Species at Risk, Conservation Strategies, and Ecological Integrity

G. G. E. Scudder
Department of Zoology and Centre for Biodiversity Research, University of British Columbia
6270 University Boulevard, Vancouver, BC, V6T 1Z4, Canada
scudder@zoology.ubc.ca

ABSTRACT

Species at risk are relatively easy to identify. Saving them is another matter. There are few success stories. With increased human populations, and consequent demands for more space and more resources, there will be an ever increasing number of species at risk. Our current conservation strategies are largely ad hoc, unintegrated, and ineffective. They must be replaced with new strategies focused on saving species at risk in the context of functioning ecosystems, if there is to be any measure of success. We need to assess the effectiveness of current protected areas, and land use planning. Our conservation planning needs to be revised and revitalized. This could be done with some clearly stated objectives, using GIS-based heuristic algorithms. It could establish a minimum set of essential conservation areas, based upon the principles of irreplaceability and complementarity. It could document what we have so far achieved, and what needs to be done in the future. It is obvious that species at risk belong and function in ecosystems, and depend upon the continued existence of their essential habitats in these ecosystems. Just setting aside protected areas is not enough. They and the adjacent areas have to be managed, and managed in an ecosystem context, with the appropriate mix of coarse- and fine-filter habitat management initiatives. Ecosystems are not static. They continually undergo dynamic change, moving through states of exploitation, conservation, release, and reorganization. To save species at risk in these ecosystems, we must guarantee that these ecosystems retain integrity, that is, the ability to maintain function in both the short and long term, in the face of constantly changing conditions. We need to understand the natural disturbance regimes, and recognize the scope, scale, and temporal patterns of change. To save species at risk we must manage our protected and other areas within the framework of ecological integrity, and understand that this can only be accomplished in community and regionally acceptable models.

Key words: conservation strategies, ecological integrity.

SPECIES AT RISK

Species at risk are relatively easy to identify. Using a diverse set of criteria, more than 1,575 such species have been listed in British Columbia, although very few have legal protection.

Only 4 species, namely the burrowing owl, sea otter, American white pelican, and Vancouver Island marmot, are legally designated under the British Columbia Wildlife Act (SOE 1998). The peregrine falcon and the bald eagle are listed in Appendix I under CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora; Environment Canada 1997), and several species, including the white sturgeon, sandhill crane, black bear, and grizzly bear are listed in Appendix II. The British Columbia Fish Protection Act, passed in 1997, provides legal protection for some aquatics, but so far no list has been promulgated.

Three extinct (Dawson's caribou or the Queen Charlotte Island population of the woodland caribou, and 2 Hadley Lake sticklebacks), 3 extirpated (sage grouse, pygmy short-horned lizard, and island marble butterfly), 21 endangered, 24 threatened, and 43 vulnerable species are listed for British Columbia by the Committee on the Status of Endangered Wildlife in Canada[1] (COSEWIC; World Wildlife Fund Canada 1998). There are 74 vertebrate taxa on the provincial Red List (candidates for legal designation as endangered or threatened), and 78 vertebrate taxa on the Blue List (species considered vulnerable or sensitive; Cannings 1998). In addition there are 234 Red-listed and 356 Blue-listed vascular plants (S. Cannings, British Columbia Conservation Data Centre, pers. comm.), and more than 800 invertebrates potentially rare and endangered (Scudder 1994, 1996*a*), with some already included on the Red and Blue lists.

The COSEWIC-listed species for the most part do not have any legal status, as Canada has yet to pass endangered species legislation. Similarly, the provincial Red- and Blue-listed species have no legal status, although a few species are

[1] Numbers updated since paper delivered.

included in the Identified Wildlife Management Strategy (IWMS), Volume 1.

The British Columbia government has stated emphatically that it will not pass any separate endangered species legislation. The Minister of Environment, Lands and Parks has declared that the current legislation, particularly the Ecological Reserve Act, the Park Act, the Wildlife Act, the Forest Act, the Forest Practices Code, the Environment and Land Use Act, the Land Act, and, more recently, the Fish Protection Act and the Identified Wildlife Management Strategy, will protect species at risk.

Unfortunately, this is not the case. For example, the IWMS has serious shortcomings, clearly identified by the British Columbia Endangered Species Coalition (1998). It lacks real habitat protection, and even first-year biology students know that you can't save species without saving habitat. The British Columbia government has directed that impacts resulting from the application of the IWMS (for both Volume 1 and Volume 2 species) cannot exceed a maximum of 1% impact on the 1995 annual allowable cut. Only 34 CEO-approved wildlife species and 4 plant communities are included in Volume 1. Yet there are more than 1,575 species at risk in British Columbia. At this time only interim measures can be applied for the marbled murrelet, an old-growth specialist requiring specific habitat types within the Coastal Western Hemlock ecosystem. Such specialized landscape units may not be easily saved in future, because in current Landscape Unit Objectives representativeness at a scale finer than the Biogeoclimatic Ecosystem Classification variant (Meidinger and Pojar 1991) will not be adopted, in spite of the recommendations in the Forest Practices Code Biodiversity Guidebook.

Most of the species at risk in the province occur in the Southern Interior and Georgia Depression ecoprovinces, in ecosystems already listed as endangered. In both of these ecoprovinces there has been a dramatic loss of habitat because of urban and agricultural development, and most of the remaining nonforested land is in private ownership. Under these circumstances, the Forest Practices Code, the Identified Wildlife Management Strategy, and the other government acts provide little protection.

British Columbia has signed the National Accord for the Protection of Species at Risk. The auditor general has documented that the federal government has done little concrete in the area of environmental protection and protection of species at risk. Bill C-65 "An Act respecting the protection of wildlife species in Canada from extirpation or extinction," which received first reading on 31 October 1996, had serious deficiencies that were well documented by the Sierra Legal Defense Fund, the Canadian Endangered Species Coalition, and more than 300 scientists who wrote twice to the prime minister and the federal minister of the environment. The listing process was unacceptable, there was no real habitat protection, and there were problems with transboundary species. Hundreds of scientists across the country continue to stress these deficiencies. Fortunately, Bill C-65 died on the order paper in the House of Commons after the 1997 election was called. There is serious concern that the new endangered species act now being drafted by the government of Canada will be even weaker than Bill C-65.

Meanwhile, Bill C-441, with the same title as Bill C-65, has been introduced as a private member bill by Charles Caccia, Liberal MP for Davenport, and chair of the Standing Committee on Environment and Sustainable Development, to fill the void. It received first reading on 8 October 1998, and is a model bill that has received high praise, namely an "A" grade from the major environmental groups. Because habitat loss is the primary threat to over 80% of Canada's species at risk, habitat protection is the key to saving species. Bill C-441 recognizes this and would protect the habitat of all endangered species on all lands. If the new federal government bill being drafted mimics Bill C-441 we could be well on the way to saving our species at risk. This seems highly unlikely, and so harmonization across the country would do little for species at risk.

