Strategic reserve design in the central coast of British Columbia: integrating ecological and industrial goals

Emily K. Gonzales, Peter Arcese, Rueben Schulz, and Fred L. Bunnell

Abstract: Few conservation reserves worldwide have been created in ways that are likely to promote the persistence of species, ecosystems, and ecological processes regarded as being representative of biological diversity. We demonstrate the application of newer approaches to systematic reserve design that could help stakeholders find designs that maximize simultaneously ecological, societal, and industrial goals. We created example reserve designs using the simulated annealing algorithm of SITES 1.0 and then contrasted these designs with a proposed reserve design negotiated as a multistakeholder process for British Columbia's central coast. Our strategic approach recommended reserve designs that included greater proportions of key conservation elements identified by stakeholders without increasing the land area or timber volume in reserves currently under consideration for protection. Our examples demonstrate that strategic approaches to reserve design can facilitate the repeatable and efficient allocation of land to conservation and development and, therefore, represent an improvement on ad hoc methods. Readily available software facilitates the exploration of alternative conservation and societal values, incorporate the interests of multiple stakeholders, and provides a focus and catalyst for discussion at the planning table.

Résumé : Peu d'aires de conservation à travers le monde ont été créées avec des moyens qui sont susceptibles de promouvoir la persistance des espèces, des écosystèmes et des processus écologiques considérés comme représentatifs de la diversité biologique. Nous présentons l'application de nouvelles approches pour la conception systématique des réserves qui pourraient aider les intervenants à trouver des configurations qui maximisent simultanément les objectifs écologiques, sociétaux et industriels. Nous avons créé des configurations de réserve à l'aide de l'algorithme de recuit simulé SITES 1,0 et comparé ensuite ces propositions avec la configuration proposée à la suite d'un processus de négociation entre les multiples intervenants dans la région côtière du centre de la Colombie-Britannique. Notre approche stratégique recommandait des configurations de réserves qui incluaient une plus forte proportion des éléments clés de conservation identifiés par les intervenants sans augmenter la superficie de terrain ni le volume de bois dans les réserves présentement considérées comme aires de conservation. Nos exemples démontrent que des approches stratégiques pour la conception de réserves peuvent faciliter une allocation efficace et reproductible des terres pour la conservation et le développement et représentent par conséquent une amélioration par rapport aux méthodes ad hoc. Des logiciels facilement disponibles facilitent l'exploration de différentes valeurs sociétales et de conservation, intègrent les intérêts de multiples intervenants et fournissent un point de convergence et un catalyseur pour les discussions à la table de planification.

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Introduction

Modern approaches to reserve design use quantitative conservation goals and simulation techniques to identify sites that include representative ecosystems and viable populations of all native species within a planning area (Schwartz 1999; Andelman et al. 1999; Akçakaya 2000; Margules and Pressey 2000). In contrast, many reserves have been established mainly for their striking physical features, to facilitate tourism, or as a consequence of popular support for particular charismatic species (Paquet 1990; Ministry of Environment, Lands and Parks 1994; Pimm and Lawton 1998; Scott et al. 2001; Groves et al. 2002). One result of these latter practices is that reserves worldwide occur disproportionately on lands of low productivity and economic value and have only rarely been established to maximize biological diversity (Pressey 1994; Dobson et al. 1997; Margules and Pressey 2000).

The "biodiversity crisis" (Pimm et al. 1995) has been used as justification for the creation of conservation reserves via ad hoc processes under the assumption that systematic approaches forestall action and risk lost opportunities (Soulé 1985; Wilson 1988; Coblentz 1990; Ruesink et al. 1995). It is equally plausible that crisis decisions jeopardize conservation goals when their scientific basis is poor and adaptive management and monitoring are neglected (Irwin and Wigley 1993; Scudder 1996; Arcese and Sinclair 1997; Nudds 1998). Popular shortcuts in reserve design, such as a reliance on "umbrella" or "flagship" species, can also result

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in designs unrepresentative of rare and vulnerable ecosystems and species (Scudder 1996; Nudds 1998; Bunnell et al. 1999, 2002; Schwartz 1999; Andelman and Fagan 2000; Groves et al. 2002). Theory suggests that conservation designs that ignore the representation of rare elements, the effects of stochastic events, population dynamics, and environmental change are likely to lose diversity faster than reserves designed with these concerns in mind (Diamond 1975; Noss et al. 1997; Bunnell et al. 1999, 2002; Schwartz 1999; Margules and Pressey 2000; Brashares et al. 2001; Groves et al. 2002; Moilanen and Cabeza 2002). Overall, these considerations suggest that decision-makers should exercise caution when placed in the position of trading political expediency for scientifically defensible approaches to conservation area design.

Many computer-assisted approaches to conservation planning have been developed to facilitate the strategic design of conservation areas over a range of factors, including the habitat requirements of species, social and economic values, and the opportunity costs of alternative conservation scenarios (e.g., Lomolino 1994; Rothley 1999; Margules and Pressey 2000; Scott and Sullivan 2000, Ardron et al. 2002; Groves et al. 2002). These methods also facilitate the repeatable prioritization of conservation sites and allow planners to test the robustness of designs to variation in stakeholder goals (Margules and Pressey 2000; Cabeza and Moilanen 2001). Given the potential competition of biological, social, and economic values, computer-assisted reserve design has become a process of seeking efficient solutions to meet the diverse goals of stakeholders (Faith and Walker 1996; van Langevelde et al. 2000).

Of the computer algorithms developed to achieve the efficiencies noted above, simulated annealing has emerged as a particularly useful method by virtue of its ability to handle large amounts of data efficiently (Kirkpatrick et al. 1983; Underhill 1994; Lomolino 1994; Csuti et al. 1997; Possingham et al. 2000; Ardron et al. 2002; Groves et al. 2002; Noss et al. 2002). Simulated annealing begins with a fixed or random set of planning units and then samples from the remaining set to find incremental solutions that maximize planning goals, minimize costs, and often achieve near-optimal results (Pressey et al. 1996; Possingham et al. 2000). Despite its potential advantages, however, few examples of strategic conservation area design exist and ad hoc methods still predominate (Andelman et al. 1999; Prendergast et al. 1999; Cabeza and Moilanen 2001; Groves et al. 2002). Our goal here, therefore, is to demonstrate an approach to strategic reserve design on the central coast of British Columbia (Fig. 1*a*) and show that simple and expedient methods exist to supplant ad hoc and crisis planning processes and provide more efficient and defensible reserve designs overall.

