Animal Conservation

Animal Conservation. Print ISSN 1367-9430

Single-species conservation in a multiple-use landscape: current protection of the tiger range

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Keywords
threatened species; management effectiveness; protected area; tiger; oil and gas; land use.

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Editor: Matthew Gompper

Received 25 July 2010; accepted 10 November 2010

doi:10.1111/j.1469-1795.2010.00428.x

Abstract

We report on land management and protected area management effectiveness in the tiger range. Wild tigers *Panthera tigris* are found in 13 countries, with habitat that is also important for ecosystem services, biodiversity and a number of other threatened species. Timber production, mineral mining, oil and gas concessions and protected areas are common land-use designations in tiger habitat. Twenty-one per cent of the current tiger range is under some form of protection, while 9% is designated as 'strictly protected,' in IUCN categories I or II. Fifteen per cent of the tiger range is under oil and gas concession. These concessions also overlap 152 protected areas, 55 of which are categorized as strictly protected. Management effectiveness tracking tool responses suggest that the majority of protected areas in the tiger range are inadequately managed to meet their objectives, and the most commonly reported management challenges are minimal enforcement and budgets. We observe that even strictly protected areas are subject to a variety of pressures, particularly resource extraction. Results imply that the establishment and enforcement of effective protected areas in each tiger landscape, sufficient to protect and grow breeding tiger populations, could help change current trends. These areas should be free from incompatible land uses, and should be adequately resourced to meet management, enforcement and monitoring challenges. Weaknesses in protected area management identified here have implications for species and ecosystem services that share the same geography as tigers. In addition, results suggest that similar issues may exist for threatened species and protected areas in other geographies as well.

Introduction

Protected areas have long been considered a core strategy for biodiversity conservation (Terborgh & van Schaik 2002; Rodrigues *et al.,* 2004; Chape, Spalding & Jenkings, 2008). Species with large home ranges and migratory species present a particular set of challenges, because their habitat requirements often extend beyond the boundaries of protected areas (Lambeck, 1997; Caro & O'Doherty, 1999; Sanderson *et al.,* 2001). For such species, the composition of land ownership and management within the species' home range is critical for predicting their long-term survival. Few studies in the past have looked comprehensively at land management across a species range, including not only protected areas but also concessions, community-use zones and other land-use designations. In addition, conflicts between land-use designations have rarely been systematically summarized for threatened species. Here, we take a comprehensive approach to evaluate land management and protected area management effectiveness for one species, the tiger *Panthera tigris*.

The tiger is a wide-ranging feline predator endemic to the forests and grasslands of south and south-east Asia, the Russian Far East and north-east China, and until the last century, Central Asia. Listed as Endangered on the IUCN Red List of Threatened Species (IUCN, 2010), the species has suffered dramatic decreases in population and habitat, with current estimates of only 3500 tigers inhabiting $<7\%$ of their historic range (Sanderson *et al.*, 2006; Dinerstein *et al.*, 2007; Seidensticker, Gratwicke & Shrestha, 2010).

The main threat to the species is direct hunting of tigers and their prey, but other important threats include habitat loss associated with agricultural, urban and infrastructure expansion, and extractive resource consumption such as logging and mining (e.g. Kerley *et al*., 2002; Linkie *et al*., 2003; O'Brien, Kinnaird & Wibisono, 2003; Dinerstein *et al*., 2007). Despite vast reductions in habitat and population over the last century, wild tigers are still found in 13 Asian countries, where their habitat overlaps with areas of high ecosystem service value, particularly carbon and water filtration, as well as areas of high plant diversity, important bird areas and the ranges of other threatened species (Kier *et al.,* 2005; Sanderson *et al.,* 2006; Birdlife International, 2010; Shapiro & Bhagabati, 2010).

Protected areas have long been considered a core part of the conservation strategy for tigers. Some protected areas, such as Nagarhole Tiger Reserve in India, Chitwan National Park in Nepal and Bukit Barisan Seletan National Park in Indonesia, were established with the objective of providing a secure place for tigers and their prey to live and breed, while ensuring adequate protection against hunting, habitat loss and human activities. Other protected areas in the tiger range were established to protect biodiversity more broadly. The effectiveness of protected areas, however, is another question. Globally, attention has been raised about the prevalence of 'paper parks,' protected areas that are legally gazetted, but are little more than lines on a map (Brandon, Redford & Sanderson, 1998; Stolton & Dudley, 1999). Many other protected areas have management measures in place, but still run short of fulfilling their objectives.

Tools to assess the management effectiveness of protected areas have been developed and are being implemented around the globe (Ervin 2003*a*; Hockings*,* 2003; Parrish, Braun & Unnausch, 2003; Hockings *et al*., 2006; Leverington *et al*. 2010). The management effectiveness tracking tool (METT) (Stolton *et al.,* 2003; Chape *et al*., 2005; WWF & WB, 2007; Leverington *et al*., 2010) is aimed at tracking progress in protected areas over time, and has also been used to compare groups of protected areas for their management effectiveness (Dudley *et al*., 2007; Leverington *et al.,* 2010). Other commonly used tools include the Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) (Ervin, 2003*b*), for evaluating the adequacy of protected area networks; and the Management Effectiveness Evaluation for Tiger Reserves (Project Tiger Directorate, 2006). These tools are not meant to replace objective biological and socioeconomic surveys, but can tap knowledge gathered through rigorous surveys, produce information quickly, in a comparable format and at a relatively low cost.

