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Scheduling priority conservation action in production landscapes: priority areas in western New South Wales defined by irreplaceability and vulnerability to vegetation loss

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Running head: Priority conservation areas in western New South Wales

Abstract

Scheduling conservation action is necessary when the available resources for conservation are insufficient to adequately protect all of the natural features (e.g. species, vegetation types, ecosystems) in a region, at least in the short-term. We propose an approach to scheduling conservation action in production landscapes. It is based on two characteristics of potential conservation areas. The first is vulnerability — the likelihood or imminence of destruction or alteration of native vegetation. The second is irreplaceability — the likelihood that an area will be needed to contribute to a set of conservation targets nominated for the region's features. We argue that highest priority for conservation action should go to those areas with both high vulnerability (urgent protection needed to avoid destruction) and high irreplaceability (few or no alternatives if destroyed). To establish the context and rationale for our approach, we review some previous methods for scheduling nature conservation. We then apply our approach to the Western Division of New South Wales, a region of about 325,000 km^2, by deriving information on the vulnerability of 248 land systems to two threatening processes (clearing and cropping) and measuring the irreplaceability of potential conservation areas. Our results are maps of areas where conservation action is most urgently needed if regional conservation targets are not to be compromised.

Keywords: Conservation value, conservation priority, reservation, protected areas, land clearing, cropping, threats

1. Introduction

The recommended methods for allocating scarce conservation resources to "priority" conservation areas are diverse (Smith and Theberge, 1986; Dinerstein and Wikramanayake, 1993; Caldecott et al., 1994; Johnson, 1995; Kiester et al., 1996; Csuti et al., 1997; Reid, 1998). Are all these approaches equally effective? In this paper, we argue that the best approach to defining conservation priority is the one that best achieves an explicit conservation goal in the face of particular constraints such as competition with other land uses or limited resources available for conservation action on the ground. The best approach will therefore vary with circumstances. We review four situations in conservation planning with the same goals but different constraints and argue that the most common, realistic and challenging situation requires conservation planners not only to make careful choices between areas but, at least as importantly, careful decisions about the scheduling of conservation action for specific areas.

To deal with this widespread situation, we show that the availability of choices between different areas for conservation management can be measured for individual land classes such as vegetation types or, in this case, land systems. Each land system or other classification can present a different range of choices for conservation action depending on the proportion of its remaining extent still needing protection. The scope for spatial choices can also be measured for potential reserves that contain a variety of land classes. The order of scheduling for conservation action in particular areas is measurable too. It is indicated by the degree of threat faced by an area - the likelihood or imminence of habitat loss or degradation - which we refer to here as vulnerability. With information on both the spatial options for achieving an explicit conservation goal and the likelihood of that goal being compromised by habitat loss or degradation, planners can make strategic decisions about where and when to allocate conservation resources.

To demonstrate the need and potential for choices in space and time, our study region is the Western Division of New South Wales. The Division has a long history of extractive land use. The introduction of sheep and cattle from the 1830s was followed in only a few decades by noticeable changes in native vegetation, soil condition and carrying capacity, compounded by the arrival of the European rabbit (Mitchell, 1991; Pickard, 1991a) and leading to

Government controls on stocking rates (Western Division Select Committee, 1984; Lunney, 1994). Clearing began soon after pastoral settlement, first for fencing and building, then to provide pit props and fuel for mines and to drive steamboats on the main rivers (Pressey, 1990). Thinning of timber to improve stock carrying capacity also began soon after European settlement and large-scale cropping commenced in the 1920s. A licencing system for clearing and cropping, both of which are concentrated in the eastern and southern parts of the region (Pressey, 1990), is intended to minimize impacts on soil, vegetation and fauna (Campbell, 1994). Overall, the effects of European settlement on the Division have been, and continue to be, adverse (Allison et al., 1990; Benson, 1991; Graham, 1992; Dick, 1992; Dickman et al., 1993; Smith et al., 1994; Graetz et al., 1995; Noble et al., 1996; Turner et al., 1996; James et al., 1999), the protected area system is inadequate and unrepresentative (Pressey and Taffs, accompanying ms), and there is an urgent need to apply the approaches to land stewardship and sustainable use now being investigated and proposed (e.g. Friedel et al., 1990; Morton et al., 1995).

In this paper, we analyse the vulnerability of land systems throughout the Western Division to two threatening processes: clearing and cropping. Grazing by domestic stock is much more widespread that either of these two activities, but information on the vulnerability of land systems to grazing is presently incomplete, being restricted to the potential for surface sealing of soils. Further work is needed to assess the response of vegetation types to grazing and to compile data on grazing history and current intensity in relation to features such as watering points. When this work has been done, it will be possible to establish priorities for protection from grazing in the same way as we set priorities in this paper for protection from clearing and cropping.

The broad approach that we propose for defining, measuring and mapping priority conservation areas is generic, the moreso because it is based on biophysical data mapped at 1:250,000 scale. Extensive abiotic or biophysical data sets at similar scales either exist (e.g. Cowling and Heijnis, submitted) or can be derived across many regions from readily accessible data (e.g. e.g. Margules and Redhead, 1995; EIC, 1999; USGS, 2000) as a basis for consistent pictures of conservation priorities. Despite the general applicability of the ideas in this study, the methods we use for measuring vulnerability at the level of land systems are specific and determined by the nature of the best available data. In particular, there is some uncertainty in the relative extent and suitability for extractive uses of unmapped land units, the landscape elements that combine to form the mapped land systems amenable to geographic analyses. In this paper, we develop an approach for using this uncertainty explicitly. Our results provide broad regional overviews of conservation priority for both day-to-day and long-term decisions about land use and the development of an expanded system of conservation areas. We finish by discussing the need and scope for refinement of the approach described here, including its application to deal with grazing as a threatening process.

2. A conceptual framework for identifying priority conservation areas

The most effective way of defining priority conservation areas - that which "best" protects biodiversity with its particular placement of conservation resources - will vary according to the goals of the exercise and the constraints on conservation actions. In Table 1 we have summarized four planning situations. The goal in each situation is to represent (sample) in conservation areas an explicitly targeted area or number of occurrences of each of the features (e.g. species, vegetation types, ecosystems) occurring in the region of interest. The constraints and available information vary between the situations and we have proposed the best approach to defining conservation priority in each. For the first two situations, the proposed best approaches have been discussed widely in the literature, but these are likely to be less relevant to real-world conservation planning than the third and fourth situations. Situation 4 is probably the most realistic and widespread and requires a different approach to prioritising areas than the others. In Section 5.2, we indicate the need to regard this proposed approach as a testable prediction, and suggest a way of testing it.

2.1. Situation 1

It is expected that the representation targets for all features will be achieved, but only if the cost of doing so, in terms of money, land area, or forgone extractive resources, is minimized (Table 1). It is also likely that, once the new conservation areas have been designed and agreed by agencies and interest groups, the expanded conservation system will be implemented quickly. This means that the agreed candidate conservation areas are the ones that will be put in place, without constraints on availability or the loss or degradation of some of them before they are formally protected. An example of such a situation would be an exercise in conservation planning limited to extensive tracts of public land where acquisition costs are minimal and there is no need for lengthy negotiations with individual private landholders (recent experience in New South Wales suggests, however, that Situation 3, below, will be much more common).

The best strategy would be to select new conservation areas by maximizing their complementarity - the extent to which individual areas complement, rather than unneccessarily duplicate, one another in achieving targets for features (Pressey et al., 1993). This maximizes the efficiency of the expanded system of conservation areas (Pressey and Nicholls, 1989) by minimizing its cost, however this is measured. High complementarity can be achieved by selecting areas using a variety of heuristic or optimizing selection algorithms (see Margules and Redhead, 1995; Csuti et al., 1997; Pressey et al., 1997; Williams, 1998 for reviews) or by methods that define complementarity in environmental space (Belbin, 1995; Faith and Walker, 1996a). Preferably, the options for selecting a complementary set of areas would be explored by using interactive decision-support systems (e.g. Bedward et al., 1992; Pressey, 1998; Davis et al., 1999) to explore the scope for replacing some candidate areas with others according to factors such as cost, continguity and land use history. Information on the relative vulnerability of features to current or likely threatening processes is not necessary for identifying the relative priority of candidate conservation areas, although it would ideally be used to set appropriate conservation targets for individual features (e.g. RACAC, 1996; Lombard et al., 1997).

2.2. Situation 2

Due to competition with other land uses or limited resources for implementation, the system of conservation areas cannot expand, at least in the short-term, to achieve all representation targets (Table 1). There is no information available on the relative vulnerability of features to current or likely threatening processes that would enable “priority” features to be defined as those most susceptible to reduction or loss. The approach promoted by several authors (Underhill, 1994; Camm et al., 1996; Church et al., 1996; Kiester et al., 1996; Arthur et al. 1997) is to maximize the number of features represented for any number or total extent of new conservation areas. In the case of rapid implementation, this means identifying the set of candidate areas of maximum allowable size that protects the largest number of features. In the case of incremental implementation, it means gaining the largest possible increment of protected features for every addition to the system of conservation areas. This general approach has been proposed only in relation to simple representation targets (at least one occurrence of each feature). For more complex and realistic targets such as multiple occurrences or minimum areas of each feature, decisions would be needed on whether and how partial achievement of targets contributed to optimal representation or the maximum increment of represented features.

2.3. Situation 3

As in Situation 2 and unlike Situation 1, the constraints on implementation are such that not all representation targets are expected to be achieved (Table 1). As in one aspect of Situation 2, implementation is likely to be rapid, most likely because the exercise is restricted to public land. A related condition could be that, once candidate conservation areas are identified and implemented, there will be an extended period of security for further resource extraction from unconserved areas (as in the forests of eastern New South Wales in the late 1990s – Anon., 1998). A key difference with Situation 2 is that information is available on the relative vulnerability of features to threatening processes. This is more realistic than Situation 2 given the predictability of patterns of habitat loss and extractive land uses in relation to geology, topography, proximity to markets, expanding urban areas and other factors (e.g. Braithwaite et al., 1993, Pressey et al., 1996; Veldkamp and Fresco, 1996; White et al., 1997). We suggest that the most effective approach to setting conservation priorities in this situation is to consider the distribution of the features most likely to be lost in the face of continuing or expanding extractive activities and then to identify a set of conservation areas, using complementarity, that efficiently represents these features. The remaining features are the ones most likely to persist in the absence of conservation action, at least in the short-term.

