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Vegetation Condition & Vegetation Mapping II.

Design of Vegetation Condition Assessment Mapping Programme

Report to
Science Division of the Department of Environment & Conservation, Government of Western Australia

by

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Executive Summary: This reports discussed the basic features of a vegetation condition assessment system to be designed and implemented in Western Australia. The nature of assessment attributes for ground-based VC surveys are analysed. Remote-sensing technology was recognised as an indispensable tool in designing the monitoring of the VC assessment. Hyperspectral and LiDAR remote-sensing platforms are paid particular attention for their ability to collect data on vegetation structure, in quality and effectiveness surpassing the ground-based data procedures. The link between the ground-based and remote-sensed assessments remains a challenge, however, numerous examples are documenting that expanding the ground-based assessments to larges scales (up to state-wide) are not only desirable, but also possible. The Report can serve as the source document for design of modern, scientifically sound and effective vegetation condition assessment and mapping system.

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The Aims of this Report & Terms of Reference

It is the aim of this report is to provide an international review of the concept of "vegetation condition" (and related concepts) and to address several vegetation mapping related issues. The particular Terms of Reference read:

Term of Reference 1: Review the utility of the existing Western Australian vegetation map (Beard's map) and associated literature (explanatory notes) to assess vegetation condition. Basically, report on the limitations of the existing vegetation map in respect to the ability of the product to provide meaningful data for vegetation condition assessments.

Term of Reference 2: Provide a synopsis of those attributes which are pivotal in a vegetation map and associated information system for the reliable assessment of vegetation condition. These attributes should be those which you would recommend, supported by the literature, be captured in a new program of vegetation mapping for Western Australia.

Term of Reference 3: Provide recommendations on the framework or design for a new Western Australian vegetation mapping program which captures the key elements required to assess vegetation condition.

Term of Reference 4: Articulate any other issues that you see as being pertinent to vegetation condition assessment and monitoring which are related to or informed by vegetation mapping and associated supporting information systems.

In the sequel I prefer to handle Terms of Reference 3 & 4 (design of a framework for vegetation condition assessment in WA), in conjecture with the Terms of Reference 2 (addressing the general discussion of attributes pivotal to vegetation assessment element of the VIMS), and then finally addressing the Terms of Reference 1 (utility of the Beard's map in designing a system for assessment of vegetation condition).

1. Need for Vegetation Condition Assessment Programme in WA

Management of natural resources is (or should be) an important tool of national economy and is enjoying certain level of research and political priorities, especially today – in times when the world is facing consequences of uncontrolled or unwise exploitation of environment by man. Climate change, soil erosion and leaching, increasing level of toxic substances in soils, water and air, loss of drinking water resources etc. are perhaps the most important ones. Vegetation is an important renewable resource and knowing its status - where it occurs, how much and what quality is an important task for vegetation survey and important source of information for decision makers.

Under the leadership of Australian conservation biologists and ecologists, the issue of assessment of ***vegetation condition*** (for summary of definitions see Mucina 2009, Section 1) became an important focus of not only of conservation-biological research, but also of state-wide and national conservation efforts. Various state-based vegetation assessment programmes were developed and put in place (see special issue of Environmental Management & Restoration 2006 for an overview of Australian initiatives; Bleby et al. 2008 and Mucina 2009 for reviews of national and global VC assessments, respectively). The National Natural Resource Management Monitoring and Evaluation Framework (Natural Resource Management Ministerial Council 2002) established the requirement for nationally agreed indicators including one on *native vegetation condition* and the VAST system by Thackway & Leslie (2008) have suggested a nation-wide methodology to address the VC assessment.

There are manifold motivations behind and rivers of the VC assessment (e.g. Gibbons & Freudenberger 2006, Parkes & Lyon 2006 etc.), including national (conservation-political and economical) drivers of the need for condition assessment such as:

- Vegetation management planning at multiple scales,
- Reporting of progress towards strategic objectives,
- Implementation of clearing control legislation,
- Implementation of conservation incentive schemes,
- Providing basis for landowner education,

In July 2008, Department of Environment & Conservation (DEC) of the Government of WA have organised a scoping workshop to establish if there is a need for a new vegetation map of Western Australia (Burrows et al. 2008, see also Wardell-Johnson et al. 2009). The major outcome of this Workshop was the clearly recognized need for an integrated information system on vegetation resources of Western Australia (Vegetation Information Management System – further **VIMS**), which would

- encompass an ambitious but highly necessary mapping programme aimed at producing a set new biodiversity-relevant vegetation maps (further **VegMap WA**) as well as mapping product featuring vegetation status, modelled changes under various climate-change scenarios, maps of carbon sequestration etc.,
- integration of available information on vegetation into a user-friendly and publicly available data-base system, and
- integration of the vegetation information with other existing relevant sources on abiotic and biotic environment of the State.

From the onset it must be made very clear that construction of a set of maps of Western Australia featuring current (real) and reconstructed (preferably pre-1750 condition) has to be seen separately from construction of maps featuring vegetation condition assessment because of quite different goals those maps would pursue.

The vegetation maps of real and reconstructed vegetation (VegMap WA) should reflect the level of our understanding of the vegetation cover of the State from the ecological and evolutionary point of view. Such maps should be models capture the importance of the current ecological fabric (dominating hierarchy of ecological factors controlling the vegetation patterns) as well as the past florogenetic (evolutionary, biogeographic) processes which shaped the vegetation landscapes of WA. These maps would feature vegetation (either real of reconstructed) in its ideal (natural) status.

The map(s) of vegetation condition (further **VC maps**), on the other hand are special purpose maps of real (actual) vegetation informing about the relative (involving benchmarks) status of vegetation from the point of view of conservation and management of biodiversity.

Naturally, there is a number of important links between the VegMap WA and VC maps. Fist and utmost, the VegMap WA will assist as basic template for setting a VC monitoring – especially through advising the VC monitoring system about the variability of vegetation types as well as their distribution and abundance in WA. It will serve as crucial in seeking of benchmarks for VC assessment.

On the other hand, the VC maps will, in the process of approximation (improvement on existing VegMap WA products) serve as source of information in retrospective modelling. They will also yield corrective information to be implemented in future new versions of VegMap WA.

The difference between the VegMap WA and the VC maps is not only in different goal such mapping systems pursue, but also in ways (approaches, methods) how these maps can be constructed.

This Report will address theoretical and methodical issues surrounding mapping of vegetation condition, and will present basic guidelines of the design of a vegetation condition assessment programme for WA.

2. Vegetation Condition Assessment System for WA

2.1 Basic Considerations

This section responds directly to Terms of Reference 4. It will feature basic strategy which could be adopted as discussion platform to formulate detailed design of a VC assessment (monitoring) programme.

When designing a VC assessment system for WA we should consider the following facts and challenges:

1. area of WA
2. high species and vegetation diversity
3. relatively low landscape diversity

Because of the large extent of the State and associated high diversity of vegetation (despite relative flat topography and not excessive latitudinal span), each major vegetation type (the level of detail to be agreed upon) should be subject to repeated VC assessment.

4. poor cover of the State by vegetation data

At present our knowledge of the vegetation variability is limited due to poor cover of the State by hard vegetation data. Therefore as the vegetation survey of the State would progress, the design of the monitoring has to be revisited regularly and adjusted (without compromising its basic aims and set-up) to accommodate new knowledge, in particular new communities to be included into monitoring system.

5. relative lack of expertise of ground staff in VC assessment
6. low population density of WA and lack of expertise in general
7. willingness of academic community to help to mitigate

Low population density of WA, academic traditions and other social factors underpin relatively poor level of expertise to embark on the monitoring of VC without proper training programme implemented first. It is therefore imperative that the assessment criteria (attributes) will be unequivocal and simple to apply, but still satisfy the requirement of scientific rigor.

8. human disturbance on small and large scales
9. climate change as major disturbance factor

Besides natural vegetation change occurring in vegetation, we acknowledge that the major source of the vegetation change will be sought in various man-made activities causing disturbance to the natural vegetation dynamic processes. Climate change as result of human forcing should be recognised as one of the most serious disturbance the VC monitoring system should capture. This consideration is in the core of the VC assessment and success of any VC assessment lies in the proper choice of the criteria (attributes) to reflect both the natural dynamics as well man-made disturbance. The criteria must be scientifically rigorous – they must reflect the current ecological knowledge. The choice of such criteria is not a trivial matter and should not be left to decision by a single scientific personality. Here I would suggest formation of a task team composed of scientists, decision makers and representatives of other stake-holder groups to identify such criteria. We should learn from the mistakes made in the past (see Mucina 2009) and do not allow short-cuts to dictate the level of scientific rigor. It is obvious that some of these processes are extremely difficult to capture (assess or measure) and therefore the choice of proxies and/or indicators should be paid a special attention. Equal attention should be paid to the data handling and interpretation which should follow scientifically rigorous data-analytical, yet transparent procedures. I tend to suggest use of multiple final outcomes (indices) reflecting the level to which vegetation responded to particular processes, rather than seek one "all-in-one" solution to capture the VC.

10. political will to conserve vegetation resources
11. social interest to exploit vegetation resources

Because of the obvious importance of biodiversity and vegetation for the human population of the State (and worldwide), the VC monitoring should become a permanent feature of the resource management activities of the State government. It should be set up as long-term monitoring programme and regular (and assured) budget should be allocated to run such an important enterprise.

Taken into consideration collected in 11 points above, I believe that a viable VC assessment system for WA must follow five Principles by being

- **Scientifically sound**
  It must be built on the level of knowledge in many fields, plant ecology, biogeography, vegetation science, data analysis in particular. It must not allow any mathematically unacceptable short-cuts or strike politically-motivated compromises on the costs of scientific rigor.
- **Hierarchically designed**
  It should combine the virtues and resolution power of ground-based research, modelling, and remote-sensing. In this way the VC assessment system will be able to respond to manifold spatial scales, albeit in different detail.
- **Temporary responsive**
  It should incorporate strong monitoring element to allow detection of trends over time – hence it must be designed as monitoring system.
- **Feasible**
  The selection of parameters (indicators) as well as data-analytical procedures must be done in a way to allow well-standardized ground-based data collection and data-evaluation and presentation.

