A Green Vision for Sumatra

Using ecosystem services information to make recommendations for sustainable land use planning at the province and district level

A Report by The Natural Capital Project, WWF-US, and WWF-Indonesia

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Executive Summary

In Indonesia, district and provincial spatial plans specify where timber harvest, plantation expansion, infrastructure development and conservation should take place. In 2010, the 10 governors of Sumatra made an island-wide commitment to conduct ecosystem-based spatial planning, which supports sustainable development and conservation. Six national government agencies and a forum of non-governmental organizations including WWF developed an ecosystem vision for Sumatra as an alternative to the existing government spatial plans.

This report demonstrates how spatial and economic analyses of ecosystem services and wildlife habitat can support the spatial planning process in central Sumatra. By assessing the benefits from nature that the people of Sumatra manage and depend on, we can identify the full costs and benefits of alternative future development trajectories. Our results are drawn from comparison of Sumatra's landscape in 2008 with the Government Plan and the Sumatra Vision for 18 districts and six main watersheds in central Sumatra. The study area includes parts of three provinces – Riau, West Sumatra, and Jambi – as well as the RIMBA priority area, one of the last remaining forested regions in central Sumatra (Figure i). Our recommendations focus on the five priority actions identified by the Indonesian government for implementing and financing ecosystem-based spatial planning in Sumatra: forest restoration, forest carbon payments, payments and programs for watershed services, best management practices for forestry, and best management practices for plantations.

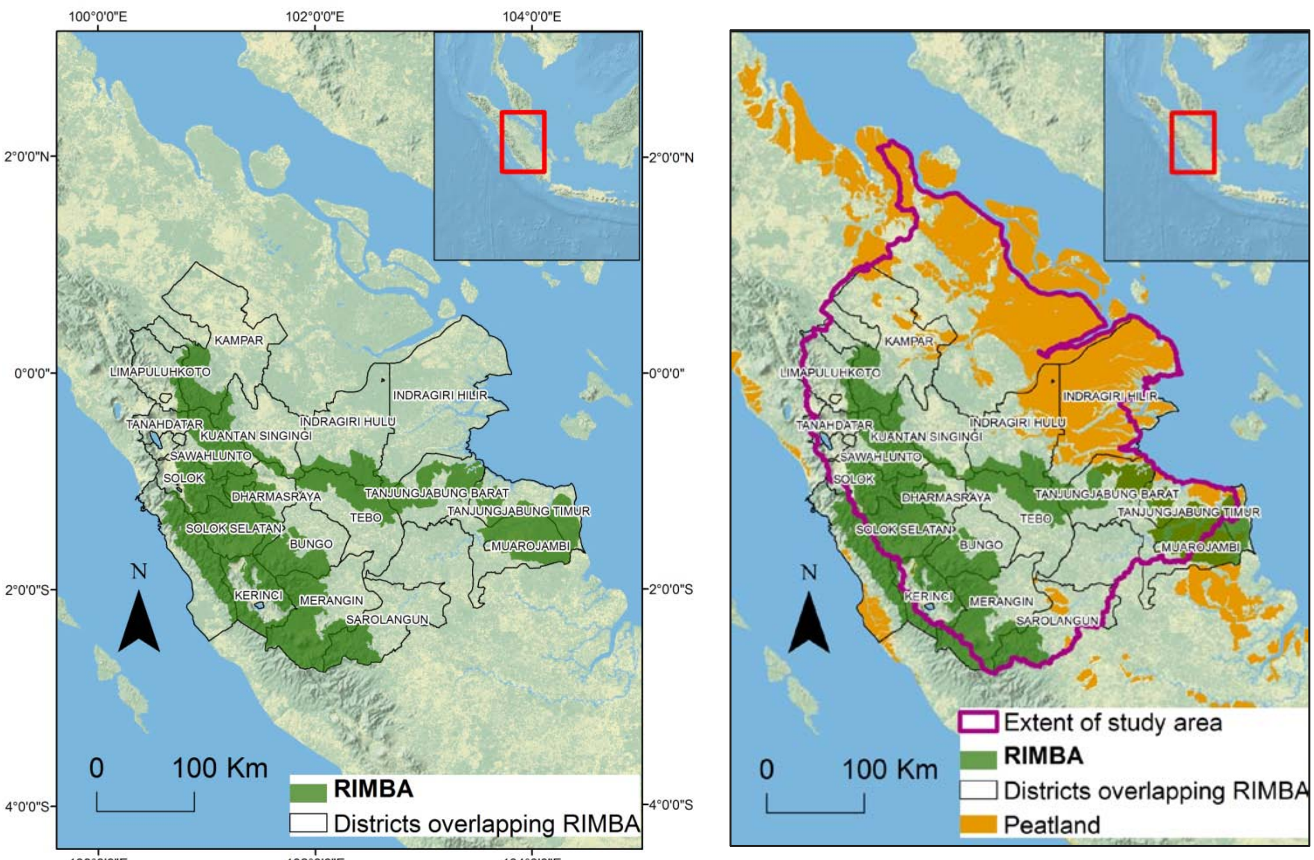


Figure i. a) The 18 districts in the study and the RIMBA priority area. b) The extent of the study area, covering the six watersheds in central Sumatra.

In each of the report's five chapters, readers will find transparent and comprehensive methods for reaching scientific and policy conclusions for each of the ecosystem services we assessed with the modeling tool InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs): climate benefits from carbon storage and sequestration; watershed services, including erosion control, water yield, and avoided nutrient pollution; habitat quality for biodiversity; and, the tradeoffs and synergies among multiple services and economic activities. There are also suggestions for further analysis and recommendations, either by replicating our approach for additional districts, or by integrating new information and methods.

Key Findings: Central Sumatra

Our key findings are instructive for spatial planners at the provincial and district levels, as well as government agencies and other institutions that are considering investing in the region. We observe that implementing the Sumatra Vision rather than the Government Plan could result in net gains in habitat quality, total carbon stock and avoided nutrient pollution relative to 2008 (Figure ii). It would also lead to moderate increases in erosion across parts of the study area; however, the total erosion would be four times greater in the Government Plan.

Relative to 2008, implementing the Sumatra Vision would result in a gain of 350 million tonnes of carbon (MtC) stored in the six main watersheds over 50 years. Conversely, the entire region would lose 1000 MtC over 50 years under the Government Plan. These carbon losses, which equal 3,667 million tonnes of CO_2 emissions, are driven by new conversion of forest and continued operation of plantations on peat swamps, which results in ongoing emissions. As a result, forest carbon projects and programs on peat swamps and in highly biodiverse upland forests in central Sumatra could offer global climate benefits. The RIMBA priority area alone could gain 60 MtC under the Sumatra Vision, whereas 100 MtC would be lost under the Government Plan, indicating an opportunity to establish forest carbon projects in the region to shift development away from business as usual and toward green prosperity.

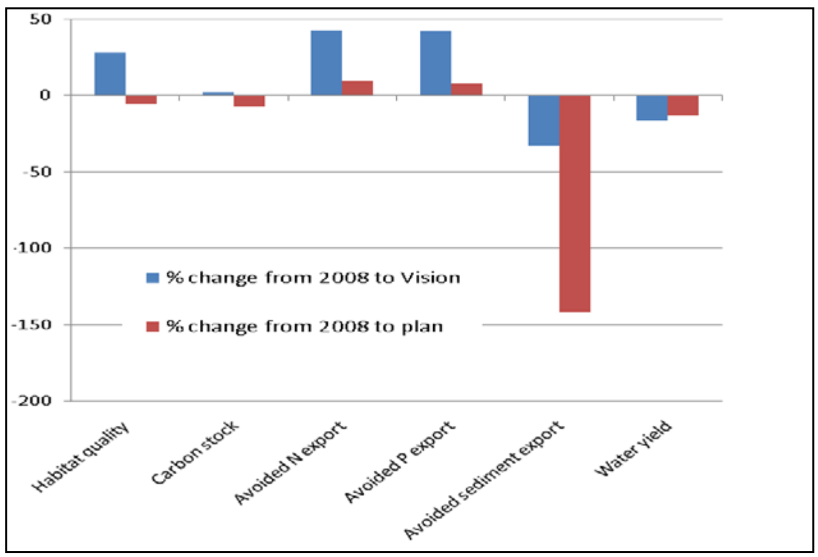


Figure ii. The difference in ecosystem services and habitat quality between the Sumatra Vision and the Government Plan, relative to 2008.

Additional ecosystem service and biodiversity benefits provided by the Sumatra Vision could be supported through priority actions identified by the Indonesian government. Plantations and production forests adjacent to high-quality habitat could reduce their impact on tigers and other biodiversity by implementing several best management practices, such as establishing riparian corridors, reducing human-wildlife conflict and poaching, and seeking environmental certification. Improved watershed management, and potentially payments for watershed services, could ensure more long-term benefits for people and biodiversity.

Several locations are of particular importance for ecosystem services. In particular, of 69 sub-watersheds studied, only one ranked in the top 25% for habitat quality and most ecosystem services (Figure iii). This sub-watershed covers most of the Reteh basin, including part of the RIMBA priority area, and is shared by 2 districts: Indragiri Hulu and Indragiri Hilir.

Under the Sumatra Vision, watershed management programs in the sub-watersheds upstream of population centers, including the towns of Tembilahan and Rengat, could protect habitat for tigers in the RIMBA priority area while reducing erosion and nutrient pollution by more than 80% in some areas. A shift to the Sumatra Vision would also provide greater erosion control upstream of Koto Panjang, the single large hydropower dam supplying the region, which could reduce dredging costs or long-term damage to turbines and other infrastructure that the people of Sumatra depend on.

Figure iii. The single sub-watershed that is ranked in the top 25% for habitat quality and most ecosystem services in central Sumatra.

Key Findings: Provinces and Districts

West Sumatra: Dharmasraya, Solok, Solok Selatan, Tanahdatar, Sawahlunto, and Limapuluhkoto districts

The western sub-watersheds in central Sumatra appear especially vulnerable to erosion. Districts in West Sumatra that could be particularly affected contain the mountainous Bukit Barisan Range: Limapuluhkoto, Tanahdatar, Sawahlunto, Solok, and Solok Selatan.

In many locations across central Sumatra, increases in most ecosystem services and habitat quality are accompanied by losses in plantation area and annual water yield. This is true for most districts in West Sumatra; however, compared to other districts, Solok is singled out for its potential to provide ecosystem services without big tradeoffs. Under the Sumatra Vision, Solok would experience large gains in erosion control *without* large losses in plantation area relative to the Government Plan, making it a good candidate for improved watershed management programs.

Jambi: Tebo, Muarojambi, Sarolangun, Tanjungjabung Barat, Tanjungjabung Timur, Merangin, Bungo, and Kerinci districts

The sub-watersheds within the Batanghari and Pengabuan Laban watersheds are also very vulnerable to erosion. Districts that have large impacts under the Government Plan include those in the lower elevations of Jambi: Bungo, Sarolangun, Tebo, Tanjungjabung Barat, Tanjungjabung Timur and Muarojambi. Kerinci and Merangin districts, with reaches in the Bukit Barisan Range, are also likely to experience increases in erosion and sedimentation. Yet, under the Sumatra Vision, Merangin would improve erosion control *without* large losses in plantation area relative to the Government Plan. These districts could avoid substantial erosion by implementing improved watershed management programs.

Under the Government Plan, four of the five districts that stand to lose the most habitat quality – 18 to 36% – relative to 2008 are in Jambi: Muarojambi, Merangin, Sarolangun and Bungo. These districts could prioritize forest restoration and other priority actions to avoid severely affecting the Sumatran tiger.

Riau: Kampar, Indragiri Hilir, Indragiri Hulu, and Kuantan Singingi districts

Like West Sumatra and Jambi, Riau province faces increases in ecosystem degradation under the Government Plan. Some districts could avoid those impacts with relatively few tradeoffs.
In particular, Kampar could avoid increases in nutrient pollution by targeting key areas for forest restoration and best management practices *without* large losses in water yield and plantation area. Under the Sumatra Vision, both Kampar and Indragiri Hulu would experience larger increases in biomass carbon stock than most other districts, with only small losses in plantation area and water yield. These minimal tradeoffs suggest strong potential for forest carbon projects in these districts at comparatively low cost.

Based on historical deforestation rates, Kampar, Indragiri Hilir, Indragiri Hulu, and Kuantan Singingi are at high risk of losing important forest habitat for tigers. Much of the remaining forests in these districts are in lowland areas that are under pressure from expanding plantations and other human activities. These districts should be prioritized for habitat conservation and priority actions that sustain forest habitat in central Sumatra.

Recommendations

Mountainous districts in central Sumatra, which have relatively low opportunity cost for agriculture, together account for 90% of the possible gains in erosion control in the Sumatra Vision relative to the Government Plan; but, they account for only 40% of the possible gains in other services and habitat quality. Sumatra could ensure large gains in avoided erosion at relatively low cost by implementing habitat restoration, forest carbon projects, and improved watershed management on slopes in the region; however, interventions in the higher opportunity cost districts in the lowlands, which are more suitable for agriculture and less prone to erosion, are necessary to realize substantial gains in habitat quality, carbon storage, and nutrient retention.

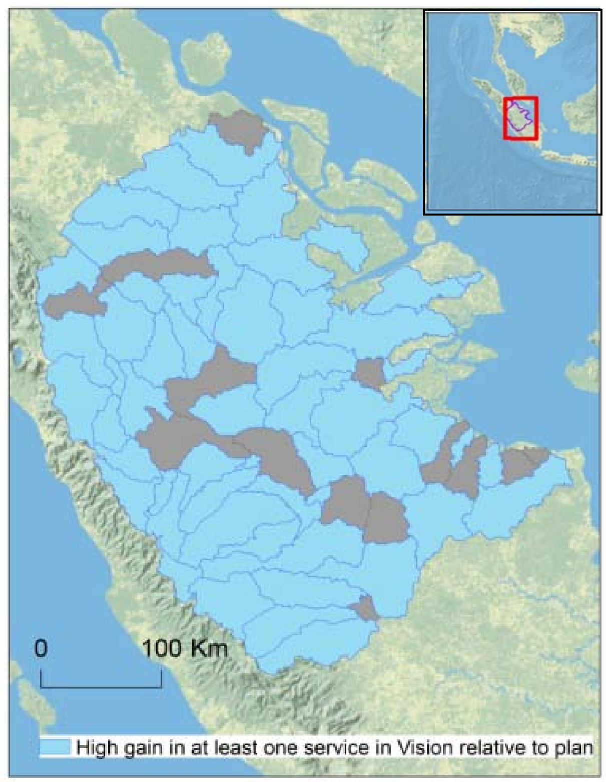


Figure iv. Sub-watersheds that could have among the highest comparative gains in one or more services by implementing the Sumatra Vision instead of the Government Plan.

Most of the sub-watersheds in central Sumatra would have high gains – in the top 25th percentile – in at least one service under the Sumatra Vision relative to the Government Plan (Figure iv). To ensure big increases in ecosystem services and biodiversity, interventions would be needed across about 75% of central Sumatra. Put another way, investment in priority actions almost anywhere in central Sumatra could result in substantial increases in ecosystem services or habitat quality. Future research should focus on identifying specific winners and losers of alternative development trajectories and potential for implementing priority actions in central Sumatra.

Chapter 1: Overview

Degradation and conversion of natural forest in Sumatra is affecting the benefits from nature that people rely on for their livelihoods and well-being. Deforestation through activities such as timber harvest and agricultural production can reduce water quality and supply for irrigation, hydropower, drinking and other uses; raise the risks of soil erosion and landslides; destroy biodiversity; and increase greenhouse gas emissions contributing to climate change. If these impacts are not quantified and managed in its development plans, Indonesia runs the risk of incurring more social costs than benefits. Hidden costs resulting from the loss of these services include impacts on human health, welfare, and livelihood opportunities; exposure to natural hazards; and reduced options for future revenue. These costs ought to be measured against the benefit in current income. With spatially explicit, quantitative information about the level and value of these services, land and water use decisions can be made that better balance development and environmental condition.

The loss of ecosystem services linked to deforestation in Sumatra, coupled with the damage to Sumatra's rich biodiversity, has raised alarm in Indonesia and abroad. In response to these concerns, the Indonesian government has agreed to take action to improve environmental, climate, and livelihood outcomes in priority places, such as central Sumatra. This report provides the results of the first science-based assessment of ecosystem service provision conducted in support of the new initiative to develop ecosystem-based spatial planning and protection of ecosystem services and biodiversity in central Sumatra.

We provide information on the current state of selected ecosystem services and wildlife habitat in the region, and the likely changes under two future scenarios: a) ecosystem-based spatial plans based on the Sumatra Ecosystem Vision for 2020 and b) current district-level spatial plans. We map the amount of high-quality wildlife habitat, carbon storage and sequestration, annual water yield, erosion control, and water purification provided by these two scenarios. Based on the differences in the amounts of these variables associated with the two scenarios, we provide recommendations about which land management actions and policies are likely to provide ecological and economic benefits. For some districts, we make preliminary recommendations about where and what kinds of activities could be undertaken with further study within each district.

Comparing differences in natural capital provided by different spatial plans, the report offers recommendations for 18 district governments in the provinces of Riau, Jambi and West Sumatra to integrate ecosystem services and biodiversity into their management and planning processes. The study area was selected because it contains important watersheds, increasing development pressures, and areas important for biodiversity, including key species such as tigers, elephants, and orangutans. A priority region called the RIMBA Integrated Ecosystem, which overlaps portions of these districts, has been designated by the Indonesian Ministry of Public Works as a demonstration area for implementing ecosystem-based spatial planning.

Our recommendations focus on the five priority actions identified by the Indonesian national government for implementing and financing ecosystem-based spatial planning in Sumatra: forest restoration, forest carbon payments, payments and programs for watershed services, best management practices for forestry, and best management practices for plantations. Programs were recommended based on their potential to result in enhancement or maintenance of biodiversity or ecosystem services. This report therefore provides an initial feasibility assessment of these priority actions based on a range of biophysical and socio-economic considerations. The results in this report are intended to inform the selection and location of these actions in the RIMBA priority area by provincial and district governments. If placed effectively, these programs have the potential to create significant progress towards other government programs and goals.

This report is organized into several broad chapters. In **Chapter 1**, we describe the purpose, background, and methodology used in analyses. **Chapter 2** describes the methods, results, and recommendations for carbon storage and sequestration. **Chapter 3** covers the same elements for three watershed services: water yield, sediment retention, and water purification. **Chapter 4** addresses habitat quality for tigers. **Chapter 5** examines the degree of spatial overlap among these layers, and the tradeoffs faced by decision makers attempting to optimize financial, human and natural capital on their landscape. Each chapter suggests next steps needed to extend these analyses, and to translate them into good decision making about ecosystem-based land use planning.

Background

In October 2008, the ten provincial governors of Sumatra and the Indonesian Ministers of Interior, Forestry, Environment and Public Works made a historic commitment to "save and conserve the ecosystem of Sumatra Island in order to balance ecological functions and economic development for the people of Sumatra, by: 1) Establishing ecosystem-based spatial planning; 2) Restoring critical areas to protect ecosystem services and 3) Protecting areas with high conservation value to protect ecosystem services, biodiversity, and the global climate" (Joint Agreement of all Sumatra Governors 2008). Furthermore, the governors agreed "on the importance of ecosystem-based spatial planning as the foundation for present and future development" (WWF 2008).

Spatial plans guide decisions about whether and where concessions are granted for extractive activities, such as oil palm and pulp and paper plantations, and where land is reserved for conservation and restoration. Although spatial planning has been undertaken in Indonesia for many years, implementation and enforcement of those plans is not universal or comprehensive. The legal basis for measures to enforce compliance with spatial land-use planning has existed only since 2007, following the Spatial Planning Law 26/2007 (Hudalah and Woltjer 2007). Strategic Environmental Assessments (SEAs) are also mandatory under the new Spatial Planning Law.

The Indonesian government's spatial planning process operates on a five-year cycle, establishing national, provincial, and district plans. Recent decentralization of Indonesian government processes means that province and district governments now have greater authority than before to adapt, modify and implement the national land use plan guidelines in their respective jurisdictions. Since the development of coarse-scale national and Sumatra-wide spatial plans in 2009, province and district governments have been designing finer-scale spatial plans. The process is intended to harmonize land-use regulations across these levels; provinces and districts are determining how to integrate ecosystem services and biodiversity into their plans, in order to meet the provincial governors' commitment.

A 'Roadmap Action Plan for Saving Sumatra Ecosystems' setting out an 'Ecosystem Vision' for Sumatra by 2020 was launched on May 11, 2010. The Ecosystem Vision provides guidance for provincial and district governments to implement the governors' commitment to conservation in Sumatra by identifying areas for protection and restoration based on an assessment of critical habitat for biodiversity (Roosita et al. 2010). Developed by the Ministry of Environment, the Ministry of Public

Works, the Ministry of Home Affairs, the Ministry of Forestry, the Coordinating Ministry of Economy, and a forum of NGOs known as Forum Tata Ruang Sumatera (ForTRUST), the Roadmap outlines measures to be taken to avoid additional ecosystem degradation through restoration of critical areas, sustainable management of areas in good condition, and development of incentive mechanisms.

Concurrent with the launch of the Roadmap, the Ministry of Public Works announced a priority area in central Sumatra, the RIMBA Integrated Ecosystem, as a demonstration site for implementing the Roadmap through ecosystem-based spatial planning and low carbon economic development. The area encompasses high-biodiversity montane, lowland and peat swamp forest, plantations, urban areas, mining and other productive use areas, and degraded areas allocated for forest restoration. The RIMBA priority area (Figure 1.1) overlaps portions of 19 districts in three provinces of central Sumatra: Riau, Jambi, and Sumatera Barat or West Sumatra.

Five priority actions for improved landscape management have been selected to drive implementation of the Roadmap in the RIMBA Integrated Ecosystem. These are 1) restoration of critical forest habitat, 2) forest carbon projects, 3) payments and other programs for watershed services, 4) sustainable management of plantations through 'best practices,' and 5) sustainable forestry management through best practices. The results in this report are intended to inform the selection and location of these programs in the RIMBA priority area. If placed effectively, these programs have the potential to create significant progress towards other government programs and goals.

Given the high levels of carbon dioxide emissions from conversion of peatlands in the RIMBA priority area and throughout Sumatra, implementing the Roadmap has the potential to make a major contribution to the Indonesian government's commitment to reduce greenhouse gas emissions by 26% from 2005 levels by the year 2020, and by 41% with external assistance, for instance through partnerships and funding agreements forged between the Indonesian government and the governments of Norway and Australia. Implementing Roadmap programs can also support the two-year moratorium on new permits to convert natural forests and peatlands to other land uses, announced in May 2010, and currently being adapted for national-level guidance.

RIMBA Integrated Ecosystem: A Profile

RIMBA is an abbreviation of the names of three neighboring provinces in central Sumatra – **Ri**au, Ja**m**bi and Sumatra **Ba**rat (West Sumatra). As presented in the Ecosystem Vision for Sumatra, the RIMBA Integrated Ecosystem covers portions of four districts in Riau Province, nine districts in Jambi Province, and six districts in West Sumatra Province, which will be managed as one integrated ecosystem region (Figure 1.1).

The RIMBA Integrated Ecosystem (about 3.9 million hectares) was designated by the national Ministry of Public Works in 2007, creating a pilot site for ecosystem-based spatial planning and habitat restoration. RIMBA contains some of the last remaining forest left in central Sumatra – a total of 2.4 million forested ha (64% of RIMBA), which encompasses montane and lowland habitats of key species in the region, including Sumatran elephants, tigers, and orangutans. The RIMBA Integrated Ecosystem (also referred to below as the RIMBA priority area) is the center of the study area which is the subject of this report. The larger study region consists of 12.5 million ha in central Sumatra (Figure 1.1) formed by six watersheds (Figure 1.2) that contains 18 districts in three provinces (Figure 1.3).

Forest and Land-Use Designations in Central Sumatra

Of the three provinces in the study area, Riau has the largest forest coverage (64% of total forest in central Sumatra), compared with 18% in Jambi and 17% in West Sumatra (Forestry Statistics of Indonesia 2007, unpublished). Despite this, Riau has the smallest proportion of its total forest area under conservation designations (9%), in comparison to Jambi (40%) and West Sumatra (66%). Across the study area, about 24% of forest is under some kind of conservation designation; that 24% includes 11% that is defined as protection forest, or areas with greater than 45% slope conserved to maintain watersheds, and 13% that is located in nature reserves and sanctuaries, which are conservation areas where all flora and fauna are protected. Designations open to extractive activity and conversion to other land uses cover 75% of the region's forested area, with 17% available for timber harvest (i.e., limited production forest), 23% open to timber harvest and conversion to timber plantations (i.e., permanent production forest), and 35% accessible by permit for agriculture and plantations, such as oil palm, *Gmelina* spp., and tea (i.e., conversion forest). A very small area (16,000 ha) is designated as hunting parks, which are not open for conversion but do not have protection status for Sumatra's charismatic fauna.

Methods and Tools for Sustainable Spatial Planning in the Study Area

The action plan outlined in the Sumatra Roadmap stipulates that ecosystem-based spatial planning should be conducted using ecosystem service information and analysis, specifically the tool InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs; Tallis et al. 2010), a geographic information systems (GIS) based software package for ecosystem services modeling, mapping and valuation (Roosita et al. 2010, p.80). InVEST provides mapped estimates of the quantity and location of ecosystem services supplied on the landscape, and how these patterns are likely to change under future land-use scenarios. Ecosystem service patterns can also be compared to biodiversity using the habitat quality module in InVEST or other sources of biodiversity information. InVEST was developed by a partnership among Stanford University, the University of Minnesota, the World Wildlife Fund and the Nature Conservancy (Natural Capital Project 2010). It has been applied in more than a dozen demonstration projects globally, and downloaded by 1,400 users thus far.

We present InVEST analyses of a region of central Sumatra covering six watersheds and containing 18 out of 19 districts overlapping the RIMBA Integrated Ecosystem (the remaining district, Pesisir Selatan, fell mostly outside the watershed boundaries and lacked sufficient data). Applied by World Wildlife Fund, as part of the ForTRUST forum of NGOs assisting with spatial planning in Sumatra, InVEST was used to assess the quantity and location of high-quality tiger habitat and four ecosystem services: carbon storage and sequestration, annual water yield, erosion control, and water purification. We provide spatially explicit, quantitative information about the difference in amounts of ecosystem services and wildlife habitat quality under the existing government spatial plan (considered as a full governance business-as-usual scenario) and the proposed Sumatra Ecosystem Vision. We assume "full governance" of each spatial plan so as to clearly compare the different ecosystem service and biodiversity implications of each plan; in effect, we hold all other drivers of future change constant, examining only the consequences of alternative land designations for the landscape and people of Sumatra. Drawing on this analysis, we use geographic, ecological and economic methods and concepts to determine program feasibility and prioritize investment in the five programs in the study area.

However, we do not value the ecosystem services assessed in this report; instead, we provide biophysical and economic information that could be used in a valuation study once beneficiaries, price signals, and replacement costs are identified.

Maps and Scenarios

We assessed ecosystem service delivery for the year 2008 (the base year) and two scenarios of land-use change (Figure 1.4). The 2008 land use/land cover (LULC) map was based on interpretation of Landsat TM images from 2007 for Riau, and 2008 for Jambi and West Sumatra by Setiabudi, a consultant for WWF Indonesia from the Southeast Asian Regional Centre for Tropical Biology (SEAMEO BIOTROP). To assess changes in forest cover from 2000 to 2008, we also used a natural forest cover map from 2000, based on Landsat imagery interpretation by the same consultant. The scenarios represent expected land use and land management under:

a) *The Sumatra Ecosystem Vision* (Figure 1.4b). This scenario represents an ecosystem-based spatial plan for sustainable land use, developed by national government agencies and ForTRUST to achieve the commitment of the ten provincial governors of Sumatra to 'save the Sumatra ecosystem' by considering habitat restoration and high value conservation areas in their planning. This plan still includes economic development and oil palm plantation expansion

b) Government Spatial Plan (Figure 1.4c). This scenario represents the existing spatial plans proposed by province and district level governments in the RIMBA priority area, which are similar to past plans. These plans have no explicit ecosystem-based spatial planning elements, and would likely lead to increased deforestation.

We take the Government spatial plan scenario (referred to below as the Government Plan[2]) to represent one possible future for the RIMBA priority area if district governments carry on with business as usual. We treat the Sumatra Ecosystem Vision scenario (referred to below as the Sumatra Vision[3]) as a new plan that aims to divert development away from business-as-usual and toward sustainable development in Sumatra. However, we note that in either future scenario, there are likely to be additional, unexpected changes in land use and land cover driven by multiple factors such as climate change, population growth, and global commodity prices that are not accounted for in the plans. In our analyses, we assess what would likely happen if either of the scenarios were fully implemented, i.e. there is full enforcement of the land use and land management practices planned and no external factors alter the plans as currently set out. We do so to examine and compare the different outcomes of the two plans and the policies they represent. The scenarios were developed by extrapolating theLULC categories of the 2008 map to the expected future LULC specified in the Vision or the Government Plan for a given area.

[2] In some of the report's maps and figures, the Government Plan is referred to as the government plan, government spatial plan, or simply the plan.
[3] In some of the report's maps and figures, the Sumatra Vision is referred to as the Sumatra Ecosystem Vision or simply the Vision.

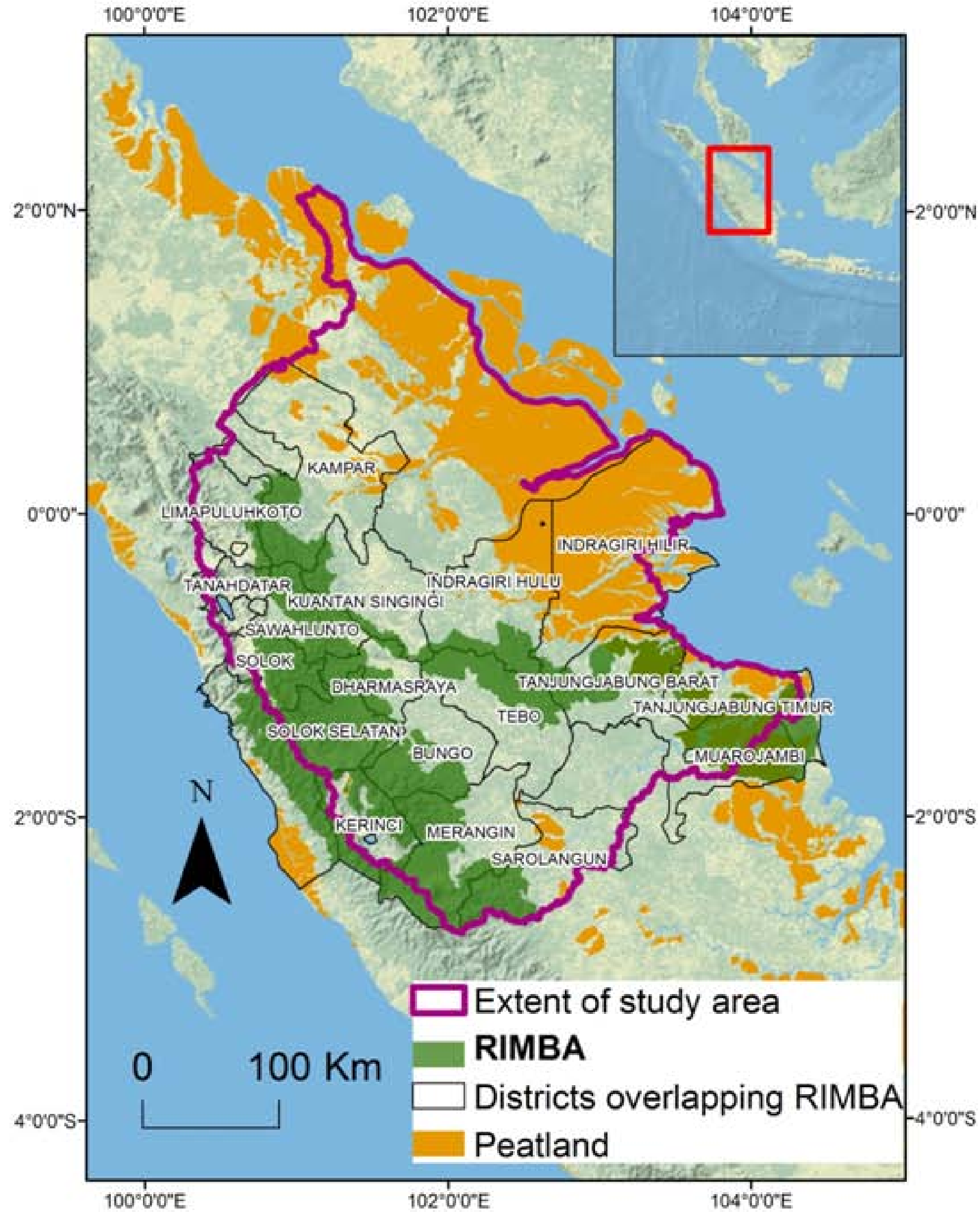


Fig. 1.1 Study area in Central Sumatra. The Bukit Barisan Mountain range runs along the western edge, while much of the rest is lowland, with peat swamps dominating in the east.

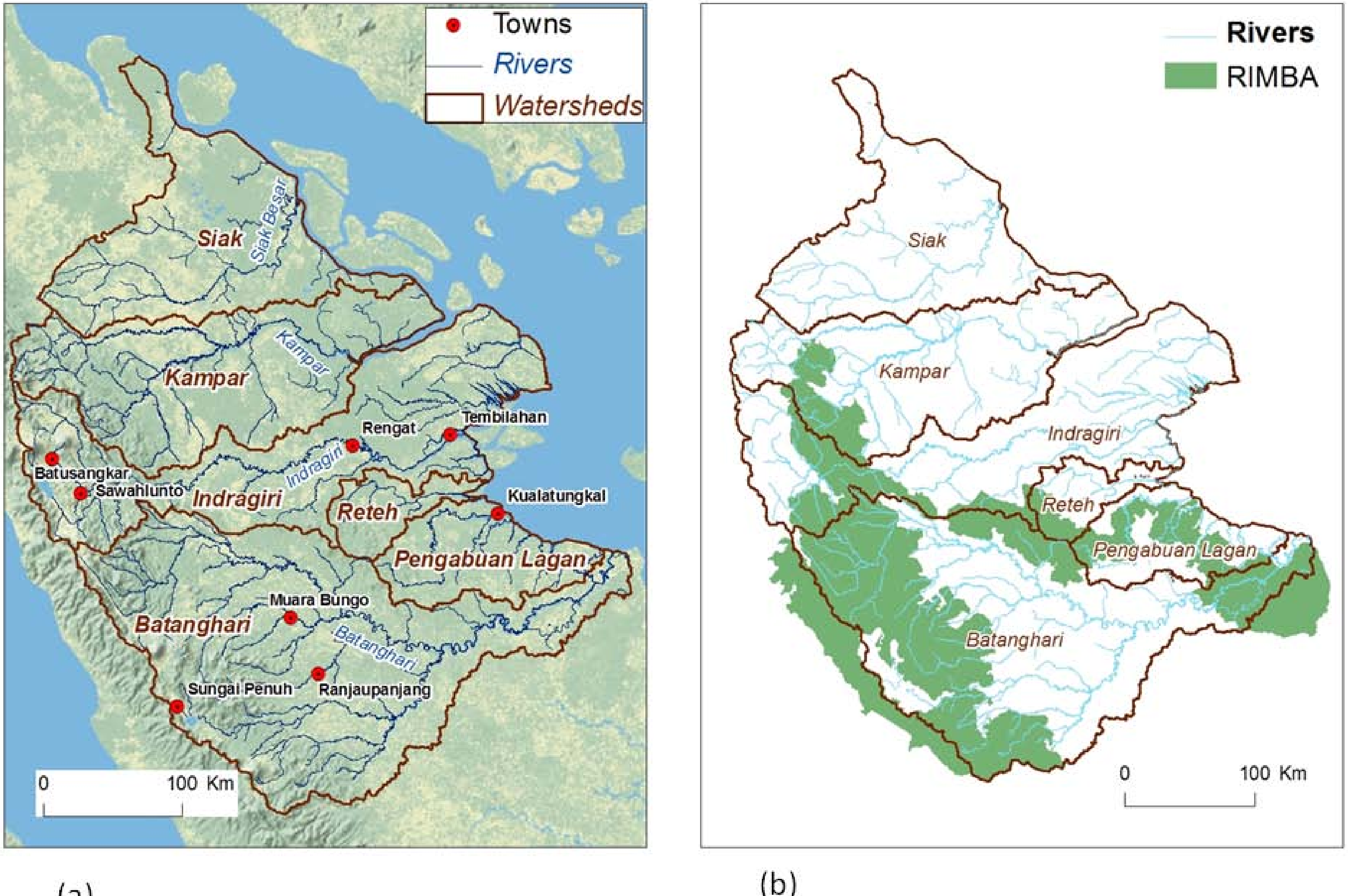
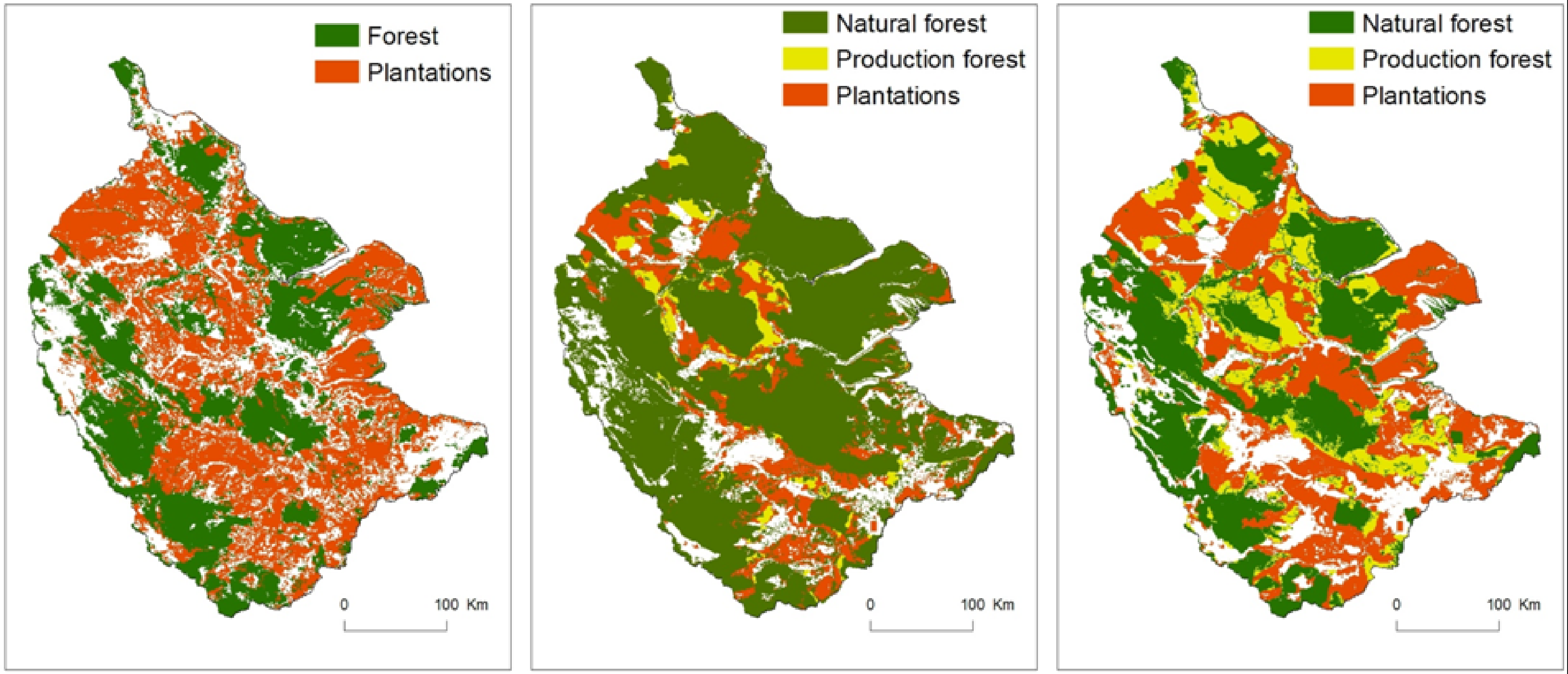


Fig. 1.2 There are six major watersheds in our study area. Most rivers flow west to east, with the upper reaches of a number of rivers being located in the RIMBA priority area (right).

Fig 1.3. The study area contains 19 districts spread out over 3 provinces (Riau, West Sumatra and Jambi) of which all but one (Pesisir Selatan) were included in this study



(a) 2008 land cover (b) Sumatra ecosystem Vision (c) Government spatial plan

Fig. 1.4. Distribution of forests and plantations under in 2008, and under the two alternative future scenarios of land use. 2008 forests include both production and natural forest. Both scenarios have more forest cover than in 2008. The Vision has more forest than the plan (the plan would have 59% more forest area than 2008, while the Vision would have 132% more than 2008). However, the increase in forests in the government plan is driven primarily by an increase in production forests, where logging and conversion can take place. When production forests are not included, the forest area in the plan and Vision scenarios would increase by 2.4% and 106% respectively. It is also likely that the government plan is more optimistic than a business-as-usual scenario, as past high deforestation rates suggest that there may be additional unplanned deforestation in a BAU scenario that the government plan does not take into account

Analysis and Peer Review

The InVEST results are provided as:

- Maps for the 2008 land cover and each future development scenario – these show the current spatial distribution of ecosystem services and habitat quality, and how these will be affected by each alternative plan.
- Maps showing the difference between the two scenarios, and between each scenario and 2008 – these show the gain or loss in ecosystem services or wildlife habitat quality from implementing the Sumatra Ecosystem Vision as compared to the Government Plan.
- Analyses of synergies and tradeoffs – these compare the relative changes in combinations of ecosystem services and habitat quality between the two scenarios for several regions, including the districts, watersheds and specific locations such as town and dams.

Our findings have been reviewed by local and global experts at WWF, ICRAF, and other institutions. We encourage further review and validation for new uses of our results and recommendations.

General Limitations of Results

Models are simple and there is uncertainty surrounding outputs: InVEST models, although grounded in theory, offer low-precision estimates of ecosystem service provision (Tallis et al. 2010). They can provide coarse assessments of ecosystem services on the land or seascape with relatively little data that can include readily available global or regional datasets, or look-up values from peer-reviewed and gray literature. We used regional, national, and global datasets for input values, estimated future conditions, and made simple assumptions about land use change and its effect on ecosystem services and habitat quality. For this reason, the recommendations in this report should be interpreted as feasibility assessments rather than as detailed guidelines for project design, setting payment levels for payment for ecosystem services (PES) schemes, or targeting precise locations of ecosystem service provision. InVEST is better suited to identify areas of relatively high and low ecosystem service provision and habitat quality, assess tradeoffs, and explore how levels of services and biodiversity may increase or decrease under alternative future scenarios.

Not all potential land-use changes considered within scenarios: Given that this report compares two simplified scenarios of land-use designations, the analysis may not include all the likely land-use changes in the area. Some of these omitted land uses could potentially have significant impacts on ecosystem services. In particular, both scenarios exhibit full enforcement of prescribed policies, and no external factors alter the plans. Neither scenario accounts for external drivers of land-use change, such as climate change and international demand for commodities.

Social and governance factors not considered in depth: These recommendations serve as a first-cut feasibility analysis based on a biophysical assessment of habitat quality and ecosystem services. Further consideration of social, economic and governance characteristics ought to be investigated to scope whether and how programs can be implemented. In particular, we do not identify which groups and settlements do and do not benefit from particular services or whether legal, social, and cultural conditions promote uptake of recommended actions. Such factors need to be assessed to determine the social appropriateness of any ecosystem service-based program. Given that these factors were not assessed, some conservation finance mechanisms that are recommended may not be appropriate under current conditions.

Recommendations for Sustainable Spatial Planning

The Five Priority Actions for the RIMBA Study Area

Five priority actions have been identified by the Indonesian government for implementing and financing ecosystem-based spatial planning in Sumatra. These actions (referred to as priority programs) are forest restoration, forest carbon projects, improved watershed management and payments for watershed services, best management practices for forestry, and best management practices for plantations. We use the following definitions to delineate the scope of policies and activities included under each program, and to develop recommendations to maintain or enhance ecosystem services:

- We define *forest restoration* as actions to restore damaged natural forests. The Sumatra governors committed to "restoring critical areas to protect ecosystem services." The Roadmap Action Plan for Sumatra outlines a Sumatra Ecosystem Restoration Conservation program (see Roosita et al. 2010, p.79 and related maps), giving priority to protected areas. In this assessment, we assume that this activity will improve habitat quality and some ecosystem services associated with forests.

- We define *forest carbon projects* as investment, purchase, donation, or other financial support for actions to reduce greenhouse gas emissions by reducing deforestation or enhancing forest areas. We make the assumption that these activities, which can result in market-eligible forest carbon credits for either compliance or voluntary markets, are related to maintenance or increase of land-based carbon stock. In some cases, these payments may require other actions, such as reforestation or peat swamp restoration. We assume that if there is no forest in the location in the 2008 map that these activities will be restorative rather than preventive.

- We define *payments for watershed services* (PWS) as contractual and voluntary transactions where a 'buyer' agrees to provide some kind of compensation or payment to a 'seller' conditional on delivery of a hydrological ecosystem service, or implementation of a land use or management practice likely to secure that service (Wunder 2005).[4] Improved watershed management is defined as any activity that is expected to maintain or increase hydrological ecosystem services that benefit users. We focus on PWS or improved watershed management for the three hydrological services modeled using InVEST: regulation of water supply (water yield), water quality (nutrient reduction), and erosion control (sediment retention), where population centers and dams are among the beneficiaries.

- We define *best management practices (BMPs) for plantations* as actions that reduce the environmental footprint of existing plantations and potentially increase revenue through

[4] More broadly, PWS has been defined by the World Agroforestry Centre (ICRAF) as interactions between ecosystem service providers and beneficiaries and related stakeholders within three paradigms: commoditized ecosystem services where procurement is based on actual service delivery and direct marketability; compensating for opportunities missed where land users are paid for accepting voluntary or mandatory restrictions on their use of land with conditionality on ecosystem or activity-based performance; and co-investment in landscape stewardship whereby investors support building livelihood assets and respect for local sovereignty in managing the environment for local and external benefits.

certification schemes. These include best management practices specified by the Roundtable to Sustainable Palm Oil (RSPO) certification for oil palm. Some examples of best management practices for plantations include avoiding expansion into High Conservation Value Forests (://www.hcvnetwork.org/), conserving forests within plantation areas to sustain biodiversity, reducing human-wildlife conflicts around plantations, and using non-polluting techniques for land preparation (e.g., zero fires, fewer fertilizers and pesticides). Here we focus on the BMPs of reducing polluting techniques, creating forested corridors, and reducing human-wildlife conflict in plantations and neighboring areas, which are particularly important for plantations bordering water bodies and areas of high biodiversity.

- We define *best management practices for forestry* as actions that reduce the activity's environmental footprint and potentially increase per unit revenue through certification schemes. These include best management practices specified by FSC certification for timber harvest. Some examples of relevant best management practices include avoiding clear cutting, limiting impact on forest carbon stock, reducing human-wildlife conflicts in the area, and maintaining forested buffers along water bodies.

Based on the comparison between 2008, the Government Plan, and the Sumatra Vision, we provide broad recommendations on the five priority programs outlined above, and more specific recommendations for a subset of key districts and other location regarding which programs they could successfully implement, and where. These recommendations are based on biophysical and some economic analysis and are most appropriately used to evaluate feasibility of improved landscape management, but more research and information will be necessary to design, site, and fund specific programs.

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Chapter 2: Carbon Storage and Sequestration

Key Findings

- Relative to 2008, implementing the Sumatra Vision would result in a gain of 350 million tonnes of carbon (MtC) stored in the study area over 50 years, of which 60 MtC would be gained within the RIMBA priority area
- Conversely, the entire region would lose 1000 MtC over 50 years relative to 2008 under the Government Plan, of which 100 MtC would be lost within the RIMBA priority area. These carbon losses (equal to 3,667 million tones of CO_2 emissions) are driven by new conversion of forest and continued operation of plantations on peat swamps, which results in ongoing emissions.
- In our prioritization exercise, Kampar and Dharmasraya districts were identified as important for potential investment in forest carbon projects for forests on mineral soils, whether soil carbon is included in the calculation or not.

Outline

Carbon storage and sequestration have been identified as key ecosystem services in peat soils and forest by the Indonesian national government (DNPI 2010); however, climate change mitigation from carbon storage and sequestration are not guaranteed. As the districts in central Sumatra choose between increased agricultural or timber expansion and increased provision of essential ecosystem services, it is essential that we understand the value of land under intensive management and the potential supply of carbon storage and sequestration on the landscape.

Peat soils have by far the highest values for carbon stock and emission intensity, and Sumatran forests harbor large carbon stocks alongside a rich array of biodiversity including tigers, orangutans, and elephants. Keeping carbon stocks locked up in peat soils while restoring and maintaining forest carbon stocks could benefit climate regulation as well as biodiversity conservation. This analysis identifies areas where implementing forest carbon projects could maintain, restore or increase carbon stock.

Forest carbon projects

Forest carbon projects are initiatives established for the purpose of mitigating climate change through reduction of greenhouse gas emissions by locking up carbon in forests and similar ecosystems, such as peat swamps. These initiatives are generally instituted in a particular place, where the carbon sequestration or avoided emissions of CO2 can be monitored and verified. They can be market-based, like cap-and-trade systems, or policy-driven, such as land-use regulations or actions supported by a national fund. Relevant existing policies and programs include REDD+ and CDM. In this report, we consider any purposeful change in land management to sequester or store carbon in forests to be eligible as forest carbon projects. This may include avoided deforestation and degradation, forest enhancement, peat swamp restoration, and reforestation.

First, we estimated total carbon stock in four pools – above-ground biomass, below-ground biomass, soil, and dead organic matter for the entire study area in the year 2008 (see Appendix 2.1), and compared the differences in stock that would occur over a 50-year time horizon from fully implementing the Sumatra Vision and the Government Plan. This *total carbon analysis* allowed us to compare the amount of carbon storage provided by the Government Plan to the amount offered by the Sumatra Vision, relative to a 2008 baseline.

Next, we calculated the carbon storage and sequestration over 50 years in natural forest areas on mineral soils *only*, and conducted a simple prioritization of districts based on average carbon stocks, deforestation probability, and opportunity cost of land at the district level. We conducted this analysis because mineral soils, although less carbon-rich than peat, can store significant quantities of carbon in the forests growing on them and are considered important for biodiversity conservation and other ecosystem services. Sixty-five percent of the forested area on our landscape lies outside peatlands, on mineral soils. Although peat forests in Sumatra should always be highly prioritized for climate change mitigation benefits, these forests should also be considered for forest carbon projects. This analysis allows us to rank districts by greatest potential for developing forest carbon projects on mineral soils and implementing offset-eligible forest carbon projects (defined below).

Last, we drew two top districts from the prioritization scheme to exemplify a third analysis. We visually identified areas on a carbon stock map for each district where forest carbon projects might have potential, comparing the Sumatra Vision to the Government Plan. In this analysis, we did not differentiate between forest carbon projects that would be eligible for compliance markets (e.g., REDD, REDD+, CDM), for co-investment, or for voluntary carbon markets.[5] Instead, we indicate that a particular location and action would be eligible for at least *one* of these options. This *carbon project analysis* demonstrates how to identify areas with the greatest potential for seeking payments for carbon storage and sequestration projects in the study area.

[5] Reducing Emissions from Deforestation and Forest Degradation (REDD) is defined as mechanisms that directly prevent deforestation that is projected to occur under a business-as-usual scenario. REDD+ activities can include land-use based climate benefits in forest areas that do not face a deforestation threat under business as usual (i.e., maintenance or enhancement of carbon stock). In both cases, the maintenance of carbon stock must be permanent and 'leakage' of deforestation to other areas must be accounted for. Over-the-counter and voluntary forest carbon projects, and co-investment, can be REDD, REDD+, or afforestation/reforestation (A/R) actions; these are not always required to be additional.

Methods

Analyses of Carbon Stocks and Sequestration in Central Sumatra

We quantified four carbon pools in the study area. We used InVEST to model carbon stocks in different land use / land cover (LULC) categories under the current landscape and the two future scenarios for three carbon pools: above ground biomass, below ground biomass, and organic matter (Appendix 2.1). We modeled soil carbon separately and added these values to the InVEST outputs (Appendix 2.2), as it is important to take into account high rates of annual carbon losses from peat decomposition following conversion of these lands into plantations, which is not possible to do within InVEST. Although land-use plans and plantation cycles often operate over decadal or shorter time frames, we modeled changes in the carbon pools over a time period of 50 years, as it generally takes many years for the full carbon implications of land-use change to become apparent.

For above-ground biomass estimates, we used data provided in Uryu et al. (2008), supplemented with estimates for Jambi province (SEAMEO-BIOTROP 1999) where available for a given LULC type. Below-ground biomass was calculated as a fraction of above-ground biomass, using root: shoot biomass ratios for tropical ecosystems provided in IPCC guidelines (IPCC 2006, Volume 4, Table 4.4). For carbon stored in dead organic matter, we used estimates of carbon in leaf litter provided in IPCC 2006 (Volume 2, Table 2.2) for tropical ecosystems, assigning zero or downscaled values for human-modified or bare land uses. For more detailed methods, see Appendix 2.2.

We generated a soil carbon layer using the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC 2009). Soil carbon content for non-peat (mineral soil) areas was estimated by averaging the carbon content of topsoil and subsoil to a depth of 100 cm. Where peat soils occurred on the landscape, we replaced the world soil layer with a peatland distribution layer from Wetlands International that included spatially explicit estimates of peat carbon content (Wahyunto et al. 2003). To calculate carbon emissions from peat conversion, we used Uryu and colleagues' (2008) estimates of median annual CO_2 emission rates due to land-use changes on peatlands. We did not calculate any soil carbon loss for the non-peat areas as we lacked data for soil carbon emissions linked to LULC changes in non-peat areas. However, these losses are likely to be much less than in the peat areas.

Our estimates of carbon stock changes are approximate. For our future scenarios, we assumed all plantation areas to have mature plantations, even though some areas are likely to be in intermediate stages between planting cycles, and thus either cleared or immature at any given point in time. However, the biomass values from Uryu et al. (2008) that we used for plantations already take this into account, using a downscaled value of biomass to account for intermediate growth stages. We also did not take into account carbon emissions from burning of peat, which often accompanies land clearing for plantations, and released an estimated 0.38 gigatonnes of carbon (GtC) in Riau alone from 1997 to 2007 (Uryu et al. 2008). We did not attempt to model the future spatial distribution and intensity of burns over our scenario time frame, which would be necessary to estimate future emissions from peat burning. Our estimates of any gains in carbon stocks in the Sumatra Vision relative to the Government Plan are therefore likely to be conservative, since the above assumptions would overestimate the carbon stocks in plantations, of which there would be more under the Government Plan than the Sumatra Vision. Finally, our estimates of future forest related carbon stocks do not account for future climate change driven alterations of forest productivity, carbon cycling, or disturbance dynamics.

Climate change may significantly affect how much carbon is stored in different ecosystems even under static land use.

We recognize that the lack of uncertainty estimates around our carbon stock values limits the accuracy of our analyses. However, by highlighting broad patterns of variation in carbon stocks, we are able to (1) indicate areas in the study region of global, regional and local value for carbon storage, (2) compare the potential for climate mitigation of ecosystem-based versus business-as-usual spatial planning, (3) identify areas of concern for greenhouse gas emissions under business-as-usual, and (4) assess the potential for carbon projects at specific sites within districts. This last assessment sets the stage for more detailed, site-based analyses to develop carbon projects that can be used to offset carbon emissions in compliance or voluntary markets and finance ecosystem-based spatial planning.

District Prioritization Analysis for Forest Carbon Projects

Because ecosystem-based spatial plans need to take into account the biodiversity and ecosystem services from all forests, whether on peat or mineral soils, we developed a simple prioritization of districts for investment in forest carbon projects on mineral soils. We defined forest carbon as carbon stock from any of the four pools assessed (above ground biomass, below ground biomass, organic matter and soil) that occur in natural forest areas and prioritized investment in areas that have high carbon content, high threat, and low cost. Specifically, we prioritized for (a) large standing stocks of forest carbon, (b) high deforestation risk based on historical trends, and (c) low opportunity cost from foregone plantation revenue if forest carbon conservation payments are implemented.

We calculated district-level deforestation risk as follows:

- From a random sample of 228,000 pixels across the entire landscape (of 138.5 million pixels), we identified the fraction of forested pixels in each district that were converted between 2000 and 2008 to plantations, since plantations were the major driver of deforestation. We considered both smallholder and large-scale plantations of acacia, cinnamon, coconut, *Gmelina* spp., oil palm, rubber, and, tea. We assumed that our selection process did not bias the estimates of conversion probability in any district.

- We also assumed a linear trend of deforestation over time, and calculated an annual average rate of deforestation by dividing the total area deforested from 2000 to 2008 by the original area of forest in 2000, and then dividing by 8. This allowed us to compute the average percentage of standing forest that is converted to plantations each year.

Opportunity Cost Methodology

We used the estimated revenue per hectare as one criterion to prioritize districts for investment in carbon projects. This value is the opportunity cost of engaging in forest carbon projects instead of another economic activity. The three principal drivers of economic activity in this region are acacia plantations, oil palm plantations, and rubber plantations. Other drivers of forest conversion include cinnamon, coconut, *Gmelina*, pine, and tea plantation, as well as subsistence agriculture. To estimate potential revenues from forest conversion to plantations within each district, we derived estimates of the profits associated with each of the three major intensive management regimes in the region (i.e., oil palm, acacia and rubber). We further refined these estimates by accounting for differences in returns across soil type (mineral vs. peat) for both oil palm and acacia, as well as elevation and slope for acacia. We used these pixel-level characteristics, and the fraction of converted land allocated to various intensive management regimes, to estimate average district-level values of intensive management (see Appendix 2.3 for detailed methods).

We did not develop pixel-specific returns using this approach, because our profit information is not spatially explicit. We used this estimated annual return per hectare to represent opportunity cost at the district level. This is sufficient to rank districts according to the possible opportunity cost of investing in forest carbon projects, but should not be interpreted as a true opportunity cost at the level of individual pixels or forest tracts.

Prioritization of Districts for Investment in Forest Carbon Projects

In this analysis, we used a simple ranking scheme to prioritize a subset of districts in central Sumatra for investment in forest carbon projects on mineral soils. First, we ranked districts by forest carbon stock in two ways: (a) considering above- and below-ground biomass only, and (b) considering all four carbon pools. We did both rankings because our soil data (from the Harmonized World Soil Database) indicated considerable variation in organic carbon in mineral soils across the landscape, and also because we had no data on likely CO_2 emissions related to disturbance and conversion on mineral soils. Including our simple estimates of soil carbon pools in our ranking exercise led to district rankings that were different from those obtained by considering biomass alone (see results). The ranking scheme one selects to identify the high-priority districts for carbon projects should depend on (1) further validation of these results, and (2) whether soil carbon will be considered or not in carbon project payment schemes.

We also ranked districts by conversion threat (based on historical deforestation rates) and land value (estimated by opportunity costs of expected revenue from plantations). Low rankings (i.e., close to 1) indicate areas with high forest carbon stocks on mineral soils, high threat, and low land value.

Next, we summed the ranks of forest carbon stock, threat and land value for each district. The lower the summed rank for a given district, the higher the priority of that district for forest carbon investment on mineral soils relative to the other districts, as these districts are likely to yield more cost-effective emissions reductions than others. In other words, under current international agreements, districts with such low rankings would be most attractive for establishment of carbon programs or payments.

Results

Total Carbon Stock Analysis

The 2008 landscape has the highest levels of carbon stock in the eastern portion of the study area (over 6000 tonnes/ha), a region which is dominated by peatlands (Figure 2.1). However, carbon-rich areas also exist elsewhere in the landscape, including non-peatland forested portions of the RIMBA Integrated Ecosystem. Over a 50-year time horizon, areas both within and outside the RIMBA priority area would have higher carbon stocks under the Sumatra Vision relative to the Government Plan. The carbon stocks in the Sumatra Vision exceed those in the Government Plan by the largest margins mostly in the eastern peatlands (Figure 2.2).

Relative to 2008, implementing the Sumatra Vision would result in a gain of 350 million tonnes of carbon (MtC) stored in the study area over 50 years, of which 60 MtC would be gained within the RIMBA Integrated Ecosystem. Conversely, the entire region would lose one GtC over 50 years relative to 2008 under the Government Plan, of which 100 MtC would be lost within the RIMBA priority area. These analyses assume perfect implementation of either plan, and therefore do not factor in additional carbon losses likely from illegal deforestation. Both scenarios would likely lead to losses in carbon storage relative to 2008 conditions in the southern part of the landscape, because both include conversion of plantation areas to carbon-poor land uses in the south, such as “dryland farming” (as specified in the land cover maps) and settlements (Figure 2.3). Although some other areas of the landscape would lose carbon under both scenarios, these losses are much greater in the Government Plan, and lead to net carbon emissions under the plan relative to 2008. In the Government Plan (Figure 2.3 b), carbon losses are driven by increased deforestation across the landscape, as well as continued operation of plantations on peat swamps in the east, which results in ongoing peat decomposition.

