Three initial OSPAR tests of ecological coherence: heuristics in a data-limited situation

Jeff A. Ardron

Ardron, J. A. 2008. Three initial OSPAR tests of ecological coherence: heuristics in a data-limited situation. – ICES Journal of Marine Science, 65: 1527–1533.

As marine protected area (MPA) networks become established worldwide, it will be necessary to track the progress made in meeting the networks' underlying ecological goals. The 12 coastal European nations of the OSPAR Convention have agreed to establish an "ecologically coherent" network of MPAs within the waters of the Northeast Atlantic by 2010. However, the meaning of ecological coherence has not been explicitly defined, and it has not been explained how it can be assessed. OSPAR's work on this topic over the past 4 years is summarized here. As the 2010 deadline approaches, the urgency to assess ecological coherence increases. Proper scientific assessment is hampered by the current lack of detailed ecological data, and policy-makers are concerned that collecting data for indicators will tax already limited resources. Unconventional approaches that can make do with what little information is available are being developed, and three initial spatial tests are presented here. A personal perspective of lessons learnt is provided.

Keywords: eco-coherence, ecological coherence, fast and frugal heuristics, marine protected area network.

Received 13 December 2007; accepted 3 May 2008; advance access publication 17 July 2008.

J. A. Ardron: German Federal Agency for Nature Conservation, Isle of Vilm D-18581, Putbus Rügen, Germany; tel: +49 38301 86 129; fax: +49 38301 86 150; e-mail: jeff.ardron@gmail.com

Introduction

During a Joint Ministerial Meeting in Bremen, Germany, in 2003, environmental ministers from European nations bordering on the Northeast Atlantic (OSPAR Convention) and the Baltic (HELCOM) signed a statement agreeing to identify a first set of marine protected areas (MPAs) by 2006, to establish what gaps remain, and to complete by 2010 a joint network of well-managed MPAs that, together with the European Natura 2000 network, is "ecologically coherent" (JMM, 2003).

This paper traces the work proceeding through the OSPAR Commission since 2004 to understand what ecological coherence means and how it may be assessed, with particular emphasis on three initial spatial tests that have been developed. The term "test" is used here instead of "indicator", because these heuristics have been developed without the data and monitoring requirements normally associated with scientific indicators. However, the two terms still share many properties.

As the paper progresses, its narrative voice shifts from passive to personal, reflecting the transition from the original aim to produce "objective" scientific indicators to my ultimate realization that, owing to data constraints, the development of the three initial tests would have to be more heuristic, based at least in part on subjective experience. Because data-limited situations abound in marine spatial planning, such a transition is likely to apply elsewhere as well.

Background

OSPAR represents the mechanism by which governments of 15 European countries, together with the European Community [EC; known collectively as Contracting Parties (CPs)], have cooperated since 1992 to protect the marine environment of the Northeast Atlantic, comprising territorial waters, EEZs, and areas beyond national jurisdiction. The annex on biodiversity and ecosystems adopted in 1998 allows for the development of MPAs (OSPAR, 2003). However, OSPAR (2006a, §7) lacks jurisdiction over fisheries and shipping, and is only able to bring the need for protective measures regarding these issues to the attention of the competent international and national authorities.

Because the OSPAR MPA network is not being designed under any single authority but rather through the cooperative efforts of its CPs, its development has been incremental. As of 31 December 2007, 106 MPAs in the Northeast Atlantic have been put forward by 8 of the 12 coastal nations, amounting to 38 178 km^2 (Figure 1). Its incremental development implies that, from the beginning, the network has never been "ecologically coherent" (OSPAR, 2006b, 2007a).

What is ecological coherence?

Although the term was used in the 2003 Bremen ministerial declaration, neither OSPAR nor HELCOM had an operational definition for ecological coherence. Likewise, though "coherent", "coherence", and in one instance "ecological coherence" are used throughout the Habitats (EC, 1992) and Birds (EC, 1979) Directives of the EC, these terms have not been explicitly defined either. "Ecological coherence" is not often used in the scientific literature, and when it is used, it can mean something quite different from what is intended in the context of MPAs. For instance, Balent (1991) used the term as a property of ecological organization, whereby the mean ecological response of the community to a pressure (such as grazing) and that of its individual species are approximately the same. The term does appear in the grey literature, often in the context of Natura 2000, where (although also not clearly defined) it is generally used to imply

