The Effect of Incremental Reserve Design and Changing Reservation Goals on the Long-Term Efficiency of Reserve Systems

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Abstract: *Selecting reserve areas based on percentages, such as 10% or 12% of a bioregion, is common in conservation planning despite widespread admission that such percentages are arbitrary and likely to be inadequate for the conservation of all biodiversity. Reserve systems based on these relatively low percentage targets are likely to require expansion in the future, resulting in the assembly of reserve systems over many years (incremental reserve design). How then will incremental reserve design, such as increasing percentage targets over time, affect the long-term efficiency of marine reserve systems? We used South Australia as a case study to investigate how changing percentage targets affects the contribution of individual planning units to efficient reserve design. Selection frequency counts provided a measure of a planning unit's conservation value. For the majority of planning units, changing targets led to a change in their conservation value indicating, for example, that planning units identified as high-value sites at a low-percentage conservation target may be of lesser importance when targets are increased. Despite the variability in the value of individual planning units at different targets, there was no loss in efficiency from incremental design of reserve systems based on systematic methods compared with purpose-built reserve systems (i.e., the system is assembled in a single iteration). The exception was when incrementally designed systems were based on South Australia's existing marine reserve system—a system developed in an ad hoc method. The result was reserve systems that were less efficient, less compact, and larger in size. This suggests that systematic approaches have an important role for efficient reserve design when there is uncertainty about the target level of reservation.*

Key Words: conservation planning, conservation targets, efficiency, incremental reserve design, irreplaceability, marine biodiversity, marine reserves

El Efecto del Diseño Incremental de Reservas y del Cambio de Metas de la Reserva sobre la Eficiencia a Largo Plazo de los Sistemas de Reservas

Resumen: *La selección de áreas de reserva con base en porcentajes, tal como 10 o 12% de una bioregión, es común en la planificación de la conservación a pesar de la aceptación generalizada de que tales porcentajes son arbitrarios y potencialmente inadecuados para la conservación de toda la biodiversidad. Es probable que los sistemas de reservas basados en estos porcentajes relativamente bajos requieran ser expandidos en el futuro; lo que resultará, al cabo de muchos años, en un conjunto de sistemas de reservas (diseño incremental de reservas). ?Cómo afectará el diseño incremental de reservas, específicamente el incremento de los objetivos de conservación en el tiempo, a la eficiencia a largo plazo de los sistemas de reservas marinas? Utilizamos al Sur de Australia como caso de estudio para investigar el efecto del cambio de objetivos de conservación sobre la contribución de las unidades de planificación individuales al diseño eficiente de reservas. Los conteos de frecuencia de selección proporcionaron una medida del valor de conservación de una unidad de planificación. En la mayoría de las unidades de planificación, el cambio de objetivos condujo a un cambio en su valor de*

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conservación lo que indica, por ejemplo, que las unidades de planificación identificadas como sitios de alto valor con objetivos de conservación de porcentaje bajo pueden tener menos valor cuando los objetivos son incrementados. A pesar de la variabilidad en el valor de las unidades de planificación individuales en objetivos diferentes, no hubo pérdida en la eficiencia por el diseño incremental de sistemas de reservas basado en métodos sistemáticos en comparación con sistemas de reservas hechas con intención (i. e., el sistema se configura en una sola iteración). La excepción fue cuando los sistemas diseñados incrementalmente se basaron en el sistema de reservas marinas existente en el Sur de Australia – un sistema diseñado mediante un método ad hoc. El resultado fue que los sistemas de reservas eran menos eficientes, menos compactos y con mayor tamaño. Esto sugiere que los métodos sistemáticos tienen un papel importante en el diseño de reservas eficientes cuando hay incertidumbre sobre el nivel del objetivo de conservación.

Palabras Clave: Biodiversidad marina, diseño incremental de reservas, eficiencia, irremplazable, objetivos de conservación, planificación de la conservación, reservas marinas

Introduction

The theory behind proportional representation in the identification of reserve systems tacitly assumes that biological diversity will be sustained if species and habitats are protected at some specific threshold. Although there is no general scientific agreement on what this threshold should be (Jennings 2000; Mendel & Kirkpatrick 2002), there are strong arguments for the application of conservation targets as a component of systematic conservation planning (Margules & Pressey 2000).