Most districts overlapping the RIMBA Integrated Ecosystem reflect the trend of the landscape as a whole, gaining carbon stocks under the Sumatra Vision relative to 2008 and being net carbon emitters under the Government Plan (Figure 2.4). By far, the highest carbon emissions under the Government Plan are from districts containing peat soils. Indragiri Hilir, which sits almost entirely on peat, stands to emit the highest amount of carbon under the Government Plan (about 500 MtC), but would sequester the most carbon under the Sumatra Vision. Although most of Indragiri Hilir is not within the RIMBA priority area, Tanjungjabur Timur is one district that contains peat areas that are also within the RIMBA priority area (Figure 2.5). Within Tanjungjabung Timur, restoration and reforestation of currently degraded peat under the Sumatra Vision would lead to carbon sequestration (Figure 2.5 b)[6], while plantation activity on peat under the Government Plan would result in continued emissions from the same regions (Figure 2.5 c). It is important to note that the peat stabilization required prior to forest restoration in such areas would likely be costly and could exceed potential revenues from forest carbon projects. However, it is possible that avoiding restorative action in such areas could compromise national or island-wide emissions reductions targets, given the high rate of emissions from peat.

When considering only forested areas – which leaves out peat soils without forest canopy – both the Sumatra Vision and the Government Plan gain carbon relative to 2008, but the Sumatra Vision gains more than twice the amount of forest carbon gained by the Government Plan (6300 and 3000 MtC, respectively).

[6] We did not model short-term greenhouse gas emissions related to seasonal variation in peat swamps.

Priority Districts for Investment in Forest Carbon Projects *on Mineral Soils*

In this prioritization, we address climate change mitigation benefits from carbon storage and sequestration in forests on mineral soils. We target districts that have high carbon stocks on mineral soils, high risk of deforestation, and low opportunity cost, in order to address where investments could be most cost-effective. Although the carbon benefits are less than those in the eastern peatlands, they are still globally significant.

We find that Tanjungjabung Barat has the highest annualized deforestation rate (5.6%), whereas Kerinci has the lowest (0.4%). Tanahdatar has the highest revenue per hectare at RP 235,847,300, followed by Tanjungjabung Timur and Tanjungjabung Barat. On the other end of the spectrum, Merangin, Sarolangun, and Limapuluhkoto all have revenues per hectare that are less than RP 80,000,000. Table 2.1 shows deforestation rates, land value and forest carbon stocks on mineral soils across 18 districts overlapping the RIMBA priority area. Table 2.2 draws on those values to prioritize districts for investment.

Table 2.1. Deforestation rates, average land value, and carbon stocks in 18 districts overlapping the RIMBA Integrated Ecosystem.

District	**Annualized deforestation rate**	**Weighted average land value (RP/ha)**	**Carbon (tonnes/ha) for all pools**	**Carbon (tonnes/ha) for above and below ground biomass only**
TANJUNGJABUNG BARAT	0.056	171,421,700	310	205
KAMPAR	0.034	153,313,800	370	216
TANJUNGJABUNG TIMUR	0.033	181,294,000	386	95
TEBO	0.029	94,271,900	251	152
MUAROJAMBI	0.026	126,192,300	287	94
DHARMASRAYA	0.023	97,133,700	390	196
INDRAGIRI HULU	0.022	155,398,800	312	207
KUANTAN SINGINGI	0.021	159,256,200	366	212
BUNGO	0.018	107,816,200	364	202
TANAHDATAR	0.015	235,847,300	634	188

INDRAGIRI HILIR	0.015	151,823,700	382	139
SAROLANGUN	0.013	61,237,700	341	215
SOLOK SELATAN	0.01	84,379,900	412	183
SAWAHLUNTO	0.007	109,162,600	354	201
MERANGIN	0.007	79,032,800	398	176
LIMAPULUHKOTO	0.004	50,908,400	383	201
KERINCI	0.004	108,754,300	710	151
SOLOK[7]	0	n/a	436	183

Table 2.2 shows district ranking corresponding to the values in Table 2.1, along with relative priority for investment in forest carbon projects. Priority is based on carbon stock, cost-effectiveness of the investment, and urgency because of deforestation risk. The top five priority districts for all carbon pools include Dharmasraya, Solok Selatan, Merangin, Kampar, and Kerinci. The top five for above-ground and below-ground biomass only are Kampar, Sarolangun, Dharmasraya, Tanjungjabung Barat, and Bungo.

Although the priorities differ depending on which carbon pools are counted in the prioritization exercise (Figure 2.6), Dharmasraya and Kampar are in the top third of priorities under either scheme. Muarojambi is in the bottom third for both approaches.

Table 2.2. Districts ranked for investment priority for forest carbon projects.

District	**Threat rank 1 = highest conversion**	**Value rank 1 = lowest land value**	**Carbon stock rank 1 = highest carbon stock: all pools**	**Carbon stock rank 1 = highest carbon stock: above and below ground biomass only**	**Summed rank based on threat, land value and all carbon pools**	**Summed rank based on threat, land value, and above and below ground biomass only**	**Investment priority based on *all carbon pools* 1 = highest priority**	**Investment priority based on *above and belowground biomass only* 1 = highest priority**
KAMPAR	2	12	10	1	24	15	4	1

[7] Our random sample of deforested pixels did not include any from Solok, which appears to have undergone relatively limited conversion to plantations compared to the other districts in this analysis.

SAROLANG UN	12	2	14	2	28	16	10	2
DHARMASR AYA	6	6	6	9	18	21	1	3
TANJUNGJA BUNG BARAT	1	15	16	5	32	21	14	4
BUNGO	9	7	12	6	28	22	9	5
TEBO	4	5	18	14	27	23	8	6
INDRAGIRI HULU	7	13	15	4	35	24	16	7
KUANTAN SINGINGI	8	14	11	3	33	25	15	8
LIMAPULU HKOTO	17	1	8	8	26	26	6	9
SOLOK SELATAN	13	4	4	12	21	29	2	10
SAWAHLUN TO	14	9	13	7	36	30	17	11
MERANGIN	15	3	5	13	23	31	3	12
MUAROJA MBI	5	10	17	18	32	33	13	13
TANJUNGJA BUNG TIMUR	3	16	7	17	26	36	7	14
TANAHDAT AR	10	17	2	10	29	37	11	15
INDRAGIRI HILIR	11	11	9	16	31	38	12	16
KERINCI	16	8	1	15	25	39	5	17
SOLOK	18	n/a	3	11	n/a	n/a	18	18

Depending on the carbon accounting scheme, either of the rankings in the last two columns of Table 2.2 might be the most appropriate to use for determining priority for investment in forest carbon projects. If a carbon accounting scheme does not measure or certify changes in soil carbon quantities, then it will be most appropriate to use the *above-ground and below-ground biomass only* ranking. If a scheme requires accounting for all four carbon pools, it may make sense to use the *all carbon pools* ranking.

Two High-Priority Districts

We provide some preliminary recommendations for the two districts, Dharmasraya and Kampar, which appear in the top third of the ranked districts with or without soil carbon accounting (Figures 2.7 and 2.8). These recommendations are not definitive, nor comprehensive, but rather highlight the kinds of insights that the analyses in this report can provide. This approach can be replicated for other districts that are to be prioritized for carbon projects.

Dharmasraya (Figure 2.7): There could be opportunities to invest in forest carbon projects that undertake reforestation in selected areas of the district, where current plantations could be replaced with forest as recommended by the Sumatra Vision, and in some areas, by the Government Plan as well. In the northern part of the district, in the areas indicated by the red squares in Figures 2.7 a and b, forest that would be lost to plantations under the Government Plan could benefit from carbon conservation payments to prevent deforestation. In the Government Plan (Figure 2.7 b), this represents a potential loss of up to 200 tonnes of carbon per hectare in the orange-colored area; in the Sumatra Vision (Figure 2.7 a), these same areas are gray, indicating little or no change in carbon stock relative to 2008, meaning that the forest carbon is maintained and the deforestation in the Government Plan is avoided.

Kampar (Figure 2.8): In the southern and eastern parts of Kampar district, restoration to forest of existing plantations on mineral soils, as planned in the Sumatra Vision, would lead to gains in carbon stocks in these areas. Additionally, peat areas, mostly in the eastern parts of Kampar, would continue to emit carbon under the Government Plan, but these emissions would stop under the Sumatra Vision, which recommends reforestation of these peat areas. In these peatlands, the red areas in the red circles in Figures 2.8 a and b, could lose more than 1000 tonnes of carbon per hectare relative to 2008; whereas restoration of these areas could lead to increases in carbon stocks of up to 200 tonnes per hectare.

These districts illustrate the opportunity to enhance, restore, or maintain the supply of carbon storage and sequestration in central Sumatra. However, as we have mentioned elsewhere, , we do not know the opportunity costs of establishing carbon projects on particular land parcels. Therefore, although our analysis indicates that the above two districts offer cost-effective opportunities for carbon storage and sequestration projects, further local study is needed to determine whether the highlighted areas in these districts do indeed have low enough opportunity costs to make forest carbon projects economically viable.

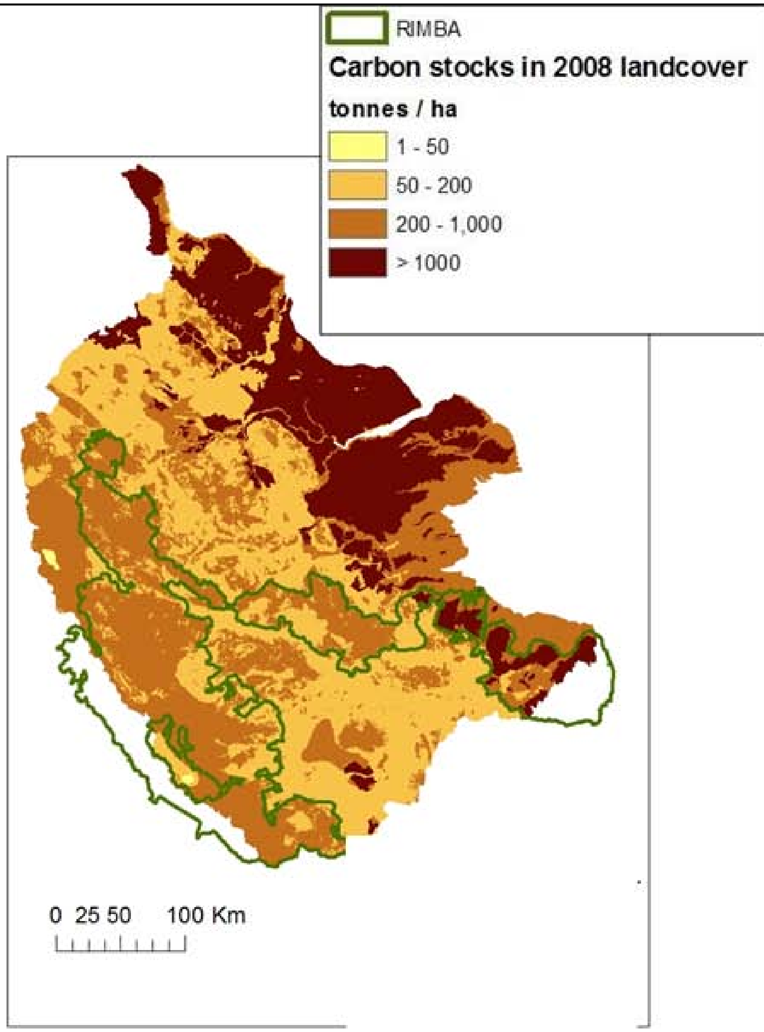

Fig 2.1. Distribution of carbon stocks on the 2008 landscape

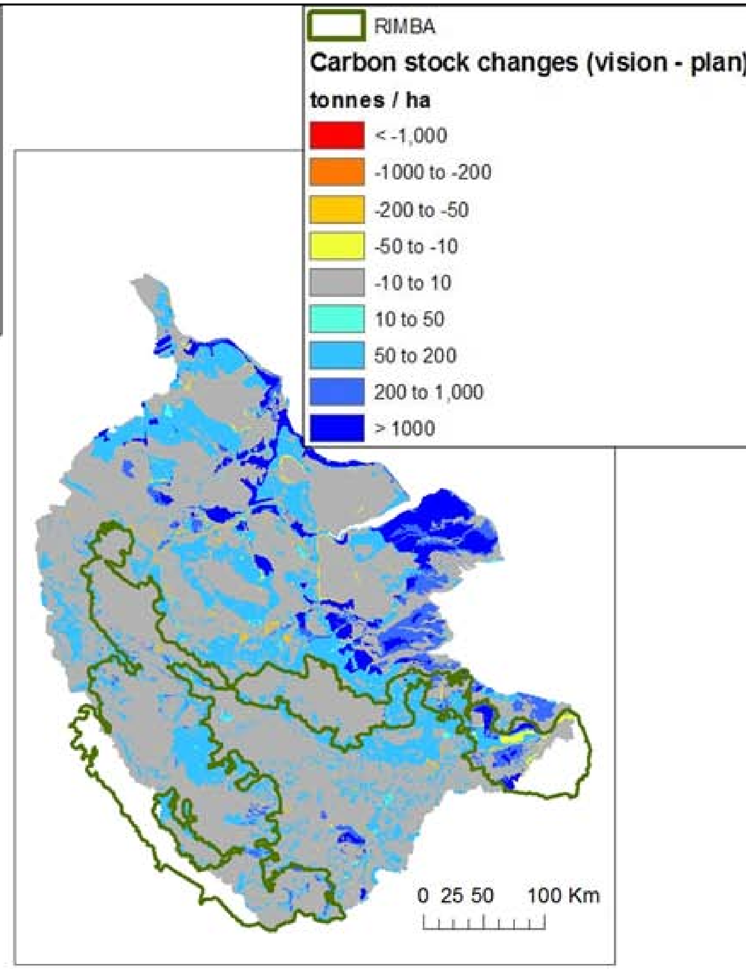

Fig 2.2. Difference between carbon stocks in the Sumatra vision and the government plan over a 50-year horizon

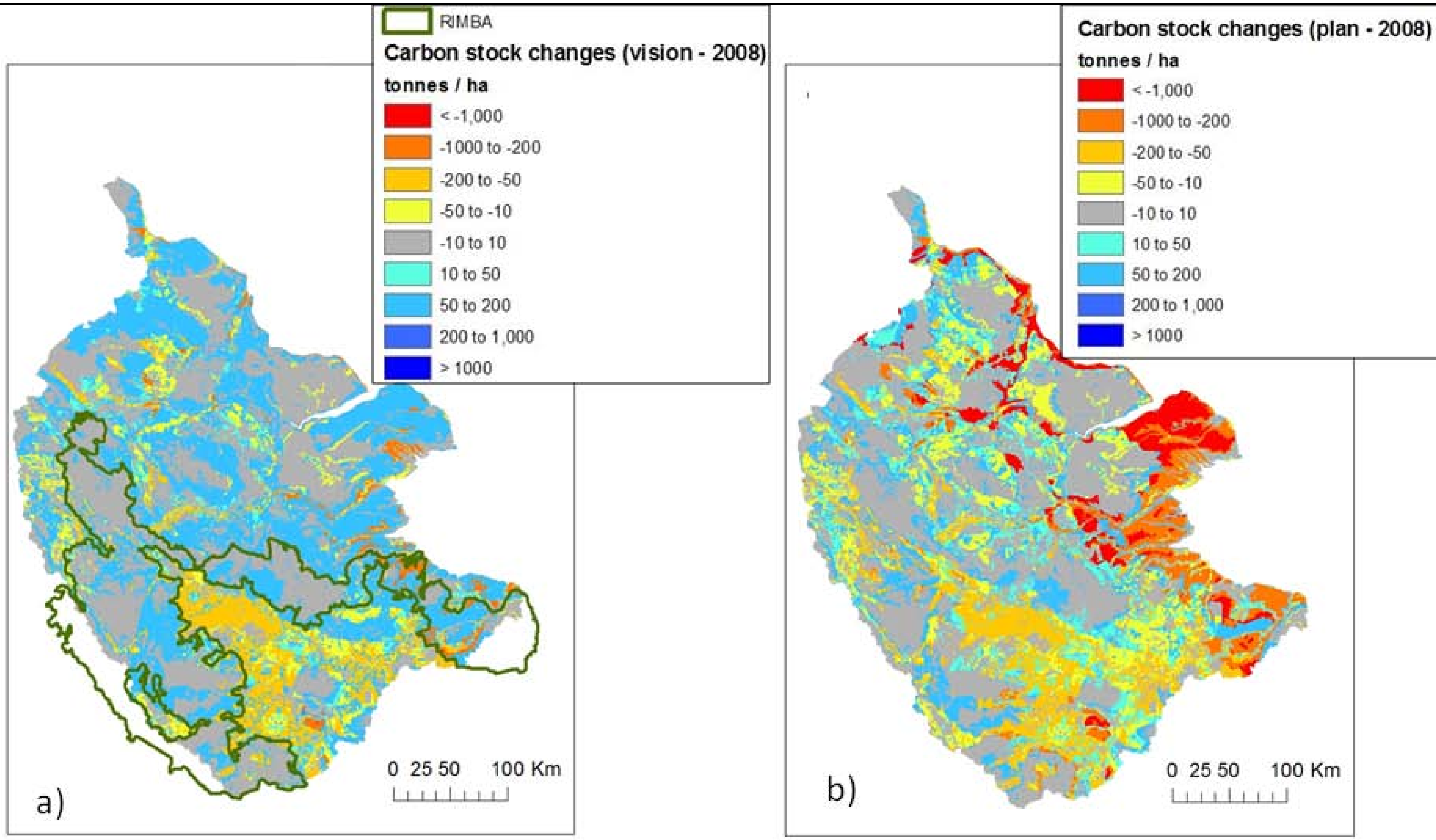

Fig 2.3. Carbon stock changes under (a) the Sumatra vision and (b) government plan over 50 years, relative to 2008. The vision would result in carbon sequestration while the plan would result in net emissions.

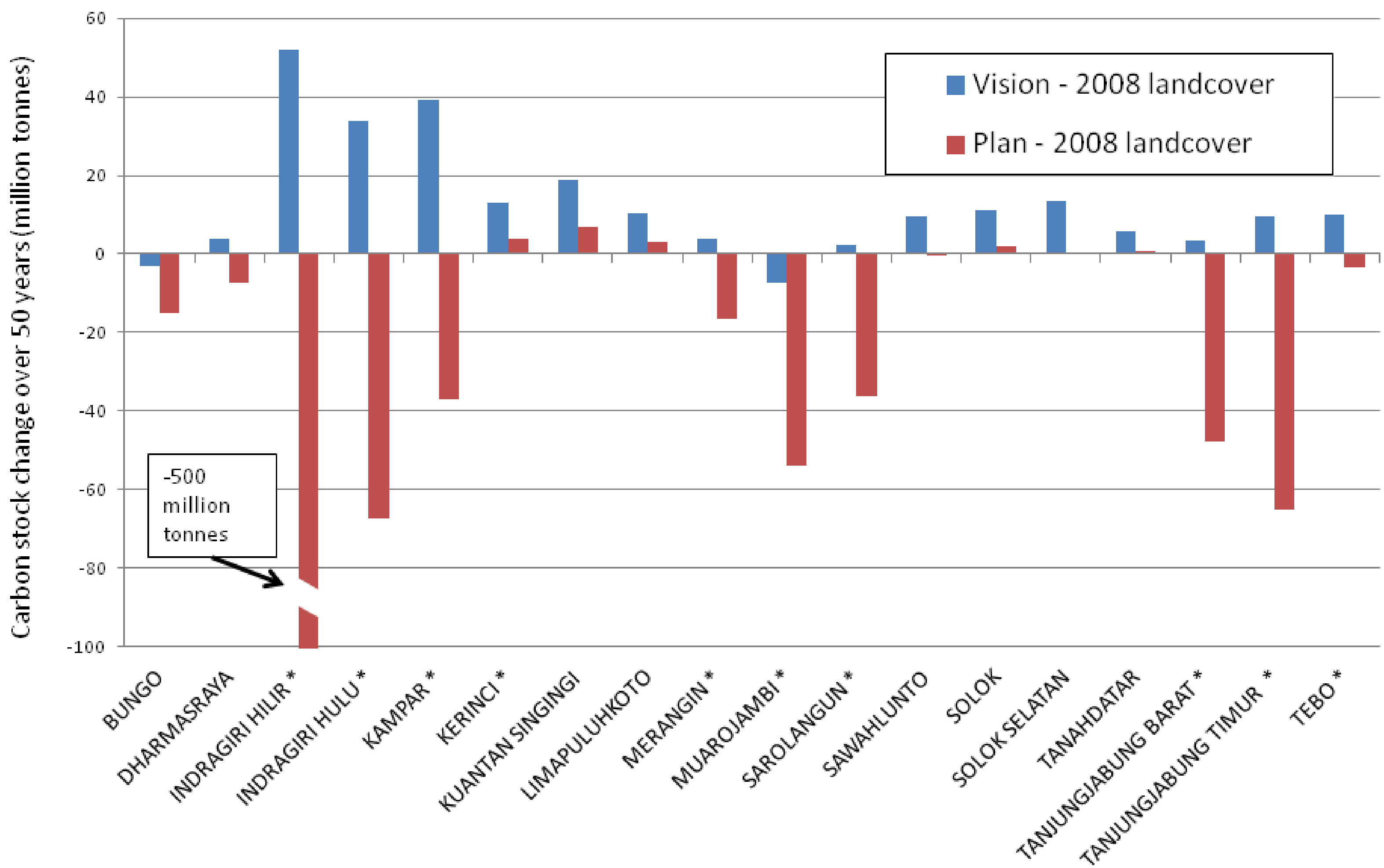

Fig. 2.4. Most districts gain carbon under the Sumatra vision and lose carbon under the government plan. The biggest losses in carbon stocks under the government plan occur in districts with peat soils (marked with a *).

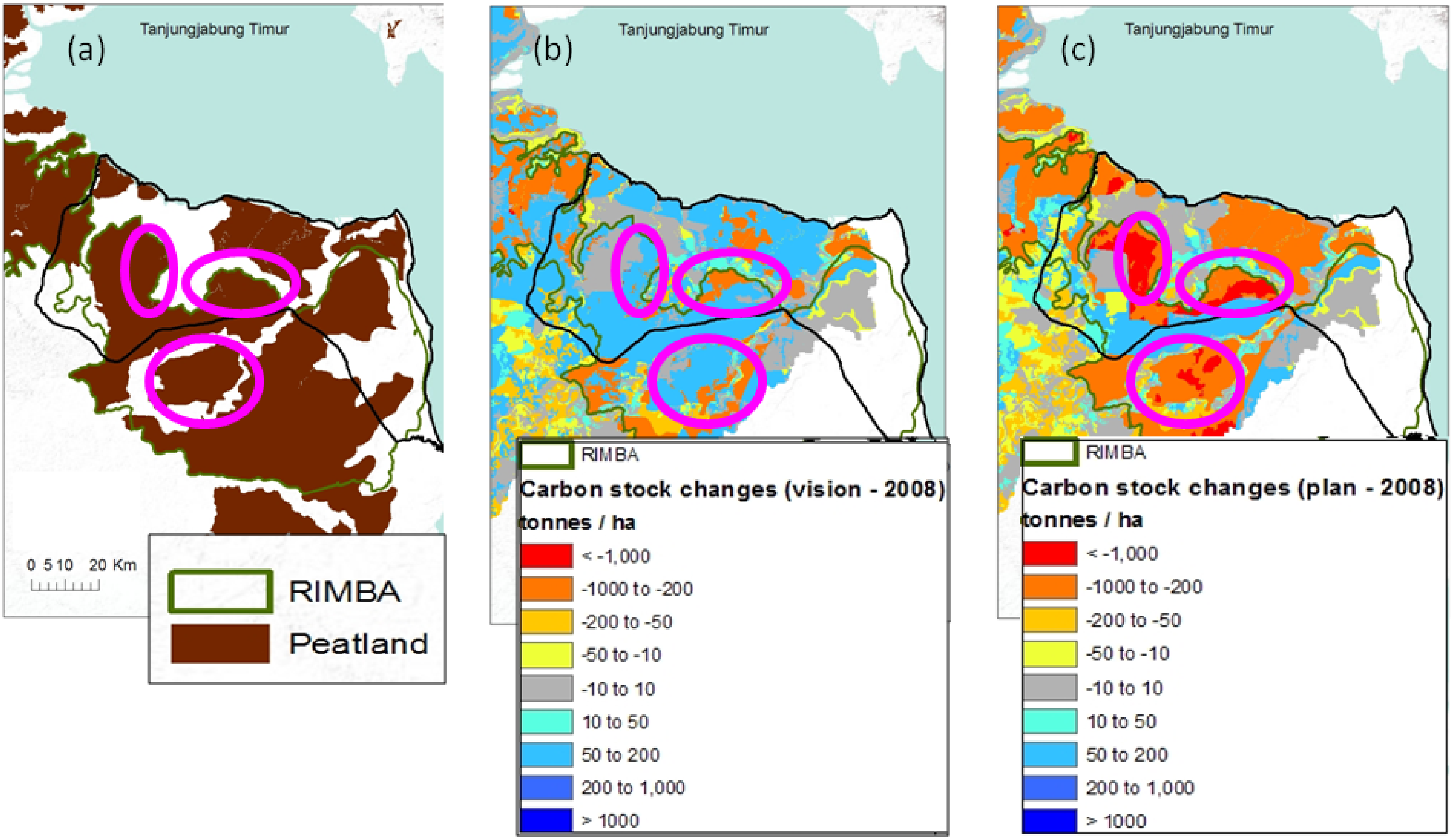

Fig. 2.5. Tanjungjabung Timur district contains peatlands that also fall within the RIMBA area (a). Some of the peat areas stand to gain carbon under the Sumatra Vision (b), which calls for reforestation of these areas (circled both within and outside the district) that are currently degraded or under plantations . But under the government plan (c), these areas would continue to lose carbon as they remain plantations.

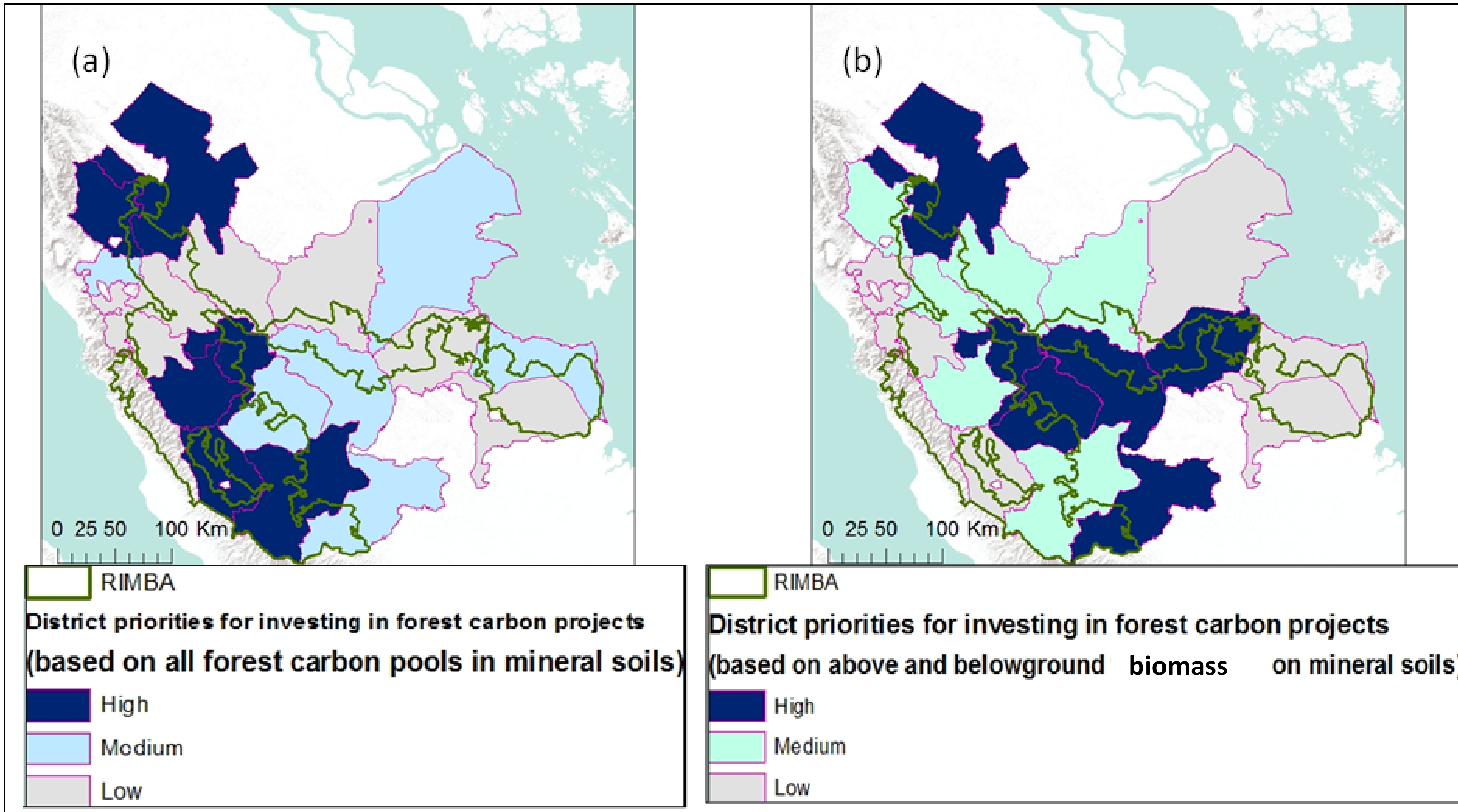

Fig 2.6. Priority districts for directing investment toward forest carbon projects on mineral soils (a) considering all carbon pools, or (b) above and belowground carbon only. High, medium and low priorities (6 districts in each bin) are defined here as the top, middle and lower third of the prioritized districts. When all carbon pools including soil carbon are included (a), the clustering of the highest priority districts in the western part of the landscape is driven by the occurrence of carbon-rich volcanic soils (andisols) in the area.

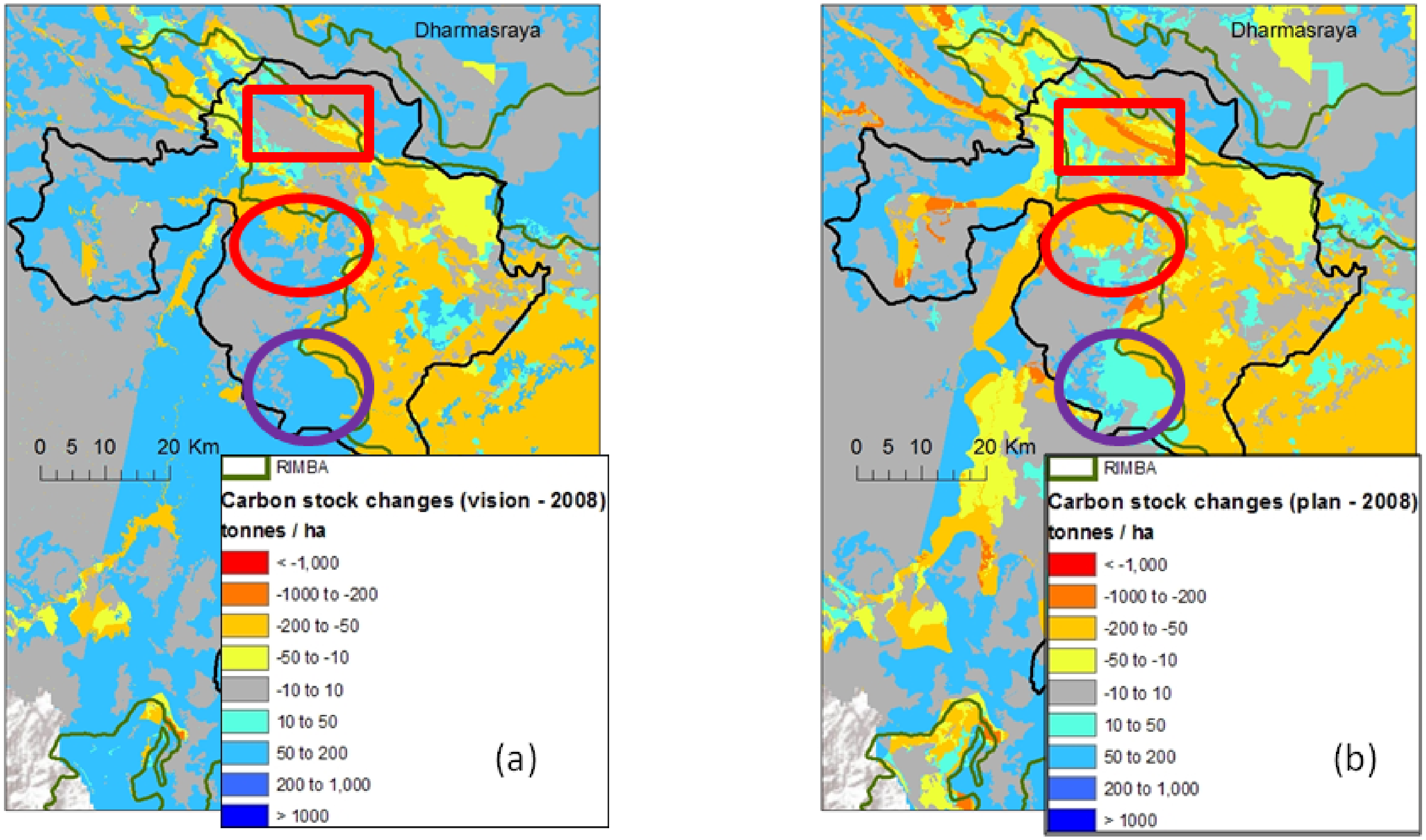

Fig. 2.7. Dharmasraya contains areas (red ovals) within the RIMBA boundary that are under plantations in 2008 and in the government plan (b). These areas would gain carbon if reforested as recommended in the Sumatra Vision (a). There are also current plantation areas (purple ovals) that would gain carbon under both the Vision and the spatial plan, as they are designated for reforestation in both scenarios. Lastly, the area in red rectangles was forest in 2008, and would remain forest under the Vision, but is slated for plantations under the government plan. These areas could benefit from carbon payments aimed at increasing forest carbon stock (ovals), and avoiding deforestation (squares).

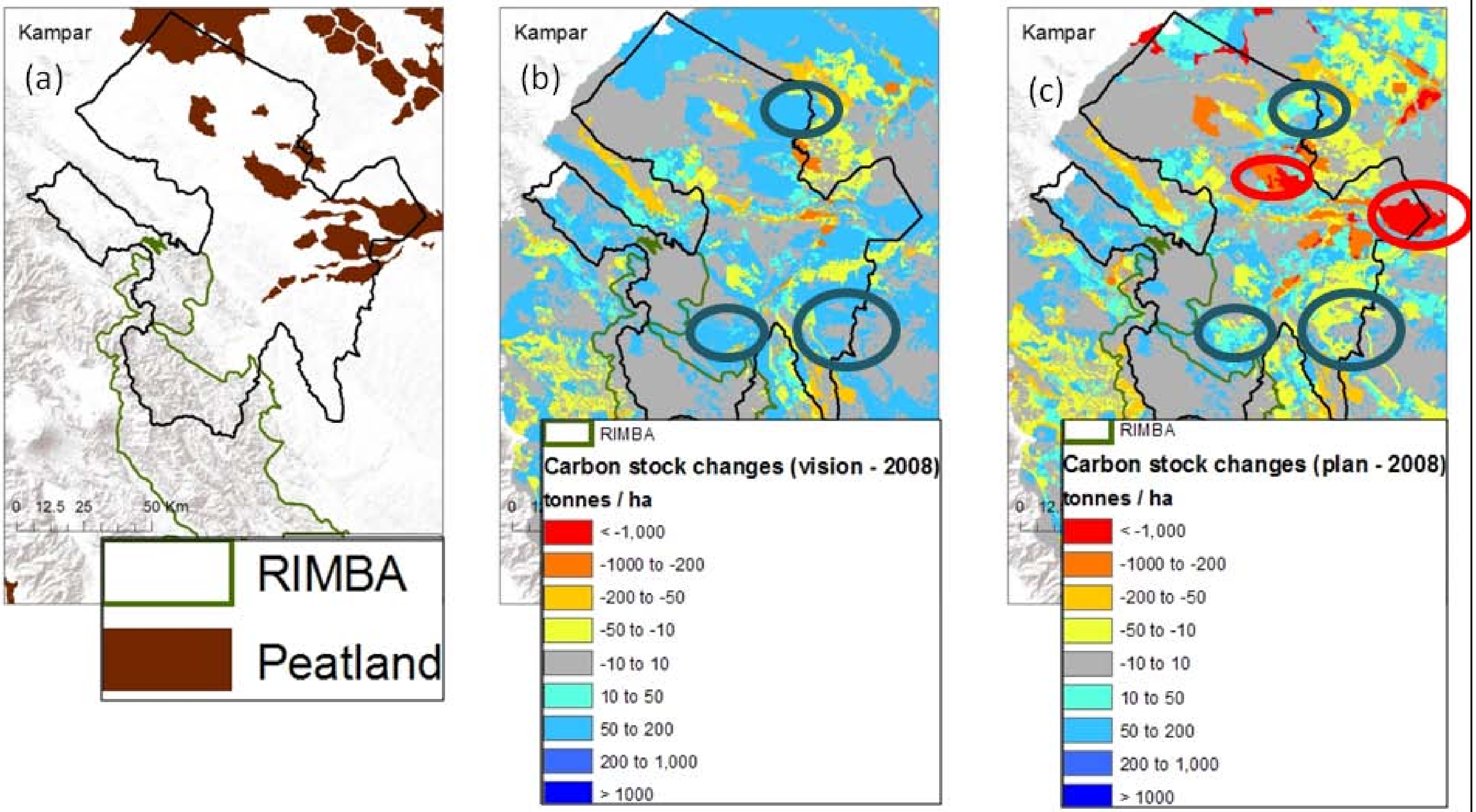

Fig 2.8. In Kampar, the highest losses under the government plan (c; red ovals) are associated with plantations on peat areas (a). Carbon stock gains would occur under the Sumatra vision (b) in these peat areas as well as on mineral soils (blue ovals), where plantations would get replaced with forest.

Recommendations

In the above examples, forest carbon conservation has potential to offer new funding streams through compliance markets, voluntary projects, and overseas aid programs. Some of the management activities that can create carbon gains relative to business as usual include afforestation and reforestation, improved forest management, rewetting of peatlands, and avoided deforestation. In each district, many of the areas where we encourage further targeting and research to evaluate carbon project opportunities have the added benefit of preserving or increasing the delivery of multiple ecosystem services, such as water quality, sediment retention and erosion control, as well as improving habitat for biodiversity, through a single activity (see Chapters 4 and 5).

These analyses indicate that conserving and restoring peatlands provide ample climate change mitigation benefits, and potentially offer revenue-generating opportunities for Sumatrans. In addition, carbon conservation activities in forests on mineral soils can generate globally relevant benefits. For carbon conservation on mineral soils, Dharmasraya and Kampar should likely be priority districts for investment.

Future Directions

The methodologies employed in this report are only a first step in identifying projects that might qualify to sell offsets in some of these markets. Like a feasibility assessment for REDD+, these analyses highlights areas that might be relevant for these kinds of projects and programs and can be investigated further and validated through field research.

In general, the analyses presented in this chapter demonstrate broad spatial patterns in the variation and magnitude of carbon stock changes under two different future scenarios. Additional work can obtain more precise estimates of carbon stocks, assess the financial feasibility of forest carbon projects, and determine what kinds of carbon projects might be the most appropriate in different locations.

We have analyzed only two districts in greater detail. In addition to extending the analysis to the remaining 16 districts, further analyses can be conducted to identify other areas eligible for carbon projects within Dharmasraya and Kampar.

Further Research and Analyses to Develop Additional Recommendations

The recommendations provided above in this report regarding the feasibility of forest carbon payments are based on limited biophysical and socio-economic information under relatively simple land-use scenarios. These recommendations are therefore coarse, but could be improved with further analysis and scoping:

REDD

To apply these findings to compliance markets or voluntary carbon certification for REDD, it is important to consider whether these projects can produce forest carbon credits that are permanent (i.e., the forest carbon pools never disappear or deplete significantly) and additional (i.e., there must be some risk of deforestation or forest degradation that the project avoids). The scenarios considered here provide a relatively simple model of deforestation risk and opportunity cost, which could be complemented with more sophisticated modeling of threats and drivers to verify that a potential project truly fits the 'additionality' criterion.[8]

It is important to note that although REDD has been approved under the post-Kyoto UNFCCC framework in Cancun, Mexico in 2010, methodologies are currently under development. Therefore, further analyses should be likely be targeted to standards set under the bilateral agreement with the government of Norway, voluntary markets (such as certification by the Voluntary Carbon Standard), or considered exploratory and potentially targeted to "early action" under the post-Kyoto rules.

Co-benefits and multiple services

In some areas, biodiversity conservation and multiple ecosystem services could be potential 'co-benefits' of a REDD+ project, if they are enhanced or maintained through REDD+ project implementation. This might be worth investigating further, since co-benefits could provide a price premium on carbon credits to project developers in the future. However, we would not expect to see a strong price premium in the regulatory market, where price is driven by marginal abatement costs, and there does not seem to be much of a premium for this currently in the voluntary market (Conte and Kotchen 2010). Still, these co-benefits may help garner support for forest carbon projects from governmental and other stakeholders, and help to prioritize among potential project sites.

Design of forest carbon projects

Much additional work is required to design and implement carbon stock or forest carbon payment programs. For instance, implementation costs are not considered in this analysis, but they vary and will influence the value of forest carbon projects to landowners and users. These costs could include fencing, hiring management or protection personnel, land purchase, monitoring, certification, and reporting. In addition, many actions will be required by district and provincial governments; these include: assessing and developing necessary regulations and institutions to ensure fair and equitable distribution of benefits; building capacity; ensuring clear, strong property rights; establishing a registry for projects and credits; building a monitoring, reporting and verification system; and identifying sources of finance. A feasibility study or gap analysis of these elements could be useful to the design and implementation of forest carbon payments.

[8] It is important to note that under post-Kyoto Protocol agreements, the Indonesian national government is expected to develop a Reference Emission Level (REL), which sets the baseline and 'business-as-usual' expectations for emissions. Additionality for each program activity or forest carbon project will be assessed against this REL. At the end of 2011, guidelines had yet to be established for RELs at the sub-national level.

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Chapter 3: Hydrological Services: Sediment Retention, Water Yield and Water Purification

Key Findings:

- The western sub-watersheds in the study area and all of the sub-watersheds within the Batanghari and Pengabuan Laban basins may be especially vulnerable to erosion. Districts that might be particularly affected include those containing the mountainous Bukit Barisan Range: Limapuluhkoto, Tanahdatar, Sawahlunto, Solok, Solok Selatan, Kerinci and Merangin; and, those in the lower elevations of these watersheds: Bungo, Sarolangun, Tebo, Tanjungjabung Barat, Tanjungjabung Timur and Muarojambi.
- Under the Sumatra Vision, watershed management programs in the sub-watersheds upstream of population centers, including the towns of Tembilahan and Rengat, could protect habitat for tigers in the RIMBA priority area while reducing erosion and nutrient pollution by more than 80% in some areas.
- Watershed protection schemes that shift land use from the Government Plan would provide greater erosion control upstream of Koto Panjang, the only large hydropower dam in the study. This would likely lowering dredging costs or long-term damage to turbines and other infrastructure.

Outline

Central Sumatra contains six main watersheds and several major rivers. The RIMBA Integrated ecosystem overlaps five of these watersheds. We assessed a subset of hydrological services within these watersheds, including water yield (for human consumption, irrigation and hydropower), sediment retention (erosion reduction), and water purification through pollutant removal. We modeled the distribution of these services in 2008, and under the Sumatra Vision and the Government Plan. Based on the modeled changes in hydrological services from 2008 to each scenario, we offer recommendations on some watershed management practices that benefit downstream service users while helping to realize the Sumatra Vision. We also point out opportunities for securing multiple benefits (hydrological services, carbon storage and sequestration, and wildlife habitat quality) based on spatial overlap among these benefits.

Methods

Study Area and Watershed Services

Our study area encompasses six watersheds in central Sumatra: Siak, Kampar, Indragiri, Reteh, Pengabuan Lagan and Batanghari (Figure 1.2a). The western edges of these watersheds are along the Bukit Barisan Mountains, and the major rivers flow from west to east. The RIMBA priority area includes sections of five of these watersheds (excepting the sixth, Siak), and a number of rivers flow through or have their headwaters within the RIMBA priority area (Figure 1.2b).

We used InVEST (version 1.005, Tallis et al. 2010) to model annual average water yield, annual average sediment retention and annual average water purification services provided by the watersheds in 2008, and under the Sumatra Vision), and the Government Plan (Figure 1.4). The scenarios are described in Chapter 1.

In addition to mapping hydrological services for each watershed, we also used the Automated Watershed Delineation module in ArcSWAT (://swatmodel.tamu.edu/software/arcswat) to sub-divide the main watersheds into smaller sub-watersheds. This was done because of processing limitations in InVEST, and also to allow us to assess variation in services at a finer scale.

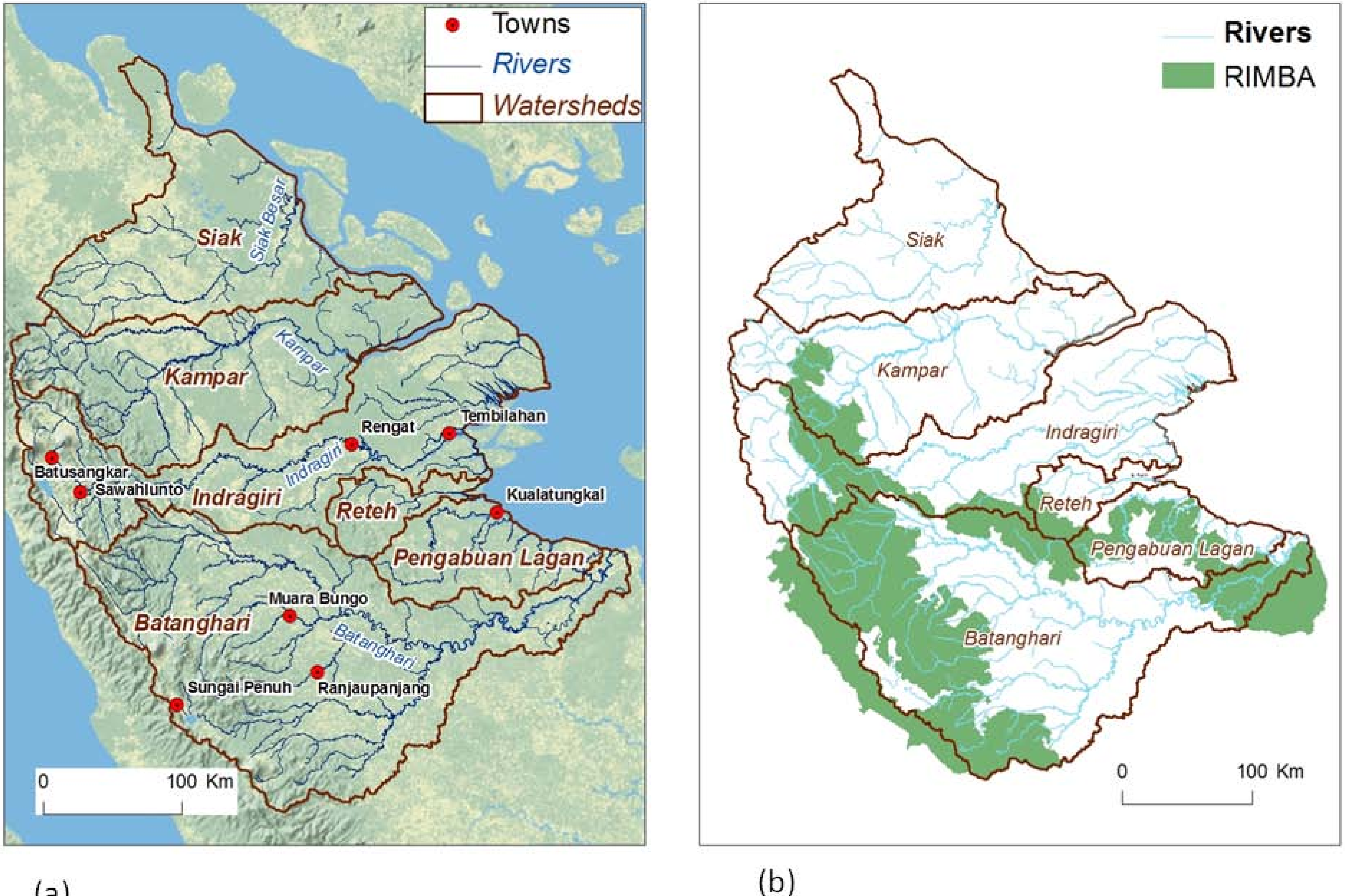
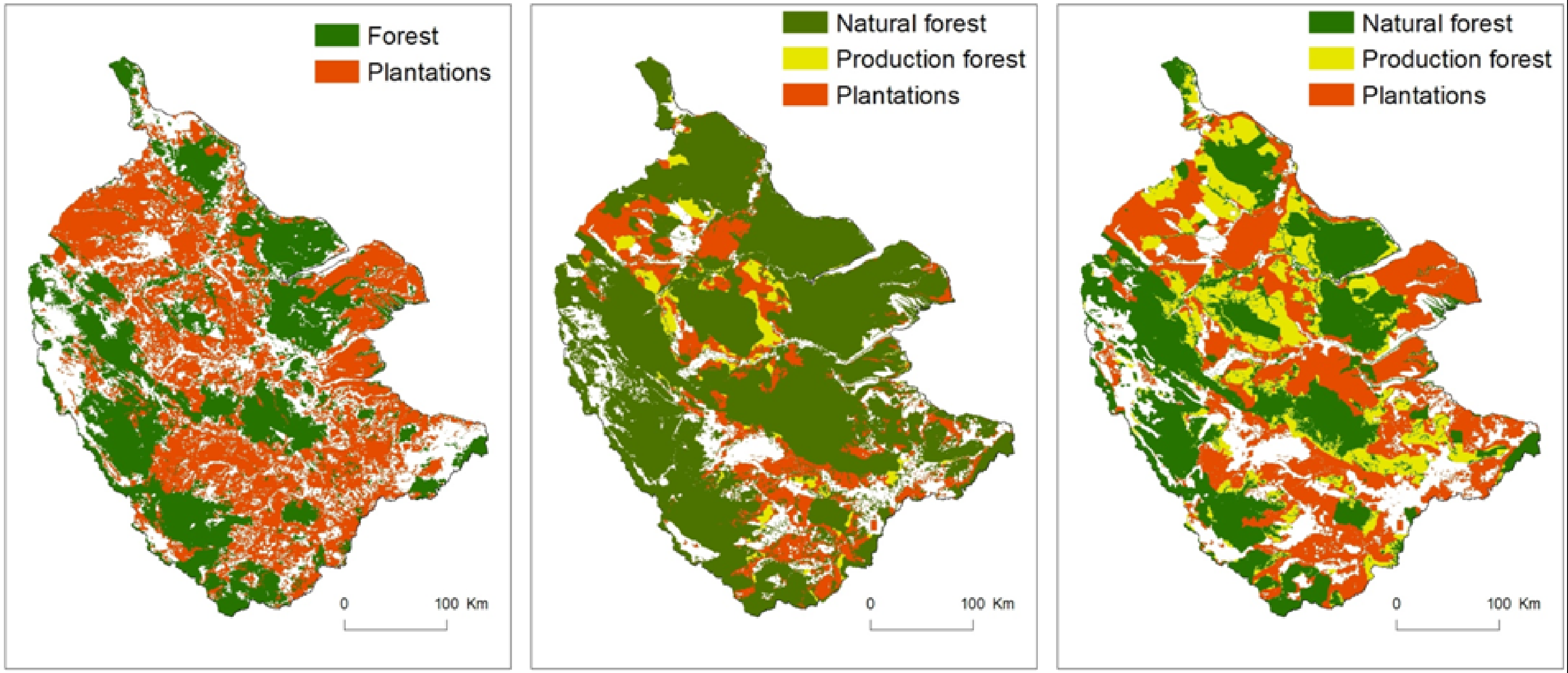


Fig. 3.1. There are six major watersheds in our study area. Most rivers flow west to east, with the upper reaches of a number of rivers being located in the RIMBA priority area (right).



(a) 2008 land cover (b) Sumatra ecosystem Vision (c) Government spatial plan

Fig. 3.2. Distribution of forests and plantations under in 2008, and under the two alternative future scenarios of land use. 2008 forests include both production and natural forest. Both scenarios have more forest cover than in 2008. The Vision has more forest than the plan (the plan would have 59% more forest area than 2008, while the Vision would have 132% more than 2008). However, the increase in forests in the government plan is driven primarily by an increase in production forests, where logging and conversion can take place. When production forests are not included, the forest area in the plan and Vision scenarios would increase by 2.4% and 106% respectively. It is also likely that the government plan is more optimistic than a business-as-usual scenario, as past high deforestation rates suggest that there may be additional unplanned deforestation in a BAU scenario that the government plan does not take into account

The services analyzed are as follows:

Water yield

We define the annual average water yield on a landscape as all precipitation that does not evapotranspire. While all of the water yield is not available to downstream users, its relative distribution across the landscape, and change across scenarios, can offer insights into the current availability of, and potential changes to, water supply for human uses. The InVEST Tier 1 water yield model is designed to evaluate how land use and land cover affect annual water yield across a landscape. This water balance model can accommodate areas with minimal access to data, and can be used with globally available data sources on annual precipitation and dryness indices (Zhang et al. 2001, Budyko and Zubenok 1961, Milly 1994). We summarize water yield for each watershed, sub-watershed and district as annual average runoff depth (mm / year, see Appendix 3.2 for calculation).

Sediment retention

The InVEST Tier 1 sediment retention model focuses only on sheetwash erosion processes, and is based on the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). The USLE predicts erosion based on the energetic ability of rainfall to move soil and cause erosion, the erodibility of a given soil type, slope, erosion protection provided by the presence of vegetation, and management practices (Roose 1996). The model also routes the sediment originating on each pixel along its flow path, with vegetated pixels along the path retaining some of this sediment based on their sediment retention efficiency, and exporting the remaining sediment to the next pixel in the flow path. We report the total sediment load exported to streams from each watershed, sub-watershed and district per year (tons / year), as an annual average.

Water purification

We used the InVEST Tier 1 Water Purification: Nutrient Retention model to simulate nitrogen and phosphorus loading into streams and water bodies within the study area. These nutrients, often generated as a result of fertilizer application and other human activities, are leading causes of water pollution. The water purification model is based on the export coefficient approach described by Reckhow et al. (1980). The premise is that surface runoff will follow predictable patterns from its sources based largely on landscape geomorphology. The model adjusts for each pixel's capability to generate nutrient runoff based on the quantity of runoff coming into it (estimated by the water yield model described above). The nutrient runoff from each pixel will be routed downslope, with some being retained along the flow path based upon nutrient retention efficiencies of the downslope pixels. Each pixel will potentially export some nutrients to streams, while also retaining some nutrients. We report the results of this model as the total nitrogen and total phosphorus loads exported from each watershed, sub-watershed and district per year (kg/year), as an annual average.

Data Inputs

When possible, we used input datasets from local or regional sources. However, since many data sources were lacking or of poor quality locally, we also clipped data from global layers. Data sources are further described in Appendix 3.1 and 3.3.

Representing change across scenarios

We expressed the change in output from 2008 to each scenario as a percent change

$$\left(\frac{W_s - W_{2008}}{W_{2008}}\right) \times 100$$

where W_s is the summed InVEST output for a given service over all pixels in a watershed, sub-watershed or district in the scenario, and W_{2008} is the summed service in 2008.

For water yield, positive and negative change values respectively represent a gain and loss of the service. However, for sediment and nutrient export, negative change values correspond to less export in the scenario relative to 2008, and thus represent a gain in service, while positive change values indicate higher export and thus, service degradation.

We mapped these services by watershed and sub-watersheds, showing relative levels of the outputs in 2008, as well as changes from 2008 to each scenario. For the 2008 maps, we used a single color scale for each variable, with the lightest shades representing the lowest levels of the mapped variable, and the darker shades representing correspondingly higher levels. Because results have not yet been validated with ground measurements, we report relative variation across the landscape rather than actual values. For the change maps, we binned the percent change into ranges. We manually chose the cutoffs for the bins based on the distribution of the values of each change variable, so as to adequately represent the range of variation within each change map, and to highlight differences in patterns of variation between the two change maps for that variable. We considered service changes within a relatively small range around zero (+/-10% for the large watersheds, and +/-5% for the sub-watersheds) to represent little or no change in a given scenario relative to 2008. Watersheds or sub-watersheds with change values within this range were represented in grey. Increases in service level from 2008 to a given scenario, for all variables, were represented in shades of blue, with darker shades representing a greater increase in service. Service losses from 2008 to a given scenario were represented as a color continuum in shades of yellow, orange and red, with yellow representing moderate losses, and the darkest shades of red representing the greatest loss in service.

Methods for Recommendations

We compared service changes in sub-watersheds containing, or upstream of, selected towns and dams. We especially focused on towns and dams whose containing or upstream watersheds overlapped the RIMBA priority area and existing tiger habitat (as identified in Wibisono and Pusparini 2010). If the Sumatra Vision indicates a higher level of service relative to the plan in these areas, then we can recommend implementation of payments and other programs to maintain or enhance watershed services in a way that is consistent with the Sumatra Vision.

We also identified areas where, in addition to the watershed service benefits assessed in this chapter, our analyses of carbon (Chapter 2) and tiger habitat (Chapter 4) suggested the potential for forest carbon projects that benefit biodiversity. Such areas could be eligible to receive a premium on carbon payments, as they would deliver both watershed services and conservation of critical wildlife habitat as co-benefits.

Last, we focused on areas assessed by the Rewarding Upland Poor for Environmental Services (RUPES) program of the World Agroforestry Centre (://rupes.worldagroforestry.org/) for potential for payment for ecosystem service (PES) schemes. For these areas, our recommendations can be taken in conjunction with those from the RUPES case studies.

Some limitations

(1) All the models output annual average results. Thus, seasonal variation in hydrological ecosystem service provision, which may be affected by changes in land use and climate, cannot be investigated using these models.

(2) We do not differentiate surface water from groundwater. The water yield model we describe estimates total runoff as the combined volume of surface and groundwater. Separating groundwater is beyond the scope of the simple water balance model that we use. Similarly, water flow through channels, gullies and rills could result in higher levels of sediment and nutrient export than our outputs indicate.

(3) The water yield model is not routed, so the water balance is calculated based only on direct precipitation and does not include run-on inflow from upstream portions of the watershed.

(4) We have not calibrated or validated our model outputs with ground measurements in Sumatra. Hence the results should be interpreted as showing relative variation across the landscape, and relative change across scenarios. Since we are basing our recommendations upon the change in values between different scenarios, and not the absolute values for each of the services, these analyses should be regarded as preliminary assessments of the current state and potential changes in freshwater ecosystem services under the two scenarios. They can also serve as a pre-feasibility assessment of the potential for watershed service-based programs in the region.

(5) The scenarios may be conservative in the representation of production forests and "conversion production forests". We assumed these forest types remain under some forest cover in the future. However, if these forests are not sustainably managed (i.e., subjected to intense logging or conversion), then the plan, which has substantially more forest in these categories than the Sumatra Vision, could fare worse in terms of sediment and nutrient export than our results suggest.

(6) These simple hydrological models do not capture important dynamics of sediment and nutrient runoff such as the contribution of stream bank / rill-inter-rill erosion, which could result in significantly higher levels of erosion than we model. Neither do they address interactions among nutrient pollutants. Accordingly, the results should be interpreted as initial assessments of broad scale patterns of variation across the landscape, and between scenarios, rather than as estimates of the magnitude of these output variables.

Results

Large Watersheds

In 2008, among the six large watersheds, Batanghari had the highest water yield, but also the highest levels of sediment and nutrient export (Figures a of 3.3 – 3.6). All six watersheds would lose annual water yield under both scenarios; the magnitude of decrease would be similar or higher under the Sumatra Vision compared to the plan (Figure 3.3 b and c). For the remaining services, in all cases the Sumatra Vision has a higher level of the service than the plan (Figures b and c of 3.4 – 3.6).

Sub-watersheds

Water yield in 2008 in the sub-watersheds decreased from west to east across the landscape, with clusters of high water yield sub-watersheds in the northwest (Siak and Kampar watersheds) and the western reaches of the southernmost watershed, Batanghari (Figure 3.7 a). The eastern peat swamps have relatively low water yield, despite being waterlogged. This is partly because of lower precipitation in this region relative to other parts of the study area. But there are several other factors that could also contribute to the low water yield from peat deposits, including the flat, low-lying terrain, which constrains the discharge of water leading to poor drainage; high plant-available water content, which is evapotranspired by plants; high evaporation of surplus water during the rainy season; and, moderate storage capacity during the dry season (UNDP Malaysia 2006, ps. 4-5). Furthermore, although water may be coming into peat from the surrounding and contributing upstream areas (thus potentially increasing water yield), the water yield model only considers yield on the pixel itself, and hence does not include inflow into peat from elsewhere, which could increase actual water yield.

Most sub-watersheds lose water yield under both scenarios (Figures 3.7 b and c). The reduced water yield could partly be a result of increased evapotranspiration due to an increase in forested area or plantations under both scenarios. Both scenarios would result in similar levels of decrease in annual average water yield relative to 2008. Thus, although there is a general tradeoff among annual average water yield and other benefits (i.e., there is generally a loss in water yield even when there is a gain in carbon stock, avoided erosion or avoided nutrient pollution due to implementing a scenario), this tradeoff is not much greater with the Sumatra Vision than with the Government Plan. In addition, this annual reduction might be accompanied by an increase in other benefits at seasonal and sub-annual time scales, such as flood mitigation during wet periods and improved water availability during dry periods, which we have not assessed in this study.