CONSERVATION STRATEGIES

In British Columbia, only 1 species, namely the Vancouver Island marmot, has land set aside under the provincial Wildlife Act to specifically protect a species at risk. For the most part, the province's commitment to saving species at risk and conserving biodiversity depends on a planning framework that accommodates 2 complementary components: a network of protected areas, and the application of integrated resource management principles outside these protected areas (B.C. Ministry of Environment, Lands and Parks and Ministry of Forests 1992).

The Protected Areas Strategy (PAS) will protect 12% of the province as a whole by the year 2000 (British Columbia 1993*a*). To this end, the government has moved from having 6.3% (5.95 million ha) of the land base dedicated to protected areas in 1990, to approximately 10.6% (10.06 million ha) by 1998 (SOE 1998). There seems little doubt that British Columbia will achieve the 12% goal by the year 2000, but there will be over-representation of higher-elevation ecosystems, and under-representation of lower-elevation and valley-bottom ecosystems, especially in the southern Interior (Pojar 1996).

In British Columbia, protected areas include national parks, ecological reserves, class A and C parks, recreational areas, and other areas that fall under the Environment and Land Use Act (SOE 1998). They do not include wildlife reserves, migratory bird sanctuaries, and regional parks (SOE 1998), although these have some conservation value. In the 1930s and 1940s parks were set aside primarily to encourage tourism, but by the 1970s and 1980s park creation began to focus on protection of unique natural environments (SOE 1998). In the 1990s, representation of British Columbia's biological and cultural diversity, recreational resources, and habitat protection became the primary objectives (SOE 1998).

The first goal of the PAS is to protect viable representatives of natural diversity (British Columbia 1993*a*). For the purpose of the PAS, the measurement of diversity is limited to an assessment of an area's richness, and this is richness as it is applied to natural, cultural heritage, and recreational values. In other words, diversity in this context is not the same as biological diversity (Scudder 1996*b*).

The second goal of the PAS is to protect, among other things, rare and endangered species and biologically exceptional sites—the latter being defined as to include the sites of high species richness, sites with endemic species, and sites of species at the extremes of their range (British Columbia 1993*a*).

The map of our protected areas in the province shows a scattered pattern of distribution involving both small and some significant large areas. It might appear that these areas are well situated to protect our species at risk. Detailed analysis shows that this is not the case. The recent mapping by the British Columbia Endangered Species Coalition shows that it is not so on a large scale and not even at a fine scale. In this mapping, based upon data from the British Columbia Conservation Data Centre, the wide-ranging large carnivores and ungulates are excluded and multiple hits at a site are obscured.

The fact that our protected areas seem not well placed for protecting our species at risk is not surprising given the differing strategies used over the years to select these parks and other areas now classified protected areas. It is clear that the protected areas are insufficient to save our species at risk.

A major problem exists in our current conservation strategies, in that these have generally lumped together strategies for conserving rarity and strategies for conserving richness within the 12% objective. These efforts are based on inadequate data, often with misplaced emphasis on vertebrates.

The Gap Analysis Workbook (British Columbia 1993*b*) notes that limited knowledge is available about most species, and that there are limited resources available to obtain the information required. However, it is important to acknowledge that over the past few years, through various Forest Renewal British Columbia (FRBC) programs, there have been some admirable new initiatives in this area; some with very significant results. Unfortunately, we must also note that FRBC has announced that it will no longer fund research on sensitive wildlife species (Pynn 1999).

Species richness measures generally focus on better-known taxa, particularly vertebrates and vascular plants (Reid et al. 1993). On the assumption that vertebrates provide an adequate umbrella for invertebrates at most levels (Murphy and Wilcox 1986), it is often postulated that vertebrate species-richness can be used as an indicator of overall natural diversity that integrates a host of community-related parameters (Scott et al. 1987). It is also assumed that areas with high species-richness in vertebrates and vascular plants tend to have high species-richness in other groups (Reid et al. 1993). This is despite knowledge that shows that, whereas many vertebrates are wide-ranging generalists, many invertebrates are characterized by restricted distributions, movements, and associations with unique habitats (Hafernik 1992).

A study of the occurrence of high species-rich areas in Britain shows that the species-rich areas of different biota do not coincide (Prendergast et al. 1993). Using distributional data sets produced from the fine scale and high intensity of recording in Britain, these authors defined species-rich "hot spots" as the top 5% of record-containing 10-km squares (ranked by number of species per 10-km square), and showed that there was little coincidence of different taxa richness "hot spots." They showed that the maximal overlap (34%) was between butterflies and dragonflies, and that there was only 12% overlap between 2 of the "flagship" conservation taxa, namely birds and butterflies. In a similar study in Uganda, Howard et al. (1998) also found little congruence in the species richness of woody plants, large moths, butterflies, birds, and small mammals.

As I noted in *The Wilderness Vision for British Columbia* (Scudder 1996*b*), to date we have not started to address this problem in British Columbia, although we could do this given clear objectives, cooperation between agencies, and sufficient funding. Good distributional data are available for most of the vertebrate groups and probably for many of the plant taxa, and recently we have developed a geo-referenced database for the distribution of our dragonflies, butterflies, and true bugs. Until the richness "hot spots" are scientifically determined for the different biotic taxa, it will not be possible to clearly define the conservation objectives, nor work out the appropriate conservation strategies for species richness.

It is important to determine if the richness "hot spots" in British Columbia coincide with the species at risk "hot spots." Although there appears to be some coincidence, as judged from our recent biodiversity assessment in the Montane Cordillera ecozone (Scudder and Smith 1999), it would be surprising if there is a good overlap across the whole province. There are now a number of studies that show that richness "hot spots" do not usually coincide with rarity "hot spots." Prendergast et al. (1993) have shown that this is the case in Britain, and Curnutt et al. (1994) have also documented this in Australian birds.

Prendergast et al. (1993) defined rare species as those that occurred in less than 16 of the 2,761 10-km squares in their British database, and found that there was a lack of coincidence. About half (43%) of the rare bird species were not found in bird "hot spots." Similarly, Curnutt et al.

(1994) found that rarity and richness "hot spots" did not coincide, but found that rare species contribute more to bird richness "hot spots" in Australia than they do in Britain. They point out that targeting areas of high diversity may be the best way to protect rare species only if very large areas are available for conservation, a view endorsed by Reid (1998). Unfortunately, this strategy is unlikely to help in British Columbia because in the relevant ecosystems in the Southern Interior and Georgia Depression ecoprovinces, there are no large areas left for conservation purposes.

Curnutt et al.'s (1994) study did not consider the problem that exists over the lack of coincidence of rarity "hot spots" in the different taxa. This problem has been well documented by Dobson et al. (1997) in their study of the distribution of endangered species in the United States. They showed the rarity "hot spots" for different groups rarely overlap. This is also likely to be the case in British Columbia, except perhaps in the Queen Charlotte Islands, the South Okanagan, the Georgia Depression, and the Peace River Basin.

So, what do we do? The PAS provides no acceptable conservation strategies for this situation. The conflict over conservation of rarity versus richness "hot spots" must be resolved. In my opinion, our present strategies are largely ad hoc, unintegrated, and ineffective across the province, driven more by politics than science. Instead, we need to adopt efficient, proven methods for choosing priority areas for conservation—methods that can consider both species at risk and biodiversity-rich areas.