Although the selection of reserve areas based on percentages (percentage targets), such as 5% or 10% of the total area of each conservation feature (McNeely & Miller 1984; WCED 1987; McNeely 1993) is arbitrary, it is thought to be justified for political expediency. Soulé and Sanjayan (1998) suggest the basis for these commonly used percentage targets is the species–area relation (MacArthur & Wilson 1967), whereby a 50% loss of species would be expected from a 90% loss of habitat area, making half of all species vulnerable to extinction. Hence, frequently cited percentage targets such as 10% or 12% are expected to be far from adequate for the conservation of all biodiversity (Pressey et al. 2003).

Considerable effort has been directed at deriving more appropriate targets, with recent estimates drawing heavily on fishery management techniques via the use of population models to predict how different levels of protection affect the extinction probabilities of exploited stocks (e.g., Mace & Sissenwine 1993; Polunin & Roberts 1993; Roughgarden & Smith 1996). Estimates of the optimal fraction of marine reserves required to maintain a sustainable population call for between 20% and 50% of the total area (Plan Development Team 1990; Lauck et al. 1998; Botsford et al. 2001). Nevertheless, such estimates should be treated cautiously because they are subject to uncertainties such as the completeness of the initial species inventory, the extent to which species depend on external factors to be sustained, management regimes outside the reserve system, and how well these estimates transfer to a multispecies approach.

Although single targets for reservation may seem unrealistic, they do enable the decision-making process to proceed and protection strategies to be implemented (Day et al. 2000; Great Barrier Reef Marine Park Authority 2002). Because failure to gain agreement risks conservation inaction and continued environmental degradation, many scientists recognize that waiting to find what is the most appropriate target is often not viable and so advocate proceeding with caution, albeit with a low initial target. Clearly, whatever targets are chosen, it is unwise to treat them as a fixed goal because it seems likely that these initial systems will need to be expanded (Roberts & Hawkins 2000; Pressey et al. 2003). This was illustrated recently with the rezoning of Australia's Great Barrier Reef Marine Park, which led to an increase in the amount of strictly protected areas from < 5% to 33% (Day et al. 2000; Great Barrier Reef Marine Park Authority 2002).

The issue of changing targets is illustrated with a simple conservation problem. Consider a matrix of conservation features distributed across 10 sites as shown in Table 1, where the goal is to choose a subset of the sites that conserve at least x% of every feature. With a 10% target as the initial goal, the optimal solution is to protect sites C and D because their reservation will capture at least 10% of each conservation feature in the fewest number of sites. If the target is increased to 30%, the optimal solution is to protect three sites: B, G, and I. Suppose sites C and D, as the optimal solution at a 10% target, are set as the initial reserve system (i.e., locked-in), but the problem now is to achieve a conservation target of 30%. The solution requires a further two sites, A and H, in addition to sites C and D, to achieve the higher target, which is less efficient than the optimal solution. Hence, the optimal solution varies with the conservation target.

This simple example highlights the inefficiencies that may result from increasing conservation targets when solutions are not nested. The implications for conservation planning arise when reserve systems are implemented incrementally because initial systems identified at a lower target may not contribute to efficient reserve design at higher targets. We explored this problem by examining a

Table 1. An example of the effect of changing conservation targets on the optimal reserve-system solution.

	Site[a]										*Conservation target*	
Conservation feature	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*10%*[b]	*30%*[c]
Macroalgal assemblages	400	1050	510	0	310	80	0	0	0	270	262	900
Granite reef	240	130	200	0	0	55	400	0	0	0	103	398
Sponge gardens	0	720	0	650	320	420	0	0	0	0	211	633
Pinna beds	220	0	0	374	46	0	0	630	1340	0	261	783
Calcarenite reef	0	165	600	0	315	264	570	0	0	0	191	574
Seagrass- *Posidonia* spp.	140	1330	0	520	0	0	0	670	0	0	440	1319
Seagrass- *Amphibolis* spp.	1132	0	400	0	0	0	1155	0	0	0	311	932
Mangrove	0	0	0	300	0	0	0	765	520	130	172	515
Samphire	1050	0	0	369	0	0	0	0	842	0	226	678
Sea lion breeding colony	1	1	1	0	0	0	0	0	0	0	1	1
Species richness	7	6	5	5	4	4	3	3	3	2		