This situation has been faced in recent years by the National Parks and Wildlife Service. In a major planning exercise in 1996, the achievement of all conservation targets for public forests in eastern New South Wales was politically intractable (Pressey, 1998) and decisions were necessary on which subset of conservation targets should be achieved within the constraint of substantial continued logging. The decisions had to be based on some assessment of the relative vulnerability of features, particularly old growth forest types and some faunal species, to logging activities. In subsequent negotiations over new reserves in the north-east and south-east, there were attempts to allocate species and forest ecosystems to vulnerability classes (Anon., 1999) and to preferentially represent the most vulnerable ones in formal reserves. It is notable that the recommended "optimal" approach to Situation 2 could produce seriously suboptimal results for this more realistic situation in terms of the persistence of features on the ground. This is because any optimal set of areas for Situation 2 would be likely to contain features that are tolerant of current threatening processes while also missing features that will decline or disappear unless they are protected urgently.

2.4. Situation 4

This situation differs from Situation 3 only in that implementation is expected to be slow (Table 1), probably because the region is wholly or partly in private ownership. Conservation resources, in terms of time for negotiation with individual landholders and annual funding for acquisition or management, are small relative to the requirements for implementing the whole system of conservation areas. Threatening processes such as habitat loss, logging and grazing will continue during the implementation of conservation action. Consequently, at least some candidate conservation areas are likely to be lost or degraded before they can be adequately protected. We propose that the best approach here is to give highest priority to areas that have two characteristics: high vulnerability to loss or degradation from current or expected threatening processes; and high irreplaceability (few or no replacements available to achieve the conservation targets) if lost or degraded. This approach should minimize the extent to which the conservation targets for the region are compromised during the protracted implementation stage of the regional plan.

If the features being considered for conservation action are individual species and conservation targets are occurrences of species (e.g. at least three localities of each species to be given protection), irreplaceability will be approximated by rarity or endemism. For planning concerned with features such as vegetation types and using conservation targets defined by areas of each type (e.g. at least 10% of the total extent or 1200 ha of each type), irreplaceability will relate to the proportion of the remaining area of each type needing conservation action. In this case, high irreplaceability would be indicated by the need to protect all or nearly all of the remaining area of the vegetation type (few spatial options), low irreplaceability by the conservation target requiring protection of only a small proportion of remaining area (many spatial options). For planning exercises concerned not with individual features but with potential conservation areas containing a mix of species, vegetation types or other features, it will be necessary to measure irreplaceability as defined by Pressey et al.

(1994) (and see Ferrier et al., in press for a new method applicable to both presence and area targets). This approach integrates information on all the features in each area to produce an index of: (a) the likelihood of needing each area in the study region to achieve the set of conservation targets; and (b) the extent to which the options for achieving the targets will be lost if the area is unavailable for conservation. Higher values indicate greater importance for the set of regional conservation targets.

Calculations of irreplaceability consider complementarity implicitly. The irreplaceability value for any area is estimated using information on the distributions of the area's features in all other areas within the region (including the sizes of all other occurrences in the case of area targets – see Ferrier et al., in press). It also considers the contribution of any existing reserves to conservation targets and is recalculated each time one or more additional areas are notionally conserved, taking into account progressive changes to unmet conservation targets. The implications of complementarity are discussed further in Sections 4 and 5.4.

We emphasize that, in Situation 4, irreplaceability alone is insufficient to define conservation priority. Some highly irreplaceable areas will not be at risk in the foreseeable future while some areas with moderate irreplaceability might all be threatened with imminent destruction in the absence of conservation action, perhaps leading to the elimination of some species or vegetation types from the region. Areas with highest priority for conservation will have both high irreplaceability and high vulnerability. The remainder of the paper deals with the application of this definition of conservation priority to a large region which is the subject of several current exercises in conservation planning and which is described well by the constraints in Situation 4. The same approach could be applied generally at a range of scales, from countries or continents to much smaller local planning areas.

Our suggested approach is similar conceptually to definitions of priority applied globally. Myers (1988) defined biodiversity hotspots as areas with exceptional concentrations of species with exceptional levels of endemism (our irreplaceability) and facing exceptional levels of threat (our vulnerability) (and see Mittermeier et al., 1998 for a more recent application of the same approach). Similarly, Sisk et al. (1994) used a quantitative and explicitly two dimensional method to plot countries according to either a species endemism or species richness index (irreplaceability, at least in the case of endemism) combined with an index of human population pressure or index of forest loss (vulnerability). They identified "areas of critical concern" as those countries that fell within the top quartiles for both the biological index and threat index. Within one of the global biodiversity hotspots – the Succulent Karoo biome of South Africa - the approach that we have developed here has influenced the identification of priority conservation areas as those having high levels of plant endemism and high vulnerability to one or more threatening processes (Cowling et al., 1999; Lombard et al., 1999). Also for assessments within regions, Cole and Landres (1996) defined ecological significance partly in terms of irreplaceability and vulnerability, but without quantifying either.

3. Methods

3.1. Data base

The study region for the analyses described here is the Western Division of New South Wales covering about 325,000 km^2 of semi-arid and arid rangelands (Fig. 1). Average annual rainfall is about 150 mm in the arid north-west corner and increases to the east and south, the highest rainfall in the Division being about 450 mm in the far north-east. Both the landscapes and main vegetation types have been mapped (Walker, 1991; Pickard and Norris, 1994). Landscapes include rocky ranges, tablelands, hills and rolling downs, alluvial plains, playas and other drainage basins, sandplains and dunefields. Vegetation formations vary widely in structure and composition with climate, hydrology, terrain and soils. They include riverine *Eucalyptus* woodlands, woodlands and open woodlands of *Eucalyptus*, *Callitris*, *Acacia* and *Casuarina*, shrublands and grasslands. Land use is dominantly stock grazing on native rangelands, but some areas in the east and south of the Division are cleared either for cropping or to increase stocking rates.

The Division has been subdivided into 248 land systems - recurring patterns of landforms, soils and vegetation (Mabbutt, 1968) - mapped at a scale of 1:250,000 (see Walker, 1991 for details). These are the natural features used in this study as the basis for assigning conservation priorities. They are the only generally recognized land types both available for the whole Western Division and amenable to geographical analyses.

3.2. Vulnerability ratings for land systems

An assessment of the vulnerability of land types, regions or countries is an estimate of the likelihood or imminence of habitat loss or degradation. This information can guide decisions on both the amount of protection necessary and the urgency of that protection. Measures of vulnerability include previous or projected rates of habitat loss (Dinerstein and Wikramanayake, 1993; Pressey et al., 1996; White et al., 1997), the size or growth rates of human populations (Sisk et al., 1994; Beissinger et al., 1996; Thompson and Jones, 1999), and the densities of threatened species (Bibby et al., 1992; Lombard et al., 1999). In this paper, we estimate the vulnerability of each of the land systems in the Western Division using assessments of the suitability of areas for clearing or cropping.

The data for our vulnerability assessments concern land units - the relatively homogeneous pieces of the landscape that make up the patterns by which land systems are defined. For example, a dunefield land system is often composed of three units - dunes, swales and drainage basins - in a particular repeating pattern. Unlike land systems, land units in the Western Division have not been mapped, but they have been described and illustrated for each of the 248 land systems and their relative extent in each land system has been estimated (Walker, 1991). VS (very small) indicates that the unit occcupies less than 5% of the land system, S (small) is 5-15%, M (moderate) is 16-30%, L (large) is 31-50%, and VL (very large) is greater than 50%.

The Department of Land and Water Conservation (DLWC) has rated the vulnerability of each land unit listed by Walker (1991) to a variety of threatening processes. For the analyses in this study, we chose two processes - clearing and cropping - particularly relevant to reservation. These can be prevented by the dedication of conservation reserves, in contrast to processes such as altered fire regimes and the spread of weeds which rely on active management within and outside reserves. There are three categories for clearing (the interpretation of vulnerability is ours): (1) no clearing (low vulnerability); (2) capable of selective thinning (moderate vulnerability); and (3) capable of intensive clearing (high vulnerability). Only soil impacts were considered by DLWC in allocating capabilities. We converted these to vulnerabilities based on the potential for impacts on plants and animals associated with land units. Land units with no capability for clearing have soil characteristics such as light texture or shallow depth that require vegetation cover to be retained. Units capable of selective thinning, usually to increase the carrying capacity for stock, are generally suitable only of a continuation of grazing. Units capable of intensive clearing would generally also be capable of subsequent cropping. DLWC categories for cropping are: (1) no cropping (low vulnerability); (2) capable of opportunity cropping (moderate vulnerability); and (3) capable of intensive cropping (high vulnerability). Land units capable of opportunity cropping are generally floodplains and lakebeds that are periodically flooded and drain within two or three months. A pre-condition for cropping approval is a fully charged soil profile, so cropping is irregular. Opportunity cropping does not generally involve prior approval to clear because the affected areas do not usually support woody vegetation covered by the licencing process, either because of natural constraints or clearing before systematic records of approvals were kept.

Allocating overall vulnerability values to land systems required information on the relative vulnerability of their land units to be combined with information on the relative extent of each unit within each land system. The categorical nature of both types of information invalidated a simple arithmetic approach (Smith and Theberge, 1987) because the width of the categories is variable and the actual position of land units across the possible values in its category is unknown. The products or sums of numbered categories therefore come with undefined errors. We developed a method for estimating the overall vulnerability of land systems that recognised these errors and made the consequent uncertainty explicit.