In this study, we use a comprehensive approach to evaluate threat across the range of a threatened species as a function of land management and protected area management effectiveness, using the tiger as an example. To do this, we evaluate the total area of the tiger range under different land-use types (from hereon referred to as land zones), including protected areas, concessions, plantations and community-use zones. We evaluate protected area management effectiveness using two measures: METT responses for protected areas, and the amount of overlap between protected areas and other land zones. We use range wide datasets where possible; but where comprehensive data are not available, we focus our analysis on three focal landscapes: the seven tiger landscapes of southern Sumatra, Indonesia; the Annamite mountain range and the dry forest habitat on the border of Cambodia, Laos and Vietnam; and the temperate forests of the Russian Far East (Fig. 1). Our analysis looks at land zones designated by central government for a particular purpose, and not necessarily unzoned land use. Actual land uses are undeniably important, but are outside the scope of our study. We define the current tiger range as the extent of tiger conservation landscapes (TCLs), which are large blocks of potential tiger habitat that had evidence of tigers in the year 2005 (Sanderson *et al*., 2006; Dinerstein *et al*., 2007). We use tigers as a case study because data on their range are available to make this analysis possible, and because the status of protected area management effectiveness has not been quantitatively evaluated for the entire range of this species. In addition, little comprehensive information exists about land management outside protected areas in otherwise good habitat for the species, or about land-use conflicts within protected areas. Our analysis complements and updates earlier assessments of tiger conservation status, while providing a framework for evaluating management status for a threatened species that ranges beyond the boundaries of protected areas.

Methods

We relied on four existing datasets to assess land management in the tiger range. These included: (1) TCLs, the best existing coverage of the tiger range (Sanderson *et al.,* 2006; Dinerstein *et al.,* 2007); (2) the World Database on Protected Areas (WDPA) global polygon dataset (UNEP & IUCN, 2009); (3) new and archived METT responses (Stolton *et al.,* 2003; UNEP-WCMC, WWF & WB, 2009); and (4) data on oil and gas concessions for the year 2009 (IHS, 2009). To complement these regional datasets, we used locally available data on protected areas and concessions in the three focal landscapes. All area calculations were completed in the Goodes Homolosine projection.

We selected nationally designated protected areas from the WDPA and manually edited the layer to remove topological errors. We next intersected it with the TCL layer and calculated the area protected rangewide, by TCL, and by IUCN category (Dudley, 2008).

We used a spatial database from IHS (2009) to assess the area of the tiger range under oil and gas concession. Each concession polygon is attributed with the rights type (open area, bidding block, valid application or under contract), and whether a concession is current or historical. Open areas are at the earliest stage of the concessioning process. They have been designated by their national government as areas that will be explored for oil and gas. Bidding blocks are areas open for bidding by companies to conduct exploration or production. Valid application blocks are areas for which

