DEFORESTATION, DEGRADATION, AND FOREST REGROWTH IN INDONESIA'S PROTECTED AREAS FROM 2000-2010

Douglas Fuller[1], J. Miettinen[2], Erik Meijaard[3]
[1] Department of Geography and Regional Studies, University of Miami, Coral Gables, FL, USA, email: dofuller@miami.edu
[2] Centre for Remote Imaging, Sensing and Processing (CRISP), National University of Singapore
[3] School of Biological Sciences, University of Queensland, email: emeijaard@gmail.com

ABSTRACT

This research used two new land cover maps from 2000 and 2010 to examine recent changes in forest cover in Indonesia's protected areas (PAs). Our analysis included national parks (NPs), and nature and wildlife reserves (NRs/WSs) where deforestation was detected from 2000-2010. Indonesia's terrestrial PAs lost approximately 0.37 million hectares (Mha), or 2.6% of their 2000 forest cover by 2010; with an additional 0.71 Mha transition from forest to the plantation/regrowth class. Although the forest regrowth of 0.57 Mha recorded during the same time frame suggests wide spread recovery of areas degraded prior to 2000, the high levels of transition from forest to plantation/regrowth class indicate that forest degradation within the protected areas is still a significant problem. Despite some improvement relative to the 1990s, we conclude that much improved management is required to address continued deforestation and degradation in Indonesia's PAs.

Keywords: Conservation Policy, Deforestation, Indonesia, Illegal Logging, Land Cover Change, MODIS Satellite Imagery

ABSTRAK

Penelitian ini menggunakan dua peta tutupan lahan baru dari tahun 2000 dan 2010 untuk memeriksa perubahan terbaru dalam tutupan hutan di kawasan lindung di Indonesia (KL). Unit analisis meliputi taman nasional (TN), serta cagar alam dan suaka margasatwa (CA / SM) di mana deforestasi terdeteksi 2000-2010. Di Indonesia terestrial KL kehilangan sekitar 0.370.000 hektar (Mha), atau 2,6% dari tutupan hutan tahun 2000 dibandingkan tahun 2010, dengan tambahan 0,71 juta ha transisi dari hutan ke kelas perkebunan / pertumbuhan kembali. Meskipun pertumbuhan kembali hutan 0,57 juta ha direkam selama waktu yang sama kajian menunjukkan pemulihan tersebar luas areal terdegradasi sebelum tahun 2000, tingginya tingkat transisi dari hutan ke kelas perkebunan / pertumbuhan kembali menunjukkan bahwa degradasi hutan di wilayah yang dilindungi masih merupakan masalah yang signifikan. Meskipun beberapa perbaikan secara relative melebihi era 1990-an, penelitian ini menyimpulkan bahwa manajemen ditingkatkan banyak yang dibutuhkan untuk mengatasi lanjutan deforestasi dan degradasi di lindung di Indonesia.

Kata kunci: Kebijakan Konservasi, Deforestasi, Indonesia, *Illegal Logging*, Perubahan Tutupan Lahan, Citra Satelit MODIS

INTRODUCTION

Over the past thirty years, deforestation in Indonesia has greatly altered the nation's forest cover and resulted in highly fragmented and degraded forests of diminished biodiversity with a high threat of extinction for many plants and animal species (Myers, 1988; Sodhi et al., 2004). Much of the forest loss has been concentrated in accessible lowland forests once dominated by commercially valuable trees such as *Shorea* and *Dipterocarpus* spp. (Jepson et al., 2001; FWI/GFW, 2002). Heavily logged and degraded forests have also been extensively converted to large commercial plantations, typically consisting offast-growing exotics for pulp and paper and palm oil production.Such plantations are increasingly established on carbon-rich peat soils associated withrare and endemic flora and fauna (Page et al., 2009; Paoli et al., 2010; Miettinen et al., 2011).

Indonesia's protected areas (PAs) have not been spared from this deforestationtrend (Curran et al., 2004; Fuller et al., 2004; Gaveau et al. 2009) and have been subjected to unsustainable, illegal logging and plantation establishment as opportunities to harvest and convert accessible unprotected forests have diminishedthrough time (Jepson et al., 2001; Obidzinski & Chaudhury, 2009).

Indonesia's first protected areas were established in the 1930s (Rijksen & Meijaard, 1999) and by 1949 there were over 100 protected sites (Mackinnon, 1997).In 1982, the Indonesian Government adopted a national policy of establishing a protected area network to conserve the nation's biodiversity (Jepson et al., 2002). This was part of a broader attempt to rationalize land use planning and follow international guidelines to set aside 10% of the country's area for biodiversity protection (FAO, 1981). At a global scale, this is especially relevant because Indonesia is one of the most species-diverse countries in the world (MacKinnon, 1997). As of 2008,536PAs had been established in Indonesia, with a total area of 28,234,206 ha, of which 93% is on land(Table 1). Not all these PAs contain significant amounts of forest, however, as a dry, seasonal climate prevails as one moves progressively east in the archipelago and fire-dominated grassland formations become increasingly common in central and eastern Indonesia.

Indonesia'sPAs appear underfunded with a total budget in 2006 of US$ 53.37 million suggesting funding levels of about US$ 2.35/ha (McQuistan et al., 2006), which is about one quarter of the global average (Emerton et al., 2006). Funding levels for Indonesia's PAs would have to increase by 153% for optimal functioning (McQuistan et al., 2006). The funding shortfall is one of the reasons of suboptimal functioning of Indonesia's PAs (Jepson et al., 2002; Gaveau et al., 2007), although depending on geographic context some PAs are obviously effective in reducing deforestation (Gaveau et al., 2009). In recognition of its insufficient ability to effectively fund and manage PAs, the Indonesian Government recently announced a plan to privatize its PA system (Simamora, 2011).

