Contributed Paper

An Index of Risk as a Measure of Biodiversity Conservation Achieved through Land Reform

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Abstract: *We measured the net progress of land reform in achieving a national policy goal for biodiversity conservation in the context of ongoing clearing of native vegetation and additions of land to a highly nonrepresentative (residual) reserve network, interior South Island, New Zealand. We used systematic conservation-planning approaches to develop a spatially explicit index of risk of biodiversity loss (RBL). The index incorporated information from national data sets that describe New Zealand's remaining indigenous land cover, legal protection, and land environments and modeled risk to biodiversity on the basis of stated assumptions about the effects of past habitat loss and legal protection. The index identified irreplaceable and vulnerable native habitats in lowland environments as the most at risk of biodiversity loss, and risk was correlated with the density of threatened plant records. To measure achievement, we used changes in the index that reflected gains made and opportunity costs incurred by legal protection and privatization. Application of the index to measure the difference made by land reform showed it had caused a net increase in the risk of biodiversity loss because most land vulnerable to habitat modification and rich in threatened plant species was privatized and land at least risk of biodiversity loss was protected. The application revealed that new high-elevation reserves did little to mitigate biodiversity decline, that privatization of low-elevation land further jeopardized the most vulnerable biodiversity in lowland native habitats, and that outcomes of land reform for biodiversity deteriorated over time. Further development of robust achievement measures is needed to encourage more accountable biodiversity conservation decisions.*

Keywords: conservation-achievement measurement, environmental classification, habitat loss, habitat irreplaceability, habitat vulnerability, protected areas, systematic conservation planning

Un Índice de Riesgo como una Medida de la Conservación de la Biodiversidad Llevada a Cabo con Reforma de Terrenos

Resumen: *Medimos el progreso neto de la reforma de terrenos en el logro de una meta política nacional para la conservación de la biodiversidad en el contexto de la continua alteración de la vegetación nativa y adiciones de terrenos en una red de reservas altamente no representativa (residual) en South Island, Nueva Zelanda. Utilizamos métodos sistemáticos de planificación de la conservación para desarrollar un índice de riesgo de pérdida de biodiversidad (RPB) espacialmente explícito. El índice incorporó información de conjuntos de datos nacionales que describen la cobertura remanente de terrenos nativos en Nueva Zelanda, su protección legal, y ambientes y modeló el riesgo a la biodiversidad sobre la base de supuestos sobre los efectos de la pérdida pasada de hábitat y protección legal. El índice cuantificó a los hábitats irreemplazables y vulnerables en ambientes bajos como los de mayor riesgo de pérdida de biodiversidad, y el riesgo se correlacionó con la densidad de registros de plantas amenazadas. Para medir el alcance, utilizamos cambios en el índice que reflejaban ganancias y costos de oportunidad incurridos por la protección legal y privatización. La aplicación del índice para medir la diferencia por la reforma de terrenos mostró que causó un incremento neto en el riesgo de pérdida de biodiversidad porque la mayor parte del terreno vulnerable a la modificación del hábitat y rico en especies de plantas amenazadas fue privatizado y el terreno con menor riesgo de*

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pérdida de biodiversidad fue protegido. La aplicación reveló que las reservas en tierras elevadas hicieron poco para mitigar la declinación de biodiversidad, que la privatización de terrenos de baja elevación puso en mayor riego a la biodiversidad en hábitats nativos y que los resultados de la reforma de terrenos para la biodiversidad se deterioraron con el tiempo. Se requiere el desarrollo de medidas de alcances robustas para fomentar decisiones más responsables respecto a la conservación de la biodiversidad.

Palabras Clave: áreas protegidas, clasificación ambiental, irreemplazabilidad del hábitat, medida de logros de conservación, planificación sistemática de la conservación, pérdida de hábitat, vulnerabilidad del hábitat

Introduction

The world's refuges for biodiversity are most seriously deficient for those species and ecosystems threatened by human land uses. Recognizing that ad hoc selection of reserves does little to improve the protection of biodiversity (Pressey 1994), most large conservation organizations now use complementarity-based systematic conservation-planning methods to support the design of more representative reserve networks.

Systematic conservation planning enables design of reserve networks that are representative (contain a full range of features to be protected), maximize retention (secure the most vulnerable component), and are efficient (achieve results with the fewest sites, smallest area, or minimum cost). Systematic conservation principles also provide an objective basis for measuring the effectiveness of conservation implementation, but rarely have been used for this purpose. Measuring conservation achievement is important because it promotes accountability for conservation expenditure and discourages expedient decisions (Pressey 1999; Pressey et al. 2002). Objective reporting of conservation achievement must include both the gains made and the opportunity costs incurred by the conservation measures chosen. This is especially important where conservation goals are being compromised by high rates of biodiversity loss.

We applied systematic conservation-planning approaches to develop an index of risk for New Zealand biodiversity. The index was derived from explicit assumptions and models. We validated the index preliminarily and used it to measure the increase or decrease in risk to biodiversity achieved in a major land-reform process implemented in the interior of the South Island.

Conservation in New Zealand

New Zealand is one of the world's biodiversity hotspots. It has an exceptional concentration of endemic species and has had an exceptional loss of primary habitat (Myers et al. 2000). About half the land area remains under some form of primary or secondary indigenous vegetation cover, and about one-third is protected legally for conservation purposes (Walker et al. 2006). This legally protected area network is a residual system (Pressey et al. 2002) composed mostly of land too high, steep, and wet to be of economic use (Mark 1985; Walker et al. 2006). Clearance of indigenous ecosystems continues in New Zealand, and the highest clearance rates are in environments where indigenous ecosystems are already most depleted (Walker et al. 2006).