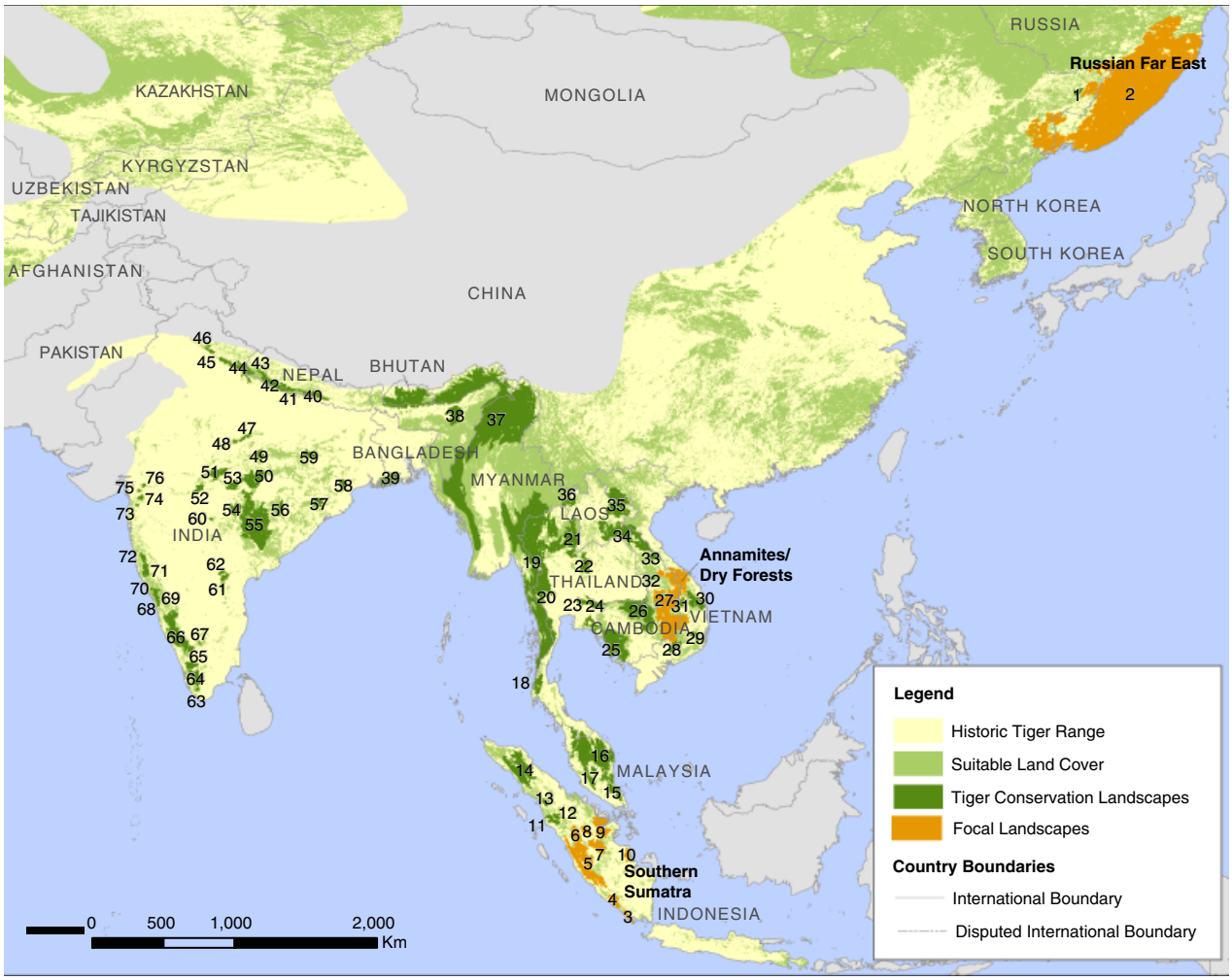

Figure 1 Tiger conservation landscapes (TCLs) with focal landscapes highlighted. Focal landscapes in this study included the seven TCLs of southern Sumatra, Indonesia; the Annamites/Dry Forest TCL of Cambodia, Laos and Vietnam; and the Russian Far East TCL. Unofficial TCL names are provided as a reference for subsequent figures and discussion. Note that the boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance. TCL names: 1, Heilongjiang; 2, Russian Far East – Changbaishan; 3, Bukit Barisan Selatan South; 4, Bukit Balai Rejang – Selatan; 5, Kerinci Seblat; 6, Bukit Rimbang Baling; 7, Bukit Tigapuluh Landscape; 8, Tesso Nilo Landscape; 9, Kualar Kampar-Kerumutan; 10, Berbak; 11, Bukit Barisan South; 12, Rimbo Panti-Batang Gadis West; 13, Sibologa; 14, Gunug Leuser; 15, Endau Rompin; 16, Taman Negara – Belum; 17, Krau; 18, Khlong Saeng; 19, Tenasserims; 20, Salak-Phra; 21, Phu Miang – Phu Thong; 22, Phu Khieo; 23, Khao Yai; 24, Thap Lan – Pang Sida; 25, Cardamom's; 26, Cambodian Northern Plains; 27, Annamites/Dry Forest; 28, Cat Tien; 29, Bi Dup-Nui Ba; 30, Kon Ka Kinh; 31, Yokdon; 32, Xe Bang Nouan; 33, Hin Nam Ho; 34, Northern Annamites; 35, Nam Et Phou Loey; 36, Nam Ha; 37, Northern Forest Complex – Namdapha – Royal Manas; 38, Kaziranga – Garampani; 39, Sundarbans; 40, Chitwan; 41, Bardia South; 42, Bardia; 43, Suklaphanta; 44, Corbett – Sonanadi; 45, Rajaji Minor; 46, Rajaji Major; 47, Panna East; 48, Panna West; 49, Bandhavgarh – Panpatha; 50, Kanha – Phen; 51, Pachmarhi – Satpura – Bori; 52, Melghat; 53, Pench; 54, Andhari – Tadoba; 55, Indravati; 56, Sunabeda-Udanti; 57, Satkosia-Gorge; 58, Simlipal; 59, Palamau; 60, Painganga; 61, Nagarjunasagar South; 62, Nagarjunasagar North; 63, Shendurney; 64, Periyar – Megamala; 65, Anamalai-Parambikulam; 66, Western Ghats: Bandipur – Khudrenukh – Bhadra; 67, Biligiri Range; 68, Western Ghats – Sharavathi Valley; 69, Dandeli – Anshi; 70, Dandeli North; 71, Radhanagari; 72, Chandoli; 73, Mahabaleshwar Landscape – South; 74; Purna; 75; Mahabaleshwar Landscape – North; 76, Shoolpaneswar. [Correction added after online publication 15 March 2011: In the legend of Figure 1, TCL names have been updated to 'Suklaphanta', 'Bardia', 'Bardia South', 'Chitwan']

valid applications have been received from companies. Areas under contract are areas where a particular company has signed a contract to conduct evaluations or studies, exploration, drilling, production or development. We selected current concessions that overlap TCLs, and omitted historical concessions from the analysis. We produced statistics on the area of each TCL under oil and gas concession, and the number of protected areas overlapping oil and gas concessions.

In the three focal landscapes, we complemented the regional protected area and oil and gas data with additional data on protected areas, timber, mining and agricultural

concessions, plantations and community-use zones. Different countries had different land zone designations and management protocols. To group them in comparable classes, we selected zones with similar primary objectives. For example, the production forest class includes oil palm, acacia and rubber plantations in Sumatra, production forests in Laos, forest lands in Russia and economic land concessions in Cambodia. The protected area class includes all protected areas from the WDPA and national databases, as well as protection forests in Laos. Land zones that had no clear categorical matches in another landscape were placed in their own category. Areas in the landscape for which management designation was not known to this study were designated 'unknown.'

We relied on a database of previously submitted METT responses to assess protected area management effectiveness in TCLs, augmented with additional METT questionnaires filled out for this study (UNEP-WCMC, WWF & WB, 2009). The METT consists of a set of multiple choice questions for protected area managers to answer in collaboration with NGO staff and scientists on the status of different management and threat indicators. Responders are asked to provide a justification and source for each response. The METT enables interpretation and reporting on a broad range of indicators by people that are most knowledgeable about the threats, biodiversity status and management in a given protected area.

Some protected areas had METT responses representing more than 1 year, and in these cases, we used the response from the latest year for our analysis. We selected questions that we believed to be most tightly linked to tiger conservation and threats, and used these to create six indicators of management: (1) boundary demarcation; (2) regulations and enforcement; (3) resource management; (4) staff numbers and training; (5) budget and budget security; (6) economic benefit to communities. Each of these categories, except resource management and economic benefit, represent the average score across two to three questions related to that theme. We also generated a summary score that expresses the normalized average response for a given protected area across the six selected management effectiveness categories (Table S1).

Results

Area protected in TCLs

Approximately 21% of the tiger range is under some type of formal protection. However, only about 9% of TCL area is protected in IUCN categories I or II, which we define as 'strictly protected areas' (Table 1). The percentage of area protected in each TCL varies widely. Of the 76 TCLs in the tiger range, nine have 0% of their area protected and 19 TCLs have $<10\%$ protected, while not a single TCL is 100% protected. Thirty-four of the 76 TCLs have no strictly protected areas, and 52 TCLs have $<10\%$ of their area in this class (Fig. 2, Table S2). The average area of strictly protected areas per TCL is 1600 km^2, but the median area in this class is only 240 km^2. These figures do not address the location of strictly protected areas, and whether they cover one large, or many smaller areas in each landscape.