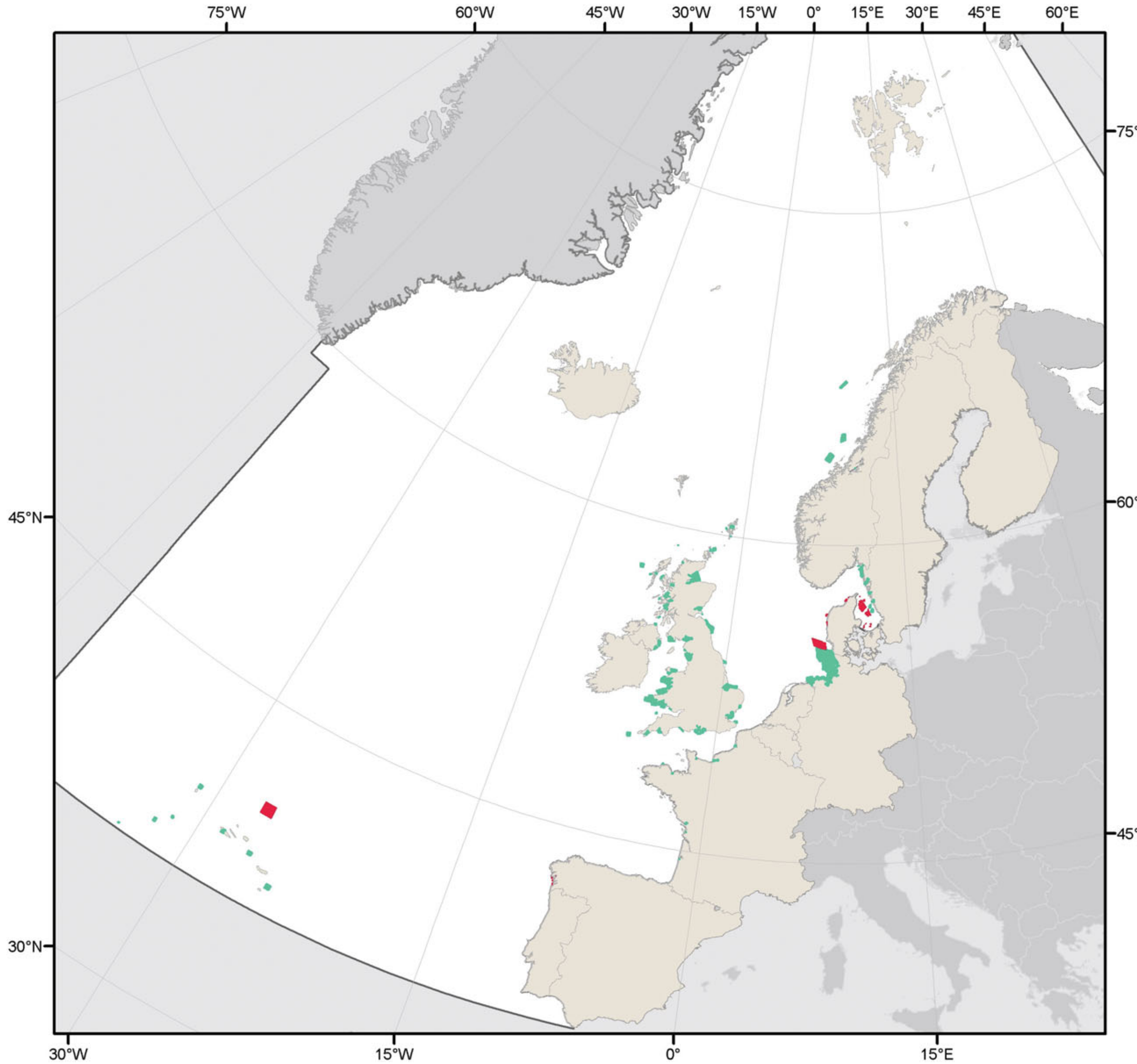

Figure 1. Map of OSPAR MPAs, as of 31 December 2007. Green areas were reported in 2005 and 2006, red areas in 2007. Some smaller areas may not be readily visible at this coarse scale.

some sort of connective structure, e.g. corridors (Good, 1998), existing among, and binding together, ecological processes and functions (STRA-REP, 1998; Bull *et al*., 2003).

OSPAR's preliminary work on this topic included 13 MPA network-design principles that were developed and elaborated upon by the UK in 2004–2006 (OSPAR, 2006c). In 2006, these general principles were then linked to explicit ecological-coherence criteria in a 50-page background document that was developed by a correspondence group led by the author on behalf of Germany (OSPAR, 2007b). In this background document, a working definition was put forward, drawing upon OSPAR (2006c), as well as upon Laffoley *et al*. (2006).

An ecologically coherent network of MPAs:

(i) interacts and supports the wider environment;

(ii) maintains the processes, functions, and structures of the intended protected features across their natural range;

(iii) functions synergistically as a whole, such that the individual protected sites benefit from each other to achieve the two objectives above; and

(iv) (additionally) may be designed to be resilient to changing conditions.

