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Sampling of land types by protected areas: three measures of effectiveness applied to western New South Wales

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Running head: Measuring the effectiveness of protected areas

Abstract

At the end of 1997, the Western Division of New South Wales had 22 reserves with a total extent of 9,458 km² or 2.9% of the region. We used five measures to follow the effectiveness of the reserve system as it developed between 1960 and 1997. Two of the measures – number and total extent of reserves – are basic statistics in any review of protected areas. The other three measures concern how well the reserve system sampled the region's land types (e.g. ecosystems, vegetation types), defined here as land systems mapped at 1:250,000. The first of these measures was representativeness - the number of land systems sampled to a threshold level. The second was efficiency - the proportion of the reserve system actually contributing to, but not in excess of, conservation targets set for each land system. The third measure of sampling effectiveness was vulnerability bias - the extent to which reserves have been dedicated in parts of the region with most risk of vegetation loss. The representativeness of the reserve system at the end of 1997 was very low. Results for efficiency showed that a substantial part of the reserve system was not contributing to conservation targets. This partly reflected extensions of reserves to improve their design, highlighting the tradeoff between design and efficiency. Values for vulnerability bias were close to those expected if reservation had been indifferent to risk of vegetation loss from clearing or cropping. Higher values would be expected if reservation had been intended to secure good examples of the more vulnerable land systems before clearing or cropping compromised conservation targets. Fluctuations in efficiency and vulnerability bias since 1960 can be related to the establishment and extension of individual reserves. We finish the paper by placing our measures of effectiveness in the context of a more comprehensive list needed to deal with issues such as environmental gradients and species' requirements for long-term persistence.

Keywords: Protected areas, gap analysis, reserve effectiveness, reserve design, reserve bias, reserve efficiency

1. Introduction

The future of biodiversity depends almost entirely on the effectiveness with which in situ protection measures can be located, designed and maintained (World Resources Institute, 1992). An important part of in situ conservation is the global system of formally protected areas, although there is increasing recognition of the vital need for coordinated, strategic approaches to “off-reserve” management (Hale and Lamb, 1997). In New South Wales, as in other parts of the world, there are many cases of protected areas being dedicated without any clear picture of regional conservation priorities and, in some cases, out of sheer expediency (Pressey and Tully, 1994). Such ad hoc decisions about new protected areas can seriously compromise their effectiveness in retaining biodiversity. More accountable use of limited conservation resources requires not only systematic planning procedures but also reliable information on the effectiveness of established or proposed protected areas (Margules and Pressey, 2000).

Two common measures of the effectiveness of protected areas are their number and total extent. These allow activity in the dedication of new areas to be measured at a point in time or tracked through time at scales varying from global to local (Groombridge, 1992; Beardsley and Stoms, 1993; Sisinni and Emmerich, 1995). A limitation of both number and extent is, of course, that the representativeness of a protected area system - the extent to which it adequately samples the range of physical and/or biological variation in a region (cf. typicalness: Smith and Theberge, 1986) - is unknown. Number and extent of protected areas are therefore necessary, but not sufficient, measures of conservation progress.

Representativeness has become a key consideration in assessments of protected area systems (Scott et al., 1996; Shafer, 1999) and is now embedded in conventions and policies (e.g. Caldecott et al., 1996; Anon., 1999). Although these developments are positive steps for nature conservation, representativeness also comes with important limitations as a sole measure of how well biodiversity has been sampled in protected areas. We focus on two limitations in this study. The first concerns efficiency. Sampling of 60% of the land types (e.g. vegetation types, ecosystems, land systems) in a region to an acceptable level could be achieved very efficiently with little “over-achievement” relative to the nominated target area for each type. Alternatively, it could be achieved very inefficiently, with many land types sampled well above targeted levels, having absorbed resources that could have been allocated elsewhere. Representativeness also says nothing about the relative conservation needs of features that are sampled in reserves or not. How

meaningful is 60% representation if the remaining 40% of land types are those most urgently in need of conservation action because of their suitability for commercial uses or vulnerability in other ways? Like number and area of reserves, representativeness is necessary but not sufficient.

In this study, we follow the growth of the reserve system in the Western Division of New South Wales, starting with the gazettal of the region's first reserve in 1960 and ending in late 1997. For every addition to the reserve system over this period, we record the number and total area of reserves, the representativeness of the system relative to conservation targets for land types (land systems in this case), and two additional measures intended to complement representativeness. The first of these is efficiency which reflects sampling bias generally. The second reflects bias specifically in terms of the relative vulnerability of land systems to loss of native vegetation. It addresses the question: to what extent has reservation favoured the habitats or environments that need the most extensive and urgent conservation action? These additional measures can exhibit different trends than representativeness as reserve systems develop. They are applicable to any region and, with adaptation, to biodiversity surrogates other than land types. Like all measures of the effectiveness of protected areas, they also have their limitations. We therefore finish the paper by placing our set of measures in the context of a more comprehensive list that reflects not only sampling of pattern but also the promotion of long-term persistence of species and natural processes.

2. Rationale for this review of protected areas

2.1 Validity of goals other than sampling

Aside from number and extent of reserves, the measures applied in this paper concern the sampling of natural variety in a system of protected areas. There are, of course, other reasons for dedicating reserves. Indeed, for many people, these other reasons might be more compelling. Strom (1990) noted that "many protagonists of national parks in the past and today, had and have little knowledge and/or concern for ... the sampling of natural systems". Important goals other than sampling, even for those concerned primarily with biodiversity, include the size and configuration of protected areas as they affect the persistence of species, and the rationalisation of reserve boundaries in relation to features such as watersheds or inholdings of private land. Common goals not concerned specifically with biodiversity are the protection of scenic, recreational and wilderness values. An additional one in the Western Division is the protection of aboriginal artefacts (Gerritsen, 1976). A quantitative analysis of the effectiveness of protected areas

based on sampling of biodiversity does not attempt to invalidate these other conservation goals. It provides a counterweight to remind decision-makers that there are opportunity costs in implementing any goal. A decision to expand an existing reserve could foreclose options for sampling species or landscapes elsewhere in the region, especially if they are threatened by commercial land uses. Conversely, planning with an emphasis only on widely scattered sampling could jeopardise the viability of some reserves. The role of measures related to sampling, although they paint only part of the overall picture of effectiveness, is to encourage strategic thinking on alternative conservation goals and to help identify the extent of agreement or conflict between them.