Table 1 Per cent of total tiger conservation landscape (TCL) area protected and number of protected areas (PAs) by IUCN category

IUCN category	Number of PAs	Area (km^2)	Per cent of total TCL area
Ia – Strict nature reserve	11	5640	0.5
Ib – Wilderness area	0	0	0.0
II – National park	126	102 671	8.6
III – Natural monument or feature	12	11 900	1.0
IV – Habitat/species management area	160	91 512	7.7
V – Protected landscape/seascape	20	2024	0.2
VI – PA with sustainable use of natural resources	34	23 646	2.0
Not known	21	17 429	1.5
Total	384	254 822	21.4

Area under concession

Oil and gas concessions (areas under contract) and potential concessions (open areas, bidding blocks and areas with valid applications) together cover 176 791 km^2, or 14.9% of the tiger range. About 110 444 km^2 of this area, or 9.3% of tiger habitat, has already been licensed to oil- and gas-producing companies and formally opened for exploration, drilling, production or other activities. The remaining 5.6% of this area has been designated for oil and gas activities by governments, but these blocks are at earlier stages of the licensing process. Both enacted and potential concessions overlap with 152 out of 384 protected areas in TCLs, or 40% of all protected areas in TCLs. Fifty-five of these are strictly protected areas, and three are classified in IUCN category III ('national monument'). In all, at least 33 of the 76 TCLs overlap with oil and gas concessions, and may realistically be affected at some point by exploration or extraction activities. Eleven TCLs have over 50% of their territory either open for licensing, or already under contract to companies for oil and gas exploration or production (Figs 3 and 4). Three TCLs are completely covered by oil and gas concessions, two of which also have over 75% of their area designated as protected areas, including strictly protected areas.

The focal landscape analyses indicate that even though a significant portion of TCLs are under formal protection, equally significant portions are allocated for concessions or alternate land uses. The proportions of land uses tend to vary by landscape. In southern Sumatra, the predominant land zones in TCLs tend to be protected areas, oil and gas concessions, plantations for timber (primarily acacia for wood pulp) and non-timber products (oil palm and rubber), with a relatively small amount of land in agricultural concessions. In the Annamites/Dry Forest TCL, the dominant

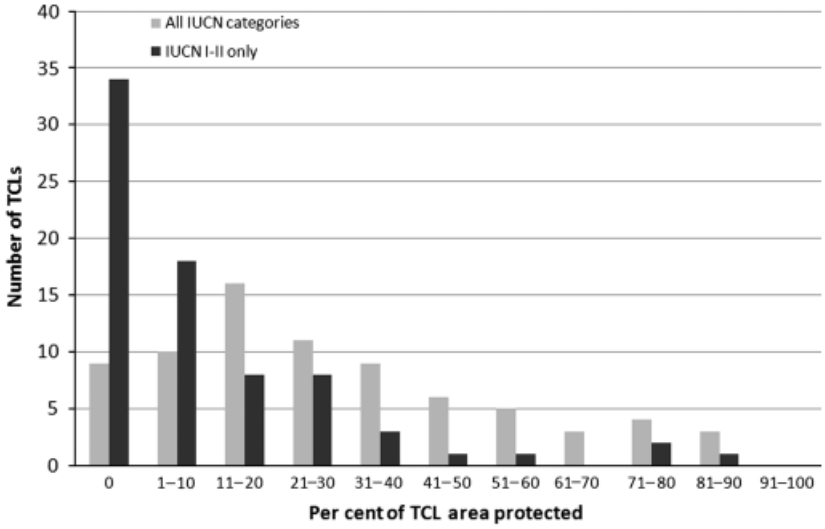

Figure 2 Number of tiger conservation landscapes (TCLs) by per cent area protected.