- **Afforbadle**
  Because of the long-time commitment, huge size of the State and the biotic complexity, financial backing for future should be well-planned and provided for.

2.2 Suitability of Existing VC Assessment Systems

Based on the report by Bleby et al. (2008) and my own review of the methodology used on global scale (Mucina 2009), there is currently **no** VC assessment system which I would recommend the nature-conservation authorities of WA to take over without serious modifications.

In my report (Mucina 2009) I have classified the VC assessment approaches according to the nature of the reporting indices into – class-based and index-based approaches.

The class-based assessment systems (such as hemeroby, Favourable Conservation Status of European Union, VAST of Thackway & Lesslie 2008; see Mucina 2009 for detail accounts) use very informal approach by defining classes (status) characterised by various levels of human influence on vegetation.

Advantages:
- well-suited for “one-off” assessments if scientific rigour or precision is not a priority;
- usually refrain from (often very problematic) calculations of final-score.

Disadvantages:
- they usually use very subjective criteria or define the criteria in fuzzy and non- unequivocal way;
- they are labour-intensive and strictly only ground-based (hence do not provide for remote-sensing based monitoring);
- suited more for small-scale assessments than country-wide assessments.

The index-based assessment systems (such as Habitat Hectares of Parkes et al. 2003 and related systems – see Section 3 in Mucina 2009) use fix set of biodiversity indicators (variables serving as surrogates for biodiversity) which are then summarised into a final score.

Advantages:
- striving for more precise field assessment by choosing standardised set of criteria;
- amenable to spatial modelling for purposes of extrapolation of the point assessments to larger areas;

- possibility of screening many of the relevant biodiversity surrogates using remote-sensing technology.

Disadvantages:

- strive for unrealistic calculation of “final score” – a sort of silver bullet suppose to summarise effect of many factors into one most informative index;
- mathematical monstrosities (wrong application of arithmetic calculus) in attempt to produce the final-score;
- problems to decide on appropriate ground-based indicators (surrogate variables) supposed to reflect the ecological and evolutionary processes underpinning the vegetation condition and its dynamics.

2.3 Western Australian Way of Assessing Vegetation Condition

The analysis of Advantages and Disadvantages listed above suggest that the index-based approach to assess VC in WA would be a better choice. The suggestion to follow Five Principles (see Section 2.1 above) implies that we have to make decision about the following steps in the first place:

1) Should the VC assessment system be ground-based, model-based or remote-sensing based (or compromise incorporating all of these)?
2) Which ground-based surrogates (if any) are reflecting best the complexity of WA vegetation?
3) Do we need to set assessment benchmarks?
4) Which remote-sensing tools (if any) should we apply?
5) How to link the ground-based and remote-sensing assessments?
6) What is the nature of our reporting targets – classes, final score, set of independent indices?

These crucial decisions will be discussed below.

2.3.1 Ground Assessment or Remote-Sensed Assessment?

Gibbons et al. (2006) recognised three broad approaches employed to assess vegetation condition:

1) On-ground assessment. The field-based (or ground-based) assessment as this approach often dubbed, is (can be) very detailed and able to capture elements or screen for indicators which are unfeasible to capture using remote-tensing tools. It is, however, expertise and labour intensive – hence can become extremely expensive if large areas are to be covered. Repeated assessment (the core business of monitoring) becomes problematic when expert judgement is involved (leading unavoidably to deviations in sampling design). Long-term financial commitment of the size usually required for the ground is not always available. In summary, it can be accurate at fine scales, but can be impractical for assessment and monitoring across broad scales.

2) Spatial modelling. This approach can be seen as hybrid of the on-ground assessment and remote-sensing (see below), however it heavily relies on the quality of the field data and suitability of the model. Using expert knowledge (Thackway & Lesslie 2006), environmental predictors (Newell et al. 2006) or a combination of environmental predictors and data from remote sensing platforms (e.g. Simpson 2006, Zerger et al. 2006) the on-ground (site-based) assessments of vegetation condition can be spatially interpolated at predicted for at a coarse scales over large areas (Gibbons et al. 2006).

3) Remote sensing. Remote-sensing assessment is (can be) fast and automatised to a high degree. Hence it is well suited for fast and repeated screening of large areas (also called monitoring). Monitoring is a central component of good conservation management (Sheil 2001). Still the demand on expertise (especially in interpretation of the data) cannot be by-passed can actually become a considerable portion to the costs of a project. Cost of the remote-sensing can also be an issue, especially if the remote-sensed data are not of classical commercial type, especially in cases when special (spatially high-resolution sensors have to be flow just for exclusive purpose of the project.

Conclusion: Each field ecological sampling design is a result of two basic elements – the aim and the means (Kenkel et al. 1989). If the aims are clear and common, it is the “means” which determine further decisions. In case of the VC assessment there is a clear trade-off between intensive and extensive approach (in other words, the dichotomic decision is the one between the precision and generality). However, each of the approaches has its advantages and disadvantages, and obviously still an alternative (my preferred) way would be to pick and expand on the advantages to create an optimal compromise.

The concept of VC implies *time scales* (vegetation is changing - acquires various stages of condition over times scales) and *spatial scales* (vegetation is a spatial phenomenon – covers stretches of lands and varies from place to place). With all academic issues surrounding the definition of both time and spatial scales and their utility aside, from the nature management point of view, the concept of VC makes sense only if (a) it is linked to an appropriate, scientifically sound and economically feasible, monitoring programme (in other words, VC has to be assessed repeatedly to depict trends and other temporal patterns) and (b) if such monitoring accounts for the spatial variability of vegetation (in other words considers hierarchical nature of vegetation complexity).

I am therefore suggesting embarking on design of a hierarchical VC assessment system which would combine *less detailed (more precise) remote-sensing* based monitoring of the entire State, while zooming on selected set of plots for *more* *detailed (less precise) ground-based* assessment. The modelling approach should be also widely adopted for specific testing purposes.

2.3.2 Ground-Based Surrogates?

Choice of the assessment attributes (also called “biodiversity surrogates” in case they are supposed to describe the dynamics of the biodiversity patterns if biodiversity is the focus of the assessment) is crucial to the success of the assessment. Ground-based assessments usually rely on the classification by Noss (1990) who discerned attributes of three types – those related to *composition, structure*, and *function*. In vegetation science the composition and structure relate to *pattern*, while function relates to *process*.

Composition is sometimes termed “texture” (Barkman 1979) and relates to presence of taxonomic (systematic) or other special functional groups – one can call them guilds (e.g. weedy species, pollinators, parasitic species etc.) or more generally plant functional types. In fact I wish to suggest that the consequent use of plant functional types has been paid so far insufficient attention in selecting the assessment attributes, despite their obvious functional relevance and sometimes simpler (than taxa) ecological message conveyed.

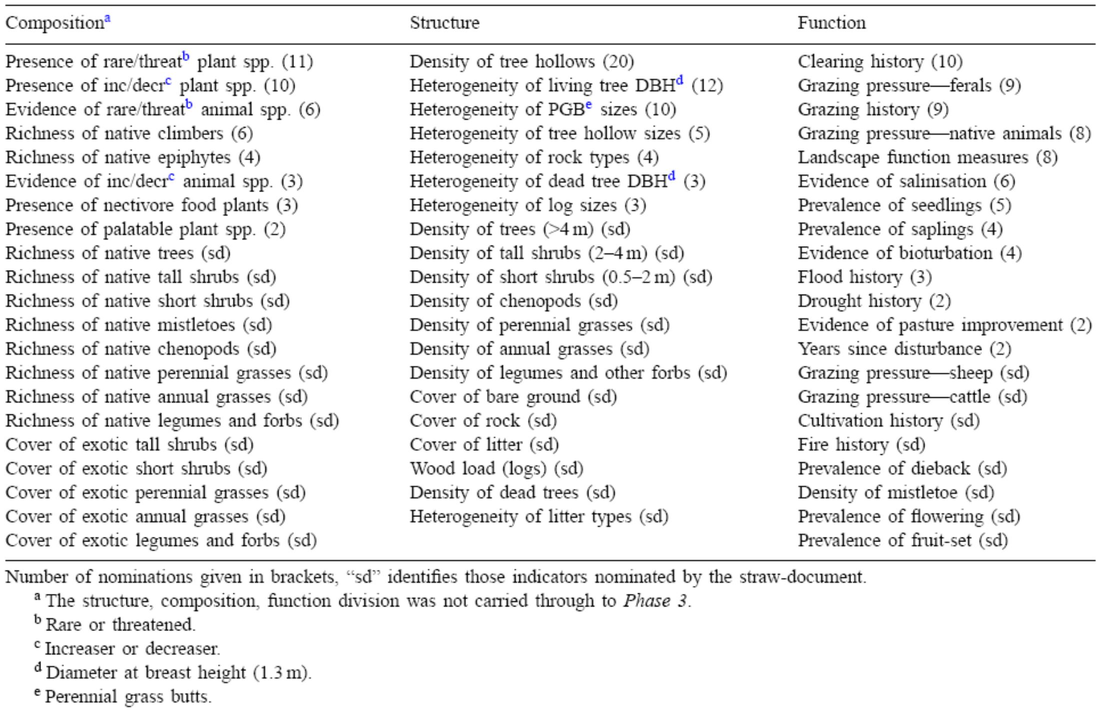
Structure refers to the vertical layering (presence of various layers) of the assessed plant communities or aspects of horizontal pattern, (usually including plant density and nature of patchiness) or presence of microhabitats (hollow trees, rocks on surface) increasing the complexity of the assessed vegetation.