Assessing ecological coherence

OSPAR (2007b) noted that ecological coherence (from now on, eco-coherence) is a holistic concept, representing a bundle of objectives and relying on many constituent parts. Individual tests cannot indicate if the goal of eco-coherence has been achieved; rather, they can only indicate whether it has not been achieved. This failure may be the result of some key elements missing or not functioning as they should. Thus, eco-coherence can only be evaluated in relative terms, as a likelihood that objectives are being met, based on a continuum of progressively more stringent assessments.

In early 2007, three different initial approaches to assessing eco-coherence were considered by the OSPAR Biodiversity Committee, which agreed that these were mutually complementary and that all should be developed further (OSPAR, 2007c):

(i) *Self-assessments*: Those involved in the network design report subjectively on how well they feel different criteria were met in the MPA selection. This initial approach, drawing upon expert knowledge and intuition, has the advantages of simplicity and quick answers. However, it lacks objective rigour, is limited as to the questions that can be reasonably answered, and evaluations may vary among experts. Drawing conclusions for the entire OSPAR Maritime Area would thus be difficult, although the approach may highlight national and local shortcomings. The self-assessment (OSPAR, 2007d) is made up of a checklist and a scoring system, and builds on a checklist developed by Day and Laffoley (2006) for the Marine Programme of the IUCN World Commission on Protected Areas.

(ii) *Species-habitat tabular assessments*: These involve cross-tabulation of species and habitats, reported to be contained within the network, against biogeographic regions. Some of these data are already being reported, thereby providing an overview of whether certain agreed-upon (or legislated) species and habitats are being protected. The current matrix lists species, habitats, and ecological processes as rows, with bioregions and relevant CPs as columns (OSPAR, 2007e), but is still under development. How this information will answer the question of eco-coherence is still unclear.

(iii) *Spatial assessments*: In this approach, the overall network is examined, based on tests that consider the spatial arrangement and spatial characteristics of the MPA network. It is, therefore, less reliant on subjective opinions or reporting accuracy than the previous two approaches. Addressing spatial questions explicitly is important because, unlike other protective measures (e.g. emission limitations, fishing-gear restrictions, extraction quota), MPAs primarily represent a spatial management tool.

Developing spatial assessments

Development of the spatial assessment of eco-coherence commenced with a literature review, upon which 30 "Assessment Guidelines" were developed as examples of the sorts of evaluations that might be carried out, but without any attempt at ranking or hierarchical ordering (OSPAR, 2007b; Ardron, 2008). Responses from CPs have generally been favourable, although questions were raised about the guidelines' application, particularly of the more advanced ones that required more elaborate data or involved mathematical equations with which some policy-makers were unfamiliar. There was a general concern that assembling extensive data and conducting (what some perceived to be) complicated assessments of eco-coherence would tax already limited national resources. Such pragmatic concerns are often at odds with the desire of scientists to develop robust indicators that produce defensible results, with a minimum of uncertainty. Clearly, this policy–science gap is not a new problem, but it underlines the need for other solutions.

As the next step following acceptance of the 30 Assessment Guidelines, I intended to design a stratified battery of spatial assessments, based on these guidelines, and to develop a scoring system from which various characteristics of eco-coherence could be derived. However, because it was still unclear just what spatial data were likely to become available across (most of) the Maritime Area, the Biodiversity Committee agreed to have a short questionnaire distributed regarding data availability. The poor response rate has perhaps been even more illuminating than the results themselves: four completed questionnaires were returned (31%), another three had only the cover page completed (23%), and no responses were received from five CPs (46%; OSPAR, 2007f). It may be inferred that biophysical spatial data are not readily available and/or assembling them to aid in a spatial assessment of eco-coherence is not currently a priority for many CPs. The responses in the completed questionnaires varied, with requested data sometimes, but not always, being available. Consequently, it seems unlikely that OSPAR-wide spatial assessments that rely on comprehensive biophysical spatial data will be performed soon. This outcome underlined the need to consider other techniques that could provide an initial indication of eco-coherence, but which did not rely on a broad-scale availability of data. In short, it meant that my earlier vision of assembling a battery of relatively basic assessments was impractical and that the entire approach would have to be rethought.

"Fast and frugal heuristics"

To get fresh ideas on the question of decision-making in data-limited situations, I turned to literature outside my field. Without going into details, it is appropriate to note the research into human decision-making conducted by the ABC Centre for Adaptive Behaviour and Cognition (Max Planck Institute for Human Development, Berlin). This research suggests that, because humans have limited time and resources (i.e. mental capacity), they choose simple decision-making strategies, which turn out to be surprisingly robust in many situations and often surpass conventional computer models, such as multiple linear regressions, and sometimes even much more computationally intensive approaches such as neural networks. These strategies are labelled "fast and frugal heuristics" (Gigerenzer *et al.*, 1999). Todd and Gigerenzer (2007) argue that, especially in data-limited situations, multiple criteria often fare more poorly than single-measure approaches. The success of the latter is better understood when accepting that different strategies are applicable in different situations, and that over time, these simple evaluations consist of several correlated elements that have been fitted to succeed within permutations of their given "environments" (Garcia-Retamero and Hoffrage, 2006). Further, it is argued that these decision-making environments can often be characterized as a J-shaped distribution of interlinked signals (indicators, in the general sense of the term), whereby one or two can be overwhelmingly influential and can lead to the development of a successful heuristic, or "rule of thumb" (Todd, 2007).