We produced four classes of vulnerability for both clearing and cropping. Two of these – high and zero - do not involve uncertainty. The high class contains land systems composed only of land units with high vulnerabilities. The zero class contains land systems that are composed only of land units with low vulnerability or are inland of the climatic limit of clearing and dryland cropping (Fig. 1) (note that vulnerability ratings by DLWC did not explicitly consider climate). Our climatic limit is a line that separates two parts of the Division. The first consists of climatically unsuitable areas where applications for clearing and dryland cropping are either not submitted or not approved, regardless of inherent soil capabilities. The second contains areas where land use is constrained only by soils and terrain, not by climate. The climatic limit integrates information on average annual rainfall with its seasonality and reliability, corresponding to an average rainfall of 250 mm in the south and about 350 mm in the north-east. We zeroed the vulnerabilities to clearing and cropping of land systems occurring inland of the climatic limit, except for those subject to post-flood opportunity cropping in the Darling River system. If any land system straddled the climatic limit and had different vulnerabilities on either after the following analyses, we divided it into two separate sections.

Due to the lack of a map base for land units, there is some inevitable uncertainty in the allocation of the remaining land systems to two intermediate classes - low and moderate. We allocated land systems to these classes in four steps (details of the method and rationale are available from the corresponding author). First, for land units with high or moderate vulnerabilities, we recorded the minimum and maximum percentage areas possibly occupied in each land system, using information on class intervals, above. We assumed that land units with low vulnerability do not contribute to the overall vulnerability of land systems. Second, we totalled the minimum and maximum values (after halving those for land units with moderate vulnerability) to produce a range of possible values for the overall vulnerability of the land system in terms of its percentage cover by highly vulnerable land units (assuming that units with moderate vulnerability contribute half as much to overall land system vulnerability as those with high vulnerability). Third, for all possible values of overall land system vulnerability, we measured the "informativeness" of splits between notional low and moderate classes for land systems. We found marked intermediate peaks in informativeness for both clearing and cropping. Splits at these points reflect real discontinuities in the data when considered across all land systems, i.e. there is a tendency for large parts of the ranges of values for land systems to lie on either side. Fourth, we allocated each land system nominally to the class that contained most of its range of overall vulnerability values but then identified the probability that it had been correctly allocated from the proportion of its total range lying within that class. Values ranged from 1.0 for land systems with ranges entirely within their allocated class to around 0.5 for those with ranges split evenly by the class boundary.

At a broad scale, our results, below, are useful as a demonstration of priority setting in relation to spatial and temporal options, for indicating the relative conservation priorities at the level of individual land systems, and for providing a context for smaller study areas within the Division. For decisions at a fine scale, our results could be inappropriate. They would not, for example, support decisions about the management of individual pastoral holdings in the Western Division without follow-up investigations. Because of the explicit, but unmapped, heterogeneity of land systems, some of the land units that contribute to the overall vulnerability of the land systems on a particular holding might be absent from that holding, causing overall vulnerabilities to be over- or under-estimated. Another scale-related problem is that land systems with low or moderate overall vulnerabilities can still contain land units with high vulnerabilities, increasing the risk of habitat loss or degradation in those units. Although these problems are obvious in our study because of the explicit heterogeneity of land systems and our approach to estimating overall vulnerabilities, they will apply equally, but implicitly, to other land classes because of unmapped internal variation in biophysical characteristics and land use potential (Scott et al., 1989; Pressey, 1992; Ferrier and Watson, 1997).

3.3. Conservation targets

We applied our definition of priority conservation areas to the Division in two ways: to land systems or parts of land systems; and to potential conservation areas that each contain a mix of land systems. For both applications our calculations of irreplaceability required quantitative conservation targets for each land system. Our derivation of conservation targets had two premises. First, targets relating to numbers of occurrences (e.g. at least one occurrence of each species - Csuti et al., 1997, Pressey et al., 1997) are inadequate for features such as land systems or vegetation types that have known areas. Second, targets set in terms of minimum areal extent should not be equal for each feature but should vary according to the perceived need for conservation action (e.g. RACAC, 1996; Lombard et al., 1997). A baseline from which to vary targets for each land system is provided by recent policy on forest reserves in Australia. Both the original and subsequent Commonwealth guidelines (Anon., 1995; JANIS, 1997) stipulate a benchmark conservation target of 15% of the pre-European extent of each forest type. Both also recognise that larger targets will be necessary for rare and/or threatened types and that smaller targets could be appropriate for extensive, intact forest types.

For consistency with these guidelines, we allocated a different areal conservation target to each land system or part land system with the formula:

$$\text{TARGET} = 10\% + (10\% \times \text{NR}) + (10\% \times \text{V})$$

where the TARGET is a percentage of the original, fully vegetated extent of the land system, NR is the natural rarity of the land system (ranging from 0 to 1), and V is its vulnerability class for clearing or cropping (one set of targets for each). Values for vulnerability classes were 0, 1 for low, 2 for moderate, and 3 for high. We measured the natural rarity of each land system as $[(A_{max} - A_i)/A_{max}]$, where A_{max} is the area of the most extensive land system in the Division and A_i is the area of the land system being considered. Conservation targets were therefore a theoretical minimum of 10% of the original area of each land system and a maximum of 50%, with vulnerability (or need for conservation action) potentially contributing three times as much as natural rarity to the overall figure. In practice, only four land systems had conservation targets less than 15% of their total extent (11.7%, 13.1%, 14.2% and 14.6%), values being similar for both clearing and cropping. Overall, targets varied from about 12% to 50%, with a mean of about 25%. Other formulations of targets are clearly possible and will change the priorities identified here.

3.4. Conservation priority in relation to individual land systems

For each land system, we plotted conservation priority separately for clearing and cropping in relation to two values: (1) the percentage of its remaining extent (still under native vegetation) needing further conservation action to achieve its regional conservation target (hereafter termed % REQUIRED); and (2) its vulnerability. The first value addresses the issue of spatial options to conserve the land system, with higher percentages indicating fewer options. It takes into account how much is already in conservation reserves and how much has been cleared or cropped (because conservation targets are expressed in terms of the original extent of each land system, any reduction in native vegetation will increase the target in terms of percentage of remaining extent). The second value relates to scheduling - land systems more vulnerable to clearing or cropping need conservation attention more urgently. We plotted land systems on axes for both to show the combinations of values. Because there are still no comprehensive, accurate data on actual areas cleared or cropped, we estimated the remaining area of native vegetation in each land system by subtracting areas covered by approvals for clearing and/or cropping.

3.5. Conservation priority in relation to potential conservation areas

Our measure of the conservation priority of potential reserves was similar conceptually to that for individual land systems, although different analytically. We again measured priority separately for clearing and cropping. For the purposes of this paper, we delineated potential conservation areas as 803 grid cells with average areas of about 400 km^2. We constructed these around the 22 existing reserves so that the reserved area of each land system could be calculated exactly. The choice of grid cell size was arbitrary and was designed to avoid identifying individual holdings and pre-empting current investigations over new conservation areas in the Division. The same analysis is possible for pastoral holdings or any other subdivisions of the region. The values for vulnerability of areas, or urgency for conservation action, on the horizontal axes of the priority plots were those of the most extensive land system in each holding (to avoid applying a measure such as weighted average to uncertain data). Values on the vertical axis of each priority plot were given by the irreplaceability of each area (Pressey et al., 1994; Ferrier et al., in press), varying from 0 to 100. Irreplaceability integrates the contribution of each area to a set of conservation targets based on all the features it contains. In the analyses presented here, irreplaceability took into account the extent to which each land system was cleared and/or cropped and the extent to which each already occurred in reserves. Ferrier et al. (in press) have described and validated the new statistical approach used here to estimate irreplaceability. Estimation of irreplaceability values is essential for large data sets because exact values can be derived only by exhaustive combinatorial analysis, infeasible for data sets larger than 80 or so areas (Pressey et al., 1994). Random sampling from all possible combinations of areas in large data sets can produce close approximations of exact values for validation (Ferrier et al., in press) but is very time-consuming.

3.6. Identification of high conservation priorities

We have defined land systems or potential conservation areas having highest priorities for conservation as those with highest values of irreplaceability (or % REQUIRED) and highest vulnerabilities - those toward the top right of priority plots such as those in Fig. 2. There are two possible approaches to delineating high priority areas in these plots. The first strictly identifies areas with both high irreplaceability and high vulnerability, e.g. the method of Sisk et al. (1994) which found countries within the upper quartile on each axis. The second approach, used in this study, uses a diagonal to delineate the top right of the plots (Fig. 2). When only a small number of priority areas need to be identified, i.e. only the far top right of the plot is relevant, this approach effectively finds areas with high irreplaceability *and* high vulnerability. When larger numbers of priority areas are of interest and the diagonal is moved toward the origin, this approach identifies areas with high irreplaceability *and/or* high vulnerability. A diagonal can therefore imply a trade-off between vulnerability and irreplaceability in identifying priority areas. Areas with lower vulnerability need to have higher irreplaceability to be given priority. Areas with higher vulnerability can have lower irreplaceability and still be given priority.

We used a stepped diagonal in the top right of each priority plot (Fig. 2a), ignoring the zero vulnerability class for the purposes of identifying priority areas. The stepped diagonal for the Western Division data gives cutoffs that are deliberately discontinuous for three reasons. First, there is no basis for a continuum of values between moderate and high classes for clearing and cropping. Second, there is evidence of a discontinuity between low and moderate classes for clearing and cropping. Third, vulnerability values within the low and moderate classes are not truly continous, but simply probabilities that areas have been allocated to the correct class. A simpler approach, using a straight diagonal in the top right of the priority plots (Fig. 2b) would be possible for data sets with truly continuous data on vulnerability (e.g. Pressey et al., 1996).

The actual values on the vertical axes of the priority plots that we chose to delineate areas of highest conservation priority are arbitrary. We set cutoffs for moderate vulnerability at 30% higher than those for high, and cutoffs for low vulnerability 30% higher than those for moderate. We then adjusted the cutoffs for % REQUIRED to find about 30 land systems with highest conservation priority and for irreplaceability to find about 100 potential conservation areas with highest priority. This approach recognises that there is a gradient of priority from top right to bottom left of the plots (Fig. 2) and that no particular values of % REQUIRED or irreplaceability are more valid than others as cutoffs. Much depends on the purpose of the planning exercise and the available resources. The number of priority areas that could be dealt with adequately might vary from a handful to several hundred depending on whether the intention is, for example, outright acquisition or widespread protective zoning.