We now provide some background to land use planning in British Columbia and the central coast. We then introduce the Preliminary Central Coast Land and Resource Management Plan (hereafter the Preliminary Plan) negotiated by representatives of environmental nongovernmental organizations, industry (primarily the forestry sector), and government (Fig. 1*b*) (Ministry of Sustainable Resource Management 2001*a*). We next outline an approach to reserve design on the central coast using SITES 1.0 (Andelman et al. 1999) and some of the key goals underpinning the Preliminary Plan. Overall, we asked if SITES helped us to find superior solutions to the conflicting goals represented in draft proposals by industry and environmental organizations.

Background

Land and resource management planning and the B.C. central coast

Central coast

The 4.8 × 10^6 ha central coast planning area is dominated by temperate rainforests and an extensive shoreline and mountainous terrain and has only about 4600 human residents (Ministry of Sustainable Resource Management 2001*b*). Currently, 99% of the plan area is under provincial jurisdiction (Crown Land), but aboriginal land claims also exist and land use decisions are in flux (Ministry of Sustainable Resource Management 2002). Approximately 26% of the forested portion of the land base is classified as suitable for timber harvest (Ministry of Sustainable Resource Management 2001*a*; Wells et al. 2003), mainly because of the distribution of marketable trees and regulations that preclude harvest under some circumstances (e.g., Wells et al. 2003). The area of the "timber harvest land base" in future will depend on technological, regulatory, environmental, and economic change.

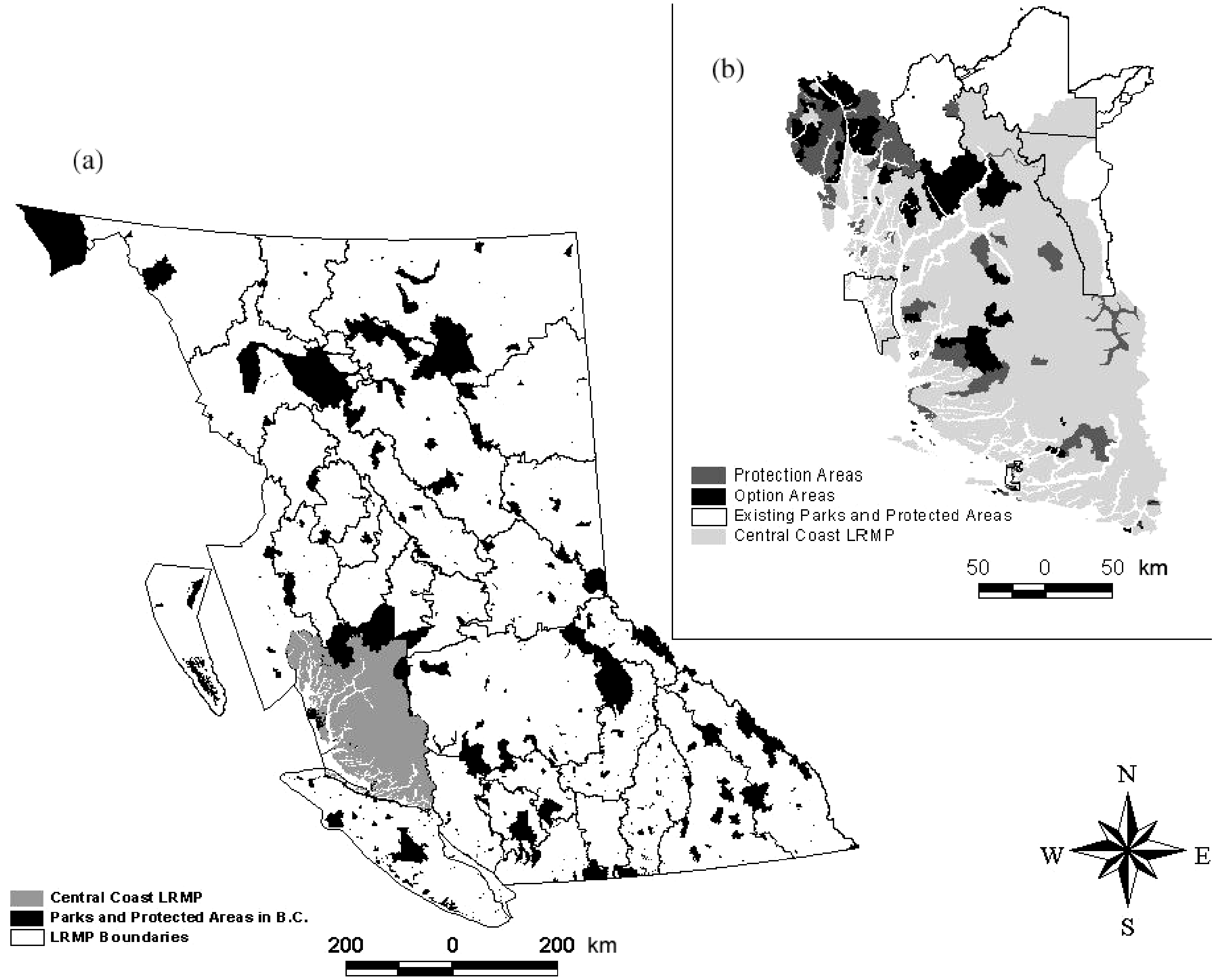
About half of the forest cover in the planning area was classified as "old growth" based on height and age-class definitions (e.g., >141 years, age-class 8–9; Jeo et al. 1999, p. 59). Younger stands occur mainly in the southern portion of the planning area because of accessibility and historic logging. Tree species represented there and of particular interest to environmental organizations included Sitka spruce (*Picea sitchensis* (Bong.) Carrière), Douglas-fir (*Pseudotsuga menzeisii* (Mirb.) Franco), western redcedar (*Thuja plicata* Donn ex D. Don), and yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) (Jeo et al. 1999). The latter two species are not differentiated in forest cover maps for the region and were considered as a group ("cedar").