While the former two groups of attributes are quite far fetched form the ecological and evolutionary processes, the attributes of Function are supposed to address the ecological (and perhaps also evolutionary) processes much more intimately. Their choice is therefore of utmost importance as it should reflect the matrix of ecological processes controlling the functioning of the assessed ecosystem as well as should reflect disruptive processes underpinning to the changes in vegetation condition levels.

Table 1 illustrates two examples of such attribute lists (Oliver 2002 and Gibbons & Freudenberger 2006, respectively). A comparison of these two tables reveals that sometimes there is disagreement on how to classify the attribute. For instance Oliver (2002) considers “cover” of special functional groups as attributes of “Composition”, while Gibbons & Freudenberger (2006) consider “cover by plant life form” as part of “Structure”. I would suggest that the latter is wrong since plant life forms represent special type of plant functional group (Lavorel et al. 1997) and their spatial organization does not necessarily follow strict spatial arrangement rules.

Correct choice of the VC assessment attributes depend son many circumstance of which the full understanding of the pattern formation and functioning of the

A)



Composition[a]	Structure	Function
Presence of rare/threat[b] plant spp. (11)	Density of tree hollows (20)	Clearing history (10)
Presence of inc/decr[c] plant spp. (10)	Heterogeneity of living tree DBH[d] (12)	Grazing pressure—ferals (9)
Evidence of rare/threat[b] animal spp. (6)	Heterogeneity of PGB[e] sizes (10)	Grazing history (9)
Richness of native climbers (6)	Heterogeneity of tree hollow sizes (5)	Grazing pressure—native animals (8)
Richness of native epiphytes (4)	Heterogeneity of rock types (4)	Landscape function measures (8)
Evidence of inc/decr[c] animal spp. (3)	Heterogeneity of dead tree DBH[d] (3)	Evidence of salinisation (6)
Presence of nectivore food plants (3)	Heterogeneity of log sizes (3)	Prevalence of seedlings (5)
Presence of palatable plant spp. (2)	Density of trees (>4 m) (sd)	Prevalence of saplings (4)
Richness of native trees (sd)	Density of tall shrubs (2–4 m) (sd)	Evidence of bioturbation (4)
Richness of native tall shrubs (sd)	Density of short shrubs (0.5–2 m) (sd)	Flood history (3)
Richness of native short shrubs (sd)	Density of chenopods (sd)	Drought history (2)
Richness of native mistletoes (sd)	Density of perennial grasses (sd)	Evidence of pasture improvement (2)
Richness of native chenopods (sd)	Density of annual grasses (sd)	Years since disturbance (2)
Richness of native perennial grasses (sd)	Density of legumes and other forbs (sd)	Grazing pressure—sheep (sd)
Richness of native annual grasses (sd)	Cover of bare ground (sd)	Grazing pressure—cattle (sd)
Richness of native legumes and forbs (sd)	Cover of rock (sd)	Cultivation history (sd)
Cover of exotic tall shrubs (sd)	Cover of litter (sd)	Fire history (sd)
Cover of exotic short shrubs (sd)	Wood load (logs) (sd)	Prevalence of dieback (sd)
Cover of exotic perennial grasses (sd)	Density of dead trees (sd)	Density of mistletoe (sd)
Cover of exotic annual grasses (sd)	Heterogeneity of litter types (sd)	Prevalence of flowering (sd)
Cover of exotic legumes and forbs (sd)		Prevalence of fruit-set (sd)

Number of nominations given in brackets, "sd" identifies those indicators nominated by the straw-document.

[a] The structure, composition, function division was not carried through to *Phase 3*.

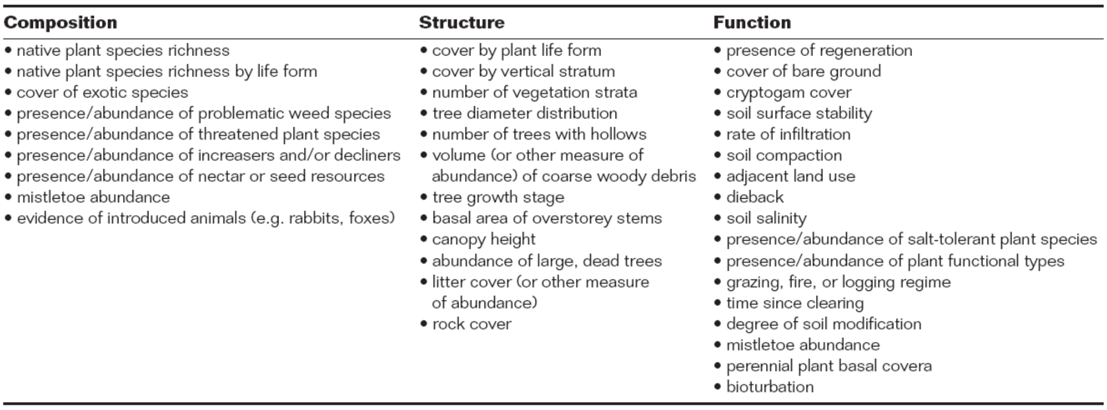
[b] Rare or threatened.

[c] Increaser or decreaser.

[d] Diameter at breast height (1.3 m).

[e] Perennial grass butts.

B)



Composition	**Structure**	**Function**
• native plant species richness • native plant species richness by life form • cover of exotic species • presence/abundance of problematic weed species • presence/abundance of threatened plant species • presence/abundance of increasers and/or decliners • presence/abundance of nectar or seed resources • mistletoe abundance • evidence of introduced animals (e.g. rabbits, foxes)	• cover by plant life form • cover by vertical stratum • number of vegetation strata • tree diameter distribution • number of trees with hollows • volume (or other measure of abundance) of coarse woody debris • tree growth stage • basal area of overstorey stems • canopy height • abundance of large, dead trees • litter cover (or other measure of abundance) • rock cover	• presence of regeneration • cover of bare ground • cryptogam cover • soil surface stability • rate of infiltration • soil compaction • adjacent land use • dieback • soil salinity • presence/abundance of salt-tolerant plant species • presence/abundance of plant functional types • grazing, fire, or logging regime • time since clearing • degree of soil modification • mistletoe abundance • perennial plant basal covera • bioturbation

Tab. 1. Two examples of lists of VC assessment attributes divided into 3 categories (composition, structure and function) (A after Oliver 2002; B after Gibbons & Freudenberger 2006).

assessed ecosystem is crucial. Because the knowledge of functioning of an ecosystem is usually a matter of specialist expertise, probably the most viable (and reliable) way to compile representative list of attributes is to involve a group of experts. For a good example of such approach see Oliver (2002). Another important consideration in choice of the attributes is the level of potential bias during the field sampling which might result from unequivocal definition of the attribute. Ill-defined attribute or attribute particularly prone to observer's error can lead to large variability of opinions in field assessment which in turn may have gross implications for biodiversity conservation (Gorrod & Keith 2009).

Conclusion: Selection of assessment attributes is a crucial step of the VC assessment and the careful consideration of the functional attributes should be paid particular attention. The selection should be done by a group of experts. The current attribute lists are heavily biased towards more complex vegetation (woodlands, forests) and neglect to some extend vegetation of shrublands and grassland. They are inappropriate for assessment of special (azonal) vegetation types such as salt marshes, succulent chenopod scrub, small-scale wetlands, epiphytic vegetation per se, vegetation of rocky surfaces, coastal dunes and the like. I would therefore suggest considering compilation of special list of attributes particular to each major vegetation type to reflect the peculiarities of the processes underpinning pattern formation under different textural and structural conditions.

2.3.3 Setting Benchmarks

Vegetation condition is a relative (comparative) concept and the comparative analysis is based on relating the assessed vegetation with comparable vegetation showing relatively unmodified, nominally pristine or fully functional conditions. The latter vegetation patch (or plot) is called *benchmark* supposed to be in *reference condition* (usually understood as benchmark of a biodiversity surrogate or condition variable). According to Gibbons & Fredenberger (2006) the use of reference conditions rests on the premise that biotic communities are generally better adapted to, and an ecosystem as a whole functions better within, environments with relatively little contemporary anthropogenic modification (Landres et al. 1999), that an ecosystem is more resilient within its natural range of variation (Holling & Meffe 1996), or that ecosystems have intrinsic value and therefore restoration should strive to return them to their historic trajectory (Society for Ecological Restoration International Science and Policy Working Group 2004).

Setting a benchmark is far form being a trivial matter. Roughly three approaches different types of benchmarks can be distinguished, including those

a) **hypothetical** including for instance the Hopkins' (1990) "pre-1750" condition,
b) **theoretical/modelled** including the prominent examples of " ungrazed climax" in rangeland condition assessments (Laycock 1975, Wilson 1984) or "potential

natural vegetation" (PNV) which is implicitly considered as benchmark in hemeroby schemes (see Mucina 1990, Section 2.1 for detailed account), and
c) **real**, under which heading I would summarize all those attempts to use real (extant) vegetation in relatively undisturbed (or best preserved) status (see for instance Parkes et al. 2003).

Besides, one can distinguish benchmarks according to their complexity – single (though sometimes including a span of variability) or multiple which implicitly account for the variability of the benchmarked surrogate.

All there types of benchmarks are contentions and motivated serious discussion. Oliver et al. (2002) submitted the use of a pre-1750 basis for deriving benchmarks to heavy criticism and articulated four major objections against its use. They argue that

- the models are likely to be least accurate for those vegetation types of most concern for biodiversity conservation (= those that are geographically restricted or have been most heavily degraded, cleared and fragmented);
- routine adoption of the pre-1750 condition/distribution and naturalness concepts, at the site level, may lead to a devaluing (from the point of view of biodiversity conservation) of native vegetation that differs in type from that predicted to have existed on-site in 1750;
- the use of pre-1750 benchmarks and vegetation mapping at particular locations may lead to attempts to restore a modelled vegetation type to what may now be an unsuitable location due to significant and effectively irreversible changes in fire regime, soil structure, fertility, salinity, flooding regime and/or ground-water level; and
- Naturalness concepts are philosophically complex and largely developed for application to large unmodified landscapes and therefore are not necessarily consistent with the most effective biodiversity conservation outcomes in highly modified landscapes.