The highest levels of sediment export (i.e., soil erosion into waterways) in 2008 were in the western sub-watersheds along the Bukit Barisan Mountains (Figure 3.8 a). Many sub-watersheds would have reduced levels of sediment export under the Sumatra Vision (Figure 3.8 b) relative to the Government Plan (Figure 3.8 c), with Kampar, Indragiri and Reteh watersheds seeing the greatest comparative reductions under the Sumatra Vision. Under the Government Plan, the western sub-watersheds along the Bukit Barisan mountains are likely to see increased erosion relative to 2008 (Figure 3.8 c). Among the large watersheds, under the Government Plan, Batanghari and Pengabuan Laban in the southern part of the landscape would see substantial increases in soil erosion (80% to over 1000%) in most of their sub-watersheds (Figure 3.8 c).

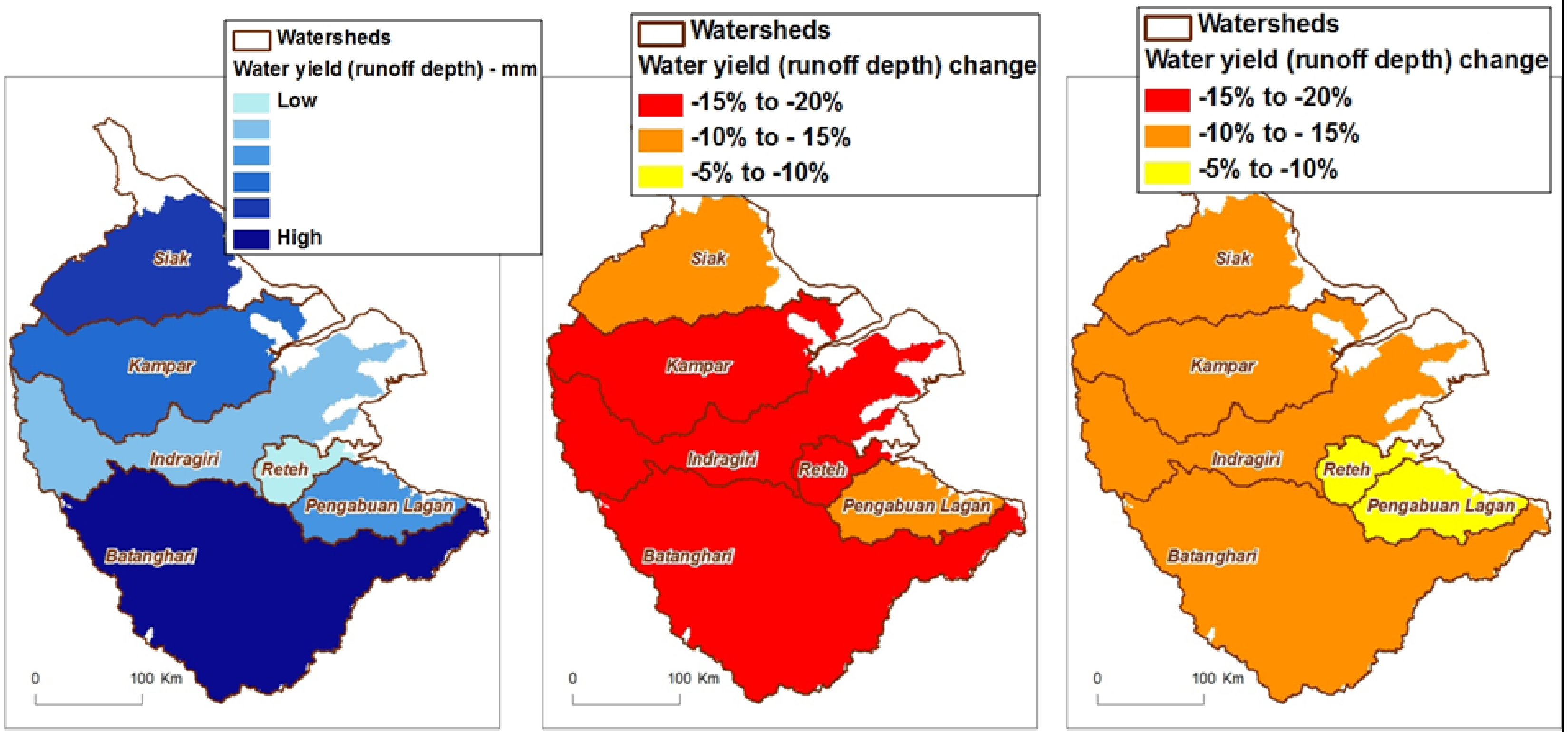
The impact of all land-use changes on sediment export occur in combination with other important variables. In some cases, land-use change may not be the predominant force. The interactions between land-use change and precipitation, soil type, and slope are particularly important factors in the resulting erosion rates. Also important are in-stream flow and sediment size. With that said, driving the InVEST results are the contrasts in land use among scenarios. Reforestation in multiple locations under the Sumatra Vision leads to reductions in sediment export across the study area relative to the Government Plan; sediment export is also lower in the Sumatra Vision than for the 2008 landscape in the Reteh and

Kampar watersheds. Under the Government Plan, broad conversion of existing forest in 2008 to plantations in the southern region lead to relatively large, widespread increases in erosion and sediment export there. In the Indragiri watershed, the differences in sediment export are primarily due to conversion of 2008 forests to plantations and degradation of additional forests from timber harvest under Government Plan; under the Sumatra Vision, many of these areas would be reforested and could be considered for carbon projects or forest restoration. The decrease in sediment export due to reforestation would take time to manifest as vegetation is restored.

In 2008, many of the sub-watersheds with the highest levels of nitrogen and phosphorus export were in the central lowlands (Figures 3.9 a and 3.10 a). These areas have a high concentration of plantations and other agricultural activity (Figure 3.2 a). Most sub-watersheds show lower export under the Sumatra Vision than under the Government Plan (Figures 3.9 b - c and 3.10 b - c). Some of the largest increases in pollutant export under the Government Plan (Figures 3.9c and 3.10c) would occur in the west along the Bukit Barisan Mountains.

Districts

Summaries of hydrological services by district (Figures 3.11 to 3.15) show similar trends of change from 2008 to each scenario as the watershed summaries. Relative to 2008, all districts would lose water yield on an annual basis (on average 15%), regardless of which scenario is pursued (Figure 3.12). While the landscape under the Sumatra Vision would produce less water annually than the plan, that difference is small. On average, districts would lose 4% more water yield under the Sumatra Vision as compared with the plan (Figure 3.11 a). All districts would experience reduced sediment and nutrient export under the Sumatra Vision as compared to the Government Plan (Figures 3.11 b - d, 3.13 - 3.15). In many districts, these reductions could be substantial (up to 85% relative to 2008 levels). As watersheds often span multiple districts, the changes in service occurring in a given district are likely to have impacts in downstream districts.



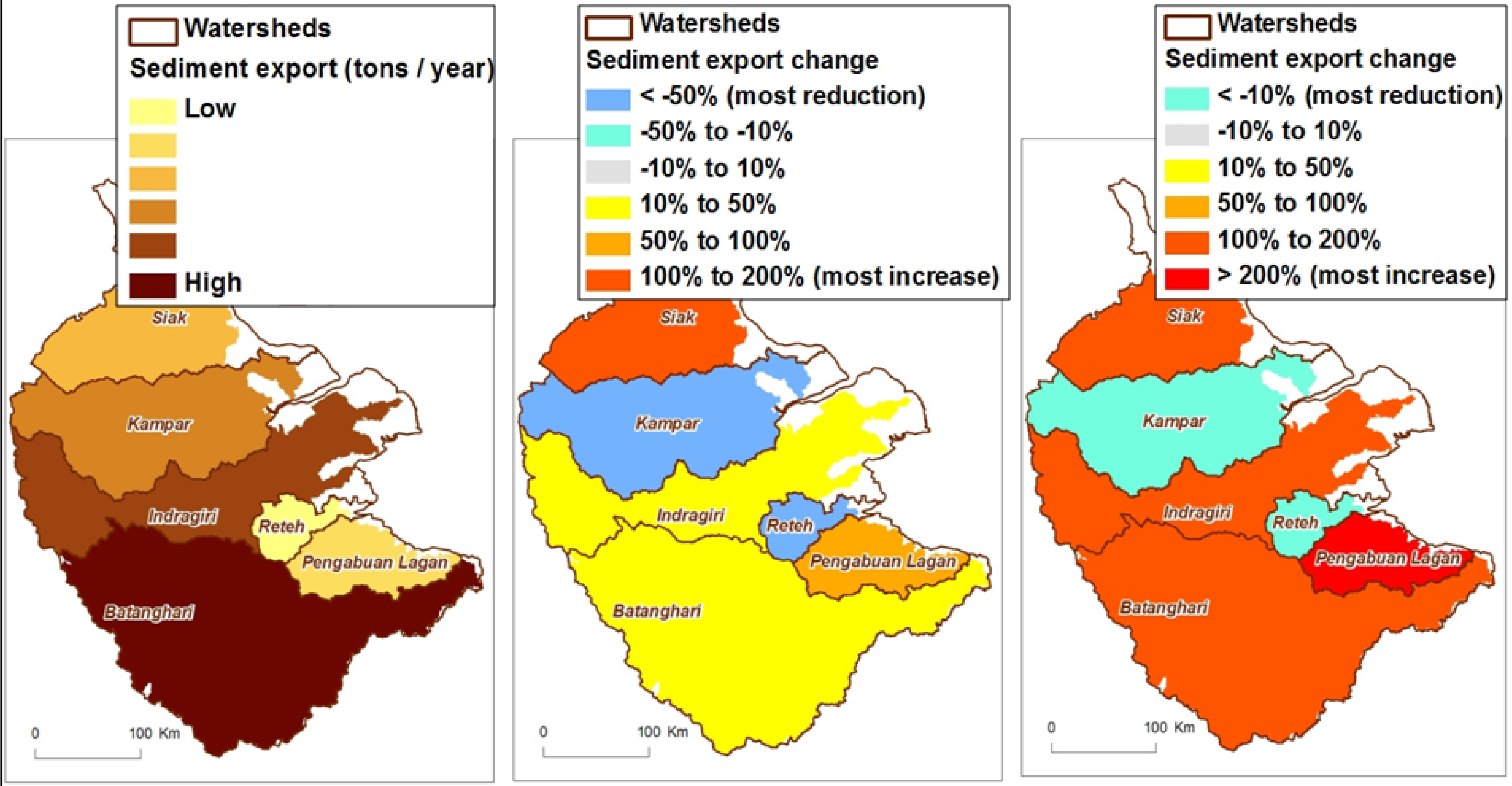
(a) Water yield in 2008

(b) Percent change in water yield from 2008 to Vision

(c) Percent change in water yield from 2008 to plan

Fig. 3.3. This and the next few figures show InVEST outputs in 2008, and % change from 2008 to each scenario, for the six big watersheds. The colored areas do not extend to the eastern and northern boundaries of the big watersheds, because the sub-watersheds layer we used for InVEST modeling did not cover some area in the east and north.

Water yield would be lost under both scenarios. Water yield decreases more in Vision than plan. The decrease in water yield could be because both scenarios have more forest cover than in 2008.

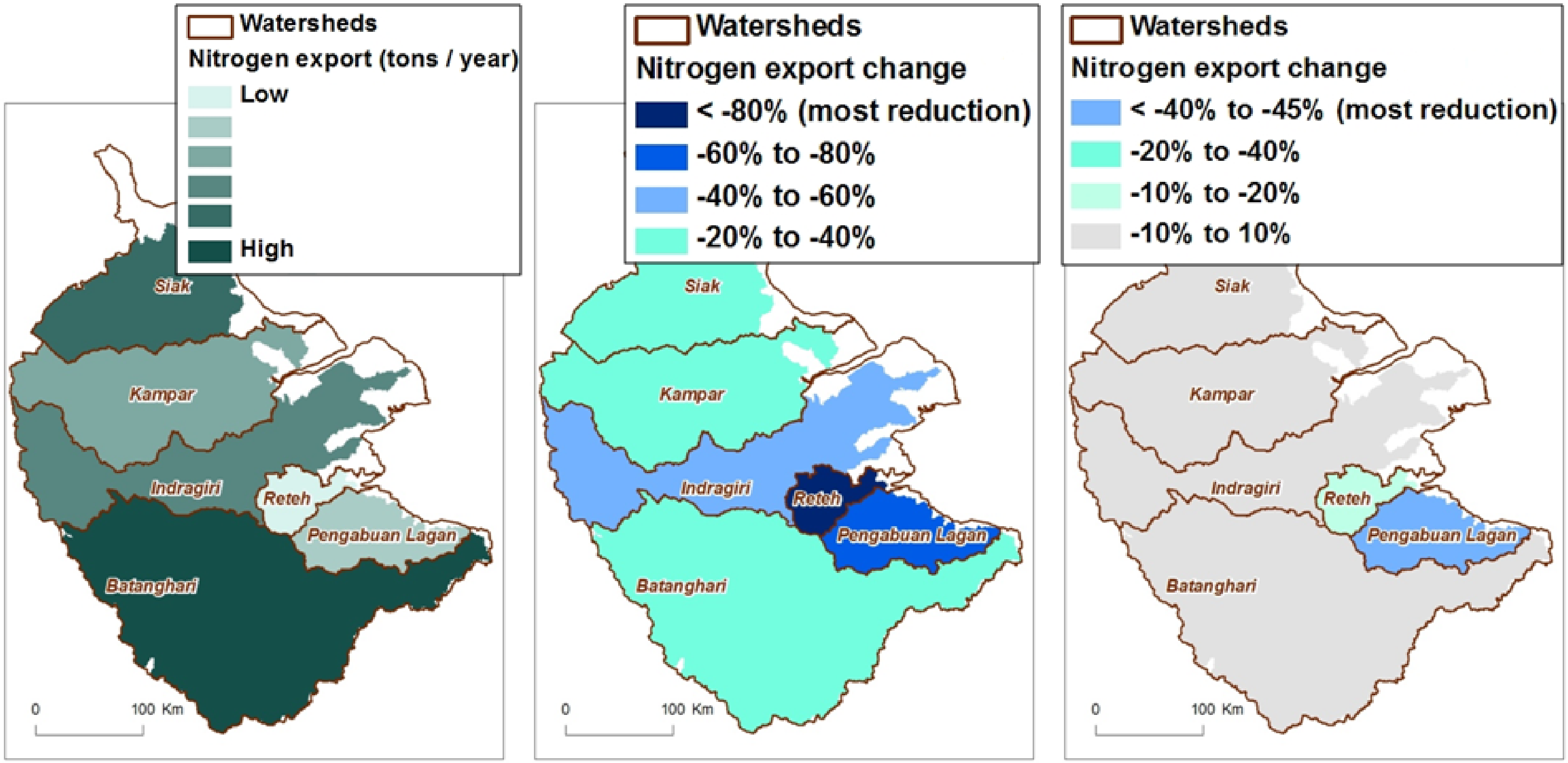


(a) Sediment export in 2008

(b) Percent change in sediment export from 2008 to Vision

(c) Percent change in sediment export from 2008 to plan

Fig. 3.4. Kampar and Reteh watersheds see a decrease in sediment export under both scenarios, with a greater decrease under the Vision. The remaining watersheds see an increase, with more sediment export under the plan.

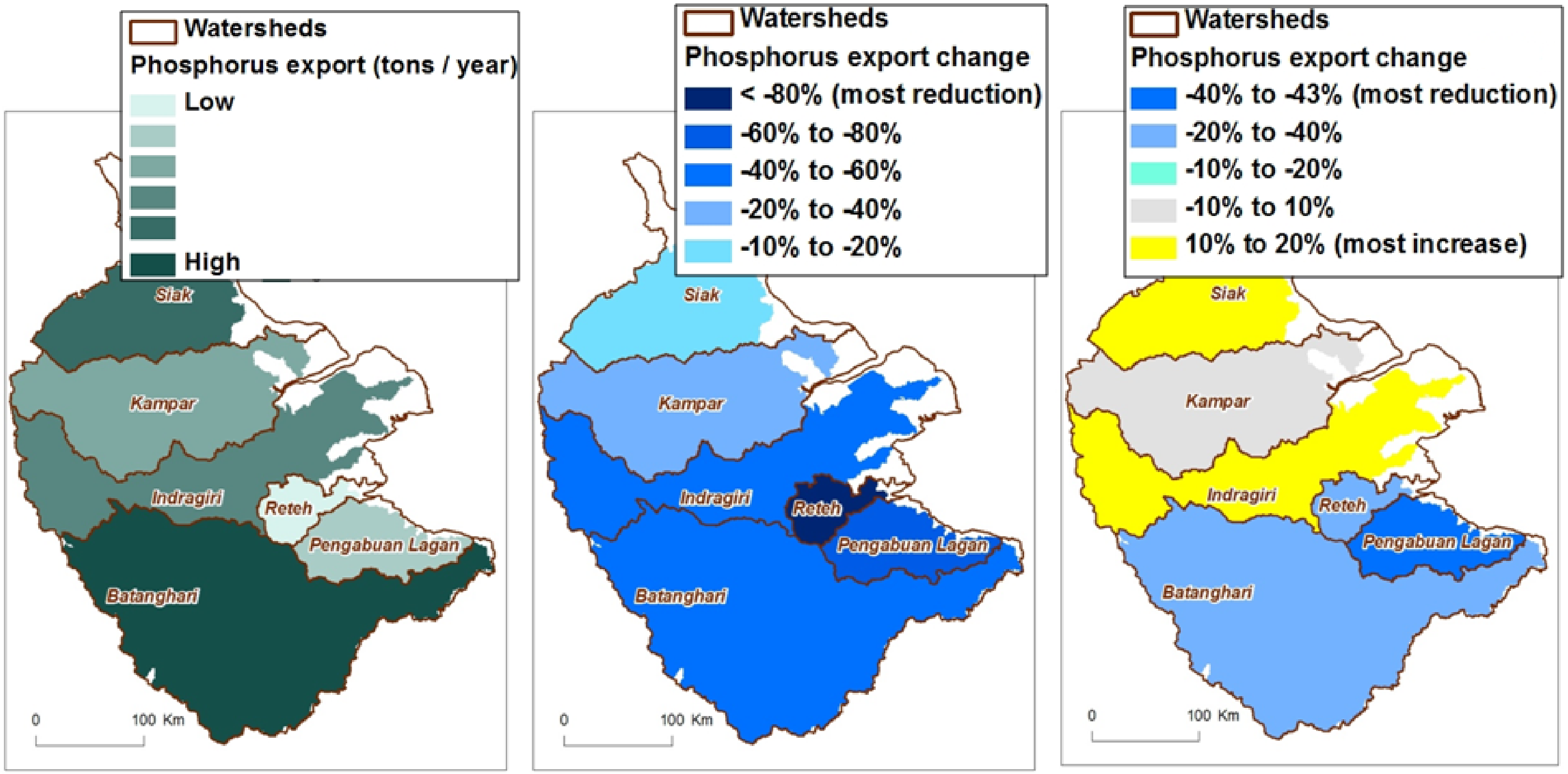


(a) Nitrogen export in 2008

(b) Percent change in nitrogen export from 2008 to Vision

(c) Percent change in nitrogen export from 2008 to plan

Fig. 3.5. All watersheds have reduced nitrogen export (i.e., pollution) under the Vision. Under the plan, nitrogen export is similar to 2008 in most watersheds, or decreases less that in the Vision (for Reteh and Pengabuan Lagan).

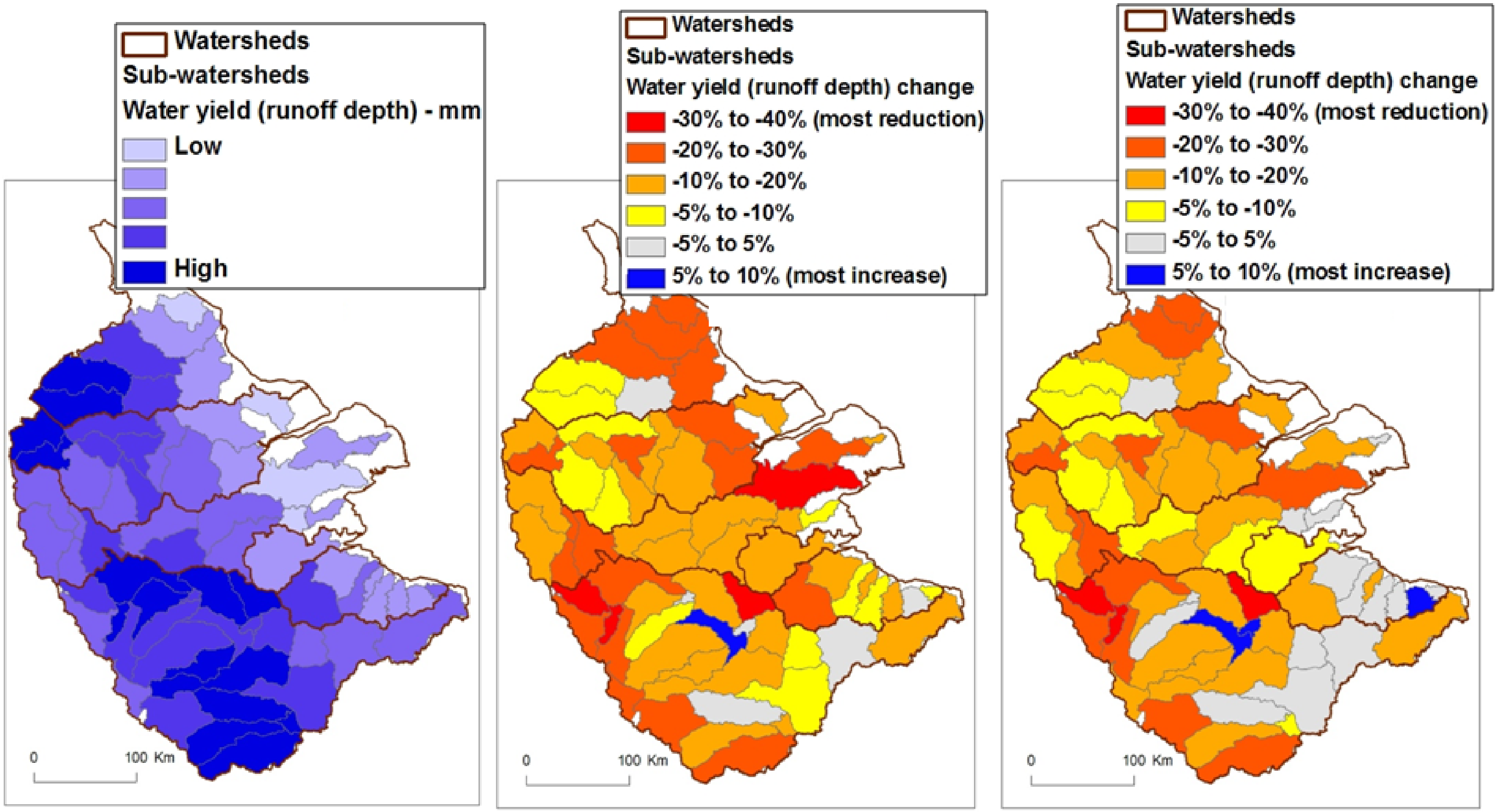


(a) Phosphorus export in 2008

(b) Percent change in phosphorus export from 2008 to Vision

(c) Percent change in phosphorus export from 2008 to plan

Fig. 3.6. Phosphorus export decreases for all watersheds under the Vision. Under the plan, it remains similar for Kampar, increases for Siak and Indragiri, and decreases for the other watersheds, but to a lesser extent than in the Vision

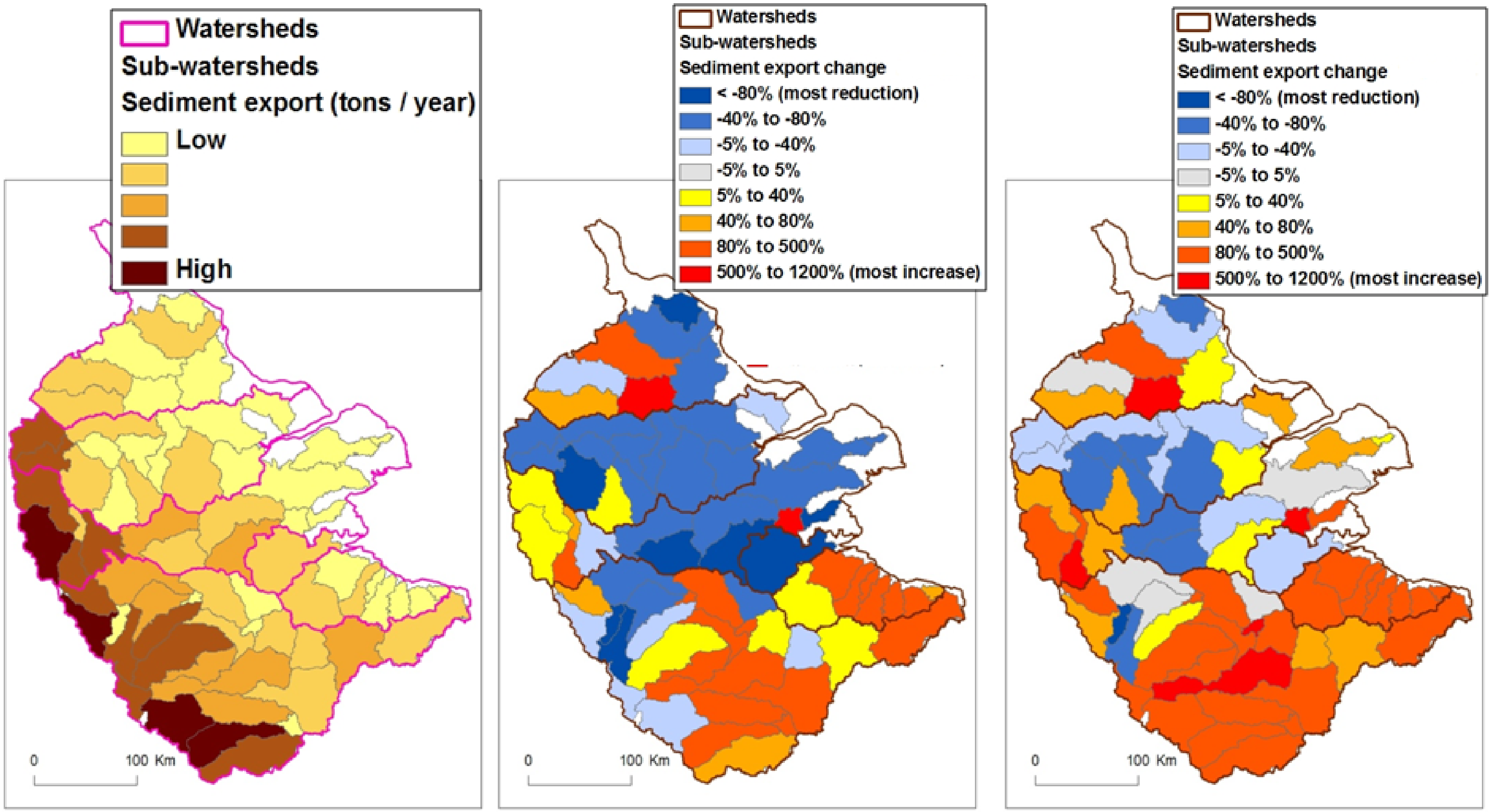


(a) Water yield in 2008

(b) Percent change in water yield from 2008 to Vision

(c) Percent change in water yield from 2008 to plan

Fig. 3.7. In this and the next few figures, the InVEST outputs are broken down by sub-watersheds. This figure shows water yield in 2008, and % change over the two scenarios.

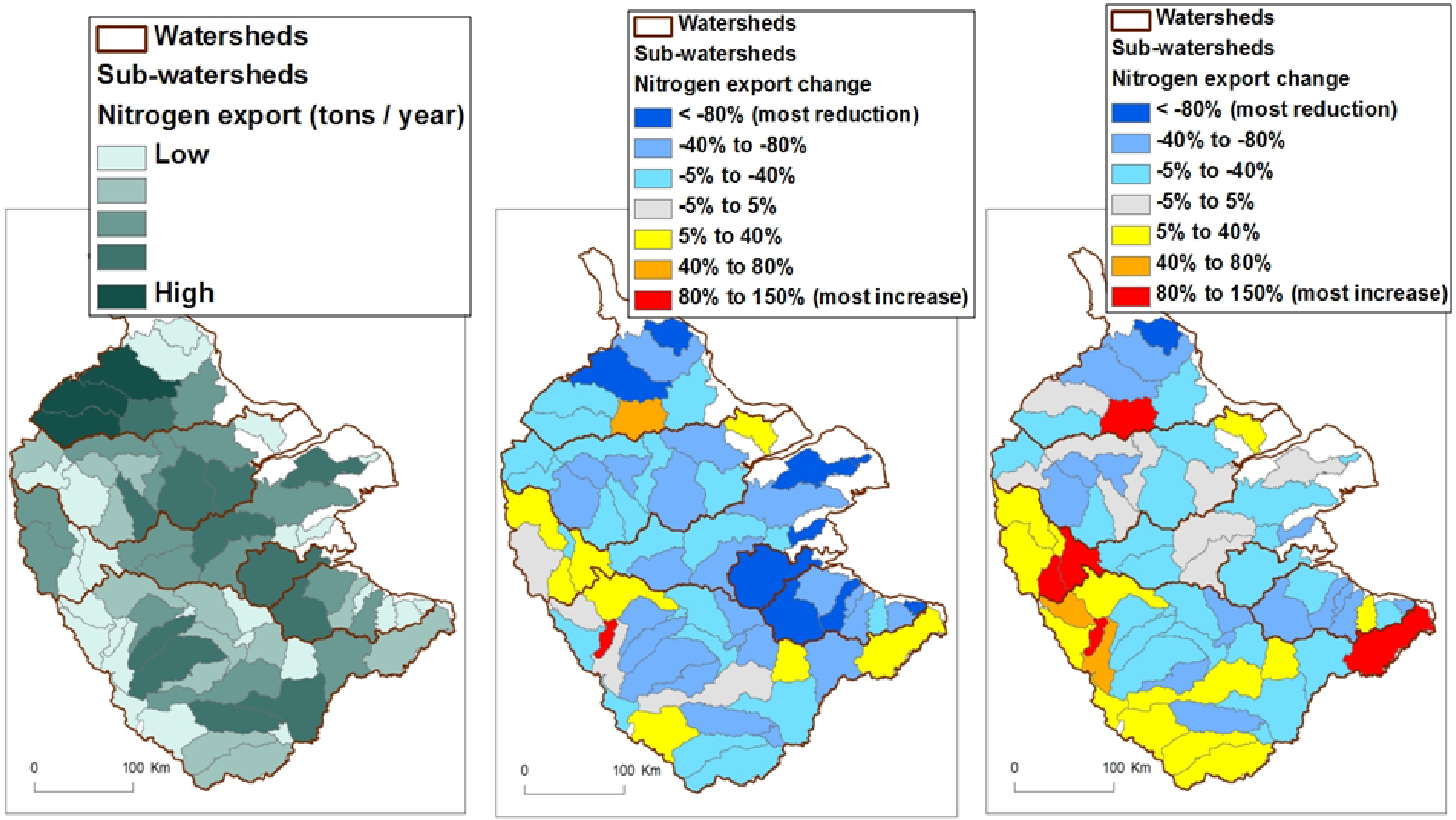


(a) Sediment export in 2008

(b) Percent change in sediment export from 2008 to Vision

(c) Percent change in sediment export from 2008 to plan

Fig. 3.8. In the 2008 land cover map (a), the highest levels of sediment export are seen along the western mountains. Sediment export would increase in the plan (c) along the western mountains, and also throughout Batanghari watershed in the south

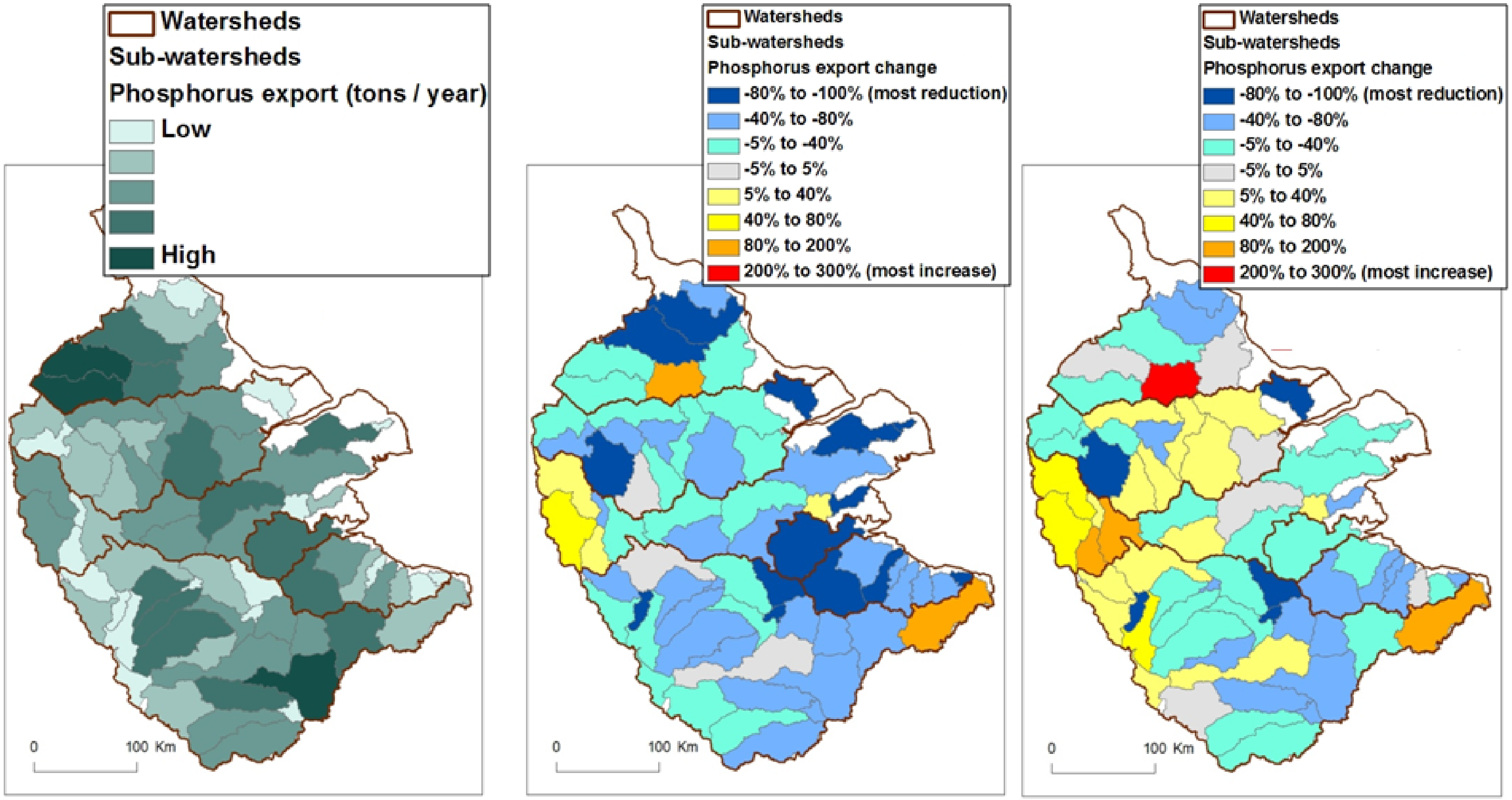


(a) Nitrogen export in 2008

(b) Percent change in nitrogen export from 2008 to Vision

(c) Percent change in nitrogen export from 2008 to plan

Fig. 3.9. Nitrogen export in the plan (c) would increase in the western mountainous regions, and especially in the southernmost big watershed, Batanghari

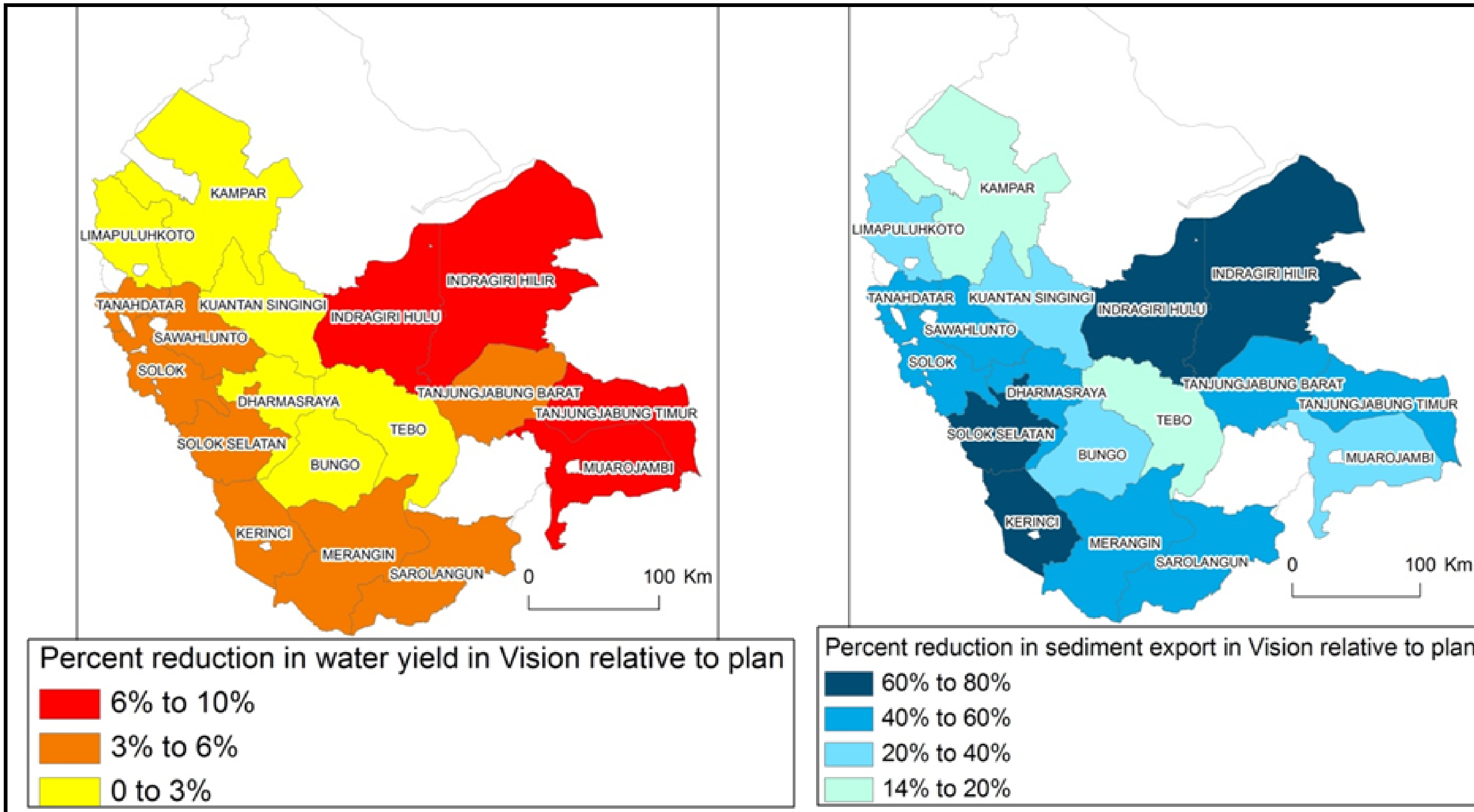


(a) Phosphorus export in 2008

(b) Percent change in phosphorus export from 2008 to Vision

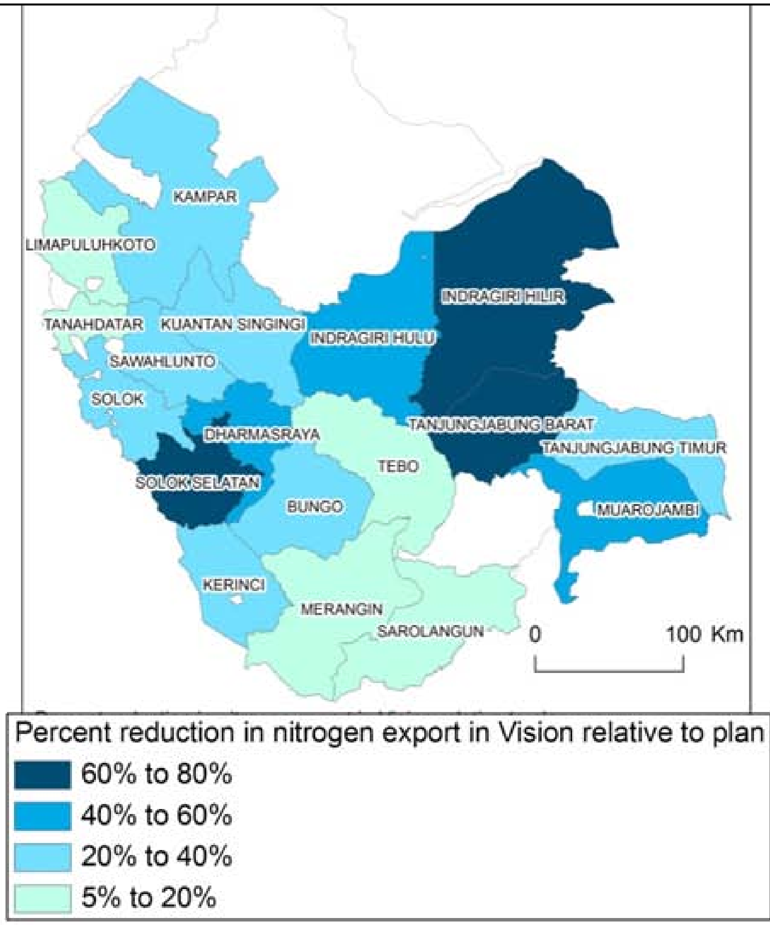
(c) Percent change in phosphorus export from 2008 to plan

Fig. 3.10. Phosphorus export under the plan (c) would increase along the western mountainous region

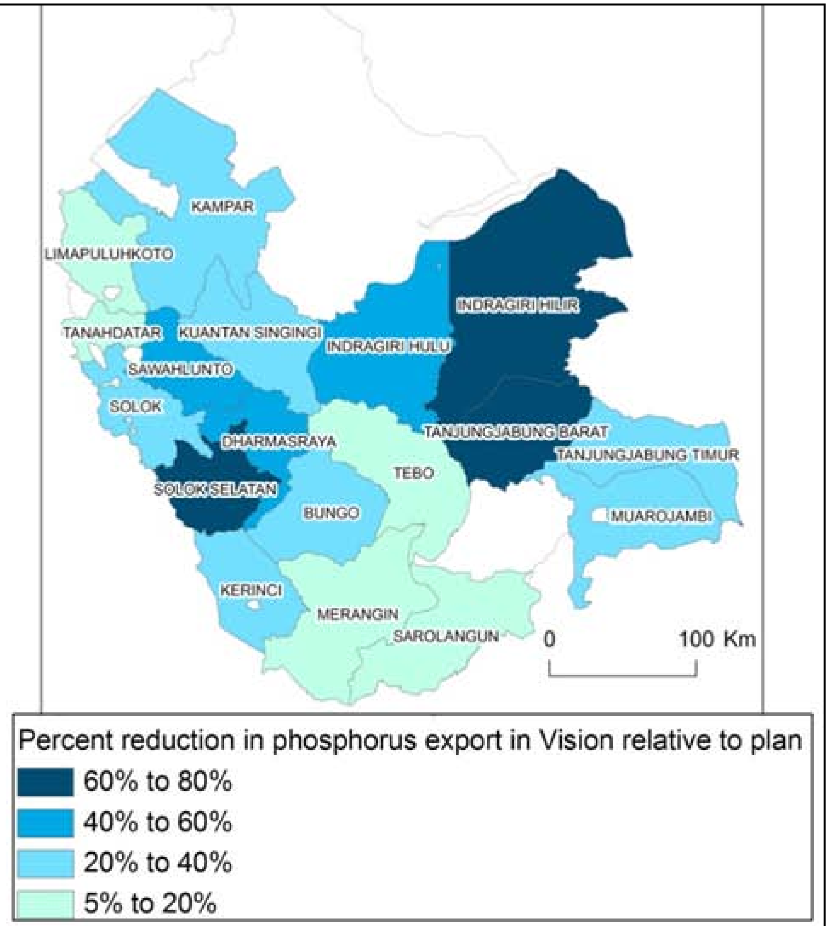


(a) (b)

Fig. 3.11. Although all districts would have slightly decreased water yield (a) under the Vision as compared to the plan, the difference in water yield between the two scenarios is small (< 10%). However, many districts would see substantial reductions (up to 80%) in sediment export (b), nitrogen export (c) and phosphorus export (d) under the Vision as compared to the plan, which would result in improved water quality and lower water treatment and dredging costs.



(c)



(d)

Fig. 3.11 continued

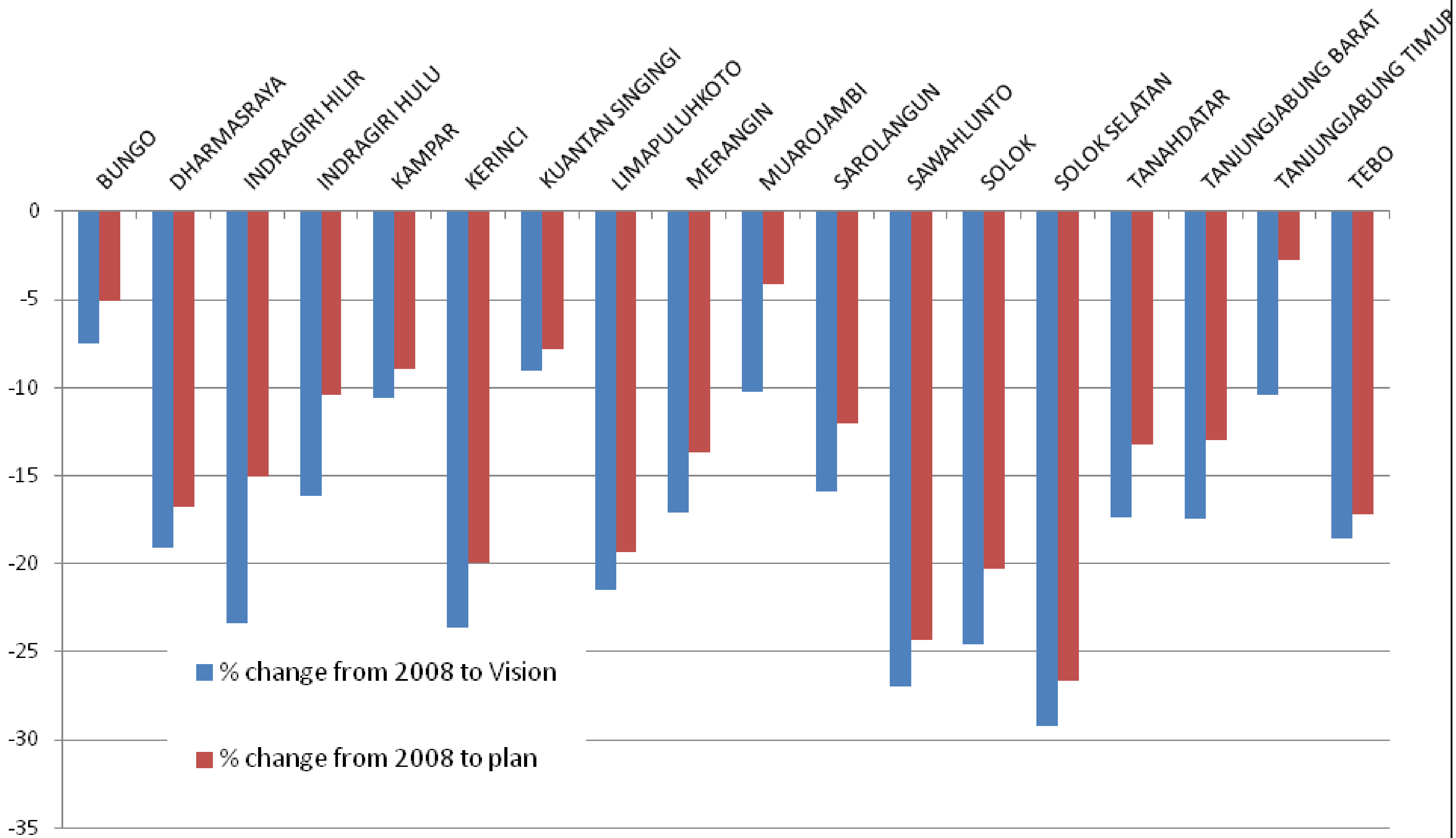


Fig. 3.12 Water yield change for each district from 2008 to scenarios. Even though all districts lose average annual water yield under both scenarios, the losses for most districts are similar among the two scenarios (within 5% of each other) .

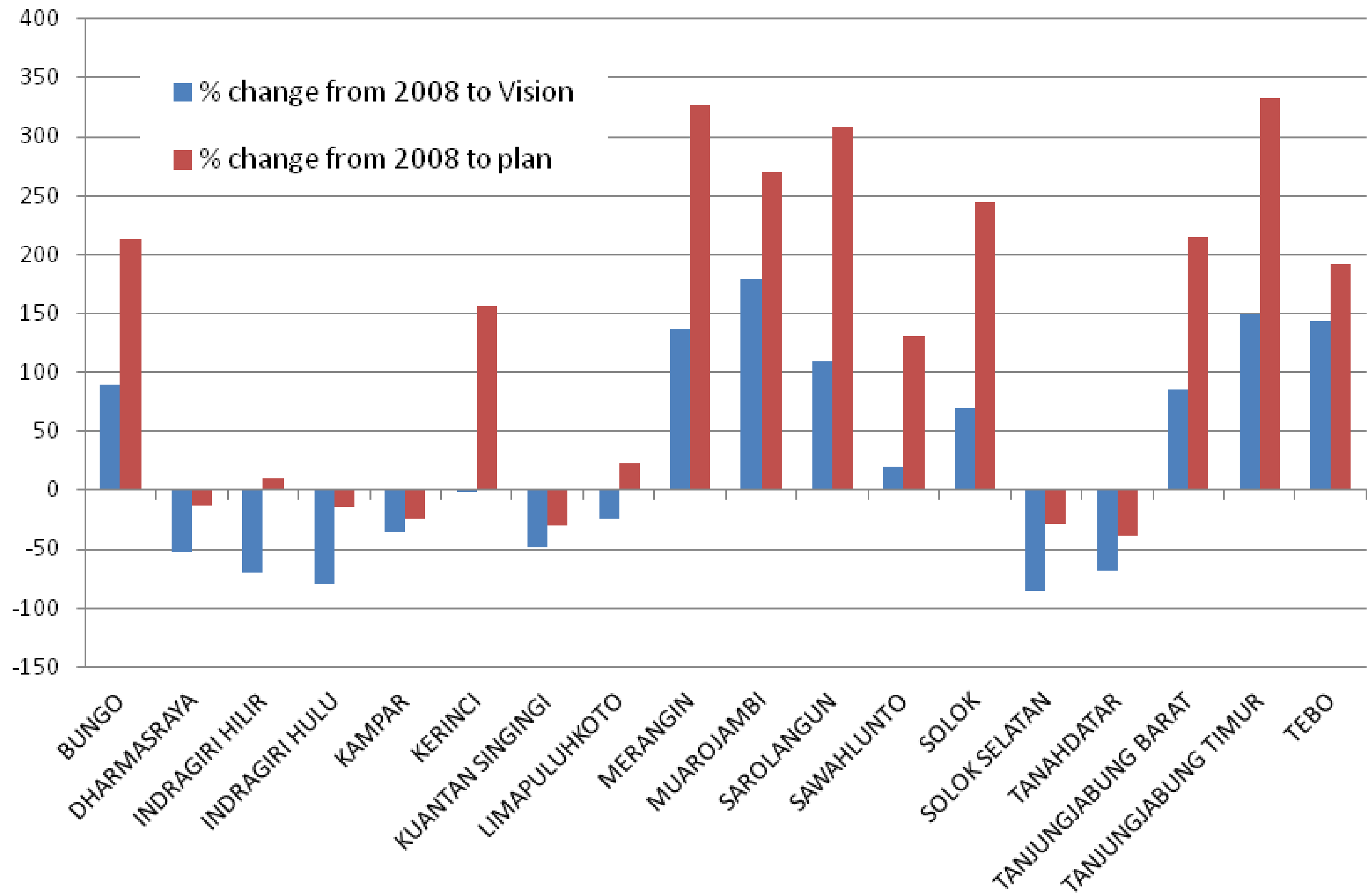


Fig. 3.13 Sediment export change by district from 2008 to each scenario. For several districts, the amount of sediment exported under the plan is over a 100% more than under the Vision.

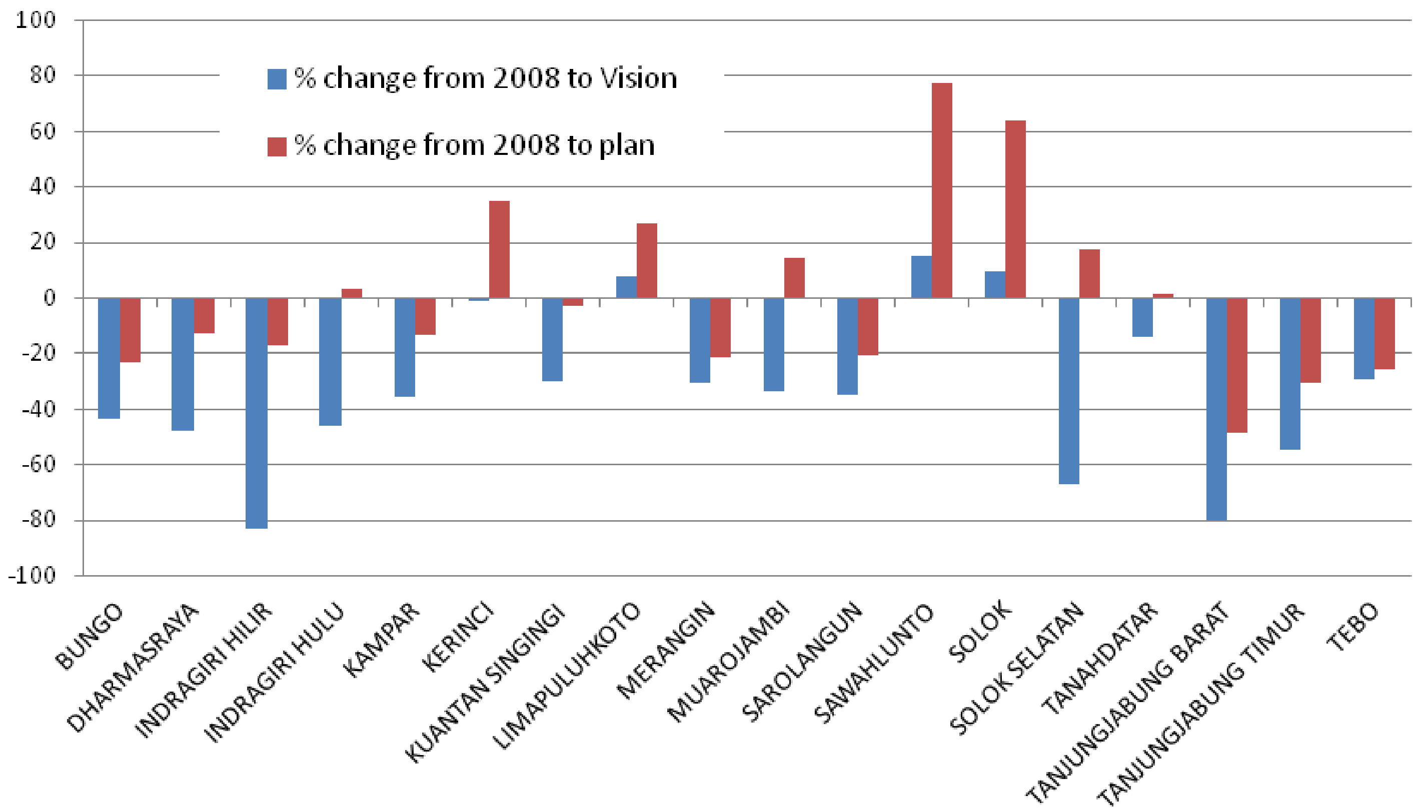


Fig. 3.14 Nitrogen export change by district. In all districts, there would be less nitrogen export in the Vision relative to the plan

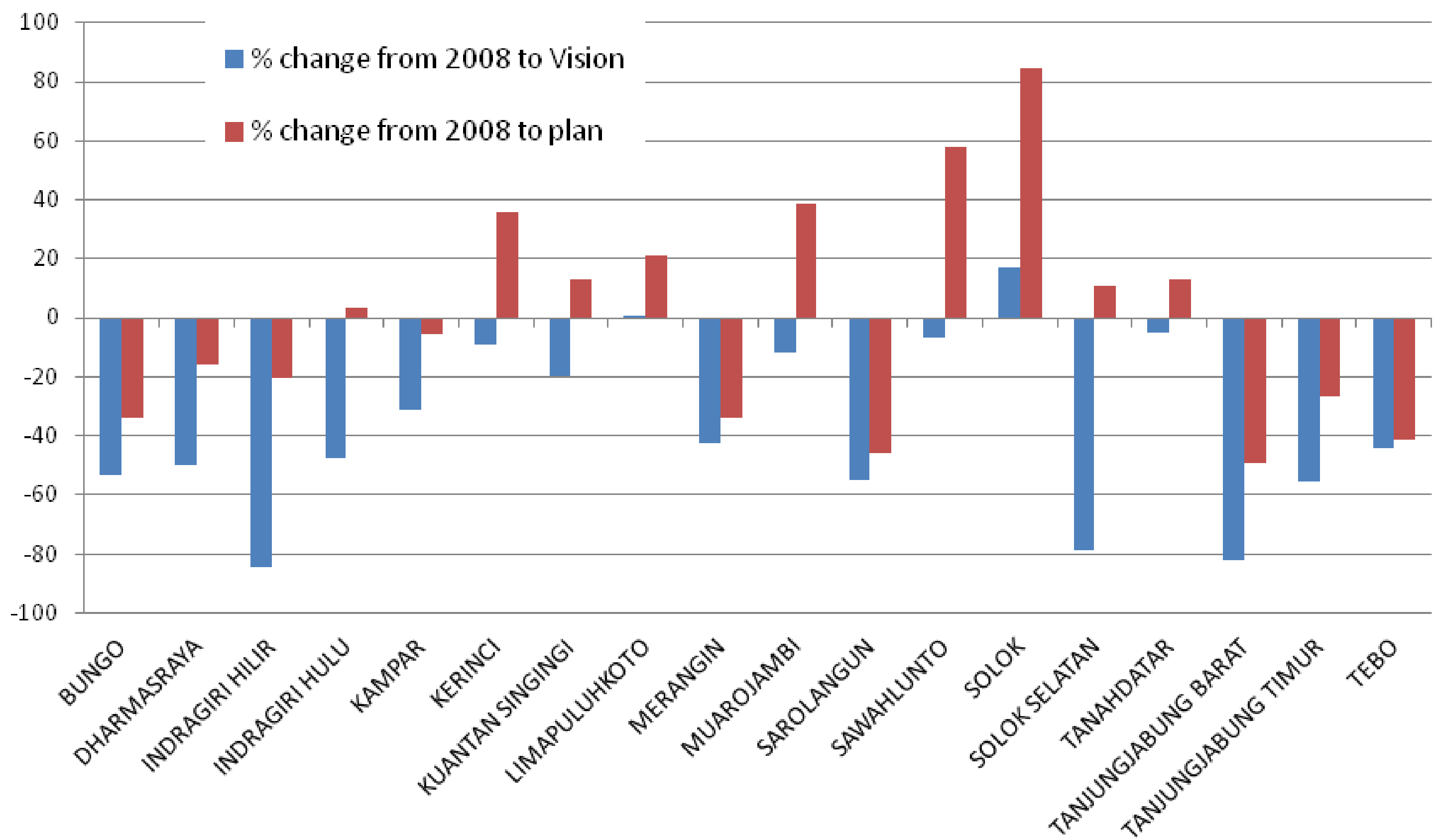


Fig. 3.15 Phosphorus export change by district. Trends are similar to nitrogen export

Recommendations

In many areas hydrological services appear to be greater under the Sumatra Vision than under the Government Plan. This finding indicates that if provincial and district land-use planners wish to improve watershed services in center Sumatra, they ought to implement the Sumatra Vision instead of the Government Plan. The findings also suggest that implementing improved watershed management in the areas of greatest contrast between the Sumatra Vision and the Government Plan are possible locations to establish several of the five priority programs discussed in Chapter 1 (forest restoration, forest carbon projects, payments for watershed services, best management practices for plantations and forestry) to benefit downstream service users.

Many sub-watersheds show decreases in hydrological services under the Government Plan (Figure 3.8). The western sub-watersheds and all of the sub-watersheds within the Batanghari and Pengabuan Laban basins may be especially vulnerable to erosion. Districts that might be particularly affected include those containing the mountainous Bukit Barisan Range: Limapuluhkoto, Tanahdatar, Sawahlunto, Solok, Solok Selatan, Kerinci and Merangin; and, those in the lower elevations of these watersheds: Bungo, Sarolangun, Tebo, Tanjungjabung Barat, Tanjungjabung Timur and Muarojambi. Reforestation and maintenance of forests in the mountainous districts along the east-facing slopes of the Bukit Barisan Mountains may substantially reduce erosion and nutrient runoff to the eastern lowland districts (Figures 3.8, 3.9 and 3.10). These activities could be included in improved watershed management or payment for watershed services schemes between districts. In addition, some of these areas might benefit from forest carbon payments or forest restoration.

