Dealing with Cumulative Biodiversity Impacts in Strategic Environmental Assessment: A New Frontier for Conservation Planning

Amy L. Whitehead*, Heini Kujala, & Brendan A. Wintle
School of BioSciences, The University of Melbourne, Parkville, VIC 3010, Australia

Keywords
Spatial conservation prioritization; conservation planning; biodiversity; development; strategic environmental assessment; cumulative impact assessment; species distribution model; irreplaceability; complementarity.

Abstract
Biodiversity impact assessments under threatened species legislation often focus on individual development proposals at a single location, usually for a single species, leading to inadequate assessments of multiple impacts that accumulate over large spatial scales for multiple species. Regulations requiring ad-hoc assessments can lead to “death by a thousand cuts,” where biodiversity is degraded by many small impacts that individually do not appear to threaten species’ persistence. Spatial prioritization methods can improve the efficiency of decision-making by explicitly considering cumulative impacts of multiple proposed developments on multiple species over large spatial scales. We present an assessment approach and a unique case study in which spatial prioritization tools were used to support strategic assessment of a large development plan in Western Australia. The application of the approach helped identify relatively minor alterations to development plans that resulted in reductions in biodiversity impacts and informed expansion of the protected area network. Using these tools to assess trade-offs between conservation and development will help identify planning footprints that minimize biodiversity losses.

Introduction
Evaluating the environmental impact of projects is a critical prerequisite for sustainable development. Anticipating and acting on foreseeable development-conservation conflicts helps cost-effectively reduce biodiversity losses because the cost of conserving species and communities increases rapidly as they become less widespread and options for their conservation narrow (Mills et al. 2014). In many countries, existing legislation and regulation requires formal assessment of activities deemed likely to pose some risk to threatened species (Chaker et al. 2006; Connelly 2011). Threatened species and environmental protection regulations have traditionally been operationalized by focusing on project-by-project impact assessments, aiming to approve, reject, or condition development projects in order to minimize impacts on threatened species or ecological communities (e.g., Mörtberg et al. 2007; Atkinson & Canter 2011). These approaches have been criticized for failing to deliver adequate biodiversity protection due to the ad-hoc and local nature of assessments (Hawke 2009). Concern has been raised about the impact of multiple discrete and/or consecutive projects that, when individually assessed, may be approved but that cumulatively will lead to “death by a thousand cuts” (Hawke 2009).

Impacts on biodiversity accumulate in multiple ways: (i) at a site, impacts may accumulate due to the effect of multiple stressors (e.g., cumulative impacts of habitat fragmentation, noise, and pollution; Halpern et al. 2008), (ii) over larger, heterogeneous environments, individual or multiple impacts may accumulate spatially as an
Cumulative biodiversity impact assessments

A. L. Whitehead et al.

impact footprint expands under multiple independent developments, changing habitat extent and connectivity (Hawke 2009), and (iii) over time impacts may accumulate at a site or across a landscape (e.g., accumulation of heavy metals in an ecosystem). Impacts of multiple individual stressors or threats can be synergistic or antagonistic. Impacts may accumulate both linearly or nonlinearly over time and space (Halpern & Fujita 2013). The cumulative impact assessment literature primarily focuses on evaluating the impacts of multiple interacting stressors at a site level, using coarse surrogates for species persistence such as ecosystem types, with little or no reference to the specific requirements, distributions, or persistence of individual species (e.g., Halpern et al. 2008; Halpern & Fujita 2013; Andersen et al. 2015). These approaches tend not to explicitly consider spatial accumulation of impacts, nor the impacts that multiple developments might have on the connectivity and viability of species populations, rendering them inadequate for assessing impacts under threatened species legislation. Here, we focus on the less examined spatial accumulation of multiple individual development impacts across large regions.