The climax notions and related benchmark settings using PNV can either directly refer to overcome equilibristic paradigm of Clementsian monoclimatic climax or invokes the notion directional development of vegetation to unique "final" status. This happens especially if the range of variation represented in the benchmark does not include the alternative states that an ecosystem may exhibit with environmental variation (Landres et al. 1999) or natural disturbance (McCarthy et al. 2004).

Using "real" (following the terminology introduced above) vegetation relative undisturbed by anthropogenic influence as source of benchmarks has also not been spared criticism, especially if the setting of the benchmarks involves single-value thresholds. One of the major critical points rose by McCarthy et al. (2004) when discussing the drawbacks of the Habitat Hectares approach (Parkes et al. 2003) related to lack of consideration of role of natural disturbance in shaping current vegetation patterns.

Conclusion: Benchmark (reference condition) is an indispensable tool of vegetation assessment. The choice of the benchmark is critical to as it may influence the outcome of the vegetation condition assessment to a very large degree. The last word of discussion around benchmarks has not been said, but I would tend to set standards of setting the benchmarks which would (1) be based on current, relatively less disturbed vegetation, (2) consider the effect of natural disturbance factors in controlling formation of vegetation patterns, and (3) which would not be based on single benchmark value, but rather consider the natural variability of the target condition variable. From this point of view the method of rapid quantification of reference condition (Gibbons et al. 2008) using predictive (GAM) modeling appears as a very promising step forward.

2.3.4 Use of Remote-Sensing Tools & Monitoring

Possibilities of remote-sensing tools in conservation assessments

Ground-based data collection is and remains for a long time the most frequently used tool of vegetation condition assessment. It is, however, often loaded with bias (selection of attributes, sampling precision) and very costly if the assessment is part of monitoring programme requiring repeated and often large-scale sampling (see Kerr & Ostrowsky 2003, Turner et al. 2003). Remote-sensing might be an answer to mitigate some of the problems, especially the issues of bias and reduction of cost of repeated sampling. Satellite platforms and sensors born of aircrafts can assist in quick, effective and bias-free sampling of number of biodiversity relevant attributes. Yes, the remote-sensing cannot be seen as the silver bullet supposed to solve all our headaches. In case of vegetation condition assessment, the actual power of remote-sensing is not in technical sophistication of the data collection, but rather in complementarity to the ground-based assessment.

Numerous recent reviews have canvassed clearly the advantages of using remote sensing in disciplines relevant to VC assessment, including conservation-oriented research (Yoccoz et al. 2001, Lefsky et al. 2002, Kerr & Ostrowsky 2003, Turner et al. 2003, McDermid et al. 2005, Pettorelli et al. 2005) or nature resources-oriented research (Franklin & Wulder 2002, Wallace et al. 2004, Boyd & Danson 2005, Gillespie et al. 2008, Xie et al. 2008).

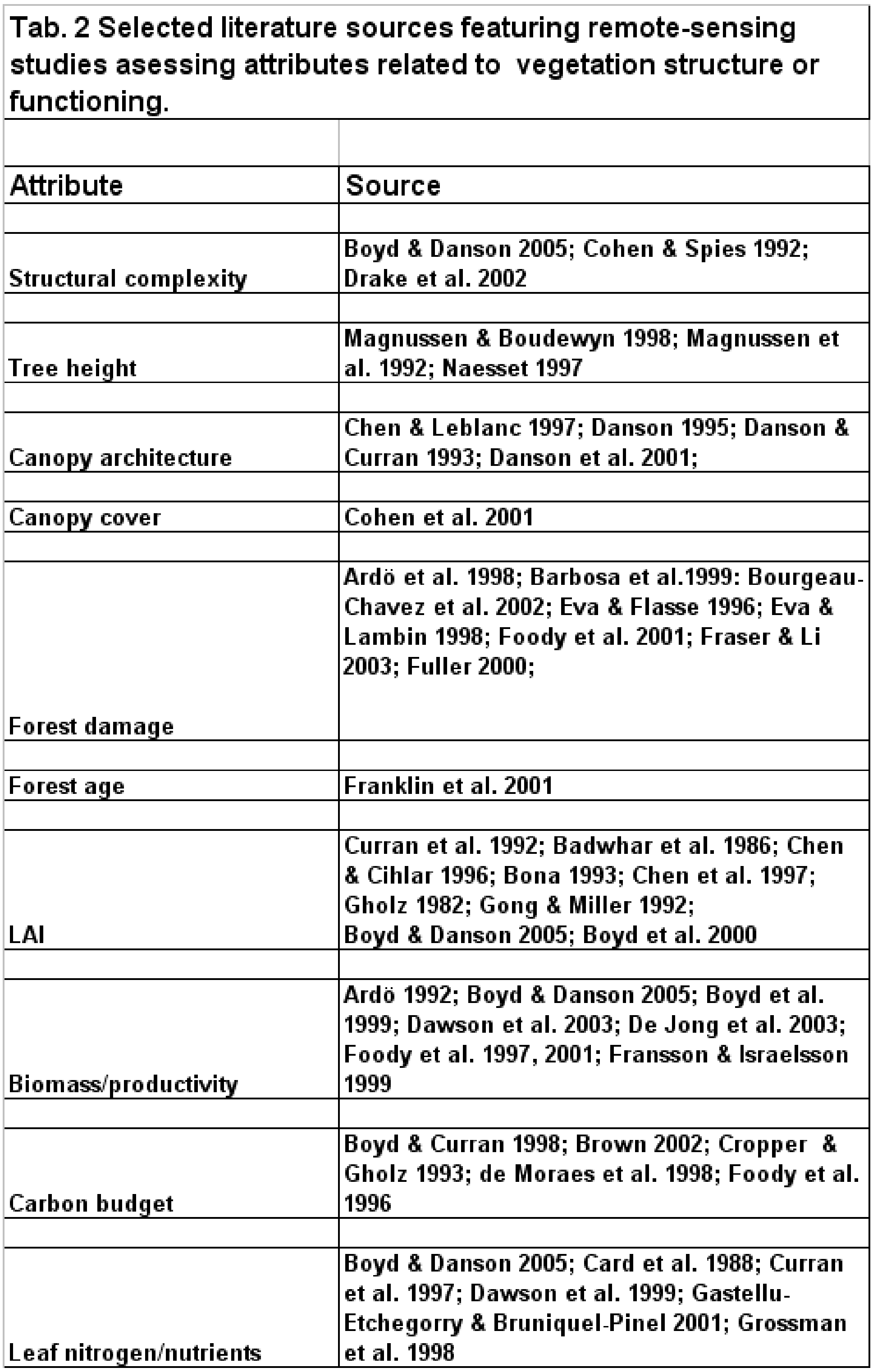
The scale of possibilities of remote-sensing to assist VC assessment are dependent on technical possibilities of the particular sensors (for a synoptic overview of the sensors, spatial and spectral resolution see Box 1 in Kerr & Ostrowsky 2003 and Table 1 in Turner et al. 2003). It is beyond the scope of this Report to review applications of remote-sensing in assisting research of biodiversity assessment. In the sequel I shall confine the discussion and conclusion only to several basic applications, such as the use of remote-sensing in (1) recognition of (dominant) species, (2) collection of data on vegetation structural complexity, and (3) collection of proxy data to model biodiversity patterns in space. Kerr & Ostrovsky (2003) listed a number of other ecological (and conservation-relevant) applications, such as identifying and detailing the biophysical characteristics of species' habitats, predicting the distribution of species and spatial variability in species richness, and detecting natural and human-caused change at scales ranging from individual landscapes to the entire world. Some of these have direct bearing on the selected aims of remote-sensed data collection I wish to discuss.

Remote-sensed Recognition of Species

Recording and recognizing dominant (structurally important) species is usually one of basic attributes ground-based VC assessment. Nowadays the advances in the spatial and spectral resolutions of sensors are making the direct remote-sensed identification of dominant (for instance canopy building) species as well as identification of individual large plant individual such as trees and shrubs possible. Besides the obligatory expert knowledge of the species identity for calibration purposes, this approach requires assistance of hyperspectral sensors. The hyperspectral sensors slice the electromagnetic spectrum into many more discrete spectral bands than commercial satellite platforms such as SPOT4 or LANDSAT, enabling the detection of spectral signatures that are characteristic of certain plant species or communities. Turner et al. (2003) listed for instance the IKONOS system from Space Imaging and the QuickBird system from DigitalGlobe as (offering multispectral imagery at resolutions of 4 m and 2.4–2.8 m, respectively, and panchromatic imagery at 1 m and 0.6–0.8 m, respectively) as platforms able to deliver. See papers by Clark et al. (2005), Schlerf et al. (2005) and Tickle et al. (2006) as examples for applications of remote-sensing technology to recognize species.

Remote-sensed Data on Vegetation Complexity in Service of VC Assessment

Hyperspectral remote sensing have been found to be useful not only to map canopy species, but also to measure a whole array of vegetation-structural attributes suppose to serve as proxy for biodiversity parameters (Roff et al. 2006; Table 2 in this Report). Laser altimetry or light detection and ranging platforms (LiDAR), are a novel remote sensing technology promising to both increase the accuracy of biophysical measurements and to extend spatial analysis into the third dimension. LiDAR sensors directly measure the three-dimensional distribution of plant canopies as well as subcanopy topography, thus providing high resolution topographic maps and highly accurate estimates of vegetation height, cover, and canopy structure (Lefsky et al. 2002; see also Fig. 1). The LiDAR data describing vegetation structure are not only used for calculation of biomass (such as often targeted in forests and woodlands) or grass cover (hence potential fodder) in rangelands (e.g. Ritschie et al. 1992), but can be used as proxies for the vegetation complexity, available niches for animal diversity using the forest layers and the like.