Within the discipline of conservation ecology, the concept of fast and frugal heuristics generally appear to have gone unnoticed, and the only review that I found was rather lukewarm in its response (Anderies, 2001), apparently failing to appreciate how these findings could be applied within the discipline.

For assessing eco-coherence, the concept suggested new possibilities: a few simple tests could conceivably be more powerful than was previously recognized. Their selection would have to be somewhat intuitive, i.e. seemingly fitting for the task from the point of view of an experienced person. Earlier OSPAR scientific work aimed at developing comprehensive assessments, looking at as many aspects as possible of an ideal MPA network that, in fact, did not exist. In light of this, the concerns expressed by some CPs had merit in that the exercise could have involved an unnecessary use of limited resources at this point in its development.

Three alternative spatial tests

Caveats

Reflecting the concept of fast and frugal heuristics, three initial spatial tests were designed to sort out quickly whether or not an MPA network shows the first signs of ecological coherence. These initial tests should be seen as the first step in a multiple-step assessment and development process. However, until the network has passed these tests, there is no need to scale up the testing framework. The three tests are ordered according to ease of assessment, as well as descriptive power, and therefore should be applied in the order given. If one test fails, then the network cannot be said to be eco-coherent, though subsequent tests may help highlight the nature of the problem.

The numerical limits suggested should not be confused with planning targets; they represent thresholds, below which eco-coherence has clearly not been achieved. Achieving full eco-coherence requires that a multitude of ecological processes is functioning interactively to represent a healthy ecosystem. Realistically, therefore, an MPA network will reside somewhere between the two extremes of a completely incoherent network and a fully coherent one, characterized by a mixture of both positive and negative attributes.

Imagining eco-coherence as a linear continuum, we can assign four equally spaced regions along it, referring to a network that is: (i) very unlikely to be eco-coherent; (ii) unlikely to exhibit much eco-coherence, but with some positive effects; (iii) likely to exhibit some degree of eco-coherence, though still missing some important properties; and (iv) very likely to be eco-coherent. Just as the border between regions (iii) and (iv) can be seen as a target to aim for in the longer term, so the border between (i) and (ii) can be seen as the threshold that defines a short-term, minimum requirement. The three tests aim to identify whether the network achieves this threshold.

The tests

The tests proposed consider thresholds for spatial distribution, representation, and threatened and/or declining species and habitats. Because research on where the thresholds lie is lacking, they have been arbitrarily set for Tests 2 and 3 to one-tenth the value commonly found in the scientific literature regarding suitable planning targets. For Test 1, a more qualitative approach is taken. The tests have been accepted by OSPAR and have been accepted for publication (OSPAR, 2008a, b).

Test 1: is the network spatially well distributed, without more than a few major gaps?

Connectivity, representativity, replication, and adequacy/viability are the four agreed-upon OSPAR criteria for eco-coherence (OSPAR, 2007b). If the network is generally not well distributed in space, then it is unlikely to exhibit characteristics of connectivity or representativity, so is unlikely to be eco-coherent (below the lower threshold). Note that its being well distributed in space does not necessarily ensure that these criteria are being met, and further tests will be required.

Well distributed in this context would mean that MPAs have been established in both nearshore and offshore areas and are fairly evenly spaced alongshore. The following guidelines for maximum distances between MPAs in the network are put forward for determining major gaps: nearshore ∼250 km (shoreline distance); offshore ∼200 000 km^2 (∼500 km diameter circle); high seas ∼1 000 000 km^2 (square with ∼1000 km sides).

How many is "a few major gaps?" Because of the different scales involved for different areas, this will depend on where one is looking. It is suggested that for nearshore areas, up to ten, for offshore, up to five, and for high seas, up to two gaps represent "a few". These numbers reflect one-quarter of the estimated total number of gaps possible in each of the three respective realms, excluding the Arctic. The extreme northern and Arctic waters should not be included in this initial test because of their ice cover and remoteness (further described in Test 2).

Of the three, this test is the simplest and yet the most holistic, with the most descriptive power. Although GIS analyses might be applied, the human eye may be even a more powerful tool. An experienced eye can note nuances, such as offshore gradients, basin connectivity, and so forth. However, anyone can plainly see the basics, particularly the gaps.

The guidelines given for identifying gaps approximately double their diameter for each of the three realms distinguished. The assumption that patchiness and protection should be scaled up along a geometric nearshore-to-high-seas gradient seems a plausible simplification (OSPAR, 2006c, 2007b).