Many spatially-explicit environmental assessments use single species or biodiversity surrogates to assess impacts due to development (Mörberg et al. 2007; Atkinson & Canter 2011). Single-species assessments are not useful for decision makers determining acceptability of impacts at a regional scale when multiple threatened species with differing initial rarity occur disparately across the landscape (Connelly 2011; Duinker et al. 2012). Spatial prioritization planning tools such as Zonation (Moilanen et al. 2005) or Marxan (Ball et al. 2009) can support regional-scale assessments by characterizing conservation outcomes under planning options for multiple species over large landscapes. Outputs can identify areas of high biodiversity value where development should be avoided or areas where development may impact biodiversity least (Bekessy et al. 2012; Kareksela et al. 2013). Spatial impact assessments during planning help planners identify development footprints that minimize cumulative impacts on biodiversity and adhere to threatened species regulations. There is an opportunity to embed these approaches within statutory strategic environmental assessment (SEA; Therivel & Paridario 2013) that sets out to reconcile environmental, social, and economic impacts of proposed developments.

We demonstrate the use of spatial prioritization tools in a region-wide land-use planning process in Western Australia (WA), where the Australian Government (AG) is assessing the impacts of a 30-year development plan for ∼8,500 km² around the city of Perth. This statutory strategic assessment, under Australia’s Environment Protection and Biodiversity Conservation (EPBC) Act (1999), seeks to assess the cumulative spatial impact of multiple individual developments on multiple species and ecological communities. We employed a three-step approach to analyze and minimize cumulative impacts of multiple residential, industrial, infrastructure, and extractive development actions on 227 biodiversity features over approximately one million landscape elements (1 ha cells) (Figure 1). We discuss the importance of sound technical solutions combined with timely, consistent, and thorough engagement with planners and decision makers to ensure that best-practice analyses were understood, accepted, and integrated into the decision-making process. We show how strong engagement contributed to significantly reduced impacts on biodiversity and informed a significant expansion of the conservation estate.

**Methods**

**Perth and Peel Strategic Assessment**

Australia’s EPBC Act allows for approval of policies, plans, or programs, under which future actions may be undertaken without the need for individual referral and approval (DSEWPAC 2012). The Perth and Peel Strategic Assessment (PPSA) seeks to assess the biodiversity impacts of ∼570 km² of proposed development that would add to ∼1,390 km² of existing development approvals. The total increase in developed area of ∼1,960 km² is to accommodate a doubling of the population to ∼3.5 million people, within 8,500 km² of south-western Australia. Development options initially proposed under the WA Planning Commission’s (WAPC) Directions 2031 and Beyond (WAPC 2010) and other key planning documents were refined to reduce environmental impacts, leading to the 2015 release of the WAPC’s Perth and Peel at 3.5 million suite of planning documents and the draft Perth and Peel Green Growth Plan (GGP). The PPSA region is part of the Southwest Australia Ecoregion, one of the 35 global biodiversity hotspots (Myers et al. 2000). Approximately 70% of the region contains important native vegetation, wetlands, and other habitats supporting threatened and endemic species and ecological communities.

**Characterizing regional biodiversity**

We mapped the distributions of 189 threatened species and 38 threatened ecological communities (TECs) listed under national and state legislation. Presence-only point data for species were obtained from online public databases, while TEC and habitat polygon data were provided by government agencies. To identify suitable
Figure 1  Schematic diagram representing the three-step modeling process used to undertake the spatial cumulative impact assessment in the Perth-Peel region of Western Australia. (A) Species occurrence data were obtained from online databases and combined with environmental data to produce species distribution models for 61 threatened species using MaxEnt at the scale of the surrounding bioregions. (B) These models were clipped to the Perth-Peel region and combined with additional biological features, including threatened ecological communities, in the spatial conservation prioritization software, Zonation, to rank the landscape for its conservation value for 227 biodiversity features. Priority conservation areas were identified as the best 30% of the landscape for conservation. (C) We used Zonation to assess the impacts of spatially explicit proposed development types, identifying areas of potential conflict with high priority areas for conservation. This was undertaken as part of an iterative process, where planning footprints were refined to avoid areas of high conflict and reassessed.
Table 1 The relative impact of development can be assessed by examining the area of habitat cleared, conflicts with existing protected areas and identified priority conservation areas and the estimated loss of biodiversity feature distributions under different development types within the final cumulative planning footprint based on the draft Green Growth Plan (DPC 2015). The mean and maximum distribution loss for each development type is based on the distributions of 227 biodiversity features within the PPSA region. Locally extinct features are those losing all of their known occurrences in the region due to development, with the number of features losing at least 50% of their distribution also shown.