Recent studies suggest that deforestation rates in Indonesia may have declined

Table 1. Protected areas of Indonesia in 2008 (PHKA 2008)

	Terrestrial		**Marine**	
	number	**area (ha)**	**number**	**area (ha)**
Nature Reserve	238	4,586,665	8	273,515.00
Wildlife Sanctuary	74	5,099,849	6	338,940.00
National Park	43	12,298,216	7	4,043,561.00
NatureRecreationPark	105	257,348	19	767,121.00
Grand Forest Park	22	344,175		
GameHuntingPark	14	224,816		
TOTAL		22,811,069		5,423,137

relative to levels observed in the 1990s (e.g., Hansen et al., 2009).However, reliable national-level data on recent deforestation in PAs and transparency in reporting land use changesrelated to forestryactivities are generally lacking (Fuller, 2006). To address the need for updates on the status of biologically diverse forest remnants in protected areas, we used two new maps derived from classification of 250-500 m resolution satellite imagery provided by the Moderate Resolution Imaging Spectroradiometer or MODIS (Miettinen et al., 2011; Miettinen et al., 2012). Unlike many previous deforestation studies based on a variety of sources (e.g., Fuller et al., 2004) these newly published maps were produced using internally consistent methodology and data at relatively high spatial resolution of 250 m, which provide appropriate spatial detail for land cover monitoring (Justice & Townshend, 1988); they are directly comparable through time and provide a novel opportunity to evaluate land cover change and conservation policy across a large,biologically diverse country that has a history of weak conservation enforcement and management (Sodhi et al., 2006; Koh, 2007; Wich et al., 2008).

RESEARCH METHOD

250-500 m MODIS reflectance image datafor bands 1-7 were obtained from the NASA EOS Data Gateway (NASA 2010) for insular Southeast Asia for the periods 1 March – 31 October 2000 and 2 January –3 July 2010, and thus spanned a full decade of potential land cover change. The imagery was composited temporally to reduce effects of cloud cover and other atmospheric constituents (e.g., aerosols) and a three phase classification procedure was used in the production of the maps (Miettinen et al., 2012). The accuracy of the maps was evaluated by using a combination of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and SPOT 4 and 5 imagery, which revealed high accuracy for the forest and nonforest classes (91.7% correctly classified in the 2000 map and

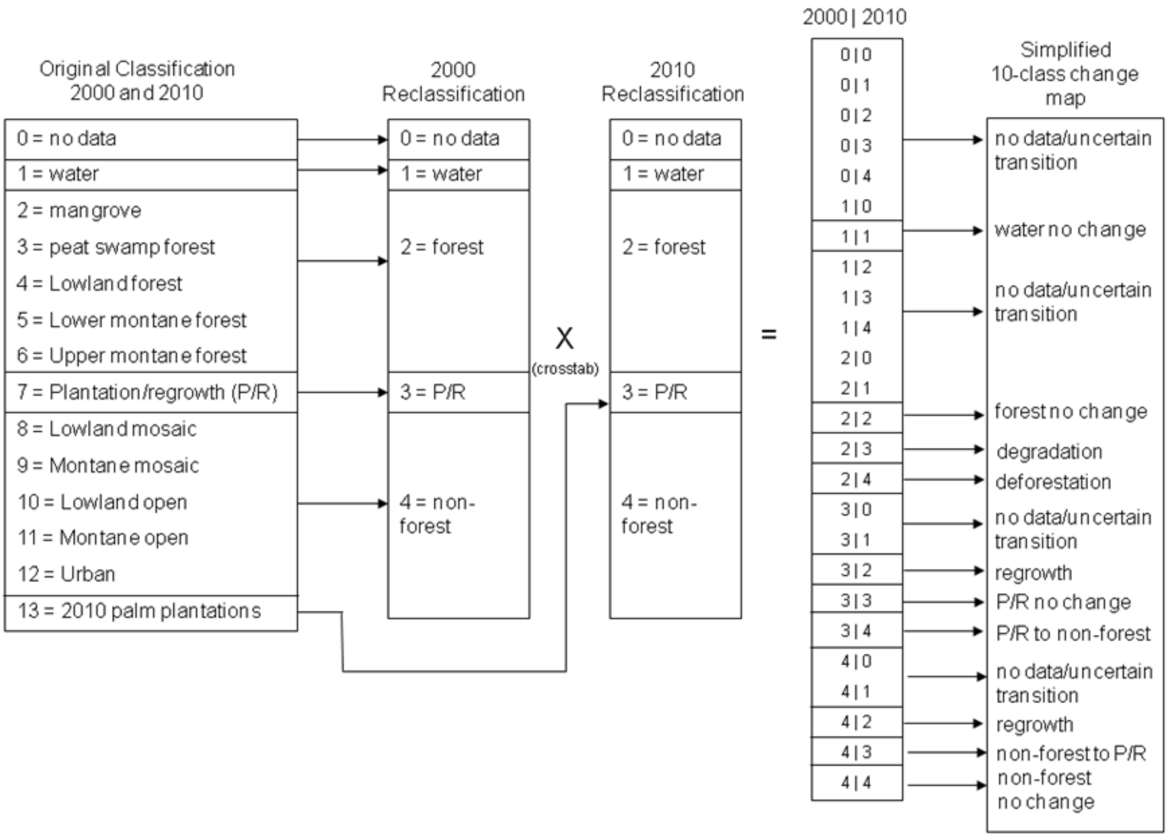


Figure 1. Flow chart showing how 2000 and 2010 land cover classes were combined to create aggregated classes used to analyze land cover changes in Indonesia's protected areas.

93.6%correctly classified in the 2010 map). Further details on the classification methods and accuracy assessment can be found in Miettinen et al. (2011, 2012).

The land cover classes in these two maps were aggregated to four semantic classes using GIS software including forest, nonforest, water and plantations/regrowth (PR) and the 2000 and 2010 maps were cross-tabulated to produce a land change map for the whole of insular Southeast Asia. These maps were further reclassified to produce a simplified 10-class land cover change map that highlighted transitions between forest, nonforest, and PR. Deforestation was defined as a transition from forest to nonforest, while degradation was defined as forest to PR. Regrowth was defined as either PR to forest or nonforest to forest. Further details on the class descriptions and semantic transitions can be found in Miettinen et al. (2012) and in Table 2, which provides a description of the classes used in the original classification (Miettinen et al., 2012). Figure 1 provides a flow chart that describes how the classes were combined and cross-tabulated to produce a 10-class change map from which forest change statistics were extracted from the protected-area polygons.