Although MPAs do not generally protect larval phases, they are meant to protect the species (and their associated habitats) producing these larvae. Therefore, spacing can be pertinent to the genetic connectivity of species that are adversely affected by human activity outside the MPAs (Johnson *et al*., 2008). Larval dispersal and genetic connectivity vary widely across species and locations. The 250-km rule of thumb for nearshore spacing is approximately ten times larger than that is commonly recommended in the MPA literature (Gaines *et al*., 2003; Palumbi, 2003; Shanks *et al*., 2003; Halpern *et al*., 2006), although there is a great deal of uncertainty in making such generalizations. It is also ten times larger than the 25 km agreed to as a target by BALANCE-HELCOM (2006), and five times larger than the 50-km assessment suggested by OSPAR (2007b).

Recommended distances for connectivity in offshore waters and high seas are not generally available. The rules of thumb suggested for these two are best estimates, based on the geography of the OSPAR area: (i) the suggested offshore circle is about the same size as the Bay of Biscay or Iceland; and (ii) the suggested side of the high-seas square is approximately the length of the Azores chain or of England and Scotland combined. It is hard to imagine anyone arguing that these would not constitute "major gaps" in the network.

Test 2: does the OSPAR MPA network cover at least 3% of most (seven of the ten) relevant Dinter biogeographic provinces?

The Dinter (2001) biogeographic classification is the most thorough system developed for the entire OSPAR Maritime Area to date, including a pelagic and benthic classification, and has been recognized as such (OSPAR, 2006c, 2007a; Richardson *et al*., 2006). Although this classification has been recommended at the scale of OSPAR-wide assessments, other, finer scale classifications, such as EUNIS, should be considered when examining smaller subareas. The ten relevant Dinter biogeographic provinces for this test are: Macaronesia Azores, Lusitanean, Lusitanean–Boreal, Boreal–Lusitanean, Boreal, Norwegian Coast, South Iceland,

Table 1. OSPAR MPA network representation (number, area, and percentage areal coverage) of the ten relevant Dinter (2001) biogeographic provinces, as of 31 December 2007.

Biogeographic province	MPAs (*n*)	Area (km^2)	Coverage (%)
SE Greenland, North Iceland	0	0	0.00
Cool temperate	92	32 242	0.48
Warm temperate	14	5 936	0.17
Boreal	61	26 672	3.72
Boreal–Lusitanean	23	3 125	0.69
Lusitanean–Boreal	4	130	0.09
Lusitanean (cool and warm)	2	107	0.09
Macaronesian: Azores	4	1 376	6.10
Norwegian Coast (all)	8	2 445	0.56
South Iceland–Faroe Shelf	0	0	0.00

Southeast Greenland–North Iceland shelf, Cool-temperate waters, and Warm-temperate waters. Note that this test does not require the use of the subprovinces and that the pelagic and benthic classes have been collapsed. Because of ice cover and remoteness, the following (sub)provinces are excluded: Cold Arctic Waters, High Arctic Maritime, Northeast Greenland shelf (NEWP), and the White Sea. Developing appropriate spatial protection in these regions is assumed to require special considerations, so these provinces should not necessarily be included in this test.

First, this test considers representativity by taking one-tenth of the value commonly advised in the scientific literature for the area that should be protected (10–50%, unweighted mean 30%; Ballantine, 1991, 1997; Carr and Reed, 1993; Roberts and Hawkins, 2000; Rodwell and Roberts, 2004; GACGC, 2006; OSPAR, 2008c, Annex II). In addition, this test infers some replication and connectivity, based on the assumption that a 3% threshold would imply that at least three MPAs are distributed within any given Dinter province and that they are well distributed. The latter part of this assumption rests upon Test 1 (see above), whereas the former part is based on examining existing patterns in the network, indicating that none of even the large MPAs account for ≥3% of a single province. Of all provinces where there are currently MPAs, all but one (Lusitanean) already have more than three, although the 3% threshold has only been met in the smallest province (Table 1; Macaronesian Azores with four MPAs and 6.1%). The Lusitanean province currently has two MPAs covering only 0.09% (Table 1). Therefore, it is reasonable to assume that, if 3% of a province is protected, it should also include several sites. Having three or more MPAs suggest that some replication may be occurring. Also, it seems unlikely that connectivity could be achieved with ≥97% of the biome unprotected.

Test 3: are most (70%) of the OSPAR threatened and/or declining habitats and species (with limited home ranges) represented in the MPA network, such that at least 5% [or at least three sites] of all areas within each OSPAR region in which they occur is protected?