New Zealand is a signatory of the United Nations Convention on Biological Diversity, and New Zealand society's goals for biodiversity are documented in the New Zealand Biodiversity Strategy (NZBS) (DOC & MfE 2000). Goal 3 is to "Halt the decline in New Zealand's indigenous biodiversity." The first objective for biodiversity conservation on land is to "[e]nhance the existing network of protected areas to secure a full range of remaining indigenous habitats and ecosystems." Systematic methods to identify irreplaceable and vulnerable biodiversity required to achieve the NZBS objectives have been slow to emerge in New Zealand, and systems for monitoring and reporting progress are overdue (Stephens et al. 2002).

South Island High Country Land Reform

High Country is the somewhat misleading New Zealand term for a region of inland South Island. About 30% of the region lies above 1200 m asl, but about 40% is below 800 m asl and covers lower hillslopes, intermontane valleys, and basin floors of gentle relief. In this region seral indigenous grasslands below treeline account for over 70% of the land cover; semi-indigenous shrublands and forest remnants for 14%; alpine rock, ice, and vegetation for 10%; and exotic pasture, forestry, and cropping cover for 4%. We refer to this region as interior South Island.

In 1992 353 pastoral leases, pastoral occupation licenses, and special leases (hereafter leases) owned by the Crown (New Zealand's governing power) covered about 2.4 million ha of land (9.3% of New Zealand) in interior South Island and had a median size of 4500 ha. Leases are perpetually renewable and convey rights to occupy and graze stock in exchange for nominal rent to the Crown, which retains title. Nonpastoral land uses such as cultivation require discretionary consent from the Crown, and extensive pastoral management has been the principal land use.

From 1992 to May 2005 two voluntary land-reform processes were used on 69 leases (Brower 2007). In the first process (tenure review, affecting about 330,000 ha) some land (about 130,000 ha) deemed to have "significant inherent value" was retained as public protected land for conservation. The remaining land was privatized, with freehold title transferred to the lessee. In a second process, governed by conservation legislation, the Crown's Nature Heritage Fund directly purchased part or all property-lease rights over 39,360 ha.

In 2003 and 2005 the New Zealand Cabinet (government's executive branch) noted that tenure review was inadequately protecting vulnerable lowland ecosystems and directed officials to increase efforts to secure them. In 2005 it mandated that ecological sustainability and protection of significant inherent values (including biodiversity) be the primary objectives of land reform and that these goals take precedence over privatization and public access.

Methods

Spatial Data Sets

We used four spatial data sets (environments, land tenure, land cover, and threatened plants) to construct and validate an index of risk to remaining indigenous biodiversity. We used 500 Level IV Land Environments of New Zealand (LENZ; Leathwick et al. 2003) as surrogate units for the potential full range of terrestrial biodiversity. We assumed each land environment (defined on the basis of soil, climate, and topography) was associated with a unique assemblage of ecosystems and species in the past (not unique in all respects, but in important features that were different from those in other environments). Following, for example, Cowling and Heijnis (2001) and Pressey and Taffs (2001), we regarded assemblages in each environment as of equal value to the biodiversity goal.

Data on land tenure came from the digital boundaries of (1) leases remaining in May 2005, (2) 69 leases that underwent land reform from 1992 to May 2005, (3) public protected land managed for conservation in May 2005 (hereafter protected land), (4) private conservation covenants (easements) in May 2005, and (5) private land without a conservation covenant.

We used the national land-cover databases (version 1 [LCDB1] from 1996 and 1997 remote imagery and version 2 [LCDB2] from 2001 and 2002 imagery) (Terralink International 2004) to identify habitat for indigenous species. We assigned 22 classes to "indigenous" and the remaining 21 classes to "nonindigenous" cover categories that no longer provide habitat for indigenous species (following Walker et al. 2006). Nevertheless, we treated the low-producing grassland class (nonindigenous in Walker et al. 2006) as indigenous on leases unless otherwise noted because low-producing grassland on leases generally retain native plant communities (e.g., Walker & Lee 2002).

We drew South Island location records of threatened plants from the National Vegetation Survey Databank, the Allen Herbarium, and Department of Conservation databases. We excluded duplicate records and records >20 years old. For analysis we extracted 402 point-location records for 40 acutely threatened plant species and 466 location records of 37 chronically threatened plant species within remaining or reformed leases. Thirty-one percent of these 868 point-location records fell within the LCDB1 low-producing grassland cover class.

Development of Risk of Biodiversity Loss (RBL) Index

We used the spatial data sets to construct an index of risk for remaining biodiversity on the basis of past habitat loss and poor legal protection within land environments.

HABITAT LOSS

Ecological theory predicts that habitat loss causes a nonlinear increase in risk to remaining biodiversity. Accelerated risk is predicted by the species–area relationship ($S = A^z$, where S is the proportion or number of species remaining, A is the proportion or area of habitat remaining, and the exponent z ranges from 0.25 to 0.35 for islands; Rosenzweig 1995; Fig. 1a). The shape of the species–area relationship varies with different biota (Desmet & Cowling 2004) and different patterns of habitat loss (Seabloom et al. 2002). Nevertheless, if the relationship is applied to all species (rather than space-demanding animals), each additional increment of habitat loss generally results in greater proportional loss of remaining species. As habitat loss advances, patches also become more isolated and have higher ratios of edge to area (e.g., Andrén 1994; Fahrig 2003). Such effects are also nonlinear and add to the risk to biodiversity from reduced area alone. Past habitat loss may also be correlated with risk of future loss because ecosystem clearance is related to the land's inherent capability for intensive human use (Pressey et al. 1996).