[a] *Conservation features are distributed across 10 sites (A–J).*

[b] *To achieve a target of 10% the optimal solution is to reserve sites C and D.*

[c] *To achieve a target of 30% the optimal solution is to reserve sites B, G, and I.*

large and real data set for the state waters of South Australia, an area of almost 60,000 km^2. We addressed the following questions: What inefficiencies are incurred by changing targets? Are some planning units that are critical at low percentage targets subsequently found to be unimportant at higher targets? Systematic methods for reserve design are useful exploratory tools with which to examine the effects of different conservation targets (e.g., 5%, 10%, 20%, and 30%) (Leslie et al. 2003; Stewart et al. 2003). We applied systematic methods to investigate the implications of changing targets for the design of efficient and representative marine reserve systems and for conservation planning more generally.

Methods

Data Set

The South Australian planning region was divided into 3119 planning units, each 5 × 5 km. Information on the amount of each biodiversity feature j, in each planning unit i, formed the data matrix $\mathbf{A} = \{a_{ij}\}$. Biodiversity features were identified from six biophysical data layers that provided consistent quality and coverage across the planning region. These were derived from government agencies of South Australia and included biogeographic regions (mesoscale 100–1000s of km); biounits (scale 10-100s of km); marine benthic habitats; coastal saltmarsh and mangrove habitats; species occurrence data (Australian sea lions, *Neophoca cinerea*; New Zealand fur seals, *Arctocephalus forsteri*); and bathymetry (depth classes). This generated a data matrix of 17,000 records of 102 biodiversity features distributed across 3119 planning units (Stewart et al. 2003). The number of biodiversity features contained within an individual planning unit ranged from 2 to 15.

Although considerable effort has gone into mapping of biodiversity across the region, little is known of the requirements for persistence of species and natural processes. Current levels of representation of biodiversity features in South Australia's existing marine reserve system are highly variable, with 32 features not represented at all and another 39 features represented at < 10% of their total extent. This bias is attributed to the ad hoc manner with which the reserve system was implemented. Consequently, the existing marine reserve system is likely to present a significant constraint to systematic and efficient marine reserve design (Stewart et al. 2003).

Reserve-Planning Scenarios

With the South Australian data set as our case study, the goal was to investigate the effect of changing conservation targets on efficient marine reserve design. We addressed the problem with two approaches. First, we examined how changing conservation targets affects the contribution of individual planning units to efficient marine reserve design. Given the considerable uncertainty about what is an appropriate conservation target, there is value in being able to identify individual planning units that are somewhat robust to this type of uncertainty. We constructed seven planning scenarios in which conservation targets ranged from 5% to 50% of the total extent of each biodiversity feature. Planning scenarios were each replicated 10 times to identify the 10 best reserve systems across the different conservation targets. The contribution of individual planning units to reserve-system design was assessed at the range of conservation targets based on selection frequency counts (described further below).

Second, we examined the efficiency of reserve-system design when conservation effort was implemented in stages. We constructed the problem of reserve design as an iterative process in which the initial reserve systems identified at lower conservation targets formed a nested subset of reserve systems identified at higher targets. We chose 30% as the higher target, although any alternative target could be used. We formulated three scenarios with different reserve systems as the starting points. The first scenario (30%, nested SAR) built on South Australia's existing marine reserve system (SAR) (an area equivalent of almost 5% of the planning region). In the second (30%, nested 5%) and third scenarios (30%, nested 10%), respectively, the initial systems were set as marine reserves identified at 5% and 10% conservation targets. All three scenarios were required to achieve a conservation target of 30% by expanding on the initial systems as described.