| Development type | Area developed (ha) | Habitat cleared (ha) | Protected areas (%) | Priority areas (%) | Mean loss (%) | Max loss (%) | Locally extinct features | Features losing at least 50% |
|------------------|---------------------|----------------------|---------------------|--------------------|--------------|--------------|------------------------|-----------------------------|
| 1. Urban         | 121,737             | 34,016               | 0.72                | 7.90               | 7.24         | 100.00       | 1                      | 5                          |
| 2. Industrial    | 28,655              | 9,408                | 0.36                | 2.69               | 2.32         | 50.00        | 0                      | 3                          |
| 3. Rural Residential | 11,007         | 5,176                | 0.02                | 1.51               | 0.63         | 33.33        | 0                      | 0                          |
| 4. Infrastructure | 19,216             | 8,153                | 0.59                | 2.14               | 2.69         | 100.00       | 1                      | 3                          |
| 5. Forestry      | 11,527              | 11,036               | 2.82                | 0.02               | 0.16         | 3.41         | 0                      | 0                          |
| 6. Mining        | 20,284              | 16,282               | 3.71                | 0.99               | 0.68         | 50.00        | 0                      | 1                          |
| 7. Final cumulative | 196,282        | 73,015               | 5.95                | 14.57              | 12.94        | 100.00       | 2                      | 14                         |

habitat for threatened species, we modeled distributions for 61 threatened species with at least 20 occurrence records within the PPSA region using MaxEnt (Appendix A; Phillips et al. 2006) (Figure 1A). Spatial data for 128 threatened species with less than 20 occurrence records and 38 TECs were included as binary maps. All data layers were clipped to areas of extant vegetation.

Conservation priority areas

We used the conservation prioritization software Zonation v.4.0 (Moilanen et al. 2005, 2014) to identify areas of conservation priority within the PPSA region for the 227 biodiversity features described above (Figure 1B). Zonation is a maximum-coverage (Camm et al. 1996) tool that identifies areas maximizing the representation of suitable habitat for multiple species over large landscapes (Appendix B; Moilanen et al. 2005, 2014). It creates a hierarchical ranking of all sites across the landscape according to conservation priority. A relatively small proportion of the top-ranked sites typically represent all species and core habitats.

In collaboration with agency staff, we developed a scheme to weight endemic and/or threatened biodiversity features more highly in the prioritization process (Appendix C). For reporting purposes, we focus on the top 30% ranked sites within the PPSA region, hereafter referred to as priority conservation areas. Spatial prioritization outputs were compared to existing protected areas within the PPSA region to assess how well the identified priority conservation areas are currently protected under different IUCN protected area categories. We also assessed the proposed expansion of IUCN category I-IVa protected areas in the PPSA region, a planning outcome of the strategic assessment process (Appendix E).

Strategically assessing the spatial accumulation of biodiversity impacts

We assessed the potential biodiversity impacts of both approved developments that are currently undeveloped and proposed developments being assessed under the PPSA. We used four spatially explicit planning footprints obtained from government from 2013 to January 2016 (Figure 1C; Table 1), including six development types: (1) urban, (2) industrial, (3) rural residential, (4) infrastructure, (5) exotic plantation forestry, and (6) basic raw materials (sand, limestone, clay, and hard rock) mining. Each development type was assumed to result in the absolute loss of biodiversity value within the impact footprint. Partial loss of value after an impact could be incorporated in Zonation where appropriate but was unnecessary here. Over the 2010–2016 planning period, footprints were refined through a review process that assessed potential biodiversity impacts. We spatially overlaid the six development types for each planning footprint to assess the spatial accumulation of impacts and to understand the iterative changes in biodiversity impact from the initial (WAPC 2010, 2012) to the current GGP proposals (DPC 2015).

We identified areas in the landscape where development scenarios overlapped with priority conservation...
A. L. Whitehead et al.

