parkin, G. (2007) *Applied Vegetation Science* **10,** 417-428.	Long-term monitoring of fen hydrology and vegetation for wetland restoration in Northumberland, UK.	1	4	9-27
Leight, A.K., Scott, G.I., Fulton, M.H. & Daugomah, J.W. (2005) *Integrative and Comparative Biology* **45,** 143-150.	Long-term monitoring of grass shrimp *Palaemonetes* spp. population metrics at sites with agricultural run-off influences.	1	5	9-27
Loman, J. & Andersson, G. (2007) *Biological Conservation* **135,** 46-56.	Monitoring brown frogs, *Rana arvalis* and *Rana temporaria,* in ponds in southern Sweden.	1	5	9-27
Lyons, J.E., Runge, M.C., Laskowski,	Monitoring in the context of structured	1	5	3-9

H.P. & Kendall, W.L. (2008) *Journal of Wildlife Management* **72,** 1683-1692.	decision-making and adaptive management in the United States.			
Martin, J., Kitchens, W.M. & Hines, J.E. (2007) *Conservation Biology* **21,** 472-481.	Monitoring programme for the conservation of the snail kite, *Rostrhamus sociabilis*, in Florida, U.S.	1	5	3-9
Martins, S.D., Sanderson, J.G. & Silva-Junior, J.D.E. (2007) *Biodiversity and Conservation* **16,** 857-870.	Monitoring of mammals in the Caxiuanu National Forest, Brazil.	1	4	3-9
Mattfeldt, S.D., Bailey, L.L. & Grant, E.H.C. (2009) *Biological Conservation* **142,** 720-737.	Monitoring of green frog, *Rana clamitans,* and other amphibians in the wetlands of North America.	1	4	3-9
Meyer, P. (2005) *Forest Snow and Landscape Research* **79**, 33-44.	Monitoring in relation to a network of Strict Forest Reserves serving as a reference system for close-to-nature forestry in Lower Saxony, Germany.	1	5	9-27
Mysterud, A., Barton, K.A., Jedrzejewska, B., Krasinski, Z.A., Niedzialkowska, M., Kamler, J.F., Yoccoz, N.G. & Stenseth, N.C. (2007) *Animal Conservation* **10,** 77-87.	Monitoring for conservation of European bison, *Bison bonasus*, in Białowieża Primeval Forest, Poland.	1	4	3-9
Ojeda-Martinez, C., Bayle-Sempere, J.T., Sanchez-Jerez, P., Forcada, A. & Valle, C. (2007) *Marine Biology* **151,** 1153-1161.	Long-term monitoring of protected fish populations in Alicante, Spain.	1	4	3-9
Orell, P. (2004) *Conservation Science Western Australia* **5,** 51-95.	Fauna monitoring in Western Australia under the Western Shield programme.	1	4	3-9
Pasqualini, V., Pergent-Martini, C., Fernandez, C., Ferrat, L., Tomaszewski, J.E. & Pergent, G. (2006) *Aquatic Conservation-Marine and Freshwater Ecosystems* **16,** 43-60.	Monitoring of aquatic plants in two Corsican coastal lagoons, western Mediterranean Sea.	1	4	n.a.

Philippart, C.J.M., Lindeboom, H.J., van der Meer, J., van der Veer, H.W. & Witte, J.I. (1996) *ICES Journal of Marine Science* **53,** 1120-1129.	Monitoring of long-term fluctuations in fish recruit abundance in the western Wadden Sea.			
		1	6	9-27
Potapov, P., Yaroshenko, A., Turubanova, S., Dubinin, M., Laestadius, L., Thies, C., Aksenov, D., Egorov, A., Yesipova, Y., Glushkov, I., Karpachevskiy, M., Kostikova, A., Manisha, A., Tsybikova, E. & Zhuravleva, I. (2008) *Ecology and Society* **13**.	Mapping the world's intact forest landscapes by remote sensing.	1	6	1-3
Potvin, M.J., Drummer, T.D., Vucetich, J.A., Beyer, D.E., Peterson, R.O. & Hammill, J.H. (2005) *Journal of Wildlife Management* **69,** 1660-1669.	Monitoring and habitat analysis of a population of wolves, *Canis lupus*, in Upper Michigan, U.S.	1	5	3-9
Prugh, L.R., Ritland, C.E., Arthur, S.M. & Krebs, C.J. (2005) *Molecular Ecology* **14,** 1585-1596.	Monitoring the population dynamics of coyote, *Canis latrans*, by genotyping faeces.	1	5	3-9
Scott, D., Scofield, P., Hunter, C. & Letcher, D. (2008) Decline of sooty shearwaters, *Puffinus griseus*, on the snares, New Zealand. *Papers and Proceedings of the Royal Society of Tasmania* **142,** 185-196.	Monitoring the decline of sooty shearwater, *Puffinus griseus*, on the Snares, New Zealand.	1	6	9-27
Shapiro, A.C. & Rohmann, S.O. (2005) *Revista de Biologia Tropical* **53,** 185-193.	Satellite imagery for conservation and management of coral reefs in Puerto Rico and the U.S.	1	6	1-3
Short, F.T., Koch, E.W., Creed, J.C., Magalhaes, K.M., Fernandez, E. & Gaeckle, J.L. (2006) *Marine Ecology* **27,** 277-289.	SeagrassNet monitoring across the Americas: case studies of seagrass decline.	1	6	1-3