We used an index of susceptibility to biodiversity loss (SBL) to represent the increase in risk to remaining biodiversity caused by and correlated with habitat loss in a land environment:

$$\text{SBL} = 0.35 \text{ proportion remaining indigenous cover in land environment}^{(0.35-1)}. \tag{1}$$

The index predicted (Fig. 1b) that susceptibility to biodiversity loss would increase more rapidly when native cover was reduced from a low level (e.g., 20%) than when

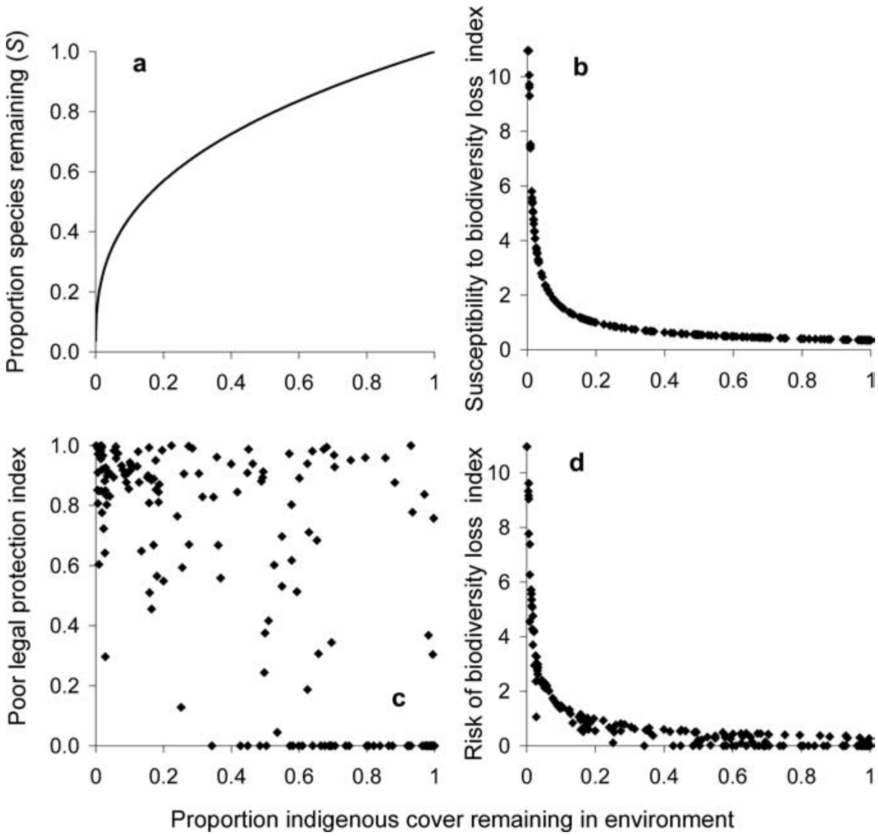

Figure 1. (a) The generalized species-area relationship ($S = A^z$, *where* $z = 0.35$) (Rosenzweig 1995). *(b) Values of the susceptibility to biodiversity loss (SBL) index (unitless) for each land environment affected by land reform. (c) Values of the poor legal protection (PLP) index (unitless) in all land environments affected by land reform (assuming protection extinguishes all risk of biodiversity loss). High values of PLP indicate a small proportion of a realistic protection baseline (either 20% of an environment or all remaining indigenous cover if <20% remained in indigenous cover) is legally protected. (d) Risk of biodiversity loss (unitless) in all land environments affected by land reform (derived by multiplying SBL and PLP).*

native cover was reduced from a high level (e.g., 90%). SBL ranged from 0.35 in an intact environment to infinity when all indigenous habitat was lost. We truncated SBL at a maximum of 10.96 for all environments (≤0.5% indigenous cover remaining).

POOR LEGAL PROTECTION

We assumed that legal protection mitigates susceptibility to biodiversity loss because indigenous ecosystems that are legally protected are less likely to be cleared (Walker et al. 2006) and receive more conservation investment to prevent attrition (e.g., pest and weed control) than unprotected land. It follows that in two environments with the same past habitat loss and SBL, biodiversity will be more at risk of loss in the environment with less of the remaining native habitat protected legally.

We developed an index of poor legal protection (PLP) to represent the portion of risk to biodiversity not mitigated by legal protection. We assumed that beyond a "baseline" proportion of protected environment, benefits from additional protection would be minor and outweighed by opportunity costs in other environments. Our species–area relationship function (Fig. 1a) predicted accelerated species loss below about 20% of original habitat remaining. We therefore set pragmatic protection baselines to achieve biodiversity persistence at either 20% of an environment or all remaining indigenous cover if <20% of an environment remained in indigenous cover. We assumed that where protection was below the baseline, risk of biodiversity loss was highest in environments with the smallest proportion of remaining indigenous habitat protected and lowest where all that remained was protected.

If all risk to biodiversity was extinguished by conservation management within legally protected areas, PLP would have a minimum value of 0.0 in environments where legal protection equaled or exceeded the baseline. In all environments with protection below baseline

$$\text{PLP} = \frac{\text{baseline area} - \text{protected area}}{\text{baseline area}}. \qquad (2)$$

High values of PLP indicated that little of the remaining indigenous habitat in an environment was legally protected, and maximum PLP was 1.0 (where no indigenous habitat was legally protected) (Fig. 1c).

Legal protection is unlikely to extinguish all risk to biodiversity (i.e., risk of clearance is not zero even in protected areas, and conservation management incompletely reduces pests and weeds). It would be more realistic to assume legal protection and associated conservation management cannot completely extinguish risk to biodiversity. With this more realistic assumption, PLP values would range from a positive minimum value (e.g., 0.25, if legal protection was assumed to offset

75% of susceptibility to biodiversity loss) to a maximum of 1.0.

RISK OF BIODIVERSITY LOSS INDEX

Our index of risk of biodiversity loss (RBL; Fig. 1d) is the product of susceptibility to biodiversity loss (SBL) and poor legal protection (PLP):

$$\text{RBL} = \text{SBL} \times \text{PLP}. \tag{3}$$

The index predicts that biodiversity at the highest risk of loss will be in environments that have been extensively cleared or altered in the past (high SBL) and have small proportions of their remaining indigenous vegetation legally protected (high PLP). With the optimistic (but false) assumption that all risk to biodiversity is extinguished within legally protected areas, RBL was zero in all environments where legal protection equaled or exceeded the baseline (Fig. 1d) because PLP was zero (Fig. 1c). With a more realistic assumption and minimum PLP >0, RBL values would range from a positive minimum value to maximum SBL (10.96).