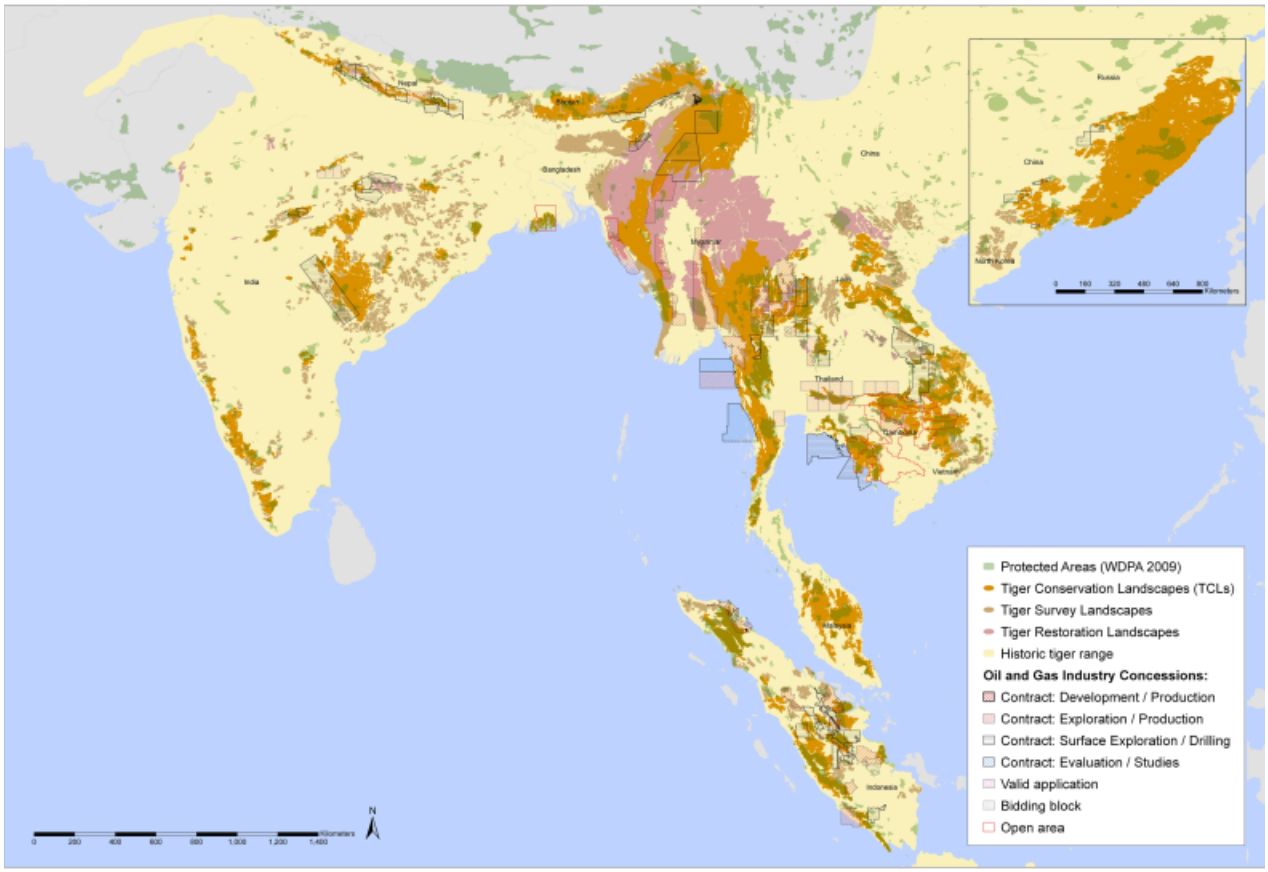

Figure 3 Oil and gas concessions that overlap tiger conservation landscapes (TCLs). TCLs are defined as large blocks of habitat with evidence of tigers in 2005. Survey Landscapes are large blocks of habitat with tiger status unknown. Restoration Landscapes are large blocks of habitat where tigers had been extirpated by 2005. Data sources: Sanderson *et al.*, 2006; IHS, 2009; UNEP & IUCN, 2009.

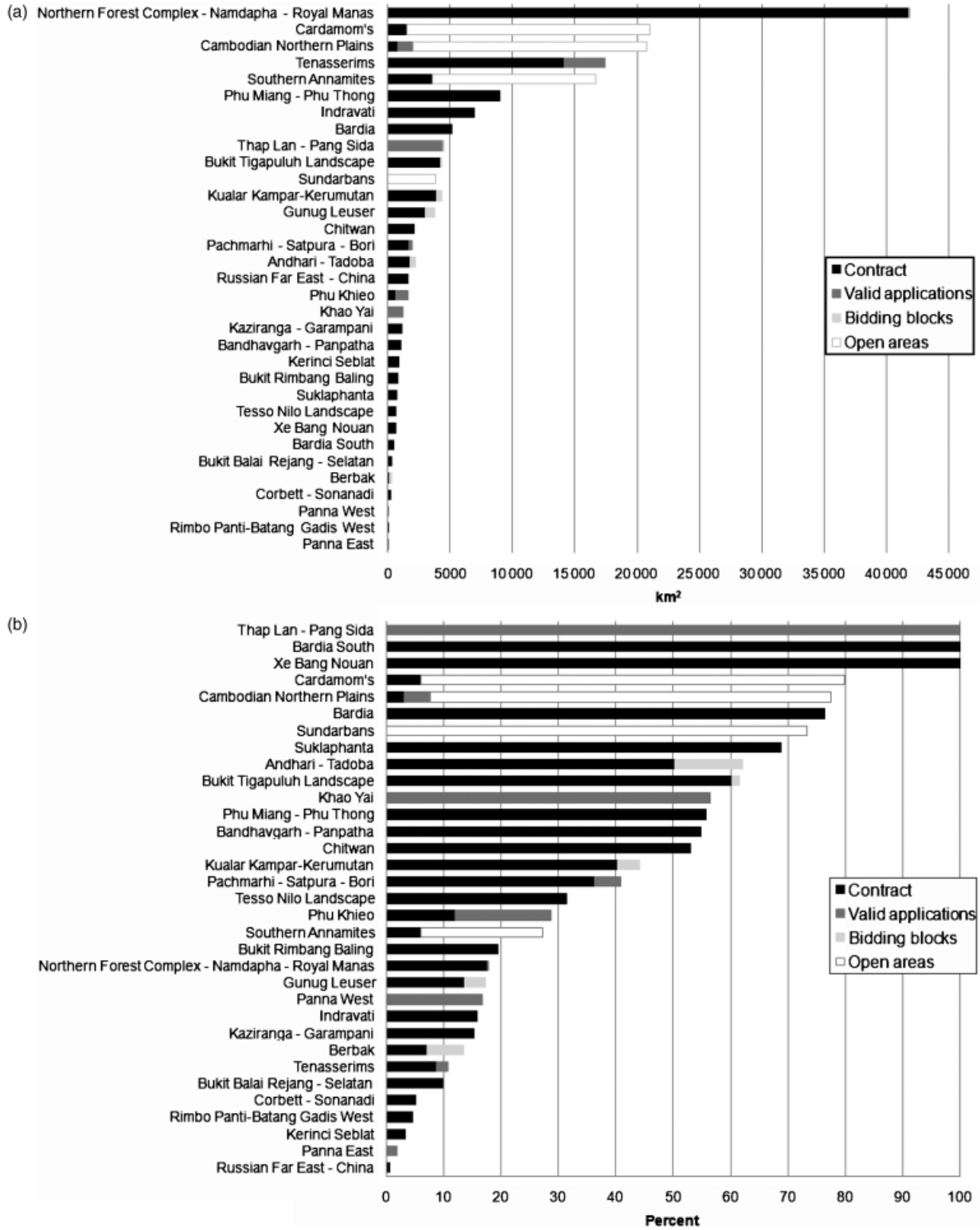

Figure 4 (a) Area of each tiger conservation landscape (TCL) under oil and gas concession**.** (b) Per cent of TCL area under oil and gas concession. [Correction added after online publication 15 March 2011: On the Y axis of Figure 4a and b, TCL names have been updated to 'Suklaphanta', 'Bardia', 'Bardia South', 'Chitwan']