Digital vector data on the 2005 distribution of Indonesia's PAs was obtained from the Indonesian Ministry of Forestry (MoF) and the terrestrial portion of the PA network was masked using the land cover maps. Data on 2000 forest cover and deforestation by PA were obtained by overlaying the 2000 forest class and the 2000-2010 deforestation class (derived from the cross-tabulation) on a rasterized version of the terrestrial PA network. Hectares (ha) of forest in 2000 and deforested pixels from 2000-2010 were calculated using GIS software and %deforestation, degradation and regrowth by PA was obtained by summing the area of the pixels that had transitioned between 2000 and 2010 and dividing by year 2000 forest area. In our analysis we considered three types of PAs in Indonesia, National Parks (NPs), Nature Reserves (NRs)and Wildlife Sanctuaries (WSs), in which commercial timber extraction or plantation development are prohibited by law.NRs and WSs were considered separately because no extractive uses are allowed as opposed to NPs where some use by local communities may be allowed. We restricted our analysis to 176 individual PA polygons where deforestation was detected after the 2000 and 2010 land cover maps were cross-tabulated. We verified the MODIS maps for individual protected areas against Landsat 7 colour composite imagery from the Enhanced Thematic Mapper Plus sensor (28.5 m spatial resolution) to qualitatively assess the suitability of MODIS 250 m imagery for monitoring forest cover in Indonesia's PAs (Appendix 1; see also table in appendix 2).

RESULT

Figure in appendix 1 shows visual comparison between 28.5 m Landsat color composites for 2000 and 2010 and the MODIS-based change maps for three PAs where relatively cloud-free Landsat images were available. The PAs were a. Gunung Palung in West Kalimantan (Borneo), b. Tesso Nilo in central Sumatra, and c. Gunung Leuser in north Sumatra. The dark green tones in the Landsat imagery generally correspond to intact forest, while the light green colors indicate either plantations/ regrowth or recently cleared forest that contained low-stature vegetation such as grassland or shrubs. The purple tones reveal bare soils or recently burned locations that are indicative of disturbance and advanced forest degradation. These color tones generally correspond well to the change classes shown in the maps in the right-hand column and thus provide qualitative verification of the classes, the accuracy of which was assessed quantitatively using the error matrices published in Miettinen et al. (2012). The scale bars relate only to the change maps, but the Landsat images are shown at approximately the same scale and extent.

Within the PA polygons analyzed, we found 13.94 Mha of forest in the 2000 land cover map with 9.16 Mha in NPs and 4.78 Mha in NRs and WSs. By 2010, the total forest cover in PAs analyzed was 12.93 Mha, with 8.44 Mha in NPs and 4.49 Mha remaining in NRs and WSs. The %deforestation (i.e., the number of deforested pixels relative to 2000 forest cover) was 2.2 and 3.5 for NPs

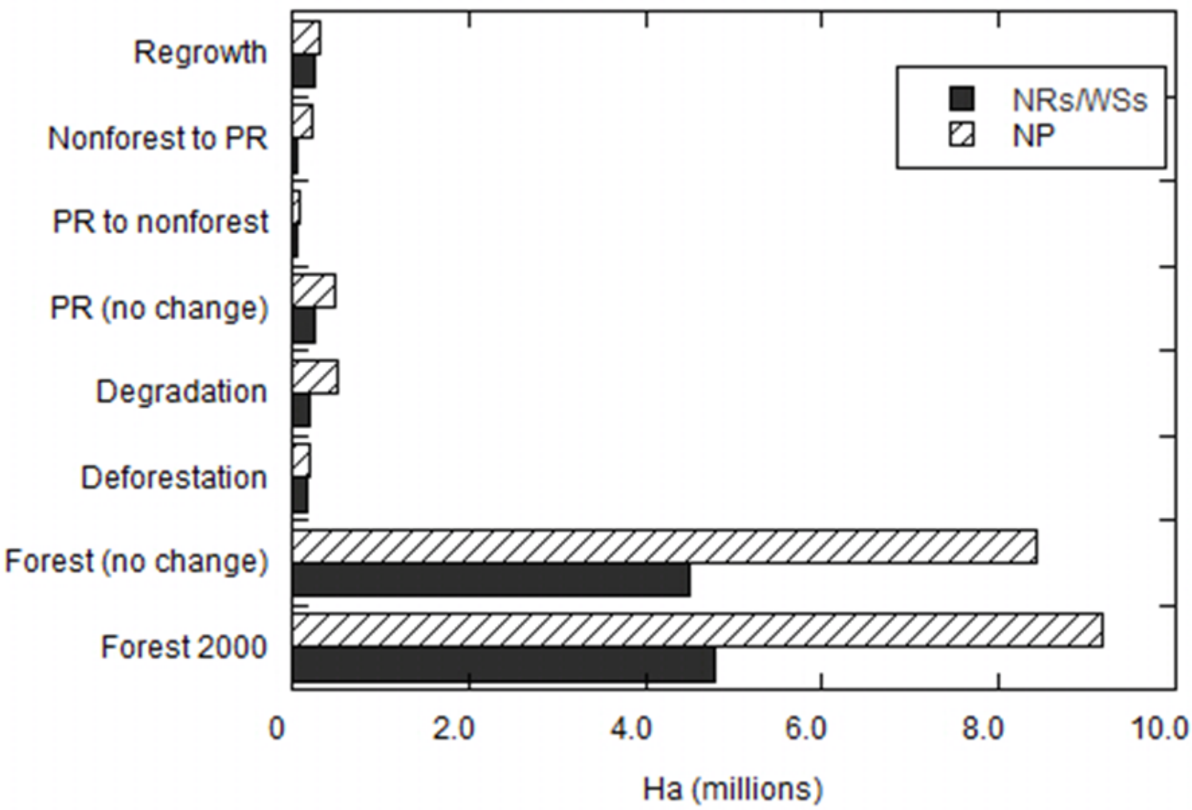


Figure 2. Forest change (in millions of hectares) by different change categories and protected area status. NPs = National Parks, NRs/WSs = Nature Reserves/Wildlife.

and NRs/WSs, respectively, which equates to annualized deforestation rates of 0.22 and 0.35 percent. The amount of degradation observed was generally greater than deforestation for both NPs and NRs/WSs. For NPs, 41/75 polygons experienced greater degradation than either deforestation or regrowth; whereas deforestation was the dominant transition in 25/75 polygons and regrowth in 9/75 NP polygons. Similarly for NRs and WSs, nearly half of all polygons (47/101) showed greater degradation than either deforestation or regrowth, while in 30/101 regrowth was the majority transition and 24/101 experienced more deforestation than the other two change classes.