2.2. Sampling as a neglected goal, not a new one

Ideas about the purposes of protected areas continue to evolve and have been very different in the past (Grove, 1992; Caughley and Sinclair, 1994; Noss and Cooperrider, 1994). Accordingly, modern reviews of reserve systems, including the importance of sampling as a goal, run the risk of judging past events by present-day values (Cox, 1983; Frawley, 1988). The degree of risk depends, though, on the period of the study. The idea of sampling predates reserves in the Western Division. By the early 1950s, an explicit purpose of reserve establishment in New South Wales was to sample major natural environments (Strom, 1969; 1983). By the mid-1960s, this approach was supported by reasonable information on the plant associations of the State (Strom, 1990). By the early 1970s, at which time well under half the 1997 reserve area had been established in the Western Division, estimates had been made of the extent of major vegetation types in Australian reserves, with gaps and priorities highlighted (Specht et al., 1974). Yet this major publication and the earlier recognition of representativeness as a conservation goal had only a limited influence on the subsequent location and content of reserves in the Western Division and elsewhere.

A strategic approach to sampling natural environments in the Division has been hindered by three major factors: active bureaucratic resistance to locking up productive land (Strom, 1990); the process of “referencing” whereby other resource agencies can scrutinise and block reserve proposals, even on land acquired for conservation (Hitchcock, 1981); and limited resources for acquisition, forcing attention toward easily available areas (Pressey and Tully, 1994). Early investigations of potential reserves were restricted largely to pastoral leases about to expire (Strom, 1983). A prolonged drought and depressed property market in the 1960s made landholders in the far north-west ready to sell their properties for the formation of Sturt National Park (Gerritsen, 1981), although gazettal of some areas took several more years. In the early 1970s,

attention was focused on properties in the Western Division coming out of 99 year leasehold tenure (McMichael, 1990; Starling, 1990). From the viewpoint of the National Parks and Wildlife Service and its predecessor, the Fauna Protection Panel, regional strategies had to be strongly infused with opportunism if any conservation gains were to be made (Strom, 1983; Starling, 1990). The pattern of reservation reflects these constrained efforts, but also reflects a more general official indifference or resistance to nature conservation in the region.

In this context, measures of effectiveness related to sampling natural variety in the Western Division are appropriate, even when applied in a chronological analysis since 1960. Retrospective assessments demonstrate how much more effective protected areas might be, at least in terms of sampling, had decisions been made differently. In doing so, they cannot change the past but can inform decisions about the future.

3. Methods

3.1. Study region

Our study region is the Western Division of New South Wales, covering about 325,000 km² 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. The main landforms and vegetation types have been mapped (Walker, 1991). Landforms 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.

Historically, the Division has been managed mainly for sheep grazing (Mitchell, 1991; Pickard, 1991), but there has been increasing pressure to clear or thin native vegetation either for agriculture or to increase carrying capacity for stock. Landholders are required to apply for licences to clear or crop (Pressey, 1990; Campbell, 1994). The process of application and approval involves detailed criteria and guidelines (DLWC, 1996) and effectively restricts clearing and dryland cropping to suitable soils and terrain in the higher rainfall areas on the eastern and southern margins of the Division (Fig. 1). Opportunity cropping after floods occurs in lakebeds and floodplain areas in the Darling River system (Fig. 1).

3.2. *Data sets*

Our analyses are based on digital boundaries of reserves, including separate parts of existing reserves that were acquired and gazetted at different dates. We used land systems to measure representativeness, efficiency and vulnerability bias. Land systems are recurring patterns of landform, soils and vegetation (Mabbutt, 1968). Most consist of two or more land units as the elements of landscape pattern (e.g., a particular configuration of dunes, swales and drainage basins can define a dunefield land system). Some 248 land systems have been mapped at 1:250,000 across the Division. Their component land units have been described (Walker, 1991) but not mapped. Analyses of the extent of each land system in reserves do not, therefore, necessarily reflect how well their component land units are reserved. The biophysical heterogeneity of land systems also means that their sampling by reserves is no indication of how well associated features such as species or cultural sites are protected. Rare species, in particular, require attention as a complementary basis for conservation planning (Dickman et al., 1993). We split some land systems across the climatic limit of clearing and dryland cropping (Fig. 1) to reflect the different vulnerabilities to clearing and cropping of the resulting parts (Pressey and Taffs, accompanying ms). In the remainder of the paper, we use the term “land systems” to refer to both entire and subdivided land systems.

3.3. *Number and total extent of reserves*

We recorded the cumulative total extent of reserves in the Division from 1960 to December 1997, taking into account additions of parts of reserves at different dates. For cumulative number of reserves, we did not consider additions to established reserves. Over the same period, we revised the other three measures of effectiveness, below, each time a new reserve was gazetted or an existing reserve was extended.

3.4. *Representativeness*

Our measure of representativeness is the percentage number of land systems with more than a targeted percentage of their total areas within the reserve system. We counted land systems as represented (fully sampled) when their reserved areas were equal to or greater than their target areas. We measured representativeness for four sets of reservation targets: 5, 10 and 15% of the total extent of each land system, and a variable scale of targets reflecting the natural rarity and

vulnerability to clearing of each land system. The variable targets were intended to reflect the relative need of land systems for conservation action. The derivation of vulnerability ratings for each land system for both clearing and cropping is described by Pressey and Taffs (accompanying ms). We allocated variable conservation targets to land systems 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 (0 for none, 1 for low, 2 for moderate, and 3 for high). We measured the natural rarity of each land system as $[(A_{\text{max}} - A_i)/A_{\text{max}}]$, 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. Variable targets therefore ranged from a possible minimum of 10% of the original area of each land system to a possible maximum of 50%.

Setting targets as percentages of the original vegetated area of each land system generally avoided the problem, if they had been percentages of extant areas, of conservation requirements being reduced by vegetation loss. Nonetheless, a few initial targets became unachievable during the period of our analyses due to progressive clearing or cropping. We therefore converted all targets to absolute areas and then expressed them as percentages of the vegetated portions of land systems at the end of 1997. For variable targets to be met at the end of 1997, we had to eliminate four small land systems that had been completely cleared and truncate targets for two others to 100% of their 1997 vegetated areas. Variable conservation targets as percentages of original areas ranged from 12 to 50 with a mean of 25. The same targets as percentages of 1997 vegetated areas ranged from 12 to 100 with a mean of 27. The variable targets are consistent with recent policy for Australian forests (Anon., 1995; JANIS, 1997) recommending a baseline target of 15% of the pre-European area of each forest type, with reductions below this figure for extensive, secure types. Our variable formula gave targets less than 15% to only four land systems. Other formulae are possible, although none is officially agreed for the Division. In the Southern Mallee region, in the far south-west of the Division, the recommended target for vegetation types is at least 20% to be reserved, no more than 30% to be cleared, and the balance to remain as native rangelands (Freudenberger et al., 1997).