Featured vertebrates in the planning region included grizzly bear (*Ursus arctos*), a vulnerable species put forward as an umbrella species, and several species of anadromous salmonids owing to their economic importance and functional role in ecosystems (Jeo et al. 1999). The white-phase "Kermode" bear (*Ursus americanus kermodensis*) has also played a prominent role as a flagship species because of its popularization in public media. Recent work suggests that about 100–200 white-phase bears, homozygous for a single gene mutation, occur mainly in the northwest portion of the planning area (Ritland et al. 2001). Habitat maps by government scientists also existed for marbled murrelets (*Brachyramphus marmoratus*), mountain goat (*Oreamnos americanus*), moose (*Alces alces*), black-tailed deer (*Odocoileus hemionus*), and Roosevelt elk (*Cervus canadensis*) (Ministry of Environment, Lands and Parks 2000) (Appendix A). Many rare and potentially endemic plant and animal species probably also exist in the planning area but so far have not been a focus for planners.

Land use planning on the central coast

The B.C. government initiated the land and resources management planning process to enjoin stakeholders in the negotiation of land use agreements for ratification by gov-

Fig. 1. (*a*) Central coast planning region, Land and Resource Management Planning boundaries, and existing protected areas within British Columbia; (*b*) Protection Areas, Option Areas, and existing parks and protected areas in and around the central coast.



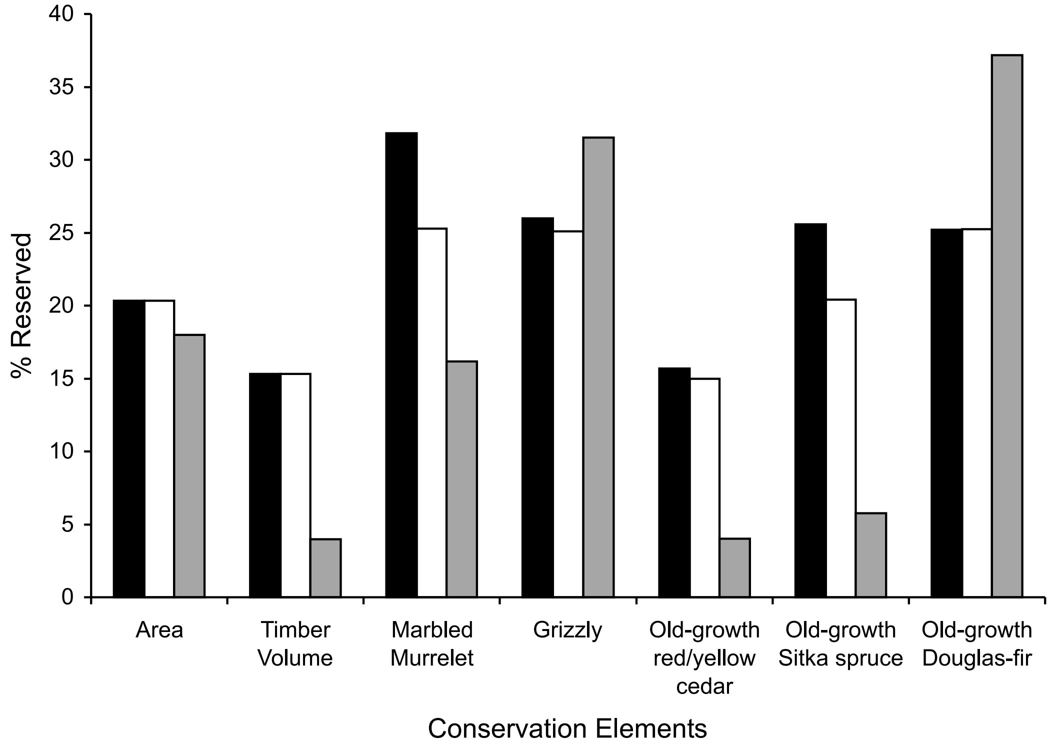
ernment (Ministry of Environment, Lands and Parks 1993). A key goal in the process was to balance environmental, economic, and social objectives to create "certainty" about the allocation of Crown Land to resource extraction, development, or protection (Ministry of Environment, Lands and Parks 1993). The central coast land and coastal resource management planning process began in 1996 and is slated for completion in 2003 (Ministry of Sustainable Resource Management 2001*a*). Over 60 stakeholder organizations participated in the central coast planning process including environmental organizations, the forest and tourism industries, and organizations representing labour and local, provincial, and federal governments. A stall in the process in 2000, however, led to a parallel process that brought forward draft proposals for the region by environmental organizations and industry. Subsequent negotiations, with government input, resulted in the Preliminary Plan (Fig. 1*b*) (Ministry of Sustainable Resource Management 2001*a*).

Planning goals on the central coast

The extended negotiation of stakeholders in the central coast planning process might have been facilitated by the use of systematic planning tools. Planning tools such as SITES 1.0 were designed to find near-optimal solutions to conflicting sets of stakeholder goals in the land use planning process. These tools facilitate the inclusion of a wide range of perspectives but also force the explicit quantification of goals and objectives. To explore this approach in the central coast, we extracted a set of goals to emulate those of the contributors to the Preliminary Plan (Jeo et al. 1999; Ministry of Sustainable Resource Management 2001*a*).

Environmental organizations documented their goals and rationale in a report commissioned from Round River Conservation Studies (Jeo et al. 1999). These goals included the following: (*i*) to maintain or restore viable populations of large carnivores, (*ii*) to maintain or restore viable populations of all salmon stocks, (*iii*) to maintain or restore representation of all native ecosystem types and successional stages across their natural range of variation, and (*iv*) to maintain or restore natural landscape connectivity (Jeo et al. 1999, p. 28). Jeo et al. (1999) further identified the grizzly bear as a key large carnivore and umbrella species. We as-

Fig. 2. Percentage of area, timber volume, wildlife habitat, and old-growth stands proposed for conservation by environmental organizations (solid bars), industry (grey bars), and the Protection Areas of the Preliminary Plan negotiated by the stakeholders (open bars). Parks existing prior to 2001 are included in all figures.



sumed that industry objectives included minimizing the area or volume of timber in protected areas.