Cumulative biodiversity impact assessments

Figure 2 (A) Priority conservation areas within the PPSA region based on the best 30% of the landscape (red to blue) of a spatial prioritization for 227 biodiversity features, irrespective of current land tenure. (B) The conflicts between priority conservation areas and the final cumulative planning footprint based on the draft Green Growth Plan (DPC 2015) are highlighted by clipping the conservation priorities to the footprint. The inset boxes highlight areas of conservation priority that are likely to be developed for (1) mining, rural residential, and industrial; (2) urban and industrial; (3) urban, industrial, and infrastructure; and (4) urban and industrial.

The areas identified as priority conservation areas was estimated by measuring proportional losses of each biodiversity feature (species habitat, point locations, or TECs), and by considering the overall proportion of biodiversity value lost across all species and threatened communities (Cabeza & Moilanen 2006). The latter analysis explicitly incorporates the spatial accumulation of impacts on individual biodiversity features through habitat loss and reduced connectivity between remaining habitats, and on the combined biodiversity value by considering the relative importance of each landscape cell for the overall representation of biodiversity in the landscape (Appendix B).

Results

The areas identified as priority conservation areas (Figure 2A) contain, on average, 87.3% of the mapped area of TECs, species habitat, and point locations within

![Figure 3](image-url)  The proportion of feature distributions lost under each development type within the final cumulative planning footprint based on the draft Green Growth Plan (DPC 2015). Considering the average loss of habitat across the feature pool can provide insights into the relative impacts of proposed development but it is also important to consider how individual features are likely to be impacted.
Cumulative biodiversity impact assessments

A. L. Whitehead et al.

Figure 4 Using spatial conservation prioritization to identify priority conservation areas where development should not occur can help planners make biodiversity-sensitive revisions to planning footprints. The initial proposal is the Directions 2031 plan, and first, second, and final revisions were part of the GGP planning process. Here, iterative changes to the planning footprint led to overall reductions in biodiversity loss, as well as reducing the impacts on key species of concern. Areas colored red represent priority conservation areas at risk of being developed under each proposal, while dark gray areas show development that will not result in the clearance of native vegetation or areas of significant values. Values describe the proportion of each feature’s distribution within the PPSA region that will be lost to development.

the PPSA region. However, the occurrence of biodiversity features varied considerably within the priority conservation areas, with the ranges of some widespread and/or lower weighted features receiving proportionally lower representation (Appendix D). Only 26% of the identified priority conservation areas (<9% of the total region) are contained within the existing protected area network, with 18 biodiversity features not protected at all. The addition of proposed conservation reserves within the PPSA region under the GGP would increase IUCN category I-IVa protected areas from 99,812 to 177,497 ha (30% of the region’s habitat), leaving fewer features without category I-IVa protection (29 vs. 63). However, only 11.7% of the priority conservation areas we identify would be protected under this proposal. The new proposal for protected areas improves the protected area network. However, further expansion of reserves in unprotected high priority areas is warranted (Appendix E).

The predicted impacts to biodiversity varied between development types and planning footprints with larger development areas leading to larger biodiversity impacts (Figure 2; Table 1). Under the final GGP cumulative planning footprint, urban development was predicted to have the largest impact, resulting in the loss of up to 34,000 ha of habitat and 7.9% of priority conservation areas. This is comprised of 13,500 ha of existing approvals and 20,500 ha proposed under the GGP. The plantation forestry and mining impacts were relatively minor (and overlapping) resulting in a mean habitat loss of 0.2–0.99%, though often occurred in existing protected areas (2.8–3.7%, respectively). At the time of writing, the GGP cumulative planning footprint was estimated to result in the loss of 73,000 ha of habitat, including 14.8% of priority conservation areas (Figure 2B) and on average biodiversity features would lose 12.9% of their current distributions. However, the potential impact varies considerably among species and communities, and for the majority, individual development types pose moderate or low habitat impacts, emphasizing the importance of cumulative assessment across all development types (Figure 3). Carnaby’s black cockatoo (Calyptorhynchus latirostris) is one species for which the cumulative impacts are higher (16.3% habitat loss) than anticipated by any individual development type (1.1–7.5%), though the...
GGP introduces special measures to restore Carnaby’s cockatoo habitat.