Recommendations for Towns, Dams and Districts

The towns and dams we identify are a subset of all those present in the study area, highlighted because they were the only ones for which we had spatial data. Similar analyses can be done for other potential beneficiaries in the region.

In each case, we underscore why and how improved watershed management is likely to benefit the users of interest (e.g. towns and hydropower facilities). There are many options for activities and actions that improve watershed management in these areas. It was beyond the scope of this study to identify which of the five priority programs mentioned above would give the most efficient and effective means for achieving the results of the Sumatra Vision scenario. Instead, we identify the areas where watershed management has great potential to improve watershed services, and where further exploration of the priority programs should be targeted.

Population Centers as Beneficiaries of Hydrological Services

The towns of Tembilahan and Rengat, in Indragiri Hilir and Indragiri Hulu districts, respectively, lie along the Indragiri River and contain tiger habitat in the RIMBA priority area within their sub-watersheds

(Figure 3.16). Conserving these areas under the Sumatra Vision through watershed management programs would protect habitat for tigers and other biodiversity, while reducing erosion and nutrient pollution by more than 80% in some areas (Figures 3.17, 3.18 and 3.19). As the upstream and downstream sub-catchments lie in different districts, the two districts will have to collaborate to implement agreed upon watershed management programs.

The contributing sub-catchments for the towns of Muara Bungo and Rantau Panjang[9], in Bungo district, contain tiger habitat that overlaps with the RIMBA priority area (Figure 3.20). Although the Sumatra Vision and the Government Plan would result in similar reductions in water yield in these sub-watersheds (Figure 3.21), the Sumatra Vision would lead to 38-60% less sediment export, 8-15% less nitrogen pollution and 7-21% less phosphorus pollution than the Government Plan (Figures 3.22 to 3.24). These results complement analyses of the benefits of jungle rubber (traditional rubber agroforestry) in Bungo district conducted by the RUPES program of the World Agroforestry Centre (://www.worldagroforestry.org/sea/Networks/RUPES/mapsite_indonesia.htm, case study description at ://www.worldagroforestry.org/sea/Networks/RUPES/download/SiteProfiles/RUPES-Bungo_FINAL.pdf). The RUPES study found that jungle rubber harbored significant biodiversity and provided a range of products to local communities that would be lost under rubber monoculture. Although we did not consider jungle rubber explicitly in our scenarios, its maintenance or expansion could be consistent with the Sumatra Vision scenario because of its similarity to secondary forest; secondary forestcan bring additional benefits through reduced sediment and nutrient export to downstream towns. Thus, payments for watershed services could be made to rubber growers aimed at maintaining jungle rubber. These efforts, coupled with ongoing efforts by the RUPES program to obtain premium pricing for eco-certified rubber from the region, could provide financing for maintaining rubber agroforests in the region.

The town of Kuala Tungkal in Tanjungjabung Timur district, Jambi province (Figure 3.25), could also benefit from watershed management programs in its contributing sub-catchments. In this area, erosion (Figure 3.26) and nutrient pollution (Figures 3.27 and 3.28) levels are lower under the Sumatra Vision than under the Plan. Since the upstream sub-catchment is in a different district, Tanjungjabung Barat, the two districts may have to collaborate to design a watershed management plan.

Hydrological Service Benefits to Dams

There is one large hydroelectric dam within our study area, Koto Panjang (Fig. 3.29), in Kampar district. Both future scenarios will lead to some reduction in total annual water supply to the dam (Fig.3.30). However, implementing the Sumatra Vision through watershed protection schemes would provide greater erosion control upstream of the dam, likely lowering dredging costs or long-term damage to turbines and other infrastructure (Fig. 3.31). In addition, such programs would protect parts of the RIMBA priority area and additional tiger habitat.

There are other smaller dams or reservoirs on the landscape whose catchment areas include tiger habitat and parts of the RIMBA priority area (e.g., in the Batanghari watershed, Fig 3.32). These dams could benefit from reduced sediment export from actions like forest restoration and payment for watershed services under the Sumatra Vision as compared to the land uses permitted in the Government Plan (Fig. 3.33). In Chapters 2 and 4, we identified areas within these catchments as having

[9] Rantau Panjang is referred to in some of the figures as Ranjaupanjang.

potential for carbon projects that would also improve wildlife habitat quality. Thus, a forest carbon project sited in these catchments could receive a premium for providing co-benefits through protection of biodiversity and watershed services.

We also assessed changes to hydrological services downstream of Lake Singkarak, the focus of another study by the RUPES program (see case study description ://www.worldagroforestry.org/sea/Networks/RUPES/download/SiteProfiles/RUPES-Singkarak_FINAL.pdf at ://www.worldagroforestry.org/sea/Networks/RUPES/mapsite_indonesia.htm). The lake functions as a reservoir for a hydropower facility (located outside our study area) that provides power to the provinces of West Sumatra and Riau. Downstream communities include the town of Sawahlunto. Both scenarios for future development lead to a 5-20% decrease in water yield (Figure 3.35) and increased sediment export (Figure 3.36). However, erosion is 73% higher under the Government Plan than it is under the Sumatra Vision. The Government Plan could also lead to 23% higher nitrogen pollution from 2008 (Figure 3.37b), whereas nitrogen export levels would remain relatively unchanged under the Sumatra Vision (Figure 3.37 a). Our results echo some of the findings of the RUPES study, which concluded that reforestation (which would be consistent with the Sumatra Vision) would not necessarily deliver increased water yield and erosion control. Given that local communities have envisioned expanding agroforestry, including shade-grown coffee cultivation, the above results suggest that controlling nutrient export by implementing best management practices for agriculture, such as limiting fertilizer application, would be a priority in this area.

The above are a subset of the possible beneficiaries of watershed management schemes in central Sumatra. Similar approaches can be applied to population centers, reservoirs and other locations where water quality and sedimentation are of concern.

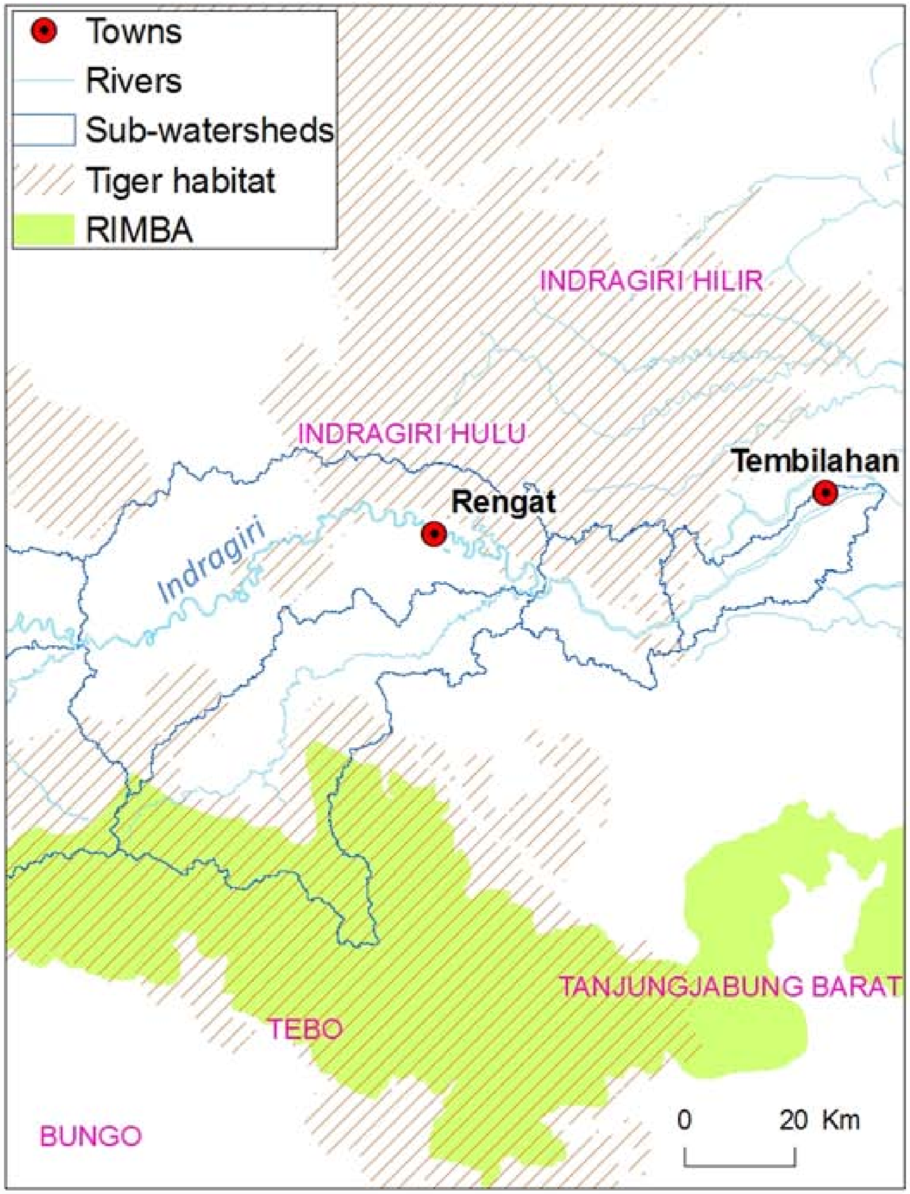


Fig. 3.16 Tembilahan and Rengat towns are on the main stem of the Indragiri river. The sub-watersheds in which these towns are located, as well contributing sub-watersheds upstream (west), overlap tiger habitat and the RIMBA area.

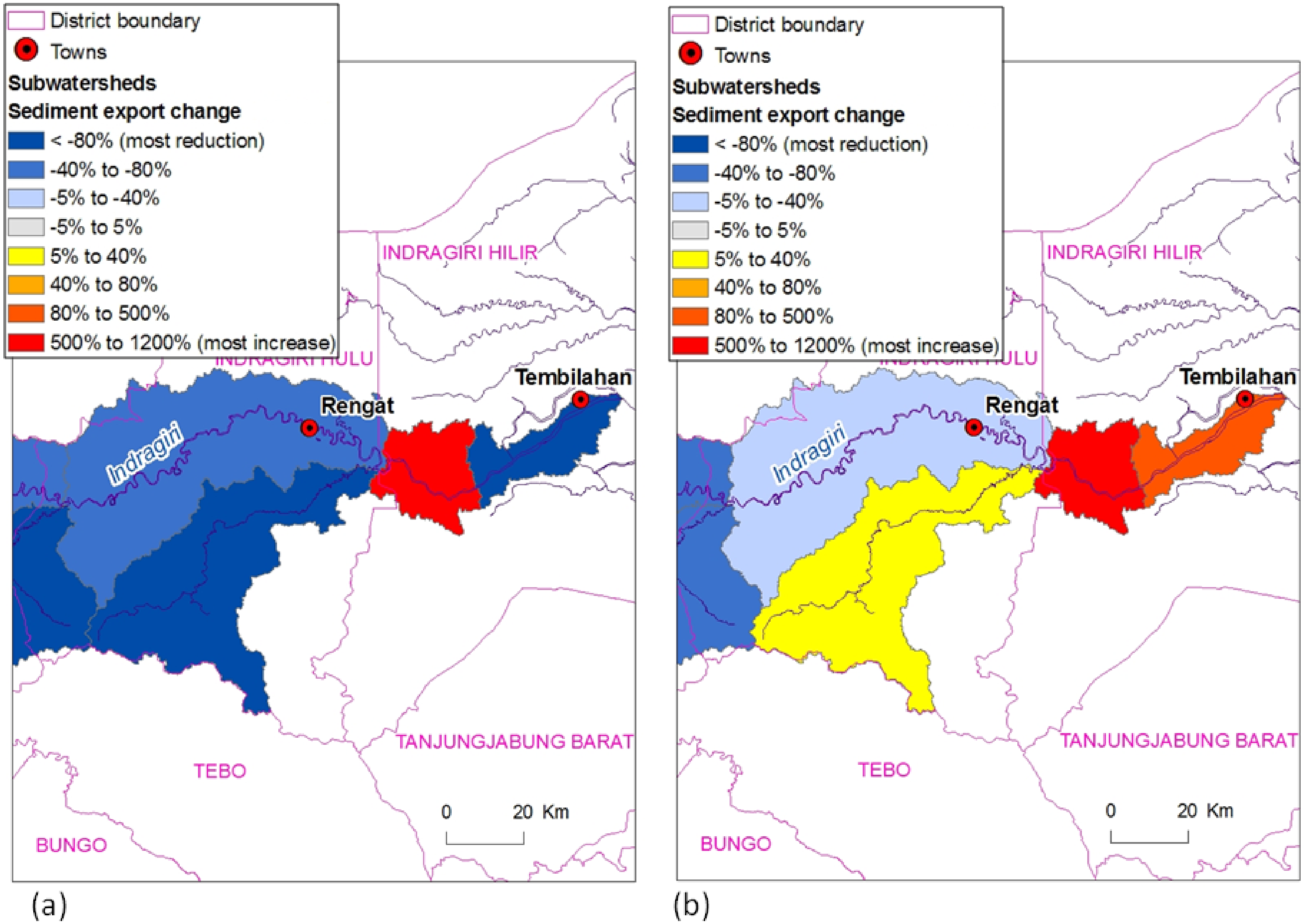


Fig. 3.17. Under the Vision (a), the sub-watersheds containing or upstream of Tembilahan and Rengat would mostly see reduced levels of sediment exported, relative to the plan (b).

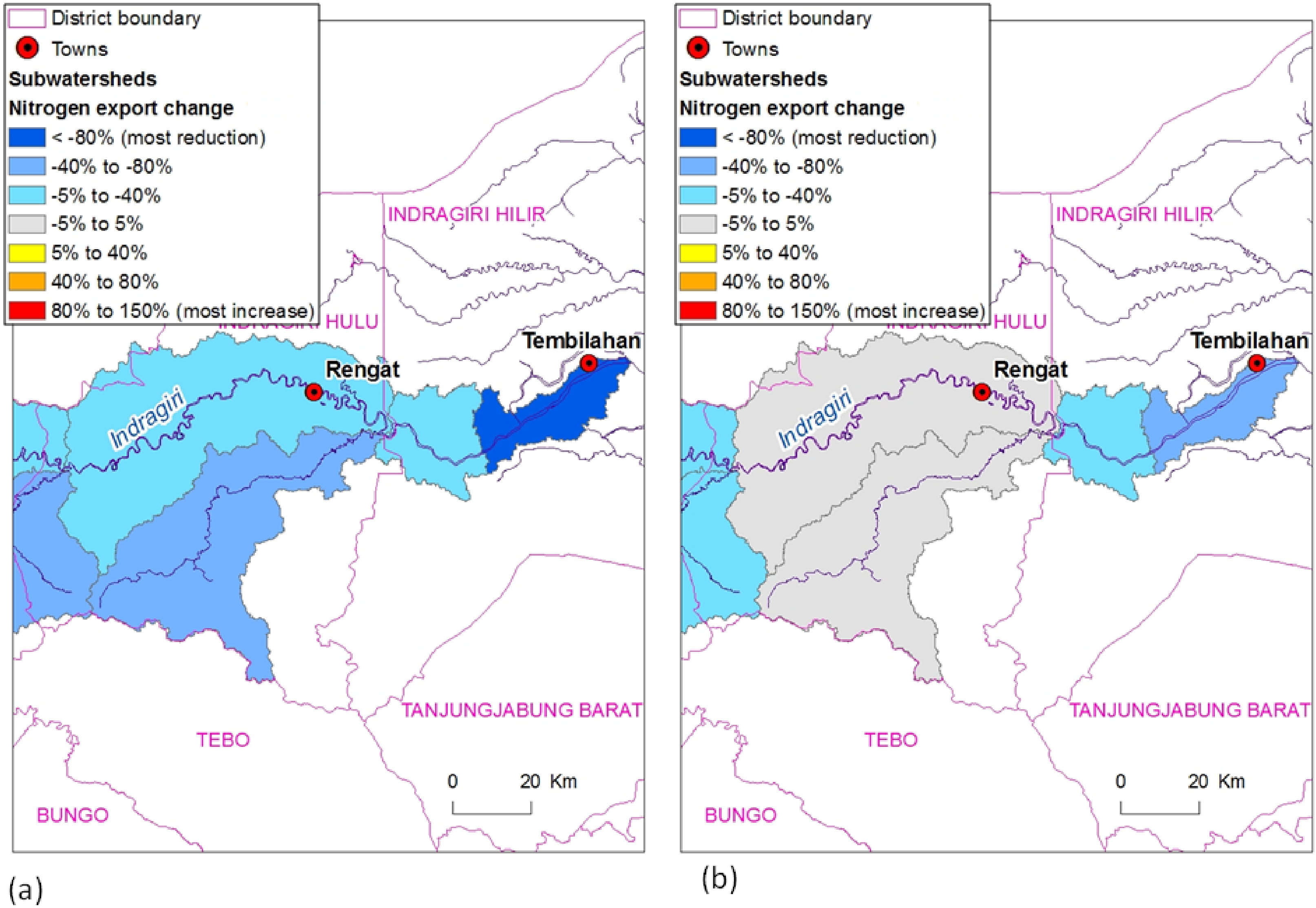


Fig. 3.18. Under the Vision (a), the sub-watersheds containing or upstream of Tembilahan and Rengat would mostly see reduced levels of nitrogen exported, relative to the plan (b).

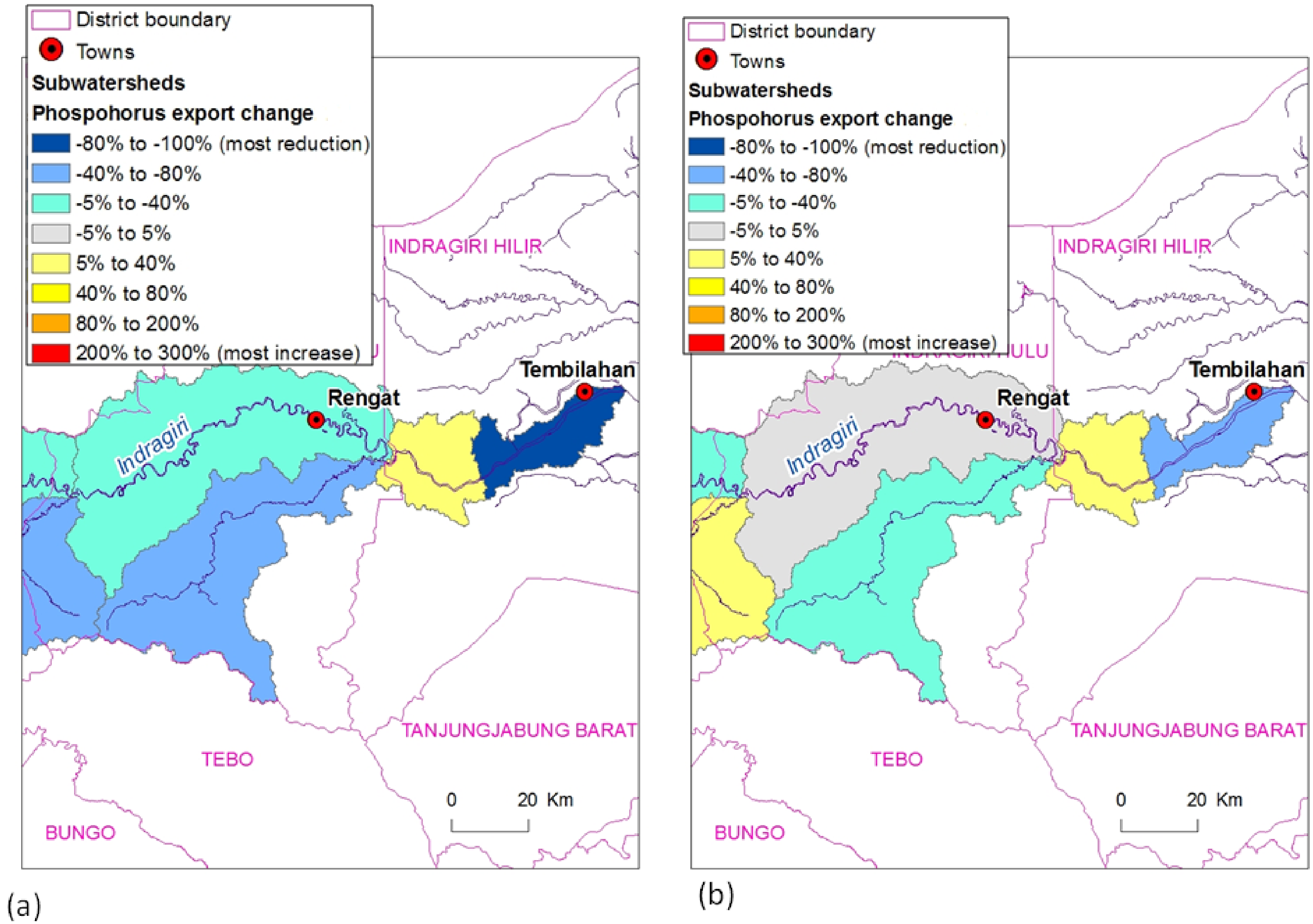


Fig. 3.19. Under the Vision (a), the sub-watersheds containing or upstream of Tembilahan and Rengat would mostly see reduced levels of phosphorus exported, relative to the plan (b).

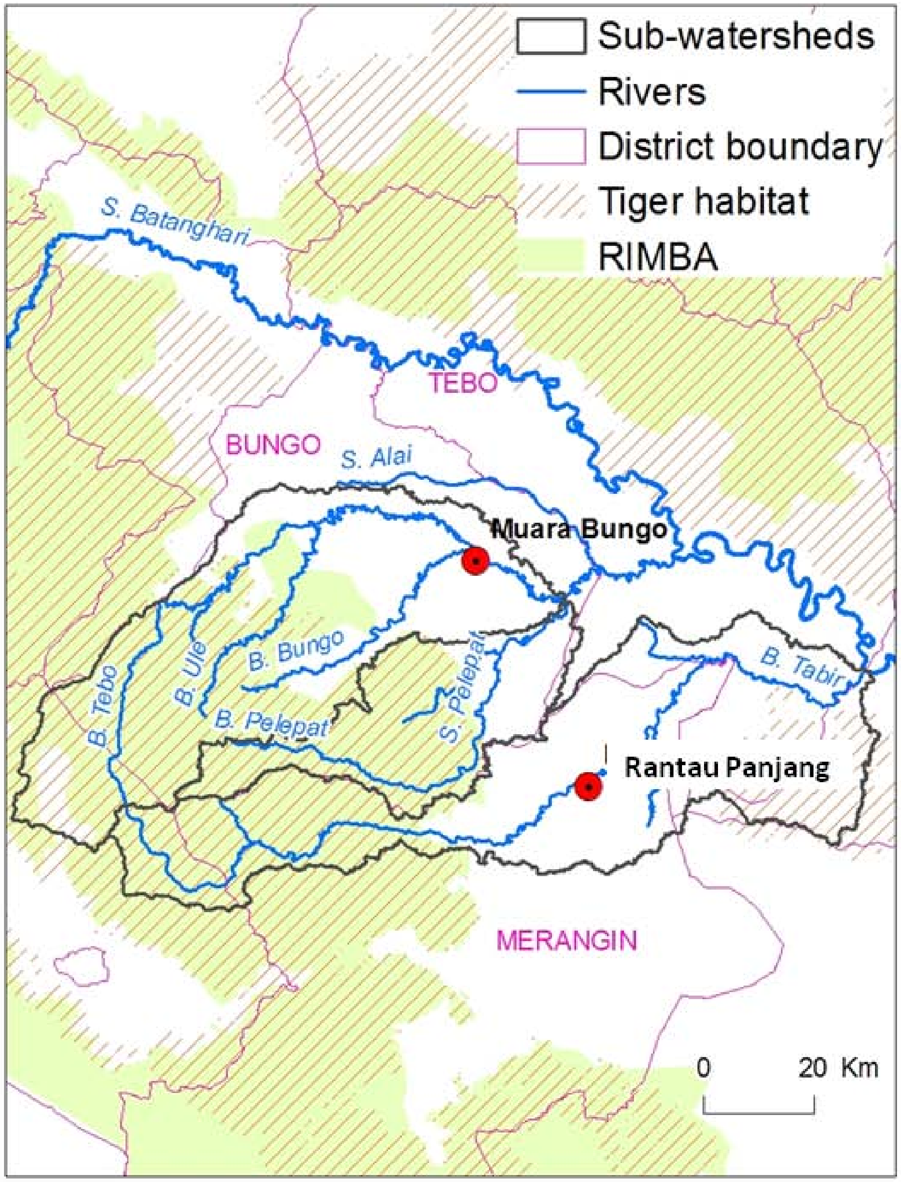


Fig. 3.20. Two towns in the Batanghari watershed. This area (Bungo district) is also the site of a study by RUPES / ICRAF on the biodiversity and ecosystem services benefits of jungle rubber.

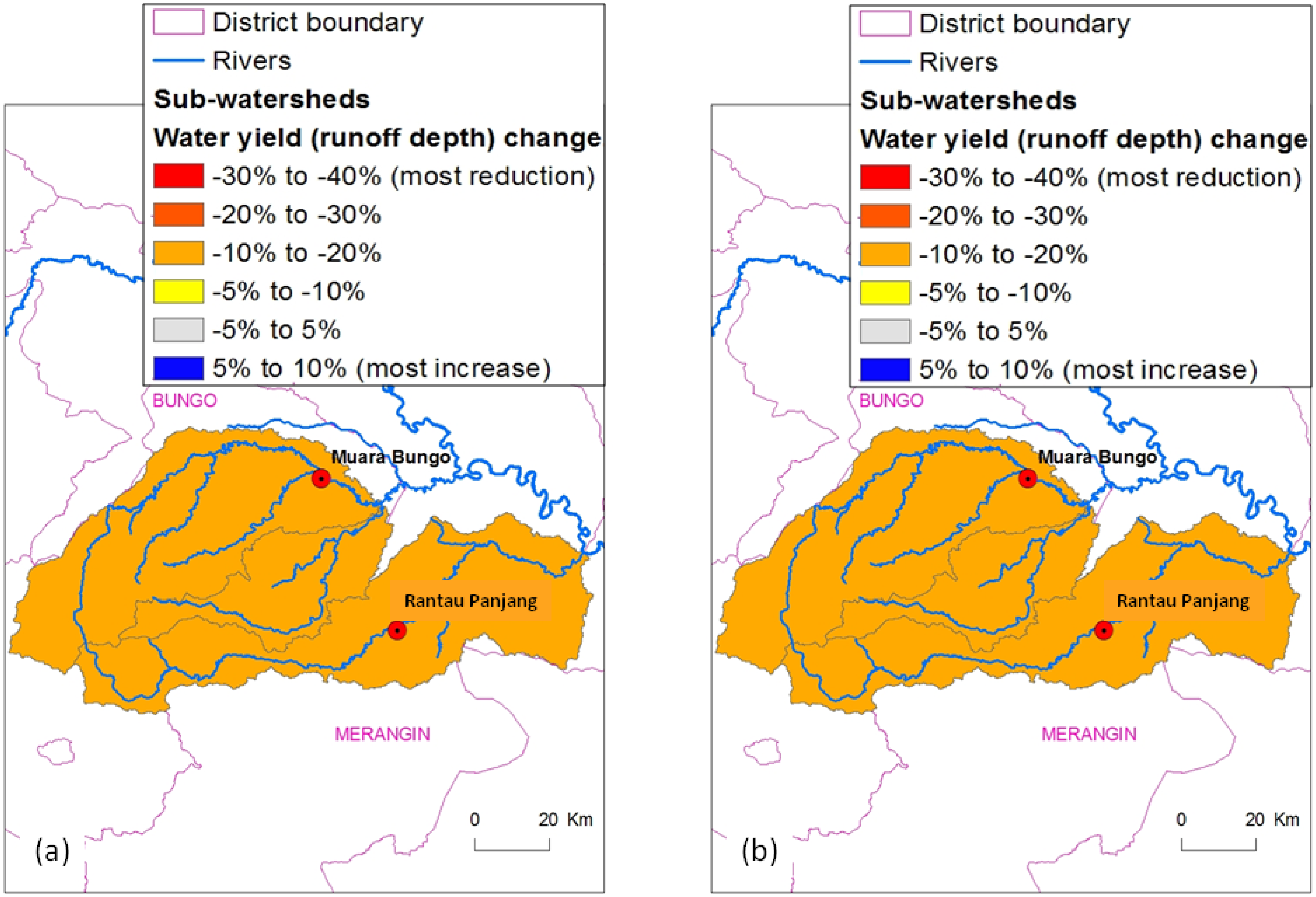


Fig. 3.21. Reduction in annual water yield would be similar under (a) the Vision as well as (b) the plan in the Batanghari watershed.

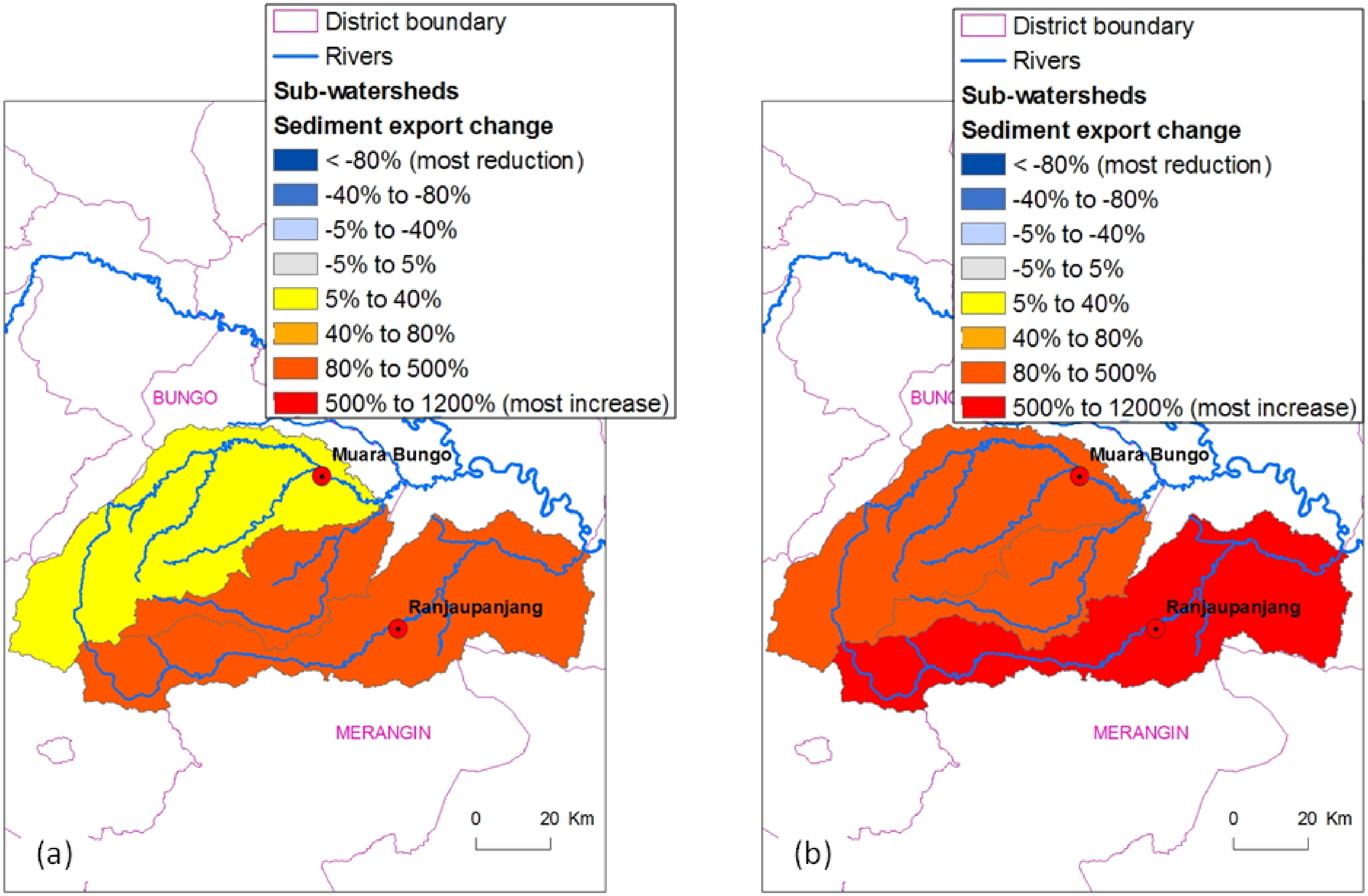


Fig. 3.22. While sediment export within these watersheds would increase under both scenarios, it would increase more under the plan (b) for these towns in the Batanghari watershed.

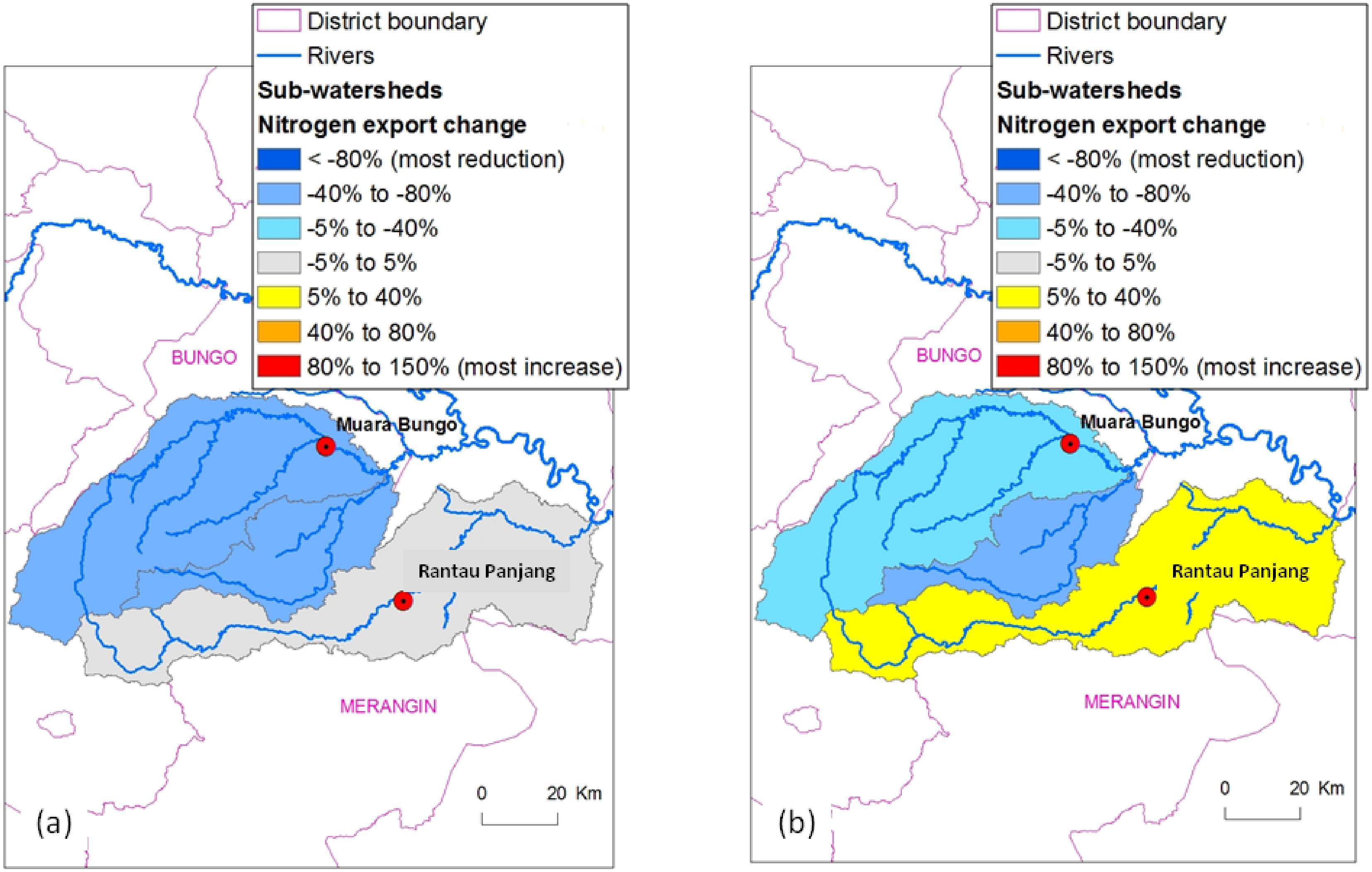


Fig. 3.23. The amount of nitrogen exported to Muara Bungo would be reduced to a greater extent under (a) the Vision than (b) the plan. The town of Rantau Panjang would see an increase in nitrogen export under the plan, but not under the Vision.

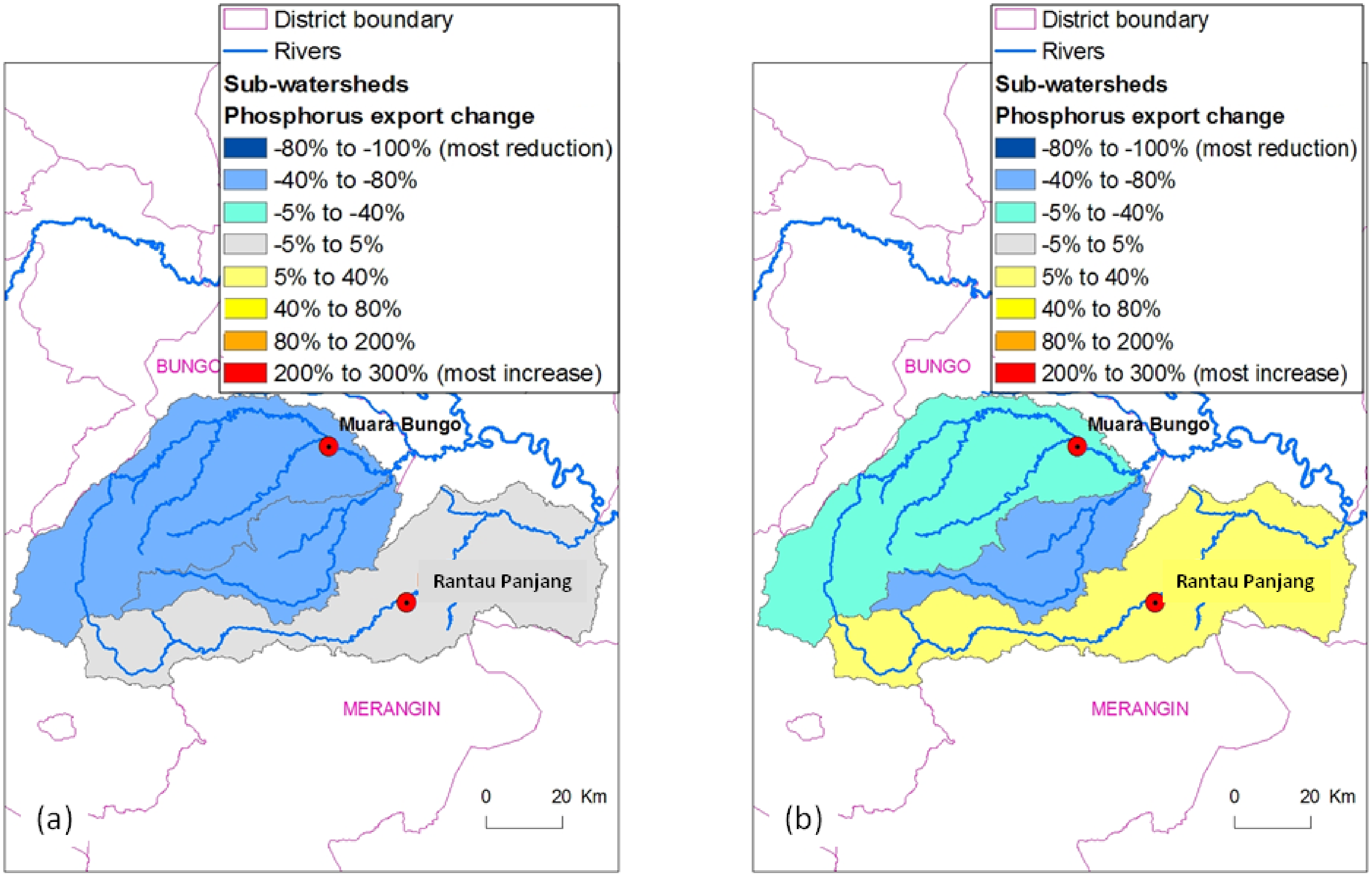


Fig. 3.24. The amount of phosphorus exported to Muara Bungo would be reduced to a greater extent under (a) the Vision than (b) the plan. The town of Rantau Panjang would see an increase in phosphorus export under the plan, but not under the Vision.

Fig. 3.25. Kuala Tungkal town is in Penguabuan Lagan watershed and contains portions of the RIMBA area as well as tiger habitat within its contributing sub-watersheds.

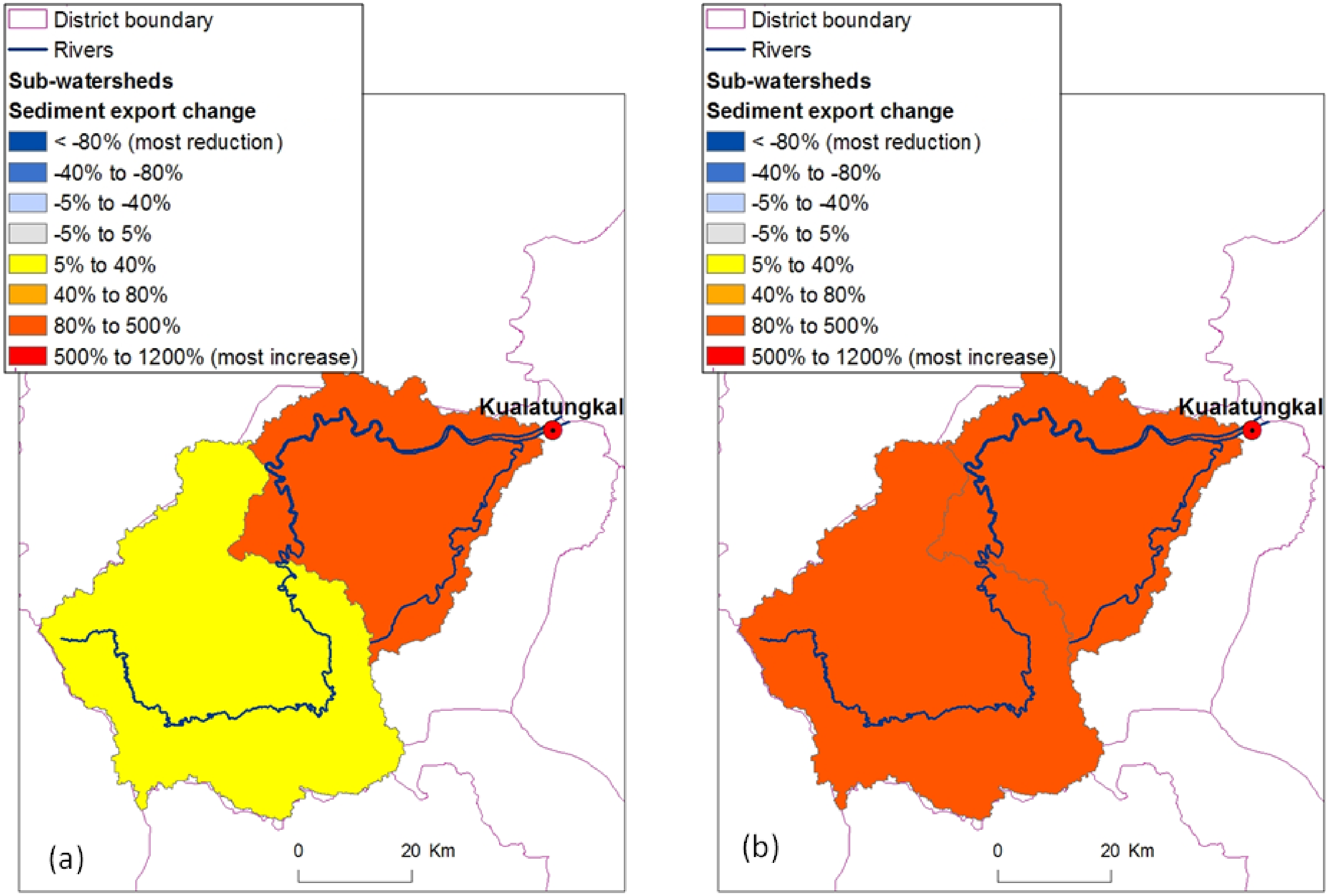


Fig. 3.26. While both scenarios would result in increased sediment export to Kuala Tungkal, the increase would be greater for the plan (b) in the Penguabuan Lagan watershed.

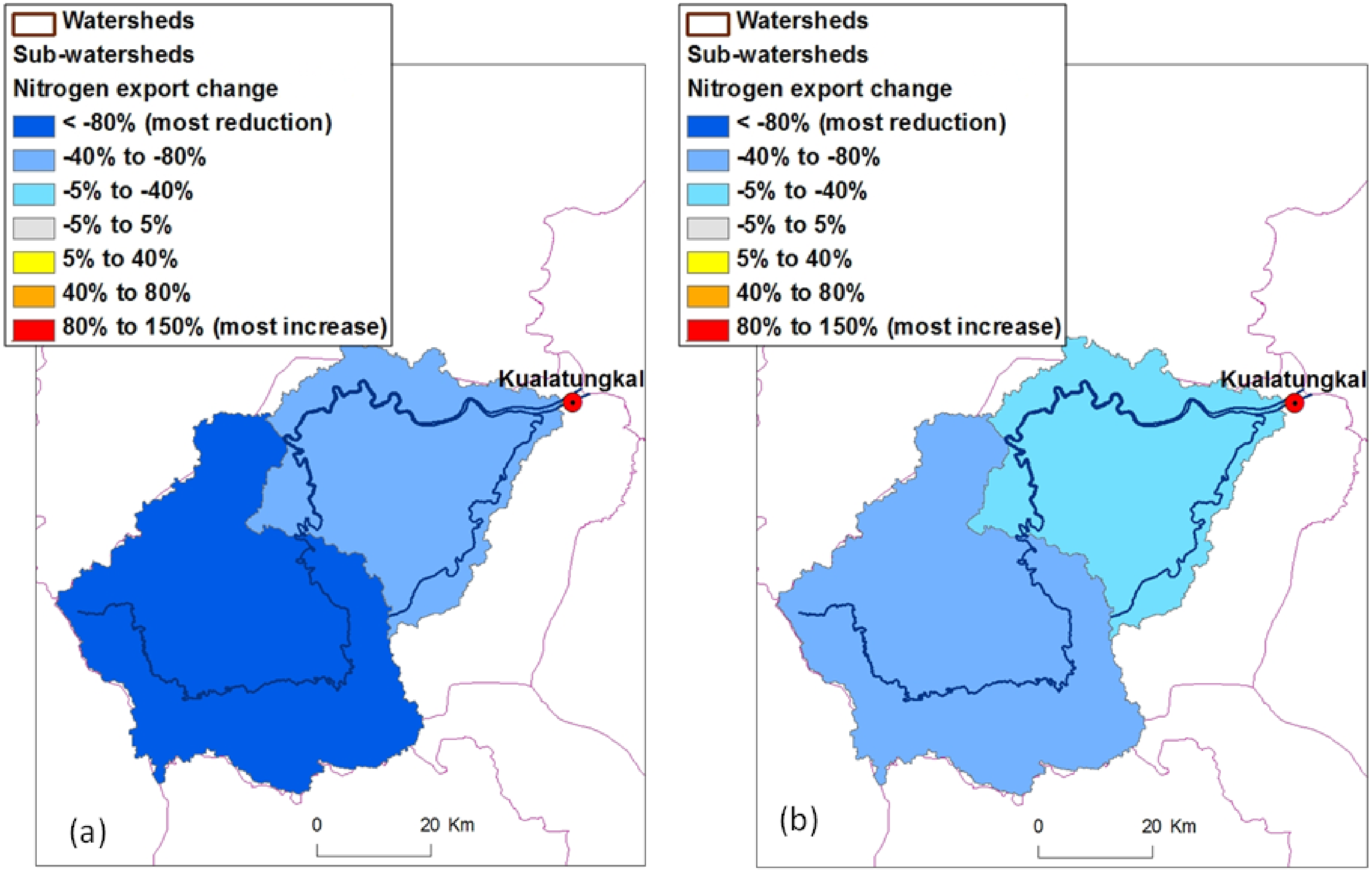


Fig. 3.27. Both scenarios would result in decreased nitrogen export, but the benefits would be greater under the Vision (a). in the Penguabuan Lagan watershed.

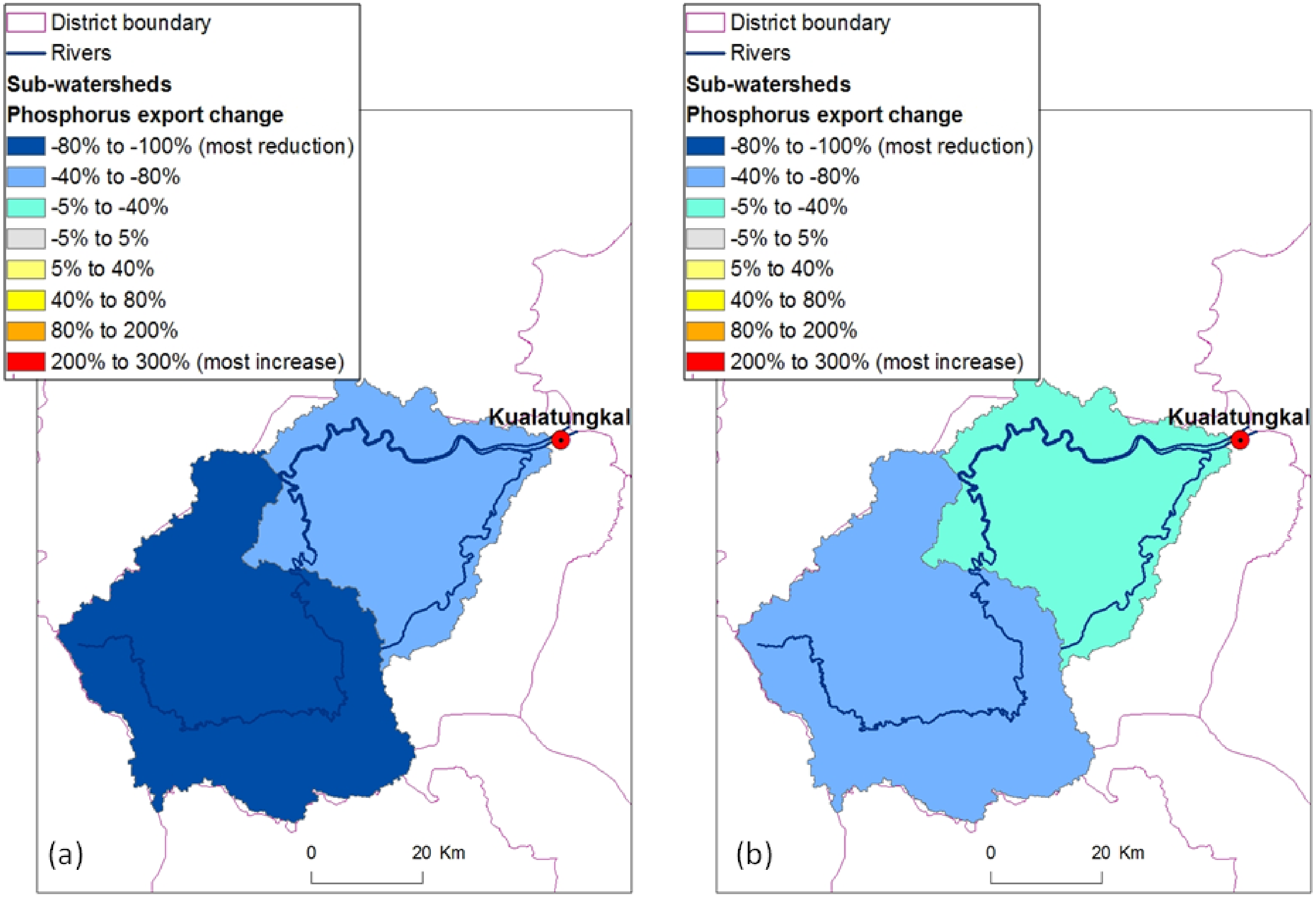


Fig. 3.28. Both scenarios would result in decreased phosphorus export, but the benefits would be greater under the Vision (a). in the Penguabuan Lagan watershed.

Fig. 3.29. Kotopanjang is a hydrolelectric dam within our study area. Its contributing sub-watersheds lie in Kampar and Limapuluhkoto districts, and overlap with tiger habitat as well as the RIMBA area.

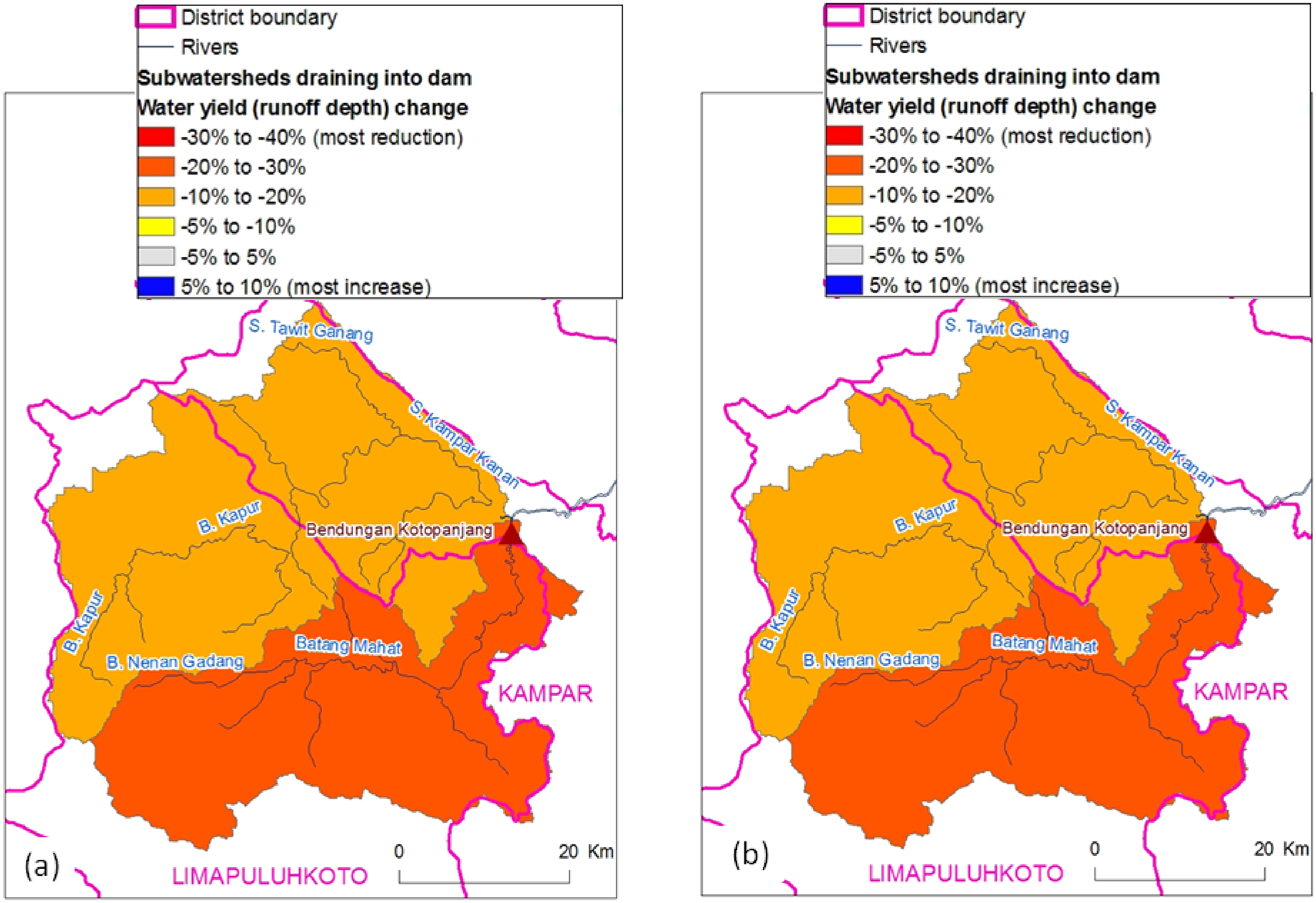


Fig. 3.30. Although annual water yield would decrease under either scenario, the changes are of similar magnitude for both scenarios.

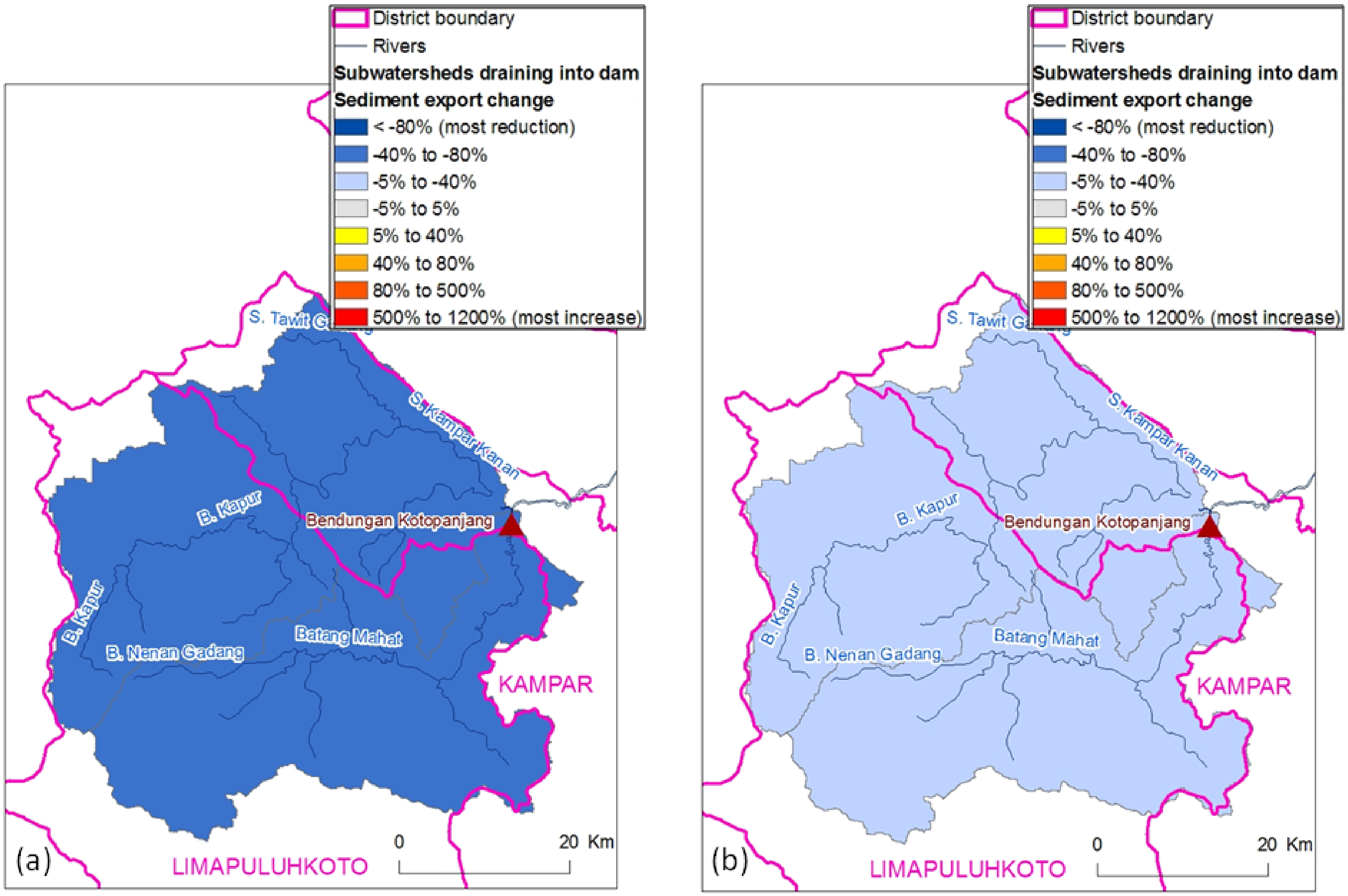


Fig. 3.31. Sediment export to the dam would decrease under both scenarios, but to a greater extent under the Sumatra Vision (a) as opposed to the Government Plan (b).