Preliminary Plan for the central coast

We used the Preliminary Plan as a benchmark against which to explore alternative designs using SITES. The Preliminary Plan identified "Protection Areas", where resource extraction is not allowed, and "Option Areas", where the determination of future use is postponed pending further study (Ministry of Sustainable Resource Management 2001*a*). Existing parks and proposed Protection Areas account for 20.3% of the plan area. Protecting all Option Areas would add a further 11.1% to protected areas in the central coast, for a total of 31.4%. The Preliminary Plan is notable for its emphasis on large protected areas situated in the northern half of the central coast (Fig. 1*b*). These areas adjoin two existing protected areas, the 321 120 ha Kitlope Heritage Conservancy Protected Area and the 981 000 ha Tweedsmuir Provincial Park and Protected Area. The Kitlope Heritage Conservancy Protected Area exists outside the central coast planning area, whereas Tweedsmuir Provincial Park and Protected Area straddles both the central coast and the Cariboo–Chilcotin planning areas (Fig. 1). Overall, this complex creates an extensive reserve system in the northern part of the planning area. By comparison, protected areas diminish in size and prevalence in the southern portion of the central coast plan area, where proportionally more industrial activity has also occurred (Jeo et al. 1999).

Comparing draft and preliminary plans

A summary of proposals by industry, environmental organizations, and the Preliminary Plan illustrates the emphasis of stakeholders, some deviations from published goals, and some potential gaps in the planning process regarding the conservation of rare ecosystem types (Fig. 2). Industry proposed that slightly less area, and much less timber volume, be reserved in protected areas than environmental organizations or the Preliminary Plan but emphasized the reservation of old-growth Douglas-fir and grizzly bear habitat relative to other proposals. The environmental organization draft proposal is notable for its emphasis on old-growth stands of Sitka spruce, cedar, and, perhaps indirectly, habitat of high value to murrelets (Fig. 2). The Preliminary Plan was intermediate between the environmental and industry draft plans for grizzly bear and murrelet habitat but closer to the environmental organization proposal in the reservation of old-growth spruce and cedar (Fig. 2).

Wells et al. (2003) examined in detail the distribution of rare and vulnerable ecosystems in relation to proposed Protection and Option Areas in the central coast. They concluded that there was a marked underrepresentation of locally and regionally rare ecosystem types in proposed protected areas. Two example ecosystems of interest to conservation include the Sitka spruce – black cottonwood (*Populus trichocarpa* Torr. & A. Gray) riparian zone and yellow-cedar bog forest. The Sitka spruce – black cottonwood riparian zone ecosystem is rare locally and globally, vulnerable to harvest, and potentially high in productivity and biodiversity (Wells et al. 2003). Yellow-cedar bog forests may contain ancient trees of high commercial value and support unique assemblages of bog or upland species.

The draft plan of environmental organizations proposed just 8.2% of approximately 37 366 ha of Sitka spruce – black cottonwood riparian zone forest and 0% of approximately 3270 ha of yellow-cedar bog forest for inclusion in reserves. The industry draft plan included 26.7% of the Sitka spruce – black cottonwood riparian zone forest but also no yellow-cedar bog forest. The Preliminary Plan included 5.9% of Sitka spruce – black cottonwood riparian zone forest and 4.1% of yellow-cedar bog forest in proposed Protection Areas. A potential problem in underrepresenting rare ecosystems is that rare and endemic species may be threatened or lost as habitats are developed (Diamond 1975; Noss 1996; Noss et al. 1997; Bunnell et al. 1999, 2002; Schwartz 1999). However, given the very large plan area and number of elements under consideration, it is unlikely that participants could have evaluated systematically various alternative designs without using formal methods. To demonstrate such an approach, we now describe the methods that we employed to compare the Preliminary Plan with alternatives using SITES (Andelman et al. 1999).

Methods

We followed Pressey and Cowling (2001) and Andelman et al. (1999) to develop example reserve designs. This process required identifying conservation and industry goals and their quantitative targets. We employed databases available in the central coast planning table's data dictionary (Appendix A). The data dictionary includes themes accepted by planning members as the best available representation within the scope of the plan. The dictionary is updated as new data become available. Our analyses were based on the data available July 2001. We used georeferenced habitat maps for seven species of vertebrates, three tree species organizations, and 158 ecosystem delineations for our analyses (based on the approach of Wells et al. 2003) (Appendix A). We included old-growth and ecosystem representation goals as conservation elements to represent the broad range of terrestrial species and ecosystem processes for which no digital data were available. Bunnell et al. (2002) offer a scientific rationale and practical application of related approaches in the Pacific Northwest.

Wildlife goals

We used habitat maps for mountain goat, black-tailed deer, moose, Roosevelt elk, black bear, grizzly bear, and marbled murrelet (Appendix A), species with varied habitat requirements and flagship or umbrella status (Jeo et al. 1999) (see above). Habitat "suitability" reflects the expected use of habitat based on an index of density, whereas "capability" estimates the ability of the habitat, under optimal conditions, to provide a species with its "life requisites" (Ministry of Environment, Lands and Parks 1999). Habitat suitability and capability indexes were divided into five classes. We aimed to reserve 30% each of "moderately high" and "high" suitability habitats (capability for grizzly). We did not include data on salmon or watercourses but note that estimates of habitat capability for grizzly were influenced strongly by the distribution of streams and run sizes (Fuhr and Demarchi 1990). We present results for murrelets and grizzly bear for efficiency.

Old-growth goals

We estimated the representation of old-growth Douglas-fir, Sitka spruce, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar and yellow-cedar (pooled) following Jeo et al. (1999, p. 59) based on forest inventory data (Ministry of Forests 1998). Our example goal was to reserve 30% of existing old-growth Douglas-fir, Sitka spruce, and cedar stand types.