3.5. *Efficiency*

Our measure of efficiency was derived from the extent of reservation of each of the land systems in the Division compared to the conservation target for that land system. For each of the four sets of targets - 5, 10, 15% and variable - we calculated what percentage of the reserve system's total extent contributed to targets for land systems, the remainder being "surplus" to requirements (Fig. 2). This measure is effectively the same as that used by Pressey and Tully (1994) and Wright et al. (1994). As in those previous studies, efficiency will decrease with increasing sampling bias due to the repeated reservation of some land systems with conservation targets already achieved. Lower efficiency means higher eventual cost, at least in terms of land area, of achieving any set of targets (Pressey and Tully, 1994). In turn, higher costs present a higher risk that all targets will not be met within the constraints imposed by land uses other than nature conservation. We acknowledge that there might be sound ecological reasons for reserving some features in excess of targets, perhaps to develop suitable reserve configurations in the interests of species persistence. Any such decisions should, however, be informed by assessing their costs as well as their benefits. Values of efficiency for past or planned reserve decisions can alert planners to some of the risks involved in achieving design goals.

3.6. *Vulnerability bias*

Systems of protected areas are often biased toward land types with least potential for commercial uses and away from those with highest vulnerability to vegetation loss or disturbance (e.g. Mark, 1985; Henderson, 1992; Beardsley and Stoms, 1993; Barnard et al., 1998; Pressey et al., 2000). For two reasons, efficiency is not informative about this sort of bias. First, efficiency does not (and should not) consider the relative vulnerability of features. Second, at least in principle, reserves can be highly efficient and still systematically miss the most vulnerable land types in a region. An additional measure of effectiveness is therefore needed.

In another paper (Pressey and Taffs, accompanying ms), we placed land systems into four classes of vulnerability to both clearing and cropping. Due to the unmapped heterogeneity of land systems, however, there are limitations on the scale at which information on the intermediate classes can be applied in the present study. For the low and moderate (cf. zero and high) classes, any occurrence of a land system in a reserve might or might not contain the finer-scale land units that confer its overall vulnerability rating (Pressey and Taffs, accompanying ms). We dealt with this uncertainty by deriving a measure that overestimates bias toward land systems with potential

for clearing or cropping, thereby showing the reserve system in the most favourable possible light. Our measure was the percentage to which targets are met for land systems in the high, moderate and low vulnerability classes divided by the percentage to which targets are met for land systems in the zero class (the zero class contains only land systems with none of their component land units at risk from clearing or cropping). In deriving these percentages, we considered only reserved areas contributing to targets for individual land systems, not areas in excess of targets. While the measure is applicable to any set of conservation targets, we used the variable targets for clearing (above) and derived variable targets for cropping with the same formula. The distribution of targets for cropping was similar to that for clearing.

3.7. Do analyses with recent data underestimate the effectiveness of old decisions?

We used biophysical data in this paper that were not available to planners and managers during the early development of the Western Division reserve system. The first land system maps only became available from the late 1970s. Prior to the establishment of reserves in the region, information on biophysical variation was either broad (Beadle, 1948) or fragmentary (see Pickard and Norris, 1994 for review). The situation had improved by the mid-1960s when potential reserves were being investigated against a State classification of plant associations (Strom, 1990), although these would not have subdivided the Western Division as finely as land systems. No other comprehensive classification of land types in the Division was developed before the series of land system maps.

Could the effectiveness of reserves established in the 1960s and 1970s be underestimated by measures based on today's relatively detailed and consistent data? Representativeness has been shown to decrease as classifications become finer (Pressey and Logan, 1994), but only when conservation targets are set as simple occurrences of land types, regardless of the area actually reserved. For targets of 5 or 10% of each land type, Pressey and Logan (1994) found no general trend in representativeness with subdivision of land types and Pressey and Logan (1995) found no effect of subdividing land types in the Western Division. Our use of land system data is therefore unlikely to markedly underestimate the representativeness of reserves established with a less detailed classification. Unfortunately, the actual effect of the scale difference cannot be tested because earlier information on vegetation types across the Division (except for Beadle, 1948) is not available as a map. Efficiency, too, probably shows strong scale-dependence only when targets are single occurrences of land types. In this case, efficiency will tend to be lower for coarser classifications. For substantial area targets, efficiency, like representativeness, is unlikely to be

strongly affected by classification scale. Finally, we do not expect the results for vulnerability bias to be an artefact of our data set. Although our vulnerability classes were not previously available, conservation planners working in the Division have long understood how climate, terrain, hydrology and soils combine to predispose areas to clearing and cropping.

4. Results and discussion

4.1. Reserve number and total extent

The number and total extent of reserves increased irregularly, but more or less in parallel since the first reserve, Round Hill Nature Reserve, was gazetted in 1960 (Fig. 3). Two extended periods of zero growth, one after the establishment of Round Hill and one after the establishment of Nombinnie Nature Reserve in 1988, are separated by a period of rapid expansion of the system, especially between 1972 and 1979 (Fig. 3, Table 1). At the end of 1997, the system of gazetted reserves consisted of eight national parks, eleven nature reserves, one aboriginal area, and two historic sites with a total extent of about 9,460 km² or 2.9% of the region.

4.2. Representativeness

Like number and total area, representativeness rose progressively from 1960 (Fig. 4). The importance of conservation targets in determining representativeness is obvious. Values are highest throughout for the smallest targets (5% of each land system) and lowest for the variable targets which average about 25% of the total area of each land system. Any system of protected areas will appear more representative when conservation targets are small, simply because sufficient areas of more features are protected. Consequently, the trend in representativeness for 5% targets (Fig. 4) is most similar to that for increasing reserve area (Fig. 3). Jumps in the plot for 5% targets as areas are added to the reserve system are absent or suppressed with larger targets. For variable targets, the addition of areas from 1976 to 1981, from 1983 to 1987, and in 1996 did not increase representativeness, partly because they contributed land systems that were already reserved to target and partly because the areas of other land systems they added were insufficient to reach their targets. Values for representativeness at the end of 1997 were 14.6% of land systems for 5% targets, 9.4% for 10% targets, 5.8% for 15% targets, and 3.6% for variable targets. A large percentage of the land systems in the Western Division was therefore under-reserved at the end of the analysis, particularly for the variable targets that probably reflect more realistic conservation requirements than the others.

Another perspective on representativeness is the spatial pattern of land systems with different percentages of their variable targets achieved (Fig. 5). Fully reserved land systems are relatively restricted and associated with Sturt National Park in the far north-west, Mootwingee National Park and Coturaundee Nature Reserve further south, the group of large mallee reserves in the south-east (Yathong, Nombinnie and Round Hill Nature Reserves), and Mungo National Park in the south. The Division is dominated by land systems with either no reservation or with less than 50% of their variable conservation targets in reserves. The large central expanse of zero reservation mainly reflects the lack of reserves there (Fig. 1), although it is partly shaped by the line separating areas climatically suitable or unsuitable for clearing (Fig. 1) across which we subdivided some land systems. This subdivision reflects real differences in vulnerability to clearing and therefore requirements for conservation as expressed in the variable targets.