Compared to forest cover in 2010 (i.e., 12.93 Mha), the number of pixels that remained in the plantation/regrowth (PR) class was relatively modest at 0.76 Mha (5.9%), or approximately equal to the total area of degradation (0.71 Mha) observed in the PAs analyzed. Similarly, the number of pixels that transitioned from PR to nonforest or nonforest to PR was also fairly low at 0.15 Mha and 0.30 Mha, respectively. By 2010, the amount of area that transitioned from nonforest to PR was nearly four times greater in NPs (0.24 Mha) relative to NRs and WSs (0.06 Mha), which suggests that regrowth was more likely in NPsthan in NRs and WSs. Figure 3 summarizes the different change quantities by PA type.

Deforestation, degradation and regrowth appeared quite variable within PAs across the archipelago. Appendix 3 shows forest change data (in hectares) for the period 2000-2010 for top-twenty PAs ranked in terms of their year 2000 forest area cover. Collectively, these relatively large, forest-covered PAs contained 88%of 2000 forest cover in the study area. In general, the PAs on Borneo and Sumatra showed higher relative amounts of deforestation and degradation than did PAs in other parts of the archipelago, although forest cover in several PAs on Sulawesi (e.g., Bogani Nani Wartabone, Lore Lindu) experienced substantial degradation. Relatively large amounts of forest degradation were noted in the Way Kambas

(52.59%) and Bukit Barisan Selatan (24.34%) NPs on Sumatra and Tanjung Puting (27.94%) on Borneo (Appendix 3). In addition, deforestation, degradation and regrowth relative to 2000 forest cover was generally greater in NPs than in NRs and WSs, which is consistent with legal restrictions described above. It should also be noted that relatively high amounts of regrowth found for PAs on New Guinea may have been an artifact of persistent cloud cover (especially for the mountain areas) in the 2000 MODIS imagery, which may have resulted in false detections of forest recovery. For this reason, we did not include regrowth observed in Lorentz NP in our analysis.

Appendix 4 highlights four NPs where observed changes in forest cover varied from relatively modest (Gunung Leuser) to high (Way Kambas). Figure 4a shows the relatively large and stable Gunung Leuser NP, ~950,000 ha) in northern Sumatra, whereas Figure 4b shows the highly disturbed case of Way Kambas NP near the southern tip of Sumatra, where over 50%of its year 2000 forest appears to have transitioned to the degraded class.Figure 3c reveals relatively stable forest cover in Gunung Palung NP, which was the subject of two recent studies (Curran et al., 2004; Trigg et al., 2006) that highlighted the problems of illegal logging and forest monitoringin Indonesia's PAs. Figure 4d reveals the situation of recent forest loss and regrowth in Tanjung Puting NP, which has received widespread public attention for its role in orangutan conservation and rehabilitation efforts.

The stable PR in the southwest portion of the park suggests the presence of shrub/ low stature secondary growth in areas destroyed by 1997-1998 fires; also parts of the park have been degazetted in the last few years for oil palm plantation development. Overall, the patterns of deforestation and degradation in these four cases are spatially coherent in that they are generally proximate to one another, suggesting that degradation, deforestation and regrowth are interrelated, and found near the PA boundaries where access to forest is generally greater than in core areas. The same coherent spatial patterns were noted for the other PAs, including lowland areas of Lorentz and Wasur NPs.

DISCUSSION

Although our results reveal some worrisome patterns related to high rates of forest cover change in certain PAs such as those degradation and deforestation hotspots shown in Table 3and Figure 4, isolated PAs such as Kayan Mentarang NP in the heart of Borneo, were relatively well protected from changes usually attributed to commercial logging, small-scale agriculture and plantation establishment. Much of this effect probably relates to limited access and steep terrain, which appears to mitigate deforestation threats somewhat (Fuller et al., 2010). In general, small protected areas are concentrated in areas of higher development potential where the opportunity costs are highest, while large areas are in distant uplands that generally attract little investment. Thus, these factors appear quite important in determining relative deforestation rates in PAs with small and large forested areas.It is important to point out, however, that the original maps produced by Miettinen et al. (2012) were intended for regional-scale land cover assessment and that relative classification errors for small PAs (e.g., < 1000 ha) provide less confidence in the forest area changes associated with these areas. Nonetheless, other studies (e.g., Morton et al., 2005) have shown that MODIS 250 m data can accurately detect clearance of moist tropical forest patches larger than 20 ha. Moreover, our analysis suggests that the problem of degradation and deforestation in PAs was not restricted to any particular province or region, but is a national phenomenon that occurred on all major islands of Indonesia(Borneo, Sumatra, New Guinea and Sulawesi).

The annual rate of deforestation observed for NPs was somewhat less than the background deforestation rate observed throughout the region during the 1990-2000 period. Our results suggest a mean annualized deforestation rate of 0.22%for NPs and 0.35%for NRs and WSs, respectively. FAO country statistics (FAO, 2006) revealed an average yearlydeforestation rate of 1.7% in insular Southeast Asia for the entire decade of 1990-2000, whileFulleret al. (2004)showed that Kalimantanexperienced an annualized deforestation rate of 2.0% between 1997 and

2002, largely due to the 1997-1998 fires. Hansen et al. (2009) estimated that the annual rate of Indonesian forest cover losshas decreased from 1.4% between 1990 and 2000 to 0.58% between 2000 and 2005, with the higherdeforestation rates found on Sumatra and Kalimantan and lower rates on New Guinea, which is consistent with our findings for PAs.Further, Miettinen et al. (2011) reported total 2010 Indonesia forest cover of 96.58 Mha of which 12.93 Mha (13.52%) was found in the PAs analyzed. This suggests that despite some degradation and deforestation, Indonesiacontinues to meetthe international target to protect a minimum of 10% of its forest biodiversity in PAs.