Two development types (urban, infrastructure) and the GGP cumulative planning footprint will likely result in the loss of all recorded locations of two plant species (*Thysanotus glaucus* and *Calothamnus macrocarpus*) within the PPSA region if mitigation measures are not implemented (Table 1, Figure 3, Appendix F). Fourteen biodiversity features may lose at least 50% of their local distributions under the GGP cumulative planning footprint.

There was an overall reduction in biodiversity impacts across the four cumulative planning footprints considered (Figure 4, Appendix F), although the area of habitat loss increased in the third revision when rural residential development was added to the planning process. Revisions decreased the proposed total area of habitat cleared from 114,065 ha (*Directions 2031*) to 73,015 ha (GGP), reducing the anticipated mean biodiversity losses from 21.2% to 12.9%, and more than halving the impact for some threatened species (Figure 4). Nearly 6,500 ha of avoided clearing in the proposed urban development zones resulted from the transition from *Directions 2031* to GGP, with an additional 163 ha set aside in *Retention Zones* that will not be developed (Table F4; Figure F2), further reducing the mean biodiversity loss from the newly proposed urban expansion from 1.11% to 0.21%.

**Discussion**

This study represents a rare case in which a systematic spatial prioritization was used to support a statutory land-use planning process; reducing losses through planning and informing protected area expansion (Figure 4 and Figures E1, E2, and F2). Assessment was based on a transparent and repeatable framework that provided planners and decision makers with comprehensive information for each species, TEC, and the combined biodiversity values. The value of repeatability was highlighted when analyses were repeated to incorporate new preferences, constraints, and features required by planners and policy officers.

Our approach efficiently visualized conflicts between proposed development and priority conservation areas, identifying the most impacted species under each scenario. By assessing the cumulative impacts, we were able to identify biodiversity losses that might not have been apparent through project-by-project assessments. The framework allowed decision makers to compare planning footprints and reduce biodiversity losses via plan revisions. Further revisions to the plan will occur after the date of publication, following public consultation.

Three key ingredients were essential for the successful application of our approach in this complex and contentious political process. First, rigorous repeatable, peer-reviewed methods that directly addressed the problem, but which were adaptable to the needs of planners and decision makers were the basic ingredient. Conservation planning tools based on irreplaceability and complementarity have 20 years of pedigree in peer-reviewed science literature and yet are intuitive enough that the relevance of these principles and tools can easily be described to planners and decision makers.

A second key ingredient was the joint willingness of planners and decision makers to engage with and explore technical, science-based inputs to the planning process. We were fortunate in this case study that the Australian and WA Government officers were eager to understand and utilize scientific approaches to assessment. Throughout the process, they maintained a high degree of engagement with our analyses, and facilitated data-sharing to ensure timely delivery of outputs.

Third, there was concerted and consistent engagement between researchers and planners throughout the project, including problem scoping, analyses and refinement, plan improvement, and communication of findings. This was achieved through over 40 face-to-face interactions, seminars to planners, decision makers, stakeholders, and by being available to discuss ideas or concerns. While this interaction comes at a high time cost to researchers and planners, in the absence of relevant technical expertise within government agencies, it is the only way to ensure that the scientific methods are carried through the planning process.

Despite the success of this case study, we underline that our framework sets out a starting point for a comprehensive biodiversity impact assessment, adaptable to different circumstances. Other applications may require analysis of the cumulative impacts of a range of partially impacting stressors, which degrade habitats without totally destroying them, or where mitigation actions partially mitigate impacts. Partial losses and mitigation can already be handled within Zonation and related tools (Moilanen *et al.* 2011), and methods could be further developed to integrate site-level cumulative impacts (*sense* Halpern *et al.* 2008). In this study, conservation priorities and impacts were estimated based on species occupancy records and species distribution modelless, ignoring many ecological processes. Therefore, we may have underestimated the impacts of development on species persistence. Refinements could consider gradual degradation of remaining habitats due to edge effects (Moilanen & Wintle 2007), nonlinear declines in species due to reduced habitat connectivity (Fordham *et al.* 2012), changes to resources that limit breeding...
Cumulative biodiversity impact assessments