Ecosystem representation goals

Ecosystem classification was based on the integration of vegetation, terrain, topography, and soil characteristics used to create Broad Ecosystem Units (Ministry of Environment, Lands and Parks 1999) and the Biogeoclimatic Ecosystem Classification system (Meidinger and Pojar 1991). We used Broad Ecosystem Units divided amongst Biogeoclimatic Ecosystem Classification zones, typed to variant, to create 158 unique forest zone ecosystem types for the central coast region (Wells et al. 2003). We specified ecosystem representation goals using an algorithm to emphasize rare types. Our goal was to reserve 50% of the rarest and 10% of the commonest ecosystem types in the plan area. To do this, we calculated a goal for each ecosystem type from the negative exponential relationship Goal = –(Ecosystem area^r/total area^r)(L – U) + L, where r describes the slope and L and U were the lower and upper limits on area goals, respectively. Our rationale for emphasizing rare over common ecosystems was to reduce problems associated with the creation of small populations and interrupted ecosystem processes as the result of reducing the size or increasing the fragmentation of rare ecosystem types (e.g., Diamond 1975; Noss et al. 1997; Bunnell et al. 1999, 2002; Schwartz 1999). For economy, we present results for the Sitka spruce – black cottonwood riparian zone forest and yellow-cedar bog forest ecosystem types.

Industry goals

We assumed that industry sought to minimize the area of land or timber volume in reserves (e.g., Fig. 2). Area or timber volume reserved can each be implemented as "costs" and minimized by algorithms (Andelman et al. 1999). Because existing parks and Protection Areas accounted for 20.3% of the plan area, we set an upper limit of 20.3% in our initial "area limited" scenarios. A further 11.1% of the plan area would be added to the reserve network if all Option Areas were also protected. Thus, we also explored a limit of 31.4% in a second area limited scenario.

We also set limits for two "timber volume" scenarios to explore the case that industry focused solely on reducing the volume of harvestable timber in Protected Areas. The approximate volume of timber in the existing parks and Protection Areas of the Preliminary Plan is about 16.5% of the total for the plan area. With Option Areas included, this figures rose to 27.4%. Timber volume scenarios were not limited in the maximum area that could be reserved to meet conservation goals.

Planning units and model conditions

We used 4204 contiguous watersheds that varied widely in size (mean = 1130 ha, SD = 4154 ha) as "planning units" in SITES. Watersheds were also employed for planning by government (Ministry of Sustainable Resource Management 2001*a*) and environmental organizations (Jeo et al. 1999), thereby defining the resolution of the analysis (Pressey and Logan 1998). Because watersheds were not used to create the boundaries of the Preliminary Plan, our area estimates for protected areas, Protection Areas, and Option Areas differ slightly from published values (Ministry of Sustainable

Resource Management 2001*a*). Existing protected areas were locked into solutions for all analyses.

We set the simulated annealing algorithm to 1 000 000 iterations for each run and repeated each scenario 10 times. The results from each run differed slightly because runs proceed randomly (Andelman et al. 1999). We report the mean values for conservation elements over 10 runs for each scenario. Mapped solutions were displayed in ArcView 3.2 (Environmental Systems Research Institute, Redlands, Calif.). Boundary length modifiers were omitted for simplicity. For each mapped scenario, we present the case defined by SITES as the most efficient solution to stakeholder goals (Andelman et al. 1999).

Results

Spatial arrangement of reserves

Mapped solutions for area and timber volume limited scenarios show that SITES chose smaller clusters of watersheds as candidate reserves than those identified in the Preliminary Plan (Figs. 1*b* and 3). Our emphasis on ecosystem representation probably enforced an ecologically diverse portfolio of planning units.

Protection Areas of the Preliminary Plan reserved some part of 104 of 158 (65.8%) ecosystem types in the plan area. With solutions constrained to 20.3% of the plan area or 16.5% of timber volume, SITES reserved 147 of 158 (93.0%) ecosystem types. With Protection and Option Areas combined, 112 of 158 (70.9%) ecosystem types were represented, whereas comparable SITES scenarios with size and volume constraints each reserved all 158 types.

To estimate generally how well SITES met our ecosystem representation targets, we calculated for each ecosystem type the quantity (area reserved – area target)/area target. By this method, values greater or less than 1.0 indicate overrepresentation and underrepresentation, respectively. Constrained to 20.3% of the plan area, SITES generally underrepresented ecosystem targets (mean = 0.58, SD = 1.41). The large standard deviation also suggests wide variation in degree of over- and under-representation across ecosystem types. Scenarios with area constrained to 31.4% (mean = 1.18, SD = 1.14) and timber volume constrained to 16.5% (mean = 1.02, SD = 1.32) or 27.4% (mean = 1.61, SD = 1.03) generally met or exceeded their targets.

SITES reserved a larger fraction of Sitka spruce – black cottonwood riparian zone forest and yellow-cedar bog forest ecosystem types than the Preliminary Plan in area-limited runs (Fig. 4). The Sitka spruce – black cottonwood riparian zone forest ecosystem type accounts for 0.79% of the plan area (Fig. 4*a*), whereas just 0.23% of Protected Areas and 0.33% of Protected Areas plus Option Areas occur as Sitka spruce – black cottonwood riparian zone forest in the Preliminary Plan. Protected areas identified by SITES included 0.99% and 0.74% of their area in Sitka spruce – black cottonwood riparian zone forest (20.3% and 31.4% area limit, respectively), corresponding to over- and about equal representation in the corresponding solutions (Fig. 4). Similarly, the Preliminary Plan protects only about 0.01% of yellow-cedar bog forest versus its coverage of 0.07% of the plan area. SITES achieved better representation, with 0.04% of

Fig. 3. Distribution of proposed protected areas (dark shades) in the SITES solutions based on (*a*) 20.3% and (*b*) 31.4% area limits and (*c*) 16.5% and (*d*) 27.4% timber volume limits. Light shading indicates the extent of the central coast planning area.