Table 2 Area of focal landscape by land zone[a]

Land zone	Southern Sumatra TCLs	Annamites/ Dry Forest	Russian Far East/ Changbaishan
Protected areas[b]	37.2	50.9	26.7
Protected areas (proposed)	1.1	–	–
Community use	–	1.8	–
Production forest[c]	17.7	5.9	78.1
Oil and gas concession	18.5	27.2	0.6
Mining concession	–	9.7	–
Agriculture (large-scale or concession)	5.2	–	4.3
Small-scale agriculture	–	–	0.07
Industry	–	–	0.5
Farm/industry	–	–	0.05
Undisturbed lands	–	–	1.6
Unknown	39.8	44.6	10.1

[a]Total land zone per cent may exceed 100 because some areas of land are assigned to multiple zones.

[b]Protected areas = designated protected areas in all countries, as well as protection forests in Laos

[c]Production forests = economic land concessions in Cambodia, production forests in Laos, forest lands in Russia and timber (primarily acacia for wood pulp) and non-timber (oil palm, rubber) concessions in Sumatra.

–, no data available.

land zones are protected areas, oil and gas, timber and mining concessions and community-use zones. In the Russian Far East, the major land zones are for protection and timber production (Table 2). Protected areas often overlap with alternate land zones. In southern Sumatra, oil and gas concessions overlap with 10 protected areas, three of which are national parks. In the Annamites/Dry Forest TCL, 8% of all area protected is also zoned for timber, mining and community use. In this landscape, nine protected areas (two of which are strictly protected areas) are also zoned for oil and gas exploration or development.

Protected area management effectiveness

Our METT database included 67 responses for 46 protected areas in 24 TCLs (Fig. S1). When the response for the most recent year is selected, the sample represents 12% of protected areas in the tiger range by number, or 16% of the total area protected in the tiger range. Approximately 20% of protected areas sampled have few or no management measures in place, 70% have some management measures in place but these measures are not fully functional and only about 10% of protected areas have a suite of management measures in place that appear to be fully effective (Fig. 5). Individual indicators of management effectiveness suggest that most protected areas are not working at their full capacity to achieve their conservation role. Categories of greatest concern across all protected areas were quality of enforcement and regulations, and budget security. Over 20% of protected areas also report that resource management and boundary demarcation requirements remain unaddressed. For each of the six indicators, only 5–15% of respondents indicated that objectives were being entirely met in their protected area (Fig. 6).

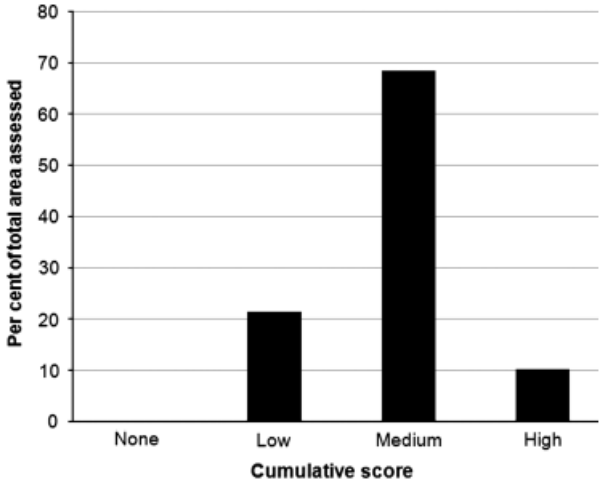

Figure 5 Cumulative management effectiveness score in protected areas.

Reports of protected area management effectiveness tend to vary by landscape and region – with those in Indonesia and the Mekong region (specifically Vietnam, Cambodia, Laos and Thailand) scoring at the low end of the spectrum, and those in the Russian Far East and India scoring at the high end of the spectrum (supporting information Table S3). We found that 60% of protected areas identified hunting, 17% identified logging for timber and 18% identified habitat conversion as one of the top two threats.

Limitations to interpretation

There are a few data limitations inherent in this study. The TCL layer represents potential habitat for tigers based on tiger observation points, land cover and human influence, but the actual habitat quality and density of tigers vary within them (Walston *et al*., 2010). Conversely, the extent of protected areas and oil and gas concessions may be underestimated, and attributes such as IUCN category and concession rights type may not be up to date (Chape *et al.,* 2005; Dudley, 2008; IHS, 2009). Because of these two factors, estimates of protected area and concession coverage in TCLs may be slightly conservative, but we believe that having more perfect databases are not likely to change the overall conclusions of the study. At the focal landscape scale, we relied on national protected area coverages rather than the WDPA, and think that this decision is appropriate for landscape-scale analyses. We were limited in this study by the lack of comprehensive regional data on land zones such as timber concessions, plantations, agriculture and municipalities. Either these data do not exist or they are scattered among a variety of government departments and commercial operators. While the focal landscape results provide a glimpse at the array of intended land uses within