Each planning scenario was replicated 10 times to identify the 10 best marine reserve systems generated. For scenarios two and three, this involved using the 10 best marine reserve systems identified at the lower target (5 and 10%, respectively) as the starting base for each replicate run. The loss in efficiency due to incremental reserve design was assessed by comparing these scenarios to a purpose-built system (i.e., no starting base as a constraint for reserve-system design) set to achieve a conservation target of 30%.

Selecting Marine Reserve Systems

The problem of systematic design of marine reserves can be formulated mathematically as a nonlinear, integer-programming problem (Possingham et al. 2000). The objective was to configure marine reserve systems that minimize a linear combination of planning unit costs and reserve system boundary length while ensuring that biodiversity targets are met (Stewart & Possingham 2002; J. Carwardine et al., unpublished data). Cost is the sum of the cost measure of planning units contained within the marine reserve system and in this paper was equal to a planning unit's area. We incorporated spatial design requirements with a boundary length modifier (BLM) to minimize reserve-system boundary length and to achieve a desired level of compactness while maintaining an efficient marine reserve system. Previously, we used exploratory planning scenarios to investigate levels of spatial clustering with different weightings for the BLM and found that a BLM value of five delivered an acceptable trade-off between compactness and efficiency for marine reserve systems generated at different conservation targets (Stewart 2004). We used this weighting for all planning scenarios examined here.

Marine reserve systems were identified using the marine reserve design software MARXAN (Ball & Possingham 2000). The software features complementarity-based algorithms, which select planning units that generate solutions to the reserve design problem. We used the simulated annealing optimizer with iterative improvement features, which generates many good marine reserve systems of different configurations. Each reserve system was scored against the objective function according to how well it met the prescribed targets and design constraints. This score is a measure of the quality of planning units that together form the reserve system. Because the problem formulation is to minimize the objective function, the reserve system with the lowest score is considered the best (near-minimum) solution.

Each planning scenario was replicated 10 times, with each replicate comprising 1000 runs of the algorithm, generating 10,000 different marine reserve systems. With many solutions generated for a given planning scenario, MARXAN generates selection frequency counts that correspond to the number of times an individual planning unit is selected out of 10,000 good solutions. Hence, selection frequency counts are a useful measure of an individual planning unit's conservation value because they highlight how often the planning unit contributes to efficient and systematic marine reserve design.

Analysis

We aimed to determine the value of individual planning units to efficient reserve design across the range of conservation targets by assessing whether an individual planning unit was selected in reserve systems more or less than could be expected by chance. This test was performed by comparing the observed selection frequency with which planning unit i was contained within marine reserve-system solutions with the true (expected) frequency, p. We derived observed mean selected frequency counts for individual planning units from the 10 replicates performed at each conservation target (5–50%) to report on the number of times an individual planning unit was selected in a reserve system out of the total times it could have been selected ($n = 10{,}000$). The parameter p is the probability that a single planning unit is selected in a marine reserve system of fixed size and is constant for all planning units in the planning region for a given scenario (Stewart et al. 2003). The reserve-system size was derived from the summary data reported for each planning scenario (calculated as the average reserve system size of the 10 best marine reserve systems identified; Table 2).

We calculated confidence limits around the expected frequency distribution and assigned individual planning units to one of three conservation states: irreplaceable, random, or tradeable, according to whether they were selected more or less than the 95% confidence limits (Pressey et al. 1994; Stewart et al. 2003). This approach was formulated to better interpret the conservation value of a planning unit across a range of conservation targets. Planning units with an observed mean selection frequency greater than the upper 95% confidence limit were classified as irreplaceable because they contributed to efficient design of marine-reserve systems more often than could be expected from random sampling alone. Planning units with an observed mean selection frequency

Table 2. Summary data for seven alternative reserve-planning scenarios (5–50% conservation targets). [a]

Conservation target (%)	*Boundary length (km)*	*Reserve system area (km^2)*	*Reserve system size*[b]	*Expected mean selection frequency*[c] *(p)*
5	2154	3763	169.9	0.054
10	3147	7170	316.5	0.101
15	4361	14010	460.4	0.148
20	3820	10539	610.2	0.196
30	5241	20752	898.1	0.288
40	5899	27575	1195.2	0.383
50	6457	34308	1487.3	0.477