This test considers the protection of threatened and/or declining species of limited mobility (for which spatial protection is likely to be effective) and habitats by taking one-tenth of the value commonly recommended as a practical minimum for spatial protection (50–60%; Rumsey *et al.*, 2004; EC, 2005). Considering the current OSPAR list, this would include 5 listed invertebrates and 14 habitats (OSPAR, 2006d). The test is by OSPAR Region rather than by biogeographic province because of the primary spatial classification used in the case reports for listing these features (OSPAR, 2006d).

The square-bracketed text is a temporary addition until the OSPAR mapping programme has been completed and is intended to be used only in regions where spatial data are not yet available. The underlying assumption is that, on average, the MPA sites would incorporate at least three patches of average size and that ~60 patches would be present in a given region.

Threatened and/or declining seabirds, though highly mobile, can be spatially linked to nesting sites as well as predictable foraging grounds. The current test does not consider their protection, which is an important gap.

Discussion

The use of simplified analyses (of any sort) inevitably raises scientific questions concerning whether such rules of thumb are ultimately supportable. On the other hand, rigorous monitoring is much more costly and often impractical, especially at broad scales such as the Northeast Atlantic. The solution to this common dilemma is to recognize that a simple initial MPA network only requires simple initial tests, but as the network develops in sophistication, so should its assessments.

The choice of these three initial tests was largely intuitive. For example, when trying to get a first impression of a given MPA network, a map providing the spatial distribution always serves as a key cue. When the map (Figure 1) is shown in public presentations, no one concludes that the OSPAR MPA network is as yet ecologically coherent, nor do I. However, if this is so obvious, why has it taken me ~2 years, off and on, and OSPAR over 4 years, to sort this question out? Can we blame it on bureaucracy? I do not think so in this case. Instead, I believe that my colleagues and I were simply unwilling to trust our eyes. The use of ecological indicators, spatial statistics, and quantitative GIS analyses was part of my background, and it seemed only appropriate that I should use my analytical training and experience to solve this knotty problem of eco-coherence. I can only hope that the 30 Assessment Guidelines developed in 2006 will be helpful sometime in the future.

It seems likely that I am not the first person to have found myself in this situation. Yet, the literature has little to say about this topic, perhaps owing to a reluctance to publish heuristics that are perceived as inferior to "purely scientifically based assessments", as one reviewer put it. Nonetheless, such scientific assessments, while preferable, may not always be possible, and alternative heuristics may be necessary to fill the gap. Given proper caveats, publishing a heuristic approach could provide helpful guidance to those in similar situations.

In response to reviewer's comments, one section explaining quick ways to estimate spatial gaps (Test 1), using a printed map and a pencil, was removed from this paper and also the OSPAR document (2008a). I agree that the section went beyond the scope of a scientific publication. Nevertheless, I remain concerned that, without such simple approaches being put forward, practitioners could mistakenly assume that costly and sophisticated analyses (such as a GIS nearest neighbour analysis) represent their only option. In my opinion, complicated implementation rather defeats the purpose of fast and frugal heuristics.

The three tests presented were first applied in 2008 as part of the annual MPA network status report (OSPAR, 2008b), requiring only very basic GIS overlap analyses. The first two tests were not met (Figure 1 and Table 1, respectively). The third test could not be applied because some CPs had not yet completed the OSPAR MPA database. The tests provided a pithy answer to the question of eco-coherence, as well as highlighting what could be done next. Although their medium- to long-term value remains to be seen, in the short term the tests appear to be fulfilling their purpose.

The development and refinement of credible scientific monitoring and analysis is interesting, but it is also safe ground for scientists. One can spend a great deal of time on details, regardless of whether they match the degree of sophistication required or help solve the question posed. Likewise, in the name of scientific completeness where nothing is to be presumed, we can find ourselves monitoring and assessing attributes of secondary or tertiary importance. Of course, there are instances where thorough scientific testing is a virtue. However, I no longer believe that this is always the case, nor do I believe that linear modelling of many indicators (e.g. through multiple regression) is a justifiable default practice. In my experience, the real world often presents us with a J-shaped distribution of signals (e.g. power–law relations), whereby just a few are key. This is really a gift that should not be ignored. It has taught us in everyday life to get by quite well with a few simple heuristics. Similarly, it should allow us as applied scientists and policy-makers to home in on just a few simple tests or indicators that will tell us a lot about what we need to know at a minimum of expense. As for the rest, the profound studies may have to wait, because meanwhile new problems that require our immediate attention are landing on our desks.

Acknowledgements

I thank the two reviewers for their helpful comments, and particularly the guest editor, Niels Daan, for his thorough editing suggestions which improved the paper greatly. I also thank the German Federal Agency for Nature Conservation for their financial support of this work.

References

Anderies, J. M. 2001. Review of: G. Gigerenzer, P. M. Todd, and the ABC Research Group. 2001. Simple heuristics that make us smart. Conservation Ecology, 5: 4. http://www.consecol.org/vol5/iss2/art4/

Ardron, J. A. 2008. The challenge of assessing whether the OSPAR Network of Marine Protected Areas is ecologically coherent. Hydrobiologia, 606: 45–53.