Gaveau et al. (2009) demonstrated a positive, mitigating effect of PAs on deforestation in Sumatra, and our study confirms that PAs are having some beneficial effect on forest cover onother major islands ofIndonesia. However, the figures derived from our analysis suggest thatPAs may mitigate deforestation in some areas while protection in others is less effective (e.g., Kutai NP). Thus, the effectiveness of PAs appears to be highly context specific. Likely factors contributing to this context include the general rate of development in an area, local political support for conservation, the opportunity costs of conservation (which can be very high, for example, when there are important mineral deposits in the same location as a protected area, as is the case in Kutai NP), and management support from non-governmental organizations. The protected area status is also important with NP-status generally resulting in lower deforestation rates than NR/WS-status. On the one hand this is surprising, considering that no extractive uses are allowed in NRs/WSs but some in NPs.

The more important factor might be that NPs are managed by national government and NRs/WSs by local government, which results in far less management and fewer staff in the latter compared to the former. More detailed analysis is needed of the socio-economic factors that most strongly influence protected area success and failure. Also, further analysis of deforestation outside PAs using techniques such as propensity score matching (Gaveau et al., 2009) would clarify the role that protected areas have in reducing deforestation compared to the counterfactual of having no protected areas at all.

In light of our findings and the dearth of funding for PA managementit is understandable that the Indonesian Government is looking for alternative strategies to reduce or stop further deforestation, forest degradation and concomitant loss of species diversity in its protected areas. Whether privatizing protected areas is the solution remains to be seen. A 10-year public-private partnership for the management of KomodoNational Park-produced significant conservation outcomes (Agardy et al., 2010), and may be a way to increase both protected area revenues and quality of management. Better management could potentially also tap into carbon market funds if effective avoided deforestation or forest regrowth can be demonstrated, which would provide additional incentives to improve management. Before this is possible, core weaknesses of the present protected area management system, as demonstrated by our data, will have to be addressed through a performance-based system that rewards improvement in key success indicators and penalizes failure. Regular monitoring of forest loss in protected areas would provide excellent input to the Government about its success in changing the present trends related to forest cover change.

REFERENCES

Agardy, T., Hicks, F.&Hooten, A. 2010. *PT. Putri Naga Komodo: Komodo Collaborative Management Initiative*

Curran, L.M., Trigg, S.N., McDonald, A.K., Astiani, D., Hardiono, Y.M., Siregar, P., Caniago, I.&Kasischke, E. 2004 "Lowland forest loss in protected areas in Indonesian Borneo". *Science* (303) p. 1000-1003.

Emerton, L., Bishop, J. &Thomas L. 2006 *Sustainable Financing of Protected Areas: A global review of challenges and options*. Gland, Switzerland and Cambridge: IUCN,

Food and Agricultural Organization. 1981. *National conservation plan for Indonesia*. Bogor: UNDP/FAO Development Project.

Food and Agricultural Organization. 2006. Global Forest Assessment 2005. FAO forestry paper 147. Food andAgriculture Organization (FAO) of the United Nations (UN), Rome.

Fuller, D.O., Jessup, T.C.& Salim, A. 2004. "Loss of forest cover in Kalimantan, Indonesia since the 1997-1998 El Niño". *Conservation Biology* (18) p. 249-254.

Fuller, D.O. 2006. "Tropical forest monitoring and remote sensing: A new era of transparency in forest governance?" *Singapore Journal of Tropical Geography* (27) p. 15-29.

Fuller, D.O., Meijaard, E.M., Christy L.&Jessup, T.C. 2010. "Spatial assessment of threats to biodiversity within East Kalimantan, Indonesia". *Applied Geog*raphy (30) p. 416-425.

FWI/GFW 2002. *The State of the Forest: Indonesia.* Washington, DC: Forest Watch Indonesia and Global Forest Watch.

Gaveau, D. L. A., Wandono, H.& Setiabudi,F. 2007. "Three decades of deforestation in southwest Sumatra: Have protected areas halted forest loss and logging, and promoted re-growth?" *Biological Cons*ervation (134) p. 495-504.

Gaveau, D.L.A., Epting,J., Lyne,O. Linkie, M., Kumara,I., Kanninen, M.& Leader-Williams,N. 2009. "Evaluating whether protected areas reduce tropical deforestation in Sumatra". *Journal of Biogeography* (36) p. 2165-2175.

Hansen, M.C., Stehman, S.V., Potapov, P.V., Arunarwati, B., Stolle, F. &Pittman, K. 2009. "Quantifying changes in the rates of forest clearing in Indonesia from 1990 to 2005 using remotely sensed data sets." *Environmental Research Lett*ers,4, doi:10.1088/1748-9326/4/3/034001.

Jepson, P., Jarvie, J.K. MacKinnon, K. &Monk, K.A. 2001. "The end for Indonesia's lowland forests". *Science* (292) p. 859-861.

Jepson, P., Momberg, F. &van Noord, H. 2002. "A review of efficacy of the protected area system of EastKalimantanProvince". *Natural Areas Journal* (22) p. 28-42.

Justice, C.O., Townshend, J.R.G. 1988. "Selecting the spatial resolution of satellite sensors required for global monitoring of land transformations". *International Journal of Remote Sensing* (9) p. 187-236.

Koh, L. P. 2007. "Impending disaster or sliver of hope for Southeast Asian forests? The devil may lie in the details". *Biodiversity& Conservation* (16) p. 3935-3938.

MacKinnon, J. 1997. *Protected areas system review of the Indo-Malayan realm*. Canterbury, United Kingdom: The Asian Bureau for Conservation Limited.

McQuistan, C. I., Fahmi, Z., Leisher, C., Halim, A. &Adi,S. W. 2006. *Protected Area Funding in Indonesia: A study implemented under the Programmes of Work on Protected Areas of the Seventh Meeting of the Conference of Parties on the Convention on Biological Diversity*. Jakarta: Ministry of Environment republic of Indonesia, The Nature Conservancy, PHPA, Departemen Kelautan dan Perikanan.

Miettinen, J., Shi, C. &Liew, S.C. 2011. Deforestation rates in Insular Southeast Asia from 2000-2010". *Global Change Biol*ogy DOI: 10.1111/j.1365-2486.2011.02398.x

Miettinen, J., Shi, C., Tan, W.J., Liew, S.C. 2012. "2010 land cover map of insular Southeast Asia in 250-m spatial resolution". *Remote Sensing Letters* (3) p. 11-20.