Of the areas identified as priorities with our approach, those further toward the top right of the plots should be given protection first. When this involves choices between areas of similar % REQUIRED or irreplaceability within the low or moderate vulnerability classes, conservation action should favour those areas with higher probability of presence in the class. This combines the use of vulnerability classes with the recognition of gradients of reliability within the intermediate classes and should minimize the risk of conservation targets being pre-empted by clearing or cropping.

4. Results and discussion

4.1. Vulnerability of land systems

Land systems vulnerable to clearing are in the east and south of the Division, outside the inland zone where effective rainfall is too low or too unreliable to warrant clearing for cultivation or increased stock carrying capacity (Fig. 3a). Within the zone where clearing applications are approved, only two land systems have high vulnerability to clearing, i.e. are totally occupied by land units suitable for clearing without substantial risk of soil loss. One of these is Lysmoyle, composed mainly of level sandplains with open woodland near the south-eastern boundary of the Division. The other is Rotten Plain, in the north-east, with only one land unit - level plains of deep cracking clays, dominated by shrubs and forbs and with fringing trees. Small areas in the climatically suitable zone have zero vulnerability to clearing. These are land systems with stony or sandy soils that present an unacceptable erosion risk. There is a concentration of land systems with moderate vulnerability to clearing in the north-east but, overall, low and moderate vulnerabilities are about equally extensive (Fig. 3a, Table 2).

The general picture for vulnerability to cropping is similar to that for clearing except for the post-flood opportunity cropping along the Darling River and its tributaries inland of the rainfall constraint on dryland cropping (Fig. 3b). These riverine areas do not appear in Fig. 3a because the areas cropped are not occupied by woody vegetation for which clearing licences are required before cultivation (or perhaps, in some cases, because they were cleared before systematic records were kept). Only one land system - Lysmoyle - has a high overall vulnerability to cropping. Within the zone suitable climatically for dryland cropping, land systems with zero vulnerabilities are more extensive than for clearing (Fig. 3b). These are again stony or sandy landscapes with considerable erosion risk or active erosion. Overall, areas with low vulnerability are much more widespread than those with moderate vulnerability (Fig. 3b, Table 2).

4.2. Priorities in relation to individual land systems

Priority plots for land systems (Fig. 4) indicate spatial options, in terms of % REQUIRED, on the vertical axes and temporal options or urgency on the horizontal axes. For many land systems, conservation targets in terms of the remaining extent of native vegetation are higher than percentages of their original extent due to clearing and cropping. Targets for a few land systems were larger than their remaining vegetated areas and had to be truncated to 100%. For a few others, % REQUIRED is zero, indicating that targets have been fully met in the existing reserve system. For both clearing and cropping there is a tendency for % REQUIRED to increase with higher vulnerability classes. This is largely because vulnerability has a major influence on our conservation targets. We regard this as appropriate - vulnerability, or the need for conservation action, is affecting the extent of protection required as well as the urgency for that protection.

High values of % REQUIRED for land systems with zero or low vulnerability for clearing or cropping (Fig. 4a,b) are not explained by the original conservation targets since these would have involved little or no weighting for vulnerability. The maximum targets, in terms of the original vegetated extent of land systems, in the zero vulnerability classes for clearing and cropping were 20% (base 10% plus maximum weighting for natural rarity). In principle, the original targets should not have been inflated by habitat loss in areas with zero vulnerability. In practice, some land systems with zero or low vulnerability to clearing had their targets increased in terms of remaining native vegetation by cropping along the Darling system, where clearing licences are not needed. Similarly, high values of % REQUIRED for some land systems with zero vulnerability to cropping are due to at least partial clearing in areas unsuitable for cultivation. Thus, although the priority assessments are only for individual threatening processes, % REQUIRED can increase the conservation priority of areas that are affected by both processes.

Land systems with high priority for protection from clearing are mostly in the moderate vulnerability class, except for one with low vulnerability and two with high vulnerability (Fig. 4a). Most land systems with high priority for protection from cropping are in the moderate class, with several having low vulnerability (Fig. 4b). Priority land systems for both threatening processes are in the east and south of the Division (Fig. 5). The priority definition identified a subset of the more vulnerable land systems for which the spatial options for conservation action are most limited (Fig. 5 cf. Fig. 3). If more land systems can be protected by, for example, broad-scale regulation of land use, the sets of priority land systems could be expanded toward the bottom left of the priority plots in Fig. 4. On the other hand, if protection in the short-term is only feasible for a few land systems, the priority sets can be reduced by shifting attention further towards the top right.

Complementarity is implicit in these analyses of priority. % REQUIRED is influenced not only by the extent to which native vegetation has been reduced in each land system but also the extent to which its conservation target has been achieved. The plots must therefore be adjusted each time more native vegetation is cleared (higher % REQUIRED for some land systems) and each time a new conservation area is established (lower % REQUIRED for some land systems).

4.3. Priorities in relation to potential conservation areas

In the priority plots for potential conservation areas in Fig. 6 there are no apparent relationships between irreplaceability and vulnerability, in contrast to those evident between % REQUIRED and vulnerability in Fig. 4. The main reason for this is that the spatial relationship between % REQUIRED and irreplaceability is not necessarily close. Some potential conservation areas could contain all or most of the remaining area of a land system and so be highly irreplaceable, even if only a small portion of the land system were needed to achieve conservation targets and the land system itself therefore had a low % REQUIRED. Areas can also be highly irreplaceable if they have a combination of land systems that gives them a high contribution to meeting several conservation targets simultaneously. There will be many situations in which little correlation would be expected between irreplaceability and vulnerability. In the Western Division specifically, many of the potential conservation areas with the most restricted land systems also have zero vulnerability to clearing and cropping because these land systems, which tend to confer high irreplaceability, are often steep, rocky and unsuitable for intensive land use. As expected, high priority areas for protection from clearing and cropping are largely in the east and south of the Division (Fig. 7), a pattern that is broadly similar to that for individual land systems (Fig. 5).

The priority plots for potential conservation areas, like those for individual land systems, should also be updated as habitat loss and the establishment of new conservation areas proceed. Irreplaceability calculations always recognise the extent to which conservation targets have already been achieved and the extent to which the spatial options for achieving conservation targets are reduced by ongoing clearing. In extreme cases, as with % REQUIRED, the original conservation targets for a few land systems were truncated to their remaining vegetated areas.

4.4. Priorities from this study compared to other approaches

We have used the priority plot for protection from clearing (Fig. 6a) to illustrate similarities and differences with three other approaches to defining priority. Fig. 8a shows the results from a heuristic reserve selection algorithm used to identify a near-minimum (Pressey et al., 1997) set of areas needed to achieve all conservation targets for clearing, taking into account the existing reserves. The algorithm naturally selected all totally irreplaceable areas (values of 1.0), a large proportion of highly irreplaceable areas (say values from 0.5 to 0.9), and a decreasing proportion of areas as with lower values of irreplaceability (Fig. 8a cf. Fig. 6a). Importantly, the algorithm selected areas from across the entire priority plot in Fig. 6a. Any set of candidate conservation areas that achieves all conservation targets for the Division will span the full ranges of both irreplaceability and vulnerability. The significance of the information in Fig. 8a is that the plot is a basis for assigning priorities for implementing conservation action in the (likely) event that all 245 selected areas cannot be protected at the same time. This highlights the difference between selection and implementation. The application of complementarity by the algorithm in the selection stage is important because it reduces the number of areas in the plot that have to be dealt with by planners and managers to achieve the nominated targets. But implementation in Situation 4, where habitat loss proceeds in parallel with conservation, requires scheduling of conservation action on the ground. Scheduling should begin in the top right of Fig. 8a to minimize the extent to which conservation targets are compromised by the loss of highly irreplaceable areas more vulnerable to clearing. As areas are lost and, where possible, replaced with others, the composition of the near-minimum set in Fig. 8a will change.

We also calculated richness with complementarity of the potential conservation areas by counting for each area the number of land systems with conservation targets still not fully achieved in the existing reserves. The top 5% of areas according to this measure are unevenly spread across the priority plot (Fig. 8b). Most importantly, many of the highest priorities in Fig. 6a, most of which were selected by the algorithm in Fig. 8a, do not appear in the richness plot. The bias is much more dramatic for rarity with complementarity, calculated for each area by summing the values for natural rarity of all land systems without conservation targets fully met in existing conservation areas (Fig. 8c). The top 5% of areas according to this criterion are all in the bottom left of the priority plot. High priorities according to our definition are missed entirely.

Both richness and rarity are likely to be limited in their effectiveness as conservation criteria in Situation 4, which we contend is the most realistic and widespread planning situation in Table 1. One important reason is that neither consider vulnerability as an indication of the urgency for conservation action. We also suggest a second reason. Compared to rarity and richness, irreplaceability is a more generally useful and accurate measure of the importance of an area for achieving a set of conservation targets (see Section 5.2 for how this should be tested). Irreplaceability is much more sensitive to conservation targets than rarity, even if the latter is applied with complementarity. Our new predictor of irreplaceability (Ferrier et al., in press) considers the extent of each feature in each area relative not only to remaining targets but to the extent of all other occurrences of those features in the data set. Rarity is likely to be useful when conservation targets are one occurrence of each feature, but is probably less useful when targets are multiple occurrences and/or areas of features. Richness, too, is target-independent or only vaguely responsive to area targets when applied with complementarity. Although richness might approximate endemism or irreplaceability if the scale of investigation is sufficiently broad, at scales relevant to designing individual conservation areas it will often correlate poorly with endemism or the extent to which a conservation goal is compromised by the loss of a particular area (Gentry, 1992; Lombard, 1995). Even if there is an overall correlation between richness and irreplaceability at the scale of individual conservation areas, the outliers from the main trend might be important in determining how well any set of conservation targets is achieved.