Risk of biodiversity loss incorporates concepts of irreplaceability and vulnerability, but not as separate dimensions. Irreplaceability refers to the importance of an area for achieving an explicit goal (Margules & Pressey 2000); an area has higher irreplaceability when less of the protection target (or baseline) is met and fewer options (less of a type or fewer populations of species) are available to meet the target. In our index, irreplaceability is higher when less of a baseline is protected (higher PLP) and when there is less left to protect (higher SBL). Vulnerability ("the likelihood or imminence of biodiversity loss to current or impending threatening processes"; Pressey et al. 1996) is incorporated in RBL because susceptibility to biodiversity loss indicates risk caused by and correlated with past loss, and poor legal protection is associated with risk of clearance and attrition.

Application to Land Reform

INITIAL VALUES OF RISK OF BIODIVERSITY LOSS

We calculated the land area and percent indigenous cover remaining in each land environment based on LCDB1 indigenous cover. In each land environment we also calculated the areas of land and indigenous cover protected through land reform (either as public land or privatized with a covenant), land and indigenous cover privatized without a covenant through land reform, and other (public or private) protected land and indigenous cover.

We then calculated initial national protection baselines and values of PLP, SBL, and RBL (i.e., the values that would have applied without land reform) in each of the 179 land environments on original (i.e., remaining and reformed) leases. For simplicity we calculated PLP and RBL based only on the most optimistic (but false) assumption that all risk to biodiversity is extinguished within legally protected areas.

VALIDATION OF THE RISK INDEX

We calculated the density (locations per 1000 ha) of acutely and chronically threatened plant records on leases within environments grouped into five ascending risk categories. These risk categories divided environments into five categories of approximately equal area (about 486,000 ha) on the basis of initial RBL. We also calculated the density of acutely and chronically threatened plant locations on leases within five elevation zones.

INDIGENOUS COVER LOSS WITH PRIVATIZATION

To determine whether and how much indigenous cover (IC) loss would follow land privatization, we compared percent indigenous cover retained on private and leasehold land within 64 land environments where remaining leases and private land each occupied $>5\%$ of total environment area. We then calculated percent loss due to privatization relative to leasehold land for each environment:

$$\text{loss due to privatization} = \frac{\%\text{IC on remaining leases} - \%\text{IC on private land}}{\%\text{IC on remaining leases}}, \tag{4}$$

where %IC is the percent area of an environment that remains under an indigenous land-cover class. For this calculation we derived IC from the most recent land cover database (LCDB2), and in order to provide a consistent basis for comparison we assumed low-producing grassland was nonindigenous everywhere. This assumption will cause underestimation of the difference in IC between pastoral leases (where nonpastoral land use is legally constrained) and private land (where land use is less constrained) and of future loss due to privatization.

We built a regression model of loss due to privatization on the proportion of indigenous cover remaining in the whole land environment. We used this equation to predict the percentage and area of remaining indigenous cover that would be cleared following privatization. This prediction assumed that after lease land was privatized, its indigenous vegetation would eventually be cleared to the same extent as other privately owned land in the same environment, and that future land-use trends would resemble those of the past.

ACHIEVEMENT MEASUREMENT

To measure the biodiversity conservation achievement of land reform, we assumed that all areas of indigenous cover privatized were not available for legal protection in the future and all remaining indigenous cover would be retained on remaining leases and on public protected and private covenanted land. We calculated final values of SBL, PLP, and RBL for each environment based on the area of indigenous cover following loss due to privatization on privatized land and the extent of protected areas after land reform. We subtracted initial from final RBL to calculate change in each environment. Change in RBL was our principal measure of biodiversity conservation achievement.

Land reform led to a net increase in RBL in some environments and a net decrease in other environments. Reduced risk to biodiversity in one environment could not compensate for, or cancel out, increased risk to a different suite of biodiversity in another environment; therefore, we summed increases and decreases in RBL separately when grouping environments.

We first measured achievement in the tenure review process. To assess progress over time we divided leases into four subsets (phases A to D) based on the date of review completion. Ten leases, affecting 31,000 ha of indigenous cover, were reviewed in the first and longest phase (A, 97 months) from January 1992 to January 2000. In phases B, C, and D (each 21 months), 14, 20, and 22 leases, affecting 54,000, 134,000, and 77,000 ha of land under indigenous cover, respectively, were reviewed. We summed changes in RBL across the environments affected in each phase and plotted summed increases and decreases per unit area against time. Next, to determine how achievement varied with the level of risk of biodiversity loss, we divided environments affected by land reform into five categories of ascending initial RBL and then summed changes in RBL across the environments within each risk category. Finally, we counted the number of environments in which protection baselines were exceeded through additional protection and the number in which protection baselines could no longer be met because indigenous vegetation required to meet baselines was privatized in tenure review. We repeated these steps to assess achievement of land reform through Nature Heritage Fund purchases.

FUTURE PROTECTION, PRIVATIZATION, AND INDIGENOUS COVER LOSS

We built regression models of the percentage of land privatized and protected by tenure review on the proportion of indigenous cover remaining in environments (initial IC) on the basis of data from 89 environments with >50 ha affected by May 2005. We used these models to forecast land areas in each environment that would be privatized or protected if all remaining leases completed tenure review and if land allocation trends continued. We used our model of loss due to privatization to estimate areas likely to be cleared on privatized land if past trends continued.

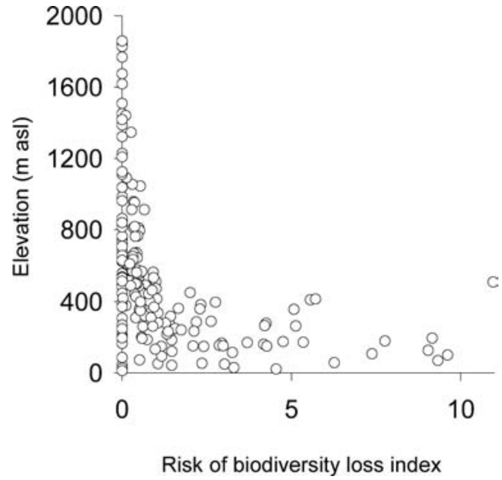

Figure 2. Average elevation of land in the 179 land environments affected by land reform in relation to risk of biodiversity loss in land environments.