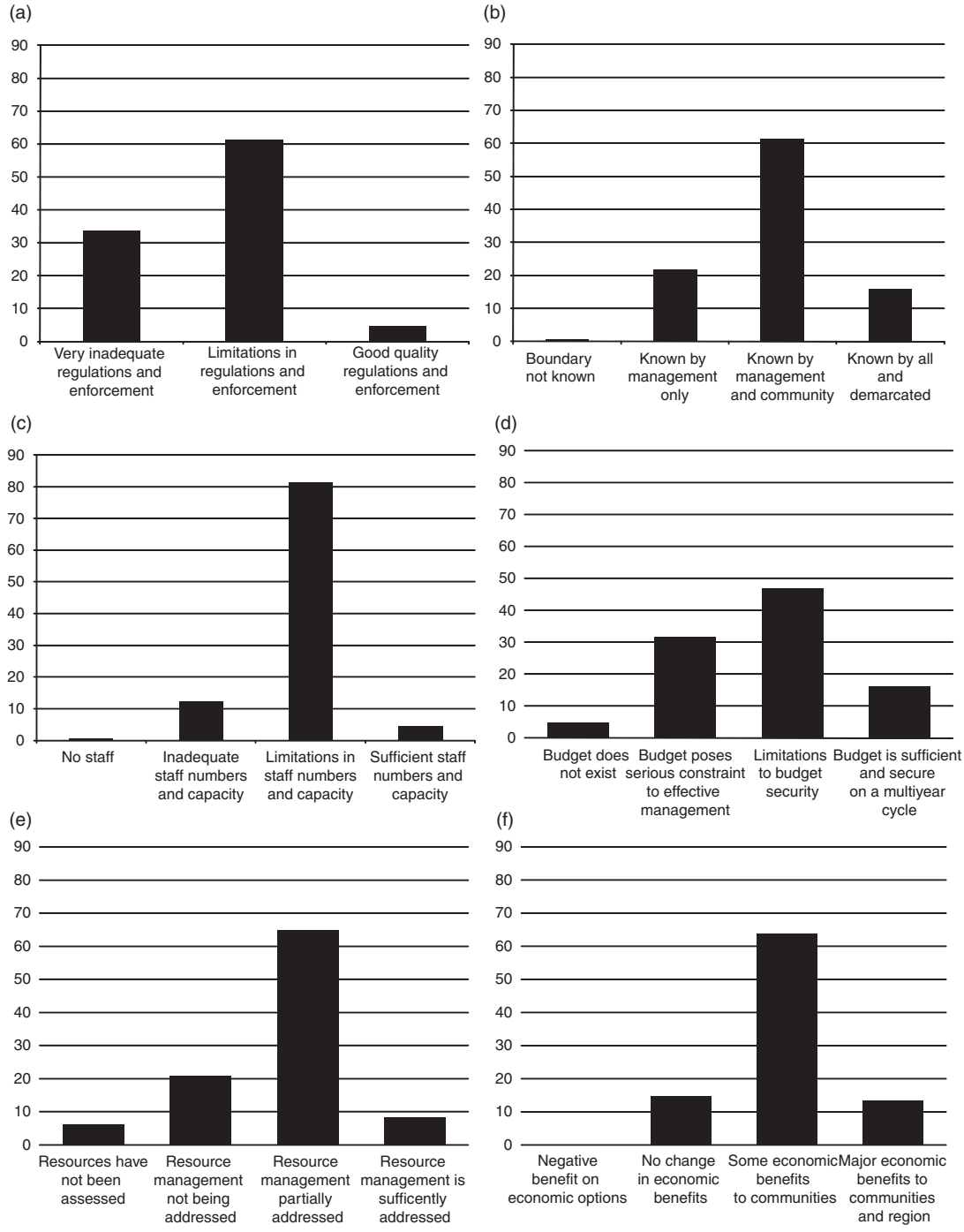

Figure 6 Six management effectiveness indicators by per cent of total area assessed. (a) Quality of regulations and enforcement. (b) Boundary demarcation status. (c) Staff numbers and training. (d) Budget security. (e) Resource management. (f) Economic benefit to communities.

TCLs, our study clearly would have benefited from regional datasets on all land zones.

We chose METT evaluations to look at protected area management as the only systematically collected dataset for a large number protected areas. We attempted to control for bias by requiring the questionnaires to be filled out by groups of protected area managers, scientists and NGO staff. While the results undoubtedly represent the perceptions of these groups (Leverington *et al.,* 2010), the fact that reports were on the whole poor is nonetheless informative. We assume the results may present a more favorable picture of protected area management in the tiger range than what actually exists, due to the fact that responding areas had NGO's assisting in them and the capacity to respond.

Discussion

Strictly protected areas, free from development and effectively enforced against hunting and other human activities, have been proposed as a core part of the tiger conservation strategy (Dinerstein *et al*., 2007; Walston *et al.,* 2010). We found that 34 tiger landscapes, or nearly half of all TCLs, lack strictly protected areas, and nine TCLs lack protected areas of any type. The Convention on Biological Diversity recommends that at least 10% of each *ecoregion* be effectively protected (CBD Decision VII/30, 2004). When the area protected in tiger landscapes is compared with the CBD target, we find that 25% of TCLs fail to meet this standard; and this failure rate increases to 70% of TCLs if only strictly protected areas are considered. We think a more relevant metric for protection in each TCL is enough space to support a viable population of tigers. Some experts suggest that a minimum population of 25–83 breeding female tigers is viable, with area requirements ranging from 140 to 6500 km^2, depending on the location of the population, its habitat type and its productivity (Kenney *et al.,* 1995; Karanth & Stith, 1999; Chapron *et al.,* 2008). The population viability studies on which these numbers were based do not take all population pressures into consideration, including environmental stochasticity, inbreeding depression, disease, prey limitations and direct hunting, and hence may underestimate viable population size. To overcome uncertainty associated with the convergence of population pressures, area requirements for protected areas in each TCL should be large enough to not only support a minimum population, but also be set in a landscape and metapopulation context to ensure long-term sustainability (Wikramanayake *et al.,* in press).