Spieles, D.J., Coneybeer, M. & Horn, J. (2006) *Environmental Management* **38,** 837-852.	Monitoring of macro-invertebrates and vegetation in two wetlands in Ohio, U.S.	1	5	3-9
Tam, T.W. & Ang, P.O. (2008) Repeated physical disturbances and the stability of sub-tropical coral communities in Hong Kong, China. *Aquatic Conservation-Marine and Freshwater Ecosystems* **18,** 1005-1024.	Long-term monitoring programme of sub-tropical coral communities in Hong Kong, China.	1	4	1-3
Thackway, R., Lee, A., Donohue, R., Keenan, R.J. & Wood, M. (2007) *Landscape and Urban Planning* **79,** 127-136.	Mapping of vegetation across Australia to develop national-level vegetation information frameworks.	1	5	3-9
Trathan, P.N., Forcada, J., Atkinson, R., Downie, R.H. & Shears, J.R. (2008) *Biological Conservation* **141,** 3019-3028.	Monitoring of the population of gentoo penguin (*Pygoscelis papua*) breeding at Goudier Island, Port Lockroy, Palmer Archipelago, Antarctica.	1	4	9-27
Vandekerkhove, K., De Keersmaeker, L., Baeté, H. & Walleyn, R. (2005) *Forest Snow Landscape Research.* **79,** 145-156.	Monitoring programme to study the spontaneous development of the woody and herbal layer when managed forests are left for free development in Belgium.	1	4	9-27
Zhang, Y.Z., Chen, Z.Y., Zhu, B.Q., Luo, X.Y., Guan, Y.N., Guo, S. & Nie, Y.P. (2008) *Environmental Monitoring and Assessment* **147,** 327-337.	Remote sensing and geographic information systems (GIS) to monitor land desertification in Yulin, north-west China.	1	4	9-27
Andrianandrasana, H.T., Randriamahefasoa, J., Durbin, J., Lewis, R.E. & Ratsimbazafy, J.H. (2005) *Biodiversity and Conservation* **14,** 2757-2774.	Participatory ecological monitoring of the Alaotra wetlands of Madagascar.	2	2	1-3

Bennun, L., Matiku, P., Mulwa, R., Mwangi, S. & Buckley, P. (2005) *Biodiversity and Conservation* **14,** 2575-2590.	Monitoring of Important Bird Areas in Africa, with Kenya as a case study.	2	5	1-3
Von Brandis, R.G. & Reilly, B.K. (2007) *South African Journal of Wildlife Research* **37,** 153-158.	Monitoring of trophy quality in South Africa to detect quality change over time.	2	4	1-3
Brashares, J.S. & Sam, M.K. (2005) *Biodiversity and Conservation* **14,** 2709-2722.	Monitoring of wildlife species in Ghana, West Africa.	2	5	9-27
Bray, G.S. & Schramm, H.L. (2001) *North American Journal of Fisheries Management* **21,** 606-615.	The volunteer angler diary programme for use as a fishery assessment tool in Mississippi, U.S.	2	5	n.a.
Buchanan, G.M., Donald, P.F., Fishpool, L.D.C., Arinaitwe, J.A., Balman, M. & Mayaux, P. (2009) *Bird Conservation International* **19,** 49-61.	Inventory and remote sensing in Important Bird Areas (IBA) in Africa.	2	6	3-9
Capt, S. (2007) *Wildlife Biology* **13,** 356-364.	Monitoring the lynx *Lynx lynx* in the Swiss Jura Mountains.	2	5	3-9
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Constantino, P.D.L., Fortini, L.B., Kaxinawa, F.R.S., Kaxinawa, A.M., Kaxinawa, E.S., Kaxinawa, A.P., Kaxinawa, L.S., Kaxinawa, J.M. & Kaxinawa, J.P. (2008) *Biological Conservation* **141,** 2718-2729.	Indigenous collaborative research and monitoring for wildlife management in Kaxinawa, Acre, Brazil.	2	4	1-3
De Leeuw, J.J., Buijse, A.D., Grift, R.R. & Vinter, H.V. (2005) *Large Rivers* **15,**	Management and monitoring of the return of riverine fish species following	2	5	9-27