[a] *The total number of planning units in the planning region is 3119.*

[b] *The reserve system size is reported as the mean number of planning units contained within the best reserve systems generated from 10 replicate runs performed at the different conservation targets.*

[c] *Expected mean selection frequencies are calculated based on the reserve system size.*

within the 95% confidence limit were classed as random, indicating they were selected no better than by a random process alone. Planning units with an observed mean selection frequency below the lower 95% confidence limit were classed as tradeable because they were selected less than expected by chance. Therefore, at any given target, planning units were assigned to one of three conservation states: irreplaceable, random, or tradeable, according to whether the observed number of times they were selected was more or less than expected by chance. We compiled the data on a planning unit's conservation state across the different conservation targets to report on the number of planning units whose conservation state was unchanged by a change in the conservation target.

To investigate the loss in efficiency of incremental reserve design, we compared reserve systems that achieved a target of 30% iteratively with that of a purpose-built reserve system. Summary data for each scenario were reported and supported the calculation of efficiency values based on the reserve system size. Efficiency was defined as Pressey and Nicholls' (1989) measure of efficiency. It varies from 0 to 1, with 1 being the most efficient solution.

$$E = 1 - X/T,$$

where E is efficiency, X is the number of planning units contained in the reserve system, and T is the total number of planning units. This definition allowed us to investigate the inefficiencies that result when conservation efforts are implemented in stages and reserve design is constrained to a configuration that expands on reserve systems identified at lower targets. We expected that reserve systems designed incrementally would be less efficient than a purpose-built reserve system, with the degree of inefficiency a feature of the data matrix, the initial reserve system, and the conservation goals. Lastly, we compared how individual planning units selected in the initial reserve systems performed in the 30% (purpose-built) systems. Analyses focused on planning units that were contained in at least 1 of the 10 best reserve systems identified at 5% and 10% targets and that formed the base for incremental reserve design. In the case in which South Australia's existing marine reserves formed the starting base, analyses were performed on the subset of planning units that represented the existing reserve system (SAR). We report on the distribution of planning units among the three conservation states at the lower target and at the 30% (purpose-built) target.

Results

Effect of Changing Targets on the Value of Individual Planning Units

Increasing the conservation target increased the average reserve-system size (Table 2), therefore the probability that a planning unit was selected at random also increased. By increasing the conservation target one would also expect the observed mean selection frequencies for individual planning units to increase. In practice, however, this was not always the case, as shown for a sample of planning units in Fig. 1. The contribution of individual planning units to efficient reserve design was more variable across the different conservation targets than expected from random selection.

To better interpret the conservation value of individual sites, we assigned planning units to a conservation state. This measure provided a coarser indication of the effect of changing targets on the conservation value of individual planning units than did selection frequencies but was well suited for the scale at which priority-setting exercises are undertaken. When comparing individual planning unit's observed selection frequencies with the 95% confidence limits for the expected selection frequency (Fig. 2), 386 planning units (<9% of the total number of planning units) were classified as irreplaceable across all conservation targets (e.g., planning unit 1003, Fig. 2). A further 556 were tradeable at every target (e.g., planning unit