Tab. 2 Selected literature sources featuring remote-sensing studies asessing attributes related to vegetation structure or functioning.

Attribute	**Source**
Structural complexity	Boyd & Danson 2005; Cohen & Spies 1992; Drake et al. 2002
Tree height	Magnussen & Boudewyn 1998; Magnussen et al. 1992; Naesset 1997
Canopy architecture	Chen & Leblanc 1997; Danson 1995; Danson & Curran 1993; Danson et al. 2001;
Canopy cover	Cohen et al. 2001
Forest damage	Ardö et al. 1998; Barbosa et al.1999: Bourgeau-Chavez et al. 2002; Eva & Flasse 1996; Eva & Lambin 1998; Foody et al. 2001; Fraser & Li 2003; Fuller 2000;
Forest age	Franklin et al. 2001
LAI	Curran et al. 1992; Badwhar et al. 1986; Chen & Cihlar 1996; Bona 1993; Chen et al. 1997; Gholz 1982; Gong & Miller 1992; Boyd & Danson 2005; Boyd et al. 2000
Biomass/productivity	Ardö 1992; Boyd & Danson 2005; Boyd et al. 1999; Dawson et al. 2003; De Jong et al. 2003; Foody et al. 1997, 2001; Fransson & Israelsson 1999
Carbon budget	Boyd & Curran 1998; Brown 2002; Cropper & Gholz 1993; de Moraes et al. 1998; Foody et al. 1996
Leaf nitrogen/nutrients	Boyd & Danson 2005; Card et al. 1988; Curran et al. 1997; Dawson et al. 1999; Gastellu-Etchegorry & Bruniquel-Pinel 2001; Grossman et al. 1998

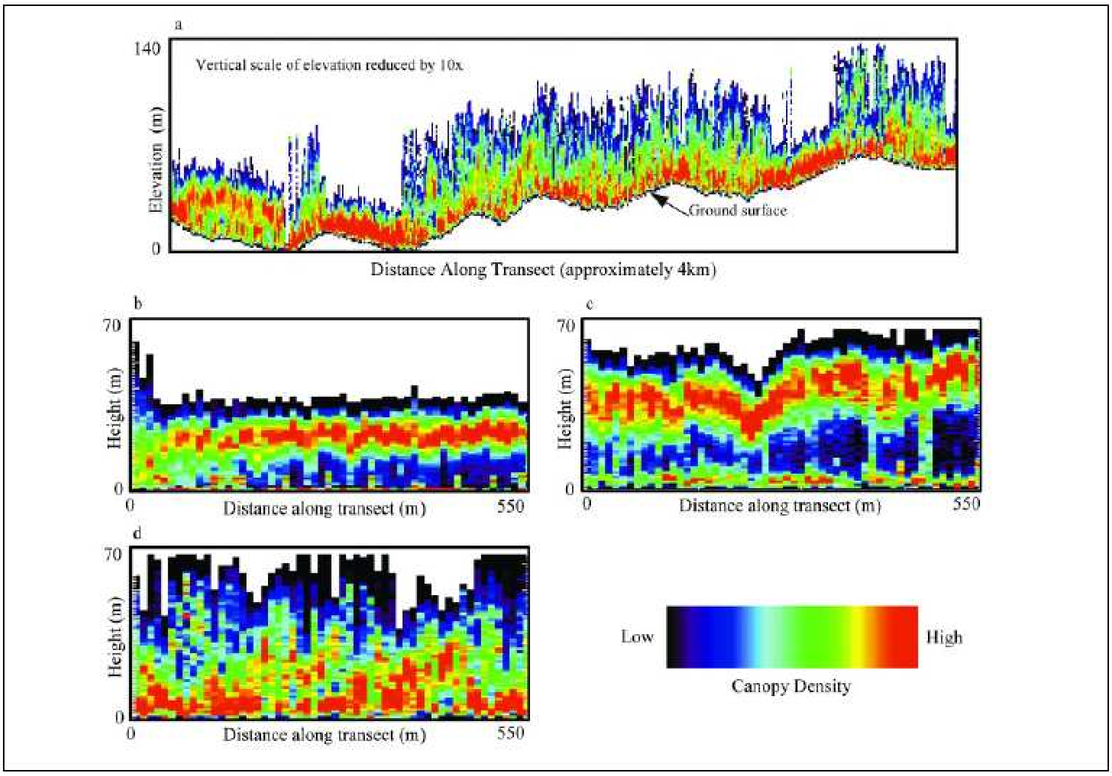


Fig. 1. Measurements of canopy structure made using NASA's SLICER (Scanning Lidar Imager of Canopies by Echo Recovery) device. Panel a shows ground topography and the vertical distribution of canopy material along a 4-km transect in the H. J. Andrews Experimental Forest, Oregon. Each column is the width of one laser pulse waveform. Panels b, c, and d show close-ups of the canopies of three 550-m transects in young, mature, and old-growth Douglas fir–western hemlock forest stands, with their ground elevations adjusted to a uniform level (after Lefsky et al. 2002).

Lim et al. (2003) has shown that a LiDAR can provide data on many attributes; they listed maximum tree height, Lorey's mean tree height, mean diameter at breast height, total basal area (BA), percent canopy openness, leaf area index (LAI), ellipsoidal crown closure, total aboveground biomass, total wood volume and stem density – an impressive set of variables describing forest structure to a great detail and allowing for predicting the species diversity and other biodiversity-relevant parameters. LiDARs need not be only air-borne, but their round-based alternatives (such as the CSIRO's ground-based laser called Echidna - see Lovell et al. 2003, Jupp et al. 2009 for application) proved to be of great value, especially when combined with an airborne scanner.

Indirect Biodiversity Assessment Using Remote-sense Proxies

Both classical satellite platforms (such as LANDSAT, SPOT4) as well as hyperspectral aircraft borne platforms have been extensively used to collect data on various aspects of vegetation quality. Number of "vegetation indices", such as NDVI and related have been devised and used as proxies to measure important vegetation-structural parameters such as LAI (Leaf Area Index, biomass, productivity, phenology and the like). Many remote-sensing platforms have been diligently collecting information on other qualities of the environment, including geology, soil texture, climate, fire frequency and the like. Linking the information on vegetation and habitat properties with ground-based data on occurrence of species (and species assemblages) opens new possibilities for vegetation condition assessment in particular and conservation biology in general. The vegetation quality (indices such as NDVI) and the environmental parameters can serve then as proxies in prediction of VC assessment attributes through modeling. Two examples should document the rationale of this approach, and demonstrate its use to deliver data on attributes relevant to VC assessment.

Saatchi et al. (2008) modeled distribution of Amazonian tree species and alpha diversity suing remote-sensing sensors such as MODIS, QSCAT, SRTM and TRMM. As the first step they have used these sensors to develop a set of environmental variables related to vegetation, landscape and climate (see Fig. 2). These variables are used in a maximum entropy method (Maxent) to model the geographical distribution of five commercial trees and to classify the patterns of tree alpha-diversity (Fig. 3) in the Amazon Basin. Among satellite data products, QSCAT backscatter, representing canopy moisture and roughness, and MODIS leaf area index (LAI) were identified as the most important variables in the modeling. Wohlgemuth et al. (2005) set themselves an ambitious goal to model vascular plant diversity at the landscape level for the whole of Switzerland. They used Generalized Linear Models to correlate species richness of vascular plants (ascertained on the ground) with three sets of variables: topography, environment and land cover. Regression models were then constructed by the following process: reduction of collinearity among variables, model selection based on Akaike’s Information Criterion, and the percentage of deviance explained. A synthetic model was then built using the best variables from all three sets of variables. Finally, the best models were used in a predictive mode to generate maps of species richness (Fig. 4) at the landscape scale using the moving window approach. Wohlgemuth et al. (2005) found that the best explanatory model consisted of seven variables including 14 linear and quadratic parameters, and explained 74% of the deviance. The authors further concluded that the approach involved using consistent samples of species linked to information on the environment at a fine scale enabled landscapes to be compared in terms of predicted species richness – a useful result to support the development of national nature conservation strategies. Beta-diversity patterns at landscape level were modeled using very similar approach by Feilhauer & Schmidtlein (2009).