Setting priorities for conservation is unavoidable. Competition for land limits the areas available, so conservation goals have to be established and obtainable within these limits (Pressey 1994, Pressey and Tulley 1994).

Our conservation strategies need to be revised and revitalized. We must first establish our conservation objectives, which will obviously include saving our species at risk. However, we also want to save other species and develop a functional conservation network. Further, since some habitats have already been set aside in protected areas, these should be incorporated into the network, where possible, and added to in the most effective way (Nicholls and Margules 1993). Finally, it is essential to ascertain the minimal area needed to achieve these objectives, while at the same time be able to test alternatives and adjust to changing priorities (Pressey et al. 1994). This is a tall order, but all of this could be done if a new approach to selecting conservation areas were adopted using some key principles for systematic conservation area selection.

The 3 principles relevant to this strategy are irreplaceability, complementarity, and flexibility (Pressey et al. 1993). Use of such principles distinguishes between irreplaceable and flexible areas, and results in very different conservation priority areas (Williams et al. 1996). GIS-based heuristic algorithm methodology has the ability to incorporate the views of community groups and government agencies, and to identify negotiable and nonnegotiable options (Pressey et al. 1995). Although it may not guarantee an optimal solution (Pressey et al. 1996), it provides conservation biologists with a definable, scientifically based conservation strategy.

Complementarity solutions have been developed for American endangered species (Dobson et al. 1997), and show that the amount of land needed to cover the endangered and threatened species in the United States may be a relatively small proportion of the land mass. Ongoing research is already showing that a similar situation prevails applying irreplaceability and complementarity solutions for COSEWIC-listed species in Canada (Freemark et al. 2000).

A similar analysis needs to be done for the Red-listed and Blue-listed species in British Columbia as a whole. Warman (2000) is already doing such an irreplaceability/complementarity analysis for the species at risk in the South Okanagan, and Forsyth and Sinclair (2000) are conducting irreplaceability research on the British Columbia lake fish fauna.

The data are available to do such analyses for the terrestrial biota for the whole province. The methodology is here. The expertise is here. Students at the University of British Columbia are now working closely with the Australian software developers, who have demonstrated many varied applications of this program. We have the will, but we don't have the funding in spite of our continued attempts to obtain it.

However, simply determining such a minimal set of priority areas, and seeing what extra lands need to be identified for conservation is not enough. The irreplaceability/complementarity methodology will not fully be able to select the best areas for conservation until the results are integrated with some of the important factors affecting viability, threat, cost, and management options (Williams et al. 1996).

Without an appropriate landscape context to allow metapopulation dynamics, species at risk will not be saved. A province-wide, integrated conservation network with core areas is needed, at least on an ecoregion scale (Noss 1992). Some attempt at this has been made in provincial land use planning, but only on a local scale (e.g., Vancouver Island, Cariboo–Chilcotin). These did not solve major conservation concerns; for example, the Garry oak ecosystem on Vancouver Island was excluded because little is on Crown lands. Currently Land and Resource Management Plan (LRMP) decisions are not well integrated and certainly do not have conservation strategies as the main objective.

The proposed state-wide network for Florida (Noss 1985, 1987, 1992) indicates the scale and scope of such planning needs. It also demonstrates what likely needs to be done to save large carnivores at risk, a fact reiterated in carnivore conservation studies in the Great Lakes region (Mladenoff et al. 1997) and the Rocky Mountains (Noss et al. 1996). Large carnivores can serve as useful umbrella species, because their conservation requirements are likely to encompass those of many other components of communities owing to their large space requirements (Schonewald-Cox and Buechner 1991), but they cannot be the sole focus (Noss 1992). For example, Flather et al. (1998) point out that grizzly bear range fails to overlap with the major species endangerment regions in the United States. From a simple inspection of the current distribution of the grizzly bear in British Columbia and examination of the British Columbia Grizzly Bear Conservation Strategy (B.C. MELP 1995) it is obvious that this species cannot serve as an umbrella species for the South Okanagan and Lower Similkameen. For example, the Mormon metalmark butterfly is confined to a few locations in the bottom of the Similkameen Valley near Keremeos (Scudder 1994, 1996*a*, Guppy et al. 1995), and is dependent on buckwheat for larvae feeding, in association with flowering rabbit-brush for adult nectar feeding—a life cycle very different from that of the grizzly bear.

For every species at risk, at least a minimal viable population and the metapopulation must be maintained, although these are not always easy to calculate and determine (Thomas 1990). A population vulnerability analysis (PVA) must be undertaken involving assessments of the population biology, namely the population phenotype, environment, and population structure and fitness (Gilpin and Soulé 1986). Although these analyses need to be done with caution (Beissinger and Westphal 1998), we should have a PVA for all of our species at risk.

If these assessments are not done correctly and do not incorporate what Hendrick et al. (1996) call an inclusive population viability analysis, basic conservation biology principles dictate that species at risk are liable to be caught in what Gilpin and Soulé (1986) describe as the demographic, the fragmentation, the inbreeding, or the adaptation vortices. Any 1 of these vortices can lead to species extinction or extirpation.

Species differ in their vulnerability to the 4 vortices (Gilpin and Soulé 1986), although some predictions can be made. For example, *r*-selected species, notably insects, fish, and rodents (especially those with good long-range dispersal), are unlikely to suffer from the inbreeding or adaptation vortices. Usually their total population sizes and rates of gene flow are enough to avoid the loss of genetic variation. However, even butterflies can be victims of the inbreeding vortex (Saccheri et al. 1998), and local populations of insects can get caught in the demographic vortex as shown by Ehrlich (1983) in his research on Edith's checkerspot butterflies. Usually in wild populations, demographic factors are of more importance than genetic factors in species at risk (Lande 1988).

Large vertebrates can persist at low population levels for some time because of longevity and because they are buffered from short-term environmental changes, but have a high probability of entering the inbreeding vortex (Gilpin and Soulé 1986). Territorial species are a special concern (Lande 1987). No single conservation strategy fits all.

Our overall conservation strategy should be to establish areas large enough to contain all of the species at risk, then maintain and manage them to assure their persistence (Harris 1993). However, small reserves continue to fill a worthy niche in conservation strategies (Shafer 1995).

ECOSYSTEM INTEGRITY

Just setting aside protected areas is not enough even if they are large. Newmark (1995) has analyzed large mammal extinctions in western North American parks and shows that extinctions in protected areas are a fact of life, and extinction rates are higher in smaller reserves. Many of British Columbia's protected areas do not have buffer zones, and few are large enough to accommodate the species at risk they profess to conserve. Even surrounding protected areas by buffer zones and special management zones may not suffice, especially if the ecosystem containing them lacks integrity.

Habitats, protected areas, buffer zones, and special management zones are contained within ecosystems, and to save them in the long term we must save these ecosystems. This is now the rationale behind the ecosystem RENEW strategy in the South Okanagan, the continuation of the earlier biodiversity inventory (Harper et al. 1993) and South Okanagan Conservation Strategy (Hlady 1993).