Results

Validation of the Risk Index

Remaining native habitats in environments at low elevations in interior South Island were at greatest risk of biodiversity loss (highest RBL, Fig. 2). Most land environments were poorly protected before land reform: initial national protection baselines were met in 56 mainly high-elevation environments (i.e., 31% of the 179 environments on original leases). The density of records of acutely threatened plants increased monotonically across categories of risk of biodiversity loss (Fig. 3a). The density of chronically threatened plants was highest in the second-highest category of risk of biodiversity loss. The density of acutely threatened plant records was higher in land below 400 m than in any other elevation zone (Fig. 3b), and density of chronically threatened plants was highest in the elevation zone at 400–800 m.

Application to Land Reform

LAND AND INDIGENOUS LAND COVER AFFECTED

The tenure review process of land reform affected indigenous cover in 122 land environments on 66 leases. Of the 328,350 ha of all land affected, 55% was privatized without a covenant, 5% was privatized with a covenant, 39% became public protected land, and 1% was retained by the Crown as a lease. Of the estimated 295,620 ha of land under indigenous cover affected by tenure review, 50% was privatized without a covenant, 5% was privatized with a covenant, 43% became public protected land, and 1% was retained as lease (Table 1). Significantly higher percentages of all land (78 ± 24%) and of land under indigenous cover (76 ± 28%) were privatized without a covenant in the latest (fourth)

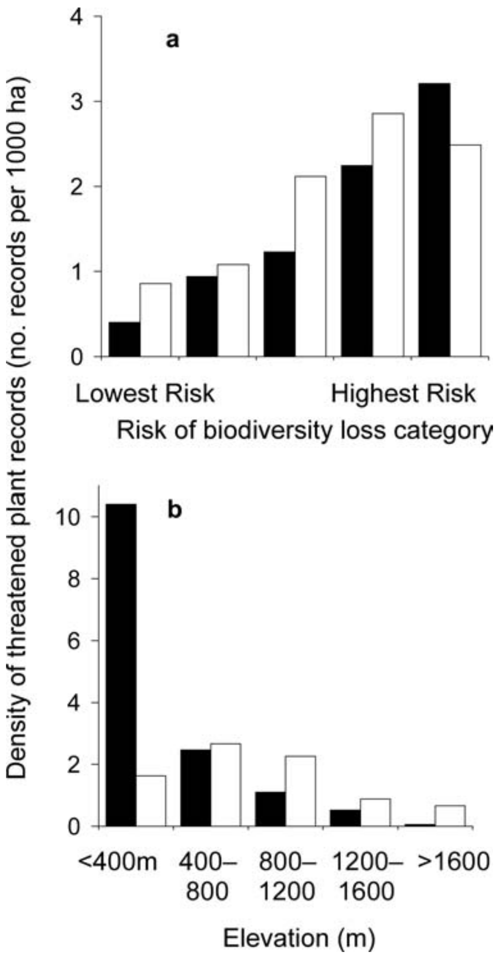

Figure 3. Density of 402 records of acutely threatened plants (black) and 466 records of chronically threatened plants (white) on crown leases in (a) five equal-area categories of risk of biodiversity loss and (b) five elevation zones.

phase of tenure review than in the three earlier phases ($p < 0.05$ by Tukey's pairwise comparison of means) (Fig. 4a). Land reform through Nature Heritage Fund purchases privatized no land and protected 39,360 ha of land under indigenous cover.

INDIGENOUS COVER LOSS WITH PRIVATIZATION

Leases in interior South Island retained significantly more indigenous cover (average 49% over 64 environments) than private land in equivalent environments (35%, $t = 3.2$, df $= 126$, $p < 0.001$), which was consistent with historical disincentives for intensive land use on leases, including legal constraints on cultivation, below-market rentals, and large property size.

The percent loss due to privatization (Eq. 4) decreased as the indigenous cover remaining in a land environment increased; this trend is best described by a third-order

Table 1. Indigenous cover protected or privatized by tenure review (all areas in ha).

		Tenure review effects on indigenous cover to date						
Category of risk to remaining biodiversity (RBL[b])	*Total area affected (ha)*	*Area protected (%) public land*	*Area privatized without a covenant (%)*	*Area protected public land (ha) (%) of protected land*	*Area privatized (ha) (%) of area privatized*	*Area predicted to be cleared (ha) (%) of reviewed land*	*Projected future effect[a] area to be cleared following privatization on current leases (ha) (% of all remaining indigenous cover on leases)*
1 (lowest risk)	52,123	74	25	38,710 (30)	12,910 (9)	2,170 (4)	46,300 (4)
2	170,721	47	45	79,390 (62)	76,490 (52)	17,130 (10)	84,000 (9)
3	62,756	15	79	9,610 (8)	49,570 (33)	15,460 (25)	61,130 (21)
4	4,581	4	96	170 (<1)	4,400 (3)	1,780 (39)	10,480 (31)
5 (highest risk)	5,440	4	88	200 (<1)	4,810 (3)	3,380 (62)	12,320 (65)
Total	295,620	43	50	128,090	148,190	39,910 (14)	214,230 (9)

[a]*Risk of biodiversity loss without land reform.*
[b]*Total areas that would be affected if patterns of land allocation continued, past land-use patterns continued, and all remaining leases were included in tenure review.*