5. General discussion

5.1. Other views on vulnerability and irreplaceability

Faith and Walker (1996b) were critical of the general approach we propose here for identifying priority conservation areas. They considered that some methods of combining aspects of representativeness with vulnerability are inconsistent and *ad hoc*. They pointed specifically to the frequent use in planning of land types, usually with unmeasured biological heterogeneity, together with essentially arbitrary proportional targets for land types to deal with both their heterogeneity and the greater need for protection of more threatened ones. As an alternative, they proposed selecting potential conservation areas in ordination space to maximize the protection of the "expected biodiversity" of a region (see also Faith and Walker, 1996a) with levels of vulnerability of areas (but not of their environmental attributes or species) determining the expected proportion (but not the identity) of species persisting there over some period of time. We would not argue with their assessments of the limitations of most land classifications, including land systems in the Western Division, as a basis for conservation planning. We also agree that the most threatened areas are not always the highest priorities for protection (and see Section 5.3, below). But there are unresolved questions with their alternative method. Vulnerability is likely to be linked partly to geography (e.g. distance to timber mills) but also to the environmental attributes of areas (e.g. ruggedness, surface geology) that help to determine species composition. Areas in similar parts of the ordination space with similar species will therefore often have similar vulnerabilities. Failure to protect these species, say because of competing land uses, can be obscured by measuring the success of conservation efforts as a single number to reflect how well protected areas span the ordination space (cf. a set of specific targets for land types). As well, although Faith and Walker (1996a,b) seek to avoid the assumptions made in conventional use of biodiversity surrogates, their method comes with its own assumptions concerning the construction of the ordination space and the idealized distributions of species within it. Similarly, treating vulnerability as an estimate of the proportions of species likely to persist in areas under certain management regimes ignores the identities of those species, along with their particular regional distributions and life-histories that determine their actual vulnerabilities. We would be interested in more comparisons and discussion of the assumptions and limitations of our approach and that of Faith and Walker (1996b).

We are also aware of two published criticisms of the use of irreplaceability in conservation planning, although neither undermines the approach we propose here. According to Williams (1998), irreplaceablity "suffers from losing the links with knowledge of the particular goal-essential species … which are important for accountability and biological management decisions". This is incorrect. Even with the original approach described by Pressey et al. (1994) it is easy to extract the the identity and number of species or other features responsible for the irreplaceability value of an area, just as it is with the complementarity methods advocated by Williams (1998). This applies particularly with the new predictor used here (Ferrier et al., in press) which begins by calculating the irreplaceability of each area in the region for each of the features it contains and is linked to a geographic information system with which individual features or sets of features can be mapped. Another criticism of irreplaceability (Faith and Walker, 1997) is that the progressive selection of conservation areas based on irreplaceability values (with recalculations between selections to apply complementarity) can fail to minimize the costs of biodiversity conservation (in terms of forgone forestry potential in their worked example) even if it minimizes the number of selected areas. This point is valid and calls for further comparisons with larger data sets. Notably, if the ratio of irreplaceability to cost had been used as the selection criterion in their worked example, the optimal result would have been obtained. A ratio of biodiversity "value" to cost might be more effective if based on "summed irreplaceability" (Ferrier et al., in press) or the sum of the irreplaceability values of an area for each of its (as yet unrepresented) features.

5.2. Definitions of conservation priority as testable predictions

A recommendation that conservation priorities should be identified in terms of richness, rarity, complementarity, irreplaceability, threat, or any other consideration is basically a prediction. It is effectively predicting that a particular measure of importance will best achieve a particular conservation goal (often defined only very generally) in the face of certain constraints and opportunities (seldom stated explicitly). Unless the goals, constraints and opportunities are made explicit and the prediction is actually tested in some way, three of the problems of conservation planning will continue. First, the match between assumed constraints and opportunities on the one hand and on-ground realities on the other will not be established. Second, the relative effectiveness of the various recommended approaches to identifying priority conservation areas under different circumstances will not be known. Third, the debate over methods for setting conservation priorities will continue unproductively in a data-free environment while the erosion of biodiversity continues apace.

Any recommended approach to setting conservation priorities is eminently testable by setting priorities in different ways under simulated conditions assumed to be applying in a region and then by measuring the achievement of stated goals. Comparisons of the efficiency of alternative approaches (Pressey et al., 1993; Kershaw et al., 1994; Williams, 1998) are useful for Situations 1 and 2 in Table 1. Situation 4 requires a different approach – the construction of alternative futures for regions by simulating ongoing loss of native vegetation (with rates and patterns preferably based on real trends) in parallel with the expansion of systems of conservation areas located according to different criteria or procedures. The resulting scenarios will vary according to both the distribution of new conservation areas and the extent to which the loss of native vegetation is pre-empted to avoid conservation targets being compromised. Simulations of land use changes are not new (Veldkamp and Fresco, 1996; White et al., 1997; Laurance et al., 1999) but have not, to our knowledge, been used to test alternative conservation criteria. Any simulations involve assumptions about rates of conservation and habitat loss, but have the advantage of requiring conservation planners to state these assumptions explicitly and to quantify them. Just as importantly, simulations can be used to establish the sensitivity of the results to variations in the starting assumptions. The robustness of particular conservation criteria can therefore be tested when rates of conservation and habitat loss vary over years or decades.

This approach rests on the same premises as the rigorous hypothesis-testing methods advocated for recovery and maintenance of individual species (e.g. Caughley and Gunn, 1996; Dickman, 1996) and for the design of actual or hypothetical reserves to favour the persistence of species (Murphy, 1990). It is also prone to at least one one of the same criticisms - that the task of conservation is so urgent that it cannot wait for rigorous studies to be completed. Our responses are similar to those of Dickman's (1996) - urgent establishment of reserves is no guarantee of effective use of limited resources, and a more rigorous definition of planning situations followed by tests of alternative conservation criteria will enhance the effectiveness of conservation planning much more widely than in the particular study areas chosen for the comparisons.

5.3. Refinements and extensions of the approach proposed in this paper

The approach proposed here for setting conservation priorities needs improving and extending in various ways. These include: compilation and application of data on past land use and the consequent condition of potential conservation areas to inform choices about where to place protection; comparisons of predictive vulnerability assessments based on landscape characteristics (this study) with those based on the distributions of rare and threatened species (e.g. Beissinger et al., 1996; Brooks et al., 1997; Lombard et al., 1999); development of methods for assessing the vulnerability of features or areas to several threatening processes acting in concert; and further work on combining targets for biodiversity pattern and process in the priority-setting framework (Cowling et al., 1999). Two additional refinements are sufficiently important to warrant some discussion here.

The need for an assessment of grazing vulnerability in the Western Division. Grazing by domestic stock affects most of the Western Division - those parts not being intensively cropped and not in conservation reserves. In terms of potential for soil surface sealing, more than half the land systems in the Western Division, covering more than 60% of the region, have a high vulnerability to grazing. Grazing is much more extensive than either clearing or cropping and has the potential for substantial impacts on the Division's biodiversity (Mitchell, 1991; Pickard, 1991a,b; Landsberg et al., 1997a,b). This study did not address the most widespread threatening process in the Western Division because it was likely that our information on the vulnerability of soils to grazing would be insensitive to biological responses. This gap needs filling urgently. The necessary information is analogous to, but more complex than that for identifying priorities in this paper. The complexity arises from two sources. First, landscapes and their associated plant species vary in their resilience and response to grazing so that vulnerability to any level of grazing will vary between and within land systems, perhaps at a scale finer than land units. Second, grazing impacts grade from negligible to severe, being less clear-cut than clearing or cropping. % REQUIRED for individual land systems and irreplaceability for potential conservation areas are partly determined by how much of each land system is "lost" or unsuitable for conservation management. This will require either the recognition of a gradient of suitability relative to grazing impacts (indicated by factors such as timing of stock introduction, densities of stock carried, and spatial patterns of grazing in relation to watering points) or an arbitrary split of the gradient into suitable and unsuitable areas. In either case, it will be necessary to consider responses to grazing that are specific to soil and terrain types and particular plant species or functional groups.

Triage and risk assessment. Effective conservation action must avoid allocating scarce conservation resources to areas whose targeted natural features will not persist regardless of conservation action (the concept of triage described by Myers, 1979). This raises the question of which areas in our study region, or in any other region, might appear to be high priorities because of high vulnerability and high irreplaceability but are, in practice, beyond help.

Some of the high-priority land systems in the Western Division are heavily fragmented by clearing and cropping as are large parts of the landscape in the adjacent wheatbelt (Sivertsen, 1994; Sivertsen and Metcalfe, 1995). Full achievement of conservation targets would require protection of all or most of these fragments, but are they "lost causes"? Even if such areas can be effectively protected, perhaps at large cost, would the necessary resources, allocated elsewhere, produce a better regional outcome for nature conservation (and see discussion by Faith and Walker, 1996b)? Answering these questions requires a more sophisticated approach to interpreting the priority plots than we have taken in this study. A first step might be the type of qualitative decision analysis or alternatives analysis outlined by Maguire (1991) or O'Brien (1997), spelling out the consequences for conservation targets and conservation resources of putting effort into protecting areas at very high risk rather than more easily defensible ones. This would expose assumptions and clarify thinking about alternative approaches (but see cautionary notes by Caughley, 1994 about the importance of problem definition and sensitivity to input data). A further desirable step would be to quantify at least some of the factors involved, preferably through predictions about the likelihood of vegetation clearance and the persistence of certain species in relation to increasing fragmentation and disturbance of habitat patches.

5.4. Conservation priority as a dynamic concept

Much of the recent literature in conservation planning now recognises the principle of complementarity - that new conservation areas should complement, rather than unnecessarily duplicate, existing ones as fully as possible in the features they contain (Pressey et al., 1993). Complementarity is inevitably goal-dependent. Areas that are complementary for one goal will duplicate one another for a different goal. This is a strength rather than a weakness of an approach to defining priority that depends on an explicit, and preferably quantitative conservation goal. It means that conservation priority only has meaning if conservation planners know what they want to achieve. The same applies to conservation goals relating to reserve design, acquisition costs, management liabilities, cultural sites, recreational values and other considerations, whether these are framed quantitatively or qualitatively.