Saving ecosystems means that ecosystems must retain their integrity (Angermeier and Karr 1994), that is, their composition and function. Ecosystems are complex and their precise spatial and temporal boundaries are often difficult to define. As complex systems, ecosystems have a number of important properties (Kay 1991, 1993). These properties include:

1. non-linear: the system behaves as a whole; it cannot be decomposed into pieces and then reconstructed by adding the pieces together;
2. multi-scaled: cannot be understood by focusing on 1 scale alone;
3. window of vitality: must have enough complexity, but not too much; complex systems strive to stay within a "window" of vitality;
4. multiple steady states: they have no preferred unique steady state;
5. dynamically stable: equilibrium points for the ecosystem may not exist;
6. catastrophic behaviour: can have sudden, dramatic changes; flip-flops;
7. informational libraries: contain genes.

Ecosystems are thermodynamically open systems, which are never in complete equilibrium. They are open because they take in energy from the sun.

Ecosystems are also self-organizing and, as such, characteristically may undergo abrupt changes when a new set of interactions and activities emerge among components and in the whole system. The form that this self-organization takes is not predictable in advance. This is because the very process of self-organization is sudden and one can get "flips" into a new regime. One of the characteristics of sudden change is that ecosystems may have several possible behavioural pathways available to each "flip." Thus, in a specific geographical location there is the potential for a number of different ecosystems, communities, and species to exist in addition to the present one. For example, much of our forested land here in British Columbia (given sufficiently heavy-handed use) could be ericaceous heath (Kimmins 1996*a*). Which pathway is followed is often, but not always, an accident of circumstances.

Once formed, an ecosystem has a certain amount of integrity. That is, it is able to successfully survive in spite of various perturbations. In other words, it has a certain self-organizing or self-stabilizing ability. However, there are limits to this ability, and at any time it could move beyond its normal stable state (Graham and Grimm 1990, Kimmins 1996*b*).

Ecosystems are not in a permanent stable state. They are continually undergoing a birth, growth, maturity, and death process. Holling (1986) refers to this as the exploitation, conservation, release, and reorganization cycle, depicted as a figure-8 (Fig. 1). Essential components of this cycle are natural disturbance events like individual tree-fall in tropical rain forests (Hubbell et al. 1999), windthrow in humid coastal forests in British Columbia, and fire and insect pest outbreaks in the interior and boreal forest (Kimmins 1996*a*).

Disturbance is a vital process in ecosystems, affecting biological diversity and ecological function (Loucks 1970, Pickett et al. 1989, Attiwill 1994*a,b*). As humans alter natural disturbance regimes, disturbance-driven ecosystems and disturbance-dependent ecosystem conditions will change (Kimmins 1996*a*).

On the local scale, movement through the "figure-8" ecosystem cyclic process is not continuous (Holling 1986). There can be temporary stationary phases. Each of these temporary stationary phases is very sensitive to certain sets of conditions. Unfortunately, it is not possible to predict what these conditions might be.

We know that in the conservation or mature state (what used to be called the climax state), most of the nutrients and energy are locked up in the biomass, and the system gradually becomes "brittle." Key structural parts become risk-prone, waiting for an "accident" to happen (Holling 1986).

All of these "accidents" can lead to the relatively fast, downward process of release; a process that usually occurs in patches, providing the ecosystem or community is large enough to accommodate patchiness. Ecological integrity requires patchiness. For functional patchiness to occur, large areas are often needed. There are very few calculations on how large an area has to be in order to maintain ecological function and integrity over the long term. Shugart and West (1981), working on long-term dynamics of forested ecosystems, estimated that the landscape must be some 50–100 times larger than the average natural disturbance patches in order to maintain a relatively steady-state ecosystem. Recently, He and Mladenoff (1999) have carried out a spatially explicit and stochastic simulation of forest landscape fire disturbance and succession in a heterogeneous landscape in northern Wisconsin, and have demonstrated the complex interactions that can occur over a range of temporal and spatial scales.

There are no estimates of how much of an ecosystem is needed to retain its integrity and sustainability. It seems likely that this cannot be done with less than 50% of an ecosystem, especially when natural disturbance regimes no longer prevail. Human-dominated ecosystems are the norm in the world today (Noble and Dirzo 1997, Vitousek et al. 1997), with fire suppression, livestock grazing, unnatural fragmentation, alien species introduction, and other unnatural disturbances a consequence. It is recommended that to maintain biodiversity, forest practices should mimic natural disturbance patterns (Bunnell 1995). These differ across forest types, and although the British Columbia Forest Practices Code specifications now try to mimic natural disturbance regimes, they do so without them being fully known. Andison

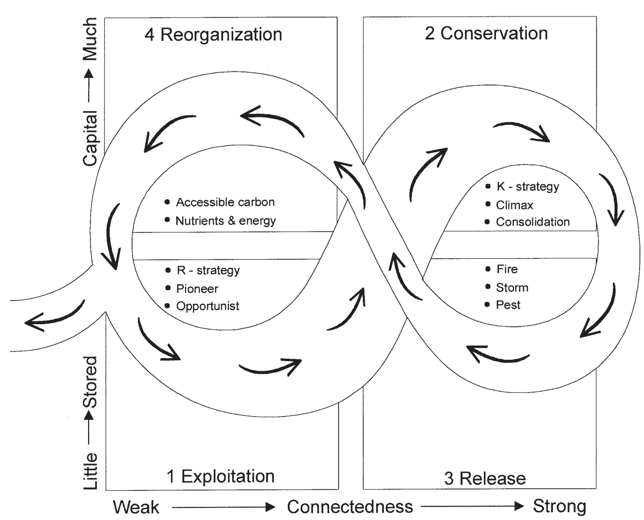

Figure 1. The "figure-8" model of an ecosystem (redrawn after Holling 1986). The arrows show the speed of the flow of events in the ecosystem cycle, where arrows close to each other indicate fast change and arrows far from each other indicate slow change. The exit for the cycle at the left of the figure indicates the stage where a flip into a greatly modified ecosystem is most likely.

(1996) has documented the consequences of applying the new code in the Prince George area; it will not result in a natural disturbance landscape.

If a mistake is made, an ecosystem could well flip into another stable state, a state very different to that now needed to maintain our species at risk. Mankind has caused such flips elsewhere in the world in the past, so this isn't science fiction. Flips can be seen to have taken place in the Mediterranean (Thirgood 1981), the New Guinea highlands and the Scottish moors, and are likely in the Amazon (Shukla et al. 1990), with loss of biodiversity as a consequence. A recent food-chain flip encompassing species that are listed as at risk, involves killer whale predation on sea otters (Estes et al. 1998), although the causes may be complicated (Kaiser 1998), and not just the anthrogenic changes in the offshore oceanic ecosystem as suggested by Estes et al. (1998).

To save our species at risk, ecosystems must be saved and allowed to function as a whole in a natural manner, that is, retain integrity. At present our planning is not on this scale. These ecosystems are already being impacted by new stressors that cannot be controlled. These include rising greenhouse gas concentrations and disruption of the natural ozone regime (Fergusson and Wardle 1998), with every indication that these perturbations will intensify over the next few decades (Schindell et al. 1998).