The distribution of poorly reserved land systems (Fig. 5) is not, in itself, a picture of future conservation priorities. We have proposed in a related study (Pressey and Taffs, accompanying ms) that, in the Western Division and elsewhere, priority areas can be defined as those for which there are fewest spatial options for conservation and those with the most urgent need for conservation action. In that study, we measured the spatial options for achieving targets for each land system by calculating the percentage of the remaining vegetated area in each land system, in addition to its reserved area, still needing conservation action. We used vulnerability classes to indicate the urgency for conservation action.

4.3. Efficiency

Unlike the previous measures, efficiency did not rise progressively (Fig. 6a,b). Falls in efficiency indicate increases in sampling bias – new reserves or additions to reserves sampling land systems with conservation targets already met. Rises in efficiency indicate reservation of previously unreserved land systems or others without targets fully met. Because some reserves had both negative and positive effects on efficiency, the direction and size of the fluctuations in Fig. 6 reflect the balance between the two. Also, because we measured efficiency across the whole reserve system as it expanded, fluctuations were dampened at later dates due to the smaller relative effect of any given reserve area (although the same measure is applicable to individual reserves: Pressey and Tully, 1994; Wright et al., 1994). Efficiency values at any date also varied with conservation targets. They were generally lower for 5% targets (and bias was therefore higher) (Fig. 6a) than for variable targets (Fig. 6b).

For 5% targets, efficiency began at 100% with the dedication of Round Hill, then fell in 1967, mainly due to over-sampling of new land systems in Kinchega (Fig. 6a, Table 1). Further falls between 1973 and 1976 were associated with additions to existing reserves in which land systems were already at or close to targets. Increases from 1977 to 1979 were due to new reserves sampling different land systems, although surplus to targets in some cases. A fall in 1988 was associated with the addition of Nombinnie Nature Reserve adding some land systems already well sampled in neighbouring reserves, and the final increase in 1996 was due to the three new reserves spread widely across previously unprotected parts of the Division. For variable targets (Fig. 6b), the fluctuations were somewhat different. The fall in 1967 for 5% targets was absorbed by the larger variable targets and efficiency did not decrease until 1973 with the large addition to Sturt National Park, followed by another fall with a further addition to Sturt in 1976. The fall in efficiency for 5% targets in 1988 (Fig. 6a) was also absorbed and turned into a slight rise by the larger targets.

Dotted lines in both parts of Fig. 6 indicate the potential increases in efficiency (reductions in bias) of the reserve system if the same additional reserve area (since 1980 and 1990) had been located to avoid any above-target sampling of land systems. For 5% targets (Fig. 6a), the efficiency of the reserve system could have been substantially higher in 1997 if no sampling bias had occurred since 1980. If maximally efficiency decisions had been made since 1990 (effectively in 1996), the efficiency of the reserve system would have been slightly higher in 1997. For variable targets (Fig. 6b), the efficiency of the reserve system would have been slightly higher in 1997 if optimal sampling decisions had been made since 1980, although the 1996 decisions were optimal. The implication of these alternative scenarios is that longer delays in making efficient decisions on new reserves lead to lower eventual efficiencies of reserve systems. For variable targets, the potential improvement in efficiency from 1980 is 3.1% of the reserve system or an additional 290 km² that could be contributing to those targets. If the most efficient decisions had been made since 1960, the improvement would be almost 15% of the reserve system or about 1,400 km².

There are, of course, practical constraints on efficiency and sound reasons why it is not the only objective of conservation planning. One constraint is the size and configuration of the areas being acquired, usually dictated by the boundaries of pastoral holdings in the Western Division. Such boundaries inevitably lead to above-target sampling of some land systems or other features. The less-than-perfect efficiency of the 1996 reserves for 5% targets (Fig. 6a) is due to previously unreserved land systems occurring more extensively than required in those reserves. This was

unavoidable without acquiring only parts of the holdings, often a difficult approach to negotiate. The same reserves made a 100% contribution to the variable targets (Fig. 6b).

Another practical constraint on efficiency is reserve design. Sturt National Park is the largest reserve in the Division (Fig. 1). There are probably corresponding benefits for park management and tourism, and perhaps for the persistence of some species, compared to a wide scatter of smaller reserves with the same total area. Our analyses indicate that improved design comes with a price in efficiency, just as the pursuit of efficiency will impose design limitations. The efficiencies of individual gazetted additions to Sturt National Park were lower than the original section dedicated in 1972, even for variable targets (Fig. 7). This does not support an argument for ignoring reserve design. It indicates the need to consider potential improvements in design relative to their advantages and disadvantages for securing regional conservation priorities.

4.4. Vulnerability bias

Vulnerability bias, calculated for variable targets, has fluctuated strongly during the development of the reserve system (Fig. 8). Increases in vulnerability bias for clearing (Fig. 8a) indicate reservation in that part of the Division climatically suitable for clearing (Fig. 1) and, within this zone, reservation of land systems with some inherent suitability for clearing. Fluctuations in vulnerability bias, like those in efficiency, were dampened through time because a given reserve area had less influence on the measure as the whole system expanded. An initial high value for Round Hill (off the scale because the ratio required division by zero) was reduced with the establishment of Kinchega National Park. Subsequent rises in the measure were due to the establishment of Yathong Nature Reserve in 1971, an addition to Yathong in 1974, the establishment of Mallee Cliffs National Park and a further addition to Yathong in 1977, the establishment of Nombinnie Nature Reserve in 1988 and the establishment of Gundabooka and Culgoa National Parks in 1996. The trends for vulnerability to cropping (Fig. 8b) were similar to those for clearing. Minor departures were due to the differences in patterns of vulnerability between clearing and cropping (Pressey and Taffs, accompanying ms). Values of vulnerability bias for clearing and cropping in 1997 were 0.7 and 0.6, respectively. Values for both were well below 1.0 for most of the time since 1960, indicating that reserves have generally contributed more to variable targets for land systems with no risk of clearing or cropping at the expense of targets for land systems exposed to vegetation loss.

Changes in vulnerability bias for clearing (Fig. 8a) were different to those in the efficiency graph based also on variable targets for clearing (Fig. 6b). Whereas efficiency reflected the reservation of above-target areas of land systems regardless of their suitability for clearing, vulnerability bias was sensitive to the location of reserves relative to climatic and other constraints on intensive land use.