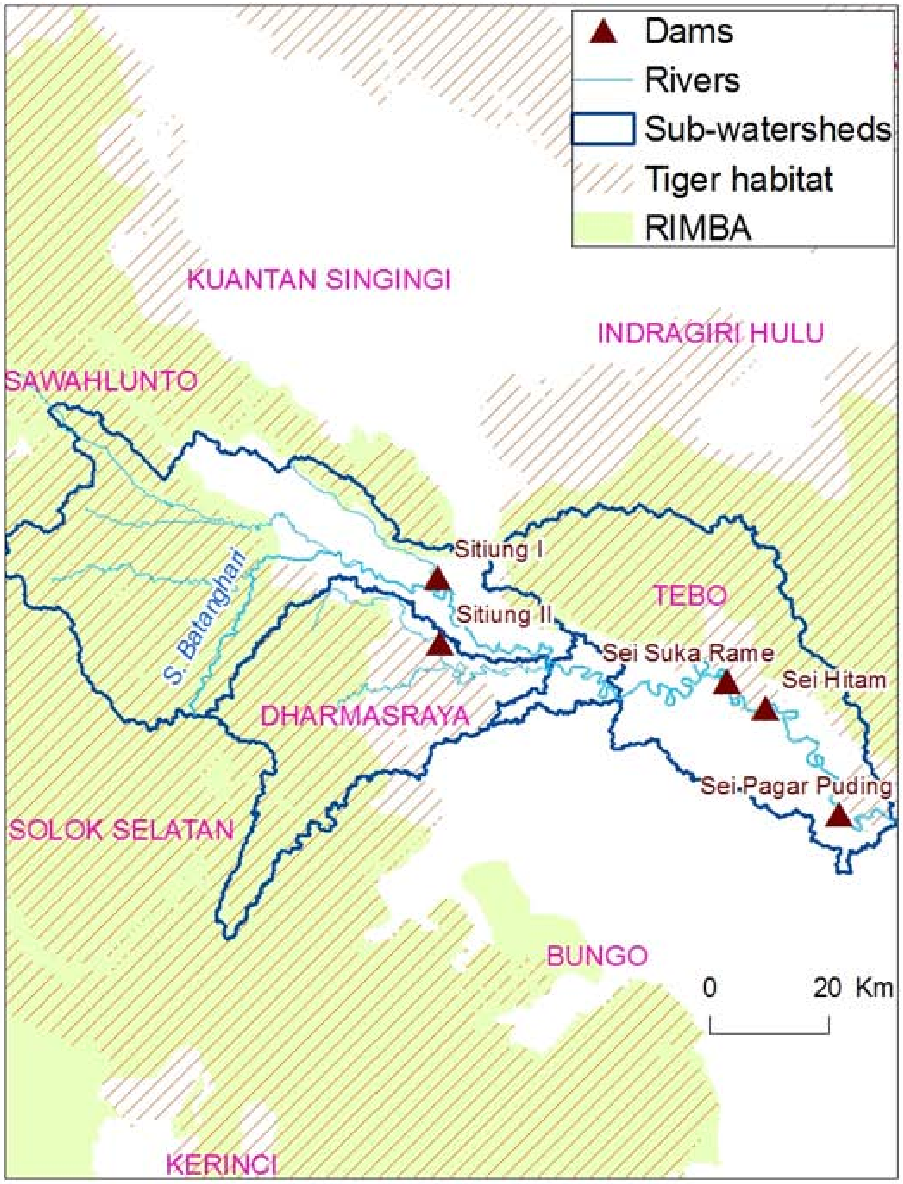


Fig. 3.32. Several small dams /reservoirs in the Batanghari watershed

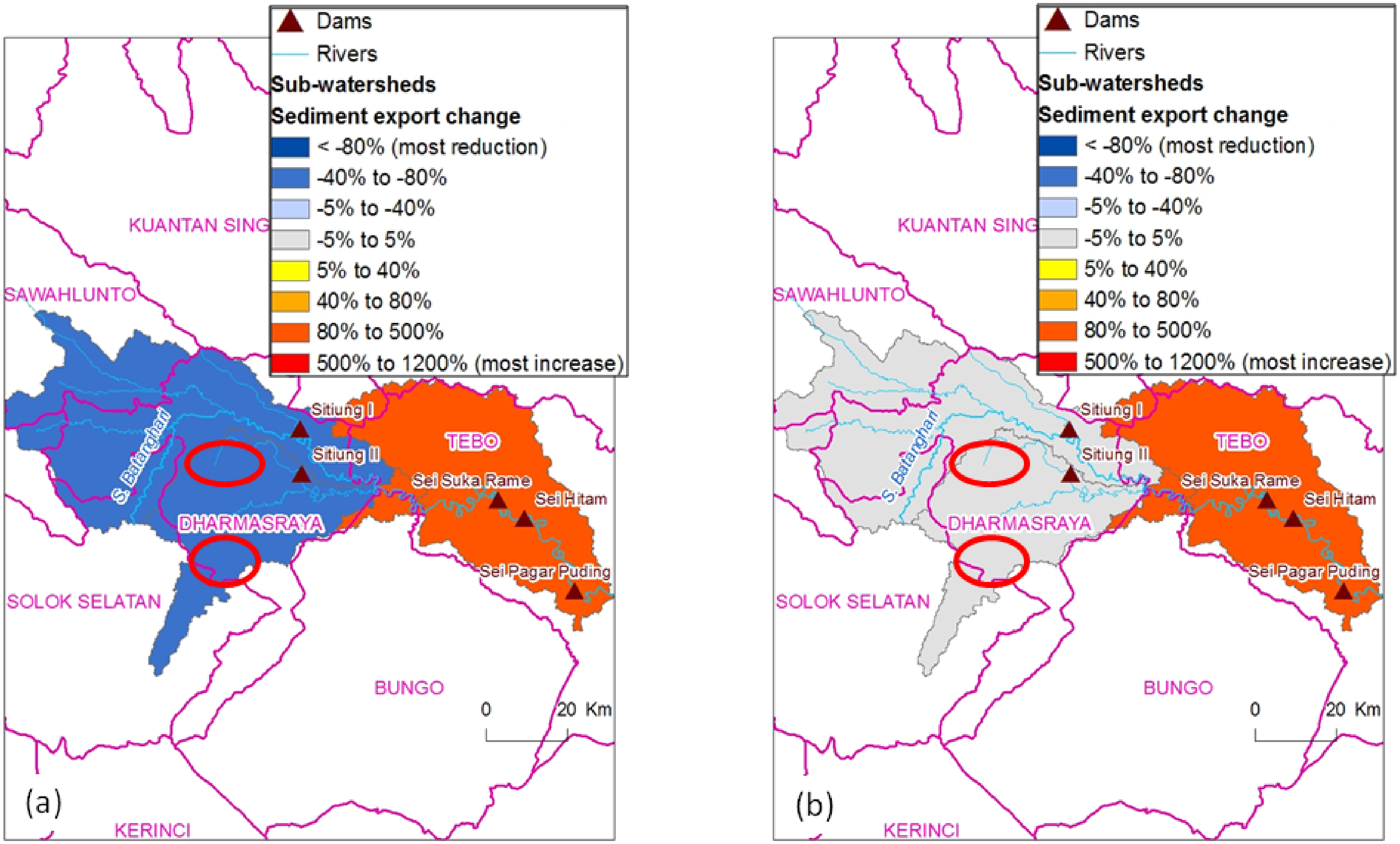


Fig. 3.33. There would be reduced sediment export relative to 2008 in these sub-watersheds under the Vision (a). Under the plan (b), sediment export levels would be similar to 2008. The red ovals are areas that were identified in Chapters 2 and 4 as having potential for forest carbon projects while providing biodiversity co-benefits through improved habitat quality. Thus, these areas could provide improved carbon sequestration, wildlife habitat and watershed services if the Vision were implemented.

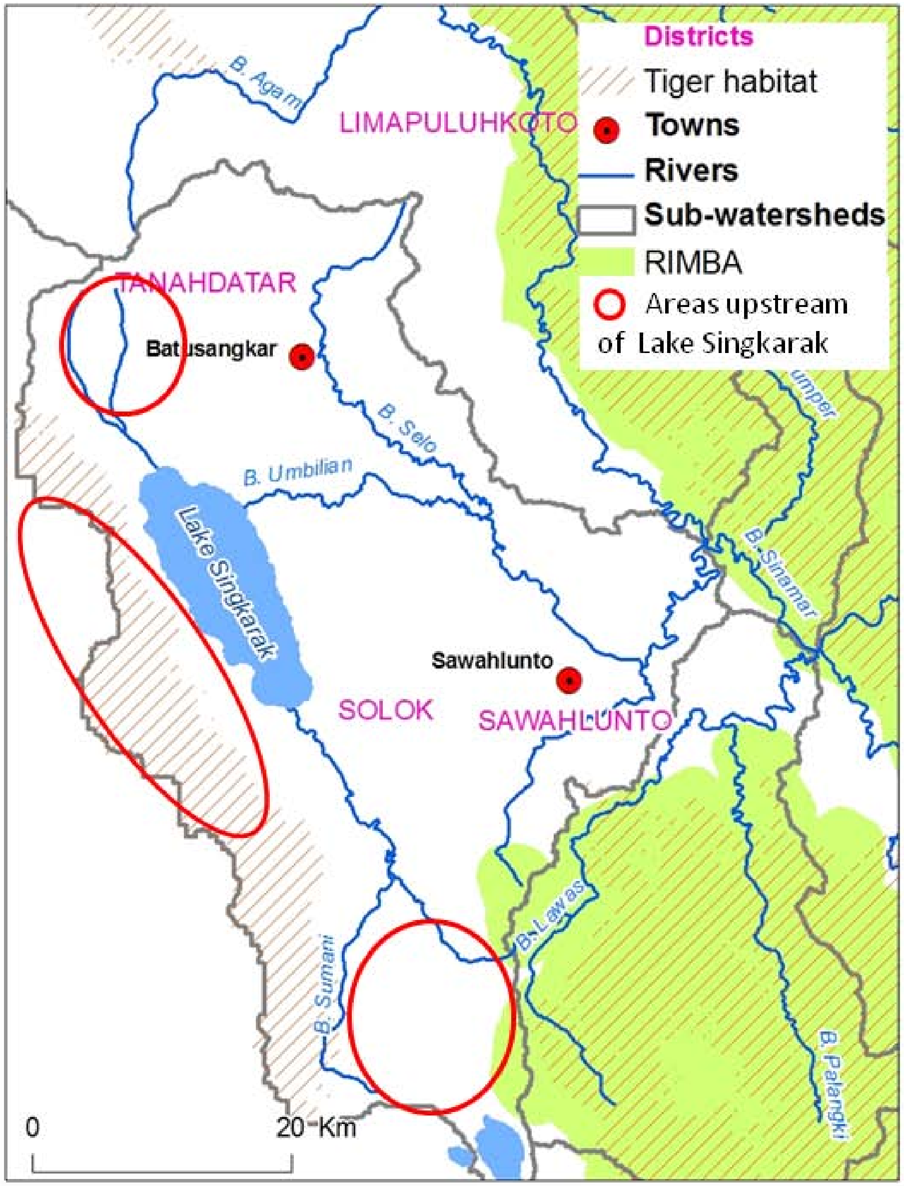


Fig. 3.34. Singkarak Lake serves as an upstream reservoir of the Indragiri river, and also supplies irrigation water, hydropower, fish and recreation services (ICRAF RUPES study). The natural flow of water from Lake Singkarak is eastward into the Umbilian river, but a portion is diverted to the hydropower facility located to the west of the lake.

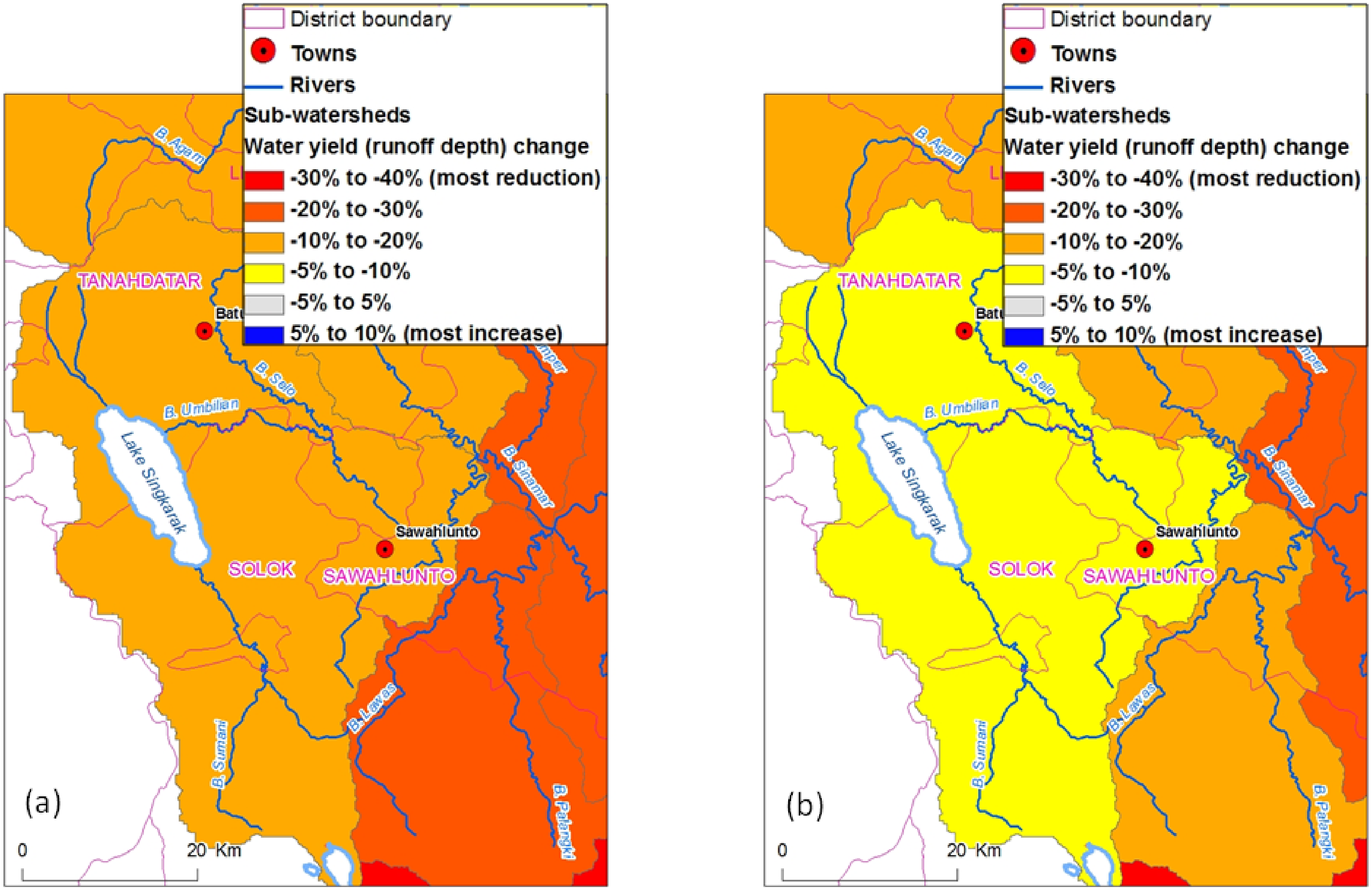


Fig. 3.35. While both scenarios would lead to some loss in annual water yield, ICRAF's RUPES study suggest that water yield changes linked to land cover change are limited, and do not substantially impact hydropower generation. Variability in rainfall between seasons, and between wet and dry years, is more important in terms of impacting water level in the lake.

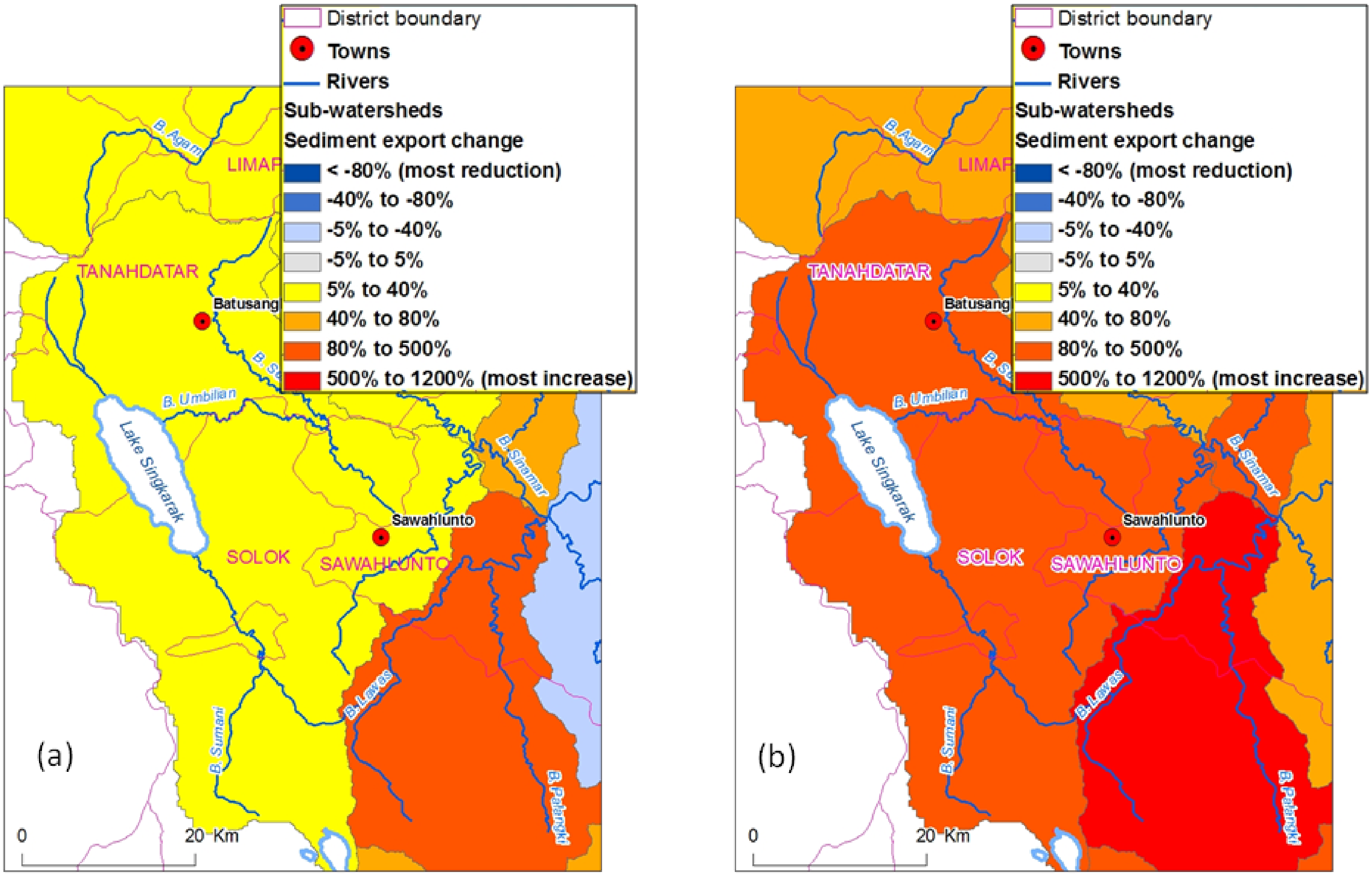


Fig. 3.36. Both scenarios would lead to increased sediment exported downstream from the watershed, but sediment export would be higher under the plan (b), relative to the Vision (a). Note that we are not talking about sediment flowing into the lake, but rather, sediment flowing downstream from the sub-watershed (towards the east)

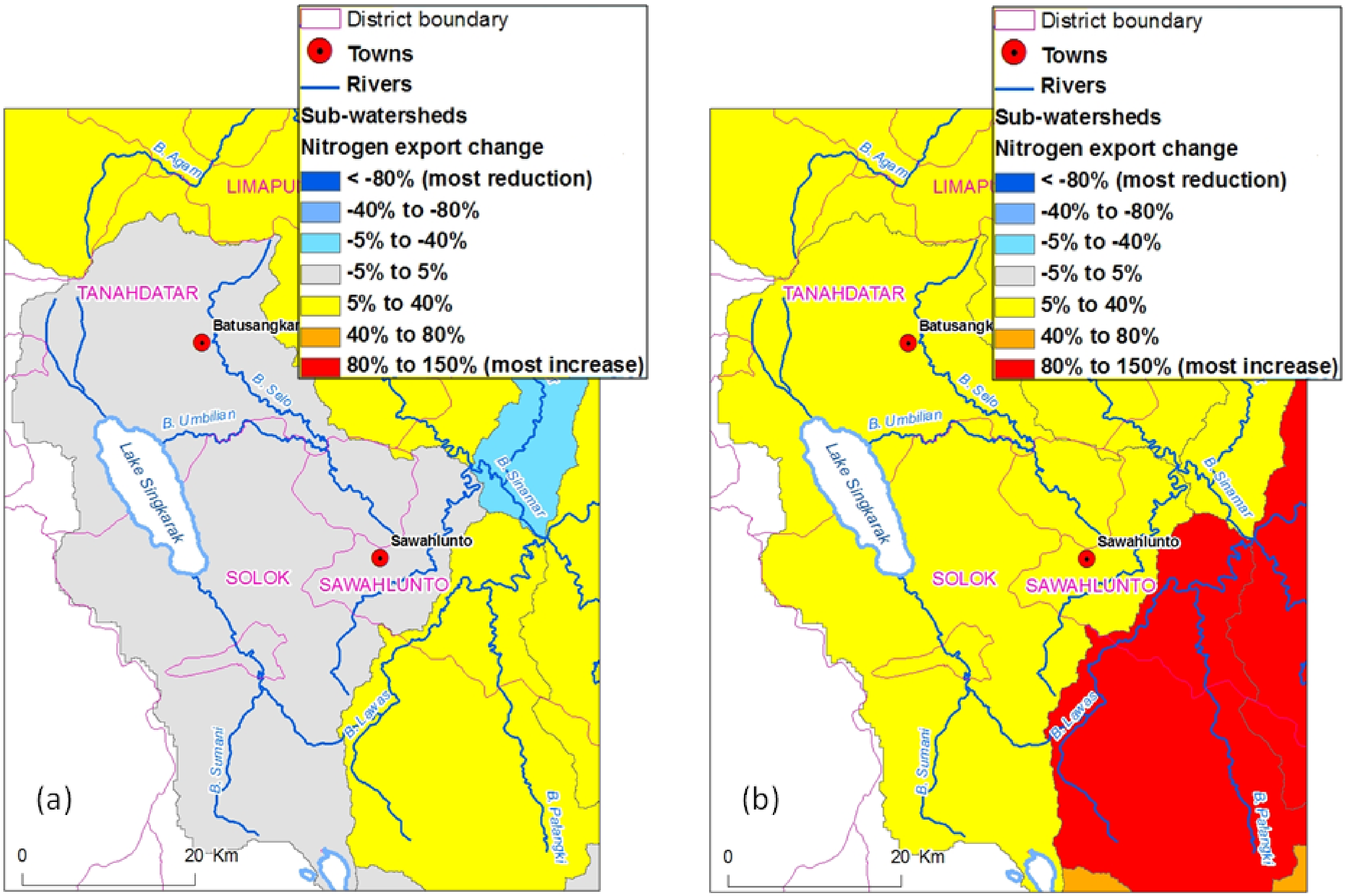


Fig. 3.37. Nitrogen export in the sub-watershed would not change much under (a) the Vision (< 2% increase relative to 2008), but would increase 23% under (b) **the Government Plan.**

Future directions

Additional analyses, ground-truthing, sensitivity analyses (e.g, changing input values based on known ranges of variables to assess robustness of results), and expert review of the work presented in this Chapter will be essential to design effective watershed management programs. We attempted to validate the water yield model outputs with monthly runoff data from sites within the study area, obtained from the Research and Development Center of Water Resources, Ministry of Public Works (Pusat Penelitian dan Pengembangan Sumberdaya Air, Kementerian Pekerjaan Umum). However, the period of the observed runoff did not match the average global precipitation and potential evapotranspiration data we used as inputs for InVEST. Therefore, it was difficult to verify and calibrate the models in this region. For future analyses, we recommended re-running the models with locally collected input data where possible, and then validating the results with observed water, sediment and nutrient runoff annual time-series data collected over the same period as the input data.

We have taken preliminary steps to connect watershed services to beneficiaries by showing changes in service levels upstream of potential users, such as towns and dams. However, more nuanced socioeconomic, institutional and legal analyses, including assessments of opportunity cost and management rights (see Goldman et al. 2010 for an example), will need to be conducted to assess how different groups of stakeholders would gain or lose access to services or income under alternative scenarios and watershed management schemes.

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Chapter 4: Habitat Quality and Biodiversity Conservation

Key Findings:

- Several districts, including Indragiri Hilir, Tanahdatar, Tanjungjabung Barat, and Tanjungjabung Timur, would experience substantial increases in habitat quality under the Sumatra Vision.
- Indragiri Hilir would have the greatest district-wide total increase in habitat quality under the Sumatra Vision, due to the restoration and reforestation of approximately 636,000 hectares of plantations on peatlands.
- Under the Government Plan, the districts that stand to lose the most habitat quality (18-36%) relative to 2008 are Muarojambi, Dharmasraya, Merangin, Sarolangun and Bungo.
- Based on deforestation risk, Kampar, Indragiri Hilir, Tebo, Tanjungjabung Barat, Indragiri Hulu, and Kuantan Singingi could be prioritized to conserve habitat for biodiversity, relative to the other districts overlapping the RIMBA priority area. Much of the remaining forests in these districts are in lowland areas that are under pressure from expanding plantations and other human activities.
- In central Sumatra, plantations and production forests adjacent to high-quality habitat could reduce their risk to habitat for biodiversity by implementing several best management practices. Some of the areas identified as having potential for forest carbon projects could also provide biodiversity co-benefits by improving or protecting habitat quality and corridors between protected areas.

Outline

The forests of the RIMBA Integrated Ecosystem and the rest of central Sumatra contain some of the last remaining habitat for a rich assortment of biodiversity including Sumatran tigers, elephants and orangutans. Future land-use decisions will determine in large part how much habitat and biodiversity persist in this landscape. We provide a coarse assessment of habitat quality for tigers as a proxy for the status of biodiversity on the landscape, which can be used to determine in what ways the two proposed spatial plans contribute to conservation goals. Although biodiversity supports a range of ecosystem services that are important for human health and wellbeing, we do not treat biodiversity as an ecosystem service here, focusing instead on its intrinsic value.

We mapped habitat quality in central Sumatra in 2008 and analyzed how it will likely change under the two alternative future scenarios: the Sumatra Vision and the Government Plan (see Chapter 1). We then ranked 18 districts overlapping the RIMBA Integrated Ecosystem in order of priority for implementing programs to conserve or restore habitat. For a subset of these districts, we discuss how and where each district could implement restoration and best management practices for plantations and forestry – three of the five priority programs for the region – to improve or maintain habitat quality, thereby benefiting biodiversity. Next, we assessed whether some areas identified in Chapter 2 as having potential for forest carbon projects could also provide biodiversity co-benefits, based on improvement or maintenance of habitat quality. The methods we employed for identifying these areas can be applied to other areas on the landscape and beyond.

Methods

We used the "biodiversity: habitat quality and rarity" model in InVEST (Tallis et al. 2010) to assess habitat quality in central Sumatra in 2008 and under two future scenarios. This model generates habitat quality maps that serve as proxies of the status of biodiversity in a given region. Good quality habitat indicates that the area is suitable for the species being analyzed and suggests potential for biodiversity conservation, but does not necessarily confirm species presence.

In this analysis, we focused on habitat quality for one important species in central Sumatra: the Sumatran tiger. We used expert input about the suitability of existing and planned land cover classes as tiger habitat, and threats to that habitat to score areas for habitat quality (Appendix 4.2). This input came from Karmila Parakkasi, a tiger researcher with WWF Indonesia working in central Sumatra. Therefore, the analysis offers an indication of the status of tiger habitat in 2008 and under the two scenarios. Because the tiger is considered an umbrella species for the conservation of other biodiversity and ecosystem services (Wikramanayake et al. 2011), these results are likely to apply to a wider suite of threatened forest-dwelling species in Sumatra, including Sumatran orangutan (*Pongo abelii*), Sumatran elephant (*Elephas maximus sumatranus*), pig-tailed macaque (*Macaca nemestrina*), and a host of other unique plant and animal species.. However, it should be noted that tigers are habitat generalists, and as a result these findings may not capture the habitat needs for species that rely on only particular habitats (i.e., are habitat specialists).

Data Inputs

To assess habitat quality, our analysis uses information about a) the suitability of different land covers and land uses as habitat for the species in question, b) the spatial distribution of threats, c) the distance over which each threat source affects each habitat type analyzed, and d) how quickly the impact of each threat decreases with distance from the source (Appendix 4.1 and 4.2).

Sources of threats to wildlife and their habitat can include areas of human activity, such as towns and settlements, plantations, mining, logging activities, and roads. We considered five sources of habitat degradation and impact on wildlife for which we had spatially explicit data: roads, plantations, mines, built-up areas, and agricultural areas (Appendix 4.1). Roads have been identified as major sources of threat to tigers in Sumatra because they fragment forests, open pathways for poaching, human-tiger conflict, and hunting by humans of the tiger prey base (Wibisono and Pusparini 2010). Habitat destruction has also been fueled by logging for timber, and conversion of forest to plantations, agriculture and other economic activities in areas where tigers live; hence, we also treat plantations and other human-use areas as threats to habitat in this analysis. We used a road network layer from the National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL, Badan Koordinasi Survei dan Pemetaan Nasional). This layer represents roads as of 2003 and includes logging roads; however, we expect that the road network would have expanded by 2008, with further changes expected under either the Sumatra Vision or the Government Plan. As we have not represented this additional expansion, we likely underestimate the extent of impact of this threat source on tiger habitat. For the four remaining sources of habitat degradation we derived threat source locations for 2008 and the two scenarios from the corresponding land-use/land-cover map.

Interpreting Habitat Quality Scores

The habitat quality score in the output maps for 2008 and each scenario ranges from 0 (worst) to 1 (best), with a score assigned to each 500m x 500m pixel (Figures 4. 1, 4.2 and 4.5 through 4.8). To assess gain or loss of habitat quality in pixels under each scenario, we subtracted each pixel's quality score in 2008 from its score under the respective scenario. In the resulting maps (Figures 4.3, 4.9, 4.10 and 4.11), pixel values greater than zero indicate a gain in habitat quality under that scenario, and values less than zero indicate a loss in quality. The larger the magnitude of the score change, the greater the gain or loss in quality in each pixel.

To assess gains and losses in habitat quality at the district level, we first summed habitat quality scores of all pixels within each district in 2008 and under each scenario. This summed habitat quality score is a relative index of the state of habitat within a district. As an example, if a district has a higher summed habitat quality score under the Sumatra Vision scenario relative to 2008 or the plan scenario, it indicates an improvement in habitat quality in that district from implementing the Sumatra Vision, compared to the 2008 land cover or the plan. To compare gains and losses in habitat quality across districts (Figure 4.4), we then calculated the percent gain or loss in summed habitat quality of each district under either scenario, relative to 2008 as

$$\left(\frac{H_s - H_{2008}}{H_{2008}}\right) \times 100$$

where H_s is the summed habitat quality score in the scenario and H_{2008} is the summed habitat quality score in 2008.

Methods for Recommendations

We focused our recommendations around four of the five priority programs (restoration, best management practices or BMPs for plantations, BMPs for forestry, and forest carbon projects) selected to implement the Roadmap for the Sumatra Vision.

First, we conducted a prioritization exercise to identify the districts in the study area that could avoid the greatest loss of habitat by introducing habitat conservation and restoration programs. Next, for some of these districts, we highlighted a few areas where forest carbon projects and restoration of corridors among forest patches would improve habitat quality for biodiversity. We also identified locations where BMPs for plantations and forestry could improve habitat quality for tigers and reduce potential for poaching and human-wildlife conflict. Since we examined opportunities for habitat conservation through watershed management programs in Chapter 3, we do not reproduce them here.

Prioritizing among districts

For the first analysis, we considered future threats to habitat quality from planned activities under the alternative land-use scenarios. To assess planned habitat conversion, we used the Government Plan as the best available approximation of planned land use for the region. We compared the changes in habitat quality that would result from implementing the Sumatra Vision versus the Government Plan, subtracting each from the 2008 landscape's habitat quality. To prioritize districts based on anticipated losses in habitat quality due to land conversion under the Government Plan, we compared their percent change in habitat quality between 2008 and the Government Plan.

We also addressed threats from unplanned activities (i.e., those not explicitly accounted for in either scenario) by including historical rates of deforestation. High rates of historical, illegal deforestation on this landscape indicate that some habitat loss is likely to come from unplanned activities, such as internal migration, accidental fires, illegal land conversion and other non-government activities, which could occur without perfect governance and enforcement of the government spatial plan. This unplanned habitat loss is not reflected in the Government Plan. We assumed that historical district-level deforestation rates from 2000 to 2008 reflect probable unplanned deforestation in the future. To prioritize districts based on risks to habitat from unplanned deforestation, we ranked districts by summed habitat quality score in 2008 and historical annualized deforestation rates between 2000 and 2008 (as calculated in Chapter 2: Carbon Storage and Sequestration), where low rankings (close to 1) indicate high summed habitat quality score and high deforestation rate (columns 3 and 4 of Table 4.1) respectively. We then summed the two ranks for each district. A low value of summed rank for a district indicates that it has substantial high-quality habitat at risk, assuming that past deforestation rates reflect future risk. We interpreted this summed rank as indicating the relative importance of a given district to implement habitat conservation measures; without such programs, districts with top ranks are at higher risk of losing their remaining high-quality habitat. Further assessments could address urgency of habitat restoration, identifying districts with little remaining habitat and high deforestation rates.

Identifying areas within districts for best management practices

For this analysis, we looked at the habitat quality map for 2008, and for a subset of high-priority districts, identified high-quality areas (habitat quality score > 0.9) near current plantations. Sunarto (2011) recorded tiger presence in plantations as far as 16 km away from forested areas; thus, plantations within at least this distance from likely tiger habitat should consider best management practices to minimize impacts on tigers. Additionally, since tigers use different types of plantations as habitat or dispersal corridors to varying degrees (Sunarto 2011), plantations further than this distance from core tiger habitat might also need to implement best management practices depending on the extent to which tigers use them. We also identified some high-quality areas in 2008 that are zoned for plantations (APL) or production forests in future scenarios. We recommended best management practices, for plantations and forestry respectively, in these areas to minimize the impacts of these future plantations and to maintain habitat quality as some of these areas get converted to production forestry.

Identifying areas where forest carbon projects would yield biodiversity co-benefits

We focused on areas that we had identified previously (in Chapter 2) as having potential for forest carbon projects. We looked at change in habitat quality within these areas relative to 2008 under either scenario. For pixels within these areas, if the habitat quality score difference between a given scenario and 2008 (i.e., score in scenario – score in 2008) was greater than 0.2, we assumed that these pixels would improve in habitat quality under that scenario, relative to 2008. If the difference score was between -0.2 and 0.2, we assumed that the habitat quality is similar in 2008 and the scenario. For these same pixels, if (score in the scenario – score in 2008) was less (more negative) than -0.2, we assumed that these pixels would lose habitat quality in the scenario relative to 2008. Based on these criteria, if clusters of pixels within these areas maintain or experience an increase in habitat quality under the Sumatra Vision, but lose habitat quality under the Government Plan, then we conclude that forest carbon projects, if implemented in those areas, would also result in improvement or maintenance of habitat quality for biodiversity.

Some limitations

(1) This is a “coarse filter” approach (Tallis et al. 2010) that can be used for an initial assessment of change in habitat quality and relative priority. Conservation status and habitat requirements for species of interest should be carefully considered to fine-tune these analyses for conservation planning.

(2) Other potential threat sources that we have not included in this analysis, such as proximity to navigable rivers, may be important determinants of habitat quality.

(3) We have not considered the direct influence of threat sources outside the central Sumatra study area. This will especially impact the estimates of habitat quality near the boundary of the study area, which may be affected by threat sources that lie just outside the borders. However, most of the RIMBA Integrated Ecosystem, the main focus of our analysis, lies well within the larger area analyzed in this study, and so experiences less of this bias.

(4) The InVEST model does not explicitly take connectivity or edge effects among habitat patches into account while assessing habitat quality, although this is partially accounted for by including distance from threat sources in our inputs. Some patches of habitat that are designated as high quality by the model may in fact not be very suitable for some species, especially tigers and other large mammals that require relatively large tracts of contiguous forest. However, identifying these patches can highlight their potential as habitat through future reforestation of corridors connecting them.

(5) Although the model identifies good habitat for the species of interest, whether these species currently exist or will persist in areas of high habitat quality also depends on other factors not explicitly considered here, dispersal ability and suitability of future climate. Some factors are partially accounted for through the threat sources that we analyzed, such as abundance of food resources, protected area effectiveness, and hunting pressure; however, more explicit consideration of these factors could improve the analysis.

(6) These analyses are applicable to a wider array of Sumatra’s flora and fauna only to the extent that the tiger functions as an umbrella species. Tigers are habitat generalists, and can persist in a range of habitats of varying quality in the absence of poaching. If there are priority species that are habitat specialists, otherwise have very different habitat requirements, or are differently affected by the threat sources we identified, they should be modeled separately, and the outputs combined with the current results.

(7) The preliminary recommendations offered in this chapter are based on biophysical criteria. Socioeconomic, legal and political context will need to be assessed to determine feasibility and to design projects based on these recommendations.

Results

In 2008 (Figure 4.1 a), the RIMBA Integrated Ecosystem contained high-quality habitat for biodiversity; however, this habitat was fragmented, especially in the eastern parts of the RIMBA priority area. Outside this area, much of the habitat was degraded, with the exception of some good quality habitat north of the RIMBA priority area (in the Tesso Nilo Tiger Conservation Landscape), and in the peatlands in the northeastern part of the study area (Kualar Kampar-Kerumutan Tiger Conservation Landscape). A comparison of our model results for 2008 with tiger occurrence data (Wibisono and Pusparini 2010) shows that the high-quality habitat areas (quality score > 0.9) identified are contained within, and largely coincide with, the patches where tiger presence has been confirmed (Figure 4.2).

The Sumatra Vision (Figures 4.1 b and 4.3 a) would maintain and restore habitat quality throughout the RIMBA Integrated Ecosystem, as well as in the eastern peatlands and the central area of the landscape to the north of the RIMBA priority area. Under the Government Plan (Figures 4. 1c and 4.3b), high-quality habitat within and outside the RIMBA priority area would shrink and become increasingly fragmented, while areas of currently poor habitat quality would experience additional declines in quality.

Most districts would gain habitat quality under the Sumatra Vision, and most would see reductions in quality under the Government Plan (Figure 4.4). The districts of Kampar and Kuantan Singingi gain some habitat quality under the Government Plan; however, they are projected to gain even more under the Sumatra Vision. The districts that stand to lose the most habitat quality (in percent change) under the Government Plan are Muarojambi, Dharmasraya, Merangin, Sarolangun and Bungo, losing 18 to 36% relative to 2008 levels.

Several districts, including Indragiri Hilir, Tanahdatar, Tanjungjabung Barat and Tanjungjabung Timur would see substantial increases in habitat quality under the Sumatra Vision (Figure 4. 4). Indragiri Hilir would have the greatest district-wide summed (not percent) increase in habitat quality under the Sumatra Vision, due to the restoration to forest of approximately 636,000 hectares of plantations (primarily oil palm, acacia and coconut) on peatlands. Although most of this area lies outside the RIMBA Integrated Ecosystem, it illustrates the potential for achieving reductions in peat-related carbon dioxide emissions while gaining substantial increases in high-quality habitat for biodiversity.

Based on the Government Plan, the districts that stand to lose the most habitat quality (18 to 36%) relative to 2008 (Figure 4.4) are Muarojambi, Dharmasraya, Merangin, Sarolangun and Bungo (Figure 4.5 a). While most other would also lose habitat quality under the Government Plan, their projected percent loss is relatively lower (3 to 12%).Therefore, should the Government Plan be implemented as proposed, the aforementioned five districts will have the most to lose if they do not take measures to maintain or restore habitat, relative to the other districts.

Prioritization of Districts to for Habitat Conservation Based on Risk and Quality

If past deforestation trends continue, there may be additional future risks to habitat that are not reflected in the Government Plan. Based on historical risk, Kampar, Indragiri Hilir, Tebo, Tanjungjabung Barat, Indragiri Hulu, and Kuantan Singingi are in the top third of the analyzed districts that would need to prioritize actions to implement programs aimed at maintaining or restoring habitat, relative to the other districts overlapping the RIMBA priority area, given the high rates of past deforestation in these districts (Table 4.1 and Figure 4.5 b). Much of the remaining forests in these districts are in lowland areas that are under pressure from expanding plantations and other human activities. Other districts with extensive high-quality habitat in the western mountainous region (Bukit Barisan) do not rank among the most at risk of losing their remaining tiger habitat soon in our deforestation risk analysis (Figure 4.5 b), probably because their slope and elevation render them less suitable for economic activity, and as such under lower threat.

We note that this prioritization should not imply that the remaining districts need not implement habitat conservation programs; they may also have areas that are critical for biodiversity and opportunities to feasibly implement the five priority programs.

Table 4.1 Habitat quality, deforestation rates and relative urgency for conservation in 18 districts overlapping the RIMBA Integrated Ecosystem.

District	**Summed habitat quality score in 2008**	**Rank of summed habitat quality (1 = highest habitat quality)**	**Deforestation rate rank (1 = highest rate) from Chapter 2**	**Sum of ranks of habitat quality and deforestation rate**	**Importance for prioritizing habitat conservation, based on summed rank**
KAMPAR	19758	2	2	4	Increasing importance
INDRAGIRI HILIR	24081	1	7	8	
TEBO	13234	5	4	9	
TANJUNGJABUNG BARAT	8773	11	1	12	
INDRAGIRI HULU	18308	3	11	14	
KUANTAN SINGINGI	10552	8	8	16	
SAROLANGUN	11352	6	12	18	
BUNGO	10187	9	9	18	
MERANGIN	16551	4	15	19	
TANJUNGJABUNG TIMUR	5633	16	3	19	
SOLOK SELATAN	11103	7	13	20	
DHARMASRAYA	6902	15	6	21	
MUAROJAMBI	5380	17	5	22	
SAWAHLUNTO	8839	10	14	24	
TANAHDATAR	1853	18	10	28	
LIMAPULUHKOTO	7231	13	17	30	
SOLOK	8174	12	18	30	
KERINCI	7127	14	16	30	

Different sets of high-priority districts are selected in the above analysis, depending on whether the criteria used for prioritizing are backward-looking (historical deforestation rates) or forward looking (expected habitat loss due to plan implementation). This suggests that the Government Plan does not reflect past deforestation trends. As the district-level spatial plans are still evolving, it may be necessary to revisit priorities among districts based on the updated plans. However, the districts prioritized based on the historical deforestation rates should continue to be regarded as high-urgency as they will continue to experience elevated threats in the absence of strong action.

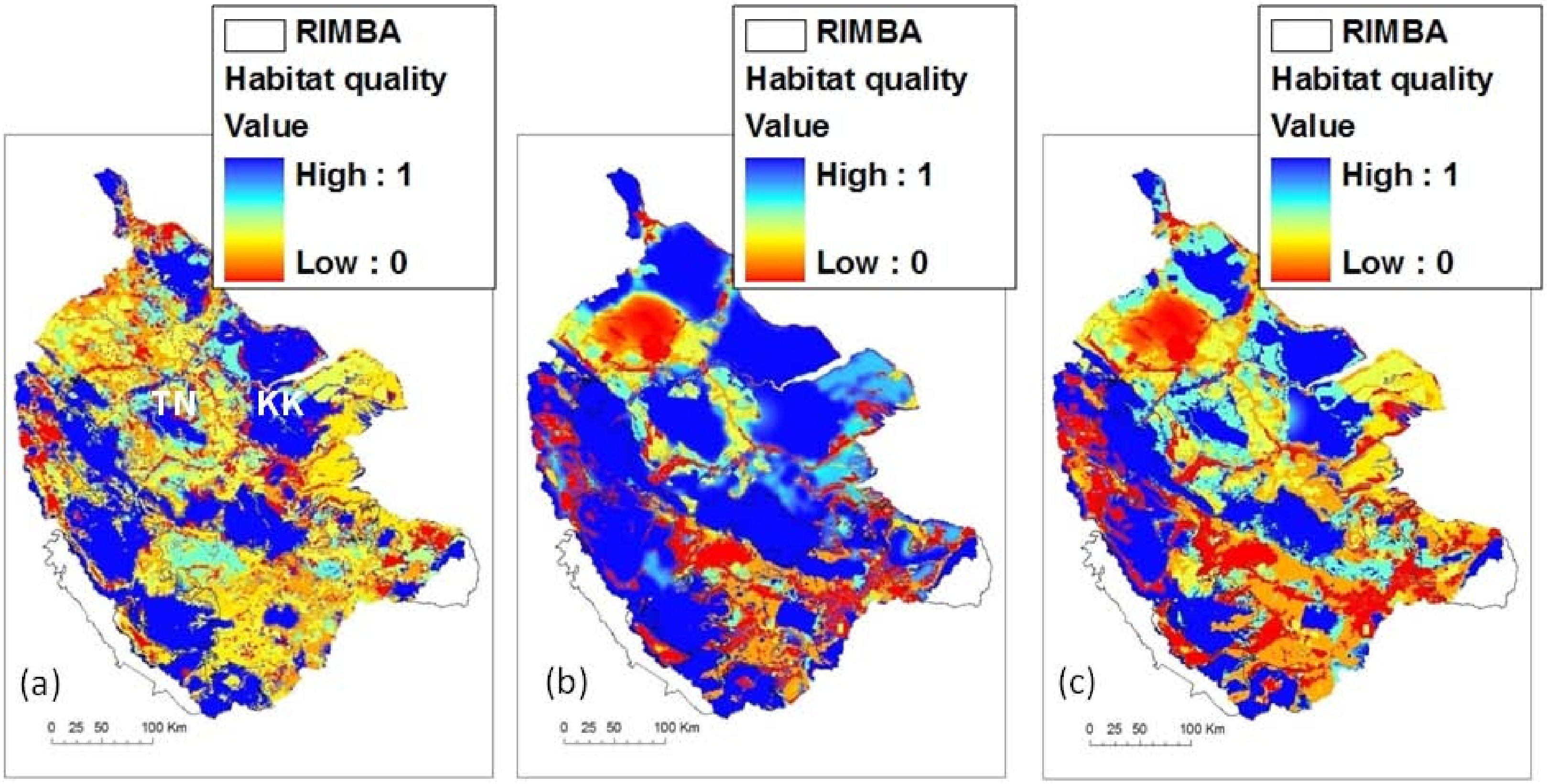


Fig. 4.1. Habitat quality in central Sumatra (a) in 2008, (b) under the Sumatra Ecosystem Vision, and (c) under the government spatial plan. (In Figure 1a, TN = Tesso Nilo, and KK = Kualar Kampar Kerumutan Tiger Conservation Landscapes)

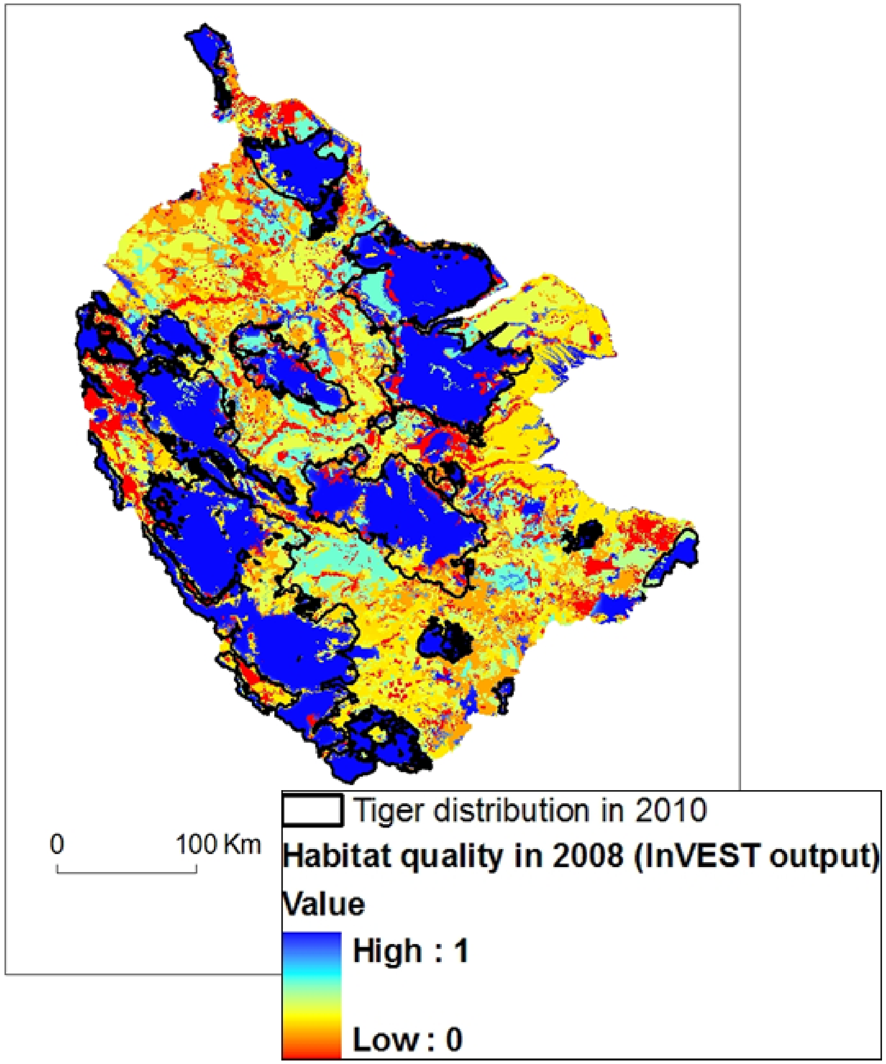


Fig. 4.2. Overlay of known tiger habitat in 2010 with habitat quality for tigers in 2008 as modeled with InVEST.

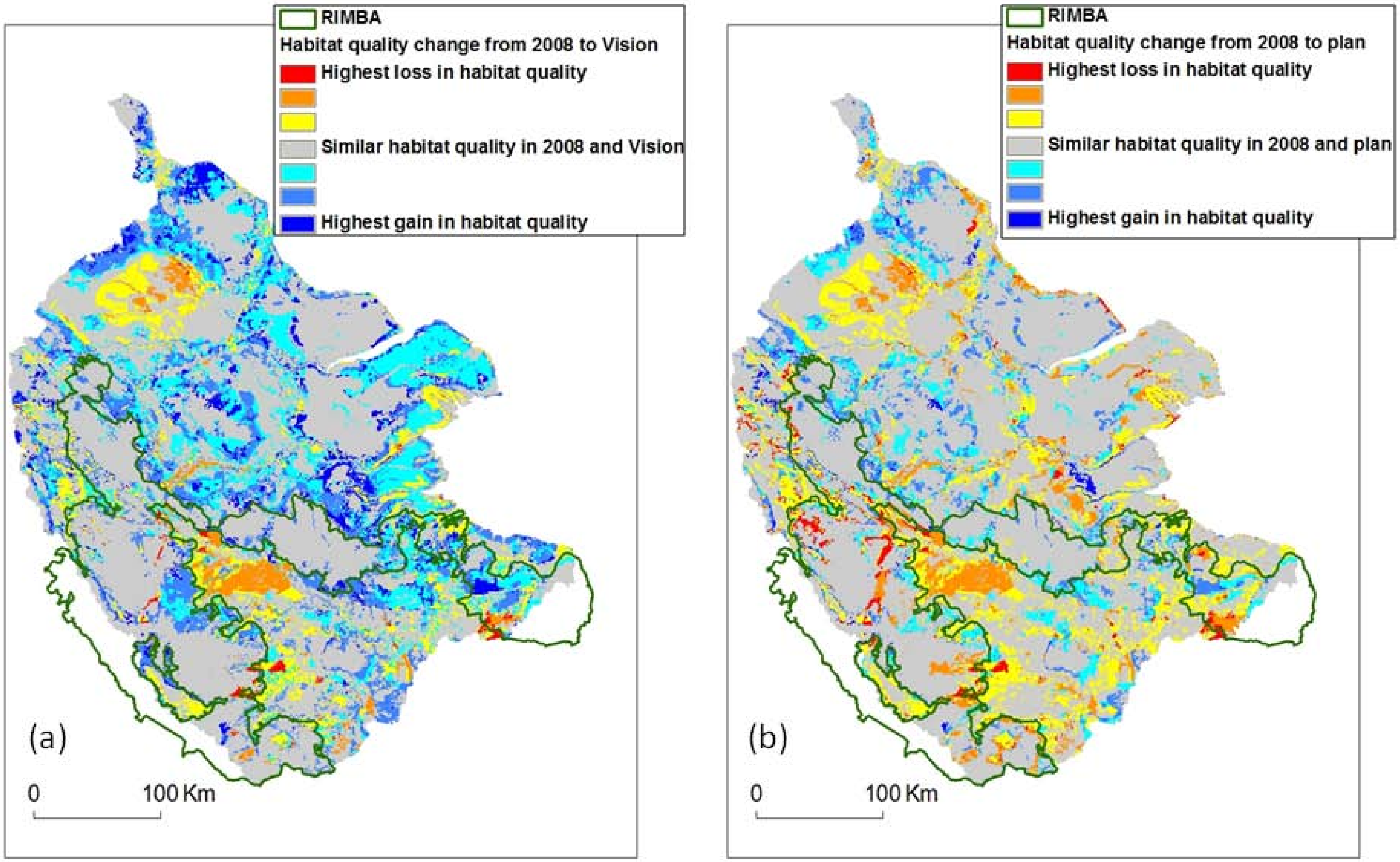


Fig. 4.3. Change in habitat quality in central Sumatra relative to 2008 under (a) the Sumatra Vision and (b) the government plan.

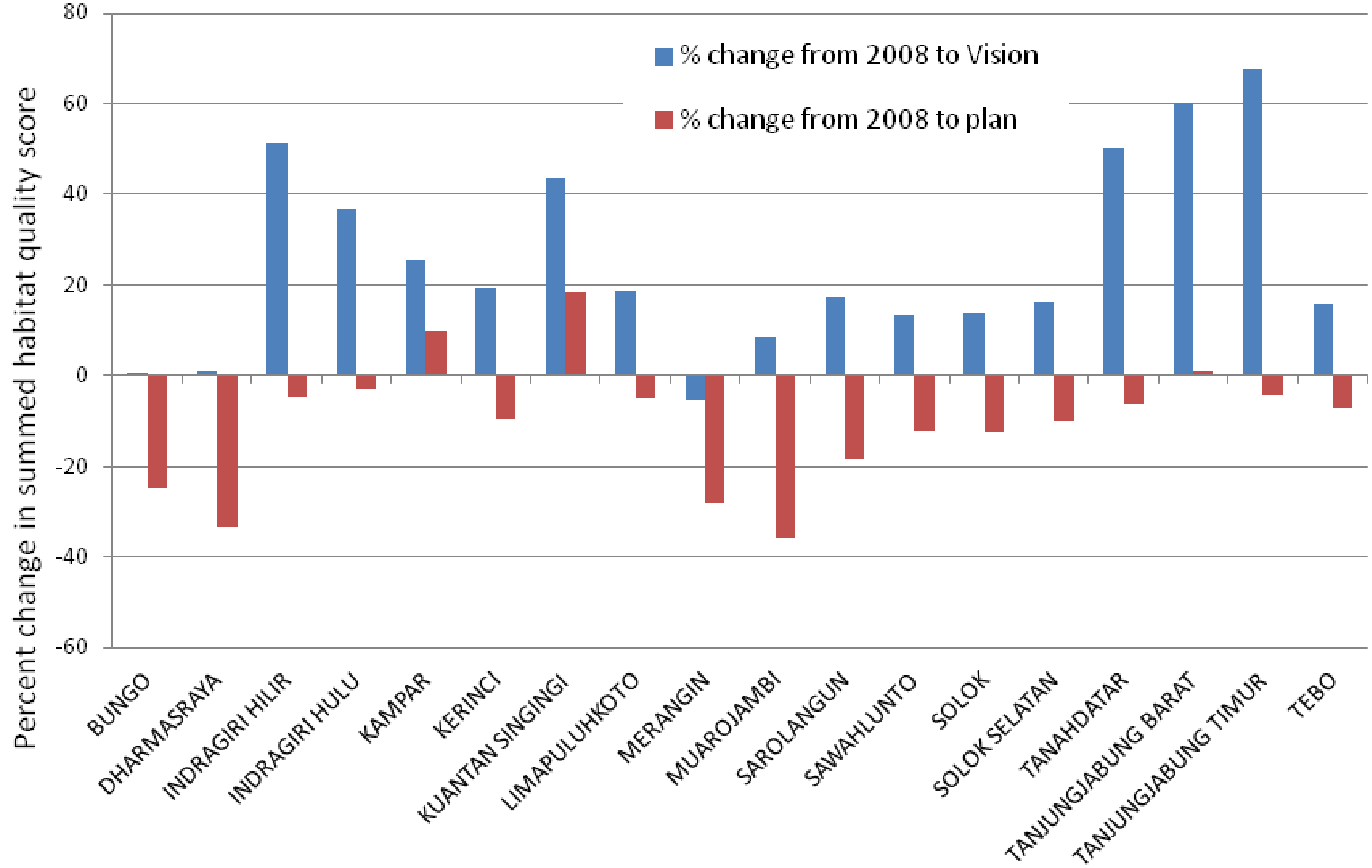


Fig. 4.4. Most districts would gain habitat quality under the Vision and lose habitat quality under the government plan.

Fig. 4.5a. All remaining high-quality habitat should be protected. However, if the government plan is implemented as proposed, habitat conservation measures might be most urgently needed in Dharmasraya, Bungo, Merangin, Sarolangun and Muarojambi. These districts were highlighted because relative to the remaining districts overlapping the RIMBA area, their percent loss of habitat quality from 2008 to the government plan would be high.

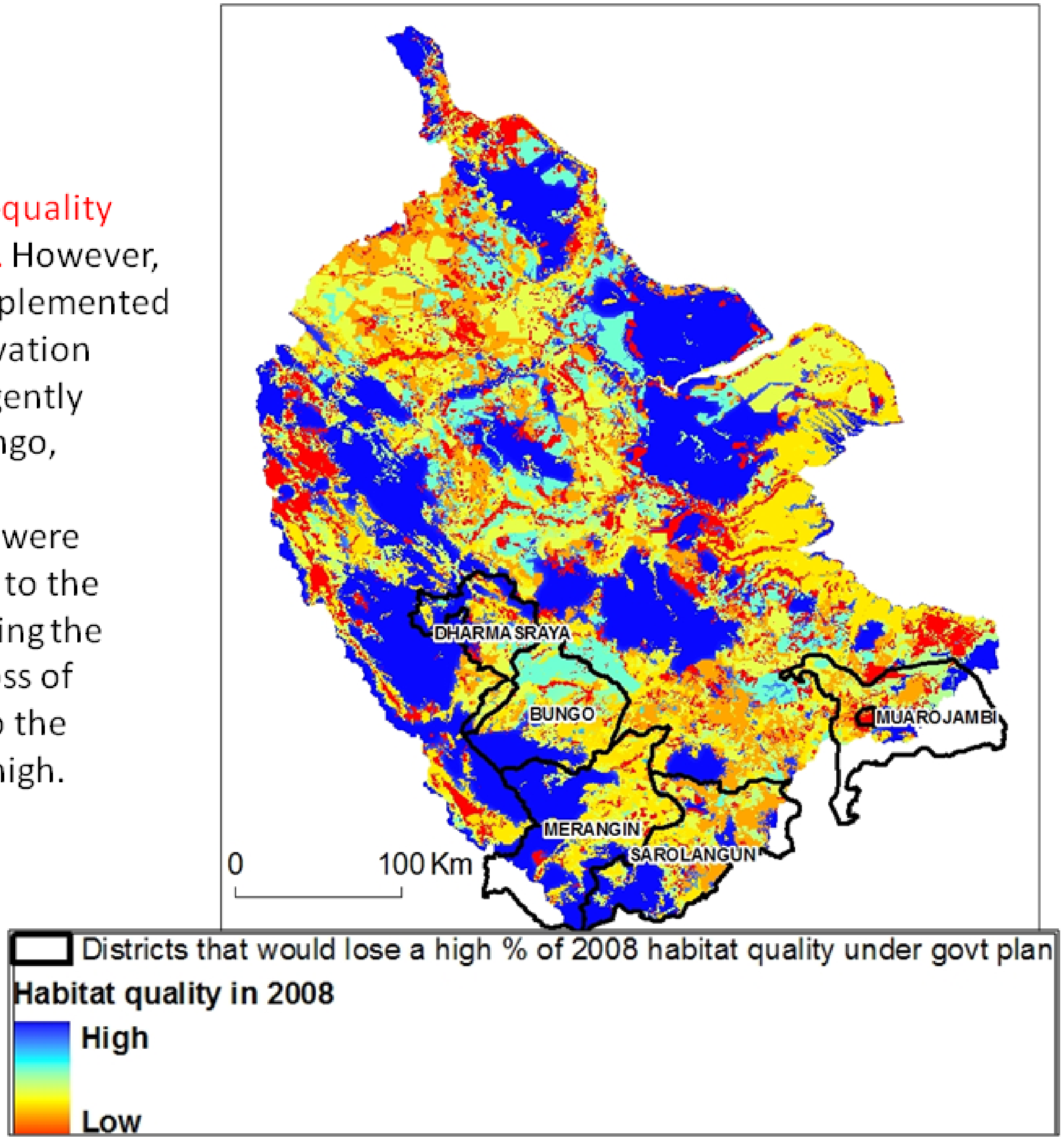
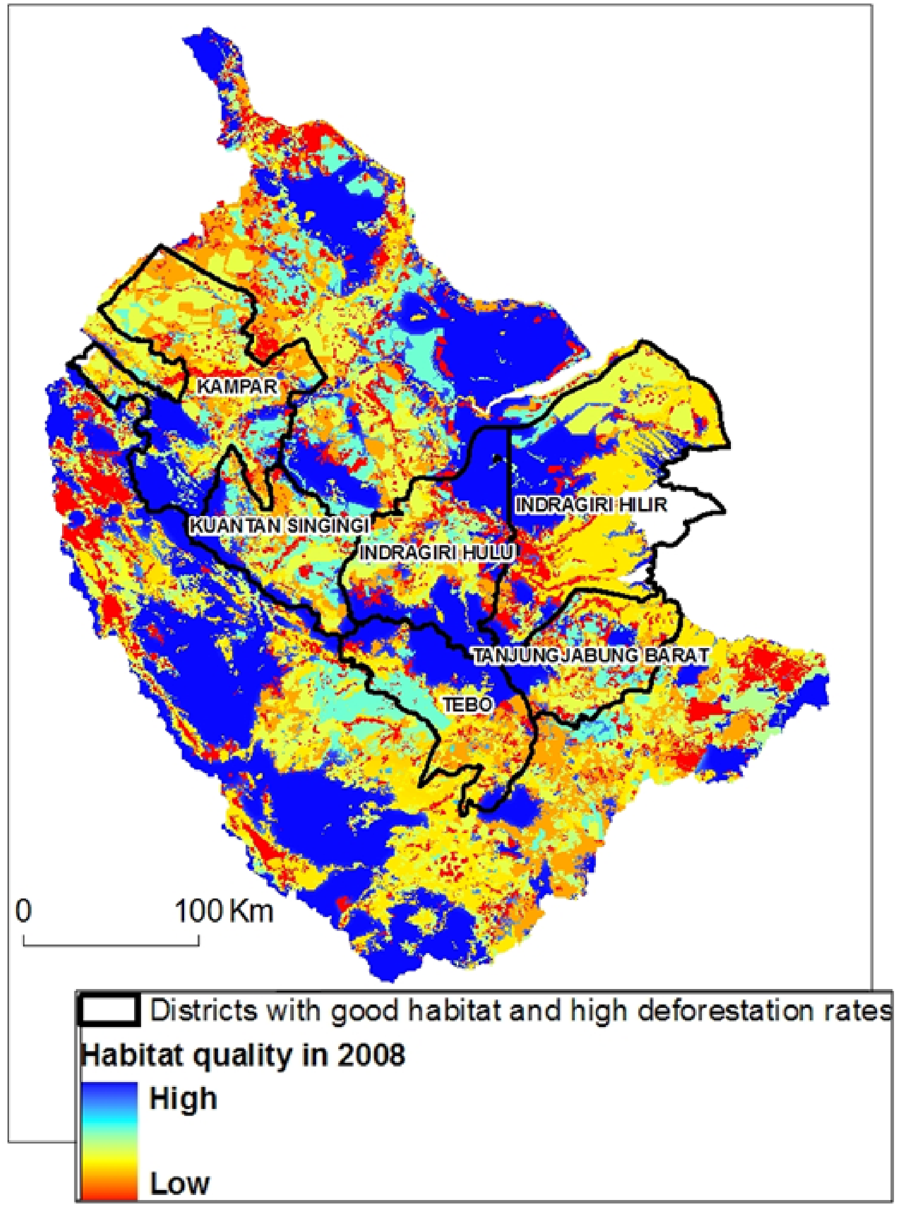


Fig. 4.5b. All remaining high-quality habitat should be protected. However, if past deforestation trends continue, habitat conservation measures might be most urgently needed in Kampar, Kuantan Singingi, Indragiri Hulu, Indragiri Hilir, Tebo, and Tanjungjabung Barat. These districts were highlighted because relative to the remaining districts, their historical deforestation rates and 2008 summed habitat quality scores are high. This indicates that they have more high quality habitat at risk of deforestation than other districts overlapping the RIMBA area.