Complementarity also requires that priorities are reassessed every time one or more areas are given protective management. The priority plots in Figs. 4 and 6 are valid only for a point in time. Each new conservation area will cause some reduction in % REQUIRED for individual land systems or irreplaceability for potential conservation areas. But a variety of other changes will also require the priority plots to be updated. Ongoing loss of native vegetation will cause % REQUIRED or irreplaceability to rise as some of the spatial options for achieving conservation goals are reduced. Conservation targets for individual land systems could be altered as the understanding of species' conservation requirements improves and as social and political attitudes shift. The data base from which priorities are derived will change as new information is collected on land units and the locations of species or as new biophysical classifications of the Division are produced. Vulnerability will change with new crop varieties, new technology, new policies on water allocation from the main rivers, new markets for rural products, and the effects of global warming on climatic constraints on land use. The listing of some of these factors reflects our belief that conservation planning in the Western Division will not be resolved in a decade or two. During this period and beyond, a realistic and effective picture of priority conservation areas in the region must remain flexible to some extent.

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Table 1
Proposed strategies for defining conservation priority in four planning situations described by constraints on implementation and available information

Situation	Possible to achieve all targets in the short-term?	Rate of implementation of candidate areas	Information on vulnerability?	Strategy for setting conservation priorities
1	YES	Rapid	N/A	Complementarity
2	NO	Rapid or incremental	NO	Maximum number of features represented for any number or total extent of conservation areas
3	NO	Rapid	YES	Complementarity applied to features with highest vulnerability
4	NO	Incremental	YES	High irreplaceability (complementarity implicit) and high vulnerability

Table 2
Summary of numbers and total areas of land systems (as percentages of the Western Division) in vulnerability classes. Different total numbers for clearing and cropping are due to different subdivisions of land systems across the climatic boundary in Fig. 1

	CLEARING		CROPPING	
Vulnerability	Number	% W. Div.	Number	% W. Div.
High	2	0.29	1	0.14
Moderate	57	18.07	19	5.07
Low	84	20.79	130	28.40
Zero	169	60.84	167	66.38
Total number	312		317	

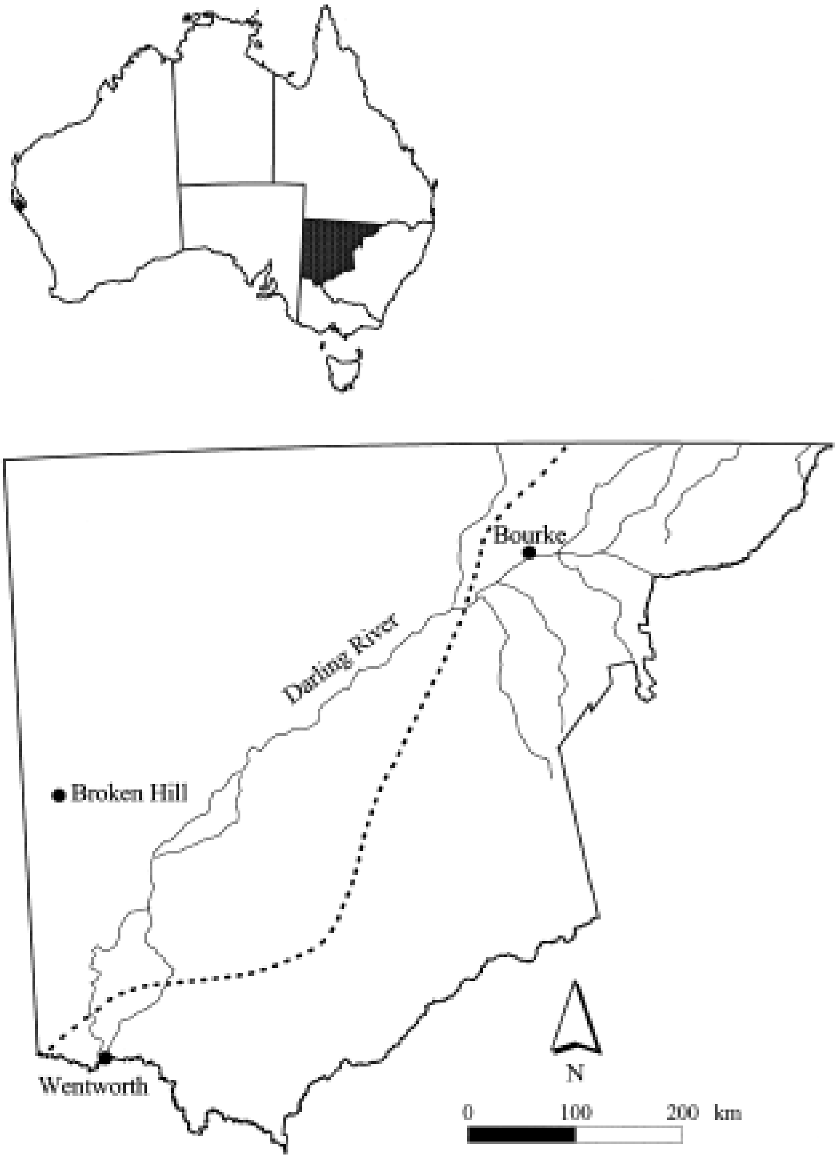

Fig. 1. The Western Division of New South Wales. The dashed line is the climatic limit of clearing and dryland cropping. Areas inland (north and west) of the line are not cleared or cropped except for opportunity cropping on lakebeds and floodplains in the Darling River system, generally without the removal of native woody vegetation.

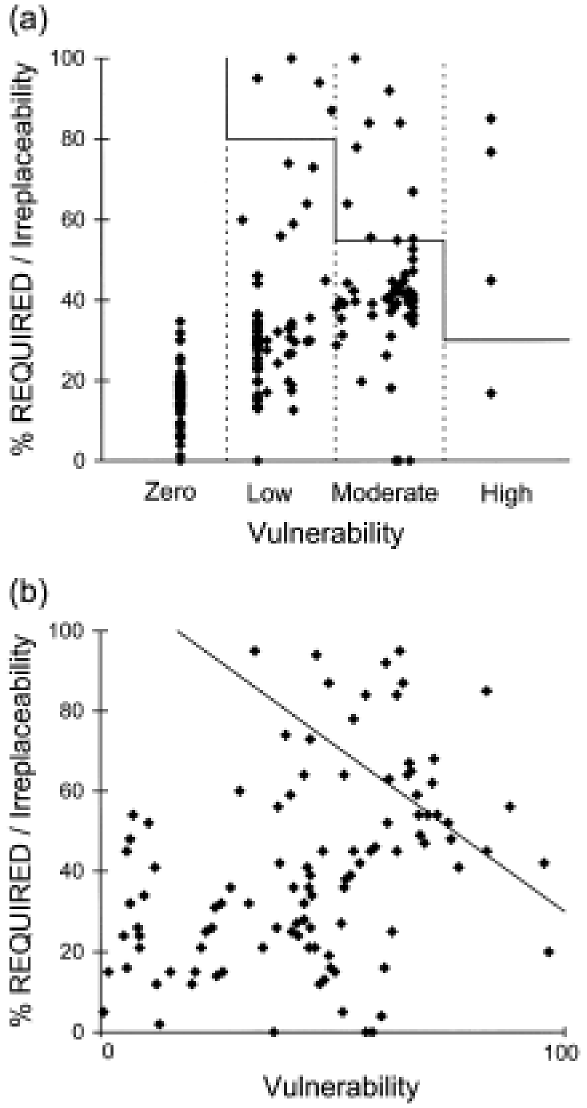

Fig. 2. Defining priority conservation areas. The vertical axes show either % REQUIRED (in the case of individual land systems) or irreplaceability (in the case of potential conservation areas). Vulnerability is shown on the horizontal axes. Points in the priority plots are either land systems or potential conservation areas. (a) Highest priority areas are in the top right of the graph, above the stepped approximation of a diagonal line used in this study to recognise the discontinuities in values between high, moderate and low vulnerability classes for land systems. (b) A more general approach to identifying highest priority areas using a simple diagonal line with continuous data on vulnerability.