If the location of reserves since 1960 had been indifferent to risk of clearing, the expected value of vulnerability bias for clearing would be 0.53 (less than 1.0 because of the larger targets for land systems in the non-zero vulnerability classes). For cropping, the expected ratio from reservation indifferent to vulnerability would be 0.60. The actual value for clearing is slightly higher than the expected value (Fig. 8a) and that for cropping is equal to the expected value (Fig. 8b). Given the ongoing expansion of clearing and cropping in parts of the Division, a conservation strategy directed at achieving conservation targets before they were compromised by vegetation loss would have produced higher values of vulnerability bias than those expected from a strategy indifferent to threat. A deliberate strategy to avoid preemption of targets by clearing and cropping would have produced values substantially higher than 1.0 (equal proportional target achievement for vulnerable and non-vulnerable land systems). Notably, even the actual 1997 values are probably optimistic. The limitations of our vulnerability classification masked the tendency for reserves to focus on low vulnerability (cf. zero vulnerability) land systems (Section 3.6). If finer-scale data on vulnerability had been available for our analyses, the situation might appear worse than expected from reservation indifferent to risk of vegetation loss.

Bias values for clearing and cropping would be slightly above 1.0 if reserves had contributed fully to targets for vulnerable land systems since 1980 (Fig. 8). Improvements could also have been made since 1990. The potential increase in vulnerability bias for clearing and cropping in 1996 was constrained by the establishment of Tarawi which contains only land systems with zero vulnerability to these land uses. Tarawi might have contributed to the conservation of land systems vulnerable to grazing, although a regional picture of grazing vulnerability is still unavailable (Pressey and Taffs, accompanying manuscript). Even if Tarawi were important for excluding grazing impacts, there is an obvious conflict between reservation for this purpose and for preventing vegetation loss in other parts of the Division. Strategic decisions are needed, in the Western Division and more generally, about which of the prevailing threats in a region have priority, at least until approaches are developed to estimate vulnerability to combinations of threats.

5. General discussion

The Western Division reserve system at the end of 1997 was inadequate by any standards. Although extensive in raw terms with a total area of 9,458 km², it occupied only 2.9% of the region. More importantly, only 15% of the land systems in the Division were adequately sampled even for the minimal 5% targets and only 4% of land systems were adequately sampled for the more realistic variable targets. Additionally, representativeness tells only part of the story about the effectiveness of the reserve system. Efficiency or sampling bias indicated that a portion of the reserve system was not contributing to conservation targets. This was partly due to the inevitable over-sampling of land systems in reserves made from ownership or management units with inflexible boundaries. It was also partly due to decisions about the enlargement of Sturt National Park and the group of mallee reserves in the south-east. Mixed up with these factors was the cost of the opportunism that has characterised the development of the reserve system.

The results for vulnerability bias add information not provided by representativeness or efficiency. At the end of 1997, reservation was close to random with respect to land systems vulnerable to clearing and cropping. There is a strong argument for a different approach. If reservation favours those parts of the Division more vulnerable to loss of native vegetation, the likelihood of conservation targets being compromised is reduced. The longer such decisions are delayed, the greater the chances that at least some targets will not be achieved. Already, the native vegetation in some land systems has been reduced below our variable targets set as percentages of original (pre-European) vegetated areas. This problem will be minimized in future by focusing conservation action in the eastern and southern parts of the Division and in areas suitable for cropping in the Darling River system.

Efficiency and vulnerability bias are applicable to a variety of data sets and at scales ranging from local to regional. Although our approach to measuring vulnerability bias was tailored to the particular categorical data available for the Western Division (Pressey and Taffs, accompanying ms) and will not be generally appropriate, the same idea can be implemented with quite different data and methods (e.g. Pressey et al., 2000). There is also scope for measuring both efficiency and vulnerability bias before areas are formally protected, just as Wright et al. (1994) measured the relative contribution to conservation targets of potential national parks in Idaho. This gives decision-makers information to weigh against considerations such as acquisition cost, condition and reserve design.

A comprehensive assessment of the effectiveness of protected areas would be substantially broader than the one presented in this paper. We have considered only two of five possible groups of measures (Table 2). Measures in group 3 (Table 2) relate to the floristic or faunistic variation within land types or the genetic variation within the ranges of species. Where such variation is not well documented, it must be inferred from environmental variation and geographical distance or barriers (e.g. Keith, 1995; Ferrier et al., 1999). Measures in group 4 relate to diverse aspects of reserve design (Table 2). Although broad guidelines for reviewing design are available (Shafer, 1990; 1999) and some informative reviews of particular regions are published (e.g. Peres and Terborgh, 1995), a comprehensive list of measures is not available for generic application. There seem to be three main reasons for this. First, some design goals are specific to particular regions (e.g. Cowling et al., 1999), as are the pressures on protected areas that determine the adequacy of their design. Second, there are strong interactions between some aspects of design (e.g. size and adjacent land uses) that affect the informativeness of any measure used alone. Third, the metrics used for most aspects of design are meaningful only when calibrated to the requirements of particular organisms. For example, the space requirements of grizzly bears (Grumbine, 1992) are clearly different from those of locally endemic plants (Cowling and Bond, 1991). Group 5 measures (Table 2) reflect how well the natural values of established protected areas are being maintained (Hockings and Phillips, 1999; Carey et al., 2000). Further work in this area is being coordinated by the Task Force on Management Effectiveness under the auspices of the IUCN World Commission on Protected Areas.

Hopefully, applications of the measures in Table 2 can prompt a variety of positive responses, including: changes in protected area policy; establishment and extension of protected areas so that systems improve according to one or more of the measures in groups 2 to 5; assessment of proposed protected areas before final decisions are made about their dedication; and more sympathetic management of areas outside formally protected boundaries. Especially with an expanded set of measures as in Table 2, any addition to a protected area system is likely to cause improvements in some directions and declines in others. For example, this study and others (e.g. Nicholls and Margules, 1993; Lombard et al., 1995) have shown that there is a trade-off between efficiency of sampling and the size of protected areas. The likelihood of further conflicting trends across a comprehensive set of measures does not invalidate its use. It emphasises that informed decisions about new protected areas should be made with an understanding of all their implications, preferably supported by quantitative reviews.

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Table 1

Chronology of reserve establishment (bold) and extension in the Western Division. The listed km² for each new reserve or addition is an estimate from a geographic information system and might differ slightly from surveyed areas in agency records. Abbreviations: est. – established; add. – addition; NP - national park, NR - nature reserve, AA - aboriginal area, HS - historic site.