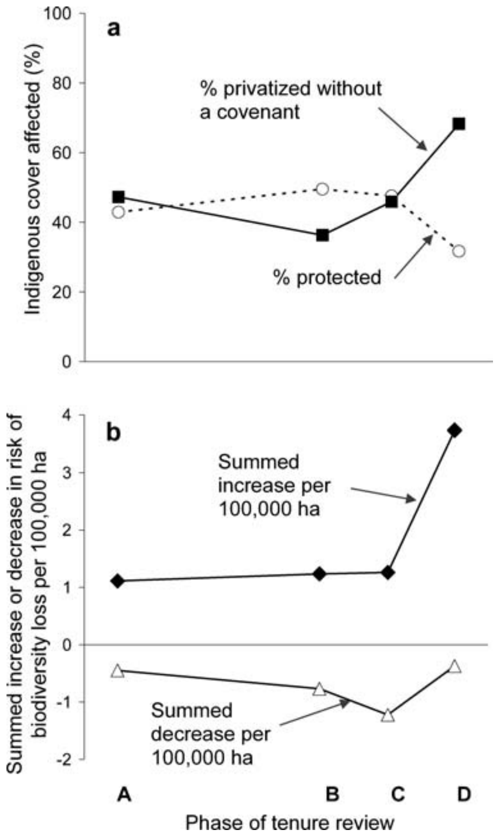

Figure 4. Conservation achievement of tenure review over time. (a) Percentage of the total area of land under indigenous cover that became public protected land and privatized. (b) Increases and decreases in risk of biodiversity loss per 100,000 ha of indigenous cover affected by the land-reform process of tenure review. Increases and decreases in the risk of biodiversity loss index were summed separately across the different land environments affected by tenure review in each temporal phase and then standardized based on area of indigenous cover affected. Phases A through D represented four successive temporal phases of tenure review from January 1992 to May 2005.

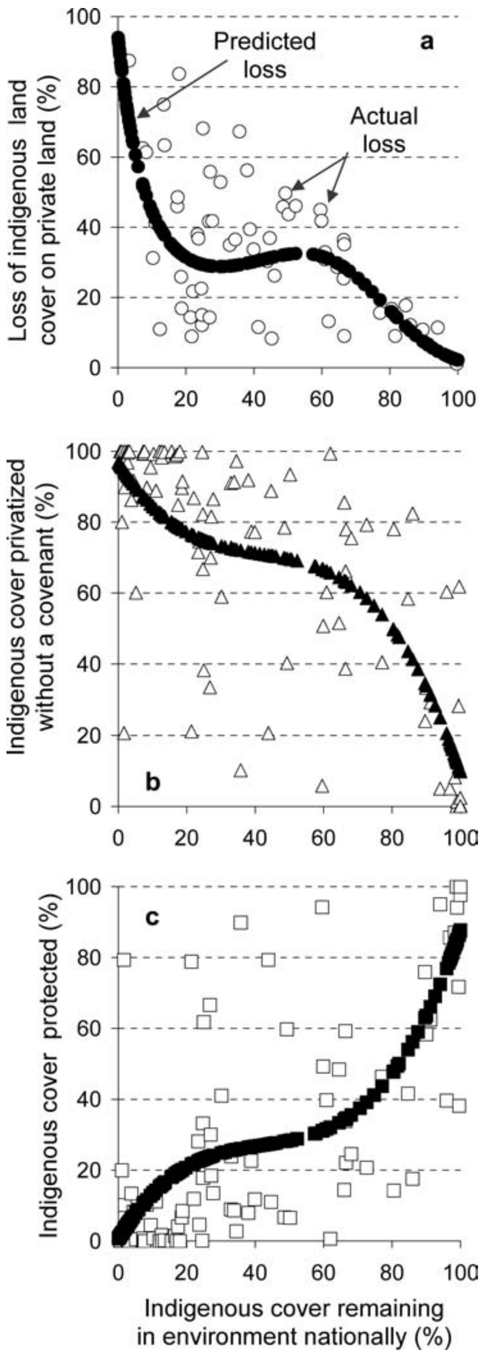

Figure 5. Actual and predicted values for three variables that are predictable with respect to the percent indigenous cover remaining in an environment nationally: (a) loss of indigenous cover on private land relative to Crown leases, showing actual (open circles) values and predicted (filled circles) values; (b) indigenous cover privatized without covenant in land reform (actual, open triangles; predicted, filled triangles); and (c) actual (open squares) and predicted (filled squares) percent indigenous cover protected as public land. Predicted values are shown for 179 land environments affected by land reform.

polynomial equation ($R^2 = 0.58$, df = 60, $p < 0.001$; Fig. 5a). This indicated that environments least suitable for intensive development retained similar percentages of indigenous land cover on private land and on leases, but that differences were large in environments most suitable for intensive land use.

This regression equation predicted high rates of future loss due to privatization (30–100% of all remaining indigenous cover) in environments with <20% indigenous cover remaining and low rates of loss due to privatization (0–15%) in environments with >80% indigenous cover remaining. In total, the equation predicted 39,900 ha (27%) of the 148,200 ha of indigenous cover already privatized by tenure review would be cleared in future, should past land-use patterns continue.

ACHIEVEMENT MEASUREMENT

Biodiversity conservation performance in tenure review deteriorated over time. Larger summed increases in risk of biodiversity loss per unit of land area affected were incurred in each successive phase, and 52% of the total increase in risk of biodiversity loss was incurred in the most recent phase (D) (Fig. 4b). Land allocations in phase D also achieved the smallest decrease in risk of biodiversity loss per unit area of any phase.

Tenure review privatized high percentages of land under indigenous cover in environments with biodiversity at greater risk of loss (Table 1). In environments within the two categories of highest risk to biodiversity, 88% and 96% of land under indigenous cover were privatized without a covenant. Less than 4% of the indigenous cover affected by land reform in these two highest risk categories became public protected land. Of the 128,090 ha of indigenous cover protected as public land by tenure review, most (92%) was in the two lowest categories of risk to biodiversity, and just 0.2% was in the highest risk category (Table 1).

These biases in land allocation were reflected in changes in risk of biodiversity loss. Risk of biodiversity loss increased in moderate and high-risk environments affected by tenure review (categories 3, 4, and 5), with the largest increases in environments where remaining biodiversity was at greatest risk of loss (Fig. 6a). Summed decreases in risk of biodiversity loss were largest in risk categories 2 and 3 (where the initial risk to biodiversity was low or moderate) and smallest in high-risk environments (i.e., in categories 4 and 5).