Morton, D.C., DeFries, R.S., Shimabukuru, Y.E., Anderson, L.O., Espirito-Santo, F.D.B., Hansen, M. and Carroll, M. 2005. "Rapid assessment of annual deforestation in the Brazilian Amazon using MODIS data". *Earth Interactions* (9) p. 1-22.

Myers, N. 1988. "Threatened biotas: hotspots in tropical forests". *The Environmentalist* (8) p. 187- 208.

NASA. 2010. *Earth Observing System Data Gateway*. Available online at: http://wist.echo.nasa.gov/api/[accessed 12 July 2010].

Obidzinski, K. &Chaudhury, M. 2009. "Transition to timber plantation based forestry in Indonesia: towards a feasible new policy". *International Forestry Rev*iew (11) p. 79-87.

Page, S., Hoscilo, A., Wosten, H., Jauhiainen, J., Silvius, M., Rieley, J., Ritzema, H., Tansey, K., Graham, L., Vasander, H. &Limin, S. 2009. "Restoration ecology of lowland tropical peatlands in Southeast Asia: Current knowledge and future research directions". *Ecosystems* (12) p. 888-905.

Paoli, G. D., P. L. Wells, E. Meijaard, M. J. Struebig, A. J. Marshall, K. Obidzinski, A. Tan, A. Rafiastanto, B. Yaap, J. W. F. Slik, A. Morel, B. Perumal, N. Wielaard, S. Husson, and L. D'Arcy. 2010. "Biodiversity Conservation in the REDD". *Carbon Balance and Management* (5) http://www.cbmjournal.com/content/5/1/7.

PHKA .2008. *Statistik Kehutanan. Volume 2. Perlindungan Hutan dan Konservasi Alam*. Jakarta: Forest Protection and Nature Conservation. Indonesian Ministry of Forestry.

Rijksen, H. D. & E. Meijaard 1999. *Our vanishing relative. The status of wild orang-utans at the close of the twentieth century*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Simamora, A. P. 2011. "Govt wants national parks to become 'profit centers'" *The Jakarta Post*. 24 March 2011.

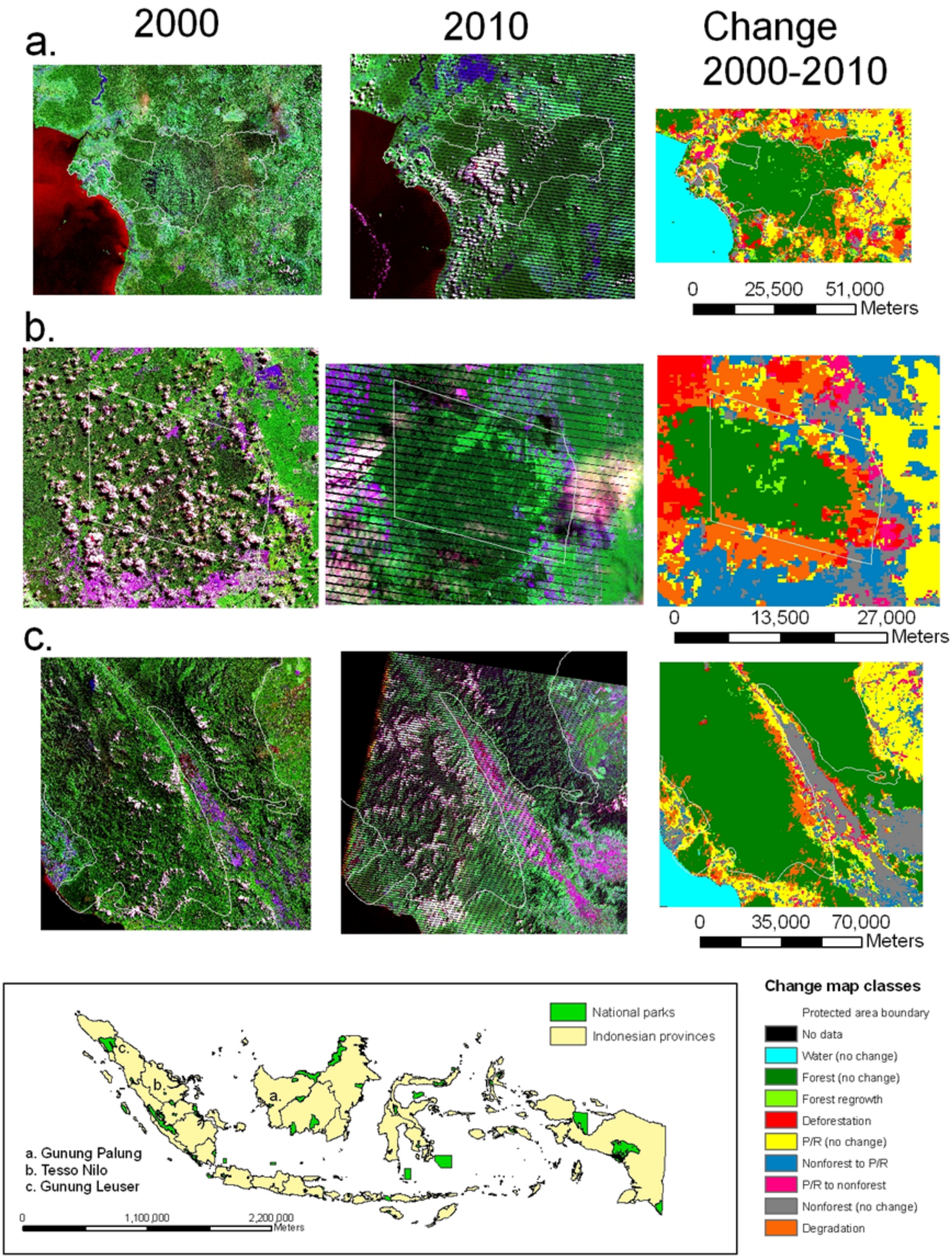
Sodhi, N. S., Koh, L.P. Brook, B.W. & Ng,P.K.L. 2004. Southeast Asian biodiversity: An impending disaster. *Trends in Ecology and Evolution* (19) p. 654-660.