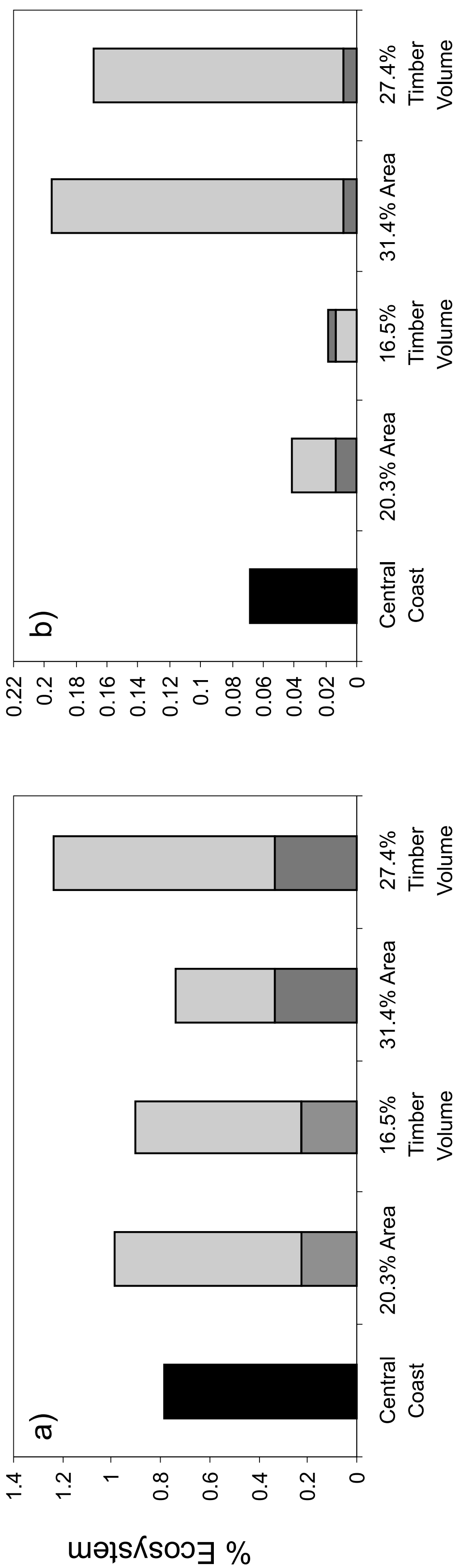


Fig. 4. (*a*) Sitka spruce – black cottonwood riparian zone forest and (*b*) yellow-cedar bog forest as a percentage of the central coast planning area (black bars) in the Preliminary Plan (dark grey bars) and in the SITES solutions subject to the area limited or timber volume limited scenarios as indicated (light grey bars).

reserves at the 20.3% area limit and 0.20% of reserves at the 31.4% area limit occurring as yellow-cedar bog forest.

SITES solutions with timber volume limits generally reserved Sitka spruce – black cottonwood riparian zone forest and yellow-cedar bog forest at more representative levels than proposed by the Preliminary Plan (Fig. 4). SITES solutions protected substantially more Sitka spruce – black cottonwood riparian zone forest than occurs in Protection Areas (Fig. 4*a*) and Protection plus Option Areas (Fig. 4*b*). Protected Areas of the Preliminary Plan reserved roughly equal percentages of yellow-cedar bog forest as SITES solutions constrained at 16.5% timber volume but less than SITES solutions constrained at 27.4%.

Area limited scenarios

Constrained to 20.3% of the plan area, SITES met representation goals for grizzly habitat and Douglas-fir old-growth stands but not for marbled murrelet habitat or old-growth Sitka spruce or cedar (Fig. 5*a*). SITES met or exceeded all representation goals at the 31.4% area limited scenario (Fig. 5*b*). SITES also reserved greater percentages of each conservation element identified (see Methods) than the Preliminary Plan at both area limited scenarios, with the exception of old-growth cedar at the 20.3% limit and old-growth spruce at the 31.4% area limit. SITES solutions limited at 20.3% of the plan area captured much higher percentages of mapped habitat for murrelets (16.6% more) and grizzly bear (13.9% more) (Fig. 5*a*). SITES limited at 20.3% area also reserved more old-growth Douglas-fir (19.8% more) than Protection Areas of the Preliminary Plan (Fig. 5*a*). With the area limit raised to 31.4%, our representation goal for Sitka spruce was also met (Fig. 5*b*). By comparison, however, the Preliminary Plan reserved 43.9% of existing old-growth Sitka spruce in Protection and Option Areas (Fig. 5*b*).