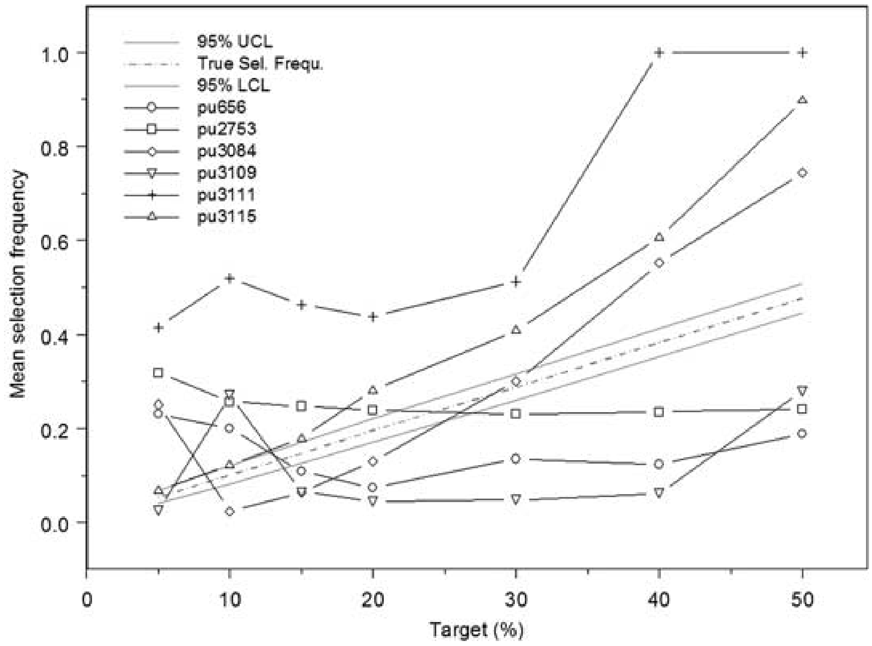

Figure 1. The effect of different conservation targets on the mean selection frequency counts for a sample of planning units (pu). Targets range from 5% to 50% and represent the target level of reservation for biodiversity features. Planning units with a selection frequency (sel. frequ.) greater than the upper 95% confidence limit (UCL) were contained in reserve systems more often than expected by random sampling alone. Planning units with a selection frequency below the lower 95% confidence limit (LCL) were contained in reserve systems less than expected by chance.

2985, Fig. 2), and 67 were random at every target (e.g., planning unit 2384, Fig. 2). The conservation state of the remaining 2110 planning units was more variable, with individual planning units shifting between the three conservation states (irreplaceable, random, and tradeable) as conservation targets varied. So although approximately two-thirds of the total number of planning units were in a variable state, a core set of planning units were irreplaceable at all targets, with their conservation state robust to the effect of changing conservation targets.

Effect of Changing Targets on the Efficiency of Incremental Reserve Design

No loss in efficiency was reported for incremental reserve systems that expanded on reserve systems identified at 5% and 10% targets (Table 3). The efficiency of these systems was comparable to a purpose-built reserve system that met the 30% target (Table 3). In contrast, basing the initial system on South Australia's existing marine reserves led to less efficient marine reserve systems than the purpose-built reserve systems. The inefficiency of reserve