Sodhi, N. S., Brooks, T. M., Koh, L. P., Acciaioli, G., Erb, M., Tan, A. K. J., Curran L. M., Brosius, P., Lee, T. M., Patlis, J. M., Gumal, M. &Lee, R. J. 2006. "Biodiversity and human livelihood crises in the Malay archipelago". *Conservation Biology* (20) p. 1811-1813.

Trigg, S.N., Curran, L.M., McDonald, A.K. .2006. "Utility of Landsat 7 satellite data for continued monitoring of forest cover change in protected areas in Southeast Asia". *Singapore Journal of TropicalGeography* (27) p. 49-66.

Wich, S.A., Meijaard, E., Marshall, A. J., Husson, S., Ancrenaz, M., Lacy, R.C., van Schaik, C.P. , Sugardjito, J., Simorangkir, T., Traylor-Holzer, K., Doughty, M., Supriatna, J., Dennis, R., Gumal, M., Knott, C.D., Singleton, I. 2008. "Distribution and conservation status of the orang-utan (*Pongo* spp.) on Borneo and Sumatra: how many remain?" *Oryx* (42) p. 329-339.

Appendix 1



Comparison between 28.5 m Landsat 7 colour composites and classified MODIS imagery from Miettinen et al. (2012). The PAs were

a. Gunung Palung in West Kalimantan (Borneo),
b. Tesso Nilo in central Sumatra, and
c. Gunung Leuser in north Sumatra.

Appendix 2

Description of Land Cover Classes

Land Cover type	Description
Water	In addition to natural water bodies this class also includes e.g large scale fisheries and prawn farming areas.
Mangrove	Mangrove area masks were created using visual image interpretation. Pixels classified as forest within these areas were labelled as mangrove.
Peatswamp forest	Forest growing on peat soil. The term "forest" refers to all forests that could not be distinguished from primary forest in visual image interpretation. Therefore, this class may include also selectively logged forests and secondary forests that have reached structural characteristics (height, canopy structure etc.) similar to primary forest.
Lowland forest	Forest growing on mineral soil in elevation up to 750m above sea level.
Lower montane forest	Forest growing on mineral soil in elevation above 750m, up to 1500m above sea level.
Upper montane forest	Forest growing on mineral soil in elevation above 1500m above sea level.
Plantation/regrowth	Plantations and natural regrowth. This class includes areas from large scale industrial plantations and small-holder plantations to dense shrublands and young secondary forests.
Lowland mosaic	Sub-pixel size (250×250m) mosaic of closed canopy vegetation and open areas in elevation up to 750m above sea level. Typically consists of small plantations, agricultural fields, urban areas, patches of forest and secondary forest. Note that sparse/patchy shrub vegetation, most notably in peatland areas, falls into this class.
Montane mosaic	Same as Lowland mosaic, but occurring in elevation above 750m above sea level.
Lowland open	Clearances and other open areas covered by seasonal crops, remnants of original vegetation, sparse ferns/grass or low shrub. Typically agricultural areas, areas undergoing land cover change or extremely degraded areas.
Montane open	Same as Lowland open, but occurring in elevation above 750m above sea level. In addition, this class includes some naturally bare areas in high elevation.
Urban	Major urban areas.
Large scale palm plantation	Contiguous closed canopy palm plantations larger than $2km^2$. Great majority of these areas are expected to be oil palm, but in some parts of the region (e.g. in Mindanao and in the coastal peatlands of Sumatra) small-holder coconut plantations cover extensive contiguous areas and are classified into this class. Note that newly established and young open canopy plantations are classified into the mosaic or open classes due to mixture of soil and vegetation reflectance.