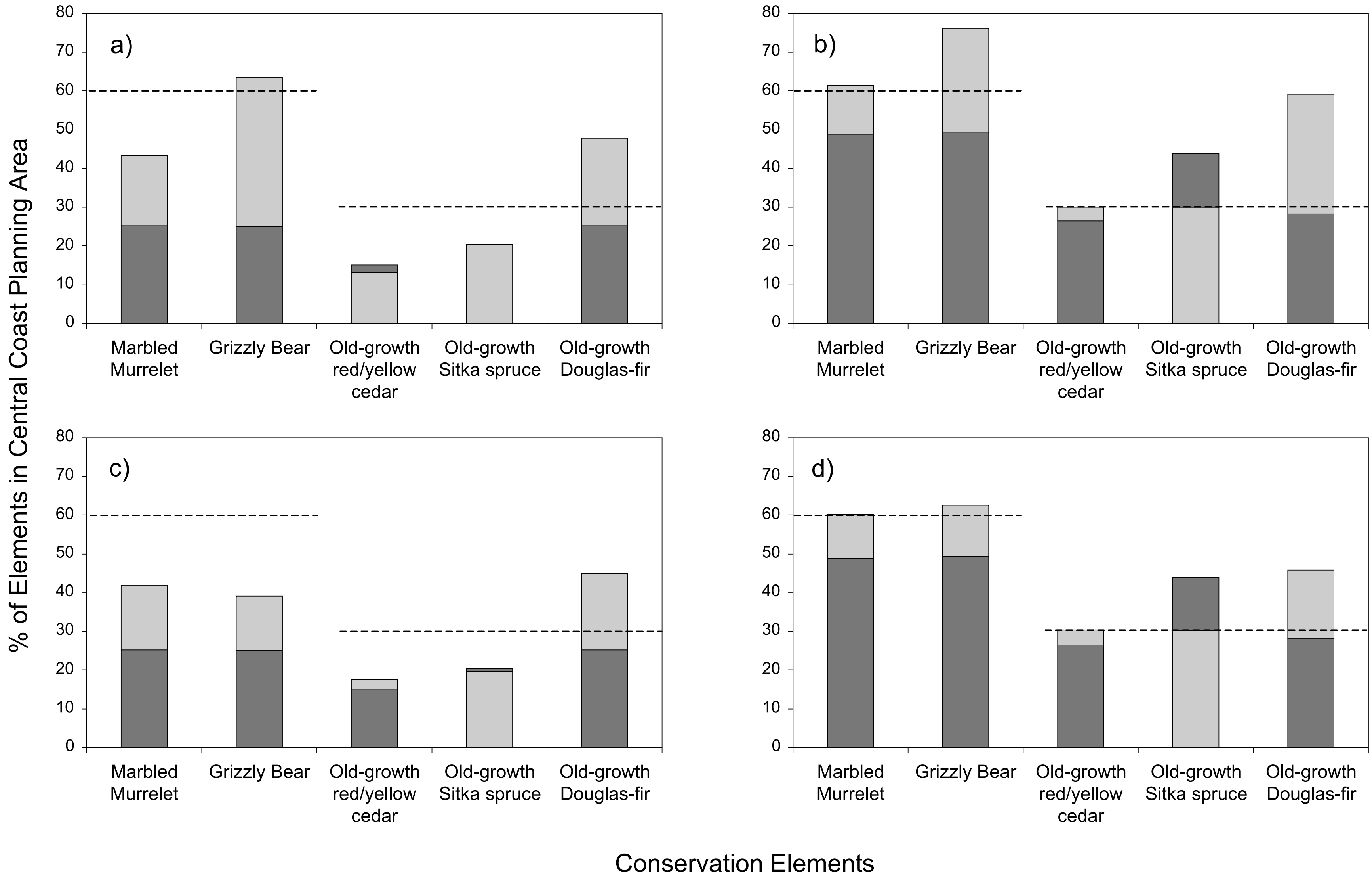
Timber volume scenarios

Constrained at 16.5% of the timber volume, SITES met representation goals for grizzly habitat and old-growth Douglas-fir but not for murrelet habitat or old-growth cedar and spruce (Fig. 5*c*). Constrained at 27.4% of the timber volume, SITES met or exceeded all five goals and protected more of each element under both volume constraints than the Preliminary Plan, except in the case of old-growth spruce. SITES solutions limited to 16.5% of timber volume captured 18% more mapped habitat for murrelets and 38.4% more for grizzly (Fig. 5*c*). SITES limited to 27.4% of timber volume also reserved 30.8% more old-growth Douglas-fir than in Protection and Option Areas of the Preliminary Plan (Fig. 5*d*). By contrast, a higher fraction of old-growth Sitka spruce was included in Protection Areas of the Preliminary Plan than in SITES solutions (Figs. 5*c* and 5*d*) because our representation goals for old-growth were set at 30%. SITES met all representation goals before reaching the 27.4% timber volume limit (Fig. 5*d*). However, in meeting these goals, SITES reserved a larger fraction of the plan area (33.8% versus 20.3% in Protection Areas and 37.6% versus 31.4% in the Protection plus Option Areas).

Discussion

Discrepancies between the Preliminary Plan and SITES solutions may have arisen because our interpretation of

Fig. 5. Percentage of wildlife habitat, old-growth stands, and ecosystem types reserved by SITES versus the Preliminary Plan under (*a*) 20.3% and (*b*) 31.4% area limits and (*c*) 16.5% and (*d*) 27.4% timber volume limits. Light grey bars indicate percentages reserved in the SITES scenarios. Dark grey bars indicate the percentages reserved in the (*a* and *c*) Protection Areas or the (*b* and *d*) Protection plus Option Areas of the Preliminary Plan. Broken lines indicate conservation targets.



stakeholder goals differed from their own because we did not translate all published goals into quantitative inputs or because additional goals were in play during the planning process but not subsequently recorded in documents available to us. Nevertheless, SITES generally preformed well, for example, by capturing 13%–38.4% more grizzly bear habitat than a plan drafted by environmental organizations or the Preliminary Plan (e.g., Figs. 2 and 5). This occurred as a consequence of setting as a goal to reserve 60% of moderately high-quality to high-quality wildlife habitat. In practice, habitat conservation goals will vary by species, based on their response to forest management and regional and global rarity, ability to persist in small populations, and popularity with the public.

Other differences between SITES solutions and the Preliminary Plan concern the reservation of old-growth stands by species. SITES solutions generally reserved more old-growth cedar and Douglas-fir than the Preliminary Plan but less old-growth Sitka spruce because we arbitrarily fixed at 30% our representation goals for these species. A strength of many computer-assisted planning tools is that planners can vary goals in response to model output and view the results of those changes in seconds to minutes. It is possible, therefore, that higher targets for Sitka spruce could have been met without compromising other values.

SITES also created reserves that were, in general, more dispersed and smaller (Fig. 3) than those of the Preliminary Plan (Fig. 1*b*). Large reserves may protect wide-ranging species more effectively than smaller, dispersed reserves, particularly if humans occupy intervening landscapes (e.g., Rivard et al. 2000; Brashares et al. 2001; Brashares 2003). By contrast, it is axiomatic that smaller, dispersed reserves facilitate representation goals, the persistence of geographically localized species, as well as connectivity for species able to make use of “stepping stone” reserves (Bunnell et al. 1999; Rutherford et al. 1999; Schwartz 1999). Overall, the emphasis on smaller, dispersed versus larger, concentrated reserves must rest on the biology of focal species, the state of intervening habitats, and the goals for conservation.