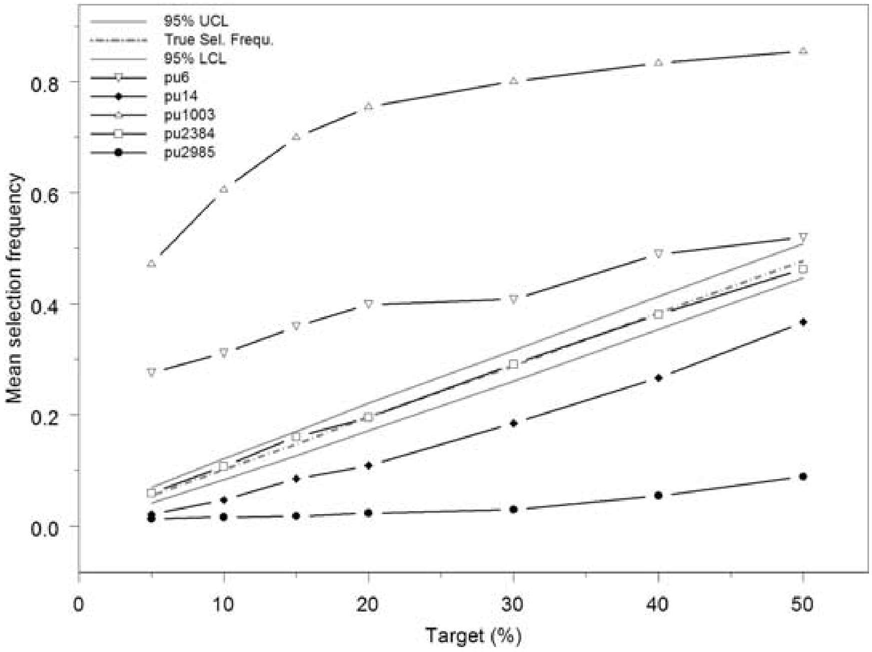

Figure 2. Selection frequencies (sel. frequ.) of a sample of planning units (pu) at different conservation targets compared with the true selection frequency (± 95% confidence limits) calculated for a marine reserve system of a size that corresponds to the number of planning units reported in Table 2. Planning units with a selection frequency greater than the upper 95% confidence limit (UCL) were contained in reserve systems more often than expected by random sampling alone. Planning units with a selection frequency below the lower 95% confidence limit (LCL) were contained in reserve systems less than expected by chance.

Table 3. Summary data for incremental reserve-planning scenarios (see Methods) that expand on marine reserve systems selected at lower targets for reserve design at the higher target of 30%.*

Scenario	*Scenario description*	*Objective function score*	*Boundary length (km)*	*Reserve system area (km^2)*	*Reserve system size*	*Efficiency*
30%, nested SAR	based on South Australia's existing marine reserve system (SAR) to achieve a 30% target	54,402	6297	22,917	1036.9	0.67
30%, nested 5%	based on reserve systems identified at 5% target to achieve a 30% target	48,234	5477	20,846	914.9	0.71
30%, nested 10%	based on reserve systems identified at 10% target to achieve a 30% target	47,721	5385	20,795	916.2	0.71

**Results are compared with the 30% purpose-built scenario reported in Table 2 that has an efficiency value of 0.71 and an objective function score of 46,956.*

systems identified in the 30%, nested SAR scenario resulted in 15% more planning units than the reserve systems identified in the purpose-built scenario to achieve the same conservation target.

Summary data described the performance of the best reserve systems identified for each incremental planning scenario in terms of the objective function score, the boundary length, cost (equal to the area of the reserve system), and size of the reserve system (Table 3). Reserve systems configured around South Australia's existing marine reserves were larger, less efficient, and more fragmented than was reported for either the purpose-built or incremental scenarios where systems identified at 5% or 10% formed the starting base. The objective function score is a single measure of how well the reserve systems achieved the multiple objectives of minimizing cost, minimizing boundary length, and achieving the 30% target. Reserve systems designed incrementally with 5% and 10% as the starting base scored comparably to the purpose-built reserve system with 30% as the conservation target. The significantly higher score reported for reserve systems based on South Australian marine reserves was indicative of the suboptimality of these solutions.

Seventy-two percent and 82% of planning units selected in reserve systems identified at 5% or 10%, respectively, maintained or improved their conservation state in the purpose-built scenario (Table 4). The percentage of planning units whose conservation state was unchanged at the 30% (purpose-built) target was 46% and 62% for the 5% and 10% targets, respectively. Only a small number of planning units went from being irreplaceable at the 5% and 10% targets to tradeable at the higher target (6% and 3%, respectively). With the majority of planning units identified in the best reserve-system solutions having the same or greater contribution to efficient reserve design at the higher targets, it is not surprising that the general performance of reserve systems was comparable (Table 3), whether they achieved the 30% target incrementally or in a single iteration. This was not the case for the subset of planning units representing South Australia's existing marine reserve system, of which only 38% maintained or improved their conservation state, whereas half were classed as tradeable at the higher target (Table 4).

Discussion

The dynamic nature of conservation planning means reserve systems are implemented incrementally, with effort staged over a number of years. This real-world constraint

Table 4. Distribution of selected planning units among the three conservation states (tradable, random, and irreplaceable) at the scenarios (see Methods) examined.[a]

Scenario	*Conservation status*	*30% (purpose built)*		
		tradeable (%)	*random (%)*	*irreplaceable (%)*
SAR[b]	irreplaceable	49.7	12.2	38.2[c]
5%	tradeable	9.3[c]	1.0[c]	1.8[c]
	random	17.7	12.1[c]	23.6[c]
	irreplaceable	6.1	4.1	24.2[c]
10%	tradeable	17.2[c]	2.3[c]	1.9[c]
	random	12.1	9.7[c]	15.3[c]
	irreplaceable	2.9	3.5	35.1[c]