BALANCE-HELCOM. 2006. Joint BALANCE (Baltic Sea Management—Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning) and HELCOM (Helsinki Commission) Experts Workshop on Ecologically Coherent Network of MPAs in the Baltic Sea and the North East Atlantic, 25–27 October 2006, Helsinki, Finland. Final minutes from the meeting.

Balent, G. 1991. Options Méditerranéennes. Série Séminaires, 15: 73–81. http://ressources.ciheam.org/om/pdf/a15/92605081.pdf

Ballantine, W. J. 1991. Marine Reserves for New Zealand. University of Auckland, Leigh Laboratory Bulletin 25. 196 pp.

Ballantine, W. J. 1997. Design Principles for Systems of "No-Take" Marine Reserves. Keynote Paper, from The Design and Monitoring of Marine Reserves. University of British Columbia Fisheries Centre Research Reports, 5: 1.

Bull, K. S. E., and Laffoley, D. d'A. 2003. Networks of Protected Areas in the Maritime Environment. A report for the Review of Marine Nature Conservation and the Marine Stewardship Process on a Stakeholder Workshop, 19 June 2003, London. English Nature Research Reports, 537. 35 pp. http://www.english-nature.org.uk/pubs/publication/PDF/537.pdf

Carr, M. H., and Reed, D. C. 1993. Conceptual issues relevant to marine harvest refuges: examples from temperate marine fishes. Canadian Journal of Fisheries and Aquatic Sciences, 50: 2019–2028.

Day, J., and Laffoley, D. d'A. 2006. Self-assessment checklist for building networks of MPAs. Report for the IUCN World Commission for Protected Areas Marine Programme (WCPA-Marine). http://www.iucn.org/themes/wcpa/biome/marine/checklist.html

Dinter, W. 2001. Biogeography of the OSPAR Maritime Area. German Federal Agency for Nature Conservation, Bonn. 167 pp.

EC. 2005. Assessing conservation status of a species: general evaluation matrix per biogeographic region within a MS. Annex C, DocHab-04–03/03 rev.3, Assessment, monitoring and reporting of conservation status—preparing the 2001–2007 report under Article 17 of the Habitats Directive. Note to the Habitats Committee, 15 March 2005, Brussels.

EC. 1979. European Commission Council Directive 79/409/EEC on the Conservation of Wild Birds. http://europa.eu.int/eur-lex/en/consleg/pdf/1979/en_1979L0409_do_001.pdf

EC. 1992. European Commission Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora. http://ec.europa.eu/environment/nature/nature_conservation/eu_nature_legislation/habitats_directive/index_en.htm

GACGC. 2006. The future oceans—warming up. Rising high, turning sour. German Advisory Council on Global Change, Special report, Berlin. http://www.wbgu.de/wbgu_sn2006_en.html

Gaines, S. D., Gaylord, B., and Largier, J. L. 2003. Avoiding current oversights in marine reserve design. Ecological Applications, 13: 32–46.

Garcia-Retamero, R., and Hoffrage, U. 2006. How causal knowledge simplifies decision-making. Mind Mach, 16: 365–380.

Gigerenzer, G., Todd, P. M., and the ABC Research Group. 1999. Simple Heuristics that Make us Smart. Oxford University Press, New York. 416 pp.

Good, J. A. 1998. The Potential Role of Ecological Corridors for Habitat Conservation in Ireland: a Review. Irish Wildlife Manuals No. 2. 72 pp. http://www.npws.ie/PublicationsLiterature/AllPublications/file,2388,en.pdf

Halpern, B. S., Regan, H. M., Possingham, H. P., and McCarthy, M. A. 2006. Accounting for uncertainty in marine reserve design. Ecology Letters, 9: 2–11.

JMM. 2003. Declaration of the Joint Ministerial Meeting of the Helsinki and OSPAR Commissions. Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) and OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, 25–26 June 2003, Bremen. JMM 2003/3. www.ospar.org

Johnson, M. P., Crowe, T. P., McAllen, R., and Allcock, A. L. 2008. Characterizing the marine Natura 2000 network for the Atlantic region. Aquatic Conservation: Marine and Freshwater Ecosystems, 18: 86–97.

Laffoley, D. d'A., Brockington, S., and Gilliland, P. M. 2006. Developing the concepts of Good Environmental Status and Marine Ecosystem Objectives: some important considerations. English Nature Research Report, Peterborough. 29 pp.

OSPAR. 2003. Recommendation 2003/3 on a Network of Marine Protected Areas. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic, Meeting of the OSPAR Commission, 23–27 June 2003, Bremen. OSPAR 03/17/1-E, Annex 9, Ref. § A-4.44a. www.ospar.org

OSPAR. 2006a. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic, Meeting of the OSPAR

Commission, 26–30 June 2006, Stockholm. Meeting Document OSPAR 06/3/4, Annex B.