While area under formal protection is certainly important, the effectiveness of these protected areas is equally important. (Chape *et al.,* 2005). METT responses for protected areas in the tiger range reveal that in general, management measures are either entirely absent, or are in place but not functioning to meet protected area objectives. The most commonly reported problems included insufficient regulations and enforcement, and budget security. Hunting was reported to be the foremost threat in the majority of protected areas sampled. We found extractive resource concessions within protected areas (even those categorized as 'strictly protected') to be a pervasive phenomenon. This finding challenges the paradigm that protected areas are long-term bastions for conservation. Observed land-zone conflicts suggest that when economically valuable resources are available; such as oil and gas, minerals, timber or arable land, protected areas tend to be at risk. In the past, this has resulted in downgrading, downsizing or degazettement of protected areas around the globe, including some in tiger-range countries such as Malaysia and India (Mascia & Pailler, 2010).

Concessions for resource extraction are common in tiger landscapes, with 15% of the tiger range designated for oil and gas, and significant portions of the focal landscapes designated for timber, mining or other uses. A consideration of the impacts of these activities is relevant here. Oil and gas exploration and extraction in wildlife habitat have resulted in disturbance during seismic exploration; deforestation for access roads, drilling platforms and pipelines; and increased rates of logging, illegal bushmeat hunting and deforestation for human settlement resulting from improved access to previously remote primary forest (Thomsen *et al*., 2001; Epstein & Selber, 2002; Thibault & Blaney, 2003; Finer *et al*., 2008; Beckmann & Seidler 2009; Copeland *et al.,* 2009). Oil and gas development in North America has influenced habitat selection by mule deer *Odocoileus hemionus* and Caribou *Rangifer tarandus* (Klein, 1991; Sawyer *et al*., 2006). In Nepal, construction of an oil and gas depot in the buffer zone of Parsa Wildlife Reserve led to deforestation of tiger habitat, conflicting with wildlife management objectives (G. J. Thapa 2010, pers. comm.). Likewise, a critical corridor across the Gola River that maintained connectivity for elephant and tiger movement from Corbett Tiger Reserve, India, toward the Nepal border was severed by the construction of an oil depot (Johnsingh *et al*., 2004; Wikramanayake *et al.,* in press). In Indonesia, oil and gas development in tiger habitat has led to illegal hunting of tigers and deforestation for infrastructure.

Timber production, mineral mines and agriculture can also result in habitat loss, but as with oil and gas, the most severe effects often occur along access roads (Wilkie *et al.,* 2000; Laurance, 2001; Bennett & Gumal, 2001; Carroll & Miquelle, 2006; Johnson *et al.,* 2006; Gurung *et al.,* 2008). In Sumatra, deforestation in tiger landscapes from 2000 to 2009 was found to occur at annual rates of 2.7% in areas designated for rubber and oil palm, and 4.3% in timber concessions for wood pulp. Forest loss in protected areas was also significant, but occurred at a fraction of the rate (supporting information Fig. S2, Hammer, Kraft & Wheeler, 2009). In the Annamites/Dry Forest landscape, the highest rates of deforestation from 2000 to 2009 were observed in community-use zones, followed by areas under unknown management and mining concessions (supporting information Fig. S3, Koeln & Bissonnette, 2000; Smith, 2010). Some experts argue that the detrimental effects of natural resource extraction can be controlled with good policies, management planning, zoning and enforcement against illegal land clearance and hunting (Chomitz *et al*., 2006; Gardner *et al.,* 2007; Wilkinson 2007; Stokes *et al.,* 2010). Indeed, the sheer extent of natural resource extraction zones in tiger habitat emphasizes the need for sound management in these areas.

Our study highlights problems with land management and governance affecting tiger habitat. It follows that adopting and implementing certain standards could lead to immediate improvements for tiger conservation. These include setting minimum area requirements for protected areas in tiger habitat based on biological and behavioral requirements; ensuring adequate resources for enforcement and monitoring and forbidding incompatible land uses in protected areas. To help this process, government departments should reconcile conflicting land zones, adopt clearer procedures for communicating about land-use plans between departments, and in general, be more transparent

about land-use plans. Improving enforcement in protected areas requires protected area managers to hire more staff, provide training and ensure that staff are equipped to accomplish their law enforcement jobs. Species population monitoring is also a critical element of protected area enforcement. Indeed, without objectively gathered data on tiger numbers, it is difficult to tell when an enforcement is working or not (Leader-Williams, Albon & Berry, 1990; Hilborn *et al.,* 2006; Walston *et al.,* 2010). Finally, given that such a large portion of the tiger range is zoned for extractive use, it is clear that appropriate management in these zones will also be critical for conserving this species.

Our findings and conservation recommendations have implications not only for tigers but also for the multitudes of species and ecosystem services that share the same land. The significant occurrence of natural resource extraction zones in strictly protected areas may be far more widespread than the tiger range, but requires further research. At the same time, the results emphasize the importance of monitoring and adaptive strategies in protected areas to ensure they are meeting their objectives.

Acknowledgments

We would like to thank M. Mascia, N. Burgess, F. Leverington, K. MacKinnon, C. Loucks, C. Besançon, A. Belokurov and A. Zakharenka for help at various stages of this project, including formulating the project idea, insight on methodology, review and advice that helped to improve the study. We thank C. Remus-Papp for providing the METT questionnaire on the web to facilitate data collection. This study was funded through an Australian Aid/World Bank grant for work on forest governance. We thank the Environmental Systems Research Institute Inc. (ESRI, Redlands, CA, USA) for their generous software donation that made this project possible. Finally, we thank the three anonymous reviewers who provided very helpful comments for improving this paper.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. TCLs with METT data.

Figure S2. Forest cover loss since 2000 in Sumatran tiger landscapes.

Figure S3. Comparison of land cover change by management type in the Annamites/Dry Forest TCL (2001–2009).

Table S1. Indicators selected for assessing threat and management effectiveness in protected areas, and interpretation of responses.

Table S2. Area of TCL protected under IUCN categories I – VI and unknown (UNEP & IUCN, 2009).

Table S3. Summary of METT responses by TCL.

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