Recommendations

For our recommendations, we assess the potential for improving or maintaining habitat quality by implementing some of the programs prioritized for improved land management in the RIMBA priority area. We use a subset of districts in the study area as examples to illustrate how our results can be applied across the study area to inform spatial planning and management and maintain, restore, and improve habitat for biodiversity. Three of these example districts (Dharmasraya, Tebo, and Kampar) were identified above as being of high priority for habitat conservation, based on the summed high–quality habitat and deforestation ranks, as well as for forest carbon projects (in Chapter 2). Although the fourth district (Tanjungjabung Timur) is not among the highest priority districts in either the habitat quality or deforestation analysis, it contains carbon-rich peat forests and converted peat areas slated for restoration under the Sumatra Vision. Tanjungjabung Timur therefore functions as a good exploratory case study for how carbon sequestration and habitat conservation and restoration goals can overlap on this landscape.

Best management practices for plantations adjacent to high-quality habitat: In 2008, Tanjungjabung Timur (Figure 4.6) and Dharmasraya (Figure 4.7) both had extensive tracts of plantations bordering high-quality forest habitat. In Tanjungjabung Timur, these peat forest patches are also fragmented (see ovals 1 and 2 in Figure 4.6). To maintain habitat quality in the district, best management practices should be implemented by these plantations to reduce their impacts on biodiversity in neighboring forests and improve habitat quality. The best management practices for plantations recommended include reducing human-wildlife conflict, establishing forested buffers, and restoring forest corridors. In particular, forest corridors between remaining high-quality patches could restore connectivity for key species.

Best management practices for forestry in or adjacent to high-quality habitat: For areas of high-quality habitat designated as limited production forest, production forest, or other types of forests open to exploitation or extraction, best management practices for forestry ought to be employed to maintain the highest possible level of habitat quality on working lands (e.g., in areas zoned for production forestry in Tebo district, Figure 4.8). The best management practices for forestry could include reducing human-wildlife conflict, reduced impact logging, minimizing or eliminating use of chemical pesticides, and avoiding negative impacts on endangered species. Any forest areas under harvest that neighbor high-quality habitat should take up best management practices to maintain wildlife corridors and sustain viable populations of key species.

Biodiversity as a co-benefit of forest carbon projects: In this analysis, we evaluate which areas assessed in Chapter 2 as having potential for forest carbon projects are also likely to provide biodiversity benefits to central Sumatra. In other words, where could measures to store or sequester forest carbon also protect or restore habitat quality for biodiversity? In Tanjungjabung Timur (Figure 4.9), Dharmasraya (Figure 4.10), and Kampar (Figure 4.11), many areas highlighted in Chapter 2 would experience an improvement in habitat quality if forest carbon projects were implemented.

Analyses such as the above can be used to demonstrate the potential for biodiversity co-benefits from forest carbon projects. In some forest carbon programs and voluntary market sales of carbon credits, biodiversity co-benefits can support premium pricing, third-party certification (e.g., by the Climate, Community and Biodiversity Alliance -CCBA), or fulfillment of criteria for REDD+ funding or low-carbon economy plans.

Finally, given the critical state of Sumatra's biodiversity and the continuing decline in habitat quality, biodiversity conservation will likely require additional action beyond an ecosystem services approach. This will be especially true if there are areas of high importance for conservation where ecosystem service-based programs may not be feasible. Such conservation action may focus explicitly on the intrinsic value of biodiversity for Sumatra and the world, and can include improving protected area effectiveness and expanding protection to include unprotected core habitat (Sunarto 2011). While such measures will require government and civil society support, they can be partially funded by donor contributions, bilateral debt-for-nature swaps, and private sector biodiversity offsets.

Fig. 4.6. Ovals 1 and 2 show high-quality peat swamp forest habitat in Tanjungjabung Timur within RIMBA. Oval 3 is another high quality forest patch in neighboring Muarojambi district, also within RIMBA. Ovals 1 and 3 are close to plantations. To preserve this habitat, these ovals should remain unconverted, and the nearby plantations should implement best management practices. The Sumatra Ecosystem Vision recommends habitat restoration in many of these plantations. Forest corridors should be established between ovals 1, 2 and 3 to improve ecological connectivity.

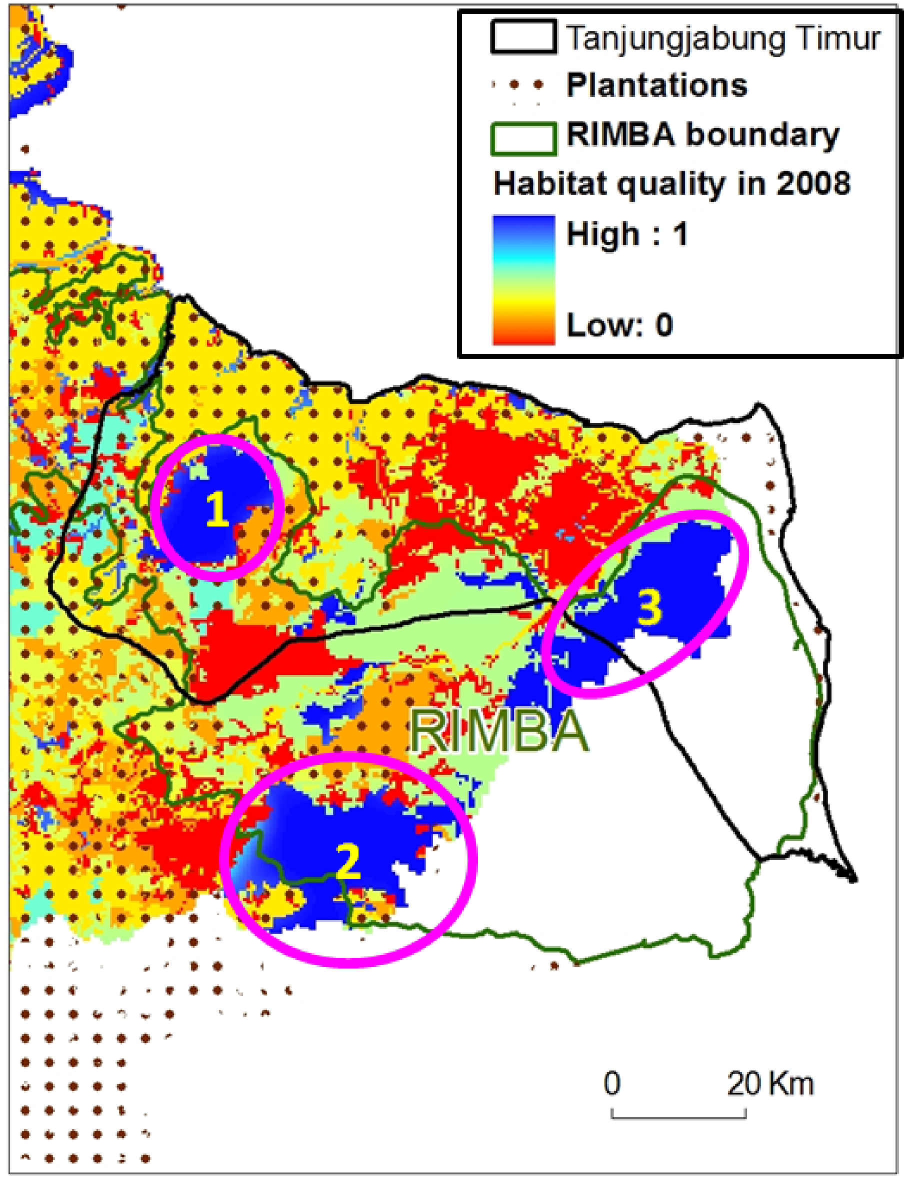


Fig. 4.7. Dharmasraya has contiguous tracts of high quality, dry lowland forest habitat near its western and northern borders that stretch beyond the district's boundaries. Plantations close to these high quality habitats, such as those within the ovals, should implement best management practices that minimize their impacts on adjacent forests. Indeed, the Sumatra Ecosystem Vision recommends reforesting some of these plantations along the edge of good quality habitat.

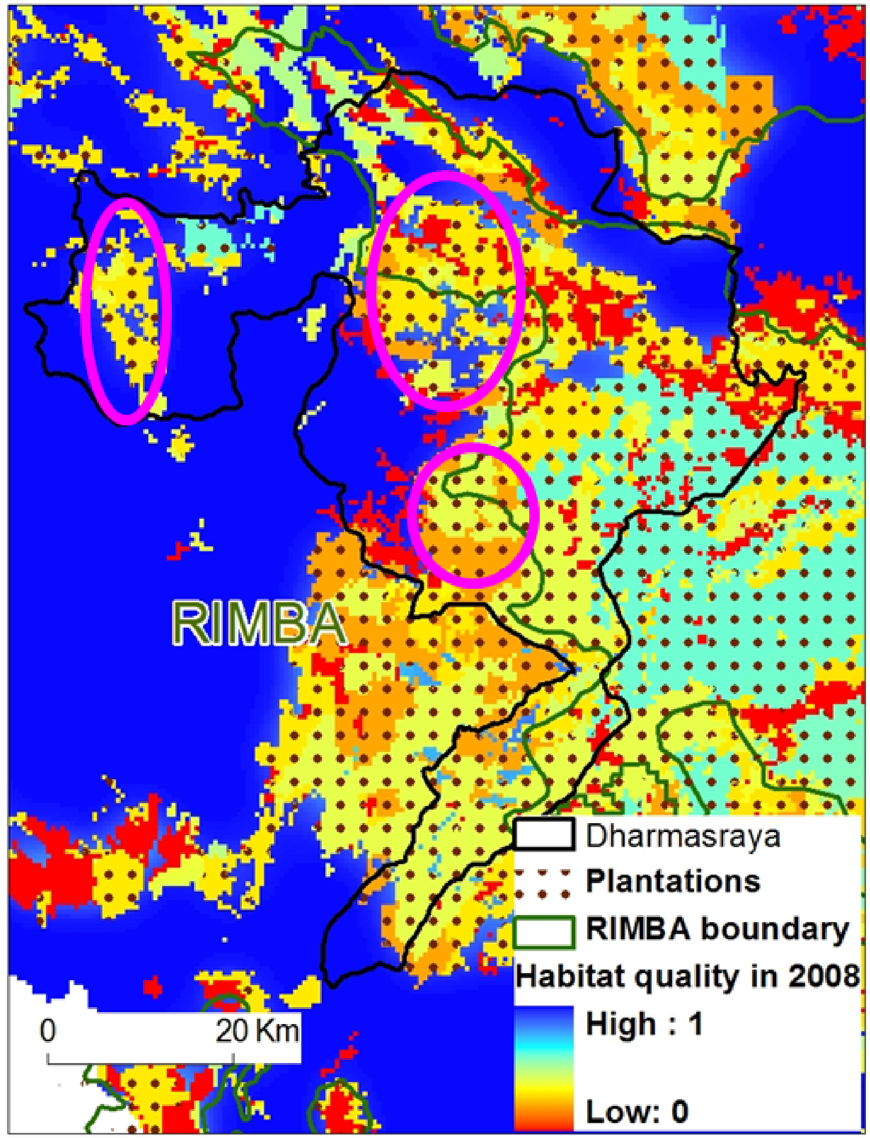
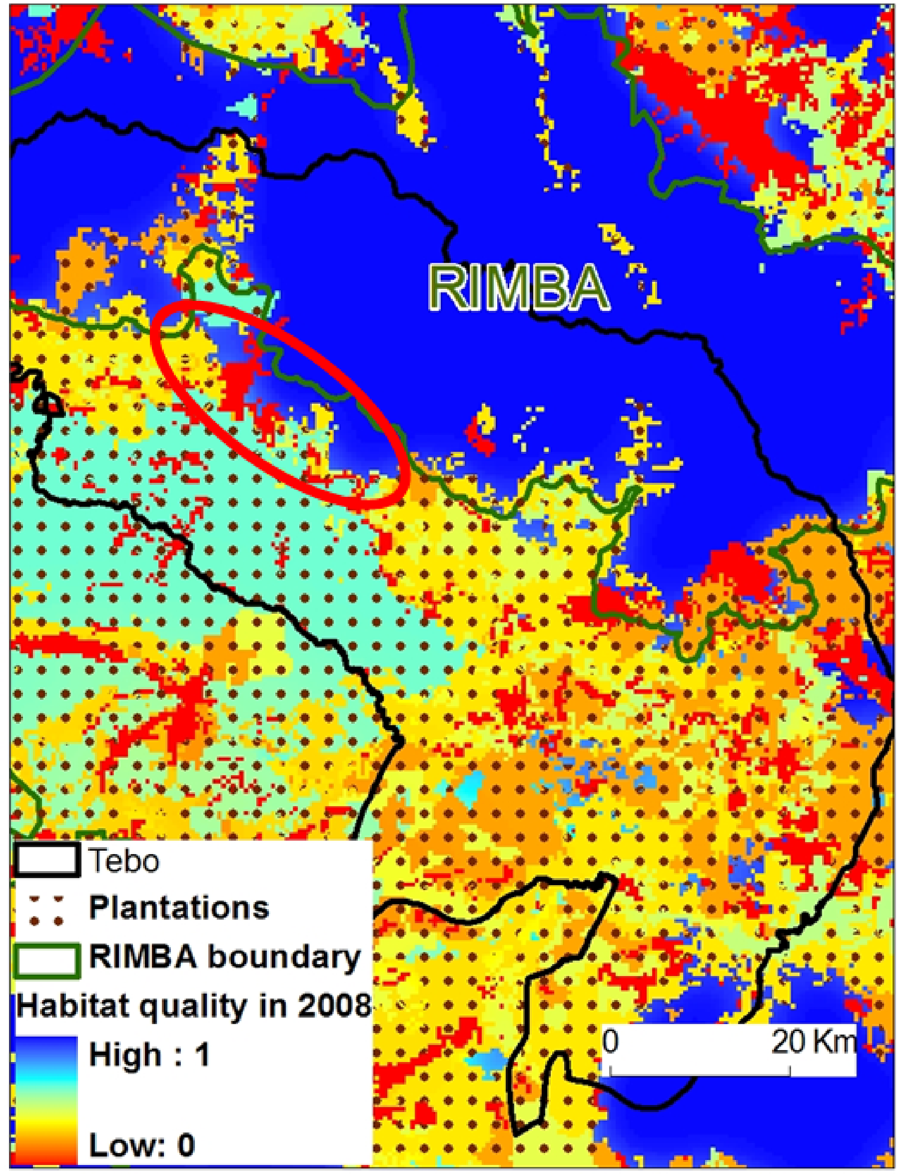


Fig. 4.8. The red oval contains areas zoned for production forests or “APL” (for possible conversion to plantations) in the government plan. These areas are within or bordering high quality habitat. We recommend that such parcels take up best management practices for forestry and plantations to minimize impacts on high quality habitat.



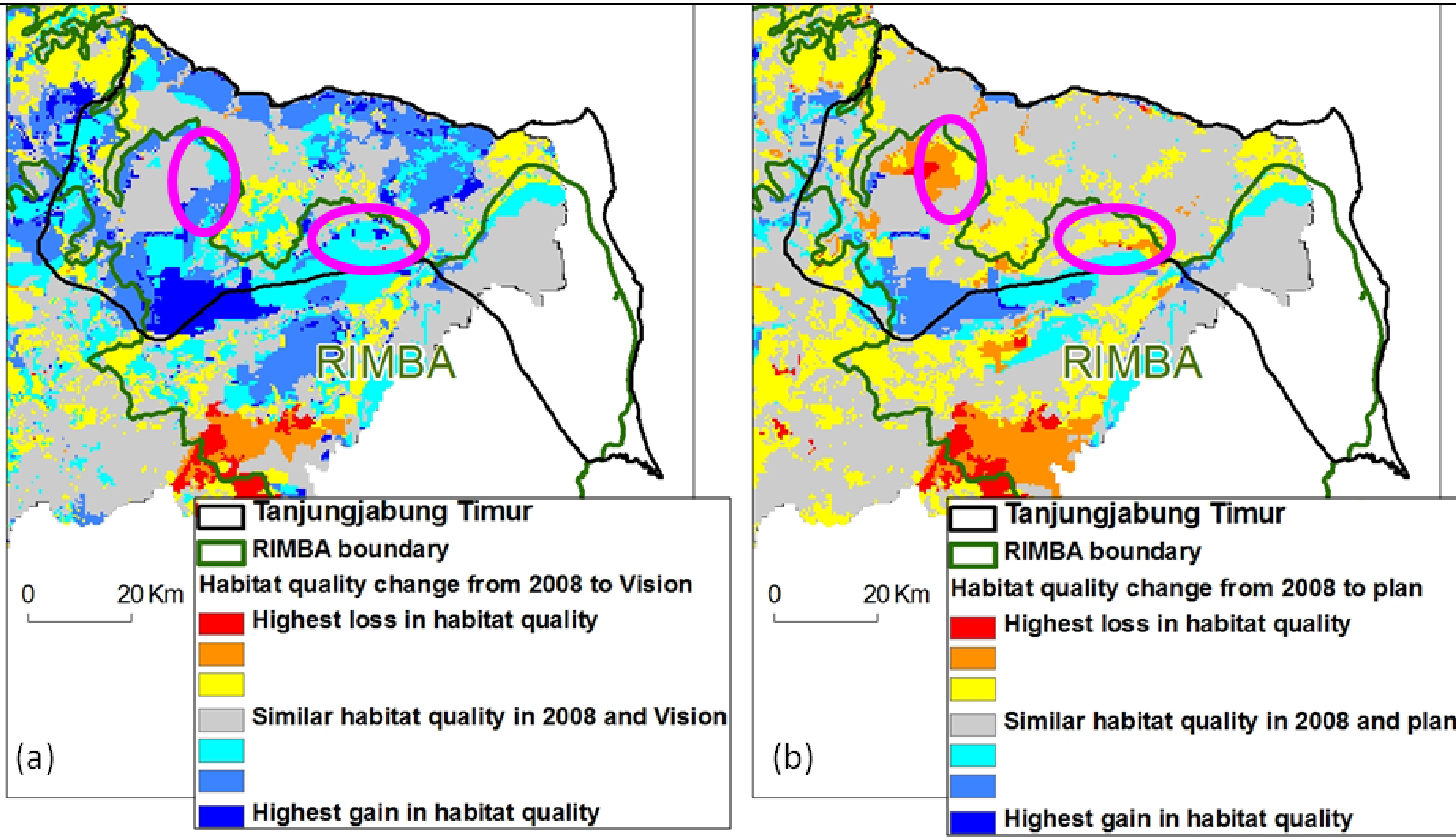


Fig. 4.9. The magenta ovals indicate peatlands that were identified in Chapter 2 as having potential for forest carbon projects. These areas would also see an improvement in habitat quality for biodiversity under (a) the Sumatra Vision relative to 2008, which could demonstrate the potential for biodiversity co-benefits for forest carbon projects on these areas. Under (b) the government plan , these areas would lose both carbon and biodiversity habitat.

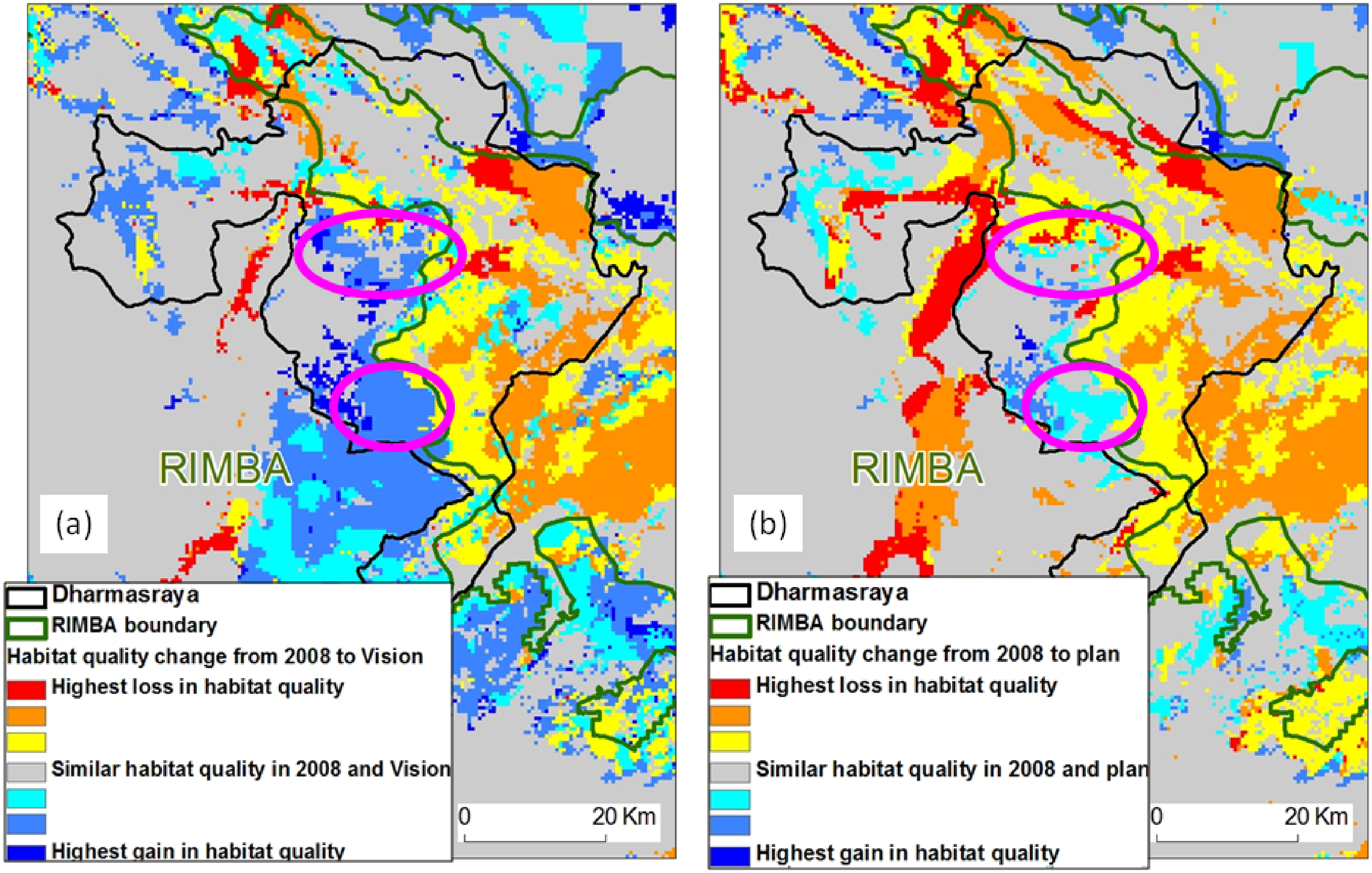


Fig. 4.10. The areas within the ovals were identified in Chapter 2 as having potential for forest carbon projects. If such projects were implemented under (a) the Vision, they are likely to also provide biodiversity co-benefits through improved habitat quality. Under (b) the government plan, there would be less or no improvement in habitat quality.

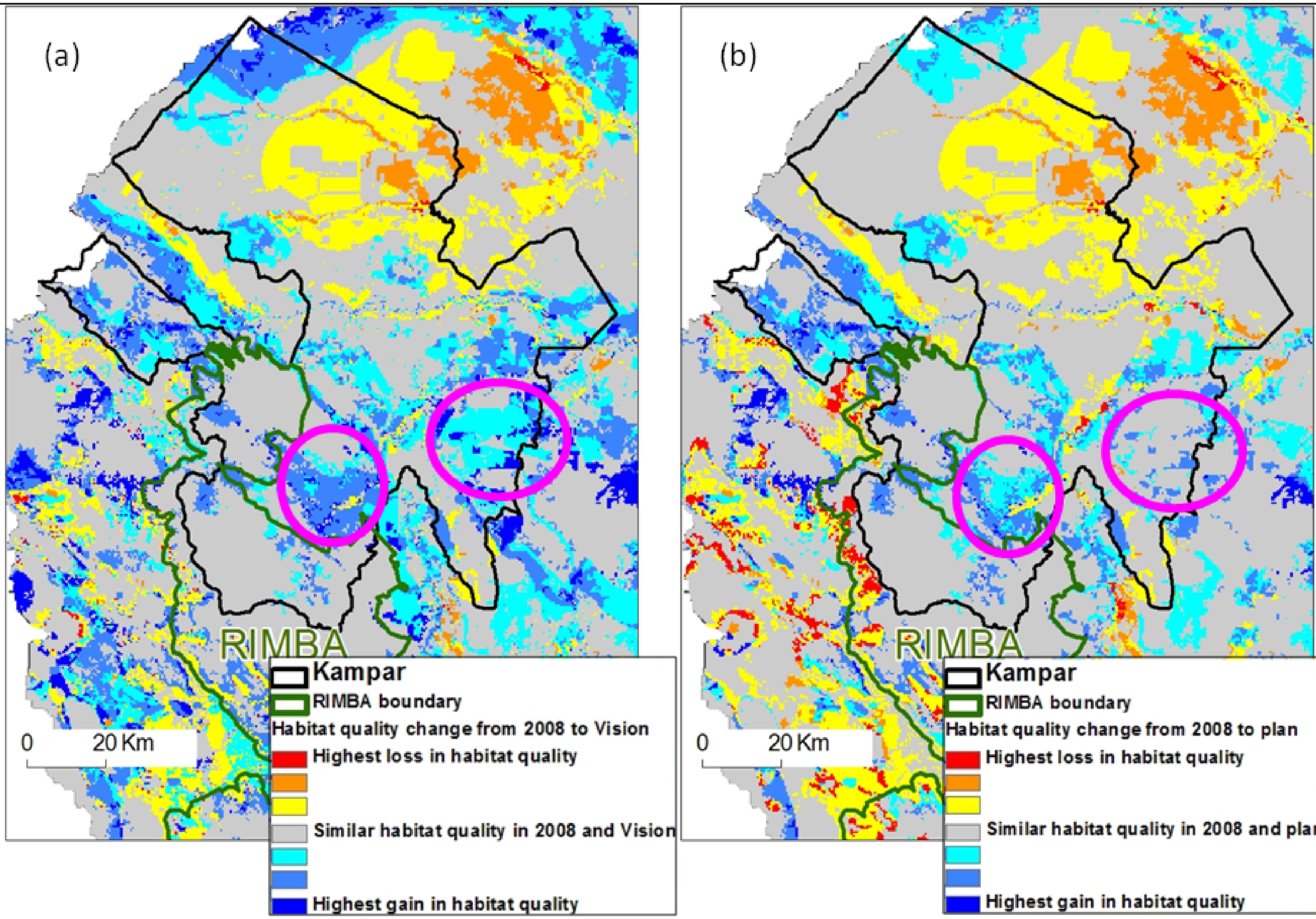


Fig. 4.11. The areas in ovals were identified as having potential for forest carbon projects in Chapter 2. The Sumatra Vision (a) could be implemented through forest carbon projects that also offer biodiversity co-benefits in these regions. Under the government plan (b), these regions would see less or no improvement in habitat quality.

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Chapter 5: Tradeoffs and Synergies among Ecosystem Services and Wildlife Habitat in Central Sumatra

Key Findings:

- Implementing the Sumatra Vision could result in net gains in habitat quality, total carbon stock and avoided nutrient pollution relative to 2008. It would also lead to moderate increase in sheetwash erosion across parts of the study area; however, the total erosion would be four times greater in the Government Plan.
- The hilly districts with relatively low opportunity cost for agriculture together account for 90% of the possible gains in erosion control in the Sumatra Ecosystem Vision relative to the Government Plan across all districts, but only 40% of the possible gains in other services and habitat quality. Sumatra could ensure large gains in avoided erosion at relatively low cost by implementing habitat restoration, forest carbon projects, and improved watershed management on slopes in the region; however, interventions in the higher-cost districts in the lowlands, which are more suitable for agriculture and less prone to erosion, are necessary to realize substantial gains in habitat quality, climate benefits from carbon storage, and avoided nutrient pollution.
- In many locations across the region, increases in most ecosystem services and habitat quality are accompanied by losses in plantation area and annual water yield. Compared to other districts, Merangin in Jambi and Solok in West Sumatra would experience large gains in erosion control *without* large losses in plantation area under the Sumatra Vision, relative to the Government Plan, making these districts good candidates for improved watershed management programs.
- Kampar in Riau would avoid increases in nutrient pollution by implementing the Sumatra Vision instead of the Government Plan without large losses in water yield and plantation area.
- Kampar and Indragiri Hulu would experience higher biomass carbon stock gains than most other districts in the study area, with only small losses in plantation area and water yield, suggesting the potential for forest carbon projects with comparatively low costs.
- Indragiri Hilir in Riau is singled out for the substantial increases in habitat quality and all services, except water yield, under the Sumatra Vision. Despite a relatively high average opportunity cost (calculated as 53,800 billion Rupiah over 50 years), the district alone provides greater ecosystem service benefits than multiple districts with lower opportunity costs. The agricultural value of remaining forested areas in Indragiri Hilir is comparable to the combined value of forest land on all the lower-cost districts that contain an equal stock of ecosystem services. As a result, implementing priority programs in key areas of Indragiri Hilir could still be a cost-effective investment.

Outline

Chapters 2 through 4 of this report each focused on a subset of our data on ecosystem services, habitat quality and opportunity costs across two alternative scenarios, the Sumatra Vision and the Government Plan. Since development and conservation interventions can impact multiple sectors, a more comprehensive and simultaneous accounting across all these dimensions is needed to better inform decision-making (Tallis and Polasky 2011). In this chapter, we assess changes across all of our ecosystem service, habitat and cost layers from 2008 to each scenario, identifying tradeoffs and synergies at the scales of the entire landscape, main watersheds, sub-watersheds, districts and specific locations. For specific districts, sub-watersheds and other locations of interest, we point out opportunities for implementing policies that can deliver gains in multiple benefits while minimizing losses across others.

Methods

Variables and Spatial Units of Aggregation

We assessed tradeoffs and synergies among habitat quality for tigers and multiple ecosystem services for the entire study area consisting of six watersheds (Figure 5.1 a), as well as for nested or overlapping biophysical and administrative subdivisions of this area, including 69 sub-watersheds (Figure 5.1 b) and 18 districts (Figure 5.2). The ecosystem services included in the tradeoff and synergy analysis were total carbon stock, biomass carbon stock (total carbon minus soil carbon), avoided sediment export, avoided nutrient (nitrogen and phosphorus) export and annual water yield. We summed the raster layers for habitat quality score and the various services in 2008 and the two scenarios (the Sumatra Vision and the government spatial plan) for the relevant spatial units (study area, watershed, sub-watershed or district), and compared the summed outputs across spatial units, and among the scenarios and the 2008 landcover map. Across districts, we also compared potential gains in services and habitat quality in the Sumatra Vision against the Government Plan, relative to the districts' average opportunity cost of forest conservation. As a rough estimate of opportunity costs, we calculated the net present value of returns from agriculture over 50 years, assuming all remaining forested land within each district were to be converted to agricultural production (see Chapter 2 for details of opportunity cost calculation).

Fig. 5.1a. The six watersheds comprising the study area in Central Sumatra

Fig. 5.1b. Sixty nine sub-watersheds cover most of the study area

Fig. 5.2. The study area contains 19 districts spread out over 3 provinces (Riau, West Sumatra and Jambi) of which all but one (Pesisir Selatan) were included in this study

Calculating Percent Change Between 2008 and Scenarios

For habitat quality, carbon stock and water yield, we calculated change between 2008 and each scenario as a percent change:

$$\left(\frac{S_s - S_{2008}}{S_{2008}}\right) \times 100 \qquad (1)$$

where S_s = summed habitat quality score (unitless), carbon (tonnes) or water yield (mm) in the relevant scenario, and S_{2008} = the variable summed in 2008 for the same spatial unit.

For avoided sediment and nutrient (N or P) export, we calculated change in service between 2008 and each scenario as:

$$\left(\frac{E_{2008} - Es}{E_{2008}}\right) \times 100 \qquad (2)$$

where E_s = summed export (tonnes) in the relevant scenario, and E_{2008} = sum in 2008. With this formula, we interpreted an increase in sediment or nutrient export relative to 2008 as a corresponding decrease in the services of avoided erosion or avoided nutrient pollution.

To assess differences between the Sumatra Vision and Government Plan scenarios, the above formulas were adapted as

$$\left(\frac{S_{vision} - S_{plan}}{S_{plan}}\right) \times 100 \text{ and } \left(\frac{E_{plan} - E_{vision}}{E_{plan}}\right) \times 100 \text{ respectively.} \qquad (3)$$

These formulas allowed us to represent improvement or degradation in habitat or services as a positive or negative percent change respectively, from 2008 to a given scenario, or from the Government Plan to the Sumatra Vision.

Ranking Sub-watersheds for Change Between Scenarios

We ranked the 69 sub-watersheds based on change in habitat score or service stock between Vision and plan ([$S_{vision} – S_{plan}$] or [$E_{plan} – E_{vision}$]) where the highest (=1) and lowest (= 69) ranks correspond respectively to the maximum and minimum change values. We then calculated the percentile of these ranks as

$$P = \frac{r \times 100}{(N+1)} \qquad (4)$$

Where P =percentile, r = rank of watershed for change in habitat or service, and N = total number of watersheds. Sub-watersheds that ranked high (i.e., had a lower numerical value of P) for one or more change variables may present better opportunities for realizing high gains in the relevant habitat or service measure, relative to other areas within the region, if the Sumatra Vision were to be implemented rather than the plan. For this analysis, we defined high-ranking sub-watersheds as those being equal to or numerically less than the 25th percentile for a given habitat or ecosystem service change value, but this threshold could be relaxed (> 25) or tightened (< 25) to select more or fewer areas respectively.

Methods for Recommendations

We tied our recommendations to the five policy programs that have been proposed for implementing ecosystem-based spatial planning in Sumatra: forest restoration, forest carbon projects, payments and programs for watershed services, best management practices for forestry, and best management practices for plantations. In this initial analysis, we have not been able to offer recommendations targeted to every one of these programs; we focus primarily on forest carbon projects and improved watershed management. The other three programs could be implemented under these two overarching themes where appropriate, although there may be additional opportunities beyond our analysis for implementing forest restoration and best management practices. We identified areas where some combination of forest carbon, hydrological services and habitat quality benefits could be improved under the Sumatra Vision relative to the Government Plan. Depending on the specific combination of benefits, these areas could be candidates for forest carbon projects that offer the other services as co-benefits, or they could primarily target hydrological services through improved watershed management that includes forest conservation and restoration. We thus offer a menu of possible policy options for specific areas; determining which ones are the most feasible and appropriate for a given location will require further analysis of biophysical and socioeconomic data, complemented by stakeholder consultation.

Results and Recommendations

Entire Study Area

Considering the entire study area, the Sumatra Vision would result in net gains in habitat quality, total carbon stock and avoided nutrient relative to 2008 (Figure 5.3). Though the Sumatra Vision would result in some increased erosion over the entire study area, the amount of sediment export would be over four times higher in the Government Plan. Both the Sumatra Vision and Government Plan would result in modest and similar losses in water yield, and the Government Plan would also result in losses in habitat quality and carbon stock. For habitat and all services assessed here, the Sumatra Vision would result in higher amounts than the Government Plan.

Main Watersheds

For the six main watersheds (Figures 5.4 a-c) results vary by watershed and habitat / service variable, but in all cases, the Sumatra Vision would show overall benefits relative to the Government Plan. All watersheds would gain carbon stock in the Sumatra Vision and lose it in the Government Plan, relative to 2008. The Sumatra Vision would also result in gains in habitat quality and avoided nutrient export, while the Government Plan would result in modest gains (but less than the Sumatra Vision) in some watersheds, but losses in these variables in others. Four of the six watersheds would experience increased erosion under both scenarios; in all of them, erosion levels would be even higher under the Government Plan. For the remaining two watersheds (Kampar and Reteh), both the Sumatra Vision and the Government Plan would result in reduced erosion, with larger reductions under the Government Plan.

Sub-watersheds

Sub-watersheds that increase most (the top 25th percentile) in both total carbon stock and habitat quality score in the Sumatra Vision relative to the Government Plan were mostly concentrated in the peatlands in the eastern part of the study area (Figure 5.5). Implementing the Sumatra Vision in these areas could therefore offer significant carbon sequestration benefits while also conserving and restoring habitat for wildlife, relative to the Government Plan. However, areas in the western part of the study area that contain important wildlife habitat (the western portions of the RIMBA priority area) do not fall within these high carbon sub-watersheds. We repeated the above analysis for biomass carbon separately, rather than lumping it with soil carbon, in order to identify watersheds that ranked high for both habitat quality and biomass carbon. The sub-watersheds with the top 25th percentile increase in biomass carbon and habitat quality (Figure 5.6) were mostly the same as the ones in the previous analysis based on total carbon, although they included three additional sub-watersheds in the western and southeastern regions of the study area. There was little additional overlap with the RIMBA priority area, suggesting that prioritizing sub-watersheds based on carbon sequestration potential alone (whether biomass or total stock) will be inadequate to cover all areas important for conservation. However, while conserving just these watersheds is not sufficient to meet all conservation goals, forest carbon projects located in these areas could offer additionality (due to gains or maintenance of carbon stock under the Sumatra Vision that would not have occurred under the Government Plan) while also offering the co-benefit of biodiversity conservation and thus at least partially meeting the conservation goals for the region.

Using the 25th percentile cut-off criterion, we also identified sub-watersheds that are likely to offer high levels of hydrological benefits in the Sumatra Vision relative to the Government Plan, in addition to high levels of carbon sequestration and habitat conservation. Several such sub-watersheds (Figure 5.7) rank high for reduced nutrient export, suggesting that implementing the Sumatra Vision here would not only sequester carbon and enhance habitat for wildlife, but also potentially benefit downstream communities through improved water quality. We recommend exploring possibilities for implementing forest carbon projects, improved watershed management schemes (including payments for watershed services) and best management practices for plantations to reduce nutrient runoff in these areas.

In Figure 5.8, we identified sub-watersheds that rank high for both increase in habitat quality score and reduction in sediment export in the Sumatra Vision relative to the Government Plan. In these areas, watershed management schemes to reduce erosion could align especially well with wildlife habitat conservation and restoration.

While the above analyses demonstrate the potential for achieving substantial gains in wildlife habitat and multiple ecosystem services in some parts of central Sumatra, they also suggest that most of the study area may not be covered if just one or two services are targeted. Therefore, we assessed whether there could be substantial additional gains in area coverage, and better overlap with tiger conservation priorities, if we were to target a wider range of services. As an example, we compared the implications for area coverage and habitat quality improvement between targeting sub-watersheds based on only carbon stock increase in the Sumatra Vision relative to the Government Plan, versus targeting them based on high potential increase in any service. The sub-watersheds in the top 25th percentile for increase in carbon only (total or biomass) would account for 42% or less of the maximum gain in habitat quality score over the entire study area that is possible under the Sumatra Vision relative to the Government Plan. These sub-watershes cover 35% or less of the study area (Figure 5.9 a, b). In comparison, all sub-watersheds in the top 25th percentile of potential increase in at least one of the analyzed services (carbon or hydrological) would do substantially better in terms of area coverage as well as meeting conservation goals, accounting for 73% of the maximum possible gain in habitat quality score, and covering 76% of the study area (Figure 5.9 c). Thus, targeting different ecosystem services as appropriate for different locations across central Sumatra (in contrast to focusing primarily on a single service such as carbon throughout the area) may not only improve the availability of ecosystem services, but also go farther towards meeting conservation goals.

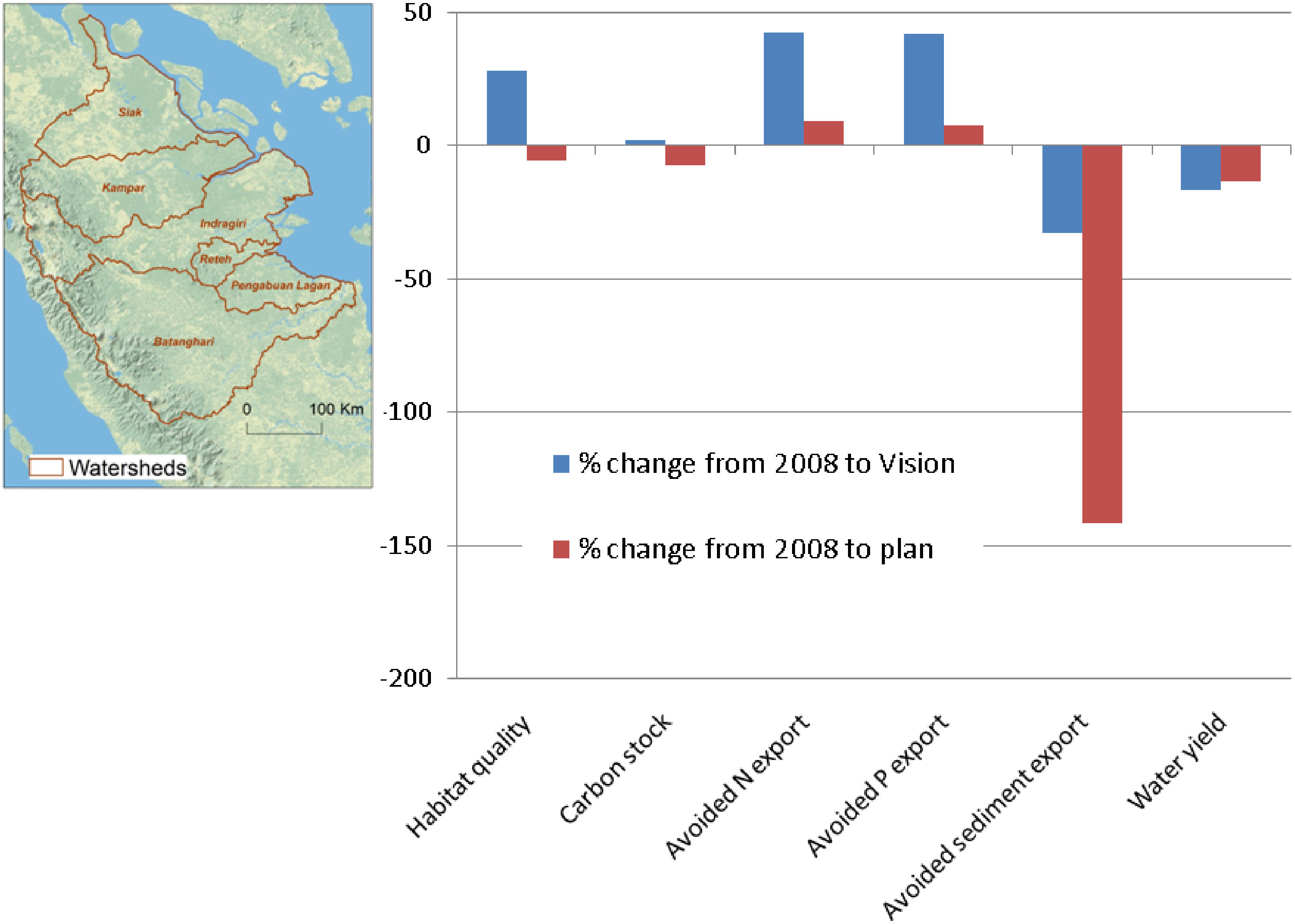
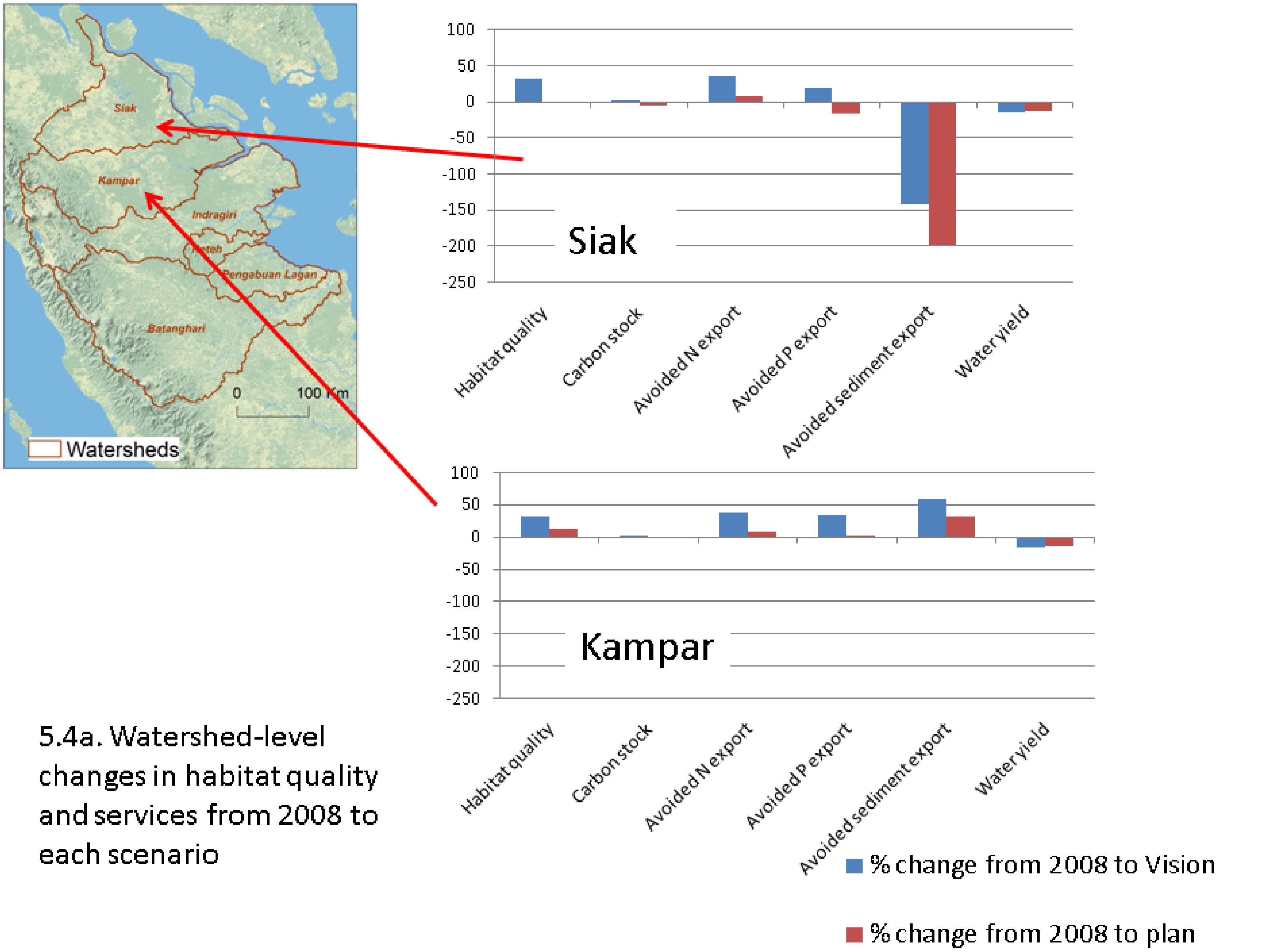
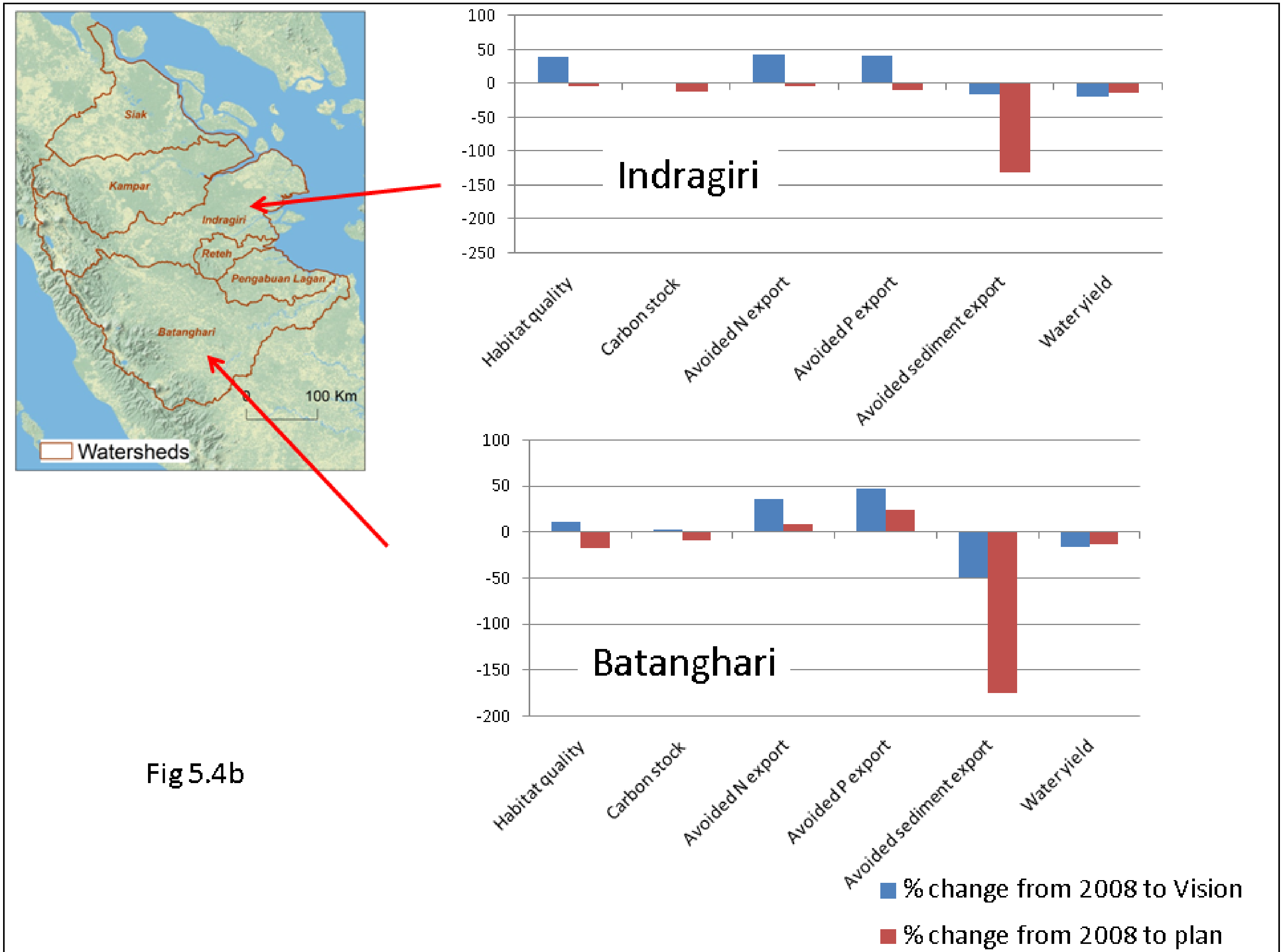


Fig. 5.3. Change in habitat quality and services from 2008 to each scenario for entire study area (the area covered by all six watersheds)

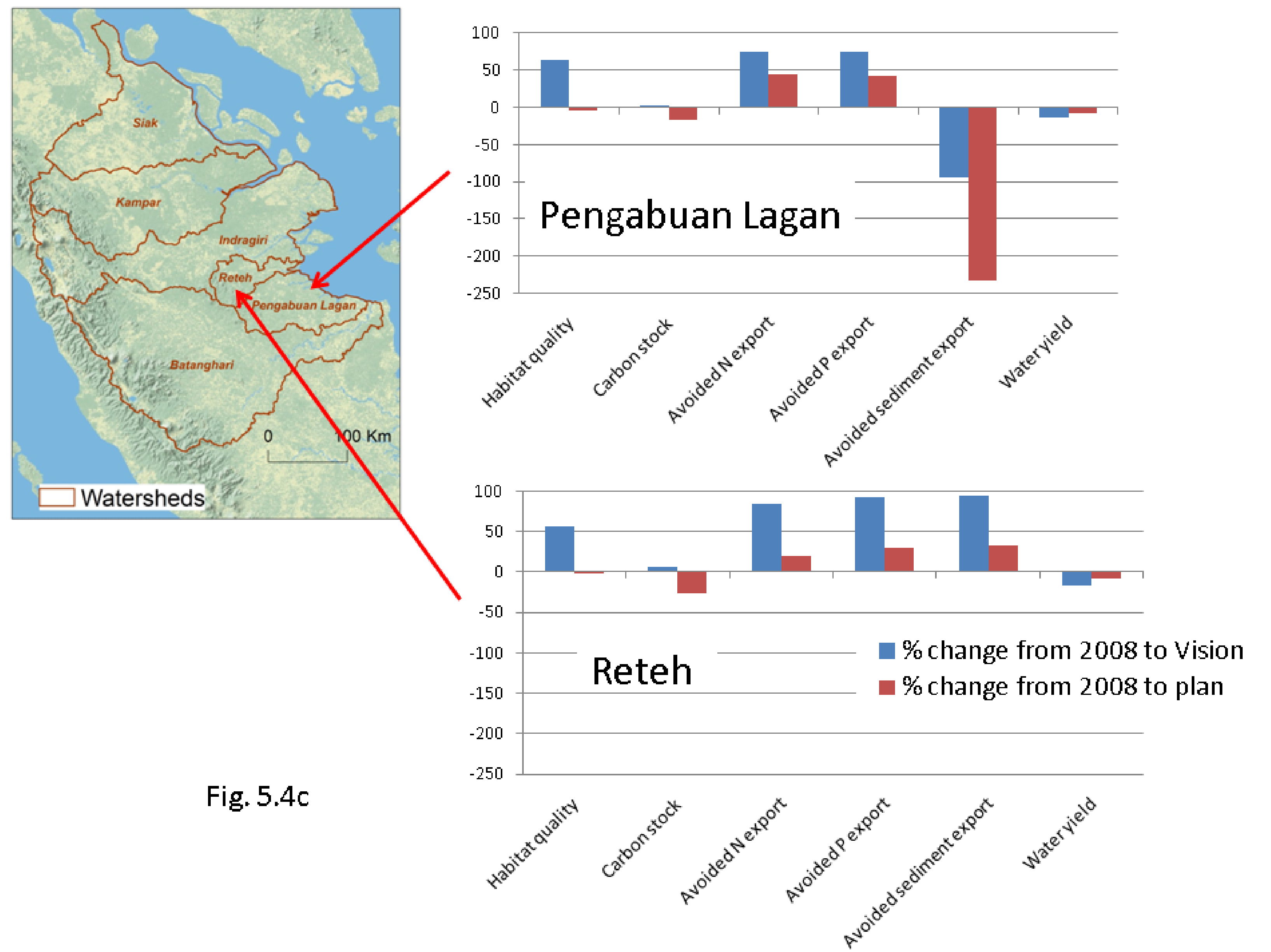


5.4a. Watershed-level changes in habitat quality and services from 2008 to each scenario



Siak
Kampar
Indragiri
Reteh
Pengabuan Lagan
Batanghari
0
100 Km
Watersheds
Indragiri
100
50
0
-50
-100
-150
-200
-250
Habitat quality
Carbon stock
Avoided N export
Avoided P export
Avoided sediment export
Water yield
Batanghari
100
50
0
-50
-100
-150
-200
Habitat quality
Carbon stock
Avoided N export
Avoided P export
Avoided sediment export
Water yield
% change from 2008 to Vision
% change from 2008 to plan

Fig 5.4b



Siak
Kampar
Indragiri
Reteh
Pengabuan Lagan
Batanghari
0
100 Km
Watersheds
Pengabuan Lagan
100
50
0
-50
-100
-150
-200
-250
Habitat quality
Carbon stock
Avoided N export
Avoided P export
Avoided sediment export
Water yield
Reteh
100
50
0
-50
-100
-150
-200
-250
Habitat quality
Carbon stock
Avoided N export
Avoided P export
Avoided sediment export
Water yield
% change from 2008 to Vision
% change from 2008 to plan

Fig. 5.4c

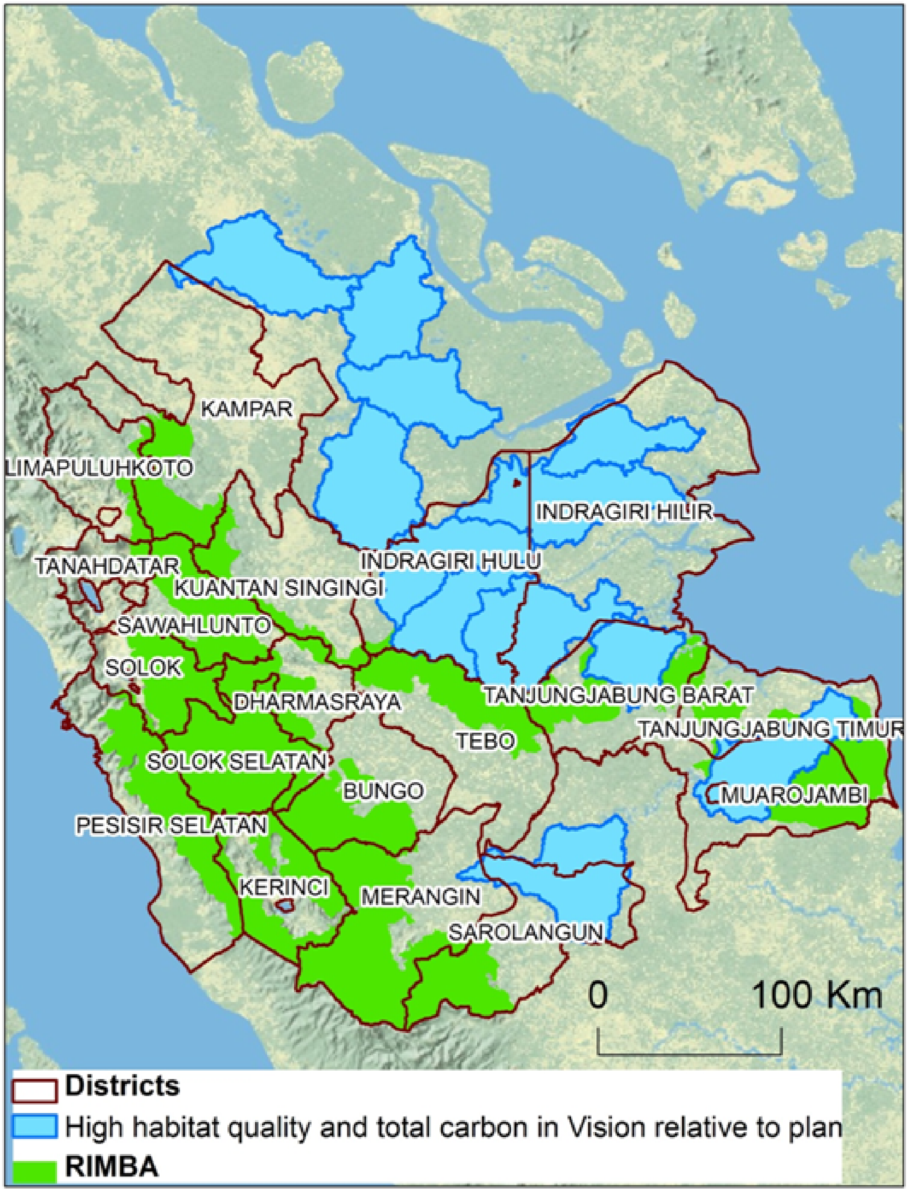


Fig. 5.5. The sub-watersheds highlighted in blue would experience large increases in total carbon stock and habitat quality in the Vision relative to the plan, compared to other sub-watersheds. The difference in habitat quality score between Vision and plan, and in total carbon stock between Vision and plan within these sub-watersheds, puts them in the top 25th percentile of all sub-watersheds in the study area for these difference scores.