[a] *Selected planning units were contained in at least 1 of the 10 best marine reserve systems generated at the lower target.*

[b] *The subset of planning units comprising South Australia's existing marine reserve (SAR) are all classified as irreplaceable because they form the starting base in every reserve system examined in the 30% nested-SAR scenario.*

[c] *Planning units maintained or improved their conservation state when purpose-built reserve systems were configured.*

has led to a shift away from single optimal solutions, toward more flexible procedures such as iterative heuristics that can assess the contribution of different planning units to the reservation goals and support decisions about where to direct conservation effort (Margules et al. 2002). These methods draw on the principles of complementarity and irreplaceability to identify planning units that contribute to efficient marine reserve design (Pressey et al. 1994; Leslie et al. 2003; Stewart et al. 2003). A planning unit's conservation value is typically assessed on the basis of the biodiversity features it contains, but it is also a factor of the reservation goals (e.g., targets), the status of the reserve system, and the site × features data matrix in general.

Using South Australia as a case study, we examined how changing the conservation target affected the conservation value of individual planning units. Planning units were not perfectly nested with regard to their selection frequency, as we predicted. The approach we used to inform where conservation effort should be directed identified priority planning units that were robust to uncertainty around the conservation target. In applying this approach to our case study, we identified a subset of planning units that were irreplaceable at the range of targets examined. For the majority of planning units, however, changing the target led to a shift in their conservation state. Only one-third of the planning units did not change their conservation state at the different targets. This result indicated that for the majority of planning units, changing the conservation target had an important influence on their conservation value to efficient marine-reserve design. One might expect this result to lead to inefficient, incremental design of reserve systems because planning units identified as priority sites under a given conservation target may be of lesser importance when identified under another target.

In fact, we found that the efficiency of the reserve systems exhibited no difference between incrementally built reserve systems derived from lower targets to those purpose-built reserve systems established at the higher target. This result is due to the composition of planning units in the initial reserve systems, which, for the majority at least, appeared robust to the effects of changing the target. The exception was when the incrementally designed reserve systems were based on South Australia's existing marine reserves. For example, half of the planning units that comprised the existing reserve system had limited conservation value at the higher target. This result is attributed to the ad hoc manner in which the initial reserve system was selected (Rodrigues et al. 1999; Stewart et al. 2003), rather than the incremental way in which reserve systems were configured. The suboptimal reserve systems identified when expanding on South Australia's marine reserves were larger, more fragmented, and required an increased number of planning units compared with the purpose-built reserve systems. In contrast, systematically designed reserve systems configured at lower targets contributed to efficient reserve design at higher targets with only minor trade-offs in area and compactness. So even for data sets that are not perfectly nested at the individual planning unit level, our results provide an example of reserve systems that can achieve higher targets through incremental reserve design without necessarily incurring trade-offs to the efficiency of the system. Our findings show that for reserve systems based on lower percentage targets that are likely to require expansion, it is more important that a systematic approach be adopted for marine reserve system design.

Our results highlight, for the first time, the issue of changing targets and its potential impact on the efficiency of incrementally designed reserve systems. Although we present a case study that reported no loss in efficiency from incremental design of reserve systems based on systematic methods, these findings represent the lower boundary of inefficiency of reserve systems created based on a lower target as the initial base. Because we formulated the scenario of incremental reserve design as a static problem and did not factor in aspects such as biodiversity degradation, threats, or extinction rates, we have not accounted for the loss of biodiversity between periods of reserve establishment. Incorporating some of these dynamic aspects of conservation planning could result in higher inefficiencies for the incremental design scenarios because biodiversity is degraded or lost in sites that remain unprotected (Meir et al. 2004). Practitioners should be aware of the dynamic nature of conservation planning, which can lead to a shift in priority areas in response to the changing goals, threats, constraints, and information on which their establishment was based. This dynamic nature emphasizes the importance of integrated management arrangements that protect biodiversity both within reserves and in the surrounding matrix as a strategy for the long-term persistence of marine biodiversity.

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