391-411.	rehabilitation of Dutch rivers.			
Ericsson, G. & Wallin, K. (1999) *Wildlife Biology* **5,** 177-185.	Hunter observations as an index of moose, *Alces alces,* population parameters in Sweden.	2	4	0-1
Evans, C., Abrams, E., Reitsma, R., Roux, K., Salmonsen, L. & Marra, P.P. (2005) *Conservation Biology* **19,** 589-594.	The Neighbourhood Nestwatch programme, a citizen-science initiative in the U.S.	2	1	0-1
Flade, M. & Schwarz, J. (2004) *Vogelwelt* **125,** 177-213.	The German Common Birds Census on population changes in German forest birds.	2	5	3-9
Gaidet, N., Fritz, H. & Nyahuma, C. (2003) *Biodiversity and Conservation* **12,** 1571-1585.	Participatory monitoring of large mammals in non-protected areas of the Zambezi Valley, Zimbabwe.	2	4	n.a.
Gray, M. & Kalpers, J. (2005) *Biodiversity and Conservation* **14,** 2723-2741.	Ranger-based monitoring in the Virunga-Bwindi region of East-Central Africa.	2	4	0-1
Hamerlynck, O. & Hostens, K. (1994) *Hydrobiologia* **283,** 497-507.	Monitoring of fyke catches of marine fish in the Oosterschelde Estuary, North Sea.	2	5	9-27
Haskell, B. (1998) *Florida Keys National Marine Sanctuary Zone Performance Report Year 1.* National Oceanic and Atmospheric Administration, Washington.	Monitoring of the Florida Keys National Marine Sanctuary in the U.S.	2	4	n.a.
Hiller, M.A. (1991) *Marine Pollution Bulletin* **23,** 645-648.	The National Estuary Programme to monitor pollution of estuaries in the United States.	2	5	n.a.
Katzner, T., Robertson, S., Robertson, B., Klucsarits, J., McCarty, K. & Bildstein, K.L. (2005) *Journal of Field Ornithology*	Volunteer-based nest-box programme for American Kestrel (*Falco sparverius*) in eastern Pennsylvania, U.S.	2	4	9-27

76, 217-226.				
Kovacs, A., Mammen, U.C.C. & Wernham, C.V. (2008) *Ambio* **37,** 408-412.	European monitoring of raptors and owls.	2	6	n.a.
Lindén, H., Helle, E., Helle, P. & Wikman, M. (1996) *Finnish Game Research*. **49**, 4-11.	The wildlife triangle monitoring scheme in Finland.	2	5	3-9
Lyons, A. (1998a) *A profile of the community-based monitoring systems of three Zambian rural development projects*, pp. 3-13. USAID-Zambia, Lusaka, Zambia.	ADMADE, a programme of the National Parks and Wildlife Services for managing wildlife in Game Management Areas in Zambia.	2	2	0-1
Mansell, M.W. (2002) *Acta Zoologica Academiae Scientiarum Hungaricae* **48,** 165-173.	Monitoring programme of lacewings (Insecta: Neuroptera) in southern Africa.	2	5	n.a.
Mitschke, A., Sudfeldt, C., Heidrich-Riske, H. & Röschmeister, R. (2005) *Vogelwelt* **126,** 127-140.	Monitoring of common breeding birds in the wider countryside of Germany.	2	5	1-3
Mulder, C., Aldenberg, T., de Zwart, D., van Wijnen, H.J. & Breure, A.M. (2005) *Environmetrics* **16,** 357-373.	Monitoring the biodiversity of plants, adult butterflies and leaf-miners in a Dutch nature reserve.	2	5	3-9
Noss, A.J., Oetting, I. & Cuellar, R. (2005) *Biodiversity and Conservation* **14,** 2679-2693.	Hunter-self monitoring of game species by the Isoseño-Guarani in the Bolivian Chaco.	2	2	3-9
Obura, D.O. (2001) *Bulletin of Marine Science* **69,** 777-791.	The participatory monitoring of shallow tropical marine fisheries by artisanal fisherpeople in Diani, Kenya.	2	2	1-3
Pattengill-Semmens, C.V. & Semmens, B.X. (1998) Fish Census Data Generated	Volunteer monitoring of fish populations in a U.S. National Marine	2	4	n.a.