Year	Establishment or addition (km ²)	Total km ²
1960	Round Hill NR est.	47
1961	-	
1962	-	
1963	-	
1964	-	
1965	-	
1966	-	
1967	Kinchega NP est. (329), Mootwingee HS est. (7)	336
1968	Kinchega NP add.	95
1969	-	
1970	Round Hill NR add.	68
1971	Yathong NR est.	444
1972	Sturt NP est. (227), Willandra NP est. (125)	352
1973	Sturt NP add.	1884
1974	Yathong NR add.	464
1975	Willandra NP add. (58), Sturt NP add. (591)	649
1976	Sturt NP add.	491
1977	Mallee Cliffs NP est. (578), Yathong NR add. (195)	773
1978	-	
1979	Kajuligah NR est. (137), Mungo NP est. (153), Nocoleche NR est. (747), Coturaundee NR est. (67), Mount Grenfell HS est. (13)	1117
1980	-	
1981	-	
1982	Sturt NP add. (3), Mootwingee NP est. (331)	334
1983	Nearie Lake NR est. (41), Mootwingee NP add. (337)	378
1984	-	
1985	Morrison's Lake NR est. (2)	2
1986	Sturt NP add. (56), Mungo NP add. (158), Pindera Downs AA est. (102)	316
1987	-	
1988	Kemendok NR est. (4), Narran Lake NR est. (45), Nombinnie NR est. (742)	791
1989	-	
1990	-	
1991	-	
1992	-	
1993	-	
1994	-	
1995	-	
1996	Tarawi NR est. (314), Gundabooka NP est. (451), Culgoa NP est. (152)	917
1997	-	
	TOTAL	9458

Table 2

Partial list of measures for a comprehensive assessment of the effectiveness of protected areas. Only groups 1 and 2 are covered in this study. The term “feature” refers to any targeted entity (e.g. ecosystem, assemblage, vegetation type, species, population)

Group 1 - Number and extent (*this study*)

- 1.1 Number
- 1.2 Total extent

Group 2 – Sampling features (*this study*)

- 2.1 Representativeness
- 2.2 Efficiency / sampling bias
- 2.3 Vulnerability bias

Group 3 – Sampling unmapped variation within features (these measures are surrogates for floristic and faunistic variation within land types and genetic variation within species or populations)

- 3.1 Environmental variation within the ranges of features
- 3.2 Geographical variation within the ranges of features

Group 4 - Design

- 4.1 Size
- 4.2 Configuration
 - * compactness
 - * proximity / connectivity
 - * replication as insurance against major disturbances
 - * alignment with climatic gradients (to allow adjustment of species ranges to climate change)
- 4.3 Defensibility of boundaries
 - * alignment with watershed boundaries
 - * adjacent land uses (present or expected)
 - * proximity to likely illegal access routes

Group 5 - Management effectiveness

- 5.1 Existence of management plans
- 5.2 Management resources
- 5.3 Encroachment by inappropriate extractive uses

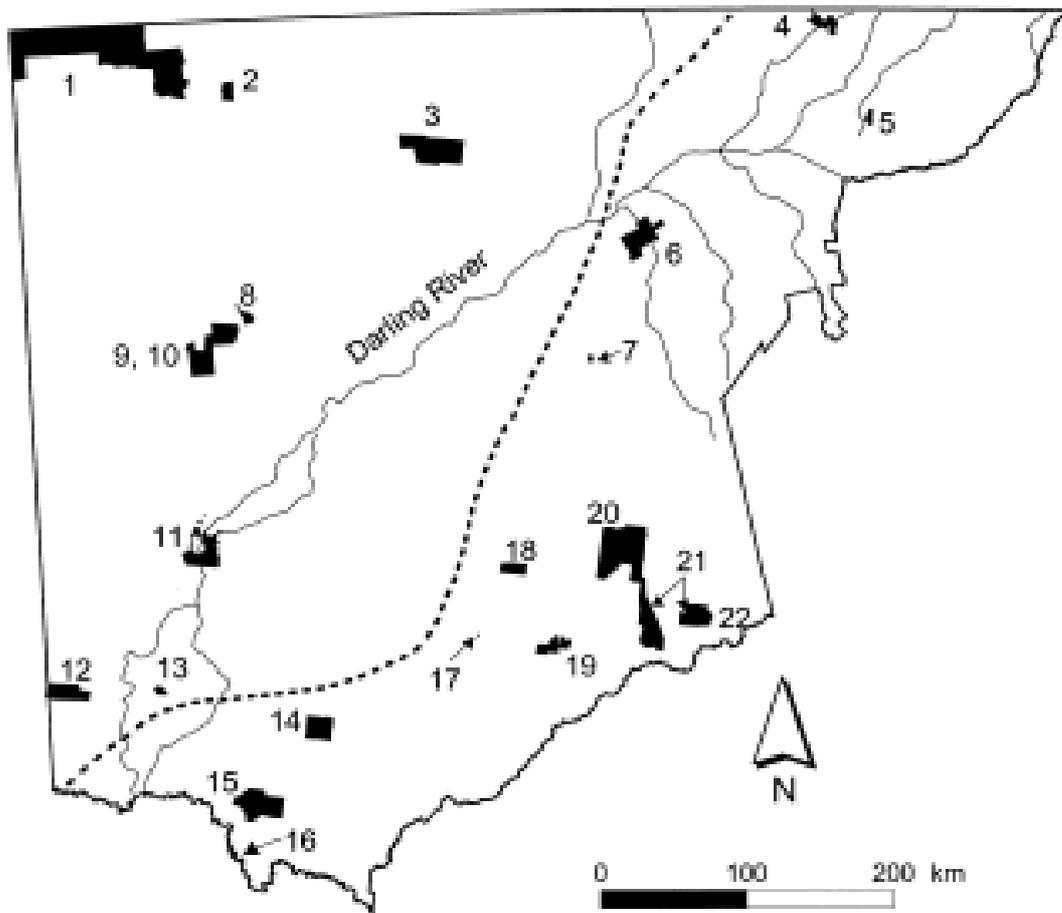


Fig. 1. The Western Division of New South Wales, showing reserves at the end of 1997. Abbreviations for reserve types: NP - national park, NR - nature reserve, AA - aboriginal area, HS - historic site. 1: Sturt NP; 2: Pindera Downs AA; 3: Nocolche NR; 4: Culgoa NP; 5: Narran Lake NR; 6: Gundabooka NP; 7: Mount Grenfell HS; 8: Coturaundee NR; 9: Mootwingee NP; 10: Mootwingee HS; 11: Kinchega NP; 12: Tarawi NR; 13: Nearie Lake NR; 14: Mungo NP; 15: Mallee Cliffs NP; 16: Kemendok NR; 17: Morrisons Lake NR; 18: Kajuligah NR; 19: Willandra NP; 20: Yathong NR; 21: Nombinnie NR (two gazetted parts separated by an area acquired but not yet gazetted); 22: Round Hill NR. 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 after floods in the Darling River system which does not generally involve the removal of native woody vegetation.