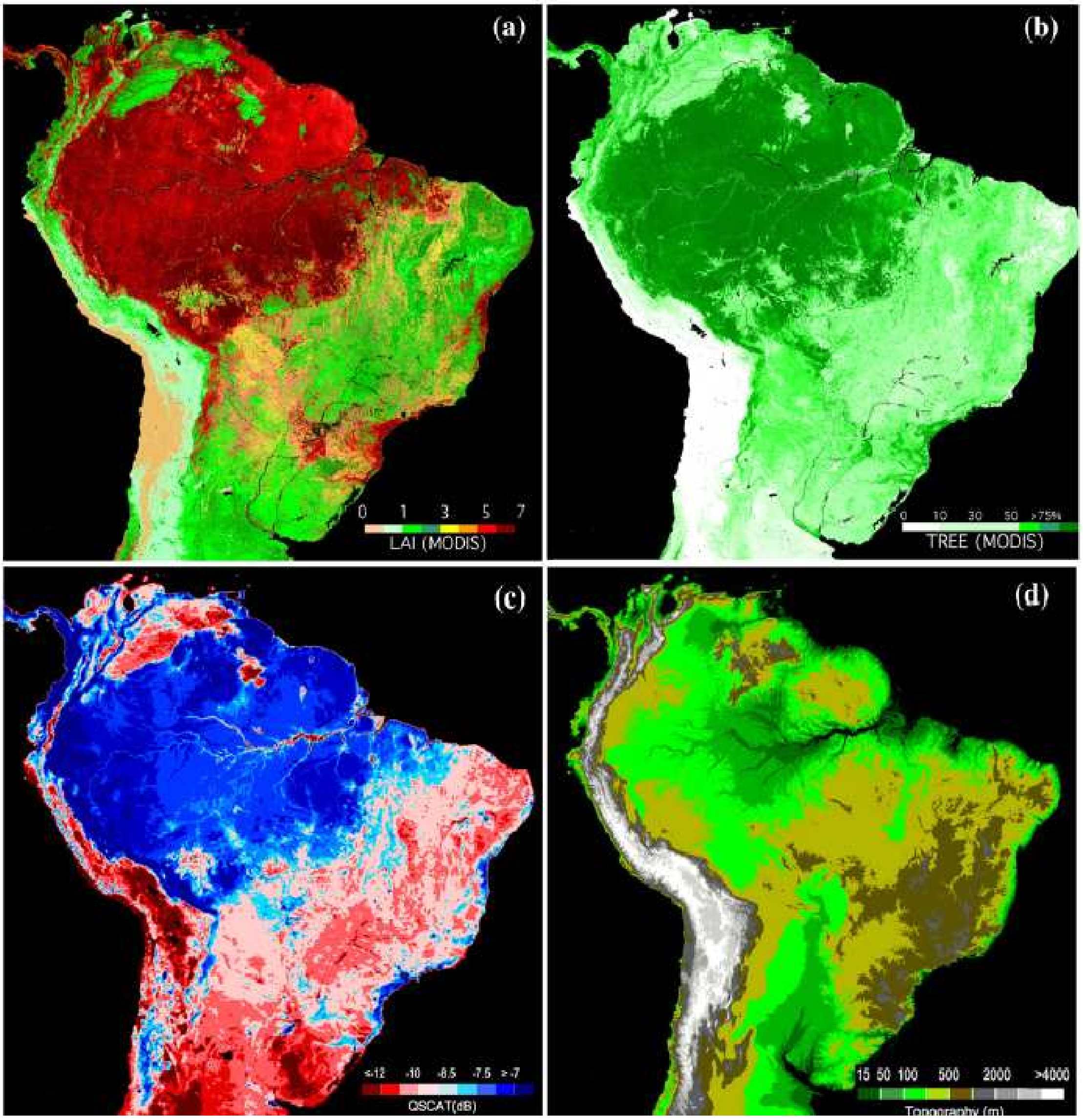


Fig. 2. A selection of the remote sensing data layers used in this study. The panels show (a) MODIS LAI annual maximum, (b) MODIS percentage tree cover, (c) QSCAT annual mean, and (d) mean elevation from SRTM 9after Saatchi et al. 2008).

Search for linking remote-sensed vegetation indices to patterns of species diversity on the ground is a vibrant field (Schmidtlein & Sassin 2004, Waser et al. 2004, Rocchini et al. 2005, 2009, Levin et al. 2007, Rocchini 2007a, b, Gillespie et al. 2008, He & Zhang 2008, He et al. 2009 etc.) receiving new impetus can be expected with introduction of new, more powerful sensors.

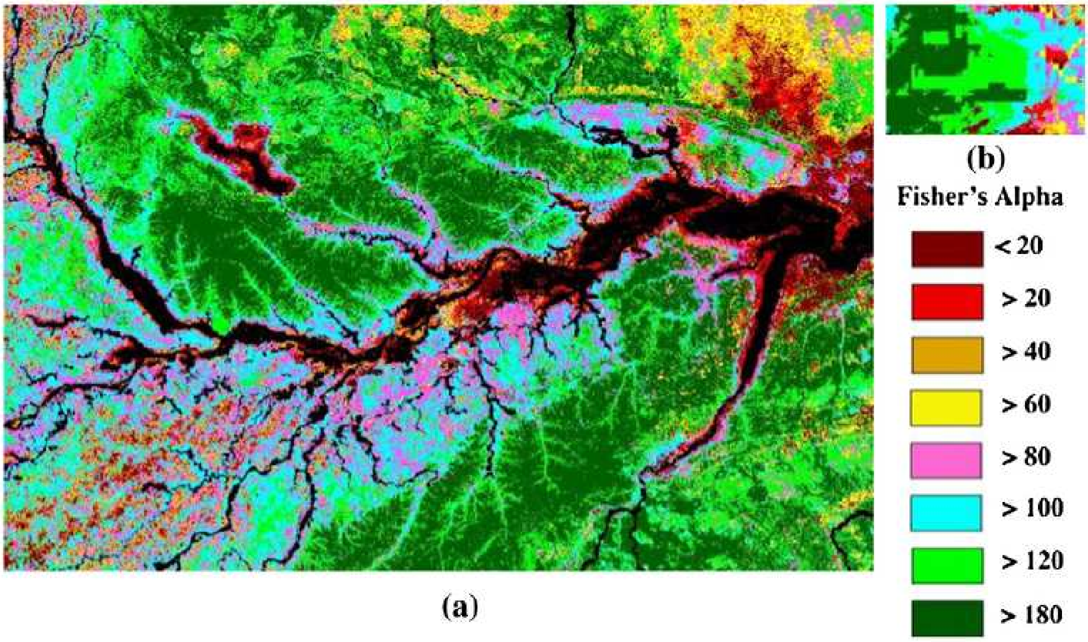


Fig. 3. Comparison of Maxent predictions of tree alpha-diversity classification over the Atlantic Coastal Forests of Bahia (Brazil) from (a) 1 km remote sensing data and (b) 5 km bioclimatic variables (after Saatchi et al. 2008).

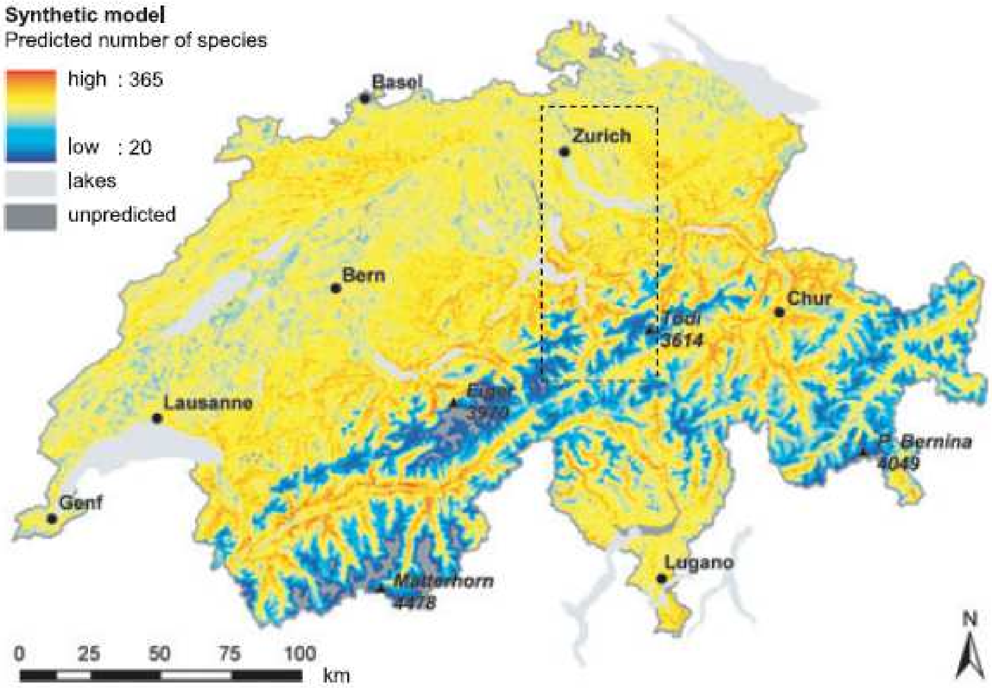


Fig. 4. Extrapolation of vascular plant species richness in Switzerland using all parameters (synthetic model) of different generalized linear (after Wohlgemuth et al. 2008).

Conclusion: Remote sensing is indispensable for ecological and conservation biological applications and in future will play a central role in conservation research. Design of a VC assessment system for Western Australia has to consider involving remote-sensing technology to address needs of the assessments in monitored plots (here linked to ground-based assessments), but also for purposes of large-scale (state-wide) regular VC assessments. The application of the remote-sensing technology should involve screening for vegetation-structural structural attributes (using LiDARs and hypespectral airborne platforms) as well as vegetation indices serving spatial modeling of biodiversity surrogates.

2.3.5 Linking the Ground and Remote-Sensing Assessments

The link between ground-based and remote-sensing assessments has been recognised as a major challenge in designing effective vegetation condition assessments including monitoring element. The nature of data collected by both types of the assessment dictates usually selection of different sets of condition attributes (and surrogates). It appears however logic that integration of both methodologies is desirable and possible. Sheffield (2006) for instance set off to explore possibilities how to measure classical condition attributes (such as those in Parkes et al. 2003) using remotely sensed imagery. In their later paper Sheffield et al. (2009) described a vegetation collection protocol for ground-based assessment that attempts to integrate the spatial resolution of several remotely sensed datasets and the spatial variation of vegetation into a framework. A particular challenge of their study was to use pre-existing vegetation survey methodology and adapt this for use with a number of remote sensing satellite systems. Reinke & Jones (2006) recognized the compatibility issues (resulting from lack of integrated design) between the field-collected data and remotely sensed data. These authors further identified a set of key criteria for consideration when designing field-based surveys of native vegetation condition (and other similar applications) with the intent to incorporate remotely sensed data. The listed criteria include recommendations on the location of assessed plots, on the need for establishment of control/reference plots, on the number of sample sites, plot size, and their distribution in the area, timing of collections and finally on attributes selected.