by Non-experts In the Flower Garden Banks National Marine Sanctuary. *Gulf of Mexico Science* **2**, 196-207.	Sanctuary in the north-western Gulf of Mexico.			
Phillips, B.F. & Melville-Smith, R. (2005) *Bulletin of Marine Science* **76,** 485-500.	Monitoring of the fishery of western rock lobster, *Panulirus cygnus*, in Western Australia.	2	5	3-9
Pollard, E., Moss, D. & Yates, T.J. (1995) *Journal of Applied Ecology* **32,** 9-16.	Monitoring of population trends of common British butterflies.	2	5	9-27
Saracco, J.F., Desante, D.F. & Kaschube, D.R. (2008) *Journal of Wildlife Management* **72,** 1665-1673.	Land-bird monitoring programmes for conservation in North America.	2	5	3-9
Savan, B., Morgan, A.J. & Gore, C. (2003) *Environmental Management* **31,** 561-568.	Citizens' Environment Watch, a volunteer environmental monitoring scheme in Canada.	2	2	0-1
Smeltzer, E. & Heiskary, S.A. (1990) Analysis and Applications of Lake User Survey Data. *Lake Reservoir Management.* **6**, 109-118.	Citizens' water quality sampling and lake user perception surveys in the United States.	2	5	1-3
Steinmetz, R. (2000) IIED Evaluating Eden Series Discussion Paper 13, International Institute for Environment and Development, London.	Monitoring of protected areas with local stakeholders in Lao P.D.R.	2	4	1-3
Strauss, E., Grauer, A., Bartel, M., Klein, R., Wenzelides, L., Greiser, G., Muchin, A., Nosel, H. & Winter, A. (2008) *European Journal of Wildlife Research* **54,** 142-147.	Monitoring of the European Hare (*Lepus europaeus*) in Germany.	2	5	3-9
Ticheler, H.J., Kolding, J. & Chanda, B. (1998) *Fisheries Management and Ecology* **5,** 81-92.	Monitoring of fisheries in the Bangweulu Swamps of Zambia.	2	4	1-3

Turner, W.R. (2003) *Landscape and Urban Planning* **65,** 149-166.	Volunteer-based bird monitoring project 'Tucson Bird Count' in the United States.	2	4	1-3
Danielsen, F., Jensen, A.E., Alviola, P.A., Balete, D.S., Mendoza, M., Tagtag, A., Custodio, C. & Enghoff, M. (2005) *Biodiversity and Conservation* **14,** 2633-2652.	Monitoring of Philippine protected areas by rangers and community volunteers.	3	4	0-1
Fernandez-Gimenez, M.E. (2000) *Ecological Applications* **10,** 1318-1326.	Mongolian nomadic pastoralists' ecological knowledge of rangeland management.	3	2	0-1
Granek, E.F. & Brown, M.A. (2005) *Conservation Biology* **19,** 1724-1732.	Marine conservation and monitoring with the involvement of local people in Moheli, Comoros Islands.	3	4	1-3
Huntington, H., Callaghan, T., Fox, S. & Krupnik, I. (2004) *Ambio* 18-23.	Traditional ecological knowledge of terrestrial ecosystem change in the North American Arctic.	3	2	0-1
Johannes, R.E. (1998) *Ocean & Coastal Management* **40,** 165-186.	Village-based management of marine resources in Vanuatu, including monitoring.	3	2	0-1
Kitson, J.C. & Moller, H. (2008). *Papers and Proceedings of the Royal Society of Tasmania,* **142,** 161-176.	Resource management practice on the part of Rakiura Maori harvesters of Sooty Shearwater, *Puffinus griseus,* in New Zealand.	3	1	0-1
LaRochelle, S. & Berkes, F. (2003) *International Journal of Sustainable Development and World Ecology* **10,** 361-375.	Traditional ecological knowledge of biodiversity on the part of the Raramuri in the Sierra Tarahumara, Mexico.	3	1	0-1
Lyons, A. (1998b) *A profile of the*	Participatory monitoring in the	3	2	0-1