A. L. Whitehead et al.

A. L. Whitehead

Conservation Letters, March 2017, 10(2), 195–204

Copyright and Photocopying: © 2016 The Authors. Conservation Letters published by Wiley Periodicals, Inc.

potential or increase mortality (Bekessy et al. 2009), and spatial or temporal uncertainties about current and future distributions of species (Moilanen & Wintle 2006; Strimbu & Innes 2011; Kujala et al. 2013). By incorporating these factors in population viability analyses (PVAs), a more comprehensive evaluation of plan adequacy, which explicitly considered species persistence under development options, could be achieved (Wintle et al. 2005; Sebastián-González et al. 2011). Such analyses require species demography and movement information, rarely available for most species in a region, though implementing PVA for a subset of well-studied species could improve assessments. On the flip side, we have assumed that habitat within the impact footprint will be completely lost after development. This may not always be the case if appropriate in-development mitigation measures can be implemented, providing the possibility of better outcomes than our analyses predict.

A particular feature of this study was the focus on threatened species and TECs; a requirement of local threatened species legislation. Given the extent of planned development, species not currently listed as threatened could become so once all development occurs. Current studies provide little optimism about the degree to which individual taxon can be used as surrogates for others in spatial conservation analyses (Lentini & Wintle 2015). Expanding analyses to consider impacts on non-listed species is a logical extension of this work.

The analytical approach presented in this study is generalizable to any situation in which multiple biodiversity values (e.g., species and ecological communities) and anticipated impacts can be mapped. The most obvious application is in strategic assessments under threatened species legislations in other jurisdictions; however, the approach is not restricted to statutory assessments. There is significant potential in integrating spatially-explicit analyses with other types of cumulative assessment that consider additive and synergistic effects of multiple stressors on ecosystems and species (e.g., Halpern et al. 2008; Halpern & Fujita 2013).

Policy recommendations/conclusions

We recommend that our approach be adopted as a requirement of statutory strategic assessments of development impacts on biodiversity and equivalent planning processes in other jurisdictions. While our framework sets out a reasonable minimum standard for assessments, the approach does not deal explicitly with species persistence. Refining approaches to modeling persistence over large areas with multiple species is a pressing research priority. Implementation of our recommendations for large land-use planning and assessment exercises requires consistent and dedicated engagement between researchers, planners, managers, and policy makers.

Acknowledgments

NERP Decisions Hub supported this work. Wintle was supported by ARC Future Fellowship (FT100100819). Carolyn Cameron motivated and instigated the study. Simon Banks, Nicole Matthews, Hana McDonald, Jess Miller, Erin Pears (AG-DotE), Tahila Rose, Simon Taylor, Sarah Woods (WA-DPC), Catherine Garlick (WA-OEPA), Bryce Bunny, Nicholas Dufty, Leo Peter, Aidan Power (WA-DoP), David Mitchell, and Christina Ramahlo (WA-DPaW) all provided data, knowledge and direction. Three anonymous reviewers provided valuable comments.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher’s web site:

- **Appendix A**: Description of MaxEnt modeling.
- **Table A1**: Abbreviated names and definitions of mapped environmental data used in species distribution models.
- **Table A2**: AUC values and the relative contribution of each environmental variables for species distribution models summarized across taxonomic groups.
- **Figure A1**: Boxplot of AUC values for 61 species distributions modeled using MaxEnt summarized across the five broad taxonomic groups.
- **Appendix B**: Description of the Zonation prioritization algorithm.
- **Figure B1**: Illustration of how the Zonation software undertakes spatial prioritization.
- **Appendix C**: Development of a species weighting scheme.
- **Table C1**: Criteria used to weight biodiversity features.
- **Appendix D**: Assessing the outcomes of prioritization for individual species and TECs.
- **Figure D1**: Proportion of each biodiversity feature’s distribution captured by the priority conservation areas, plotted against distribution size.
- **Appendix E**: Assessing the effectiveness of the existing protected area network.
- **Figure E1**: Current and proposed protected areas within the PPSA region, and their overlap with priority conservation areas.
- **Figure E2**: The proposed expansion of the conservation reserve system under the draft Green Growth Plan Conservation Program.
Table F2. Biodiversity features (species or TECs) predicted to lose more than 50% of their habitat under the different development types.