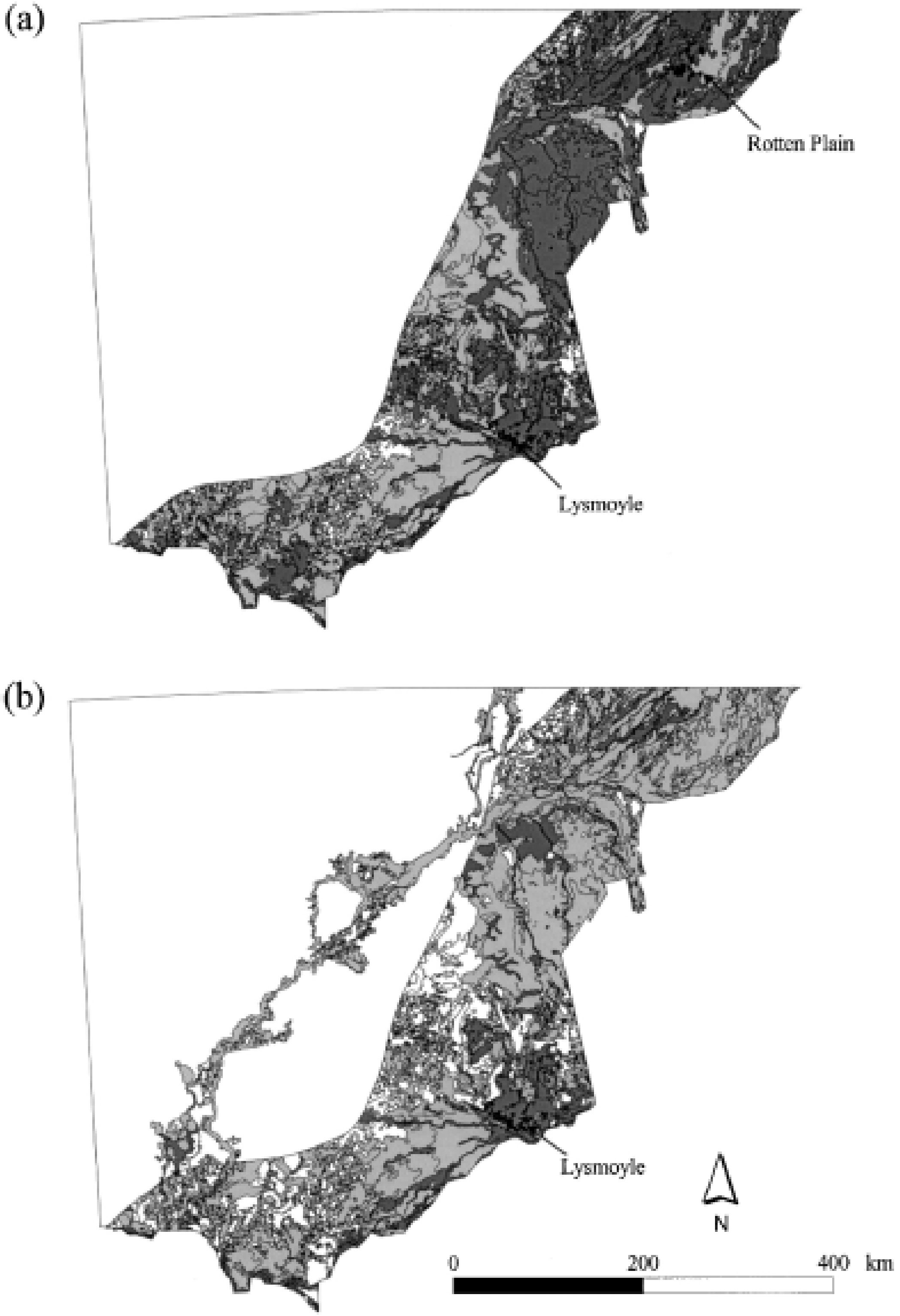

Fig. 3. Classes of overall vulnerability of land systems to (a) clearing and (b) cropping. Black = high (arrows indicate the locations of named land systems with high vulnerability), dark grey = moderate, light grey = low, white = zero.

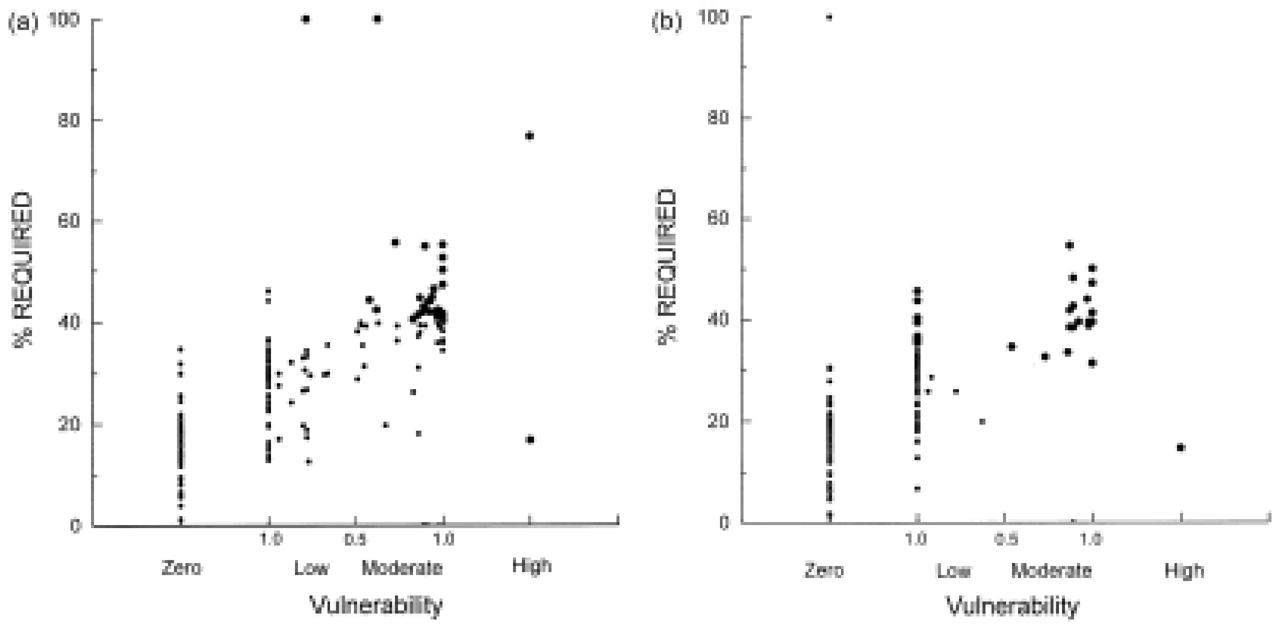

Fig. 4. Priority plots for individual land systems. 312 land systems are plotted for clearing (a) and 317 for cropping (b), some of the original 248 land systems having been subdivided if their vulnerabilities varied on either side of the climatic limit in Fig. 1. Small grey points are land systems below a stepped diagonal line (as in Fig. 2a) positioned to leave about 30 land systems in the top right of the graphs. Land systems indicated by large black points are above the stepped diagonal and are the highest priorities for conservation. There are 35 of these for clearing (a) and 26 for cropping (b). Horizontal positions of points within the low and moderate vulnerability classes indicate the probability (from 0.5 to 1.0) that the land systems lie within their respective classes.

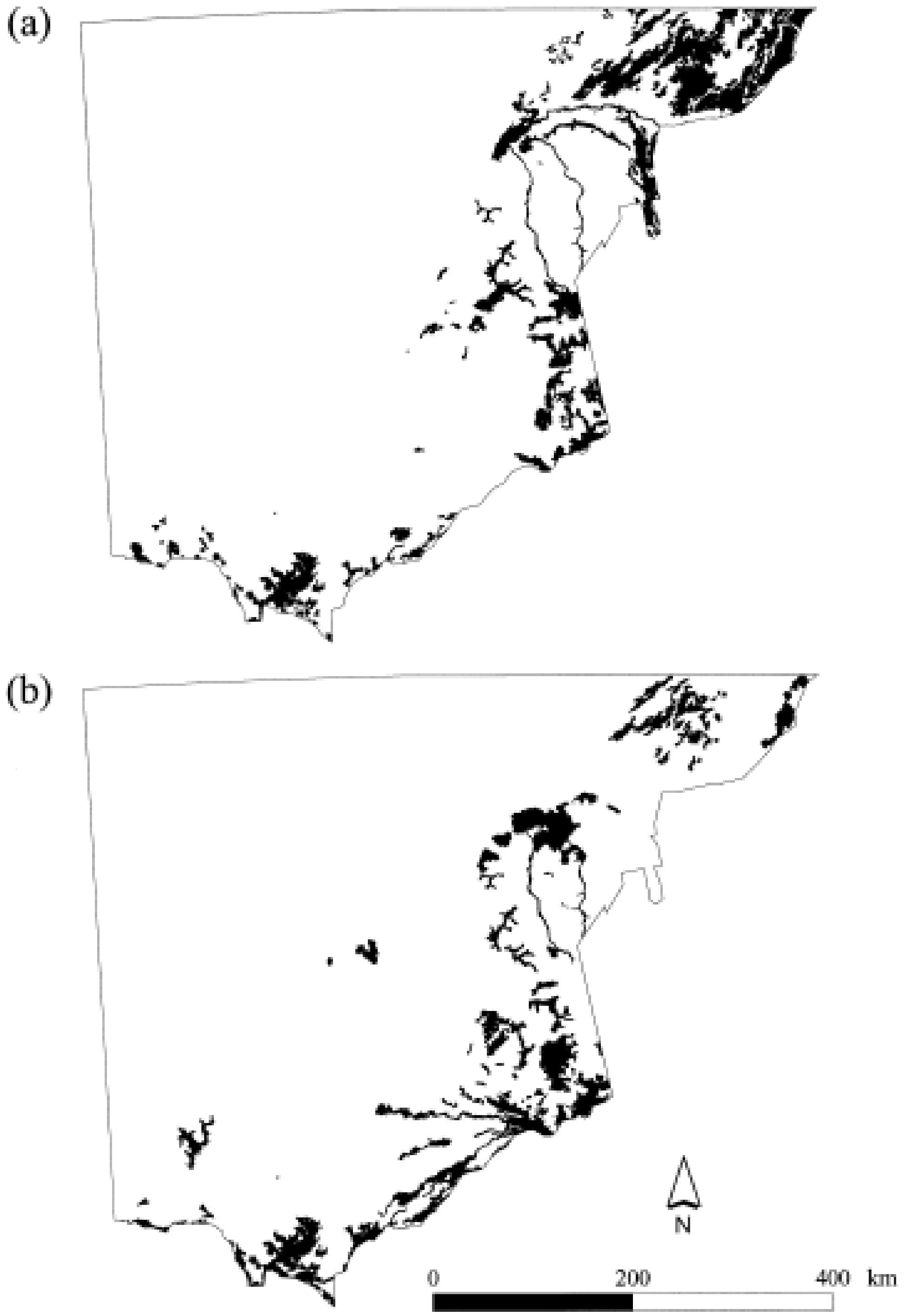

Fig. 5. Distribution of land systems identified in Fig. 4 as having highest priority for protection from (a) clearing and (b) cropping.