Some remote-sensing platforms are able to collect information (data) on attributes traditionally reserved for ground-based assessments (e.g. canopy cover, gap sizes, complexity of layering). Undoubtedly the ground-based assessment can be improved upon by relegating the data collection of such attributes rather to remote-sensing sensors since they would be not only more precise and quick, but would also guarantee standardized re-sampling devoid of any collectors' bias.

Conclusion: I concur with Wallace et al. (2006) that the capacity of site-based measurements alone to provide vegetation-monitoring information relevant to management questions is extremely limited. Satellite remote sensing imagery, because of its regular, spatially complete and consistent coverage has a unique capacity to provide change information to complement and target ground assessment. Any new design of a VC assessment system should strive for linking the ground-based and remote-sensed assessment protocols in order to speed up, formalize (standardize) the data collections at various spatial scales.

2.3.6 Aggregating Indices and Alternatives

Aggregating Biodiversity Surrogates

Aggregating biodiversity indicators into a shape of a single-value index is a common practice in conservation research and conservation policy making (see Cocciufa et al. 2008 for an interesting review of such indices in use in European Union. It is tempting, especially for presentation (mapping) and reporting purposes to create such indices and many could not resist such temptation of finding simple a "silver bullet" solution to a complex problem (Mucina 2009). Creating a summary (aggregated) index able to indicate the vegetation status or detect change is indeed valid pursue. However, if not approached critically and with scientific rigour some elements of such process can go wrong. The errors can not only shed doubtful light onto the value of such indices, but most importantly can lead to wrong conclusions and recommendations.

Among many pitfalls the most important ones are (1) wrong selection of surrogates (biodiversity indicators, assessment variables), (2) ungrounded differential weighting of their importance, and (3) violation of basic rule of arithmetic calculus when creating the aggregated index. Mucina (2009, Section 3) has discussed at length these problems using some examples (in the first place the Habitat Hectares (Parkes et al. 2003) and similar techniques. Considering that the selection of surrogates and their weighting can be served satisfactorily, is there a way how to summarize importance of many surrogates measures/estimated using incommensurable sampling scales into once sensible aggregated index?

The answer to this question is "yes", if one pays appropriate attention to nature of the sampling scales and use of proper transformations. Here I wish to document this issue on example of so called Natural Capital Index (NCI) developed by a group of Dutch researchers (De Heer 2002, Tekelenburg et al. 2004, ten Brink 2000, ten Brink & Tekelenburg 2002).

Natural Capital Index

The index is called ***Natural Capital Index (NCI)*** and it combines qualitative and quantitative information on the state of habitats and their biological diversity by computing a 2-dimensional product (habitat quality X habitat quantity). NCI developed to evaluate whether or not progress is being made towards one of the three central objectives of the Convention on Biological Diversity (UNEP 1999), however it can be implemented as an index of vegetation condition expressed as the among and quality of remaining vegetation in a defined space (hence it can be mapped using either grid mapping system, political units such as districts, of or pre-defined map featuring distribution of extant vegetation patches.

In the NCI formula the “quantity” is a straightforward measure: extent of remaining vegetation of certain type. The estimation of “quality” (= vegetation condition in our particular case) remains the contentions element of the calculation of NCI and therefore deserves more attention. The core of the problem here is that many index-oriented approaches (sensu Mucina 2009) to vegetation condition assessment are base don multiple surrogates – variables scored on different scales. If ordinal (or quasi-ordinal) scales are used the problem is reduced to rescaling of the sampling scales.

Czúcz et al. (2008) have suggested an ingenious procedure how to achieve the rescaling. In field assessments ecologists tend to use frequently ordinal (or interval) scales (see Steven 1946 for terminology and rationale of different sampling scales). This decision might be motivated by wish of speeding up the sampling and avoid tedious and costly measurements, but as pointed out by (Hahn & Scheuring 2003) “subjective” estimations are adopted even in cases when interval or ratio scaled data would also be available. This is based on the characteristics of human perception, which is intrinsically ordinal (Annett 2002). Czúcz et al. (2008), borrowing terminology from anthropocentric disciplines, such as psychology, sociology or ergonomics, in such cases the “measured” values can be regarded as the ordinal manifestation (“manifest variable”) of an underlying continuous “latent” (Bartholomew & Knott 1999).

The calculation of the NCI requires that these variables be rescaled to ratio scales. Maxwell & Delaney (1985) show that if we can find a permissible transformation φ (sensu Stevens 1946) for the manifest variable (y), so that there can be a link function established between φ (*y*) and the latent variable Θ behind, so that unit changes in φ(*y*) reflect unit changes in Θ, then φ(*y*) is an interval scale Itself (after Czúcz et al. 2008).

Though there is no predefined latent variable for ecosystem quality, we assumed the latent existence of an abstract habitat quality (*HQ*) as a “general ecosystem health status”, similarly to the abstraction leading to the concept of IQ and the underlying “*g factor*” (Jensen 1998) as a measure of “general intellectual abilities” in the field of psychology. In order to be consistent with the NCI concept, we considered this abstract quality expressed as a ratio to idealized “baseline” habitat quality: the state of the examined habitat as it would have been without human impacts.

The next step was to establish the link between the ordinal naturalness values and the underlying latent habitat quality (*HQ*). This as done by gauging the perception of the link by selected group of researchers leading to identification of two simple weighting schemes covering the scope of the replies: a linear “equal steps” approach (*HQ*lin), and a (quasi)“exponential” approach (*HQ*exp; Fig. 5). The proposed habitat quality weights (Table 3 in this Report) are interpreted as quality relative to an imaginary “ideal ecological state” of the habitat type, which equals presumable pristine state in the case of most habitats, but also incorporates low intensity traditional land use in the case of some semi-natural habitat types.

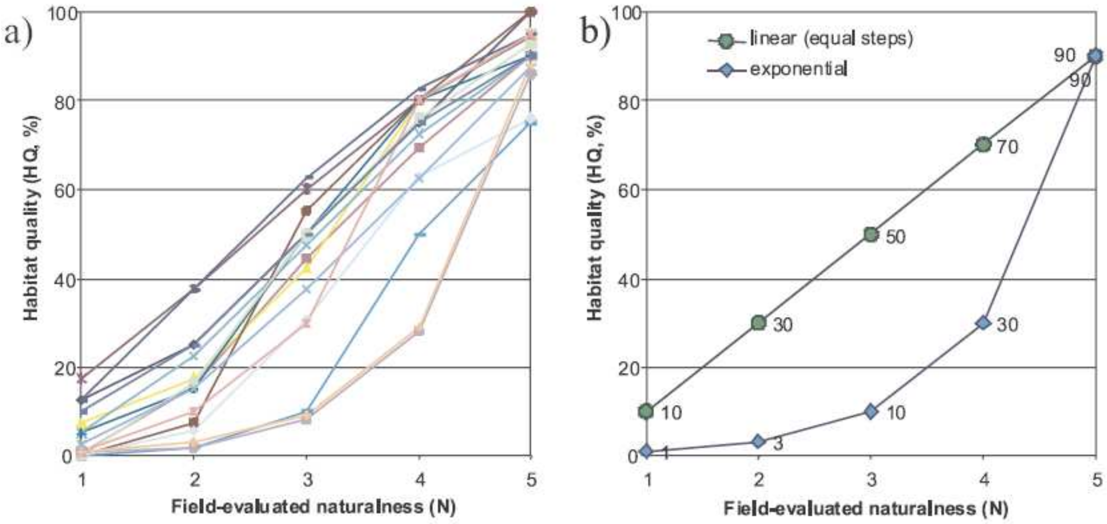
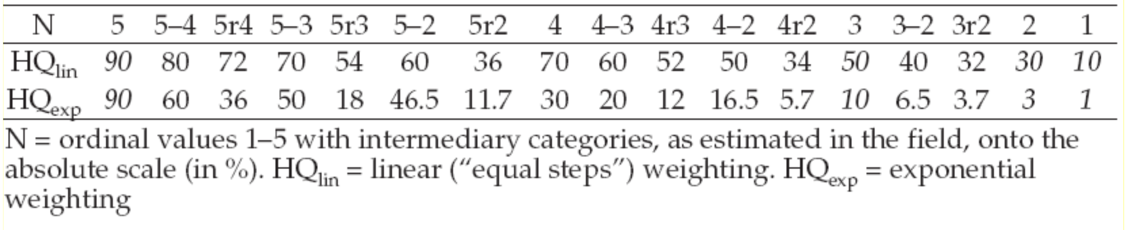


Fig. 5. Suggestions for meaningful transformation of ordinal naturalness values onto an absolute [0–1] scale for habitat quality relative to an ideal (intact) baseline: a) the replies received from the key participants of the field work; b) the resulting consensus transformations (after Czúcz et al. 2008).



N	5	5–4	5r4	5–3	5r3	5–2	5r2	4	4–3	4r3	4–2	4r2	3	3–2	3r2	2	1
HQ_{lin}	*90*	80	72	70	54	60	36	70	60	52	50	34	*50*	40	32	*30*	*10*
HQ_{exp}	*90*	60	36	50	18	46.5	11.7	30	20	12	16.5	5.7	*10*	6.5	3.7	*3*	*1*

N = ordinal values 1–5 with intermediary categories, as estimated in the field, onto the absolute scale (in %). HQ_{lin} = linear (“equal steps”) weighting. HQ_{exp} = exponential weighting

Tab. 3. The two weighting schemes used for transforming the ordinal levels of “naturalness-based habitat quality” (after Czúcz et al. 2008).