Table F3. Biodiversity features (species or TECs) predicted to lose more than 50% of their habitat under the cumulative planning footprints.

Figure F2. The proposed urban expansion zones within the initial Directions 2031 and Beyond proposal and Green Growth Plan.

Table F4. Changes in the proposed urban development impacts from initial to final revision of the footprint.

References

Andersen, J.H., Halpern, B.S., Korpinnen, S., Murray, C. & Reker, J. (2015). Baltic Sea biodiversity status vs. cumulative human pressures. *Estuarine Coastal Shelf Sci.*, **161**, 88-92.

Atkinson, S.F. & Canter, L.W. (2011). Assessing the cumulative effects of projects using geographic information systems. *Environ. Impact Assess. Rev.*, **31**, 457-464.

Ball, I.R., Possingham, H.P. & Watts, M.E.J. (2009). Marxan and relatives: software for spatial conservation prioritisation. Pages 185–195 in A. Moilanen, K.A. Wilson, H.P. Possingham, editors. *Spatial conservation prioritisation: quantitative methods and computational tools*. Oxford University Press, Oxford, UK.

Bekessy, S.A., White, M., Gordon, A., Moilanen, A., Mccarthy, M.A. & Wintle, B.A. (2012). Transparent planning for biodiversity and development in the urban fringe. *Landscape Urban Plann.*, **108**, 140-149.

Bekessy, S.A., Wintle, B.A., Gordon, A., Fox, J.C., Chisholm, R., Brown, B. et al. (2009). Modelling human impacts on the Tasmanian wedge-tailed eagle (Aquila audax fleayi). *Biological conservation*, **142**, 2438-2448.

Cabeza, M. & Moilanen, A. (2006). Replacement cost: a practical measure of site value for cost-effective reserve planning. *Biol. Conserv.*, **132**, 336-342.

Camm, J.D., Polasky, S., Solow, A. & Csuti, B. (1996). A note on optimal algorithms for reserve site selection. *Biol. Conserv.*, **78**, 353-355.

Chaker, A., El-Fadl, K., Chamas, L. & Hatjian, B. (2006). A review of strategic environmental assessment in 12 selected countries. *Environ. Impact Assess. Rev.*, **26**, 15-56.

Connelly, R.B. (2011). Canadian and international EIA frameworks as they apply to cumulative effects. *Environ. Impact Assess. Rev.*, **31**, 453-456.

DPC. (2015). *Perth and Peel Green Growth Plan for 3.5 Million*. Department of Premier and Cabinet, Perth, WA.

DSEWPAC. (2012). *A guide to undertaking strategic assessments*. Australian Government, Canberra.

Drukker, P.N., Burbidge, E.L., Boardley, S.R. & Greig, L.A. (2012). Scientific dimensions of cumulative effects assessment: toward improvements in guidance for practice. *Environ. Rev.*, **52**, 121029052013006.

Fordham, D.A., Resit Ackettay, H., Araujo, M.B. et al. (2012). Plant extinction risk under climate change: are forecast range shifts alone a good indicator of species vulnerability to global warming? *Glob. Change Biol.*, **18**, 1357-1371.

Halpern, B.S. & Fujita, R. (2013). Assumptions, challenges, and future directions in cumulative impact analysis. *EcoSphere*, **4**, 1-11.

Halpern, B.S., Walbridge, S., Selkoe, K. et al. (2008). A global map of human impact on marine ecosystems. *Science*, **319**, 948-952.

Hawke, A. (2009). *The Australian Environment Act: Report of the Independent Review of the Environment Protection and Biodiversity Conservation Act 1999*. Department of the Environment, Water, Heritage and the Arts, Canberra, ACT.

Kareksela, S., Moilanen, A., Tuominen, S. & Kotiaho, J.S. (2013). Use of inverse spatial conservation prioritization to avoid biological diversity loss outside protected areas. *Conserv. Biol.*, **27**, 1294-1303.