Since there is a dramatic CO_2 increase in the atmosphere (Schindell et al. 1998), and the Vostok ice cores from the Antarctic show a close correlation between CO_2 and temperature (Raynaud et al. 1993), most atmospheric scientists now accept that increased greenhouse gases will lead to global warming (Harrington 1987, Houghton and Woodwell 1989, Schneider 1989, McBean and McEwan 1990). Although there are some differences between the various General Circulation Models, they all reveal that there will be an increase in global temperature, due to CO_2 doubling, of 3.5–5.2°C, and that the increase in the earth's surface temperature will be greatest in the higher latitudes (Wetherald 1991). Accumulated temperature changes in Canada from 1993 to 1997, relative to 1951–1980 averages, show a definite increase in the western Arctic (Fergusson and Wardle 1998).

British Columbia can expect the average temperature to be 2–4°C higher in June to August and 4–6°C higher in December to February (Hengeveld 1989, Canadian Climate Program Board 1991). A 3°C-warming would present our ecosystems with a warmer world than has been experienced in the past 100,000 years (Schneider and Louder 1984), while a 4°C-rise would make the earth the warmest since the Eocene, some 40 million years ago (Barron 1985, Webb 1992).

If the present rate of CO_2 accumulation continues, and this seems likely according to the Goddard Institute (GISS) model (Schindell et al. 1998), doubling of CO_2 appears possible as early as 2030 AD, and highly probable by 2050 AD (Bolin et al. 1986, Schindell et al. 1998). That means it may be only 31 years from now!

Such a warming trend would not only be large compared to natural fluctuations in the recent past, it could also be 10–100 times faster than long-term natural average rates of change (Schneider et al. 1992). Such a rate of change may exceed the ability of most species to adapt (Peters 1991), and will have repercussions throughout all of our ecosystems (Melillo 1999). There will be changes in the grasslands and the forests (Pitelka et al. 1997, Alward et al. 1999).

This climate warming will have a very large impact on our biodiversity and species at risk, because it is sure to change both ecosystem structure and function (Peters 1991). There will be species movement and ecosystem community disruption at least comparable to what has happened in the past (Webb 1981, Wolfe 1985, Delcourt and Delcourt 1987, FAUNMAP Working Group 1996, Bennett 1998, Cain et al. 1998): ecosystems as a whole do not move. Species will respond to climate change individually, and with a 3°C-increase we can expect a 250-km latitude change and/or a 500-m altitude change in their range as a minimum (McArthur 1972, Dorf 1976, Furley et al. 1983). Such range movements are already suspected in insects (Parmesan 1996).

This has serious implications for our conservation planning because our species at risk may no longer remain in reserves and other areas set aside for them (Peters and Darling 1985). To save our species at risk in this context, there must be appropriate landscape continuity and corridors, or we may have to move our protected areas. All species at risk, with their very different means and modes of dispersal (Hansson et al. 1992) must be accommodated.

This is conservation planning on a scale not contemplated now, a scale that crosses administrative boundaries, as well as political and international borders. It is a scale already adopted in attempts to save the grizzly bear in the Yellowstone to Yukon conservation initiative (Locke 1998), and calls for international cooperation and legal agreements (Keiter and Locke 1996).

The present LRMP process, while locally relevant for the short term, is on a wrong scale for these long-term considerations. If today's problems in obtaining agreement at the various LRMP tables are a guide, imagine the task now at hand. Politicians will hate it, local communities will not understand it, and big business will be sure to oppose it. Yet, it is essential if species at risk are to be saved within the usually accepted 100- to 500-year conservation horizon, a horizon that deals with our grandchildren and our grandchildren's grandchildren.

Politicians must scrap the self-imposed 12% protected areas maximum, which has no scientific validity. Industry's short-term demands should no longer be acceptable. Large-scale landscape conservation planning in an ecosystem context must be adopted, wherein at least 50% of the area of each of

Table 1. Ecosystem Services[a] (after Costanza et al. 1997).

Gas regulation	Pollination
Climate regulation	Biological control
Disturbance regulation	Refugia
Water regulation	Food production
Water supply	Raw materials
Erosion control and sediment retention	Genetic resources
Soil formation	Recreation
Nutrient cycling	Cultural
Waste treatment	

[a] Includes ecosystem "goods" along with ecosystem services.

our land-based ecosystems is managed for maintenance of their ecosystem integrity. Yet economic viability must be sustained and the ever-increasing population accommodated.

Can it be done? I don't know, but conservation biologists must try. The fact that we are here, talking about species at risk, means that we have not made much progress. At this time we can't even get endangered species legislation established, and that is the easy part.

I don't think these conservation objectives can be achieved by relying on appeals to save species at risk or biodiversity in general. These issues do not sell to anyone except the converted.

I have stressed the ecosystem integrity context and believe this is a much more saleable point if we stress ecosystem services (Table 1). These ecosystem services are invaluable (Daily 1997) and readily appreciated. Mention clean air and clean water, and everyone is interested, since their survival depends on them.

We will not achieve the conservation objectives by giving scientific lectures to the converted. It is the general public that needs to understand the conservation concerns and objectives. Biologists must go to all sectors of society (Powledge 1998), explain the options, and then work to facilitate locally acceptable solutions within well-defined conservation objectives. Objectives that are scientifically sound, long term, ecosystem based, and well integrated. We must work with the aid of GIS-based land use planning tools that have the capacity to provide both flexibility and continuous reassessment. The public must be drawn into our planning process.

The South Okanagan, with so many species at risk, is an ideal place to try these new conservation strategies. A group put together by K. Freemark from the Canadian Wildlife Service in Ottawa along with D. Olson of Olson + Olson Planning and Design Consultants, a Calgary environmental planning and landscape architecture firm, has now embarked on an "Integrated Landscape Planning and Assessment" study in this highly impacted area.

Relatively speaking, the scientific part of this program is easy or, at least, the area with which most of us are already involved and comfortable. Government and industry buy-in is a must. Public involvement is essential. Education is imperative. Such a multifaceted effort in the South Okanagan is underway. It is a beginning.

In order to succeed, we must get all members of society to respect nature—respect and value the benefits that the natural world provides us. Only then will we save species at risk.

ACKNOWLEDGEMENTS

Research for this paper was supported by grants from the Natural Sciences and Engineering Research Council of Canada. W. Klenner and J. Pojar provided useful comments on the paper, but are in no way responsible for any of the statements contained therein. I thank my daughter, N. Scudder, for typing the early draft of the manuscript and for improving the text. L. Lucas kindly did the final processing and preparation of Table 1 and Figure 1.

LITERATURE CITED

Alward, R. D., J. K. Detling, and D. G. Milchunas. 1999. Grassland vegetation changes and nocturnal global warming. Science 283:229–231.

Andison, D. W. 1996. Managing for landscape patterns in the sub-boreal forests of British Columbia. Ph.D. thesis, Univ. British Columbia, Vancouver, BC. 197pp.

Angermeier, P. L., and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives. BioSci. 44:690–697.