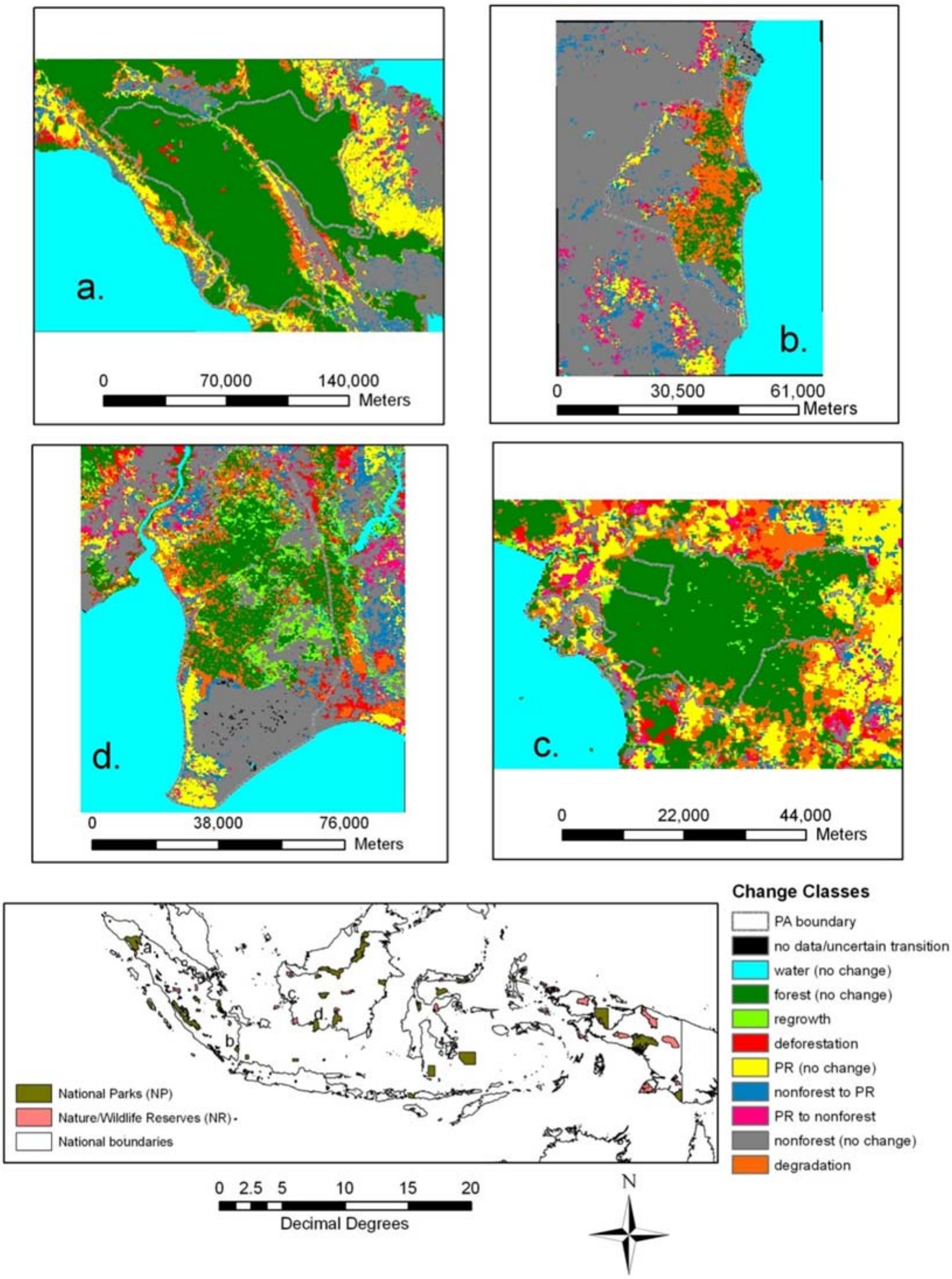
Source: Miettinen et al. 2012

Appendix 3

Forest change data (in hectares) for the period 2000-2010 for top-twenty PAs (National Parks and Wildlife/Nature Reserves) ranked in terms of their year 2000 forest area cover. Percent change relative to 2000 forest area shown in parentheses.

NATIONAL PARKS	Island	Forest area 2000	Deforestation	Degradation	Regrowth
Lorentz	New Guinea	1534982	59500 (3.88)	8367 (0.55)	No data
Kayan Mentarang	Borneo	1340454	2077 (0.15)	7459 (0.56)	2547 (0.19)
Kerinci Sebelat	Sumatra	1186547	3792 (0.32)	56283 (4.74)	46438 (3.91)
Gunung Leuser	Sumatra	978008	11316 (1.16)	47792 (4.89)	7188 (0.73)
Betung Kerihun	Borneo	810457	1937 (0.24)	4025 (0.50)	12700 (1.57)
Sebangau	Borneo	514893	9510 (1.85)	12181 (2.37)	17371 (3.37)
Bukit Raya Bukit Baka	Borneo	281938	325 (0.12)	5807 (2.06)	1600 (0.57)
Bogani Nani Wartabone	Sulawesi	266173	701 (0.03)	27440 (10.30)	8783 (3.30)
Bukit Barisan Selatan	Sumatra	252163	7062 (2.80)	61381 (24.34)	647 (0.26)
Lore Lindu	Sulawesi	203881	7642 (3.75)	16703 (8.19)	1275 (0.63)
Lalobataaketajawe Halmahera	Halmahera-Maluku	199063	75 (0.04)	625 (0.31)	24294 (12.20)
Tanjung Puting	Borneo	171640	8421 (4.91)	47183 (27.94)	36738 (21.40)
Manusela	Seram-Maluku	145978	1174 (0.80)	3271 (2.24)	2403 (1.64)
Berbak	Sumatra	115745	1625 (1.40)	6743 (5.83)	4637 (4.00)
Bukit Tiga Puluh	Sumatra	112082	3669 (3.27)	4706 (4.20)	24038 (21.45)
Gunung Palung	Borneo	86601	431 (0.50)	8949 (10.33)	2725 (3.15)
Batang Gadis	Sumatra	79144	363 (0.45)	10251 (12.95)	6257 (7.91)
Gunung Halimun Salak	Java	68188	7363 (10.80)	9791 (14.40)	4811 (7.06)
Way Kambas	Sumatra	61213	3201 (5.23)	32192 (52.59)	2852 (4.66)
Wasur	New Guinea	59053	28431 (48.14)	11349 (19.18)	29595 (50.12)
Foja	New Guinea	889669	25182 (2.83)	1730 (0.19)	18372 (2.07)
Jayawijaya	New Guinea	535458	12721 (2.38)	1091 (0.20)	39811 (7.44)
Tamrau	New Guinea	488724	1175 (0.24)	213 (0.04)	0
Enarotali	New Guinea	223248	22301 (9.99)	1123 (0.50)	32144 (14.40)
Morowali	Sulawesi	173710	6680 (3.85)	1850 (1.06)	3855 (2.22)
Bukit Rimbang Baling	Sumatra	131513	394 (0.30)	8351 (6.35)	3426 (2.60)
Bukit Tangkiling	Borneo	123740	10953 (8.85)	868 (0.70)	6435 (5.20)
Yapen Tengah	New Guinea	111859	306 (0.27)	712 (0.64)	625 (0.56)
Pegunungan Kumawa	New Guinea	108905	37 (0.03)	156 (0.14)	1241 (1.14)
Pegunungan Wayland	New Guinea	107817	2513 (2.33)	31 (0.03)	10042 (9.31)
Pulau Waigeo Barat	New Guinea	107416	1444 (1.34)	1350 (1.26)	1300 (1.21)
Bupul Kumbe	New Guinea	102067	2534 (2.48)	161 (0.16)	7805 (7.65)
Misol Selatan	New Guinea	101489	400 (0.39)	150 (0.15)	1387 (1.37)
Pulau Waigeo Timur	New Guinea	100397	3219 (3.21)	169 (0.17)	2019 (2.01)
Kerumutan	Sumatra	96303	400 (0.42)	1125 (1.17)	725 (0.75)
Bukit Sapat Hawung	Borneo	96025	1513 (1.58)	15921 (16.58)	11245 (11.71)
Gunung Nyiut Penrisen	Borneo	86383	269 (0.31)	13400 (15.51)	10619 (12.29)
Pegunungan Arfak	New Guinea	78301	12 (0.02)	1637 (2.09)	0
Wondi Boy	New Guinea	74746	1124 (1.50)	3060 (4.09)	481 (0.64)
Buton Utara	Sulawesi	70099	779 (1.11)	10105 (14.41)	2685 (3.83)

Appendix 4



Forest change maps for four protected areas and their immediate surroundings: a. Gunung Leuser NP, b. Waykambas NP, c. Gunung Palung NP and d. Tanjung Puting NP. The locations of all national parks, wildlife and nature reserves are shown on the national map below the change maps, as is the location of the PAs shown in the change maps (a.-d.).