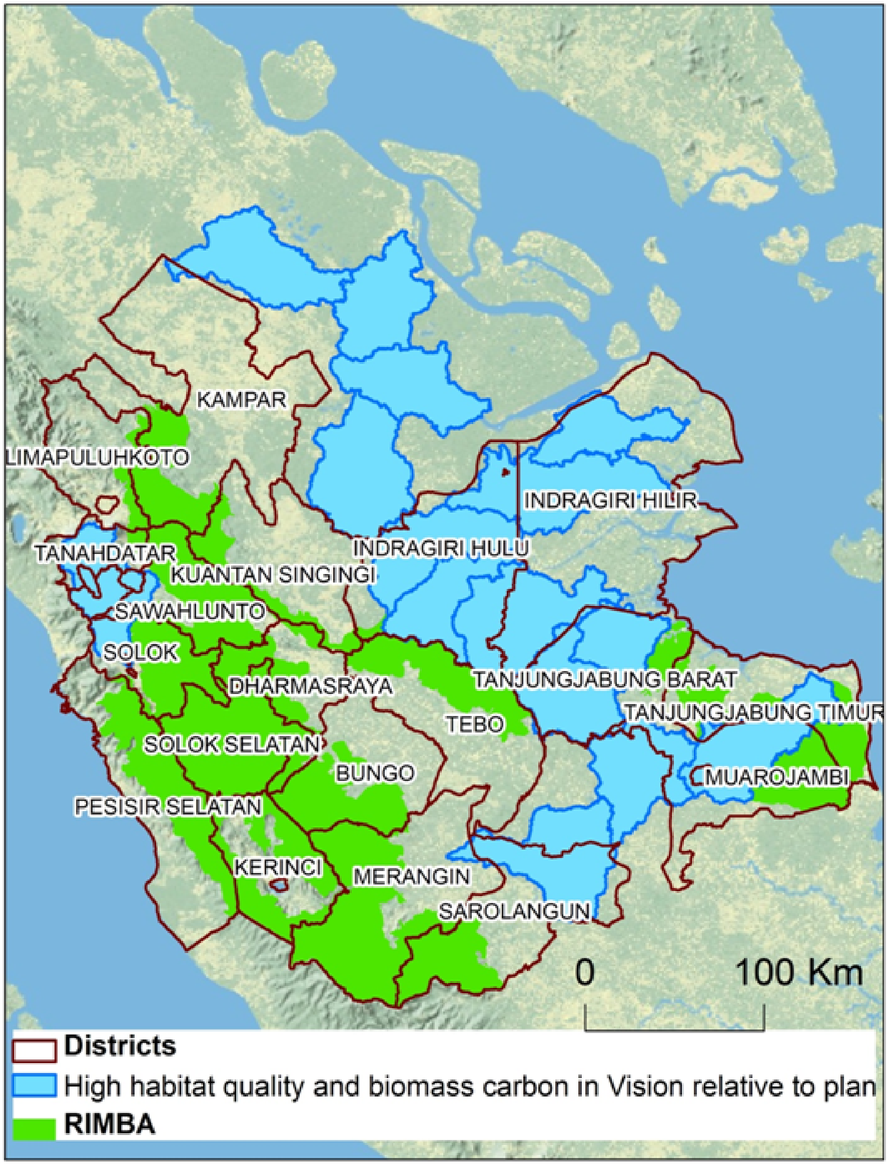


Fig. 5.6. The sub-watersheds highlighted in blue would experience large increases in *biomass* carbon stock and habitat quality in the Vision relative to the plan, compared to other sub-watersheds. The difference in habitat quality score between Vision and plan, and in biomass carbon stock between Vision and plan within these sub-watersheds, puts them in the top 25th percentile of all sub-watersheds in the study area for these difference scores.

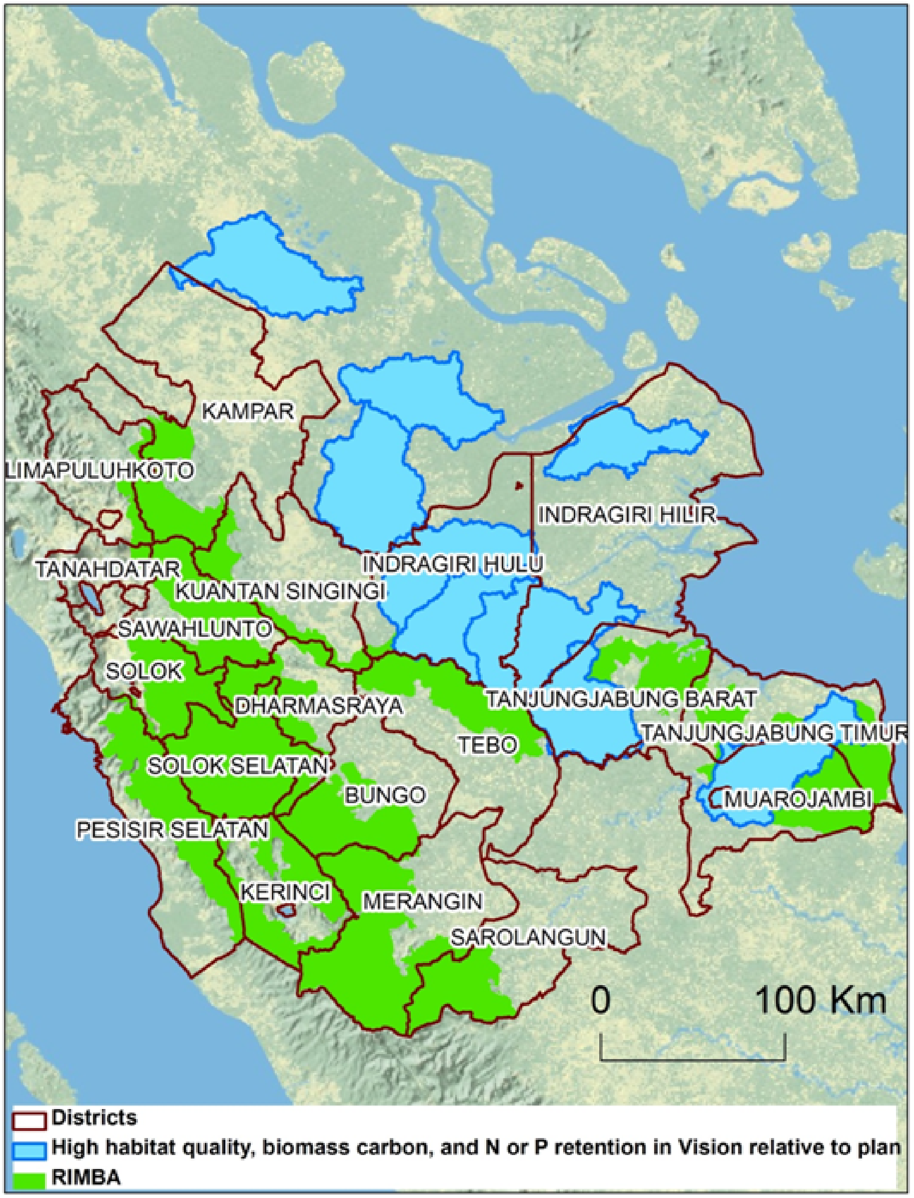


Fig. 5.7. The sub-watersheds highlighted in blue would experience relatively large increases in summed habitat quality score and biomass carbon stock, and large reductions in nutrient export in the Vision relative to the plan, compared to other sub-watersheds in the study area.

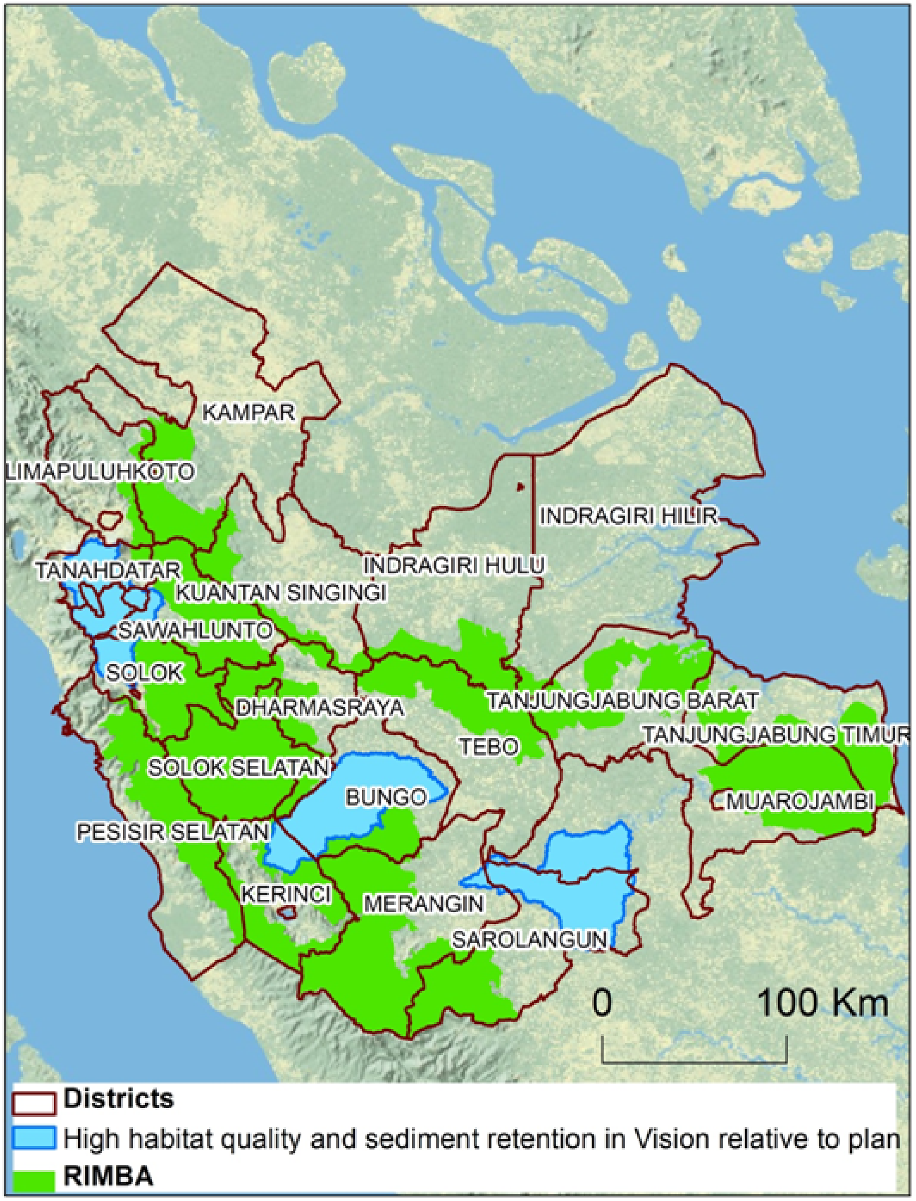


Fig. 5.8. The sub-watersheds highlighted in blue would experience relatively large increases in summed habitat quality score, and large reductions in sediment export in the Vision relative to the plan, compared to other sub-watersheds in the study area.

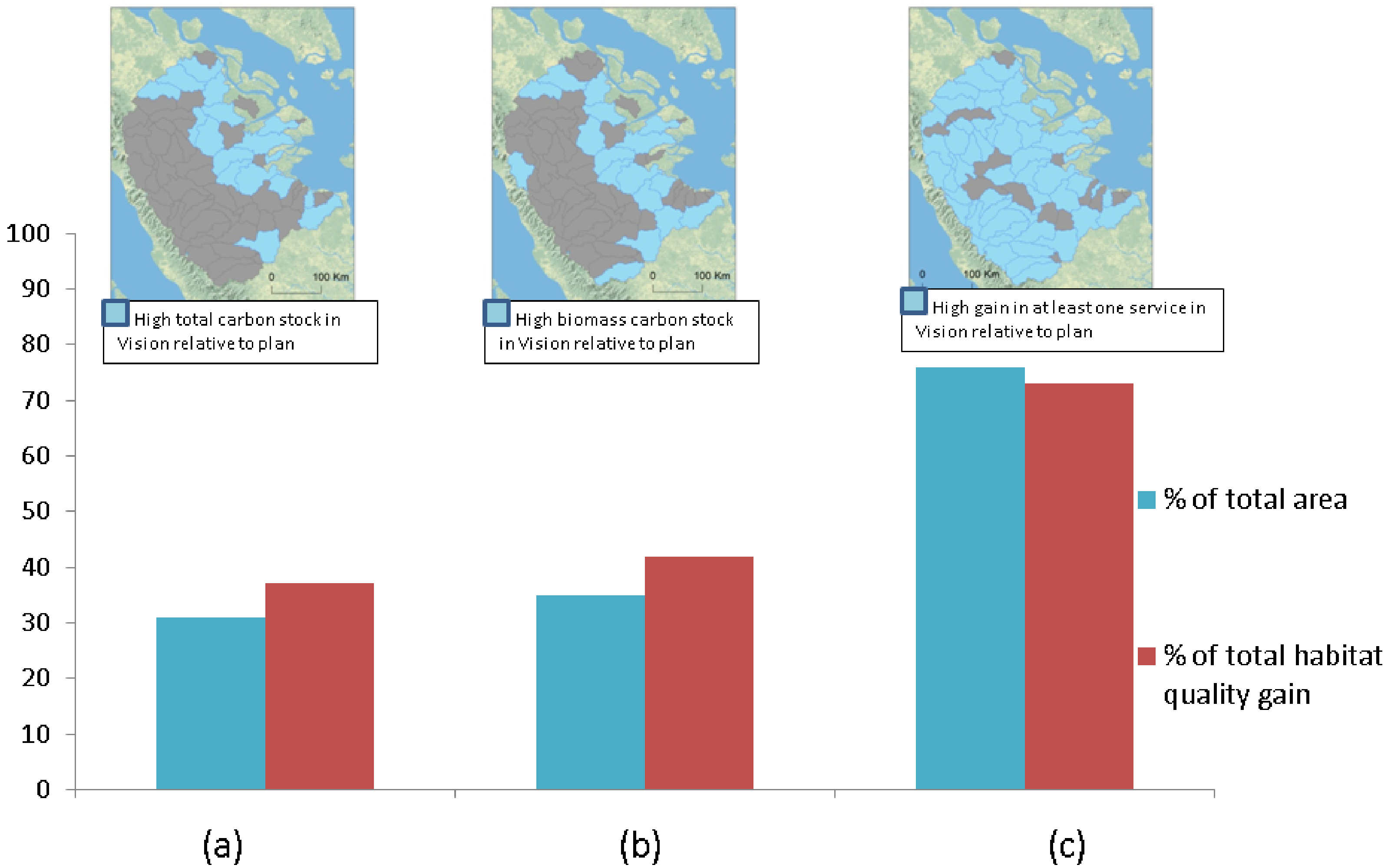
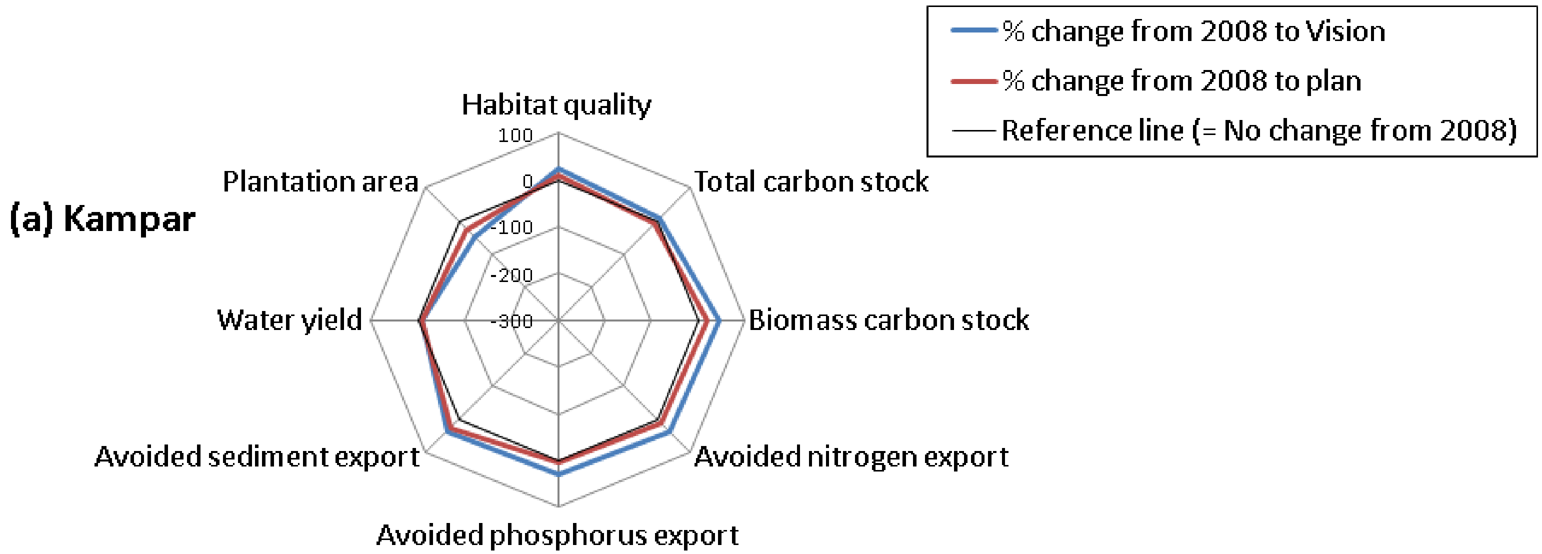


Fig. 5.9. Sub-watersheds highlighted in blue are in the top 25th percentile for increase (in Vision relative to plan) in (a) total carbon only, (b) biomass carbon only and (c) at least one of the services analyzed in this study. Prioritizing sub-watersheds based on (c) would substantially improve area coverage, as well as bring higher gains in wildlife habitat score in the Vision relative to the plan.

Districts

In most districts, plantation area would increase from 2008 to the Government Plan scenario and decrease under the Sumatra Vision (Figure 5.10). These scenarios illustrate the tradeoffs districts must face: increases in habitat quality and some services often come at the expense of some plantation area. For instance, Indragiri Hilir would retain close to 100% of its 2008 plantation area under the Government Plan, but would lose most of its plantations under the Sumatra Vision (Figure 5.10 b). The loss of plantation area in Indragiri Hilir under the Sumatra Vision would be accompanied by substantial increases in habitat quality score, biomass carbon stock, avoided nutrient export and avoided erosion, suggesting that the benefits to society from reducing the amount of plantations in this district may be substantial. Some districts, such as Tebo, Muarojambi, Tanjungjabung Timur and Solok (Figures 5.10 g, h, i and j), may suffer experience increased erosion under both scenarios, but in these cases, the erosion damage under the Government Plan could be substantially higher under than under the Sumatra Vision. In these districts, any increases in revenue from the relatively modest increases in plantation area under the Government Plan may be more than offset by the increased damages from erosion.



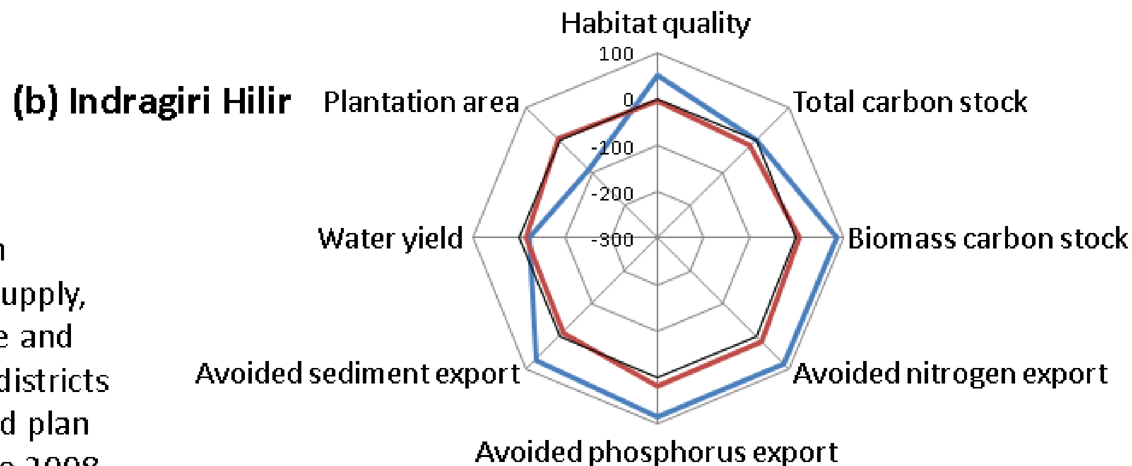
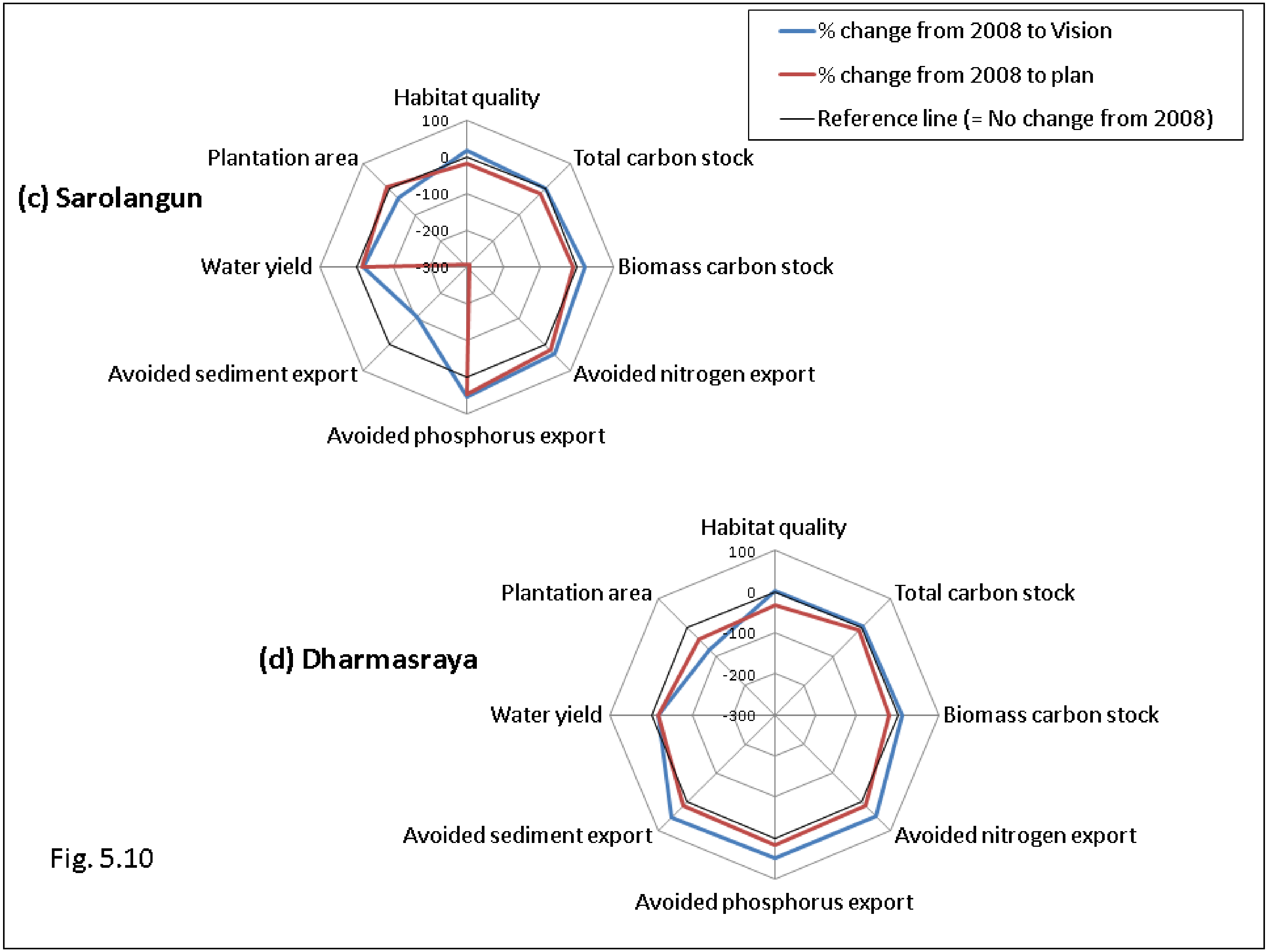


Fig. 5.10. Change in ecosystem service supply, habitat quality score and plantation area for districts under the Vision and plan scenarios, relative to 2008 levels



% change from 2008 to Vision
% change from 2008 to plan
Reference line (= No change from 2008)
(c) Sarolangun
Habitat quality
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
100
0
-100
-200
-300
(d) Dharmasraya
Habitat quality
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
100
0
-100
-200
-300

Fig. 5.10

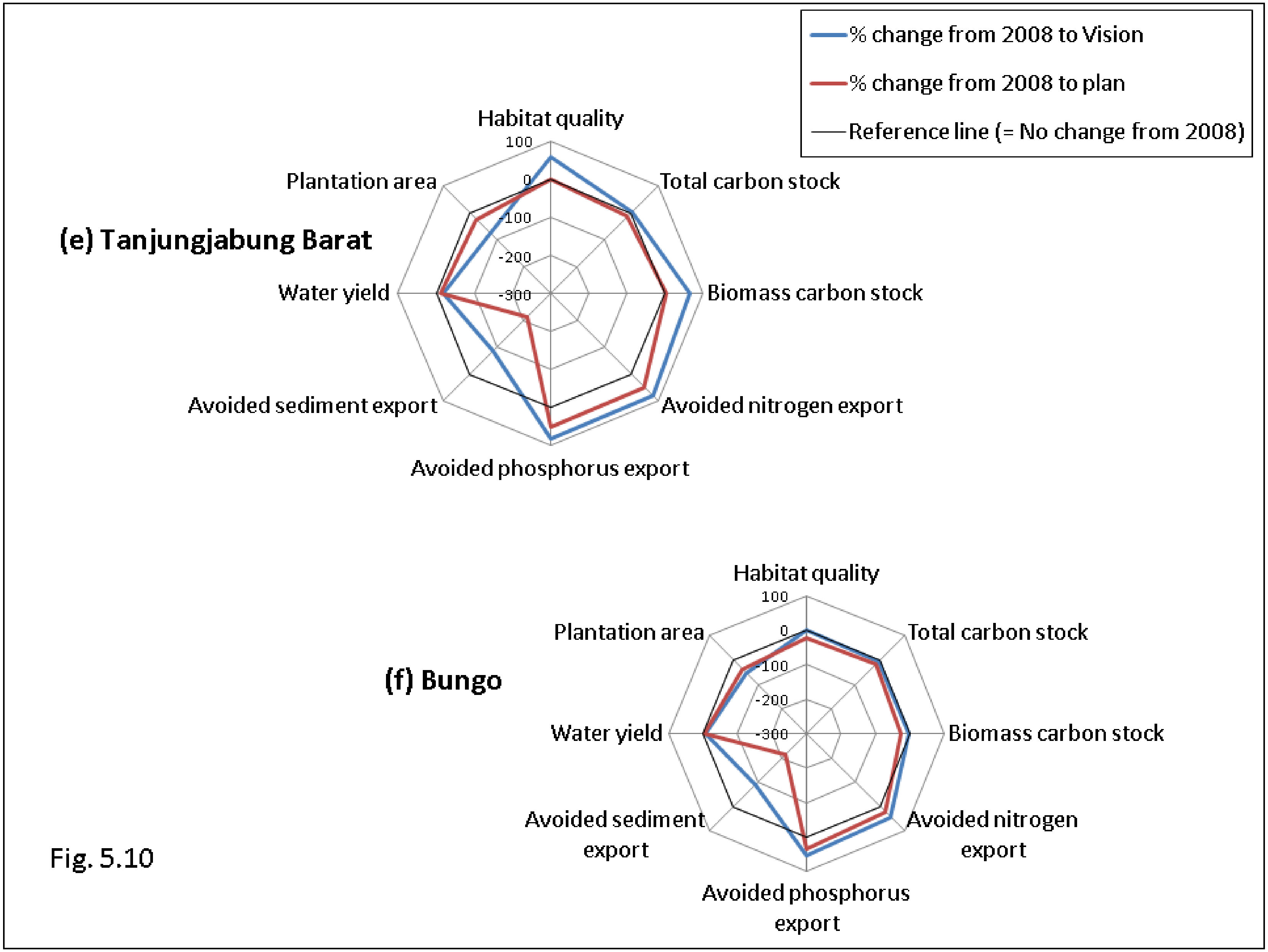
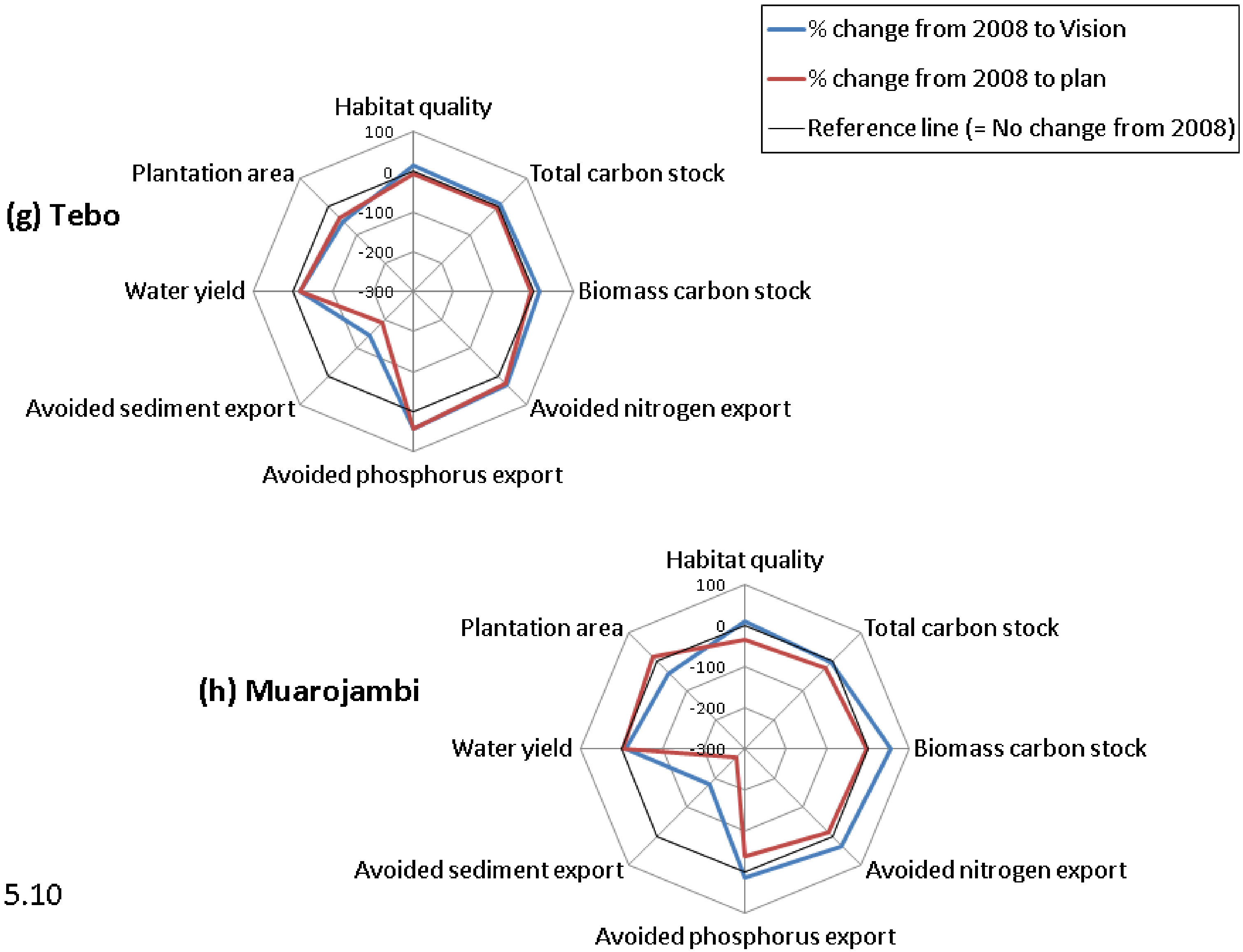

% change from 2008 to Vision
% change from 2008 to plan
Reference line (= No change from 2008)
(e) Tanjungjabung Barat
Habitat quality
100
0
-100
-200
-300
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
(f) Bungo
Habitat quality
100
0
-100
-200
-300
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area

Fig. 5.10



% change from 2008 to Vision
% change from 2008 to plan
Reference line (= No change from 2008)
(g) Tebo
Habitat quality
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
100
0
-100
-200
-300
(h) Muarojambi
Habitat quality
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
100
0
-100
-200
-300

Fig. 5.10

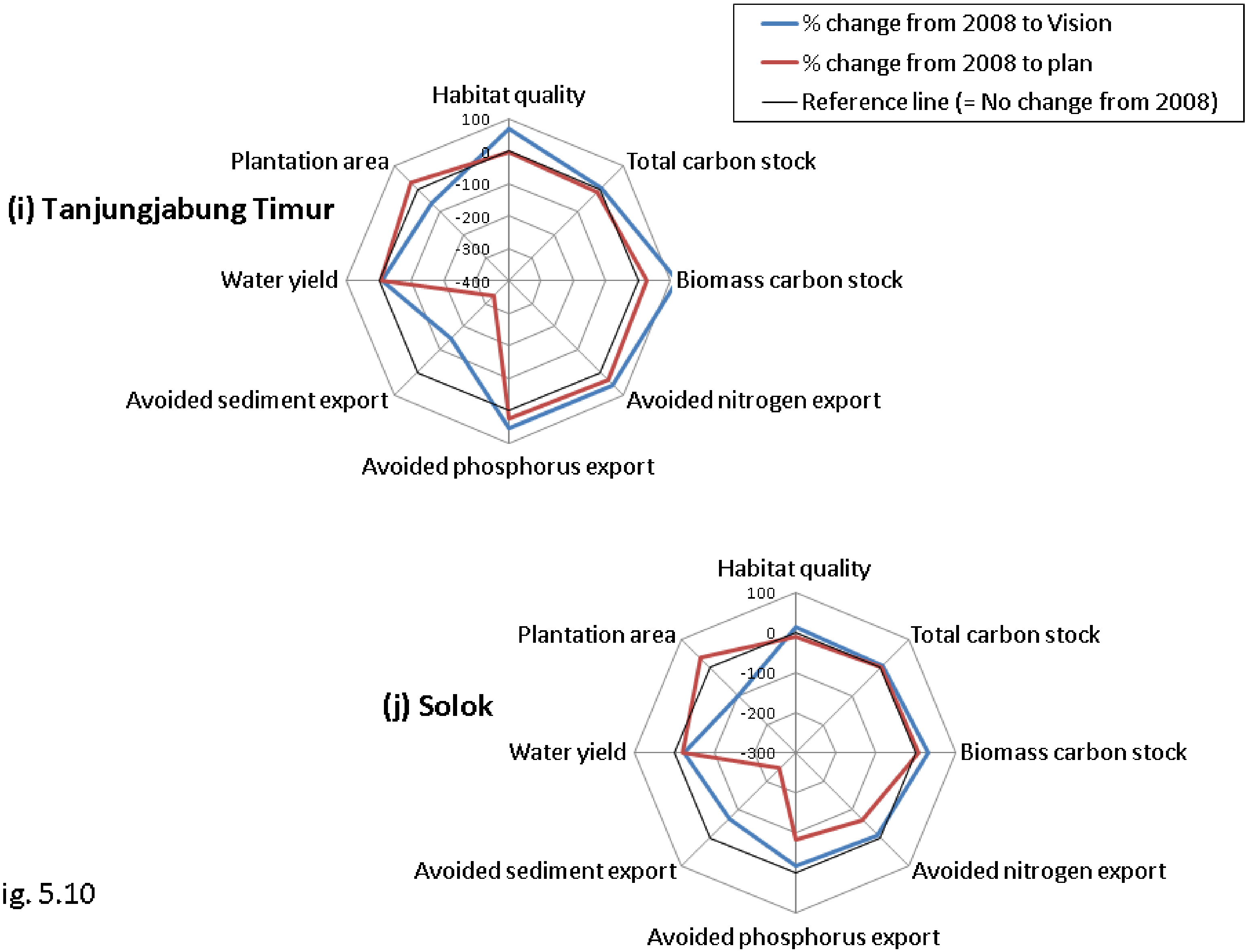
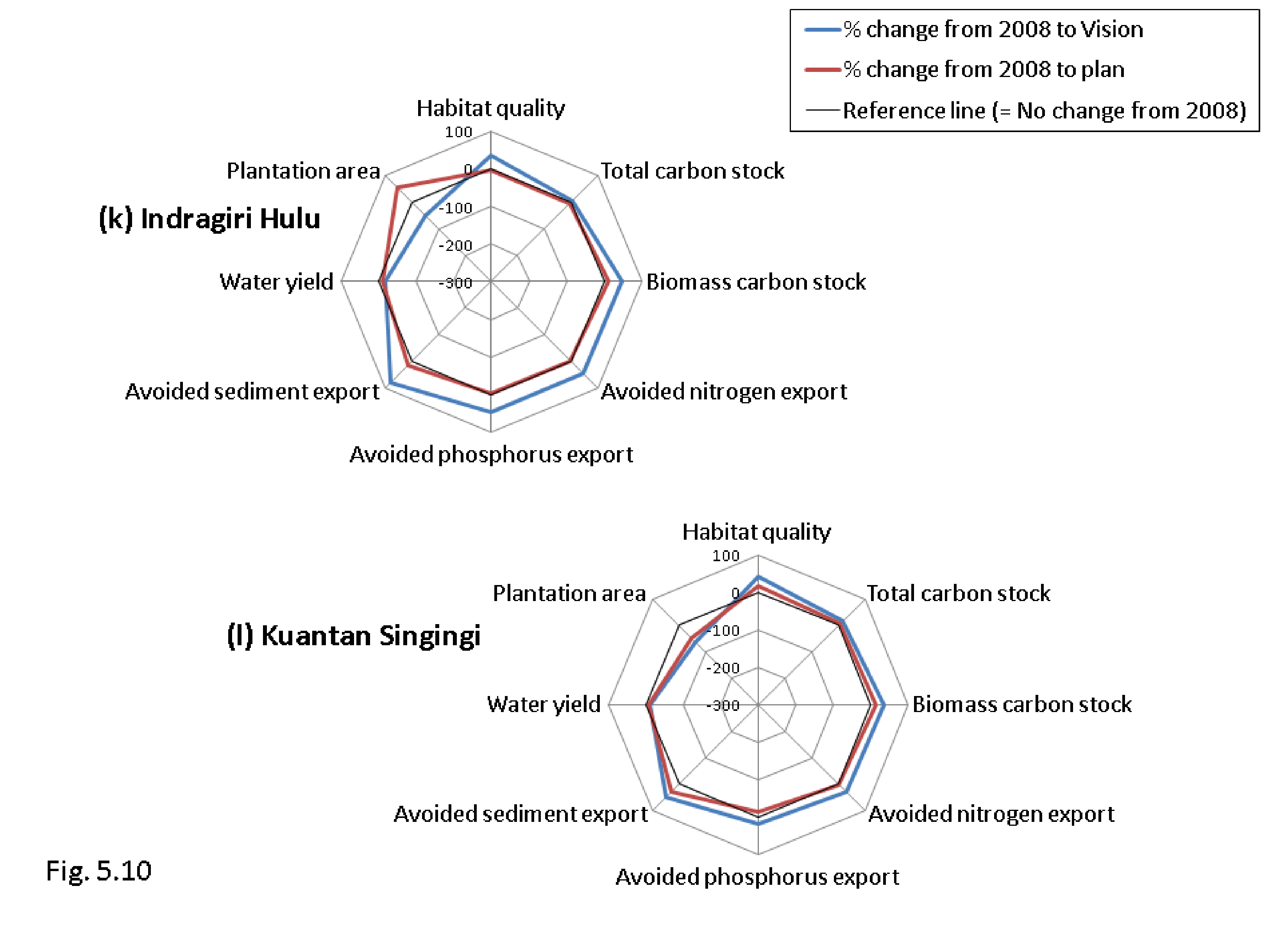
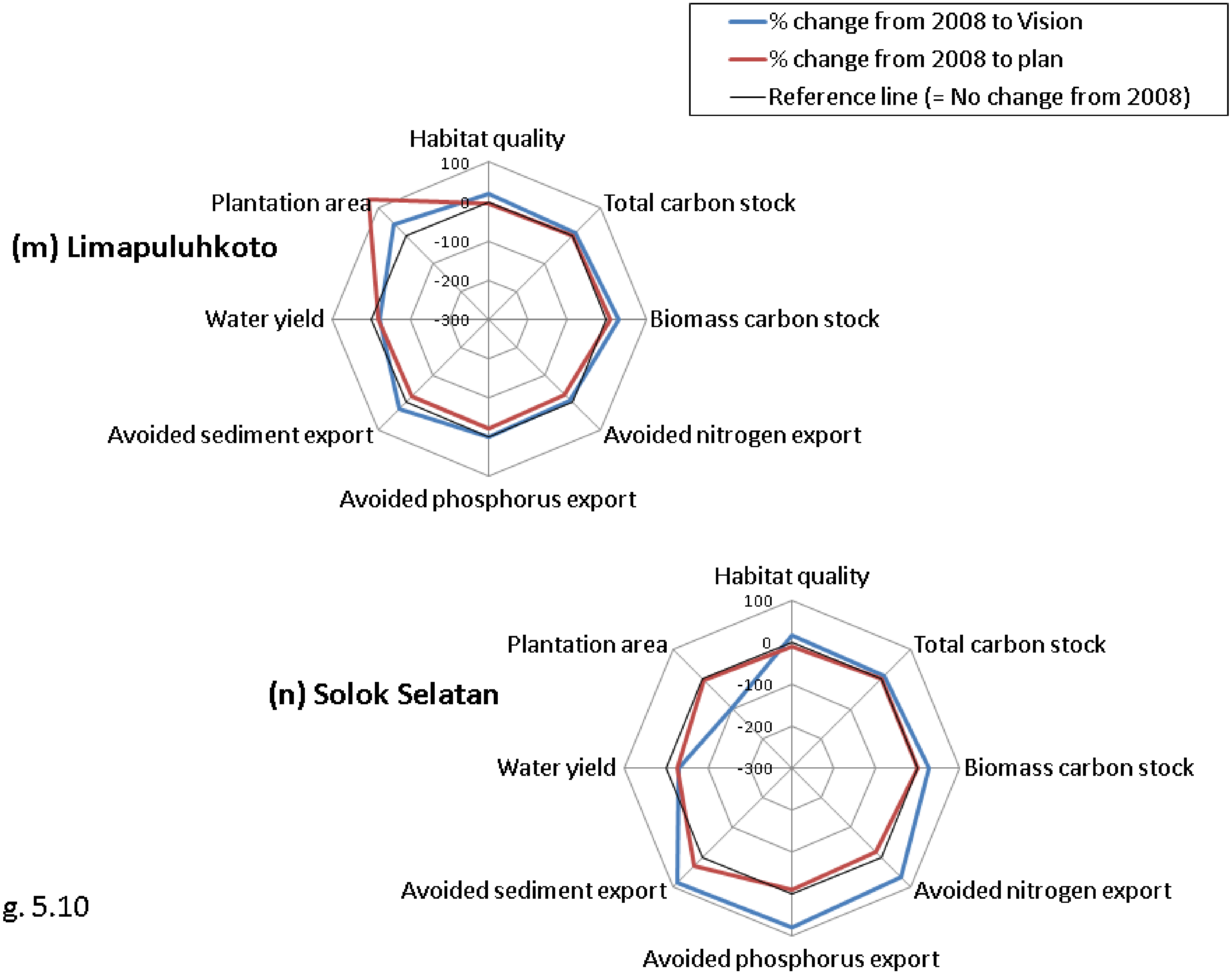

% change from 2008 to Vision
% change from 2008 to plan
Reference line (= No change from 2008)
(i) Tanjungjabung Timur
Habitat quality
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
100
0
-100
-200
-300
-400
(j) Solok
Habitat quality
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
100
0
-100
-200
-300

Fig. 5.10



% change from 2008 to Vision
% change from 2008 to plan
Reference line (= No change from 2008)
(k) Indragiri Hulu
Habitat quality
100
0
-100
-200
-300
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
(l) Kuantan Singingi
Habitat quality
100
0
-100
-200
-300
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area

Fig. 5.10



% change from 2008 to Vision
% change from 2008 to plan
Reference line (= No change from 2008)
(m) Limapuluhkoto
Habitat quality
100
0
-100
-200
-300
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
(n) Solok Selatan
Habitat quality
100
0
-100
-200
-300
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area

Fig. 5.10

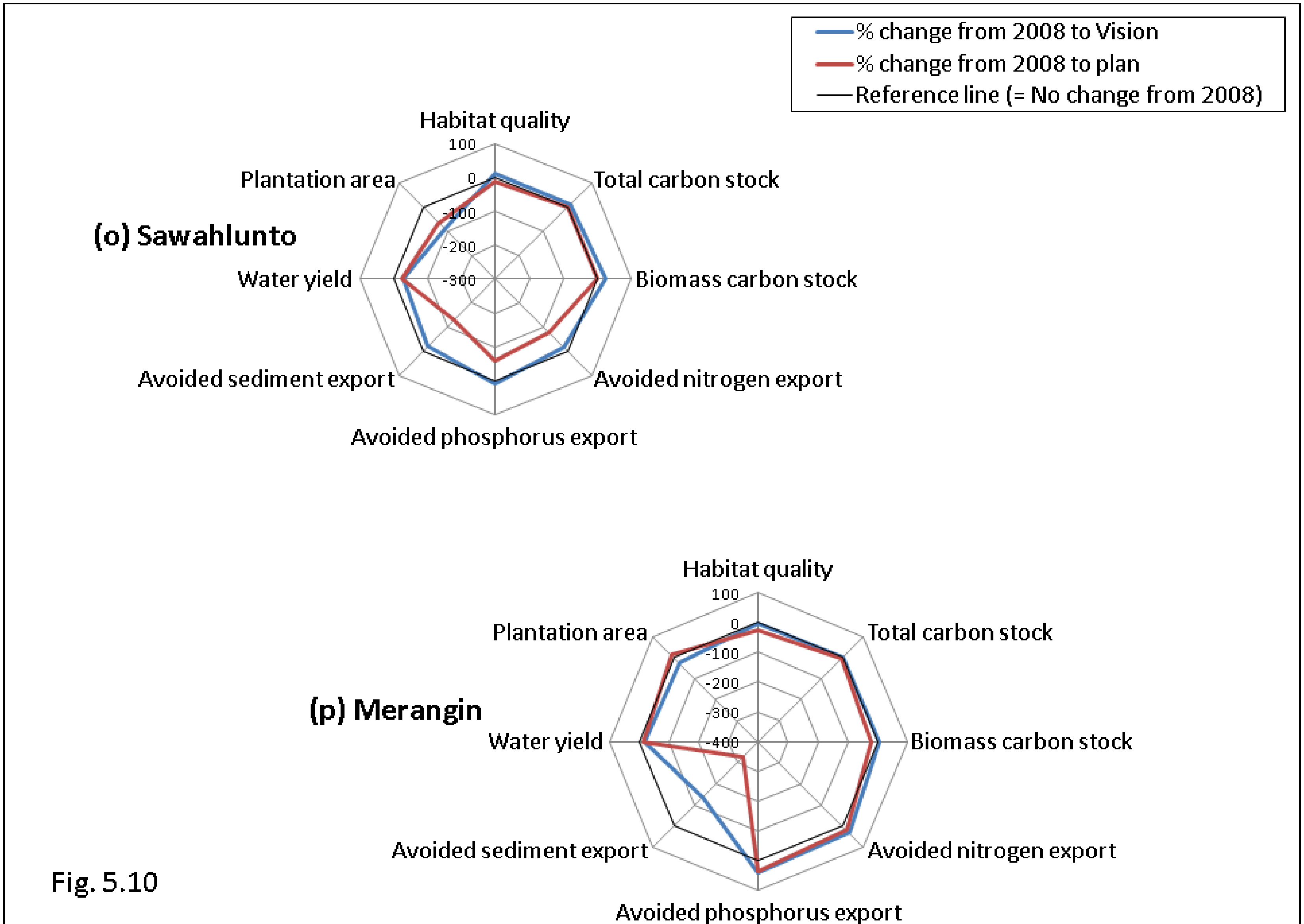
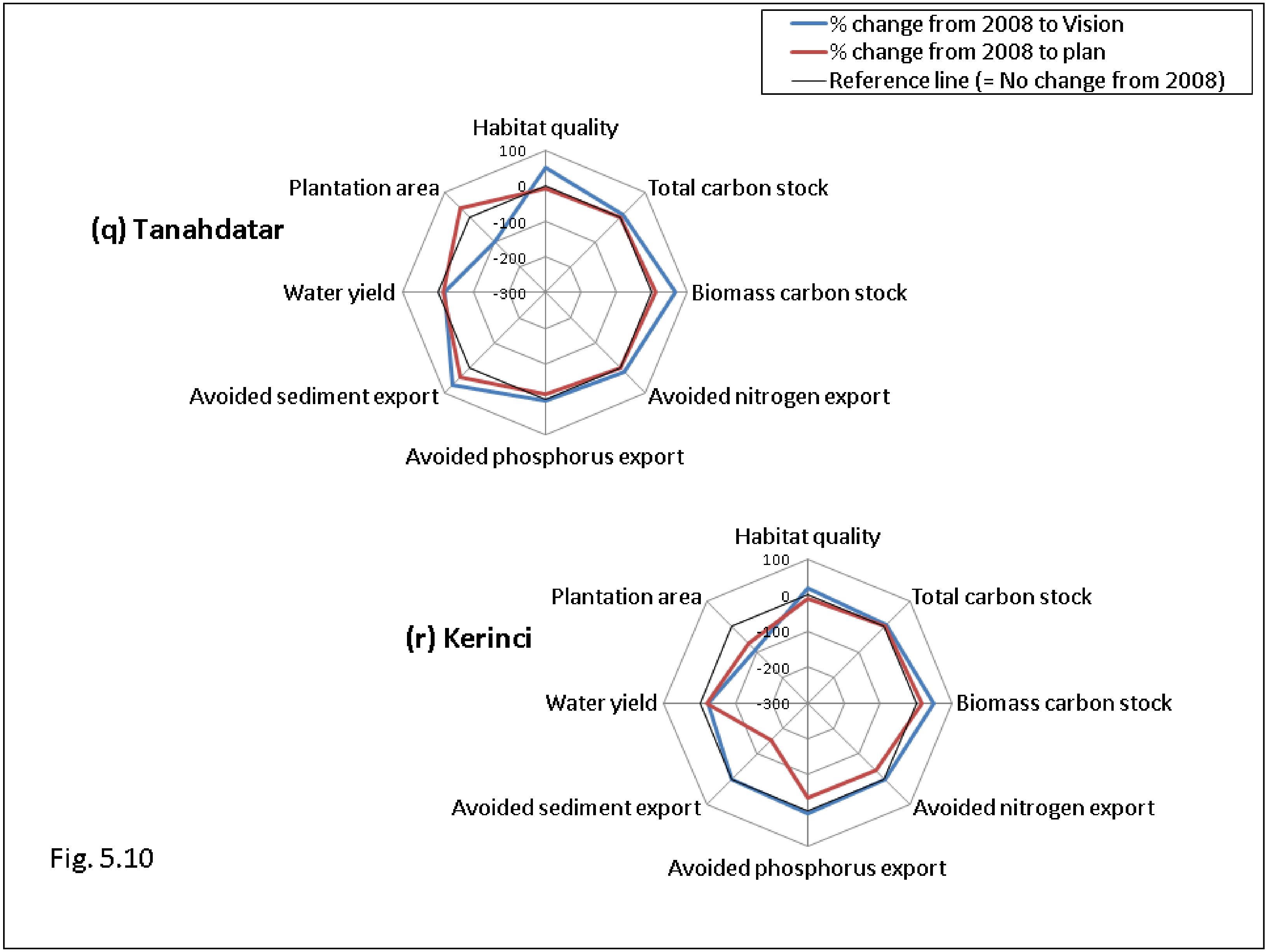

% change from 2008 to Vision
% change from 2008 to plan
Reference line (= No change from 2008)
(o) Sawahlunto
Habitat quality
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
100
0
-100
-200
-300
(p) Merangin
Habitat quality
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
100
0
-100
-200
-300
-400

Fig. 5.10



% change from 2008 to Vision
% change from 2008 to plan
Reference line (= No change from 2008)
(q) Tanahdatar
Habitat quality
100
0
-100
-200
-300
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area
(r) Kerinci
Habitat quality
100
0
-100
-200
-300
Total carbon stock
Biomass carbon stock
Avoided nitrogen export
Avoided phosphorus export
Avoided sediment export
Water yield
Plantation area

Fig. 5.10

In Figure 5.11, we plotted the cumulative gains across districts in habitat score and service supply (as a percent of total possible gain for all districts) in the Sumatra Vision relative to the Government Plan, ranking the districts in increasing order of opportunity cost. The districts with relatively low opportunity cost (ranks 1 through 11) together account for 90% of the possible gains in avoided sediment export over all districts, but only 40% or less of the possible gains in other services or habitat quality. Most of these low-ranked districts lie in the mountainous western parts of the study area where land value for agriculture is lower than in other areas. The Sumatra Vision could result in large gains in avoided erosion at relatively low cost by restoring forests or reducing deforestation on slopes in this region; however, interventions in the higher-cost districts in the lowlands (ranks 12 through 18) that are more suitable for agriculture will be needed in order to realize substantial gains in habitat quality, carbon stocks and nutrient retention. In particular, Indragiri Hilir (the 12th ranked district for opportunity cost, highlighted in red boxes in Figure 5.11) would have a substantial marginal increase in habitat quality, nutrient retention and carbon stocks (especially total carbon) relative to the next cheapest district (Muarojambi, ranked 11). Indragiri Hilir sits almost entirely on peat, and has extensive plantations.

Even though the potential agricultural returns from forest conservation in Indragiri Hilir are higher than in the 11 lower-cost districts, investing in conservation in Indragiri Hilir could bring large gains in ecosystem services and wildlife habitat (Table 5.1, top row) that exceed the possible gains over several of the lower-cost districts combined (Table 5.1, middle row). By multiplying the average per-hectare net present value of forest land for a given district by the amount of forest area in the district in 2008, we roughly estimate the total opportunity cost of forest conservation in each of these districts (Table 5.1, row 3). The opportunity cost thus calculated for Indragiri Hilir is 53,800 billion Rupiah over 50 years, which is similar to, or less than the combined opportunity cost of the cheaper districts. Thus, even though Indragiri Hilir is not by itself the cheapest district to invest in conservation, the high potential gains in service and habitat scores within this one district, relative to smaller gains spread out over multiple lower-cost districts, might make Indragiri Hilir a cost-effective district for intervention. This may be especially true when transaction costs of investing in multiple districts are taken into account.

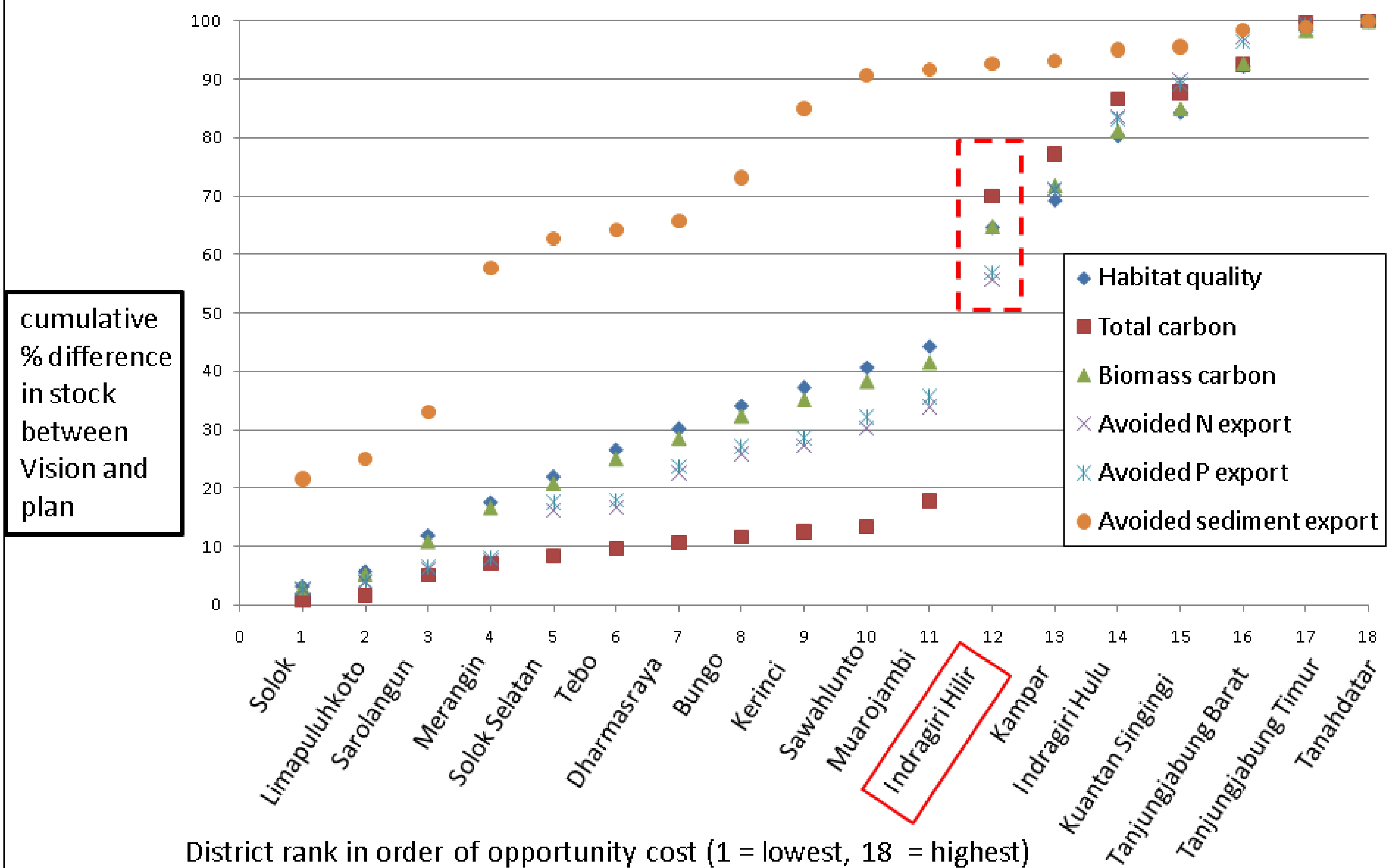


Fig. 5.11. Marginal gains in habitat and service stocks in Vision relative to plan (as a percent of total possible gain over all districts) for districts ranked in increasing order of opportunity cost. Indragiri Hilir is highlighted because of its high marginal gain in habitat quality and most services (red dotted box) relative to the next cheaper district.

Table 5.1. Opportunity costs and potential service gains in Indragiri district compared to districts with lower opportunity costs.					
	Habitat quality	**Total carbon**	**Biomass carbon**	**Nitrogen retention**	**Phosphorus retention**
Percent marginal gain in habitat score or ecosystem service supplied by Indragiri Hilir over the next cheapest district, Muarojambi (see Fig. 5.11)	20	52	23	22	21
How many of the cheapest districts (ranks 1 through 11) would cumulatively supply up to this much service?	4	11	5	6	6
Net present value (over 50 years) of remaining forest in the above cheapest districts (billions of Rupiah)	42,300	147,700	63,190	81,730	81,730

The above example is not meant to imply that investment in ecosystem services and wildlife habitat conservation should be limited to a few districts only, but rather, that high opportunity cost does not necessarily preclude such investments. High gains in benefits could well justify investing in selected districts with high opportunity costs, and Indragiri Hilir stands out a particularly interesting district in this regard.

Maximizing Benefits While Minimizing Losses at the District Level

Managing an ecosystem for one set of benefits could result in a loss of other benefits. In our analyses, two notable tradeoffs we observed were losses in plantation area and annual water yield with a concomitant increase in measures of other services and habitat quality. While tradeoffs are often unavoidable, we can attempt to minimize them by selecting areas for ecosystem services-based programs where the potential gains in targeted services are high relative to the potential foregone benefits.

Compared to other districts, Merangin and Solok districts would experience high gains in avoided sediment export, and Kampar would experience high gains in avoid nutrient export, without large losses in plantation area in the Sumatra Vision relative to the Government Plan (Figure 5.12). Thus, these districts may be good candidates for implementing watershed conservation programs that provide substantial benefits without foregoing much plantation activity. Solok and Kampar would also experience relatively small losses in water yield between the two scenarios (Figure 5.13), further indicating that these two districts should offer opportunities for enhancing and maintaining watershed services with relatively modest tradeoffs. Indragiri Hulu (Figure 5.12) and Kampar (Figure 5.13) would experience higher biomass carbon stock gains than most other districts, accompanied by relatively small losses in plantation area and water yield respectively, suggesting the potential for forest carbon projects with comparatively low tradeoffs for these two factors.