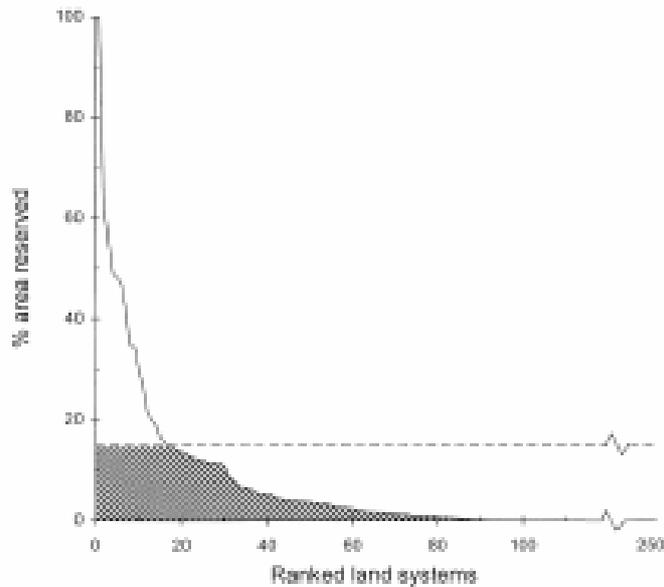


Fig. 2. Diagrammatic representation of the method for calculating efficiency. For convenience, land systems are ranked on the horizontal axis according to the percentages of their total areas in reserves, shown on the vertical axis. The dashed horizontal line is the conservation target, in this case 15% of the total area of each land system. We measured efficiency by expressing the shaded area under the target line as a percentage of the total reserve area, i.e. the percentage of the reserve system contributing to, but not in excess of, targets. We based the actual calculations on absolute (cf. percentage) areas.

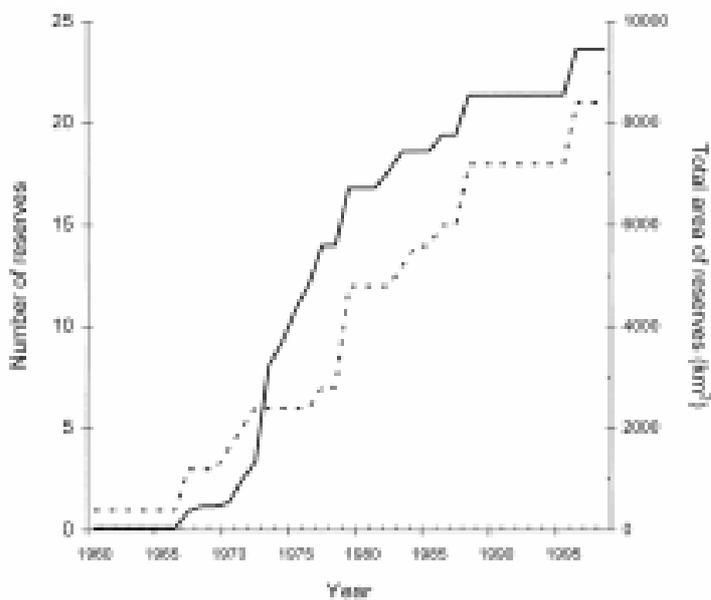


Fig. 3. Increases in the number of reserves (dashed line) and total extent of reserves (solid line) in the Western Division, 1960-1997.

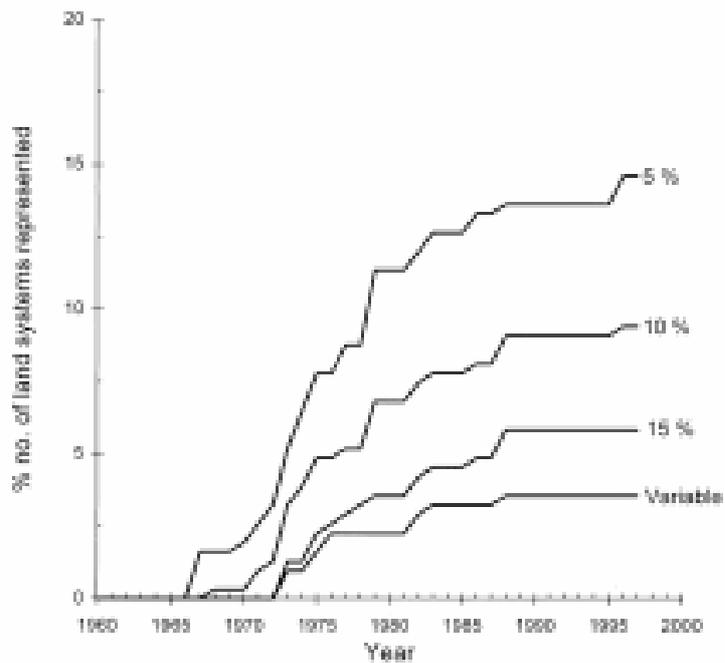


Fig. 4. Increases in the representativeness of the Western Division reserve system, 1960-1997, according to four sets of conservation targets: 5, 10 and 15% of the total area of each land system and a set of variable targets based on the natural rarity and vulnerability to clearing of each land system.

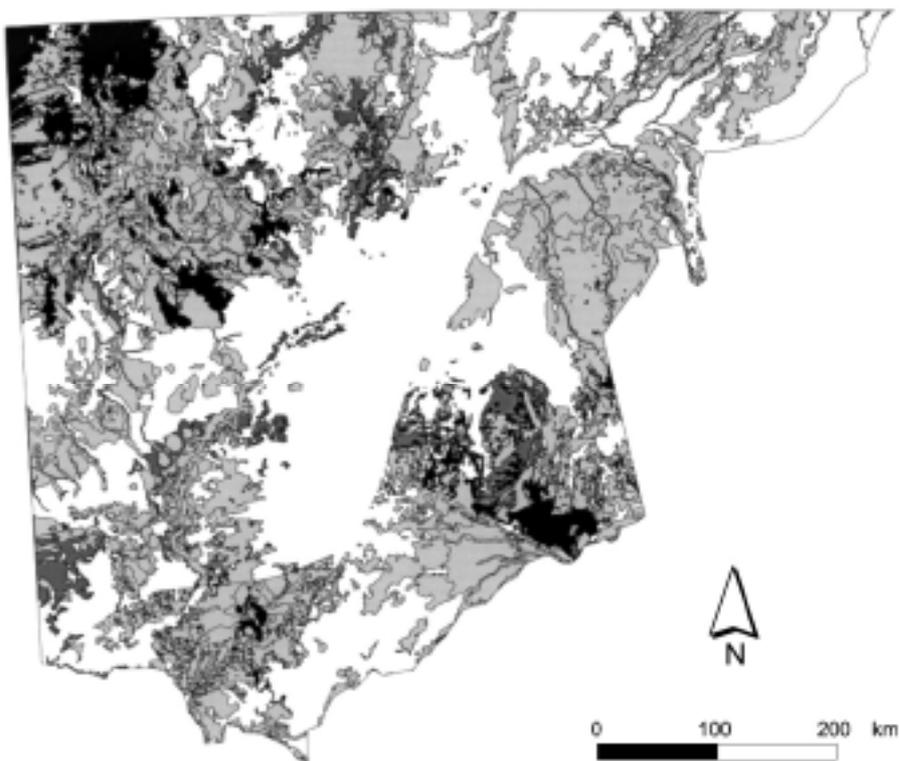


Fig. 5. Geographical distribution of land systems with different percentages of their variable conservation targets sampled by reserves at the end of 1997. Black - 100%; dark grey - 51-99%; light grey - 1-50%; white - 0%.