OSPAR. 2006b. 2005/2006 Report on the Status of the OSPAR Network of Marine Protected Areas. OSPAR Biodiversity Series, 268.

OSPAR. 2006c. Guidance on Developing an Ecologically Coherent Network of OSPAR Marine Protected Areas. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic. Reference Number 2006-3. www.ospar.org

OSPAR. 2006d. Case Reports for the Initial List of Threatened and/or Declining Species and Habitats in the OSPAR Maritime Area. OSPAR Biodiversity Series, 276.

OSPAR. 2007a. 2006 Report on the Status of the OSPAR Network of Marine Protected Areas. OSPAR Biodiversity Series, 319.

OSPAR. 2007b. Background Document to Support the Assessment of Whether the OSPAR Network of Marine Protected Areas is Ecologically Coherent. OSPAR Biodiversity Series, 320.

OSPAR. 2007c. Summary Record. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic, Meeting of the OSPAR Biodiversity Committee, 26–30 March 2007, Brussels. Meeting Document BDC 07/12/01.

OSPAR. 2007d. Guidance for the Design of the OSPAR Network of Marine Protected Areas: a Self-Assessment Checklist. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic. Reference Number 2007-6. www.ospar.org

OSPAR. 2007e. A Simple Matrix Approach to Assessing the Ecological Coherence of the OSPAR MPA Network. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic, Meeting of the Working Group on Marine Protected Areas, Species and Habitats, 5–8 November 2007, Brest, France. Meeting Document MASH 07/6/9-E, Annex 1.

OSPAR. 2007f. Results from the Questionnaire Regarding Available Spatial Data. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic, Meeting of the Working Group on Marine Protected Areas, Species and Habitats, Brest, France, 5–8 November 2007. Meeting Document MASH 07/6/5-E.

OSPAR. 2008a. Three Initial Spatial Tests Looking at the Ecological Coherence of the OSPAR Marine Protected Area (MPA) Network. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic, Meeting of the Biodiversity Committee, 25–29 February 2008, The Hague, Netherlands. Meeting Document BDC 08/4/8/1-E.

OSPAR. 2008b. Summary Record. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic, Meeting of the Biodiversity Committee, 25–29 February 2008, The Hague, the Netherlands. Meeting Document BDC 08/12/1-E.

OSPAR. 2008c. 2007 Report on the Status of the OSPAR Network of Marine Protected Areas. OSPAR Convention for the Protection of the Marine Environment of the Northeast Atlantic, Meeting of the Biodiversity Committee, 25–29 February 2008, The Hague, the Netherlands. Meeting Document BDC 08/4/8-E.

Palumbi, S. R. 2003. Population genetics, demographic connectivity, and the design of marine reserves. Ecological Applications, 13: 146–158.

Richardson, E. A., Kaiser, M. J., Edward-Jones, G., and Possingham, H. P. 2006. Sensitivity of marine-reserve design to the spatial resolution of socioeconomic data. Conservation Biology, 20: 1191–1202.

Roberts, C. M., and Hawkins, J. P. 2000. Fully Protected Marine Reserves: a Guide. WWF Endangered Seas Campaign, Washington, DC, and Environment Department, University of York, York, UK. http://assets.panda.org/downloads/marinereservescolor.pdf

Rodwell, L. D., and Roberts, C. M. 2004. Fishing and the impact of marine reserves in a variable environment. Canadian Journal of Fisheries and Aquatic Sciences, 61: 2053–2068.

Rumsey, C., Ardron, J., Ciruna, K., Curtis, T., Doyle, F., Ferdana, Z., Hamilton, T., *et al.* 2004. An ecosystem analysis for Haida Gwaii, Central Coast, and North Coast British Columbia. Report to the BC Coast Information Team. 184 pp.

Shanks, A. L., Grantham, B. A., and Carr, M. H. 2003. Propagule dispersal distance and the size and spacing of marine reserves. Ecological Applications, 13: 159–169.

STRA-REP. 1998. National and Regional Approaches for Ecological Networks in Europe. Document presented by Rob H. G. Jongman (Wageningen, The Netherlands) and I. B. Kristiansen (Roskilde, Denmark), and submitted by ECNC, 6 May 1998, Strasbourg. Committee of Experts for the Development of the Pan-European Ecological Network (STRA-REP) (98) 18. http://www.strategy-guide.org/docs/rep98e18.doc

Todd, P. M. 2007. How much information do we need? European Journal of Operational Research, 177: 1317–1332.

Todd, P. M., and Gigerenzer, G. 2007. Environments that make us smart. Current Directions in Psychological Science, 16: 3.

doi:10.1093/icesjms/fsn111