Currently, the location of the Kitlope Heritage Conservancy Protected Area and Tweedsmuir Provincial Park and Protected Area adds to an existing emphasis of the Preliminary Plan for large, more or less contiguous protected areas in the north of the central coast plan area (Fig. 1*a*). By contrast, there is little evidence of planning for connectivity north to south or east to west in the southern half of the plan area (Fig. 1*b*). East–west connectivity in the southern plan area could facilitate gene and species migration between interior and coastal British Columbia and annual movements to higher elevations. North–south links could facilitate the persistence of sedentary species under conditions of climate change as well as migrant species by providing stopover sites and travel corridors. Species are likely to respond to global climate change partly by shifting their ranges longitudinally and altitudinally (Skaggs and Boecklen 1996; Flagstad et al. 2001). Rutherford et al. (1999) recommended that reserve designs anticipate such changes by including stepping stones to facilitate movement. Cowling et al. (1999) recommended the geographic representation of genetic and ecosystem diversity for long-term persistence.

Some of the most deleterious effects of forest fragmentation (e.g., Robinson et al. 1995) have not been replicated in forested ecosystems of the Pacific Northwest (Tewksbury et al. 1998; Bunnell 1999*a*, 1999*b*). Thus, it may not always be appropriate to design reserves in western forests based on experience elsewhere in North America. Where specific proposals appear to fail in regard to connectivity, planners might consider examining the role of the nonharvested land base in maintaining landscape linkages. Landscape-level connectivity in the central coast will be influenced in future by the status of unmanaged forests in the nonharvested land base, which now account for about 74% of the forested area (Wells et al. 2003). Thus, even with moderate downward revisions to the nonharvested land base in future, broad-scale connectivity might be maintained as a natural consequence of terrain and the low density of human residents.

In regions of higher human influence, planners may opt to minimize the edge to area ratio of reserves in the design process (Andelman et al. 1999; Bunnell et al. 1999, 2002). Alternatively, ecosystem types or planning units could be defined at a broader scale of resolution, which would result in larger reserves but possibly at the expense of rare ecosystems. A further exploration of designs for the central coast subject to size, edge, and other spatial constraints could also be tried to assess trade-offs of spatial arrangement and ecosystem representation. Overall, however, we suggest that our current examples demonstrate the utility of computer algorithms as tools in the planning process. In particular, disparate views can be represented as target goals, digested as minimized solutions, and then altered in response to graphical analysis (Andelman et al. 1999).

In all cases, however, planners must recognize that theories of reserve design are largely untested (e.g., Arcese and Sinclair 1997; Schwartz 1999; Bunnell et al. 1999). In this regard, adaptive management and monitoring offer precautionary approaches to the conservation of biological diversity amid sustained development and human use (Walters 1987; Arcese and Sinclair 1997; Bunnell et al. 1999, 2002). Good management in the case of the central coast will depend on our rate of learning to maintain biodiversity in forested ecosystems over the long term. This rate will be maximized if we design areas with adaptive management and monitoring goals in mind and, in particular, aim to detect successes and failures over the intermediate term. Strategic approaches might be used in this case to increase the precision of landscape-level comparisons by placing constraints on the spatial arrangement of ecologically equivalent planning areas of managed and unmanaged forest. Adaptive management and monitoring methods have already been identified as key components of the species recovery plan for marbled murrelets in British Columbia (Arcese and Sutherland 2002; Burger 2002).

Despite the advantages to strategic reserve design (Pressey 1994; Cowling et al. 1999), ad hoc approaches remain widespread (Margules and Pressey 2000; Cabeza and Moilanen 2001). Prendergast et al. (1999) found that land managers were often unaware of computerized conservation planning tools or misunderstood their use. Misconceptions included that data of superior quality were required, that systematic methods were slower than equivalent ad hoc approaches, or that systematic methods were unable to accommodate "real world" problems. A substantial data dictionary facilitated planning in the central coast (Appendix A). However, the central coast planning process has been a lengthy one, spanning 6 years to date. Our current results were produced in about 2 months, and preparing SITES to run our example scenarios took about 2 weeks. Because the time-consuming aspect of spatial analysis usually occurs in the data collection phase, data were not the rate-determining factor in the central coast. Thus, given that sufficient data exist, strategic approaches are not likely to require more time than ad hoc approaches.

Although high-quality data are always preferred, and uncertainty exists about the precision of individual habitat maps used here (e.g., marbled murrelet; Burger 2002), computer algorithms helped us to extract the maximum amount from the data available (Pressey and Cowling 2001). Overall, we feel that strategic reserve design offers a repeatable way to increase the efficiency of complex area conservation, ecosystem representation, and economic planning exercises (Andelman et al. 1999; Cabeza and Moilanen 2001; Pressey and Cowling 2001). These approaches complement and facilitate expert input to develop quantitative targets and evaluate alternative designs.

Conclusions

SITES solutions generally reserved more wildlife habitat and more old-growth forest and achieved better representation of rare ecosystem types in the central coast than did the Preliminary Plan with similar constraints imposed. These solutions demonstrate that computer algorithms are available to identify potential reserves, examine competing alternatives, facilitate discussion, and generally serve as decision-support tools for stakeholders in the reserve design process. We assume that the example designs reviewed here can be improved on and do not represent final results. Our approach could be repeated by others and modified as new information is obtained. Simulations can be conducted rapidly to facilitate workshop formats or compiled to prioritize planning units for conservation (Andelman et al. 1999). We recommend that strategic approaches to reserve design be used to provide focus and as a catalyst for discussion at planning tables. These planning tools should encourage teams to review and modify proposed designs based on theory, natural history information, and local and traditional knowledge. Applying such tools in cases that involve complex sets of biological, social, economic, and political goals and constraints should make planning processes more explicit, repeatable, and defensible (Pressey and Cowling 2001).

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Appendix A

Table A1. Data available from the central coast data dictionary that we used in our analysis (http://srmwww.gov.bc.ca/vir/lrmp/index.htm#contents).

Map description
Central Coast Land and Coastal Resource Management Plan Boundary
Watershed Atlas Watershed Boundaries
Regional Forest Cover Mapping
Timber Harvesting Land Base (THLB)
Biogeoclimatic Ecosystem Classification (BEC)
Broad Ecosystem Inventory (BEI)
Ungulate Capability and Suitability (Roosevelt elk, black-tailed deer, moose, and mountain goat)
Marbled Murrelet Suitability
Black Bear Suitability
Grizzly Bear Capability
Preliminary Central Coast Land and Resource Management Plan