In 2 of 122 environments affected by tenure review, protection baselines were met through the protection of areas of indigenous cover. Nevertheless, in 36 (30%) of the affected environments, protection baselines were sacrificed because some remaining indigenous vegetation required to meet these baselines was privatized by tenure review. These 36 environments accounted for 11% of all New Zealand environments initially at risk (i.e., with initial legal protection below a pragmatic baseline).

Nature Heritage Fund purchases for conservation led to no increases in risk of biodiversity loss (Fig. 6b). These purchases achieved a summed reduction in risk of biodiversity loss of 20% of that achieved through the tenure review process.

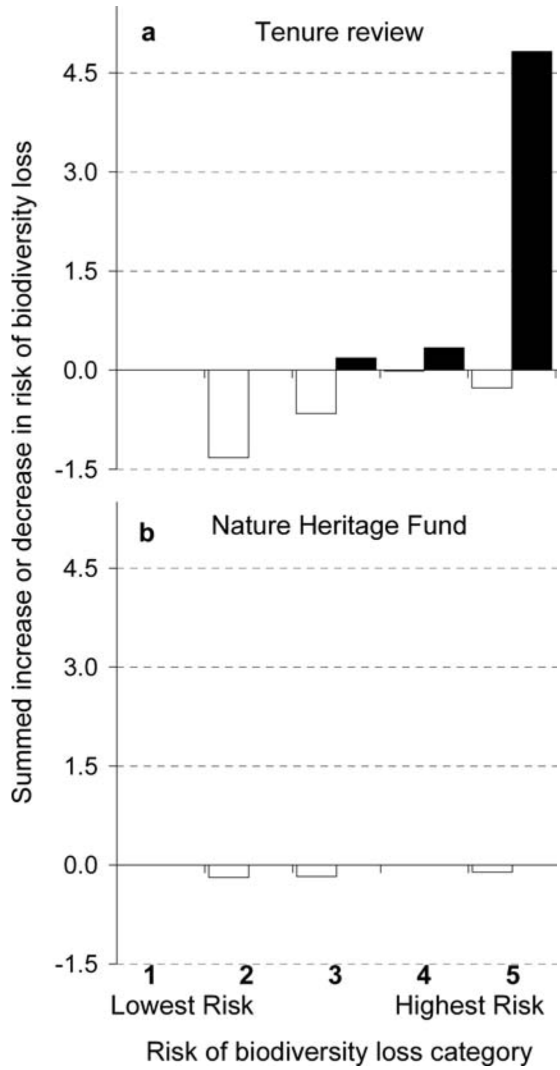

Figure 6. Biodiversity conservation achievement with land reform for environments in five categories of risk of biodiversity loss. Increases and decreases in risk of biodiversity loss in environments affected by (a) tenure review and (b) Nature Heritage Fund purchases. Increases and decreases in the risk of biodiversity loss index were summed separately across the different land environments affected in each category. An increase in risk (black) represents decreased security of biodiversity in some environments and a decrease in risk (white) represents increased security in other environments.

FUTURE LAND PROTECTION, PRIVATIZATION, AND INDIGENOUS COVER LOSS

Regression models showed predictable trends in land allocation in tenure review with respect to the proportion of indigenous cover remaining in the whole environment (Figs. 5b & 5c). The percentage of indigenous cover privatized decreased ($R^2 = 0.53$, df $= 85$, $p < 0.001$; Fig. 5b) and the percentage protected increased ($R^2 = 0.53$, df $= 85$, $p < 0.001$; Fig. 5c) with the proportion of remaining indigenous cover in the whole environment.

When applied to predict future privatization and clearance on leases, the models predicted a further 741,600 ha of indigenous cover would be privatized and 174,300 ha cleared if patterns of land allocation continued, if past land-use patterns continued, and if all remaining leases completed tenure review (Table 1). This would remove 65% of native basin and valley floor habitats at greatest risk of biodiversity loss (initial RBL category 5; Table 1).

Discussion

Development, Validation, and Application of the Index

We measured the net progress achieved though land reform toward a national policy goal for biodiversity conservation in the context of ongoing native vegetation clearance and additions to a highly nonrepresentative (residual) reserve network in interior South Island, New Zealand. To do this, we developed and applied an index of risk to biodiversity based on available national data sets with known limitations (Walker et al. 2006) and declared assumptions.

An index of risk to biodiversity must reliably direct attention to areas where persistence is most compromised by threats. In developing and applying our index, we faced the reality that choice of spatial surrogates for biodiversity and threats was not trivial and inevitably depended on what data were available (Margules & Pressey 2000). Conservation-achievement measures based on different data sets would inevitably differ from ours. Other challenges well known to conservation planners included formulation of realistic yet practicable assumptions and the impediment of deficient biodiversity inventory.

The density of threatened plant records on interior South Island leases was strongly correlated with our risk of biodiversity loss index. This result was prima facie validation of the index and suggested our combination of surrogates identified factors that did in fact threaten species within environments. The distribution of threatened plant records on leases was also consistent with a decrease in the number of threatened plant species with elevation across New Zealand (de Lange et al. 2004). Nevertheless, more rigorous testing of the relationship between risk of biodiversity loss and threatened species would require de novo sampling because our data set represented a single biotic group and did not arise from statistically robust stratified search effort. Enhanced species distribution data would enable testing of assumptions about protection effectiveness and inform the choice of species–area relationship exponent (z). Although the trends our results revealed would remain the same, a larger z would distribute risk of biodiversity loss more evenly across environments, whereas a smaller z would emphasize risk in depleted habitats. Alternative, improved indices of risk to biodiversity could be constructed to fit enhanced data.