Kujala, H., Moilanen, A., Araujo, M.B. & Cabeza, M. (2013). Conservation planning with uncertain climate change projections. *PLoS One*, **8**, e53315.

Lentini, P.E. & Wintle, B.A. (2015). Spatial conservation priorities are highly sensitive to choice of biodiversity surrogates and species distribution model type. *Ecography*, **38**, 1101-1111.

Mills, M., Nicol, S., Wells, J.A. et al. (2014). Minimizing the cost of keeping options open for conservation in a changing climate. *Conserv. Biol.*, **28**, 646-653.

Moilanen, A., Franco, A.M.A., Early, R.I., Fox, R., Wintle, B.A. & Thomas, C.D. (2005). Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems. *Proc. R. Soc. B.*, **272**, 1885-1891.

Moilanen, A., Leathwick, J.R. & Quinn, J.M. (2011). Spatial prioritization of conservation management. *Conserv. Lett.*, **4**, 383-393.
Cumulative biodiversity impact assessments

Moilanen, A., Pouzols, F.M., Meller, L. et al. (2014). Zonation: spatial conservation planning methods and software. Version 4 user manual. C-BIG Conservation Biology Informatics Group, Department of Biosciences, University of Helsinki, Helsinki, Finland.

Moilanen, A. & Wintle, B.A. (2006). Uncertainty analysis favours selection of spatially aggregated reserve networks. *Biol. Conserv.*, **129**, 427-434.

Moilanen, A. & Wintle, B.A. (2007). The boundary-quality penalty: a quantitative method for approximating species responses to fragmentation in reserve selection. *Conserv. Biol.*, **21**, 355-364.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A.B. & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, **403**, 853-858.

Mörtberg, U.M., Balfors, B. & Knol, W.C. (2007). Landscape ecological assessment: a tool for integrating biodiversity issues in strategic environmental assessment and planning. *J. Environ. Manage.*, **82**, 457-470.

Phillips, S.J., Anderson, R.P. & Schapire, R.E. (2006). Maximum entropy modeling of species geographic distributions. *Ecol. Model.*, **190**, 231-259.

Sebastián-González, E., Sánchez-Zapata, J.A., Botella, F., Figuerola, J., Hiraldo, F. & Wintle, B.A. (2011). Linking cost efficiency evaluation with population viability analysis to prioritize wetland bird conservation actions. *Biol. Conserv.*, **144**, 2354-2361.

Strimbu, B. & Innes, J. (2011). An analytical platform for cumulative impact assessment based on multiple futures: the impact of petroleum drilling and forest harvesting on moose (Alces alces) and marten (Martes americana) habitats in northeastern British Columbia. *J. Environ. Manage.*, **92**, 1740-1752.

Therivel, R. & Paridario, M.R. (2013). The practice of strategic environmental assessment. Routledge, Taylor & Francis, Hoboken.

WAPC. (2010). *Directions 2031 and beyond: metropolitan planning beyond the horizon*. Western Australian Planning Commission, Perth, WA.

WAPC. (2012). *Economic and employment lands strategy: non-heavy industrial*. Western Australian Planning Commission, Perth, WA.

Wintle, B.A., Bekessy, S.A., Venier, L.A., Pearce, J.L. & Chisholm, R.A. (2005). Utility of dynamic-landscape metapopulation models for sustainable forest management. *Conserv. Biol.*, **19**, 1930-1943.

Endnotes

1. http://www.environment.gov.au/protection/environment-assessments
2. http://www.dpc.wa.gov.au/Consultation/StrategicAssessment/Pages/Default.aspx
3. www.dmp.wa.gov.au/Geological-Survey/Basic-Raw-Materials-1411.aspx; http://www.planning.wa.gov.au/publications/6274.asp
4. www.dpc.wa.gov.au/Consultation/StrategicAssessment/Documents/01-Strategic-Assessment-Summary.pdf
5. Atlas of Living Australia (www.ala.org.au); NatureMap (https://naturemap.dpaw.wa.gov.au/)