community-based monitoring systems of three Zambian rural development projects, pp. 14-22. USAID-Zambia, Lusaka, Zambia.	Livingstone Food Security Project in Southern Province of Zambia.			
Lyons, A. (1998c) *A profile of the community-based monitoring systems of three Zambian rural development projects*, pp. 23-36. USAID-Zambia, Lusaka, Zambia.	Participatory monitoring in the Rural Group Business Programme in three districts of Zambia.	3	2	0-1
Lyver, P.O., Davis, J., Ngamane, L., Anderson, A. & Clarkin, P. (2008) *Papers and Proceedings of the Royal Society of Tasmania* **142,** 149-159.	Hauraki Maori traditional knowledge for the conservation and harvesting of Titi, *Pterodroma macroptera gouldi,* in New Zealand.	3	1	0-1
Poulsen, M.K. & Luanglath, K. (2005) *Biodiversity and Conservation* **14,** 2591-2610.	Participatory monitoring of biodiversity in southern Lao P.D.R.	3	4	0-1
Rabearivony, J., Fanameha, E., MampiandraI, J. & Thorstrom, R. (2008) *Madagascar Conservation & Development* **3,** 7-16.	Ecosystem management of the Manambolomaty lakes Ramsar site, Western Madagascar.	3	3	1-3
Van Rijsoort, J. & Zhang, J.F. (2005) *Biodiversity and Conservation* **14,** 2543-2573.	Participatory monitoring of biodiversity in Yunnan, China.	3	4	0-1
Roba, H.G. & Oba, G. (2009) *Journal of Environmental Management* **90,** 673-682.	Community participatory monitoring of grazing lands in northern Kenya.	3	1	0-1
Schultz, L., Folke, C. & Olsson, P. (2007) *Environmental Conservation* **34,** 140-152.	Ecosystem management in Kristianstads Vattenrike, Sweden, including volunteer-based monitoring of biodiversity.	3	1	0-1
Setty, R.S., Bawa, K., Ticktin, T. &	Participatory resource monitoring	3	2	0-1

Gowda, C.M. (2008) *Ecology and Society* **13**.	system for non-timber forest products: the case of the Amla (*Phyllanthus* spp.) fruit harvest on the part of the Soligas in South India.			
Stuart-Hill, G., Diggle, R., Munali, B., Tagg, J. & Ward, D. (2005) *Biodiversity and Conservation* **14,** 2611-2631.	A community-based natural resource monitoring system in Namibia.	3	2	0-1
Szabo, E.A., Lawrence, A., Iusan, C. & Canney, S. (2008) *International Journal of Biodiversity Science and Management* **4,** 187-199.	Participatory protected area management in the Rodna Mountains National Park, Romania.	3	4	n.a.
Topp-Jørgensen, E., Poulsen, M.K., Lund, J.F. & Massao, J.F. (2005) *Biodiversity and Conservation* **14,** 2653-2677.	Community-based monitoring of natural resource use and forest quality in the montane forests and miombo woodlands of Tanzania.	3	2	0-1
Townsend, W.R., Borman, R., Yiyoguaje, E. & Mendua, L. (2005) *Biodiversity and Conservation* **14,** 2743-2755.	Cofan Indians' monitoring of freshwater turtles in Zabalo, Ecuador.	3	2	0-1
Turner, N.J., Ignace, M.B. & Ignace, R. (2000) *Ecological Applications* **10,** 1275-1287.	Traditional ecological knowledge of aboriginal peoples in British Columbia, Canada.	3	1	0-1
Uychiaoco, A.J., Arceo, H.O., Green, S.J., De la Cruz, M.T., Gaite, P.A. & Alino, P.M. (2005) *Biodiversity and Conservation* **14,** 2775-2794.	Monitoring and evaluation of reef protected areas by local fisherpeople in the Philippines.	3	2	0-1

Legend:

Scheme category: 1, scientist-executed monitoring; 2, monitoring with local data collectors; and 3, participatory monitoring.

Spatial scale of impact: 1, household; 2, village; 3, district; 4, regional; 5, national; and 6, international.

Implementation time: 0-1; 1-3; 3-9; and 9-27 years.

N.a., no data available.

Table S2. Decision-making from published environmental monitoring schemes. Number of published environmental monitoring schemes divided on categories and (a) their spatial scale of impact and (b) the minimum time from the start of the monitoring data collection to the findings being ready for decision-making.

(a)

Spatial scale of impact	**House-hold**	**Village**	**District**	**Regional**	**National**	**Inter-national**	**Total**
Category 1. Scientist-executed monitoring	0	0	0	20	17	8	45
Category 2. Monitoring with local data collectors	1	5	0	11	18	2	37
Category 3. Participatory monitoring	6	10	1	5	0	0	22
Total	7	15	1	36	35	10	104

(b)

Implementation time	**No data**	**0-1 year**	**1-3 years**	**3-9 years**	**9-27 years**	**Total**
Category 1. Scientist-executed monitoring	5	0	7	19	14	45
Category 2. Monitoring with local data collectors	7	5	10	10	5	37
Category 3. Participatory monitoring	1	19	2	0	0	22
Total	13	24	19	29	19	104