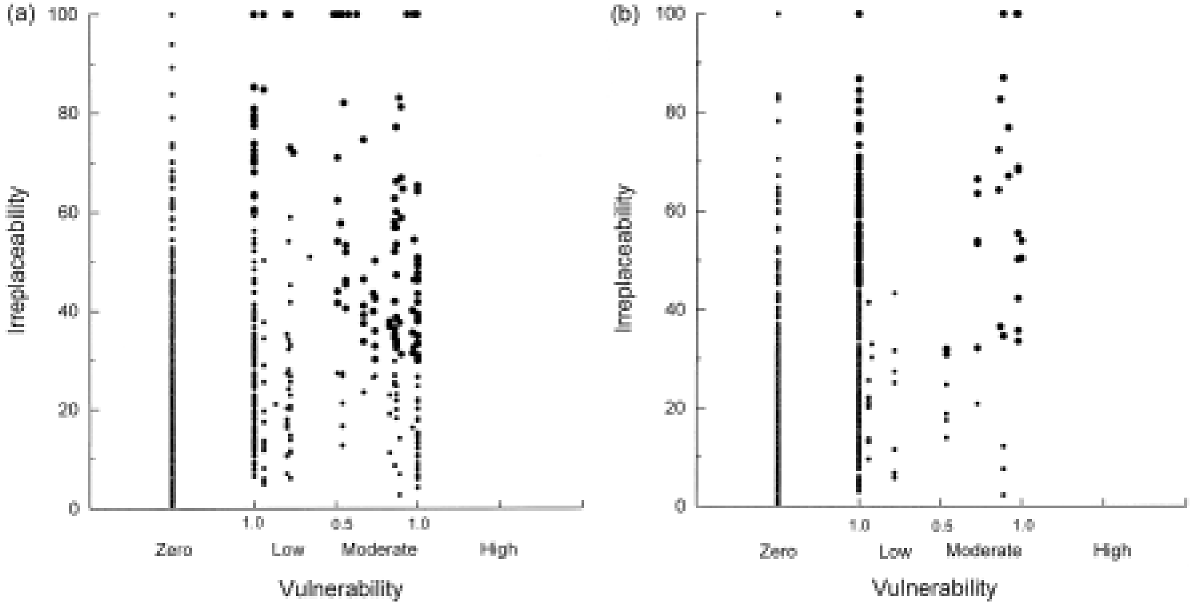

Fig. 6. Priority plots for 803 potential conservation areas. Small grey points are potential conservation areas below a stepped diagonal line (as in Fig. 2a) positioned to leave about 100 areas in the top right of the graphs. Potential conservation areas indicated by large black points are above the stepped diagonal and are the highest priorities for conservation. There are 126 of these for clearing (a) and 101 for cropping (b). Vulnerability relates to the most extensive land system in each area. Horizontal positions of points within the low and moderate classes for clearing and cropping indicate the probability (from 0.5 to 1.0) that the land systems lie within their respective classes.

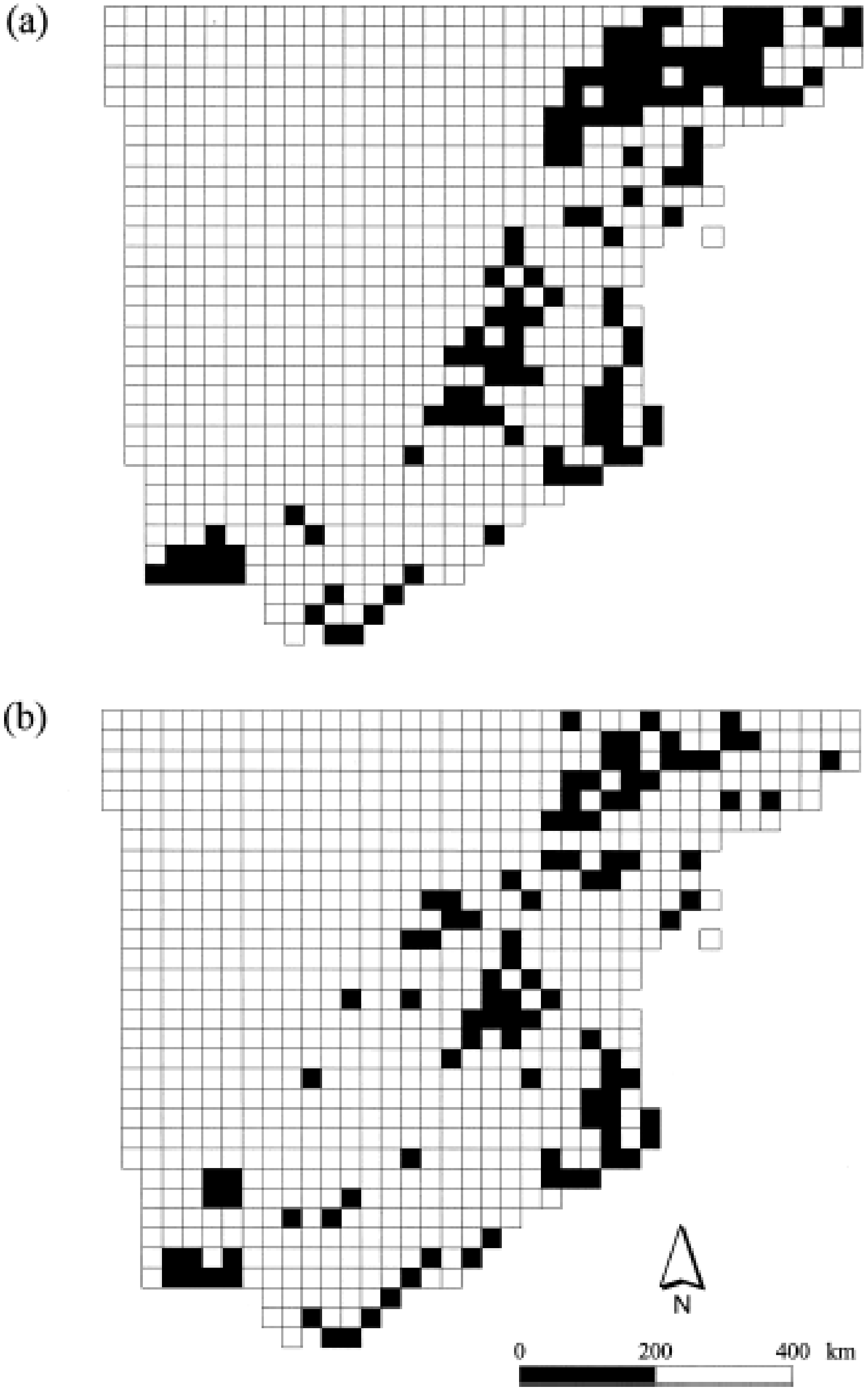

Fig. 7. Distribution of potential conservation areas identified in Fig. 6 as having highest priority for protection from (a) clearing and (b) cropping.

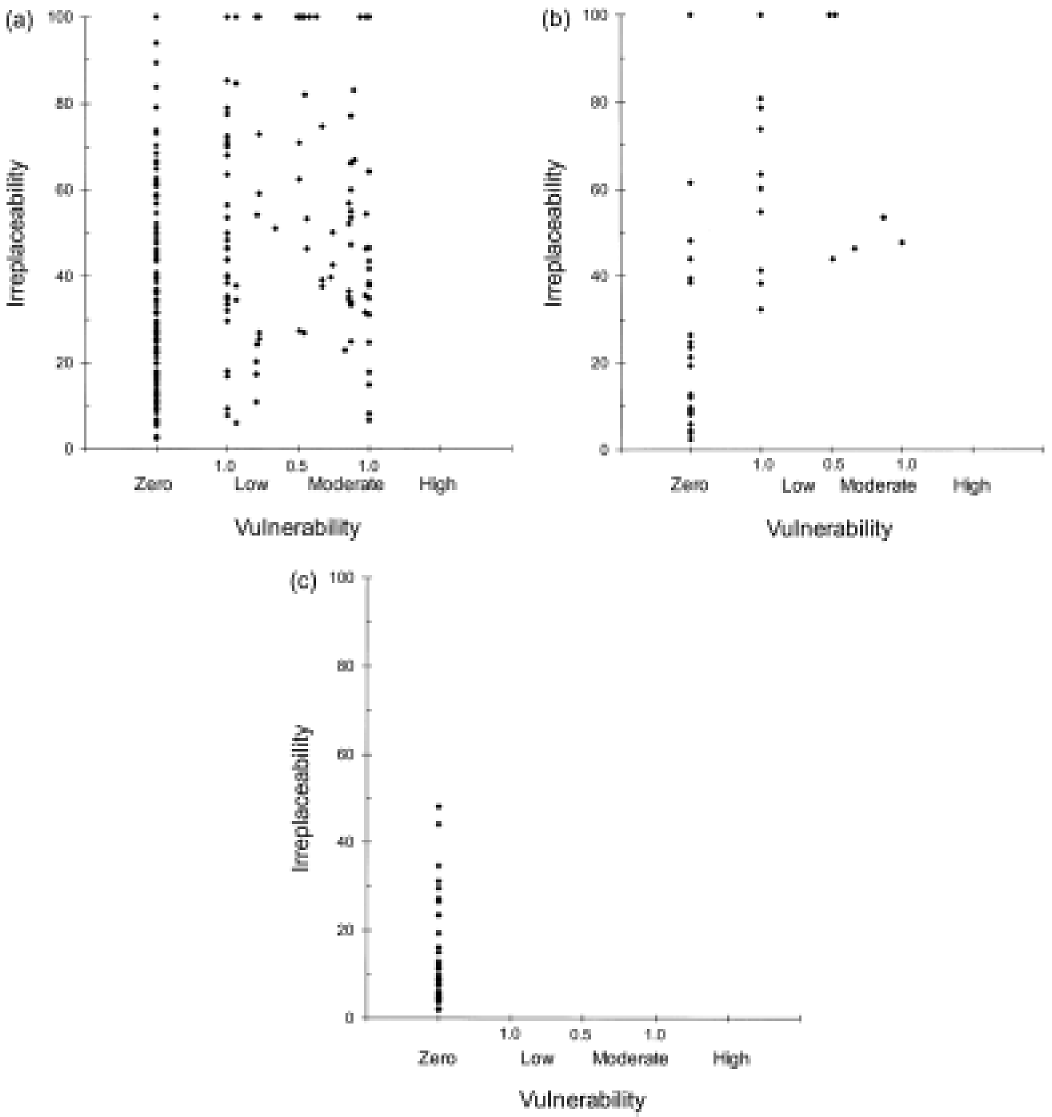

Fig. 8. Three sets of potential conservation areas (subsets of the 803 shown in Fig. 6a) plotted according to irreplaceability for achieving conservation targets on the vertical axes and vulnerability to clearing on the horizontal axes. (a) 245 areas selected by a heuristic algorithm to achieve all conservation targets, taking into account existing conservation areas. (b) the top 5% of areas in terms of richness of land systems with targets not fully met in existing conservation areas. (c) the top 5% of areas in terms of summed rarity of land systems with targets not fully met in existing conservation areas. Horizontal positions of points within the low and moderate vulnerability classes indicate the probability (from 0.5 to 1.0) that the land systems lie within their respective classes.