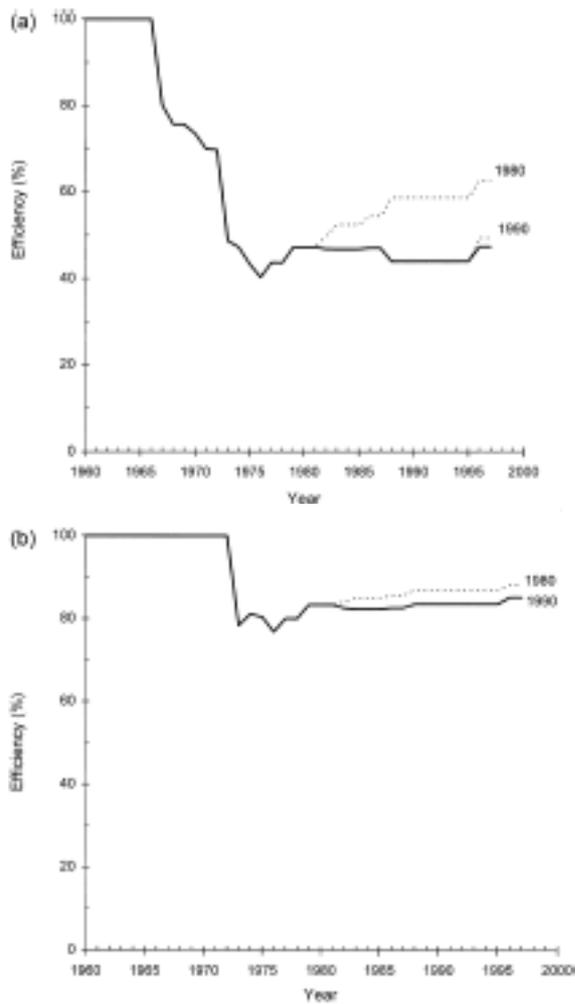


Fig. 6. Variations in the efficiency of the Western Division reserve system, 1960-1997. Solid line in (a) shows efficiency for 5% conservation targets and in (b) for variable targets. Dashed lines for 1980 and 1990 show the maximum possible values if the most efficient decisions on new reserves had been made since 1980 and 1990, respectively.

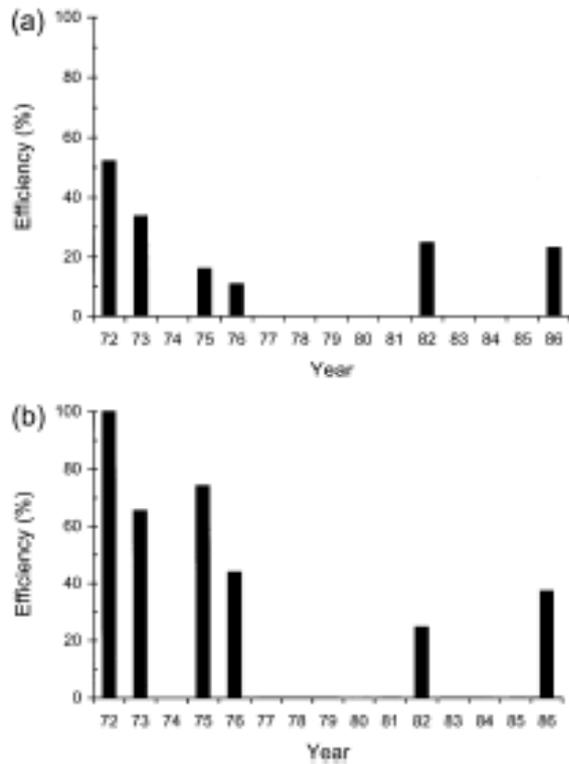


Fig. 7. Efficiencies of individual gazetted parts of Sturt National Park at the time they were dedicated. (a) 5% conservation targets; (b) variable targets.

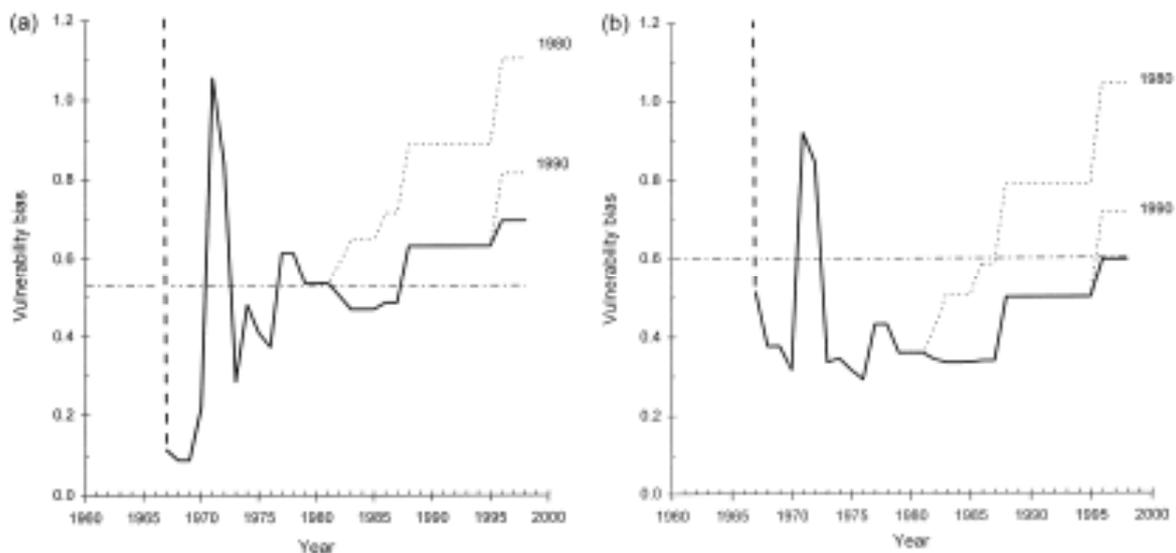


Fig. 8. Variations in the vulnerability bias of the Western Division reserve system, 1960-1997. Solid line in (a) shows vulnerability bias for 5% conservation targets and in (b) for variable targets. Dashed lines for 1980 and 1990 show the maximum possible values if decisions on new reserves had contributed maximally to targets for the more vulnerable land systems since 1980 and 1990, respectively. Dashed horizontal lines at 0.53 in (a) and 0.6 in (b) indicate the expected values of vulnerability bias if reservation decisions had been indifferent to vulnerability. Previous to the heavy dashed vertical lines in (a) and (b), values for vulnerability bias involved division by zero.