Attiwill, P. M. 1994*a*. The disturbance of forest ecosystems; the ecological basis for conservation management. For. Ecol. and Manage. 63:247–300.

_____. 1994*b*. Ecological disturbance and the conservative management of eucalyptus forests in Australia. For. Ecol. and Manage. 63:303–348.

Barron, E. J. 1985. Explanations of the Tertiary global cooling trend. Palaeogeogr., Palaeoclimatol. and Palaeoecol. 50:17–40.

Beissinger, S. R., and M. I. Westphal. 1998. On the use of demographic models of population viability in endangered species management. J. Wildl. Manage. 62:821–841.

Bennett, K. D. 1998. The power of movement in plants. Trends in Ecol. and Evol. 13:339–340.

Bolin, B., B. R. Doos, J. Jaeger, and R. A. Warrick, eds. 1986. Greenhouse effect, climate change and ecosystems. SCOPE 29. Wiley and Sons, Chichester, U.K..

British Columbia. 1993*a*. A protected areas strategy for British Columbia. Province of B.C., Victoria, BC.

_____. 1993*b*. A protected areas strategy for British Columbia: gap analysis workbook for Regional Protected Areas Teams, working draft, June 1993. Province of B.C., Victoria, BC.

British Columbia Endangered Species Coalition. 1998. Comments on Identified Wildlife Management Strategy

(Volume 1): species at risk and the Forest Practices Code. B.C. Endangered Species Coalition. Vancouver, BC. 41pp.

British Columbia Ministry of Environment, Lands and Parks. 1995. Grizzly bear conservation in British Columbia: a background report. B.C. Minist. Environ., Lands and Parks, Wildl. Branch, Victoria, BC.

_____, and Ministry of Forests. 1992. Biodiversity in British Columbia. B.C. Minist. Environ., Lands and Parks and B.C. Minist. For., Victoria, BC.

Bunnell, F. L. 1995. Forest-dwelling vertebrate faunas and natural fire regimes in British Columbia: patterns and implications for conservation. Conserv. Biol. 9:636–644.

Cain, M. L., H. Damman, and A. Muir. 1998. Seed dispersal and the Holocene migration of woodland herbs. Ecol. Monogr. 68:325–347.

Canadian Climate Program Board. 1991. Climate change and Canadian impacts: the scientific perspective. Environ. Can., Climate Change Digest 91-01. 30pp.

Cannings, S. 1998. 1998 Red and Blue lists for BC. B.C. Nat. 36(4):15–16.

Costanza, R., R. D'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253–260.

Curnutt, J., J. Lockwood, H.-K. Luh, L. Nott, and G. Russell. 1994. Hotspots and species diversity. Nature 367:326–327.

Daily, G. C., ed. 1997. Nature's services: societal dependence on natural ecosystems. Island Press, Washington, DC and Covelo, CA.

Delcourt, P. A. and H. R. Delcourt. 1987. Long-term forest dynamics of the temperate zone: a case study of late-quaternary forests in eastern North America. Springer-Verlag, New York, NY.

Dobson, A. P., J. P. Rodrigues, W. M. Roberts, and D. S. Wilcove. 1997. Geographic distribution of endangered species in the United States. Science 275:550–553.

Dorf, E. 1976. Climate change of the past and present. Pp. 384–412 *in* C.A. Ross, ed. Paleobiogeography: benchmark papers in geology, no. 30. Dowden, Hutchinson and Ross, Stroudsburg, PA.

Ehrlich, P. R. 1983. Genetics and extinction of butterfly populations. Pp. 164–184 *in* C. M. Schonewald-Cox, S. M. Chambers, F. MacBryde, and L. Thomas, eds. Genetics and conservation: a reference for managing wild animals and plant populations. Benjamin-Cummings, Menlo Park, CA.

Environment Canada. 1997. Convention on International Trade and Endangered Species of Wild Flora and Fauna, CITES Office, Wildlife Services. List of Appendices I, II, and III species (CITES Control List No. 12 effective 1997-09-08). Available from: www.ec.gc.ca/cws-scf/cites/.

Estes, J. A., M. T. Tinker, T. M. Williams, and D. F. Doak. 1998. Killer whale predation on sea otter linking oceanic and nearshore ecosystems. Science 282:473–476.

FAUNMAP Working Group. 1996. Spatial response of mammals to Late Quaternary environmental fluctuations. Science 272:1601–1606.

Fergusson, A., and D. I. Wardle. 1998. Arctic ozone: the sensitivity of the ozone layer to chemical depletion and climate change. Environ. Can.

Flather, C. H., M. S. Knowles, and I. A. Kendall. 1998. Threatened and endangered species geography. BioSci. 48:365–376.

Forsyth, D. M., and A. R. Sinclair. 2000. Ranking potential conservation areas by their "replaceability"; fish in lakes in British Columbia, Canada. P. 197 *in* L. M. Darling, ed. Proc. Conf. Biology and Management of Species and Habitats at Risk, Kamloops, BC, 15-19 Feb. 1999. Vol. One. B.C. Minist. Environ., Lands and Parks, Victoria, BC, and Univ. College of the Cariboo, Kamloops, BC. 490pp.

Freemark, K., H. Moore, D. Forsyth, A. Sinclair, D. White, T. Barrettt, and R. Pressey. 2000. Identifying sites for conserving biodiversity in Canada using a complementarity approach: preliminary results. Unpubl. ms.

Furley, P. A., W. W. Newey, R. P. Kirby, and J. M. Hotson. 1983. Geography of the Biosphere. Butterworths, London, U.K.

Gilpin, M. E., and M. E. Soulé. 1986. Minimum viable populations: processes of species extinction. Pp. 19–34 *in* M. E. Soulé, ed. Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland, MA.

Graham, R. W., and E. C. Grimm. 1990. Effects of global climate change on the patterns of terrestrial biological communities. Trends in Ecol. and Evol. 5:289–292.

Guppy, C. S., J. H. Shepard, and N. Kondla. 1995. Butterflies and skippers of conservation concern in British Columbia. Can. Field-Nat. 108:31–40.

Hafernik, J. E., Jr. 1992. Threats to invertebrate biodiversity: implications for conservation strategies. Pp. 171–195 *in* P. L. Fiedler, and S. K. Jain, eds. Conservation biology: the theory and practice of nature conservation, preservation and management. Chapman and Hall, New York, NY and London, U.K.

Hansson, L., L. Söderström, and C. Solbreck. 1992. The ecology of dispersal in relation to conservation. Pp. 162–299 *in* L. Hansson, ed. Ecological principles of nature conservation: applications in temperate and boreal environments. Elsevier Applied Science, London, U.K. and New York, NY.

Harper, W. L., E. C. Lea, and R. E. Maxwell. 1993. Biodiversity inventory in the South Okanagan. Pp. 249–265 *in* M. A. Fenger, E. H. Miller, J. F. Johnson, and E. J. Williams, eds. Our living legacy: proceedings of a symposium on biological diversity. Roy. B.C. Mus., Victoria, BC.

Harrington, J. B. 1987. Climate change: a review of causes. Can. J. For. Sci. 17:1313–1339.