The above are examples of the kinds of insights that can be obtained from our district-level summaries. Further interpretation of these figures could yield additional conclusions relevant to policy for districts.

Assessing Tradeoffs to Specific Beneficiaries to Guide Policy Recommendations

Ultimately, in order to design appropriate policies, tradeoffs in ecosystem services have to be assessed with respect to their potential impacts on specific beneficiaries. While we do not yet have the detailed socioeconomic data necessary to make very precise policy recommendations, we can take some initial steps by focusing on some of the potential beneficiaries previously identified in our analysis of hydrological services (Chapter 3 of this report).

For instance, the town of Kualatungkal in Penguabuan Lagan watershed contains portions of the RIMBA priority area and includes tiger habitat within its contributing sub-watersheds (Figure 5.14 a). Implementing the Sumatra Vision here would improve tiger habitat while providing benefits to the residents of the town through erosion control and nutrient retention, relative to the Government Plan (Figure 5.14 b). However, increased sediment export could be a concern under either scenario, and especially under the Government Plan. These watersheds would lose some carbon stock under the Government Plan, whereas they could maintain or slightly increase their carbon storage under the Sumatra Vision. These results suggest that good watershed management is a priority for this area. Projects for forest carbon, erosion control or nutrient pollution reduction could be explored here.

Kotopanjang is a hydroelectric dam within our study area whose contributing sub-watersheds lie in Kampar and Limapuluhkoto districts and overlap with tiger habitat as well as the RIMBA priority area (Figure 5.15 a). While both the Sumatra Vision and the Government Plan could improve the state of habitat and multiple services here, these benefits would be higher under the Sumatra Vision (Figure. 5.15 b). In particular, the Sumatra Vision would result in a 30% improvement over the Government Plan in erosion control, which could be a significant benefit for the hydropower facility due to reduced dredging and maintenance costs. There might be some loss in annual water yield, but the loss would be similar in the two scenarios. Forest carbon projects and improved watershed management upstream of the dam have the potential to benefit users.

Last, we focused on a sub-watershed containing Lake Singkarak, another important source of hydropower, and the town of Sawahlunto (Figure 5.16 a). Implementing the Sumatra Vision here would lead to an increase in carbon stock and habitat quality, while the Government Plan would result in a decrease in habitat quality and similar carbon stocks relative to 2008 (Figure 5.16 b). While hydrological services could decrease under both scenarios, the decrease would be substantially more under the Sumatra Vision than the Government Plan. This suggests that good watershed management is a priority here.

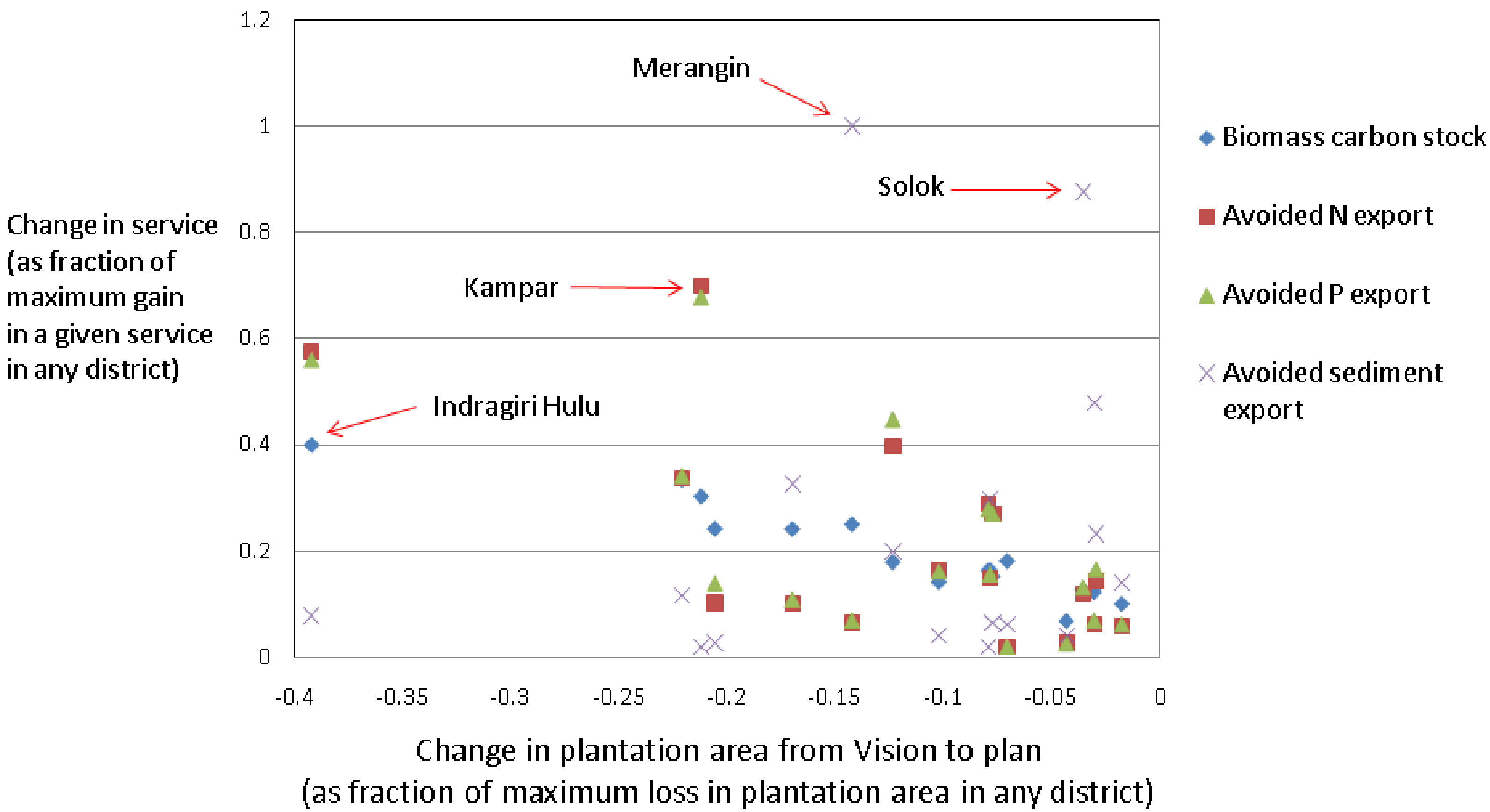


Fig. 5.12. District-level tradeoffs among losses in plantation area and gains in ecosystem services in the Vision relative to the plan.

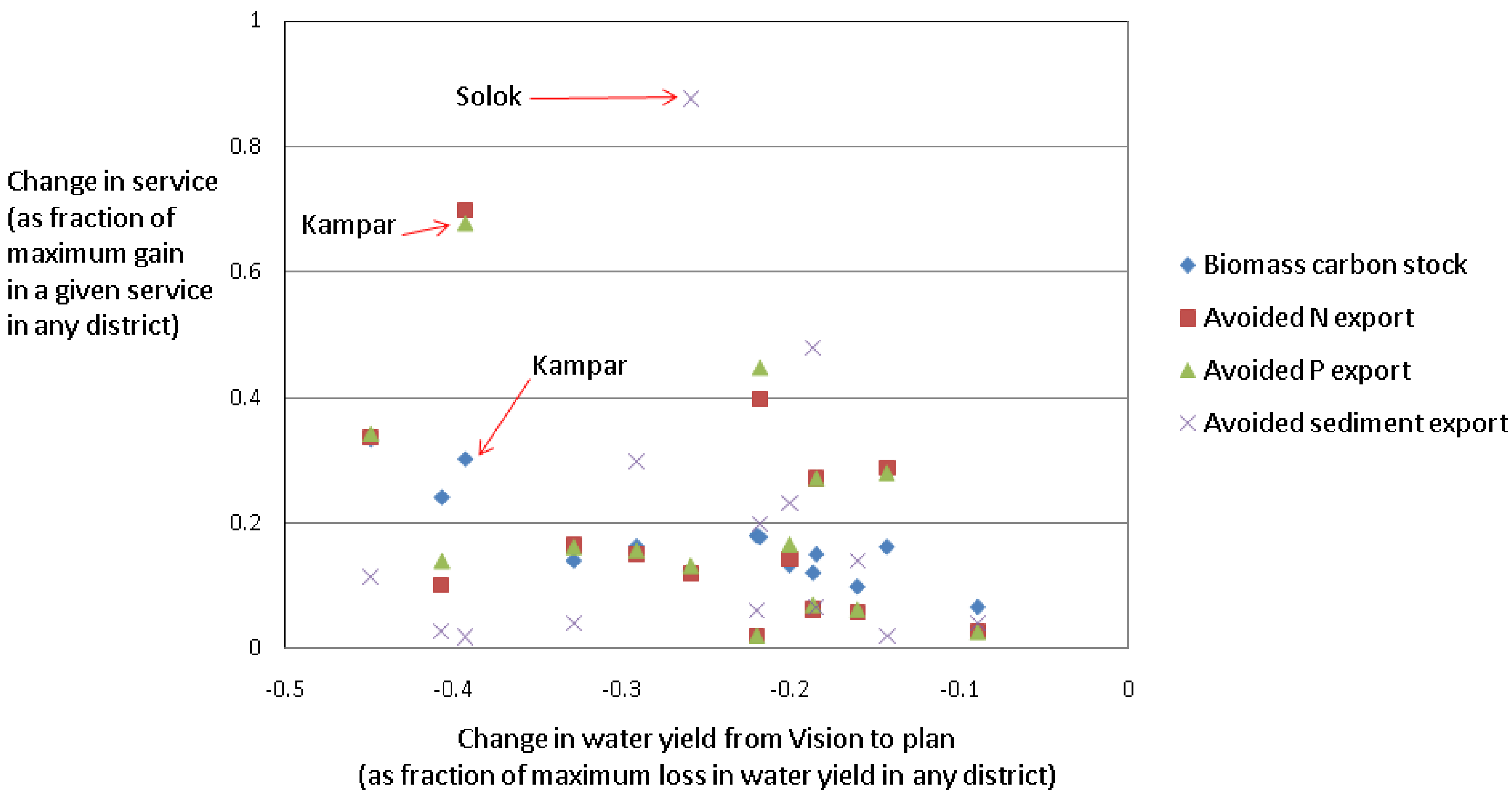


Fig. 5.13. District-level tradeoffs among losses in water yield and gains in other ecosystem services in the Vision relative to the plan.

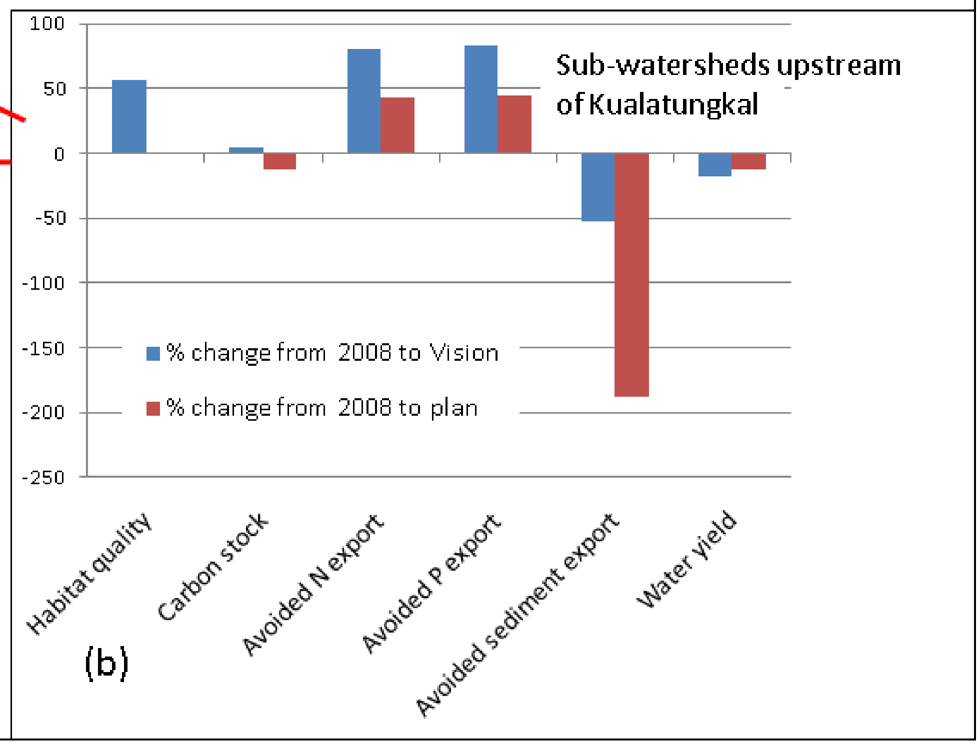
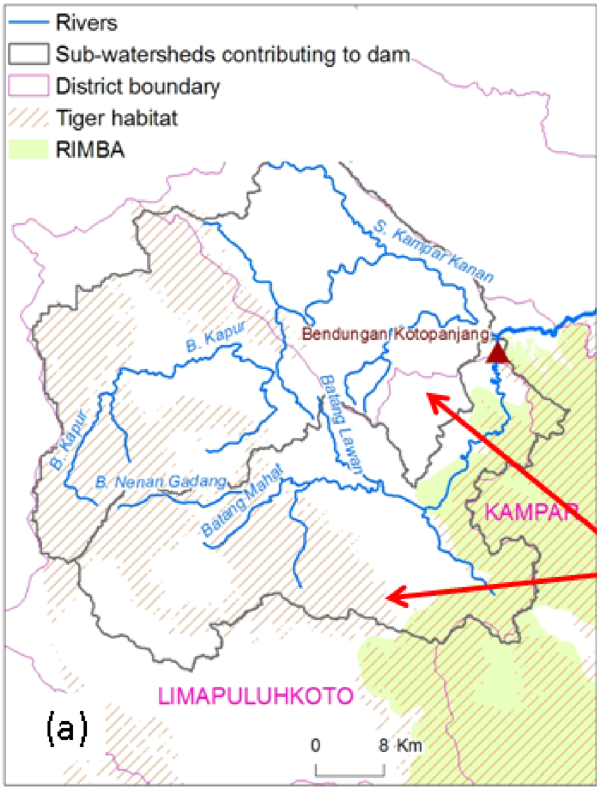


Fig. 5.14. The town of Kualatungkal could benefit from projects upstream that would reduce erosion and nutrient export, and maintain or enhance carbon stocks. Such projects could also improve habitat for tigers



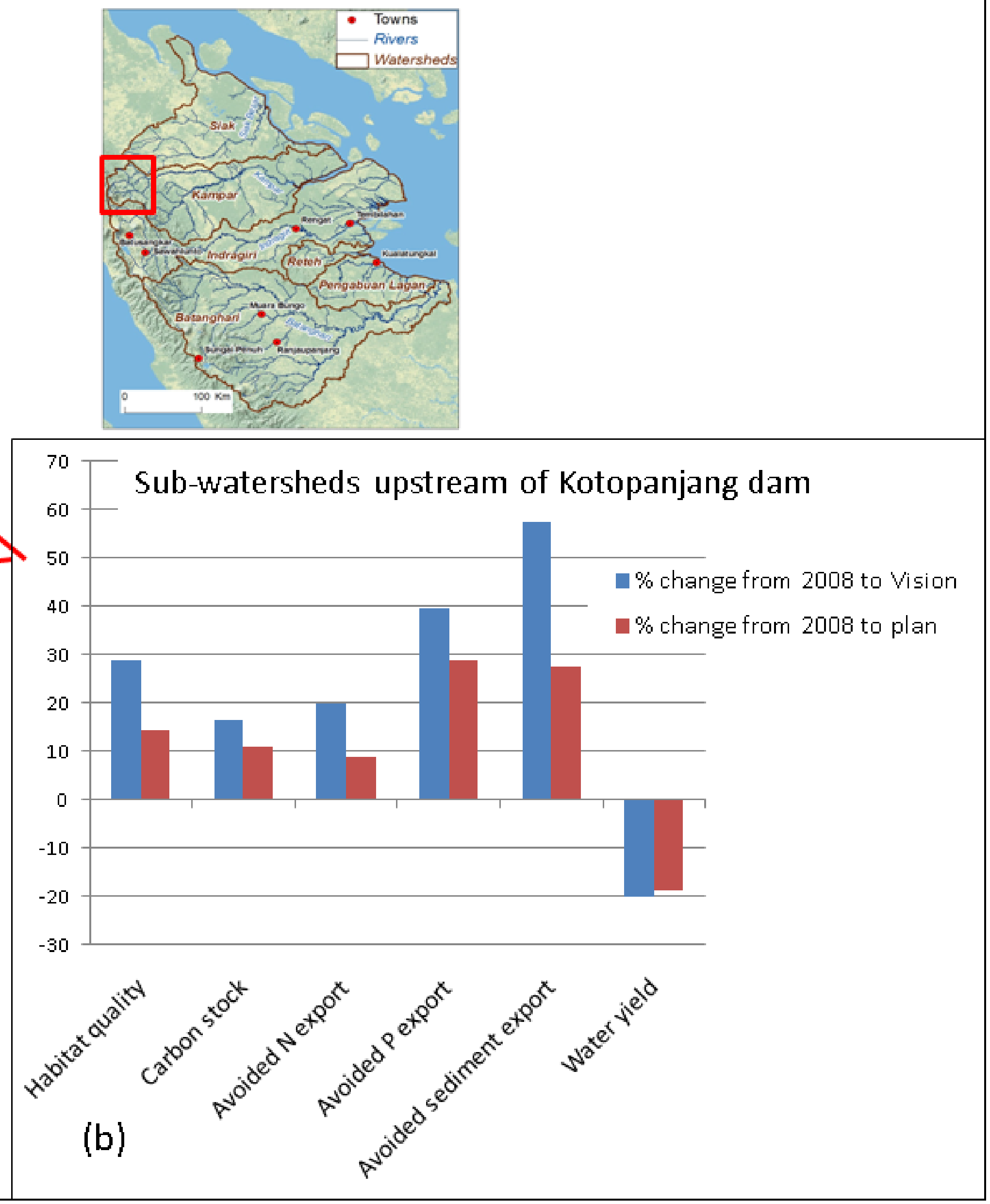


Fig. 5.15. The hydropower facility of Kotopanjang could benefit from watershed management programs upstream. Such programs could substantially reduce sediment exported to the dam, while also enhancing tiger habitat and carbon stock

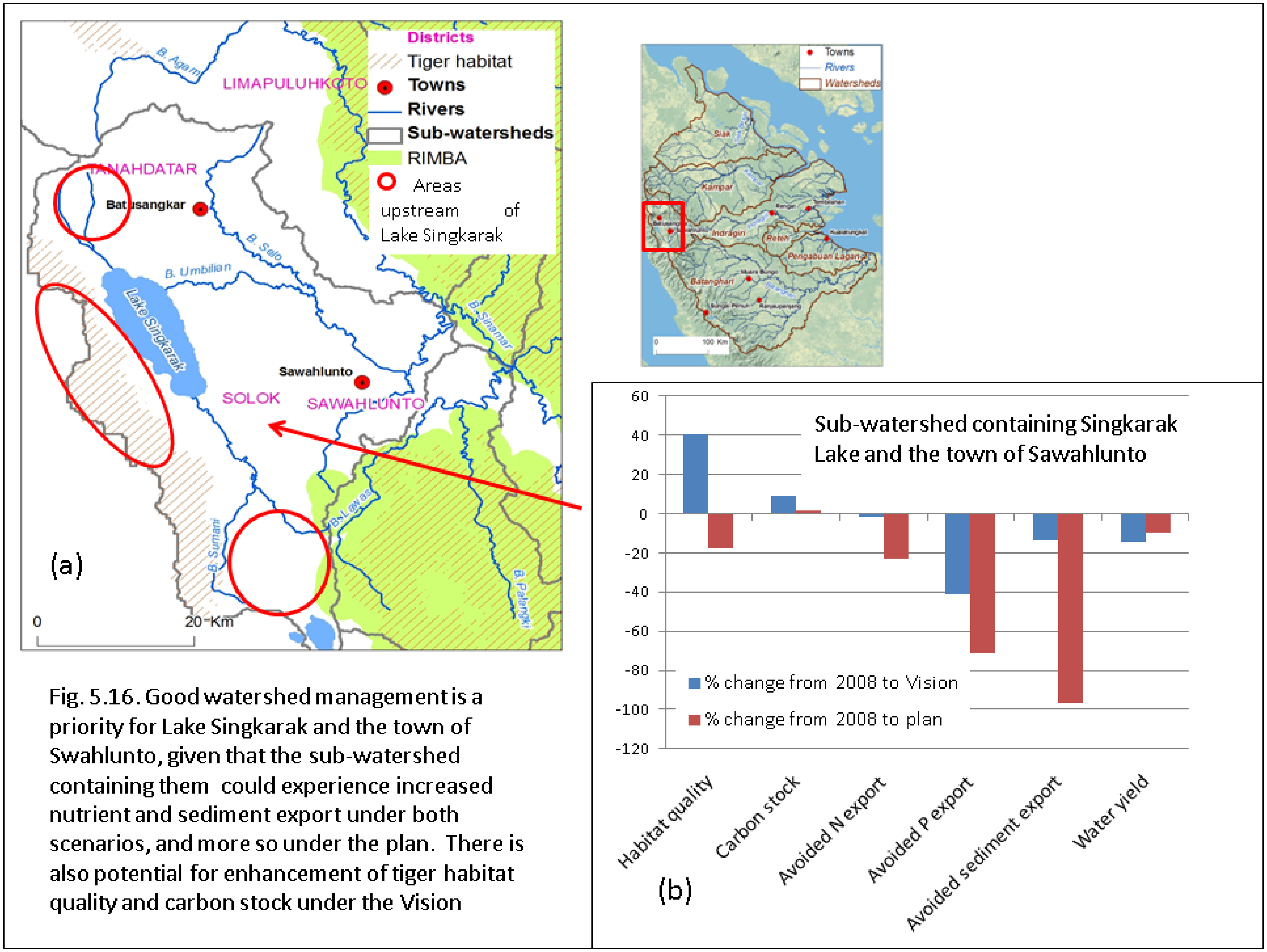


Fig. 5.16. Good watershed management is a priority for Lake Singkarak and the town of Swahlunto, given that the sub-watershed containing them could experience increased nutrient and sediment export under both scenarios, and more so under the plan. There is also potential for enhancement of tiger habitat quality and carbon stock under the Vision

These analyses demonstrate how information about ecosystem services and conservation priorities can be used to identify policies and target places that minimize tradeoffs and attain a set of sustainable development goals.

Additional Considerations

Conduct Analyses at Appropriate Scales and Locations for Decisions

Although assessing tradeoffs and synergies can provide useful insights for policy design, it is important to do separate analyses at the appropriate scale for decisions, as the nature of these interactions can vary by scale and location. For instance, we would observe increased erosion and decreased nutrient pollution at the scale of the entire study area under both scenarios (Figure 5.3), but these trends vary depending on the specific watershed or district for which watershed management policies may be designed. For habitat conservation and carbon storage and sequestration, analyses spanning a larger area (multiple watersheds and districts) may be more appropriate.

The difference in trends of overlap among services and habitat across locations is due in part to the underlying heterogeneity of the landscape. Thus, the carbon-rich peat lowlands could offer substantial carbon sequestration benefits under the Sumatra Vision, but modest hydrological benefits in some areas; whereas, the hilly region of the study area could offer high benefits in hydrological services, but less carbon sequestration than the peatlands.

Loss in Annual Water Yield

One tradeoff that we observe throughout our analyses is a potential loss in annual water yield across both scenarios and at all scales. This could be due to increased vegetation on the landscape under either scenario, whether through reforestation or through expansion of plantations. The loss of annual water yield with increased tree cover has been report elsewhere (e.g. Bruijnzeel 2004, FAO and CIFOR 2005). However, there is much debate about the nuances of what this decreased water yield could mean in terms of impacts on water users; it could be either positive or negative (e.g. seasonal flows and timing, flood mitigation, and base flow). Without additional local data and field studies, our analysis does not allow us to assess whether or not increased vegetation would result in benefits (e.g. through more regular water supply during dry periods, or through flood mitigation) or losses (e.g. through reduced water availability downstream). In any case, the potential losses in water yield are modest and similar across both scenarios. We use our water yield results mainly to identify districts where the potential losses in water yield are the smallest relative to the gains in other services (Figure 5.13), rather than to look for gains in this service across either scenario.

Future Directions

Although the list below is not exhaustive, some potentially useful future areas of investigation are as follows:

We have only analyzed a select set of services. Incorporating additional services, such as health benefits, agricultural productivity, non-timber forest product provision, the potential for ecotourism, and crop pollination by natural pollinators would allow for a more comprehensive accounting of the benefits and costs of alternative development scenarios. In particular, smoke and haze from Indonesian peat forest fires are known to have significant health and economic impacts across Southeast Asia (Heil and Goldammer 2001); these impacts need to be further quantified and could add persuasive arguments in support of the benefits of preventing further deforestation. Furthermore, while we focused on terrestrial services in this analysis, a study of land-sea interactions would likely reveal additional relevant insights. For instance, reducing erosion may also be beneficial for marine environments and the services they provide, such as marine fisheries and coastal tourism.

These are preliminary assessments of biophysical variation in ecosystem services. These analyses should be updated through ground-truthing, validation and expert review, and by using improved input data where possible. Detailed institutional information and socioeconomic analyses of stakeholders and beneficiaries of ecosystem services will also be needed to devise equitable and feasible policies.

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Appendices

Appendix 2.1 Input values for above-ground, below-ground and dead organic matter carbon pools (tonnes/ha)

LULC	LULC_NAME	C_above	C_below	C_dead
1	Dry Lowland Forest rather closed canopy	172.49	72.38	4.00
2	Dry Lowland Forest medium open canopy	120.32	50.76	4.00
3	Dry Lowland Forest very open canopy	51.94	21.62	3.00
4	Peat Swamp Forest rather closed canopy	117.03	43.24	2.00
5	Peat Swamp Forest medium open canopy	109.98	40.89	2.00
6	Peat Swamp Forest very open canopy	29.14	10.81	2.00
7	Swamp Forest rather closed canopy	103.40	38.07	2.00
8	Swamp Forest medium open canopy	76.00	28.20	2.00
9	Swamp Forest very open canopy	20.68	7.52	1.00
10	Mangrove Forest rather closed canopy	87.89	21.15	1.00
11	Mangrove Forest medium open canopy	65.80	15.98	1.00
12	Mangrove Forest very open canopy	17.39	4.23	1.00
13	Young Mangrove	17.39	4.23	1.00
14	Forest Re-growth (Belukar)	15.51	5.64	1.00
15	Shrubs (Semak/Belukar Muda)	20.68	8.46	1.00
16	Forest Re-growth on Swampy	15.51	5.64	1.00
17	Shrubs on Swampy	20.68	8.46	1.00
18	Swamp Grasses/Fernland	6.11	1.41	1.00
19	Overgrowing Clear cut-Shrubs	7.52	1.88	2.00
20	Grassland	6.11	1.41	0.00
21	Cleared, for Acacia Plantation	0.00	0.00	1.00
22	Cleared, for Oil Palm Plantation	0.00	0.00	1.00
23	Cleared	0.00	0.00	2.00
24	Sand Mining	0.00	0.00	0.00
25	Burnt	0.00	0.00	2.00
26	Young Acacia Plantation	48.88	11.75	1.00
27	Acacia Plantation	97.29	23.50	1.00
28	City Park (Hutan Kota)	14.10	3.29	0.00
29	Young Oil Palm Plantation	51.23	12.22	1.00
30	Oil Palm Plantation	51.23	12.22	1.00
31	Small Holder Oil Palm	39.01	9.40	0.00
32	Small Holder Young Oil Palm Plantation	39.01	9.40	1.00
33	Mosaic of Small Holder Oil palm and Rubber	55.46	13.16	1.00
34	Rubber Plantation	103.40	24.91	1.00
35	Small Holder Rubber	71.91	17.39	1.00

36	Coconut Plantation	37.60	8.93	1.00
37	Mixed Agriculture	26.32	6.11	1.00
38	Mixed Garden	14.10	3.29	1.00
39	Paddy Field	4.35	0.94	1.00
40	Water Body	0.00	0.00	1.00
41	Town	0.00	0.00	0.00
42	Settlement	7.05	1.88	0.00
43	Factory	0.00	0.00	0.00
44	Airport	3.53	0.94	0.00
45	Fishpond	0.00	0.00	0.00
46	Mill-Oil	0.00	0.00	0.00
47	Cloud or no information [10]	73.95	27.26	2.00
48	Gmelina Plantation	97.29	23.50	0.00
49	Caldera	0.00	0.00	0.00
50	Cinnamon Plantation	26.32	6.11	2.00
51	Cleared for Oil Palm Plantation	0.00	0.00	1.00
52	Cleared post Acacia harvested	0.00	0.00	1.00
53	Cloud [10]	73.95	27.26	2.00
54	Coal Mining	0.00	0.00	1.00
55	Dry Lowland Forest (0-500 m) medium open canopy	120.32	50.76	3.00
56	Dry Lowland Forest (0-500 m) rather closed canopy	172.49	72.38	3.00
57	Dry Lowland Forest on Metamorphic Rock medium open canopy	120.32	50.76	2.00
58	Formation on limestones medium open canopy	172.49	41.36	2.00
59	Dry Lowland Forest on Metamorphic Rock rather closed canopy	172.49	72.38	2.00
60	Dry Lowland Forest on Metamorphic Rock very open canopy	52.17	22.09	1.00
61	Dry Lowland Forest (0-500 m) very open canopy	52.17	22.09	3.00
62	Formation on limestones very open canopy	52.17	12.69	1.00
63	Formation on limestones rather closed canopy	172.49	41.36	3.00
64	Fresh Water Swamp Forest medium open canopy	76.14	28.20	2.00
65	Fresh Water Swamp Forest rather closed canopy	103.40	38.07	2.00
66	Fresh Water Swamp Forest very open canopy	29.14	10.81	2.00
67	Hill Forest (500-1000 m) medium open canopy	143.35	53.11	3.00
68	Hill Forest (500-1000 m) rather closed canopy	143.35	53.11	3.00
69	Hill Forest (500-1000 m) very open canopy	71.68	26.32	2.00
70	Hill Forest on Metamorphic Rock medium open canopy	143.35	53.11	1.00
71	Hill Forest on Metamorphic Rock rather closed	143.35	53.11	1.00

[10] Most areas designated "Cloud" or "Cloud or No Information" on the 2008 land cover map were in or near forested areas. We assigned them the median carbon value of all forested land cover types.

	canopy			
72	Hill Forest on Metamorphic Rock very open canopy	71.91	26.79	1.00
73	Illegal gold Mining Area	0.00	0.00	1.00
74	Low Forest & thickets of the Ericaceous zone closed canopy	33.84	7.99	1.00
75	Montane Forest (2000-2500 m) medium open canopy	130.66	35.25	4.00
76	Montane Forest (2000-2500 m) rather closed canopy	130.66	35.25	4.00
77	Montane Forest (2000-2500 m) very open canopy	65.33	17.86	1.00
78	Mosaic of Settlement & Mixed Garden	10.58	2.35	1.00
79	Pinus merkusii Plantation	47.00	11.28	1.00
80	Riparian Forest medium open canopy	76.00	28.20	1.00
81	Riparian Forest rather closed canopy	103.40	38.07	2.00
82	Riparian Forest very open canopy	20.68	7.52	1.00
83	Submontane Forest (1000-2000 m) medium open canopy	143.35	53.11	2.00
84	Submontane Forest (1000-2000 m) rather closed canopy	143.35	53.11	3.00
85	Submontane Forest (1000-2000 m) very open canopy	71.68	26.32	2.00
86	Submontane Forest on Metamorphic Rock rather closed canopy	143.35	34.31	0.00
87	Tea Plantation	26.32	6.11	0.00
88	Topogen Peat Swamp Forest	89.70	33.37	2.00
89	Young Mangrove rather closed canopy	52.64	12.69	1.00
101	APL [11]	26.32	6.32	1.00
102	Bare Land	0.00	0.00	2.00
103	Dryland Farming	13.16	3.16	1.00
104	Fishery	0.00	0.00	1.00
107	Industry	0.00	0.00	0.00
108	Mining	0.00	0.00	0.00
109	Plantation [12]	50.29	12.07	1.00
111	Natural Forest (under the cloud covers) [13]	130.66	42.77	2.00
113	Caldera	0.00	0.00	0.00
114	Converted Production Forest [14]	73.95	27.26	2.00
115	Limited Production Forest [13]	130.66	42.77	1.00
116	Low Forest & thickets of the Ericaceous zone	33.84	8.12	2.00

[11] APL is the designation for land that has been set aside for future development in the government spatial plan. As we do not know what specific land use a given APL parcel will have in future, we assigned all APL areas a carbon stock equal to the median of all land cover types specified to be under direct human use (including production forests, plantations and built-up areas).

[12] If areas that are not plantations in the 2008 land cover map are designated as "plantation" in either scenario, we assigned them to a generic plantation class and gave them a carbon stock equal to the median of all plantation types.

117	Nature Reserve Forest [13]	130.66	42.77	2.00
119	Production Forest [14]	73.95	27.26	2.00
120	Protected Forest [13]	130.66	42.77	2.00
124	Protected Area [13]	130.66	42.77	2.00
126	Forest [13]	130.66	42.77	2.00

[13] If areas were designated as forests, protected areas or limited production forests, but we did not know the specific type of forest, we assigned them the median carbon stock of all forest types (except very open forest – we assumed that forests, unless they were designated production forests, are in moderate to good condition).
[14] Production forests whose forest type was unknown were assigned the median carbon stock of all forest types (including very open forest)

Appendix 2.2. Methodology for calculating carbon storage and stocks

For above-ground biomass (AGB), we use data provided in Uryu et al. (2008), supplemented with estimates for Jambi province (SEAMEO-BIOTROP 1999) where available for a given LULC type. Uryu et al. (2008) estimated biomass values (metric tonnes/ha) as medians of published (when possible, region-specific) biomass values for different LULC classes extracted from a literature search. Most of the LULC classes in Uryu et al. (2008) are consistent with those in our LULC scenario maps, and the values are directly transferred in those cases. When a LULC class in our map does not appear in Uryu et al. (2008), we take the median value of similar classes (e.g., generic "plantation" and "forest" classes in our scenario maps are assigned the median values of all plantations and mature forest classes, respectively). We multiply AGB by a factor of 0.47 (IPCC 2006, Vol. 4, Table 4.3) to convert to t/ha of carbon.

Below-ground biomass is calculated as a fraction of AGB, using root : shoot biomass ratios for tropical ecosystems provided in IPCC guidelines (IPCC 2006, Vol. 4, Table 4.4). For carbon stored in dead organic matter, we use estimates of carbon in leaf litter provided in IPCC 2006 (Vol. 2, Table 2.2) for tropical ecosystems, assigning zero or downscaled values for human-modified or bare land uses.

We generate a soil carbon layer using the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC 2009) for non-peat areas. Soil carbon content for non-peat areas is estimated by averaging the carbon content of topsoil and subsoil to a depth of 100 cm. To do this, the percent carbon in topsoil and subsoil in each soil polygon is averaged and multiplied by the average bulk density of topsoil and subsoil to calculate the average density of carbon in the polygon. Multiplying the carbon density by the volume of the polygon gives a rough estimate of the carbon content in the top 100 cm of soil of non-peat soils, which is then expressed in metric tonnes/ha. Where peat soils occur on the landscape, we replace the world soil layer with a peatland distribution layer from Wetlands International that includes spatially explicit estimates of peat carbon content (Wahyunto et al. 2003).

Uryu et al. (2008) calculated median annual CO_2 emission rates due to peat decomposition tied to specific land cover changes from forest to non-forest (due to plantations, clearing and other activities - see Table 7 of their report). We use these estimates to calculate annual carbon loss from peat soil attributable to these changes. From the baseline soil carbon map, we subtract the annual peat carbon loss from each pixel that changed from forest to another state in a given scenario. These values are multiplied by 50 to assess carbon changes over the full 50 years of the modeling. We do not calculate any soil carbon loss for the non-peat areas as we lack data for soil carbon emissions linked to LULC changes in non-peat areas. However, these losses are likely to be much less than in the peat areas.

Our estimates of carbon stock changes are approximate. For our future scenarios, we assume all plantation areas to have mature plantations, even though some areas are likely to be in intermediate stages between planting cycles, and thus either cleared or immature at any given point in time. However, the biomass values from Uryu et al. (2008) that we use for plantations already take this into account, using a downscaled value of biomass to account for intermediate growth stages. We also do not take into account carbon emissions from burning of peat, which often accompanies land clearing for plantations, and released an estimated 0.38 Gigatonnes of carbon in Riau alone from 1997 to 2007 (Uryu et al. 2008). We do not attempt to model the future spatial distribution and intensity of burns over our scenario time frame, which would be necessary to estimate future emissions from peat burning. Finally, our estimates of future forest related carbon stocks do not account for future climate change driven alterations of forest productivity, carbon cycling, or disturbance dynamics.

Appendix 2.3. Methodology for calculating value of intensive management (forest conversion)

- We randomly sample 228,000 pixels across the 2008 land use / land cover (LULC) map
- from these randomly sampled pixels, we can identify the fraction of cells deforested since 2000 (forest to plantation) that are engaged in each of the various land uses that are included in our plantation category;
- assuming that this currently-observed fraction will hold throughout our project time horizon, we can use these percentages to create a weighted-average value of plantation land;
- having identified the relative contribution of each of our intensive management categories to total forest conversion in a district, we can then multiply the fraction of converted forest attributable to each of the above categories by the value of that land use to estimate the average returns to forest conversion in each district.

Here are the steps that we follow to arrive at our estimates of intensive management value within each of our districts of interest

1) Calculate the value of acacia harvest for mineral and peat soils and for pixels with different combinations of elevation (200 m is the key threshold) and slope (15% is the key threshold) with the following assumptions:
    a. acacia harvest occurs after five years of growth across all soil types on plantations and after eight years of growth for small holders (note that there are not small-holder acacia plantations in our random sample of 228 thousand pixels) – given our 50-year time horizon, that means that each pixel of acacia plantation is assigned a net present value based on 10 rotations while pixels of small-holder acacia are assigned a net present value based on 6 rotations;
    b. the remaining assumptions are based on information provided by Mr. ERIZAL from the House of Forest Inventory and Mapping Forestry Services of Jambi Province to Pak Suparmoko:
        i. there is only a single price listed for acacia, so we assume that there will be a constant real price over the time horizon;
        ii. furthermore, we assume that the interest rate is 10% throughout the analysis.
2) Calculate the value of oil palm harvest for both mineral and peat soils with the following assumptions taken from Herman et al. (2009) unless otherwise noted:
    a. oil palm trees bear fruit with different yields between years 3 and 25 of their life, at which point the trees are felled and a new cycle begins (so there are two rotations during our 50-year time horizon), with the maximum yield from 8-13 years;
    b. small-holder operations receive compensation based on fresh fruit bunches (ffb), while plantations are paid based on oil yield;
    c. annual-average prices from 2001-2009 and 1999-2008 available for ffbs (from the Estate Service of East Kalimantan) and oil (from Oil World and Reuter's), respectively;
        i. it is possible for us to assume several different price trajectories over the span of our 50-year time horizon, and we choose three:

1. the high-value approach assumes that prices for both ffb and oil will start at the highest recorded level in the dataset and that there is no inflation,
2. the average-value approach assumes that prices for both ffb and oil will start at the average level of the prices observed in the data set and that there is no inflation,
3. the low-value approach assumes that prices for both ffb and oil will start at the lowest observed level in the data set and that there is no inflation;

d. we assume that the plantation costs from Herman et al. (2009) are for a 1000-ha plantation and that small-holder profits are 35% of plantation profits;
e. finally, we do not distinguish between the profitability of peat and mineral soils, as we do not have accurate information about the additional costs of establishing a plantation on peat land.

3) Calculate the value of rubber harvest with the following assumptions based on information provided by Mr. ERIZAL from the House of Forest Inventory and Mapping Forestry Services of Jambi Province to Pak Suparmoko:
   a. trees produce a constant amount of sap over the seven years before they are harvested for firewood;
   b. in the eighth year, the trees are harvested and sold for timber, with replanting occurring immediately after harvest – over our 50-year time horizon, we assume that there will be six rotations on rubber plantations;
   c. there is no difference in cost or revenue between small-holder and plantation rubber operations.
4) We next need to develop an average value of land in each of our districts of interest, which we do by weighting the returns to each LULC category that falls within the plantation classification by the area of land in the district that was converted from forest to this LULC category between 2000 and 2008:
   a. for each LULC category that has a previously-determined value associated with it, we simply multiply this value by the percentage of forest that was converted to this LULC;
   b. for the LULC categories that are not associated with previously-determined values, we make the following assumptions:
      i. pine plantations are given the per hectare value associated with acacia grown on land below 200 m in elevation and less than 15% slope;
      ii. cinnamon, coconut, gmelina, and tea are given the value associated with rubber;
      iii. the rest of the categories (mixed agriculture, mixed garden, mosaic of settlement and mixed garden, mosaic of small-holder oil palm and rubber, and paddy field) are given 75% of the lowest value associated with the acacia, oil palm, and rubber plantations, which turns out to be small holder oil palm.

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Appendix 3.1. Data sources for hydrological models

Data Layers Used in Multiple Models:

Digital Elevation Model (DEM): We used a 90m resolution DEM from HydroSHEDS (://hydrosheds.cr.usgs.gov/). We re-sampled the DEM to 30m pixel size using bilinear interpolation, and ran the fill sinks function in the ArcGIS Hydrology toolbox to fill sinks prior to running InVEST, which requires filled and corrected DEM.

Sub-watersheds: We sub-divided the study area into smaller sub-watersheds as InVEST currently cannot process very large watersheds in a single iteration, and also to be able to analyze spatial variation at finer scales. We generated a sub-watersheds layer from the DEM using the Automatic Watersheds delineation module of ArcSWAT.

Precipitation: We started by using the precipitation data from the National Water Public Works agency of Indonesia, provided by WWF Indonesia. However, these data had gaps and inconsistencies, such as annual average precipitation at different locations calculated using ranges of years that were not clearly specified. So we used a global annual average precipitation layer ("bio_12" grid, 30 arc-seconds or ~1 km resolution at the equator) from WorldClim (.worldclim.org).

Data Inputs for Water Yield Modeling:

Potential evapotranspiration (PET): We used "global map of monthly reference evapotranspiration" (10 arc-minutes, ~18.5 km resolution at the equator), downloaded from the FAO GeoNetwork spatial data portal (://www.fao.org/geonetwork/srv/en/main.home).

Land cover coefficients for the water yield model: For each land cover class in the 2008 LULC map, we started by using the default values for evapotranspiration coefficient and root depth (as provided in the InVEST user guide). These were then further modified as follows. The vegetation coefficients (etk) were refined based on our best knowledge of LULC characteristics and Sumatran farming and growth conditions, as well as using data from FAO (://www.fao.org/docrep/x0490e/x0490e0b.htm). The root depth values were estimated from (Canadell et al., 1996) and the FAO crop water information website (://www.fao.org/landandwater/aglw/cropwater/cwinform.stm#database).

Soil depth: We used the "Digital soil map of the world, version 3.6" (1:5,000,000 resolution) and the "Effective soil depth" (5 arc-minute resolution, ~9.25 km at the equator) layers, both available from the FAO GeoNetwork spatial data portal (://www.fao.org/geonetwork/srv/en/main.home). We linked the soil mapping unit polygons from the digital soil map to the depth table associated with the effective soil depth layer. This table contains the fractions of five depth horizons (ranging from very shallow to very deep) in each soil mapping unit. We took the midpoint of each depth range (for example, the shallow class had which a depth range of 10-50 cm was assigned a depth value of 35 cm, and the "very shallow" class that had a depth of <10 cm was given a depth value of 5cm). We then assigned each soil mapping unit polygon a depth, calculated as the weighted average of all the depth classes present within that unit, where the weighting factor was the fraction of a given depth range within that unit. Finally, for peat areas we used midpoints of depth ranges obtained from the Wetlands International peat soil layer (Wahyunto et al 2003) instead of the FAO layers.

Plant-available water content fraction: We used a global layer of “maximum available soil moisture” (5 arc minutes, ~9.25 km at the equator) downloaded from the FAO GeoNetwork spatial data portal (://www.fao.org/geonetwork/srv/en/main.home). Raster values were converted to dimensionless fraction by dividing this “maximum soil moisture” grid by 1000.

Data Inputs for Sediment Export Modeling

Rainfall erosivity: We used the Lenvain equation for erosivity as used by the Indonesian government (Ministry of Forestry, 2009). This equation expresses erosivity as a function of monthly precipitation:

$$Rm = 2.21 * (Pm\wedge 1.36)$$

where Rm is monthly erosivity and Pm is the monthly precipitation. The Rm was summed over the twelve months to get the annual erosivity. In order to apply this method, we obtained monthly precipitation data from the FAO GeoNetwork spatial data portal (://www.fao.org/geonetwork/srv/en/main.home, “Global map of monthly precipitation - 10 arc minutes”), which provides monthly averages of precipitation and other climate variables from 1961 to 1990. The results of this method were compared to the erositivity map in the Jambi region obtained from a previous study (see below) and were found to be in the same value range.

Soil erodibility: We used an erodibility layer for Jambi that was developed by the Regional Development Planning Board of Jambi as part of a 2008 study (unpublished) on vulnerability to erosion in the Jambi province. We obtained erodibility data for Riau and West Sumatra from the Division of Water Management of the Riau Forestry Department. These two datasets covered most of the study area, with the exception of a strip straddling the boundary of Jambi with the other two provinces. For this area, we estimated erodibility based upon the soil characteristics in surrounding areas where there are erodibility values.

Land use land cover (LULC) coefficients for sediment export modeling: We initially estimated cropping and practice factors based on values provided in the InVEST user guide (Tallis et al. 2010) for different land cover types. We refined these parameters based on the Jambi study in which there is a detailed description of LULC parameters for the crop factor (C), management factor (P).

Data Inputs for Nutrient Export Modeling

LULC coefficients for nutrient export modeling: Initially, we used the export coefficients detailed in Reckhow et al. (1980). We updated these values for the Sumatran context using values from Chew and Pushparajah (1995, Table 2 on pg. 230, ://books.google.co.ls/books?id=PfjxThK1MDUC&lpg=PP1&hl=en&pg=PA230#v=onepage&q&f=false) and Mackensen and Folster (2000). For future analyses, we recommend replacing the values of oil palm and rubber nutrient export coefficients with the “Runoff / leaching loss” values from Table 14 on page 245 of Chew and Pushparajah (1995), instead of the values we used from their Table 2, as the latter values better reflect nutrient export to streams. The retention coefficients were estimated based on Uusi-Kamppa et al. (1997).

Appendix 3.2. Calculation of runoff depth from water yield

The runoff depth of a polygon (such as a district or a watershed) is calculated as

$$\frac{(p \times \sum_x y_x)}{A}$$

where

p is the area of each pixel

y_x is the depth of water yield in pixel x (i.e., the output from the InVEST water yield model), where x is a pixel contained within the polygon.

A is the area of the polygon

Appendix 3.3. Tables of input coefficients for hydrological models

LU_NAME	lucode	etk	root_depth	load_n	load_p	eff_n	eff_p	usle_c	usle_p	sedret_eff
Acacia Plantation	27	1000	7000	21000	500	25	25	150	200	60
Airport	44	50	100	100	1	5	5	10	100	5
APL	101	650	5000	0	0	0	0	200	500	35
bare land	102	50	100	70	1	5	5	800	250	25
bare land	123	50	100	70	1	5	5	800	250	25
Burnt	25	50	1500	120	1	5	5	600	250	30
Caldera	113	10	10	50	1	5	5	10	10	5
Cinnamon Plantation	50	900	2000	2500	100	25	25	150	200	50
Cleared	23	250	1500	70	70	0	0	300	200	30
Cloud or no information	47	1000	1500	1610	1	50	50	10	100	70
Coconut Plantation	36	850	7000	47200	8600	25	25	150	200	50
Converted Production Forest	114	1000	6500	1610	1	40	40	100	150	45
Dry Lowland Forest medium open canopy	2	1100	7300	1610	1	40	40	13	100	60
Dry Lowland Forest rather closed canopy	1	1300	7300	1610	1	40	40	10	70	80
Dry Lowland Forest very open canopy	3	800	7300	1610	1	40	40	15	100	60

dryland farming	103	500	2600	9030	1400	10	10	300	250	25
fishery	104	1000	2000	10	1	1	1	0	10	50
Forest	126	1100	7000	1610	1	30	30	15	50	50
Forest Re-growth (Belukar)	14	900	7000	1000	1	15	15	100	150	60
Forest Re-growth on Swampy	16	1000	7000	1000	1	15	15	80	150	80
Formation on limestones medium open canopy	58	800	7300	1500	1	10	10	13	70	70
Formation on limestones rather closed canopy	63	1000	7300	1500	1	10	10	10	50	80
Formation on limestones very open canopy	66	700	7300	1500	1	10	10	10	100	60
Fresh Water Swamp Forest	64	1100	5000	1000	1	50	50	13	70	70
Gmelina Plantation	48	800	2500	1500	1	25	25	150	200	50
Hill Forest (500-1000 m) medium open canopy	67	1100	7300	1500	1	40	40	13	70	70
Hill Forest (500-1000 m) rather closed canopy	71	1300	7300	1500	1	40	40	10	50	80
Hill Forest (500-1000 m) very open canopy	69	1000	7300	1500	1	40	40	15	100	60
industry	107	50	1	13790	3010	1	1	500	100	5
Limited Production Forest	115	1100	7000	1200	1	20	20	15	50	60
Low Forest & thickets of the Ericaceous zone	116	1100	5000	1500	1	20	20	10	50	70
Low Forest & thickets of the Ericaceous zone	74	1100	5000	1500	1	20	20	10	50	70
Mangrove Forest medium open canopy	11	1200	7300	700	1	60	60	13	70	80
Mangrove Forest rather closed canopy	10	1350	7300	700	1	60	60	10	50	90
Mangrove Forest very open canopy	12	1000	7300	700	1	60	60	15	100	70
Mill-Oil	46	50	1	0	0	1	1	500	100	5

mining	108	100	1	70	1	5	5	500	500	5
Mixed Agriculture	37	650	2100	11000	3000	15	15	200	500	35
Mixed Garden	38	650	5000	9000	140	10	10	200	500	35
Montane Forest (2000-2500 m) medium open canopy	75	1100	7300	16100	1	50	50	13	70	60
Montane Forest (2000-2500 m) rather closed canopy	76	1300	7300	16100	1	50	50	10	50	70
Montane Forest (2000-2500 m) very open canopy	77	1000	7300	16100	1	50	50	15	100	50
Mosaic of Settlement & Mixed Garden	78	650	7300	5000	1000	10	10	200	200	35
Mosaic of Small Holder Oilpalm and Rubber	33	850	7000	7000	5000	15	15	150	250	50
Natural Forest (under the cloud covers)	111	1300	7300	1610	1	50	50	10	50	70
Nature Reserve Forest	117	1300	7300	1610	1	50	50	10	50	70
Oil Palm Plantation	30	850	7000	70000	9800	20	20	150	200	50
Overgrowing Clear cut-Shrubs	19	300	5100	800	1	25	25	200	150	50
Paddy Field	39	850	2100	12530	1820	10	10	100	150	70
Peat Swamp Forest medium open canopy	5	1200	5500	100	1	30	30	13	70	80
Peat Swamp Forest rather closed canopy	4	1350	5500	100	1	30	30	10	50	90
Peat Swamp Forest very open canopy	6	1100	5500	100	1	30	30	15	100	70
Pinus merkusii Plantation	118	850	7000	2500	100	25	25	70	200	50
plantation	109	850	5000	2500	100	25	25	150	200	50
Production Forest	119	1100	7000	1500	1	40	40	50	150	40
protected area	124	900	6000	1500	1	50	50	150	200	50
Protected Forest	120	1100	7000	1610	1	50	50	70	150	60
Rubber Plantation	34	900	5000	7980	1820	20	20	150	200	60

Settlement	42	200	200	10000	3000	1	1	600	150	5
Shrubs (Semak/Belukar Muda)	15	400	5100	1610	1	30	30	150	150	60
Shrubs on Swampy	17	800	5100	500	1	30	30	20	170	80
Small Holder Oil Palm	31	850	5000	70000	9800	20	20	150	200	50
Small Holder Rubber	35	900	5000	7980	1820	20	20	150	250	60
Small Holder Young Oil Palm Plantation	32	750	7000	50000	5000	25	25	150	350	40
Submontane Forest (1000-2000 m) medium open canopy	83	1000	7300	1610	1	50	50	13	70	70
Submontane Forest (1000-2000 m) rather closed canopy	84	1100	7300	1610	1	50	50	10	50	80
Submontane Forest (1000-2000 m) very open canopy	85	900	7300	1610	1	50	50	15	100	60
Swamp Grasses/Fernland	18	1000	2600	5	5	30	30	200	170	80
Tea Plantation	122	700	3500	2500	100	25	25	150	200	30
Tea Plantation	87	700	3500	2500	100	25	25	150	200	30
Town	41	50	1	10000	2000	5	5	500	100	5
Water Body	40	1000	2000	0	0	60	60	0	10	60
Young Acacia Plantation	26	500	5000	18000	300	20	20	150	200	40
Young Mangrove	13	900	5000	500	1	25	25	60	150	70
Young Mangrove rather closed canopy	89	950	5000	500	1	25	25	50	50	80
Young Oil Palm Plantation	29	600	5000	50000	5000	25	25	150	300	40

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Appendix 4.1. Input table for threat sources in the habitat quality model, showing maximum distance of influence, relative weight (impact) of threats and decay parameter.

A decay value of 1 indicates a linear decline in threat intensity with distance from threat source. These values were derived from interviews with local experts at WWF-Indonesia.

MAX_DIST (km)	WEIGHT	DECAY	Threat
5.0	0.7	1	agriculture
10.0	0.7	1	built-up areas
30.0	1.0	1	mines
6.0	0.7	1	plantations
10.0	0.7	1	roads

Appendix 4.2. Input values for habitat suitability scores and sensitivity of land cover types to threats.

Sensitivity threat score of 1 indicates most sensitive habitat, value of 0 indicates not sensitive.

		Sensitivity of habitats to threat sources				
Land use	**Habitat suitability score**	**Agriculture**	**Built-up areas**	**Mines**	**Plantations**	**Roads**
Dry Lowland Forest rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Dry Lowland Forest medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Dry Lowland Forest very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Peat Swamp Forest rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Peat Swamp Forest medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Peat Swamp Forest very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Swamp Forest rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Swamp Forest medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Swamp Forest very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Mangrove Forest rather closed	1.0	1.0	1.0	1.0	0.7	1.0

canopy						
Mangrove Forest medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Mangrove Forest very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Young Mangrove	1.0	1.0	1.0	1.0	0.7	1.0
Forest Re-growth (Belukar)	0.5	1.0	1.0	1.0	0.7	0.8
Shrubs (Semak/Belukar Muda)	0.4	1.0	1.0	1.0	0.7	1.0
Forest Re-growth on Swampy	0.5	1.0	1.0	1.0	0.7	1.0
Shrubs on Swampy	0.5	1.0	1.0	1.0	0.7	1.0
Swamp Grasses/Fernland	0.5	1.0	1.0	1.0	0.8	1.0
Overgrowing Clear cut-Shrubs	0.5	1.0	1.0	1.0	0.2	1.0
Grassland	0.5	1.0	1.0	1.0	0.7	1.0
Cleared, for Acacia Plantation	0.0	0.0	0.0	1.0	0.0	1.0
Cleared, for Oil Palm Plantation	0.0	0.0	0.0	1.0	0.0	1.0
Cleared	0.0	0.0	0.0	1.0	0.0	1.0
Sand Mining	0.0	0.0	0.0	0.0	0.0	0.0
Burnt	0.0	0.0	0.0	1.0	0.0	1.0
Young Acacia Plantation	0.2	0.2	0.0	1.0	0.0	1.0
Acacia Plantation	0.6	0.2	0.0	1.0	0.0	1.0
City Park (Hutan Kota)	0.0	0.2	0.0	1.0	0.0	1.0
Young Oil Palm Plantation	0.2	0.2	0.0	1.0	0.0	1.0
Oil Palm Plantation	0.4	0.2	0.0	1.0	0.0	1.0
Small Holder Oil Palm	0.2	0.2	0.0	1.0	0.0	1.0
Small Holder Young Oil Palm Plantation	0.2	0.2	0.0	1.0	0.0	1.0
Mosaic of Small Holder Oil palm and Rubber	0.2	0.2	0.0	1.0	0.0	1.0
Rubber Plantation	0.6	0.2	0.0	1.0	0.0	1.0
Small Holder Rubber	0.3	0.2	0.0	1.0	0.0	1.0
Coconut Plantation	0.3	0.2	0.0	1.0	0.0	1.0
Mixed Agriculture	0.0	0.0	0.0	1.0	0.0	1.0
Mixed Garden	0.0	0.0	0.0	1.0	0.0	1.0
Paddy Field	0.0	0.0	0.0	1.0	0.0	1.0
Water Body	0.3	0.7	0.8	1.0	0.8	1.0
Town	0.0	0.0	0.0	1.0	0.0	1.0
Settlement	0.0	0.0	0.0	1.0	0.0	1.0
Factory	0.0	0.0	0.0	0.0	0.0	0.0
Airport	0.0	0.0	0.0	1.0	0.0	1.0
Fishpond	0.0	0.8	0.8	1.0	0.8	0.5
Mill-Oil	0.0	0.0	0.0	1.0	0.0	1.0

Cloud or no information[15]	1.0	1.0	1.0	1.0	0.7	1.0
Gmelina Plantation	0.6	0.2	0.0	1.0	0.0	1.0
Caldera	0.0	0.0	0.0	0.0	0.0	0.0
Cinnamon Plantation	0.3	0.2	0.0	1.0	0.0	1.0
Cleared for Oil Palm Plantation	0.0	0.0	0.0	1.0	0.0	1.0
Cleared post Acacia harvested	0.0	0.0	0.0	1.0	0.0	1.0
Cloud[15]	1.0	1.0	1.0	1.0	0.7	1.0
Coal Mining	0.0	0.0	0.0	0.0	0.0	0.0
Dry Lowland Forest (0-500 m) medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Dry Lowland Forest (0-500 m) rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Dry Lowland Forest on Metamorphic Rock medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Formation on limestones medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Dry Lowland Forest on Metamorphic Rock rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Dry Lowland Forest on Metamorphic Rock very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Dry Lowland Forest (0-500 m) very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Formation on limestones very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Formation on limestones rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Fresh Water Swamp Forest medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Fresh Water Swamp Forest rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Fresh Water Swamp Forest very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Hill Forest (500-1000 m) medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Hill Forest (500-1000 m) rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Hill Forest (500-1000 m) very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Hill Forest on Metamorphic Rock medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0

[15] Most areas designated “Cloud” or “Cloud or No Information” on the 2008 land cover map were in or near forested areas. We treated them as forest in this analysis.

Hill Forest on Metamorphic Rock rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Hill Forest on Metamorphic Rock very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Ilegal gold Mining Area	0.0	0.0	0.0	0.0	0.0	0.0
Low Forest & thickets of the Ericaceous zone closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Montane Forest (2000-2500 m) medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Montane Forest (2000-2500 m) rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Montane Forest (2000-2500 m) very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Mosaic of Settlement & Mixed Garden	0.0	0.0	0.0	1.0	0.0	1.0
Pinus merkusii Plantation	0.6	0.2	0.0	1.0	0.0	1.0
Riparian Forest medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Riparian Forest rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Riparian Forest very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Submontane Forest (1000-2000 m) medium open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Submontane Forest (1000-2000 m) rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Submontane Forest (1000-2000 m) very open canopy	1.0	1.0	1.0	1.0	0.7	1.0
Submontane Forest on Metamorphic Rock rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
Tea Plantation	0.3	0.2	0.0	1.0	0.0	1.0
Topogen Peat Swamp Forest	1.0	1.0	1.0	1.0	0.7	1.0
Young Mangrove rather closed canopy	1.0	1.0	1.0	1.0	0.7	1.0
APL[16]	0.2	0.0	0.0	1.0	0.0	1.0
bare land	0.0	0.0	0.0	0.0	0.0	0.0
dryland farming	0.0	0.0	0.0	1.0	0.0	1.0
fishery	0.0	0.0	0.0	0.0	0.0	0.0
industry	0.0	0.0	0.0	0.0	0.0	0.0
mining	0.0	0.0	0.0	0.0	0.0	0.0
plantation	0.2	0.2	0.0	1.0	0.0	1.0
Natural Forest (under the cloud covers)	1.0	1.0	1.0	1.0	0.7	1.0

[16] APL is the designation for land that has been set aside for future development in the government spatial plan. In this analysis, we assume APL lands will be converted to plantations or other agricultural use.

Caldera	0.0	0.0	0.0	1.0	0.0	1.0
Converted Production Forest	0.7	0.5	0.4	1.0	0.8	0.5
Limited Production Forest	0.8	0.6	0.4	1.0	0.9	0.6
Low Forest & thickets of the Ericaceous zone	0.5	0.6	0.7	1.0	0.7	1.0
Nature Reserve Forest	1.0	1.0	1.0	1.0	0.7	1.0
Production Forest	0.6	0.4	0.4	1.0	0.5	0.5
Protected Forest	1.0	1.0	1.0	1.0	0.7	1.0
protected area	1.0	1.0	1.0	1.0	0.7	1.0
Forest	1.0	1.0	1.0	1.0	0.7	1.0