In application of our index of risk of biodiversity loss, a major assumption was that future patterns of indigenous vegetation clearance in relation to environment would mimic those of the past. Future changes in land-use policy might alter rates and patterns of clearance, and this source of uncertainty could potentially be examined by modeling alternative scenarios. Here, we may have underestimated future loss of indigenous cover on former lease land for two reasons. First, loss of native grassland over the last decade was underreported in our land-cover databases (Walker et al. 2006), and land-use intensification has accelerated markedly in New Zealand over this period (Parliamentary Commissioner for the Environment 2004). Second, some areas privatized by tenure review are now exempt from rules constraining indigenous vegetation clearance under the Resource Management Act (1991) and so are more vulnerable to clearance than other private land.

Consequences of Land Reform

Land reform in interior South Island, New Zealand, appears to have been a classic example of locating new reserves in places where they contribute least to the representation and security of biodiversity (Pressey 1994; Margules & Pressey 2000). New protected areas were mainly located in environments where biodiversity was already best protected and at little risk of indigenous vegetation clearance under any tenure type.

Our measure of conservation progress used the optimistic assumption that conservation management in public protected land extinguished all risk to biodiversity. Even with this optimistic assumption, our results showed that the large areas of high-elevation land reserved through land reform contributed little to the security of biodiversity. This is because conservation achievement was not measured in hectares (Pressey 1994) but in units reflecting net progress toward protecting ecosystems and species that actually need protection (Pressey & Taffs 2001). In interior South Island ecosystems and species that actually need protection are at low elevation and at high risk of loss to intensive development. Almost all those affected by land reform were privatized with no protective mechanisms.

Maintenance of biodiversity requires protection of the long-term capacity of the landscape to support species populations (Carroll et al. 2004). Yet half the indigenous habitats affected by inland South Island land reform (to May 2005) were privatized and our models predict this will lead to substantial further loss of indigenous habitats in interior South Island if past land-clearance trends continue. The models indicate that the scale of this loss will be sufficient to appreciably increase national rates of indigenous vegetation loss (Walker et al. 2006) and further jeopardize the capacity of inland South Island landscapes to sustain native species. Low and mid-elevation habitats supporting the highest densities of threatened plant species will be disproportionately reduced.

Pressey (1994) and Pressey et al. (2004) predict that new residual reserves in areas safe from ongoing land clearance will have opportunity costs in the form of irretrievable reductions of more vulnerable features. Here, we quantified the opportunity cost of land reform in terms of increased risk to lowland biodiversity. Manifestations of these costs are likely to be global extinction of low and mid-elevation endemic species, direct extirpation of species through loss of critical habitat, and long-term extinction debt (Carroll et al. 2004) as indigenous remnants become increasingly isolated in an exotic matrix.

Alternative Approaches

New Zealand's Government endorsed the New Zealand Biodiversity Strategy (Department of Conservation [DOC] and Ministry for the Environment [MfE] [2000]) in 2001. In 2003 it revised its objectives for the South Island High Country to include outcomes consistent with the strategy. In 2005 it stated that its priority High Country objectives were ecological sustainability and protection of significant inherent values (which include biodiversity). Yet change in our index of risk to biodiversity revealed that land reform is failing to meet biodiversity and ecological sustainability objectives and that the performance of tenure review had deteriorated over time.

These results indicate that further major damage to biodiversity could be avoided by ceasing tenure review in its current form. To sustain the landscape's capacity to support biodiversity into the future, alternative policies and processes are needed that retain the lowland native habitats and connected elevation sequences of native vegetation that now remain on leases. Our results suggested that ecological sustainability and biodiversity objectives would be better met by retaining leases under conservative land management constraints. They also indicated that whole-lease conservation purchases might achieve a wider range of objectives, although we caution that associated destocking might lead to land-use intensification in threatened habitats elsewhere, as recorded by Pressey et al. (2002).

Incorporation of principles of irreplaceability and vulnerability into the design of alternative policy tools will be important if they are to achieve desired biodiversity outcomes (Cowling et al. 2003). In interior South Island land reform is voluntary, site availability is uncertain, reserve acquisition is protracted, and rates of biodiversity loss are high. In such situations Meir et al. (2004) demonstrate by simulation that design of optimal reserve-network blueprints may be counterproductive. Thus, a simple decision-support tool, such as our index of risk of biodiversity loss, might be more effective for protecting biodiversity here. The index would reveal opportunities to protect irreplaceable and vulnerable biodiversity as these became available and could be iteratively updated to reflect changing priorities.

Need for Systematic Biodiversity Measurement and Reporting

Rather than meeting goals to protect indigenous biodiversity, New Zealand's land reform appears to have hastened its decline. The absence of measurement of progress toward biodiversity goals may have contributed to this outcome.

Government agency reports on land reform in interior South Island show hectares of ecosystems and environments reserved and species protected but do not mention the privatization of native ecosystems or adverse effects on indigenous species (e.g., Land Information New Zealand 2005, unpublished data). The opening of new conservation parks may also convey the impression that land reform is achieving conservation gains. Such publicizing of gains but not losses are misleading—akin to reporting revenue without expenses and calling it net profit. Crucially, such reporting conveys no information about net progress in protecting ecosystems and species that were actually threatened (Pressey & Taffs 2001). Explicit and systematic conservation-performance measures are needed to ensure that the public and decision makers see a more complete biodiversity balance sheet.

Systematic conservation-planning principles provide explicit baselines and standards against which decision makers can measure actual achievement. Yet measurement and reporting of net conservation achievement has been rare worldwide. The New Zealand case is not unique. Reserve acquisition worldwide competes with commercial, economic, and social objectives for the land. High rates of habitat loss compromise conservation goals, and it is politically expedient to choose protected areas where they least conflict with competing aspirations. Decision makers everywhere will give more weight to objectives for which there are robust performance measures. To achieve effective protection for biodiversity, conservation biologists must develop practical methods to measure and report honestly on the costs and benefits for biodiversity of conservation decisions. These audit tools must become embedded in administrative practice so that biodiversity is better accounted for in land-allocation decisions.

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