Harris, L. D. 1993. Some spatial aspects of biodiversity conservation. Pp. 97–108 *in* M. A. Fenger, E. H. Miller, J. F. Johnson, and E. J. Williams, eds. Our living legacy: proceedings of a symposium on biological diversity. Roy. B.C. Mus., Victoria, BC.

He, H. S., and D. J. Mladenoff. 1999. Spatially explicit and stochastic simulation of forest-landscape fire disturbance and succession. Ecol. 80:81–99.

Hendrick, P. W., R. C. Lacy, F. W. Allendorf, and M. E. Soulé. 1996. Directions in conservation biology: comments on Caughley. Conserv. Biol. 10:1312–1320.

Hengeveld, H. 1989. Future climate scenarios for Pacific Canada. Pp. 13–23 *in* E. Taylor, and K. Johnson, eds. Proc. of the symposium on the impacts of climate variability and change on British Columbia. Vancouver, 14 December 1988. Atmospheric Environ. Serv., Environ. Can., Vancouver, BC. Sci. Serv. Div. Rep. PAES-89-1.

Hlady, D. A. 1993. South Okanagan conservation strategy. Pp. 307–310 *in* M. A. Fenger, E. H. Miller, J. F. Johnson, and E. J. Williams, eds. Our living legacy: proceedings of a symposium on biological diversity. Roy. B.C. Mus., Victoria, BC.

Holling, C. S. 1986. The resilience of terrestrial ecosystems: local surprise and global change. Pp. 297–317 *in* W. C. Clark, and R. E. Munn, eds. Sustainable development of the biosphere. Cambridge University Press, Cambridge, U.K.

Houghton, R. A., and G. M. Woodwell. 1989. Global climate change. Sci. Amer. 260(4):36–44.

Howard, P. C., P. Viskanic, T. R. Davenport, F. W. Kigenyi, M. Baltzer, C. J. Dickinson, J. S. Lwanga, R. A. Mathews, and A. Balmford. 1998. Complementarity and the use of indicator groups for reserve selection in Uganda. Nature 394:472–475.

Hubbell, S. P., R. B. Foster, S. T. O'Brien, K. E. Harms, R. Condit, B. Weschsler, S. J. Wright, and S. Loo de Lao. 1999. Light-gap disturbances, recruitment limitation, and tree diversity in a Neotropical forest. Science 283:554–557.

Kaiser, J. 1998. Sea otter declines blamed on hungry killers. Science 282:390–391.

Kay, J. J. 1991. A non-equilibrium thermodynamic framework for discussing ecological integrity. Environ. Manage. 15:483–495.

_____. 1993. On the nature of ecological integrity: some closing comments. Pp. 201–212 *in* S. Woodley, J. Kay, and G. Francis, eds. Ecological integrity and the management of ecosystems. St. Lucie Press, Delray, FL.

Keiter, R. B., and H. Locke. 1996. Law and large carnivore conservation in the Rocky Mountains of the U.S. and Canada. Conserv. Biol. 10:1003–1012.

Kimmins, J. P. 1996*a*. Importance of soil and role of ecosystem disturbance for sustained productivity of cool temperate and boreal forests. Soil Sci. Soc. of Amer. J. 60:1643–1654.

_____. 1996*b*. The health and integrity of forest ecosystems: are they threatened by forestry? Ecosystem Health 2:5–18.

Lande, R. 1987. Extinction thresholds in demographic models of territorial populations. Amer. Nat. 130:624–635.

_____. 1988. Genetics and demography in biological conservation. Science 241:1455–1460.

Locke, H. 1998. The Yellowstone to Yukon conservation initiative. Pp. 255–259 *in* N. W. Munro, and J. H. Williston, eds. Linking protected areas with working landscapes conserving biodiversity. Proceed. of third international conference on science and management of protected areas, 12–16 May 1997. Sci. and Manage. of Protected Areas Assoc., Wolfville, NS.

Loucks, O. L. 1970. Evolution of diversity, efficiency, and community stability. Amer. Zool. 10:17–25.

McArthur, R. H. 1972. Geographical ecology. Harper and Row, New York, NY.

McBean, G. A., and A. D. McEwan. 1990. Global climate change: a scientific review presented by the World Climate Research Programme. World Meteorological Organization, International Council of Scientific Unions.

Meidinger, D., and J. Pojar, eds. 1991. Ecosystems of British Columbia. B.C. Minist. For., Victoria, BC. Spec. Rep. Ser. 6. 330pp.

Melillo, J. M. 1999. Warm, warm on the range. Science 283:183–184.

Mladenoff, D. J., R. G. Haight, T. A. Sickley, and A. P. Wydeven. 1997. Causes and implications of species restoration in altered ecosystems. BioSci. 47:21–31.

Murphy, D. D., and B. A. Wilcox. 1986. Butterfly diversity in natural habitat fragments: a test of the validity of vertebrate-based management. Pp. 287–292 *in* J. Verner, M. L. Morrison, and C. J. Ralph, eds. Wildlife 2000: modelling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, WI.

Newmark, W. D. 1995. Extinction of mammal populations in western North American National Parks. Conserv. Biol. 9:512–526.

Nicholls, A. O., and C. R. Margules. 1993. An upgraded reserve selection algorithm. Biol. Conserv. 64:165–169.

Noble, I. R., and R. Dirzo. 1997. Forests as human-dominated ecosystems. Science 277:522–525.

Noss, R. F. 1985. Wilderness recovery and ecological restoration: an example for Florida. Earth First! 5(8):18–19.

_____. 1987. Protecting natural areas in fragmented landscapes. Nat. Areas J. 7:2–13.

_____. 1992. Land conservation strategy. Pp. 10–25 *in* The wildlands project. Wild Earth Special Issue. Cenozoic Society.

_____, H. B. Quigley, M. G. Hornocker, T. Merrill, and P. C. Paquet. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. Conserv. Biol.

10:949–963.

Parmesan, C. 1996. Climate and species' range. Nature 382:765–766.

Peters, R. L. 1991. Consequences of global warming for biological diversity. Pp. 99–118 *in* R. L. Wyman, ed. Global climate change and life on earth. Routledge, Chapman and Hall, New York, NY and London, U.K.

_____, and J. D. Darling. 1985. The greenhouse effect and nature reserves. BioSci. 35:707–717.

Pickett, S. T., J. J. Amesto, and S. L. Collins. 1989. The ecological concept of disturbance and its expression at various hierarchical levels. Oikos 54:129–136.

Pitelka, L. F., and the Plant Migration Workshop Group. 1997. Plant migration and climate change. Amer. Sci. 85:464–473.

Pojar, J. 1996. A biological/conservation perspective. Pp. 36–40 *in* S. Jessen, ed. The wilderness vision for British Columbia. B. C. Chapter, Can. Parks and Wilderness Soc., Vancouver, BC.

Powledge, F. 1998. Biodiversity at the crossroads. BioSci. 48:347–352.

Prendergast, J. R., R. M. Quinn, J. H. Lawton, B. C. Eversham, and D. W. Gibbons. 1993. Rare species, the coincidence of diversity hotspots and conservation strategies. Nature 365:335–337.