The natural capital index (NCI) of a region is an integrative measure for the remaining ecological value (“natural capital”), defined by the following formula (ten Brink 2000):

NCI = ecosystem quantity X ecosystem quality

where both quality and quantity are expressed on an absolute [0–1] scale, compared to an “optimal” or “intact” baseline. The concept is based on the assumption that biodiversity loss can be modelled as a process driven by two main components: habitat loss (due to conversion of natural areas into agricultural fields or urban area) and habitat degradation (caused by pollution, fragmentation, invasive species, etc.). Thus, NCI summarizes the extent to which a landscape has preserved its original (baseline) natural capital (see Figs. 6 & 7).

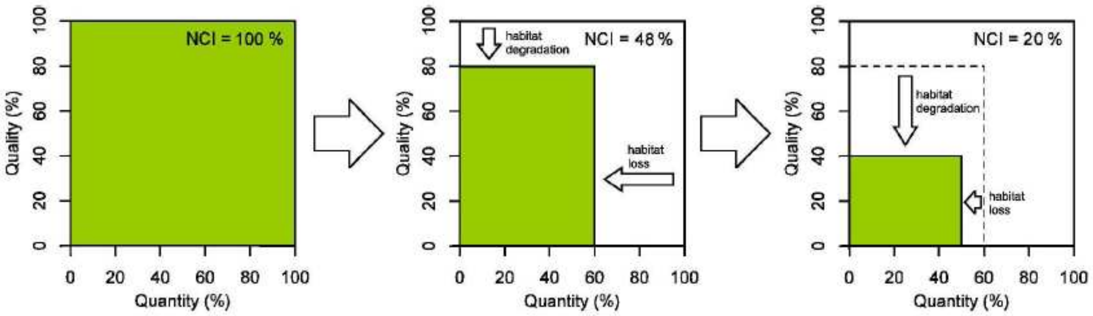


Fig. 6. Natural capital is defined as the product of remaining ecosystem size (quantity) and its quality. For example, if the remaining ecosystem size is 50 %, and its quality is 40 %, then 20 % of the natural capital remains (from Czúcz et al. submitted; courtesy of B. Czúcz).

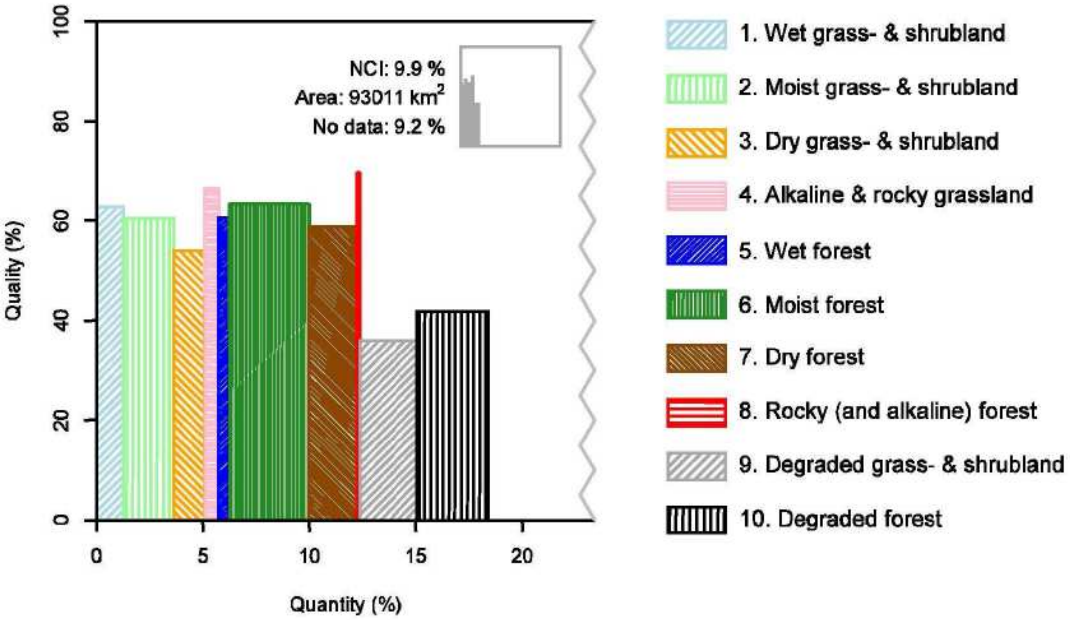


Fig. 7. The natural capital index (vbNCIlin) of Hungary, shown in a disaggregated structure identifying contributions of 10 main habitat groups. To add perspicuity to the NCI components, the scaling of the axes is not identical, to provide a visual overview of the magnitudes, a pictogram with identically scaled axes is shown in the upper right corner (from Czúcz et al. submitted; courtesy of B. Czúcz).

Vegetation-based NCI can be calculated for the whole mapped area or any subset of the area at any scale using the following formula (see Czúcz et al. 2008):

$$NCI = \frac{1}{A_r} \sum_{i \in H_r} A_i HQ_i,$$

where:

*A*r: area of the examined region (in arbitrary units, e.g. km^2),
*H*r: (the set of) all the individual habitat patches within the examined region,
*A*i: the estimated area of a habitat patch (in the same units as *A*r),
*HQ*i: the estimated naturalness (quality) of the habitat patch (% of the baseline value).

Alternative Formats of Reporting

In case the decision falls on class-based assessment (see Mucina 2009 for definition and examples), the challenge remains how to report (map) on assessments showing more than one class (hemeroby level, naturalness degree) in samples of the same vegetation patch. The averaging of the values (which are per definition at best of ordinal nature) as done for instance by Thackway & Lesslie (2008) is not the best idea due to violations of rules of data handling. Using a spectrum profile (similar to the NCI reporting, see Fig. 7 in this report) might be one of the options. Rescaling of the values using the Czúcz et al.'s procedure described above and approximation of the naturalness/hemeroby values on a ratio scale might be considered as well. Such value could then serve as basis for extrapolations (linked to remote-sense data collections) as describe din Section 2.3.5 of this report.

2.4 Utility of the Beard's Vegetation Map for VC Assessment

John S. Beard, almost single-handily, has produced nearly complete vegetation map of Western Australia (for a brief history of the WA vegetation survey spanning roughly 1972-1981 and the mapping and accompanying text products see Beard 1975, 1979, 1981). This set of maps have had profound influence on vegetation mapping in Australia and in recognition of so called "physiognomic approach" (Beard 1973) to vegetation classification and mapping. The Beard's map is considered a master piece of physiognomic vegetation mapping, however it remains often overlooked that floristic criteria did play a very important role in shaping the mapping methodology and presentation of the final products. In Beard's own words (Beard 1981, p. 77): "The classification is based upon the physiognomy (structure and life-form) of the ecologically dominant stratum to determine plant formations. Floristic dominance (or character species if no clear dominance is apparent) is used for secondary classification, dividing plant formations into plant associations."

However trend-setting and scientifically sound the Beard's map(s) can be, they cannot be used as serious source serving the needs of design of vegetation condition assessment for the following reasons:

1) The Beard's maps are not maps of real vegetation; they reconstruct the vegetation cover of Western Australia to pre 1788 condition (the time of onset of the European settlement in Australia associated with large scale disturbance to "natural" vegetation cover. Or this reason the maps cannot be used reliable for seeking and setting benchmarks of any modern vegetation condition assessment system.

2) The precision and resolution of the Beard's maps fall short of modern requirements. Undoubtedly, the limited possibilities of the product presentation in printed format dictated much of the decision of the basic mapping scales and underpin the generalisations and simplification in leading the boundaries between vegetation units. Modern tools of remote-sensing and GIS methodology are from this point of view undoubtedly superior to the classical ground-based approach used by J.S. Beard.

3) The Beard's maps do not provide an opportunity for repeated, comparable mapping be it only for comparative purposes due to unavoidable personal bias in judgements made by J.S. Beard in selection of ecologically important species (be it dominants or character species) as well as in process of vegetation reconstruction in places where vegetation had been removed.

4) Last but not least, the choice of physiognomic criteria in classification underpinning the mapping the primary criteria does reflect the spirit of the days when J.S. Beard was busy mapping the vegetation of Western Australia. Physiognomy is however rather poor indicator of ecological and evolutionary processes. For instance, the extremely species-rich and diverse (in terms of vegetation typology) "Heath" of SW Australia is depicted on Beard's map of Swan area (Beard 1980) only by two mapping units (judging from two separate codes sharing the same mapping colour in the mapping legend). Western Australia needs new vegetation map – a map based on current scientific paradigms and reflecting the current level of knowledge on patterns origins and distribution of plant biodiversity reflecting the past and current evolutionary and ecological processes.

John Beard's map of Western Australia is a monumental opus witnessing the scientific thinking and discovery spirit of not so distant past. It will for ever be cherished as document of large historical and cultural value – a source where new Vegetation Survey of Western Australia will seek inspiration from, but also a benchmark which the new Vegetation Survey of Western Australia aims to surpass.

3. General Conclusions and Recommendations

Recommendation 1: Concept of vegetation condition is an important resource management tool in hands of nature conservation authorities. Its development and application in WA has to be therefore recognised by the government and the political representatives of the social opinion an important investment into the future of nature resource management of the State.

Recommendation 2: Despite the fact the Australia is undoubtedly the world-leader in the field of research and application, I cannot recommend any of the existing VC assessment systems (VAST, Habitat Hectares, BioMetric) to be implemented in the State of Western Australia.

Recommendation 3: I have not identified any appropriate VC assessment system used overseas to be rigorous enough and responding to the needs of the natural resource survey and use in WA.

Recommendation 4: The VC assessment and monitoring in WA should reflect the regional (state) needs and it should be designed to reflect our commitment to scientific rigor and practical applicability.

Recommendation 5: The development of a VC assessment in WA should be one of the priorities to be tackled by a special dedicated team of experts including all important stakeholders, spearheaded by ecologists located at WA universities. The process should be owned and managed by DEC, Science Division.

Recommendation 6: Beard's physiognomic maps of Western Australia cannot play any serious role in design of the vegetation condition assessment system.

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