Pressey, R. L. 1994. Ad hoc reservations: forward or backward steps in developing representative reserve systems? Conserv. Biol. 8:662–668.

_____, S. Ferrier, C. D. Hutchinson, D. P. Silversten, and G. Manion. 1995. Planning for negotiation: using an interactive geographic information system to explore alternative protected area networks. Pp. 22–23 *in* D. A. Saunders, J. L. Craig, and E. M. Mattiske, eds. Nature conservation 4: the role of networks. Surrey Beatty and Sons, Sydney.

_____, C. J. Humphries, C. R. Margules, R. I. Vane-Wright, and P. H. Williams. 1993. Beyond opportunisms: key principles for systematic reserve selection. Trends in Ecol. and Evol. 8:124–128.

_____, I. R. Johnson, and P. D. Wilson. 1994. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. Biodiversity and Conserv. 3:242–262.

_____, H. P. Possingham, and C. R. Margules. 1996. Optimality in reserve selection algorithms: when does it matter and how much? Biol. Conserv. 76:259–267.

_____, and S. L. Tully. 1994. The cost of ad hoc reservation: a case study in western New South Wales. Aust. J. Ecol. 19:375–384.

Pynn, L. 8 February 1999. Forest renewal cutbacks hit wildlife impact studies. Vancouver Sun. Pages 1–2.

Raynaud, D., J. Jouzel, J. M. Barnola, J. Chappellaz, R. J. Delmas, and C. Lorius. 1993. The ice record of greenhouse gases. Science 259:926–934.

Reid, W. V. 1998. Biodiversity hotspots. Trends in Ecol. and Evol. 13:275–280.

_____, J. A. McNeely, D. B. Tunstall, D. Bryant, and M. Winograd. 1993. Biodiversity indicators for policy-makers. World Resources Institute, Washington, DC.

Saccheri, I. M. Kuussaari, M. Kankare, P. Vikman, W. Forteliu, and I. Hanksi. 1998. Inbreeding and extinction in a butterfly metapopulation. Nature 392:491–494.

Schindell, D. T., D. Rind, and P. Lonergan. 1998. Increased polar stratospheric ozone losses and delayed eventual recovery owing to increasing greenhouse-gas concentrations. Nature 392:589–592.

Schneider, S. 1989. Global warming. Sierra Club Books, San Francisco, CA.

_____, and R. Louder. 1984. The coevolution of climate and life. Sierra Club Books, San Francisco, CA.

_____, L. Mearns, and P. H. Gleick. 1992. Climate-change scenarios for impact assessment. Pp. 38–55 *in* R. L. Peters, and T. E. Lovejoy, eds. Global warming and biological diversity. Yale University Press, New Haven and London, U.K.

Schonewald-Cox, C., and M. Buechner. 1991. Housing viable populations in protected habitats: the value of a coarse-grained geographic analysis of density patterns and available habitat. Pp. 213–226 *in* A. Seitz, and V. Loeschcke, eds. Species conservation: a population-biological approach. Binkhäuser, Basel, Switz.

Scott, J. M., B. Csuti, J. D. Jacobi, and J. E. Estes. 1987. Species richness: a geographical approach to protecting future biological diversity. BioSci. 37:782–788.

Scudder, G. G. 1994. An annotated systematic list of the potentially rare and endangered freshwater and terrestrial invertebrates in British Columbia. Entomol. Soc. of British Columbia. Occas. Pap. 2. 92pp.

_____. 1996*a*. Terrestrial and freshwater invertebrates of British Columbia: priorities for inventory and descriptive research. Res. Branch, B.C. Minist. For., and Wildl. Branch, B.C. Minist. Environ., Lands and Parks, Victoria, BC. Working Pap. 09/1996. 206pp.

_____. 1996*b*. The protected areas strategy and biodiversity conservation. Pp. 99–101 *in* S. Jessen, ed. The wilderness vision for British Columbia. B. C. Chapter, Can. Parks and Wilderness Soc., Vancouver, BC.

_____, and I. M. Smith, eds. 1999. Assessment of species diversity in the Montane Cordillera ecozone. Agric. and Agri-food Can. and Environ. Can., Ottawa, ON. Ecol. Monit. and Assessment Network, Burlington, ON. Available from: www.cciw.ca/eman-temp/reports/publications/99_montane/.

Shafer, C. L. 1995. Values and shortcomings of small reserves. BioSci. 45:80–88.

Shugart, H. H., and D. C. West. 1981. Long-term dynamics of forest ecosystems. Amer. Sci. 69:647–652.

Shukla, J., C. Nobre, and P. Sellers. 1990. Amazon deforestation and climate change. Science 247:1322–1325.

State of Environment Reporting (SOE). 1998. Environmental trends in British Columbia 1998. B.C. Minist. Environ., Lands and Parks, Victoria, BC. 43pp.

Thirgood, J. V. 1981. Man and the Mediterranean forest: a history of resource depletion. Academic Press, London, U.K.

Thomas, S. D. 1990. What do real population dynamics tell us about minimum viable population sizes? Conserv. Biol. 4:324–327.

Vitousek, P. M., H. A. Mooney, J. Lubchencko, and J. M. Melillo. 1997. Human domination of earth's ecosystems. Science 277:494–499.

Warman, L. 2000. A systematic method for identifying priority areas to conserve rare species using "replaceability"; a test case for the South Okanagan. P. 807 *in* L. M. Darling, ed. Proc. Conf. Biology and Management of Species and Habitats at Risk, Kamloops, BC, 15-19 Feb. 1999. Vol. Two. B.C. Minist. Environ., Lands and Parks, Victoria, BC, and Univ. College of the Cariboo, Kamloops, BC. 520pp.

Webb, T. III. 1981. The past 11,000 years of vegetational change in eastern North America. BioSci. 31:501–506.

_____. 1992. Past changes in vegetation and climate: lessons for the future. Pp. 59–75 *in* R. L. Peters, and T. E. Lovejoy, eds. Global warming and biological diversity. Yale University Press, New Haven and London, U.K.

Wetherald, R. T. 1991. Changes of temperature and hydrology caused by an increase of atmospheric carbon dioxide as predicted by general circulation models. Pp. 1–17 *in* R. L. Wyman, ed. Global climate change and life on earth. Routledge, Chapman and Hall, New York, NY and London, U.K.

Williams, P., D. Gibbons, C. Margules, A. Rebelo, C. Humphries, and R. Pressey. 1996. A comparison of richness hotspots, rarity hotspots, and complementary areas for conserving diversity of British birds. Conserv. Biol. 10:155–174.

Wolfe, J. A. 1985. Distribution of major vegetational types during the Tertiary. Pp. 357–375 *in* E. T. Sundquist, and W. S. Broecker, eds. The carbon cycle and atmospheric CO_2: natural variations Archean to present. Amer. Geogr. Union, Washington, DC.

World Wildlife Fund Canada. 1998. Focus on B.C. World Wildlife Fund, Toronto, ON. 1998 Species Recovery Bull., 8pp.